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FAKULTA STROJNÍ

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Diagnostika kavitace v hydraulickém tlumiči

(Diagnostics of cavitation phenomena in a hydraulic shock absorber)

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Rozsah práce:	původní zpráva	přílohy
Počet stran:	55	XVI
Počet obrázků:	25	2
Počet tabulek:	1	0
Počet grafů:	4	14
Počet příloh:	10	-

Liberec 2010

TECHNICKÁ UNIVERZITA V LIBERCI
Fakulta strojní

Katedra energetických zařízení | Studijní rok: 2009/2010

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

Jméno a příjmení **Jan Hujer**

Studijní program **bakalářský – B2341 Strojírenství**

Obor **2302R022 Stroje a zařízení**

Zaměření **Energetické stroje a zařízení**

Ve smyslu zákona č. 111/1998 Sb. o vysokých školách se Vám určuje bakalářská práce na téma:

Diagnostika kavitace v hydraulickém tlumiči

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1. Provést rešerši literatury zabývající se vznikem kavitace v hydraulickém oleji
2. Popsat metody vhodné k diagnostice kavitace v hydraulickém oleji (optické, akustické)
3. Provést kalibrační měření spektra bublinek pomocí ABS na zkušební trati
4. Zpracovat metodiku měření kavitace na kavitační komoře
5. Provést úvodní měření vzniku a vývoje kavitace za škrticím elementem hydraulického tlumiče na kavitační komoře

Forma zpracování bakalářské práce:

- původní zpráva: 30
- grafické práce: 10 v příloze

Seznam literatury (uveďte doporučenou odbornou literaturu):

- Brdička M., Samek L., Taraba O.: Kavitace, Diagnostika a technické využití. SNTL. Praha. 1981, 336 s.
- Noskijevič J.: Kavitace. Academia. Praha. 1969, 280 s.
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DIAGNOSTIKA KAVITACE V HYDRAULICKÉM TLUMIČI

Anotace: Bakalářská práce je zaměřena na diagnostiku kavitace v hydraulickém tlumiči. Úvodní kapitola obsahuje popis konstrukce a funkčních principů základních typů hydraulických tlumičů. V další kapitole jsou uvedeny některé typy hydraulických kapalin a jejich vlastností. Pro hydraulickou kapalinu, která byla použita v následných měřeních, bylo provedeno měření hustoty, povrchového napětí a viskozity. Následující kapitola obsahuje teoretický úvod do problematiky kavitace. Další část práce je zaměřena na popis metod používaných při diagnostice kavitace. Důraz je kladen na metody a zařízení, které jsou k dispozici v laboratoři Technické univerzity v Liberci. Kapitola o měření popisuje aplikace vybraných metod pro diagnostiku kavitace na kalibrační komoře. Jsou zde uvedeny popisy jednotlivých zařízení a dále výsledky kalibračních měření pomocí akustického bublinkového spektrometru a optického měření stínovou metodou. Poslední část práce popisuje kavitační komoru určenou pro detekci kavitace v reálných tlumičích a metodiku měření na tomto zařízení

Klíčová slova: Kavitace, hydraulický tlumič, hydraulický olej,
diagnostika kavitace, model tlumiče.

DIAGNOSTICS OF CAVITATION PHEMOMENA
IN A HYDRAULIC SHOCK ABSORBER

Annotation: The bachelor thesis is focused on the diagnostic of cavitation in the shock absorber. The introductory chapter includes the design description and working principles of basic types of shock absorbers. The review of hydraulic liquids and their properties are introduced in the following chapter. The density, surface tension and viscosity measurements were performed for the hydraulic fluid used in following measurements. The following chapter includes theoretical introduction to the cavitation phenomena. Next part of the work is focused on methods used in the cavitation diagnostic. A special emphasis is placed on methods and devices available in the laboratories of the Technical university of Liberec. The measurement chapter describes applications of selected methods on the cavitation diagnostics on the calibration chamber. The description of the devices and results of the individual measurements using acoustic bubble spectrometer and optical methods (shadow photography) are given in this chapter. The final part of the work describes cavitation chamber for the detection of cavitation in the real shock absorbers and measurement methodology on this device.

Key words: Cavitation phenomena, Shock absorber, hydraulic power fluid,
diagnostics of the cavitation phenomena, hydraulic shock absorber model.

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Poděkování

Tímto bych chtěl vyslovit velké díky panu Ing. Milošovi Müllerovi PhD. za ochotu, lidský přístup a trpělivost při konzultacích k bakalářské práci, za poskytnutí studijních materiálů a pomoc při měřeních. Také bych chtěl poděkovat panu Ing. Martinovi Stuchlíkovi za pomoc při měření povrchového napětí. Velký dík patří i mé rodině za podporu při studiu.

Jan Hujer

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δ	stlačitelnost hydraulického oleje [Pa^{-1}]
V	objem hydraulického oleje [m^3]
p	tlak působící na hydraulický olej [Pa]
h	výška volné hladiny hydraulického oleje nad základní rovinou [m]
ρ	hustota hydraulického oleje [$kg.m^{-3}$]
w	rychlost proudění hydraulického oleje [$m.s^{-1}$]
F	síla na odtržení platinového prstence při měření povrchového napětí [m.N]
U	konstanta platinového prstence [m]
σ	povrchové napětí hydraulického oleje [Nm^{-1}]
Z	konstanta válce [nedefinováno]
D_r	smykový spád viskozimetru [s^{-1}]
α	dílky na indikačním přístroji viskozimetru [-]
ν	kinematická viskozita hydraulického oleje [m^2s^{-1}]
μ	dynamická viskozita [Pa.s]
p_g	parciální tlak plynu uvnitř kavitační bubliny [Pa]
p_v	parciální tlak nasycených par uvnitř kavitační bubliny [Pa]
p_l	tlak okolní kapaliny na kavitační bublinu [Pa]
p_c	kapilární tlak na rozhraní kapalina - bublina [Pa]
σ	povrchové napětí kapaliny [$N.m^{-1}$]
R	poloměr kavitační bubliny [m]
R_0	počáteční poloměr kavitační bubliny [m]
p_{l0}	tlak kapaliny při $R = R_0$ [Pa]
R_c	kritický poloměr kavitační bubliny [m]
p_{Rc}	kritický tlak [Pa]
p_{g0}	tlak plynu uvnitř bublinky při počátečním poloměru [Pa]
$p_B(t)$	tlak uvnitř bubliny v závislosti na čase [Pa]
$p_\infty(t)$	tlak kapaliny v nekonečnu v závislosti na čase [Pa]
ρ_l	hustota kapaliny [$kg.m^{-3}$]
R´	rychlost změny poloměru bubliny [$m.s^{-1}$]
	rychlost pohybu kapaliny na rozhraní bubliny s kapalinou [$m.s^{-1}$]
R´´	zrychlení změny poloměru bubliny [$m.s^{-2}$]
	zrychlení pohybu kapaliny na rozhraní bubliny s kapalinou [$m.s^{-2}$]

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TUL Technická univerzita v Liberci

KCH Katedra chemie

KST Katedra částí a mechanismů strojů

KEZ Katedra energetických zařízení

ABS Akustický bublinkový spektrometr

1 ÚVOD

Hydraulický teleskopický tlumič je součástí mnoha zařízení a zabezpečuje několik funkcí, z nichž nejdůležitější jsou tlumení nárazů a kmitů. Pro správnou funkci tlumiče je nutno, aby tlumičová kapalina obsahovala minimum nerozpuštěného vzduchu, jehož přítomnost může značné ovlivnit charakteristiku tlumiče. Je známo, že rozpustnost vzduchu v kapalinách klesá s klesajícím tlakem a naopak. Proto se v místech, kde dochází k poklesu tlaku objevují bublinky. Když se tyto bublinky dostanou do míst s vyšším tlakem, dochází k jejich vybuzeni a oscilacím. Během oscilací některé bublinky kolabují a mohou poškozovat části tlumiče případně způsobit lokální spalování tekutiny. Vznik a aktivity těchto bublinek nazýváme kavitací. K poklesu tlaku v tlumiči dochází zejména na různých škrtících elementech. Kavitace je tedy v případě hydraulických tlumičů značně nežádoucím jevem. V současnosti je problém kavitace řešen speciální konstrukcí nebo přetlakováním tlumičů plyny, což s sebou nese nemalé finanční náklady. Použití přetlaku podmiňuje správné utěsnění tlumičů, se kterým je spojena řada dalších problémů. Je však třeba si uvědomit, že ani tímto způsobem nelze uvolňování vzduchu zcela odstranit, protože jakýkoli pokles tlaku vede ke snížení rozpustnosti vzduchu. Jedním ze současných trendů v konstrukci tlumičů vývoj jednoduchého (beztlakového) tlumiče, kde bude přítomnost vzduchových bublin maximálně potlačena. Vývoj takového tlumiče vyžaduje široké spektrum znalosti z mnoha oborů a nasazení moderních technologií pro výzkum, mezi něž patří metody diagnostiky akustické diagnostiky, optické metody a mnohé další.

Cílem této práce je:

- seznámit se se základními principy hydraulických tlumičů a problematikou kavitace v hydraulickém tlumiči.
- prostudovat možnosti detekce vzniku a vývoje kavitace v tlumiči a provést rešerši literatury zaměřené na toto téma.
- provést ověření použitelnosti metod k detekci kavitace na kalibrační komoře.
- seznámit se s modulem kavitační komory v hydrodynamické laboratoři z hlediska možností aplikace metod detekce kavitace a jejím ovládáním.
- na základě získaných poznatků připravit metodiku detekce kavitace na kavitační komoře a provést úvodní spuštění modulu kavitační komory.

2 HYDRAULICKÉ TLUMIČE

2.1 Tlumiče a odpružení vozidla

Tlumiče jsou tlumicí prvky mechanických soustav užitkových zařízení. Lze je rozdělit na mechanické, plynové a kapalinové. S kapalinovými (hydraulickými) tlumiči se můžeme setkat např. u sedadel řidičů, automatických praček a hlavně ve vozidlech všech typů (osobní, přívěsná, stavební, zemědělská, kolejová, ...). Hydraulický tlumič je zde součástí podvozku vozidla - odpružení (soustava pružina – tlumič). Nejvíce se tlumič používá v odpružení osobních automobilů a nejvíce namáhaný je u nákladních automobilů. Obecně vykoná tlumič při běžném provozu okolo 1200 funkčních cyklů na jeden kilometr a přitom plní velmi důležitou funkci. Je proto vhodné problematiku vozidlových tlumičů popsat.

Odpružení vozidla zajišťuje komfort a bezpečnost jízdy, kdy při nárazech a kmitání náprav vozidla v důsledku nerovností vozovky dochází pouze k omezenému přenosu těchto nárazů a kmitů na podvozek a karoserii. Chrání tak osoby a náklad vozidla před otřesy a zvyšuje životnost dílů vozidla. Hlavně ale zabezpečuje stálý styk pneumatiky s povrchem a to i u nerovné vozovky, čímž je dosaženo přenosu sil v soustavě kolo – vozovka. Vozidlo je tedy řiditelné a jízda bezpečná.

Předpokladem pro správnou funkčnost odpružení je funkčnost tlumiče. Na jeho funkčnost má vliv řada činitelů. Jedním z nich je také kavitace, jejímž projevem je zpěnění tlumičového oleje, spalování tlumičového oleje a narušování povrchu ventilového systému.

2.2 Princip hydraulických tlumičů

Hydraulický tlumič plní funkci tlumení nárazů a tlumení kmitů. Při pohybu vozidla nerovnosti vozovky rozpohybují pružně uloženou karoserii vozidla. Tlumič se snaží karoserii „uklidnit“ tlumící sílou. Z hlediska přeměn energií se vnější mechanická energie přemění pomocí pístu stlačujícího tlumičový olej na tlakovou energii. Součinitel stlačitelnosti tlumičového oleje může být např. $6{,}71.10^{-10}\ Pa^{-1}$. Když provedeme myšlenou úpravu následujícího vztahu pro stlačitelnost kapaliny a vyjádříme si tlak, zjistíme, že i velmi malá změna objemu vytvoří obrovský tlak díky velmi malé hodnotě součinitele stlačitelnosti kapaliny.

$$\delta = -\frac{1}{V}\cdot\frac{\partial V}{\partial p} \quad \left[\frac{1}{Pa}\right] \tag{2.1}$$

Následně proudí stlačovaný tlumičový olej skrz soustavu škrtících elementů tlumiče. Proudí z místa s obrovským tlakem do místa s nízkým tlakem. Tato změna tlaku je téměř okamžitá. Průběh změny tlaku lze popsat pomocí Bernoulliho rovnice 2.2, zde v tlakovém tvaru. Následující rovnice 2.3 vysvětluje přímo přeměnu tlakové energie na kinetickou energii a o mnoho menší tlak. Při zanedbání výškového členu je na levé straně rovnice (stlačovaná část oleje) obrovský tlak a téměř nulová rychlost. Naopak na pravé straně rovnice (nestlačovaná část oleje) je vysoká rychlost protékajícího oleje skrz škrtící elementy a téměř nulová tlaková energie.

$$h_1 \cdot \rho_1 \cdot g + p_1 + \frac{w_1^2}{2} \cdot \rho_1 = h_2 \cdot \rho_2 \cdot g + p_2 + \frac{w_2^2}{2} \cdot \rho_2 \qquad (2.2)$$

$$p_1 + \frac{w_1^2}{2} \cdot \rho_1 = p_2 + \frac{w_2^2}{2} \cdot \rho_2 \qquad (2.3)$$

$$\Downarrow$$

$$w_1 \langle\langle w_2 \quad p_1 \rangle\rangle p_2$$

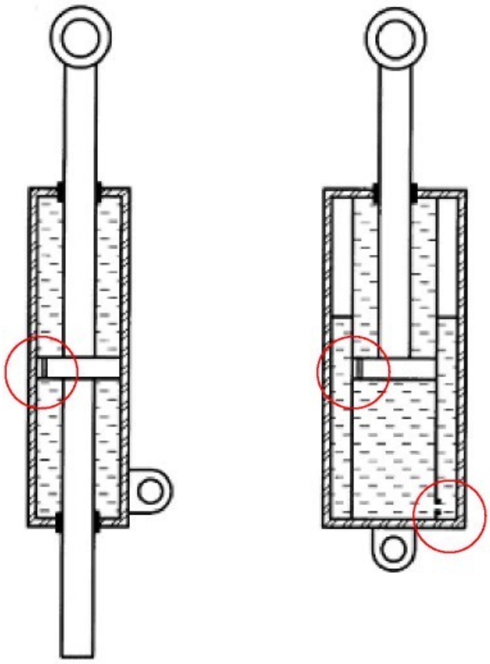
Z energetického hlediska v souhrnu dochází k přeměně tlakové energie disipací na tepelnou energii. Příčinou je hydraulický odpor soustavy škrtících elementů tlumiče, turbulence, zatopený proud oleje do nestlačované části, zpěnění a další jevy, podílející se na disipaci energie.

Popsaná změna tlaku v tlumičovém oleji hydraulického tlumiče by mohla zapříčinit vznik kavitace. Proto se pro zamezení kavitace hydraulické tlumiče různě upravují.

2.3 Konstrukce hydraulických tlumičů

Hydraulické tlumiče lze z konstrukčního hlediska rozdělit na dva typy - na teleskopické tlumiče a pákové tlumiče. Pákové tlumiče se již nepoužívají a dnes se setkáváme výhradně s tlumiči teleskopickými.

Teleskopické tlumiče lze rozdělit na tlumiče s průběžnou tyčí, dvouplášťové a jednoplášťové. Na obrázku 2.1 je jednoduše zobrazena konstrukce teleskopických tlumičů a umístění škrtících elementů, ve kterých dochází ke kavitaci.

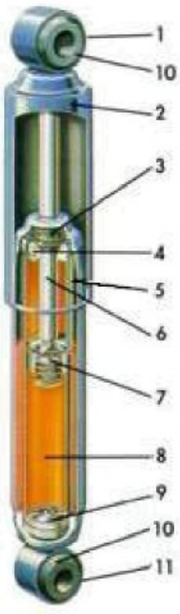


Tlumič s průběžnou tyčí | Dvouplášťový tlumič | Jednoplášťový tlumič

Obr. 2.1: Jednoduchá schémata teleskopických tlumičů s označením míst škrtících elementů (vzniku kavitace) [2]

2.4 Dvouplášťový teleskopický kapalinový tlumič

Konstrukci tohoto tlumiče popíšeme na běžném automobilovém tlumiči. Tlumič sestává z vnitřního (pracovního) válce a vnějšího válce. Vnitřní válec je vyplněn tlumičovým olejem, který při pohybu pístnice s pracovním pístem protéká skrz škrtící elementy (zde pístové ventily) tohoto pístu. Při pohybu pístnice do tlumiče se mění využitelný objem vnitřního válce o objem části pístnice zasunuté dovnitř. Přebývající olej proudí přes další škrtící elementy (zde spodní ventily) ve spodní části tlumiče do vnějšího válce. Prostor ve vnějším válci nazýváme vyrovnávací. Je tvořen z části olejem a z části buď přetlakovaným technickým plynem (pak můžeme název kapalinový zaměnit za přídavné jméno plynokapalinový), nebo je tento prostor spojen s volnou atmosférou a je tvořen vzduchem (pak tlumič nazýváme v nezměněné podobě dvouplášťový teleskopický kapalinový tlumič). Technickým plynem pro přetlakování bývá nejčastěji dusík. Přetlak je různý, daný výrobcem a velikostí tlumiče, např. 0,4 – 0,8 MPa. Tímto je popsána konstrukce pro technologii tlumení. Dále je zde mnoho dalších částí (upevňovací kloub, těsnění, ucpávky, …). Obrázek 2.1 vysvětluje pochody při činnosti (přepouštění, změna objemu, …) uvnitř tlumiče a následující obrázek 2.2 zobrazuje kompletní konstrukci včetně jednotlivých dílů popisovaného tlumiče.

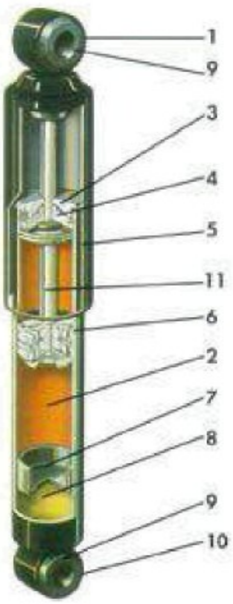


1. horní upevňovací kloub
2. ochranná trubka
3. těsnění pístnice
4. vedení pístnice
5. vnější válec s plynem
6. pístnice
7. pracovní píst, škrtící elementy (pístové ventily)
8. vnitřní válec s tlumičovým olejem
9. škrtící elementy (spodní ventily)
10. pouzdro
11. spodní upevňovací kloub

Obr. 2.2: Dvouplášťový teleskopický kapalinový tlumič [3]

2.5 Jednoplášťový teleskopický kapalinový tlumič

Konstrukce tohoto tlumiče popíšeme opět na běžném automobilovém tlumiči. Tlumič sestává z jednoho válce, který je válcem pracovním. Vnitřek je tvořen pístnicí s pístem a škrtícími elementy (zde pístové ventily), dělícím pístem, tlumičovým olejem a technickým plynem. Tento technický plyn je nejčastěji opět dusík. Tlumič je jím plněn přetlakem, např. 2,5 – 3,5 MPa a je opět různý dle výrobce a velikosti tlumiče. Dělící píst rozděluje válec na dvě části a odděluje olejovou část a plynovou část. Tím se zabrání promíchání oleje a plynu. Funkce tohoto tlumiče je obdobná jako u předchozího tlumiče z kapitoly 2.4, zde ale dochází k průtoku pouze skrz jednu soustavu škrtících elementů. Existují také konstrukční varianty bez dělícího pístu, kde je provedena úprava proti promíchání oleje a plynu pomocí odrazové příčky, nebo uklidňovacím pístem. Popsaná základní konstrukce obsahuje ještě další konstrukční prvky (upevňovací kloub, pouzdra, …). Na obrázku 2.1 je zjednodušeně zobrazena konstrukce a lze jím vysvětlit jak probíhá činnost tlumiče. Na obrázku 2.3 je popsána kompletní konstrukce popisovaného tlumiče.



1. horní upevňovací kloub
2. tlumičový olej v pracovním válci tlumiče
3. těsnění pístnice
4. vedení pístnice
5. ochranný kryt
6. píst, škrtící elementy (pístové ventily)
7. dělící píst
8. plyn
9. pouzdro
10. spodní upevňovací kloub
11. pístnice

Obr. 2.3: Jednoplášťový teleskopický kapalinový tlumič [3]

2.6 Škrtící elementy tlumičů

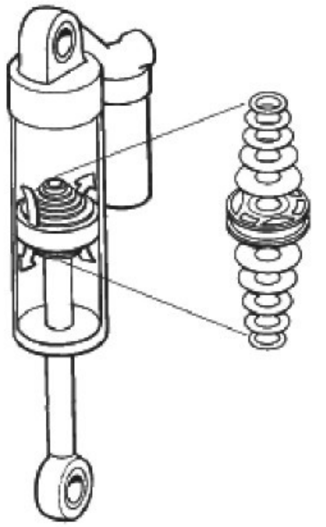
Škrtící elementy vytvářejí hydraulický odpor škrcení průtoku tlumičového oleje. Z konstrukčního hlediska existují dva typy - otvory a ventily.

2.6.1 Otvory

Škrtící element „otvor“ je jednoduchá úzká průchozí díra s konstantním průřezem. Pro různou rychlost pístnice a tedy různý tlak je pak díky tomuto konstantnímu průřezu různé tlumení. Pokud je rychlost pístnice velká, nestačí tlumičový olej protékat a škrcení je silné a opačně při malých rychlostech tlumičový olej protéká bez požadované odezvy škrcení a tlumení je nedostatečné. Při prvním popsaném stavu, kdy je rychlost pístnice obrovská je obrovský i nárůst tlaku. Z Bernoulliho rovnice lze vyjádřit, že tlumičový olej o stavu obrovské tlakové energie s téměř nulovou rychlostí se změní na stav obrovské rychlosti a nízkého tlaku. Toto je předpokladem pro vznik kavitace. Tlumičový olej se zpění. Dojde ke změně charakteristiky tlumiče.

2.6.2 Ventily

V současné době se nejvíce používá provedení ventilů jako tuhá deska nebo kuželka a poddajná planžeta. Přítlačná síla u tuhé desky nebo kuželky je vyvozena přítlačnou pružinou a u poddajné planžety je přítlačná síla vyvozena napětím svazku předepjatých planžet. Výhodou ventilu je změna průtočného množství, daná sekundárním otvorem a přítlačnou sílou. Ventil je navržen tak, aby sekundární otvor, který je obdobou škrtícího elementu „otvor“ poskytoval konstantní průtočný průřez pro malé rychlosti a pro velké rychlosti se tlaková síla na ventil zvýší natolik, že se pružinou přitlačovaný ventil nadzvedne ze sedla a tím se zvětší průtočný průřez. Dosáhne se tak optimálního tlumení a eliminují se podmínky pro vznik kavitace.



Obr. 2.4: Motocyklový tlumič s předepjatými planžetami [4]

2.7 Model tlumiče

Diagnostika kavitace v hydraulickém tlumiči je při různých podmínkách provozu vozidla prakticky nemožná. Za tímto účelem se vyrábějí modely hydraulických tlumičů, ve kterých se simuluje stav provozu hydraulického tlumiče a provádí se diagnostika. Jedním takovým zařízením je i zkušební zařízení Hydrodynamické laboratoře, Katedry částí a mechanismů strojů Technické univerzity v Liberci. Nachází se v areálu kolejí Vesec v Liberci na Doubí.

Popis tohoto zařízení a metodika diagnostiky bude popsána v dalších kapitolách.

3 HYDRAULICKÝ OLEJ

3.1 Průmyslové oleje

Průmyslové oleje jsou oleje používané v průmyslových zařízeních. Průmyslový olej se vyrábí ze základového oleje přidáním aditiv, která zlepšují jeho požadované vlastnosti. Základový olej existuje minerální a syntetický. Minerální olej je ropný produkt získaný frakční destilací ropy. Syntetický olej je vyroben moderními chemickými technologiemi ze základních ropných frakcí nebo základních chemických látek. Výhodou syntetických olejů oproti minerálním olejům je předvýrobní definování požadovaných vlastností daných stejnou stavbou všech molekul. Stavba molekul minerálního oleje oproti syntetickému oleji je dána komplexností směsi uhlovodíků vzniklou při výrobě frakční destilací. Aditivy nejčastěji bývají antioxidanty pro zlepšení oxidační stability, inhibitory koroze pro snížení korozního působení oleje a modifikátory tření pro vytvoření ochranné vrstvy na povrchu tělesa zabraňující přímému kontaktu třecích ploch.

Průmyslové oleje lze rozdělit podle účelu. Průmyslový olej pak označujeme jako strojní, turbínový, kompresorový, převodový, hydraulický,...

Klasifikace průmyslových olejů je uvedena v ČSN 65 6601. Je provedena podle viskozitní třídy, což je číselná hodnota kinematické viskozity v [m^2s^{-1}] při 40°C ve středu intervalu hodnot této viskozitní třídy a viskozitního indexu VI [-]. Kinematická viskozita jako základní parametr klasifikuje a označuje průmyslové oleje: ISO VG *číselná hodnota kinematické viskozity*, např. ISO VG 32. Řada hodnot pro označení kinematické viskozity je 2, 3, 5, 7, 10, 15, 22, 32, 46, 68, 100, 150, 220, 320, 460, 680, 1000, 1500.

3.2 Hydraulické oleje

Hydraulické oleje se vyrábí v širokém spektru vlastností a výrobců. Důležité vlastnosti sledované výrobci a uváděné v technickém listu jsou hlavně viskozita, viskozitní index, bod vzplanutí a bod tuhnutí. Další informace o vlastnostech je možné získat např. z bezpečnostního listu například barvu, zápach, hustotu, tlak nasycených par, rozpustnost ve vodě, korozi na mědi, neutralizační číslo, odlučivost vzduchu, ... Množství uváděných hodnot se liší dle výrobce. Některé z těchto údajů představují důležité hodnoty i pro výpočty a zpracování v počítačových programech měřicích zařízení pro diagnostiku kavitace. Jedná se zejména o hustotu, kinematickou viskozitu, tlak nasycených par, povrchové napětí. Dále je pak nutné znát tepelnou vodivost, teplotní vodivost a rychlost zvuku v daném hydraulickém oleji.

V následující tabulce je uveden výběr několika olejů klasifikace ISO VG 32 s kinematickou viskozitou okolo 32 mm^2s^{-1} s hodnotami veličin, které jsou pro nás důležité.

Značka oleje	Označení	Hustota	Viskozita	Tlak nasycených par	Povrchové napětí
Jednotka		kg.m-3	$mm^2.s^{-1}$	kPa	$N.m^{-1}$
Poznámka		při 15ºC	při 40ºC	při 20ºC	
PARAMO	OT-HP 3	880	32	<0.01	-
ESSO	HLP	855	31	-	-
ESSO	NUTO H 32	872	32	<0.013	-
MOBIL	HLPD 32	873	32	<0.01	-
MOBIL	SHC 524	854	30	<0.013	-
BRITISH PETROLEUM	Bartran HV 32	871	32	-	-
MOGUL	HV 32	875	32	<0.01	-
SHELL	Tellus 32	875	32	-	-
TEXACO	Rando HD 32	870	32	-	-
AGIP	OSO 32	885	30	-	-

Tab. 3.1: Vybrané vlastnosti různých značek hydraulických olejů

3.3 Hydraulický olej zkušební komory

Zkušební model hydraulického tlumiče v Hydrodynamické laboratoři KST TUL na Doubí používá hydraulický olej dodaný firmou Brano Group a.s. pro jimi žádané zkoušky na tomto modelu hydraulického tlumiče. Vlastnosti tohoto oleje nejsou známy. Z tohoto důvodu bylo nutné změřit dříve vyjmenované důležité veličiny. Z časově-ekonomických důvodů a dostupnosti měřících zařízení se jedná o měření hustoty, povrchového napětí a viskozity.

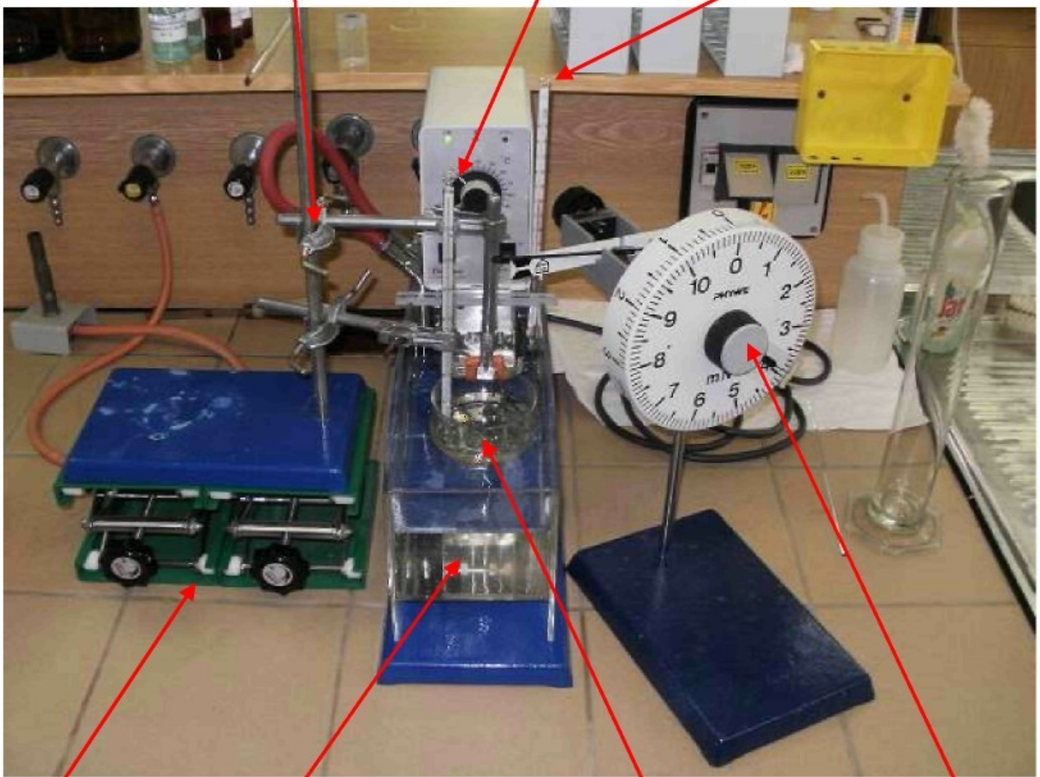
3.3.1 Měření hustoty hydraulického oleje

Hustota byla změřena v laboratořích Katedry chemie Technické univerzity v Liberci při příležitosti měření povrchového napětí. Bylo použito skleněného hustoměru (areometr) LABORA s referenční teplotou 20ºC a pro rozsah hustot 800 – 850 $kg.m^{-3}$. Měření bylo provedeno opakovaně při teplotě 20ºC v odměrném válci a vždy vykazovalo stejnou hodnotu ρ=848$kg.m^{-3}$.

Obr. 3.1: Skleněný hustoměr [5]

3.3.2 Měření povrchového napětí hydraulického oleje

Měření povrchového napětí σ [Nm^{-1}] hydraulického oleje v závislosti na teplotě t [ºC] bylo provedeno v laboratořích Katedry chemie Technické univerzity v Liberci odtrhávací metodou. Měřící zařízení se skládalo z torzního dynamometru PHYWE Germany s platinovým prstencem, termostatické lázně HAAKE C10, laboratorních zvedáků, krystalizační misky, teploměrů a stojánku s úchytkami.



Obr. 3.2: Sestava pro měření povrchového napětí

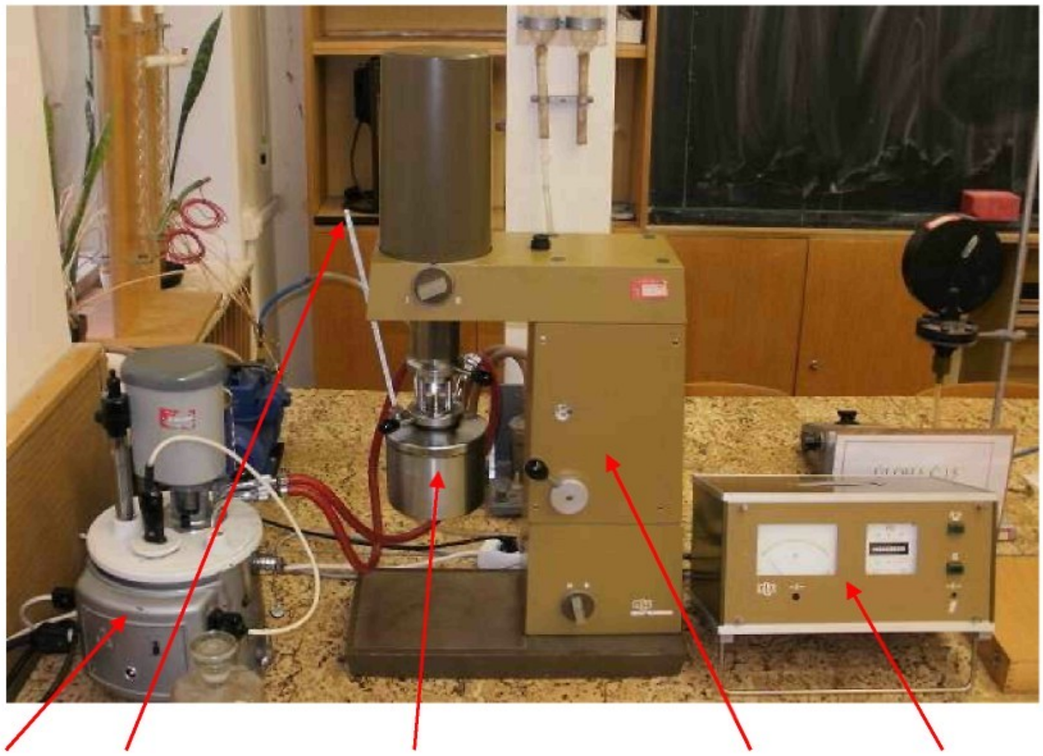
Při měření byla v termostatické lázni měněna teplota po 5ºC a to od 20ºC do 40ºC. Při těchto teplotách byla opakovaně desetkrát měřena síla F [m.N] nutná pro odtržení v našem případě platinového kruhového prstence od fázového rozhraní. Následně bylo na základě zjištěné síly a konstanty U[m] platinového prstence dopočítáno povrchové napětí. Pro výpočet byl použit statistický program kapesního kalkulátoru CASIO. V příloze P1 jsou naměřené a vypočítané hodnoty tohoto měření a v příloze P2 jsou graficky znázorněny.

Pro výpočet bylo použito následujícího vztahu 3.1 a konstanty platinového prstence U=0,061m.

$$\sigma = \frac{F}{2 \cdot U} \left[\frac{N}{m} \right] \qquad (3.1)$$

3.3.3 Měření viskozity hydraulického oleje

Měření viskozity bylo provedeno v laboratořích technických měření Katedry energetických zařízení TUL. Jednalo se o měření viskozity v závislosti na teplotě pomocí rotačního viskozimetru Rheotest 2. Viskozimetr Rheotest 2 má instalovanou vodní lázeň s termostatickým ohřevem. Viskozimetr a pomocná zařízení jsou na následujícím obrázku.



termostat teploměr termostatická lázeň s válci a olejem viskozimetr indikační přístroj

Obr. 3.3: Viskozimetr

Princip měření je založen na přenosu síly mezi dvěma válci prstencem měřené kapaliny. Vnější válec je pevný. Je ve styku s temperovací lázní a tím temperuje měřenou kapalinu. Vnitřní válec se otáčí a je připojen na válcovou šroubovitou pružinu. Pružina se při různém zatížení otáčejícího se válce od měřené kapaliny různě deformuje. Tato deformace je mírou přenášeného kroutícího momentu a je snímána odporovým potenciometrem, který je zapojen do můstku. Výstupem můstku je hodnota proudu odpovídající přenášenému momentu. Následně se na indikačním přístroji odečítaly dílky α [-] a pomocí uvedených výpočtových vztahů 3.2, 3.3 a 3.4 byla dopočítána dynamická viskozita μ [Pa.s] a kinematická viskozita ν [$m^2.s^{-1}$]. Pro výpočet byla použita naměřená hustota ρ=848kg.m^{-3}, konstanta válce Z=0,51 a smykový spád D_r=729 [s^{-1}], což je pro dané nastavení viskozimetru konstanta odečtená z tabulky.

$$\tau_r = Z \cdot \alpha \left[\frac{N}{m}\right] \tag{3.2}$$

$$\mu = \frac{\tau_r}{D_r}[Pa \cdot s] \tag{3.3}$$

$$\nu = \frac{\mu}{\rho}\left[\frac{m^2}{s}\right] \tag{3.4}$$

Viskozita hydraulického oleje je zpracována v příloze P3 a závislost na teplotě graficky znázorněna v příloze P4.

3.3.4 Výzkum kavitace v průmyslových olejích

Výzkum kavitace v průmyslovém oleji je většinou vázán na aplikační sféru hydraulických prvků a mechanismů (tlumiče, zubová čerpadla, armatury, …). Následující rešerše je z článků uvedených ve zdroji [7].

Samotným výzkumem kavitace v oleji se zabývá např. skupina vědců z University of Twente v Enschede, Nizozemsko. Meged, Y.; Venner, C.H.; Napel, W.E. v článku *Classification of lubricants according to cavitation kriteria* pojednávají o klasifikaci různých druhů olejů (minerální, syntetický, …) podle kavitačního kritéria. Základem tohoto výzkumu byla potřeba vytvořit metodiku hodnocení kavitačních vlastností olejů, protože neexistovala žádná mezinárodní standardizace v této oblasti. Vědecká práce je tvořena dvěma oddíly. Jeden se zabývá numerickými simulacemi s Reynoldsovými rovnicemi a teorií elastické deformace. Na základě těchto simulací se formulují vlastnosti olejů, např. kavitační energie, okolní tlak. Praktický oddíl se zabývá testováním 20 olejů. Toto testování bylo provedeno hliníkovým hrotem spojeným s oscilátorem. Hrot byl ponořen v oleji a po určitou dobu vibroval. Přitom byla periodicky měřena hmotnost hrotu a dopočítána změna hmotnosti. Tím byla zjištěna kavitační eroze při definovaných podmínkách a daném oleji. Poznatky obou částí práce byly shrnuty dohromady a korelovány. Vytvořily tak podklad pro konstruktéry hydraulických zařízení dle druhu oleje.

Výzkumu kavitace pro aplikační sféru se věnují například W. Kollek, Z. Kudźma, M. Stosiak a J. Mackiewicz. V článku *Possibilities of diagnosing cavitation in hydraulic systems* uvádějí různé metody testování. Jeden z experimentů je založen na působení podtlaku na sloupec vzorku oleje. Přitom se sledují velikosti vznikajících kavitačních bublin. Dalším experimentem je simulace dějů v čerpadle. Pomocí pístového mechanismu, vytvářejícího v komoře ze speciálního skla podtlak, simulují vznik kavitačních bublin.

Výzkumu vzniku kavitace na modelu ventilu se zabývají MARTIN, C.S., MEDLARZ, H., WIGGERT, D.C., BRENNEN, C. ve článku *Cavitation inception in spool valves*. Výzkum byl proveden na zvětšeninách skutečného ventilu a zabývá se sledováním podmínek pro vznik poškození ventilů hydraulických mechanismů pro různé otevření ventilů a různá Reynoldsova čísla.

4 KAVITACE

4.1 Jev kavitace

Kavitace je fyzikální jev, zahrnující vznik, růst a zánik dutin v kapalině. Kavitace je v mnoha případech na závadu, ale v určitých případech může být i prospěšná. Negativně působí v hydraulických strojích a zařízeních. Stává se tak v čerpadlech, ve vodních turbínách, armaturách, hydraulických systémech a také v hydraulickém tlumiči. V těchto strojích je hlavním projevem kavitace erozivní účinek na povrchy materiálu součástí strojů. Žádoucí účinky kavitace se projevují při čištění složitých tvarových povrchů, odplynění kapalin, odbarvování organických roztoků, urychlování chemických reakcí a v medicinálních aplikacích.

Kavitační bubliny jsou tvořeny plynem, parami kapaliny, nebo kombinací obou a vznikají za určitých podmínek daných tlakem a teplotou kapaliny v určitém místě - kavitační oblasti. Při poklesu tlaku na tlak nasycených par (tzv. kavitační tlak) dojde k porušení kontinuity a lze vizuálně pozorovat vznik bubliny. Pokud tlak setrvá na hodnotě kavitačního tlaku nebo poklesne, budou bubliny růst. Pokud tlak vzroste, dochází k implozi a bublina zanikne. Při zániku se plyn v dutině smršťuje a pára kondenzuje a okolní kapalina se snaží prostor zaplnit, čímž dojde k velkému rázu. To je příčinou zmíněné kavitační eroze.

4.2 Rozdělení kavitace

Kavitaci lze rozdělit dle několika hledisek: principu vzniku, teploty a tlaku, tvaru, místa výskytu, kvalitativního popisu, počtu cyklů, principu generování, oblasti výskytu a aplikace a dalších.

Rozdělení dle principu vzniku: *Parní kavitace* - hlavní podíl vnitřku bubliny je pára, difúze plynu z kapaliny lze zanedbat a množství plynu se tedy při expanzi nemění.

Plynová kavitace - do bubliny z nasycené kapaliny vniká difúzí plyn, je tvořena plynem a objem bubliny roste pomalu

Rozdělení dle teploty a tlaku: *Konstantní tlak, růst teploty na bod varu* - kavitace jako var kapaliny.

Pokles tlaku, konstantní teplota – např. při proudění.

Rozdělení dle tvaru: *Kapsovité* - bubliny zaplňují určitou oblast, např. v tryskách.

Vláknové - bubliny jsou řetězcem ve tvaru vlákna, např. na koncích lopatek lodních šroubů.

Rozdělení dle místa: *Kavitační oblast uvnitř proudu.*

Kavitační oblast na obtékané ploše.

Rozdělení dle kvalitativního popisu: *Počínající kavitace* - malé právě vnikající bubliny.

Rozvitá kavitace - větší bubliny, roste množství.

Zanikající kavitace - bubliny mizí a zanikají.

Rozdělení dle počtu cyklů: *Kavitace stabilní* - velký počet cyklů.

Kavitace přechodná - jeden nebo málo cyklů.

Rozdělení dle principu generování: A) *tlakové principy generace*

Hydrodynamická kavitace - pozorujeme ji v místech, kde proudící kapalina zrychluje a kde dochází poklesu tlaku, např. v potrubí, čerpadlech, turbínách, ...

Akustická kavitace - bubliny vznikají působením změn tlaku ultrazvukovými pulzy, např. čištění povrchů, medicinální aplikace, ...

B) *energetické principy generace*

Optická kavitace - bubliny vznikají na základě energie letících laserem generovaných fotonů, které jsou zaostřeny do daného místa.

Částicová kavitace – je založena na působení elementárních částic mikrosvěta a jejich energie v přehřátých kapalinách.

Kavitace v hydraulickém tlumiči lze zařadit do hydrodynamické kavitace. Další zařazení neprovádím, protože se může vyskytovat ve více variantách. Například může být počínající, rozvitá a i zanikající dle fáze, ve které se v daném měření nacházíme.

4.3 Popis jevu kavitace

Kavitační bublinu lze popisovat bez závislosti na čase, ve statické rovnováze, nebo jí lze popsat dynamicky se závislostí na čase. Při popisu se vychází z různých předpokladů na vlastnosti kapaliny a bubliny. Mezi tyto vlastnosti patří stlačitelnost, vlivy vazkosti, povrchové napětí, termodynamické vlastnosti kapaliny, druh stavové změny plynu bubliny, rychlost růstu a zániku bubliny, ...

V kapalině vzniká velké množství kavitačních bublin o spektru různých velikostí. Mezi těmito bublinami mohou být malé vzdálenosti a mohou se navzájem ovlivňovat. Pak by nebylo prakticky možné provést popis kavitace. Proto je vhodné uvažovat osamocenou bublinu v kapalině.

4.4 Kavitační jádra a pevnost kapaliny v tahu

Abychom mohli popsat statickou rovnováhu kavitační bubliny v kapalině, je nutné vysvětlit prvopočáteční jevy důležité pro vznik kavitace. Jestliže má vzniknout kavitace, je nutné, aby v kapalině byla tzv. kavitační jádra. Kavitační jádra jsou velmi malé bublinky, ze kterých vznikne kavitační bublina. Tato mikroskopická kavitační jádra vzniknou překonáním pevnosti kapaliny v tahu. Pevnost kapaliny v tahu je napětí potřebné k odtržení molekulových vrstev kapaliny. Po překonání kohezních sil vrstev molekul dojde k porušení homogenity kapaliny a v místech tohoto porušení jsou kavitační jádra. Předpokladem pro překonání této pevnosti je její zeslabení mikrobublinkami nerozpuštěných plynů nebo tuhými nečistotami. Teoreticky čistá kapalina má pevnost v tahu o hodně větší než kapalina reálná.

4.5 Kavitační bublina ve statické rovnováze v kapalině

Statická rovnováha kavitační bubliny v kapalině se používá pro určení parametrů při začínající kavitaci. Tuto statickou rovnováhu lze popsat za určitých předpokladů. Mezi tyto předpoklady patří: bublina se nachází v kapalině a vnitřek je tvořen plynem a parou kapaliny v níž se nachází, bublina je dokonale kulatá, nezanedbáváme povrchové napětí kapaliny, sdílení tepla mezi vnitřkem bubliny a okolní kapalinou je dokonalé, nedochází k difúzi plynu z kapaliny do bubliny, nebo z bubliny do kapaliny.

Následně budeme uvažovat bublinu, kde tlak uvnitř je konstantní a roven součtu parciálních tlaků plynu p_g a nasycených par p_v. Budeme-li hledat zmíněnou rovnováhu, tak tento součet představuje jednu stranu rovnosti. Druhou stranou rovnosti je působení okolní kapaliny na bublinu tlakem p_l, ke kterému je přičten kapilární tlak p_c rozhraní bublina – kapalina. Kapilární tlak je roven podílu dvojnásobku kapilárního napětí σ a poloměru bubliny R. Jestliže tyto strany dáme do rovnosti, můžeme napsat tuto rovnici.

$$p_g + p_v = p_l + p_c \tag{4.1}$$

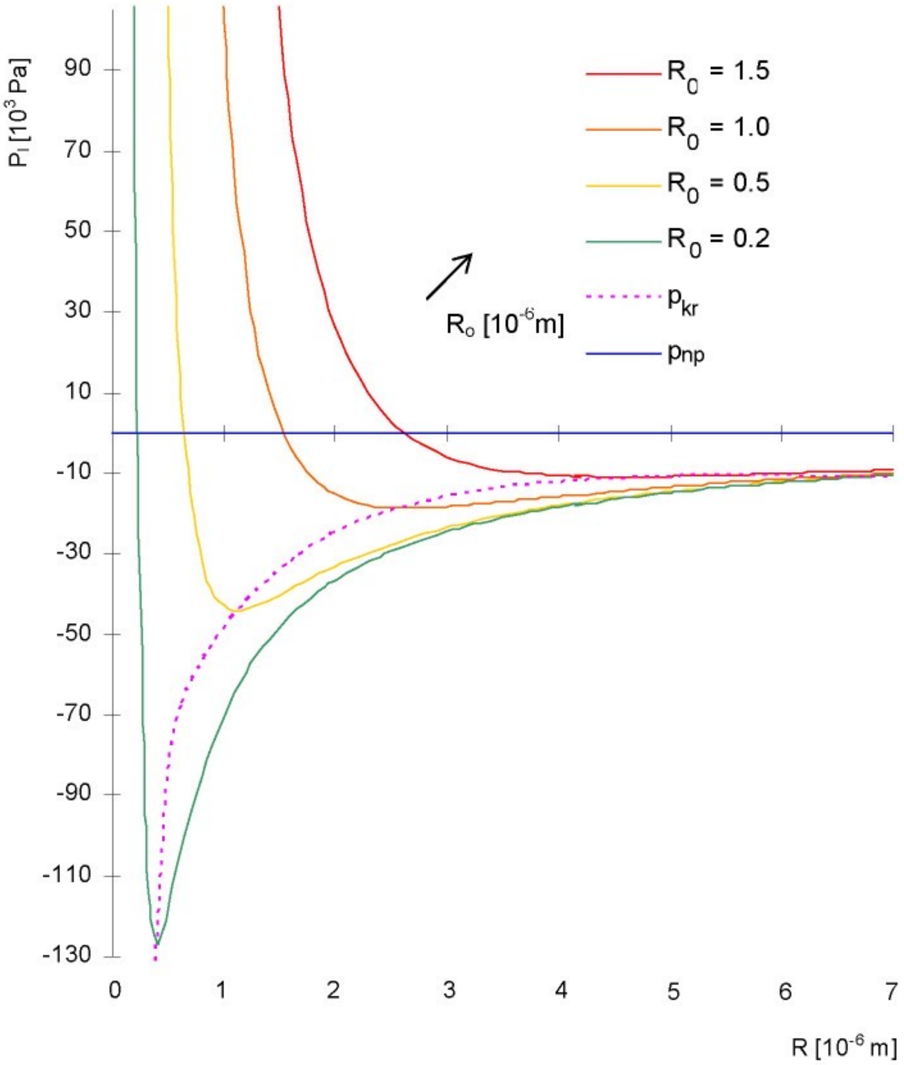
$$p_g + p_v = p_l + \frac{2\sigma}{R} \tag{4.2}$$

Uvedenou rovnici lze úpravami popsanými např. v [11] přepsat do tvaru pro okolní tlak kapaliny p_l. V této úpravě je použita rovnice pro stavovou změnu ideálního plynu z počátečního stavu do obecného stavu. Předpokládá se ideální plyn a izotermická změna stavu. Počáteční stav veličin bude označován s dolním indexem 0. Nově se zde tedy objevuje počáteční poloměr bubliny R_0 a tlak kapaliny p_{l0} při tomto počátečním poloměru.

$$p_l = p_v + \left(p_{l0} - p_v + \frac{2\sigma}{R_0} \right) \cdot \left(\frac{R_0}{R} \right)^3 - \frac{2\sigma}{R} \quad (4.3)$$

Rovnici 4.3 lze graficky znázornit po dosazení fyzikálních vlastností kapaliny, číselných hodnot $\boldsymbol{p_v}$, $\boldsymbol{p_{l0}}$, $\boldsymbol{\sigma}$ a volbě parametru $\boldsymbol{R_0}$.

Graf byl vytvořen pro v měření použitý hydraulický olej o teplotě 25ºC s povrchovým napětím $\boldsymbol{\sigma}$ = 33,36.10^{-3} Nm^{-1}. Tlak nasycených par byl použit obecně pro tento druh oleje $\boldsymbol{p_v}$ = 1000 Pa. Atmosférický tlak byl použit obecný $\boldsymbol{P_{l0}}$ = 101 325 Pa. Počáteční poloměr bubliny byl zvolen ve čtyřech hodnotách R_0 = 0.2 . 10^{-6}, 0.5 .10^{-6}, 1.0 .10^{-6}, 1.2 .10^{-6} m.



Graf 4.1: Závislost rovnovážného tlaku v kapalině na poloměru bublinky

Použijeme-li znalosti matematické analýzy, tak kladná hodnota první derivace tlaku v kapalině dle poloměru kavitační bubliny určuje funkci rostoucí a naopak záporná hodnota této derivace funkci klesající. Jestliže dojde ke změně poloměru bubliny, která se nachází v rovnováze a tato změna vymizí, můžeme říci, že statická rovnováha bubliny byla stabilní dle rovnice 4.4. Pokud změna poloměru bubliny nevymizí a naopak se bude zvětšovat, můžeme říci, že statická rovnováha byla nestabilní dle rovnice 4.5.

$$\frac{\partial p_l}{\partial R} < 0 \tag{4.4}$$

$$\frac{\partial p_l}{\partial R} \geq 0 \tag{4.5}$$

Jestliže položíme danou derivaci rovno nule, nalezneme extrém funkce – kritický bod, jemuž odpovídá kritický poloměr bubliny R_c a kritický tlak v kapalině p_{Rc}.

$$\left(\frac{\partial p_l}{\partial R}\right)_{R=R_c} = 0 \tag{4.6}$$

Tato minima – kritické body jsou v grafu 1 rozpoznatelné. Kdybychom nalezli řešení rovnice 4.6 pro všechny počáteční poloměry, vznikla by křivka spojující všechny kritické poloměry a kritické tlaky. V grafu 1 jsou body minima funkce 4.3 spojeny čárkovanou fialovou čarou. Tato křivka rozděluje funkční závislost 4.3 pro daný poloměr na větev stabilní a nestabilní. Větev nalevo od kritického bodu je stabilní a větev napravo od kritického bodu a kritický bod je nestabilní. Při libovolném výskytu bubliny může dojít k zvětšení nebo zmenšení poloměru, k tzv. poruchám.

Popis chování bubliny na stabilní větvi

Jestliže se bublina nachází na stabilní větvi ($R<R_c$) a její poloměr se zvětší (aniž by překročil kritický poloměr) nebo zmenší, tak se po této poruše bublina navrátí do rovnovážného stavu. Vysvětluje se to tím, že při zvětšení poloměru bubliny klesne tlak v bublině nepřímo s třetí mocninou poloměru bubliny a kapilární tlak klesne pouze s první mocninou poloměru. Tím tedy význam kapilárního tlaku vzroste a navrátí ji do rovnovážného stavu. Analogicky lze popsat zmenšení poloměru bublinky, kdy naopak tlak v bublině roste s třetí mocninou a kapilární tlak roste pouze s první mocninou.

Popis chování bubliny na nestabilní větvi

Jestliže se ale bublina nachází na nestabilní větvi ($R>R_c$) a její poloměr se zvětší, objem bubliny bude růst. Vysvětlit to lze na základě hodnoty tlaku plynu v bublině. Je malý oproti tlaku nasycených par, protože bublina je velká. Se změnou poloměru nedochází k výrazné změně tlaku plynu uvnitř bubliny. Pak celkový tlak v bublině můžeme považovat za tlak nasycených par. Co se ale bude měnit je kapilární tlak. Ten se zmenší s rostoucím poloměrem a tak tlak nasycených par bude při snižování kapilárního tlaku podporovat růst bubliny. Naopak při zmenšení poloměru bubliny kapilární tlak poroste a způsobí zmenšení bubliny. Zmenšení bude až na kritický poloměr.

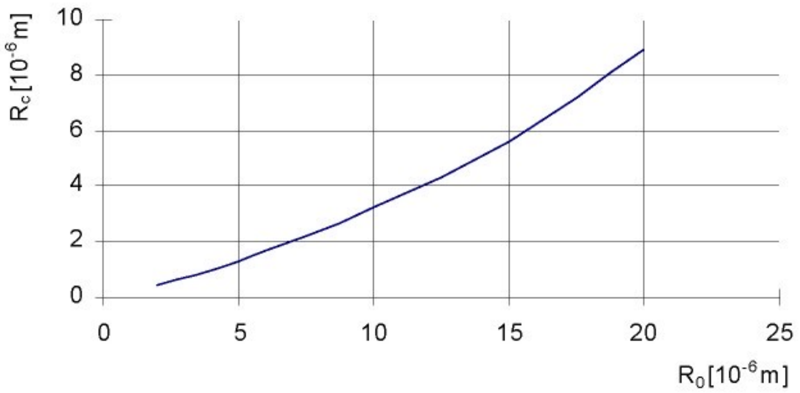
Popis chování bubliny v kritickém stavu

Pokud se bude bublina nacházet v kritickém bodu, tak mohou nastat dvě varianty rovnováhy, stabilní a nestabilní. Stabilní je v případě zmenšení poloměru bubliny a nestabilní je při zvětšení poloměru bubliny.

Matematickou úpravou vztahů 4.6 a 4.3 můžeme kritický poloměr $\boldsymbol{R_c}$ v závislosti na počátečním poloměru $\boldsymbol{R_0}$ vyjádřit následujícím vztahem.

$$R_c = R_0 \cdot \sqrt{\frac{3 \cdot R_0}{2 \cdot \sigma} \cdot p_{g0}} \qquad (4.7)$$

Tato závislost je znázorněna v následujícím grafu pro v měření používaný olej.

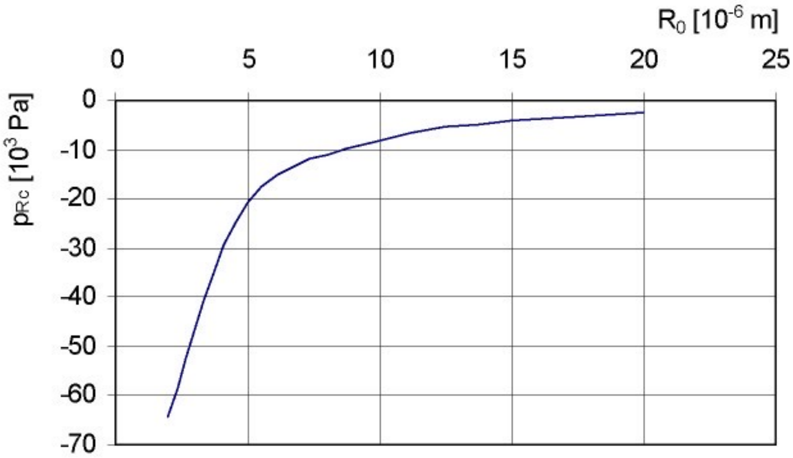


Graf 4.2: Závislost kritického poloměru na počátečním poloměru

Kritický poloměr $\boldsymbol{R_c}$ dosadíme do rovnice 4.3 a získáme vztah popisující kritický tlak $\boldsymbol{p_{Rc}}$.

$$p_{Rc} = p_v - \frac{2}{3} \cdot \frac{2 \cdot \sigma}{R_c} \qquad (4.8)$$

Závislost 4.8 je pro námi používaný olej v následujícím grafu.



Graf 4.3: Závislost kritického tlaku na počátečním poloměru

4.6 Dynamika kmitající kavitační bubliny

Popis dynamiky kavitační bubliny zahrnuje řadu okolních vlivů, jak je uvedeno v kapitole 4.3. Je důležité říci, že kavitační bublina při své aktivitě vykonává roztahování a smršťování, což představuje kmitavý pohyb. Odvození bylo provedeno několika autory a dle autora se metodika odvození může lišit. Rovnice 4.9 se nazývá Rayleigh-Plessetova a popisuje dynamiku kmitající kavitační bubliny. Tato práce se dynamikou kavitační bubliny nezabývá.

$$\frac{p_B(t) - p_\infty(t)}{\rho_l} = R \cdot R'' + \frac{2}{3} \cdot (R')^2 + \frac{2 \cdot \sigma}{\rho \cdot R} + \frac{4 \cdot \mu \cdot R'}{\rho \cdot R} \qquad (4.9)$$

5 METODY DIAGNOSTIKY KAVITACE

5.1 Diagnostika kavitace

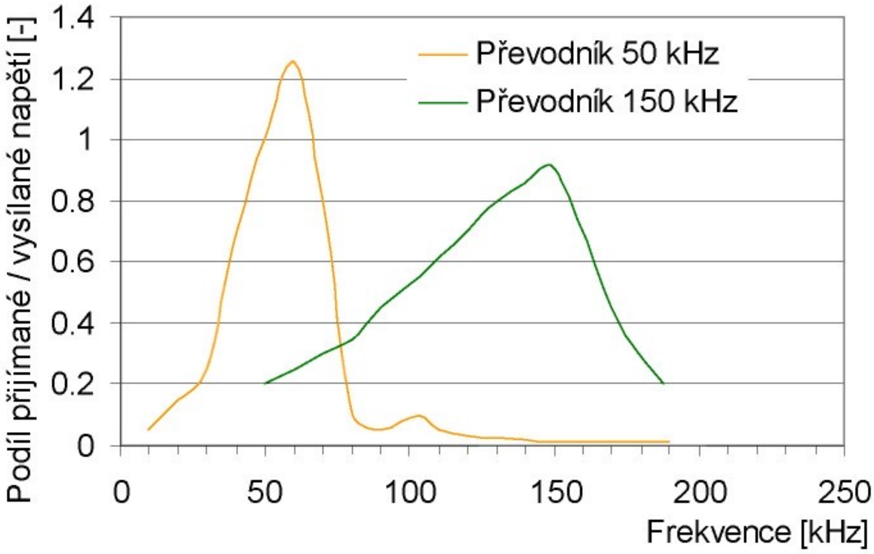
Kavitaci diagnostikujeme různým způsobem. Existuje mnoho metod pro konkrétní aplikace v čerpadlech, turbínách, armaturách, apod. Obecné metody jsou metoda optická a metoda akustická. Optické metody diagnostiky kavitace jsou např. metody stínová, šlírová a PIV. Akustické metody jsou např. detekce kolapsů bublin pomocí hydrofonů, nebo metoda měření spektra bublinek pomocí akustického bublinkového spektrometru (ABS). V této práci jsou vysvětleny pouze některé.

5.2 Metoda ABS

Metoda ABS je speciální akustická metoda. ABS znamená akustický bublinkový spektrometr. Měříme s ním množství bublinek v závislosti na poloměru a objemový zlomek bublinek v závislosti na poloměru. Metoda je založena na šíření zvuku ve vícesložkovém systému látek. Jedna látka je spojitá a v ní je rozptýlena druhá látka. Spojitá látka je v našem případě tekutina – hydraulický olej a v ní je rozptýlena plynná látka – kavitační bubliny. Takovéto prostředí nazýváme disperzním prostředím. Pro disperzní prostředí platí, že rychlost zvuku, která disperzním prostředím prochází, závisí na frekvenci tohoto zvuku. Všechny možné závislosti týkající se prostředí, spektra bublinek, šíření zvuku a další, lze popsat matematicky. Vzniknou tak rovnice, které se řeší speciálními numerickými metodami ve výpočetním softwaru. Výsledkem výpočtu jsou již zmíněné závislosti.

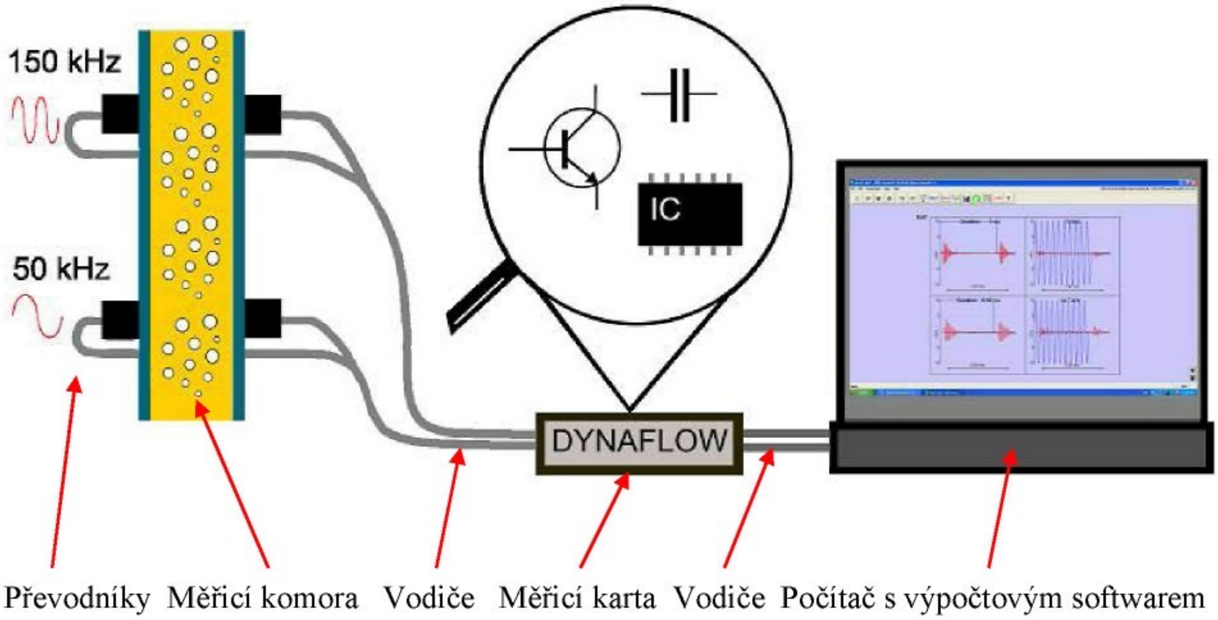
Pro řešení rovnic je potřeba získat signál zvuku, který prošel prostředím a zadat vstupní fyzikální vlastnosti měřené tekutiny a okolního prostředí, dále pak parametry signálu a výpočtu. Vstupní vlastnosti okolního prostředí jsou atmosférický tlak a teplota vzduchu. Vstupní vlastnosti týkající se měřené tekutiny jsou Poissonova konstanta plynu uvnitř kavitační bubliny, teplotní vodivost plynu uvnitř kavitační bubliny, tlak nasycených par tekutiny, rychlost zvuku v tekutině, viskozita tekutiny, hustota tekutiny a povrchové napětí tekutiny. Mezi parametry signálu a výpočtu patří vzdálenost převodníků, volba parametrů signálu a množství měřených poloměrů. Mezi parametry signálu patří minimální a maximální frekvence, počet vyslaných signálů pro výpočet průměrných hodnot a další. Nakonec se zadávají parametry pro omezení řešení. Jedná se o minimální a maximální poloměr bublin a počet velikostí bublin.

Zvukový signál se vysílá a přijímá pomocí piezokeramických převodníků. První piezokeramický převodník – vysílač vysílá zvukový signál. Druhý piezokeramický převodník – přijímač přijme zvukový signál vyslaný prvním převodníkem. Převodníky jsou tvořeny aktivní částí, opěrnou částí a styčnou částí. Všechny tyto části jsou zality ve speciálním materiálu. Rozměry a materiál všech částí a zalití jsou navrženy dle určitých pravidel. Liší se od sebe pro přímý kontakt s tekutinou při ponoření do tekutiny, nebo pro další vrstvu, oddělující převodník od tekutiny. Při našich měřeních používáme konstrukci převodníku vhodnou pro kontakt přes další vrstvu. Převodníky se umísťují proti sobě a musí být od sebe akusticky odizolovány, aby se zvukový signál nepřenášel přímo přes konstrukci. Na druhou stranu musí být zabezpečen dobrý přenos zvukového signálu mezi převodníkem a měřeným prostředím. Zajišťuje se to pomocí vhodného prostředí, které má podobnou akustickou impedanci jako materiál převodníku. Vhodný materiál je v našem případě plexisklo (PMMA) a dále indiferentní gel, který se nanese na převodník. Převodník s gelem se přimáčkne na velmi malou mezeru k měřícímu okénku z plexiskla a poté se převodník stabilně ustaví. Piezokeramické převodníky jsou kalibrovány pro různý interval vysílání a přijímání. Z tohoto důvodu se používají převodníky pro střední oblast hodnoty frekvence 50 kHz a 150 kHz. Tím se zahrne celá oblast od hodnot frekvence menší jak 50 kHz a větších jak 150 kHz. Následující graf 5.1 znázorňuje, jak přibližně vypadají oblasti použití převodníků, které jsou součástí měřicího zařízení ABS.



Graf 5.1: Charakteristiky převodníků ABS

Při měření je z měřicí karty opakovaně vysílán signál různé frekvence, který je zesílen výkonovým zesilovačem. Do prvního převodníku – vysílače přichází zesílený zvukový signál a je převodníkem vyslán do měřeného prostředí. Přijímač přijímá zvuk, který prošel disperzním prostředím, kterým je „utlumen“. Zvukový signál přijímače je zesilovači zesílen a vede se do měřicí karty. Měřicí karta je AD/DA převodník signálu. Z měřicí karty se data převedou do počítače. Následující obrázek 5.1 ukazuje základní měřicí sestavu.



Obr. 5.1: Základní měřicí sestava ABS

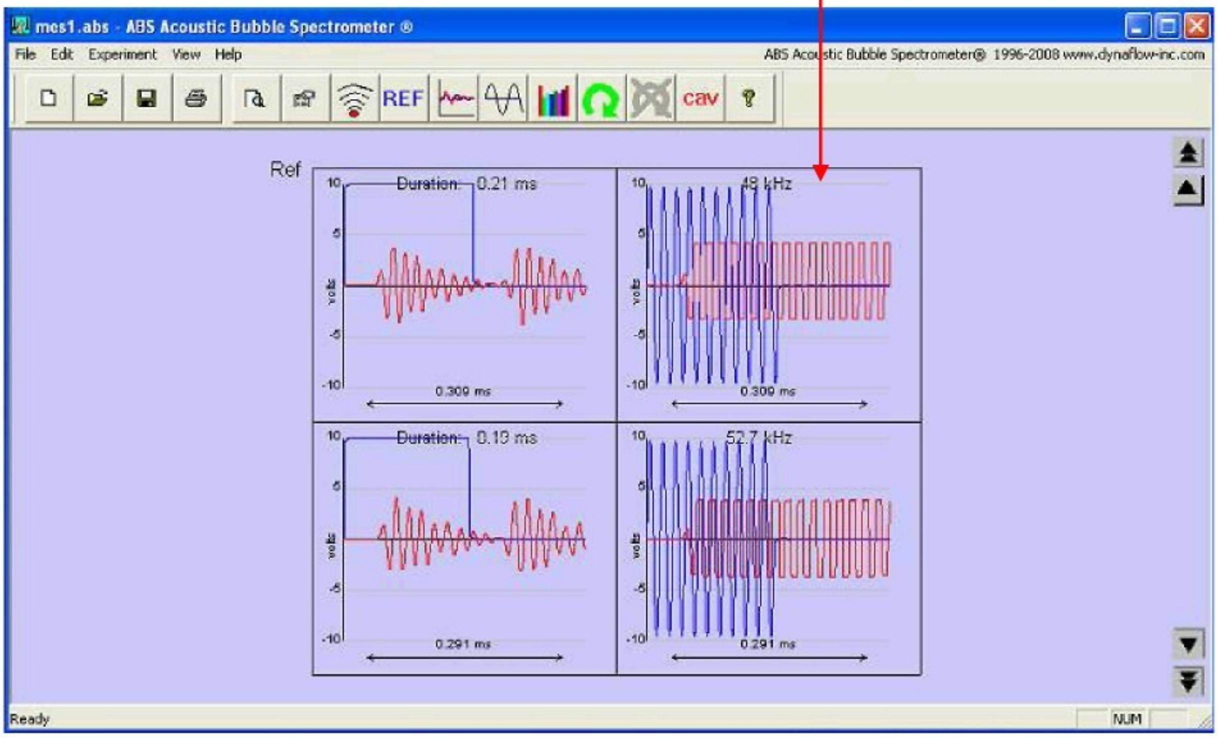
Data z měřicí karty v počítači zpracovává speciální výpočtový software. Matematické řešení spočívá ve vyřešení Fredholmových integrálních rovnic prvního řádu. Tyto rovnice mají tvar dle obecného vztahu 5.1, kdy neznámá funkce počtu bublinek v závislosti na poloměru N(R) je v integrálu s tím, že meze integrálu neobsahují proměnnou. Funkce f(ω) je závislá na frekvenci signálu zvuku a je zjištěna vlastním měřením. Výpočtové numerické algoritmy softwaru byly navrhnuty pracovníky výrobce.

$$f(\omega) = \int_{y_{10}}^{y_{hl}} k(\omega, R) \cdot N(R) \cdot dR \qquad (5.1)$$

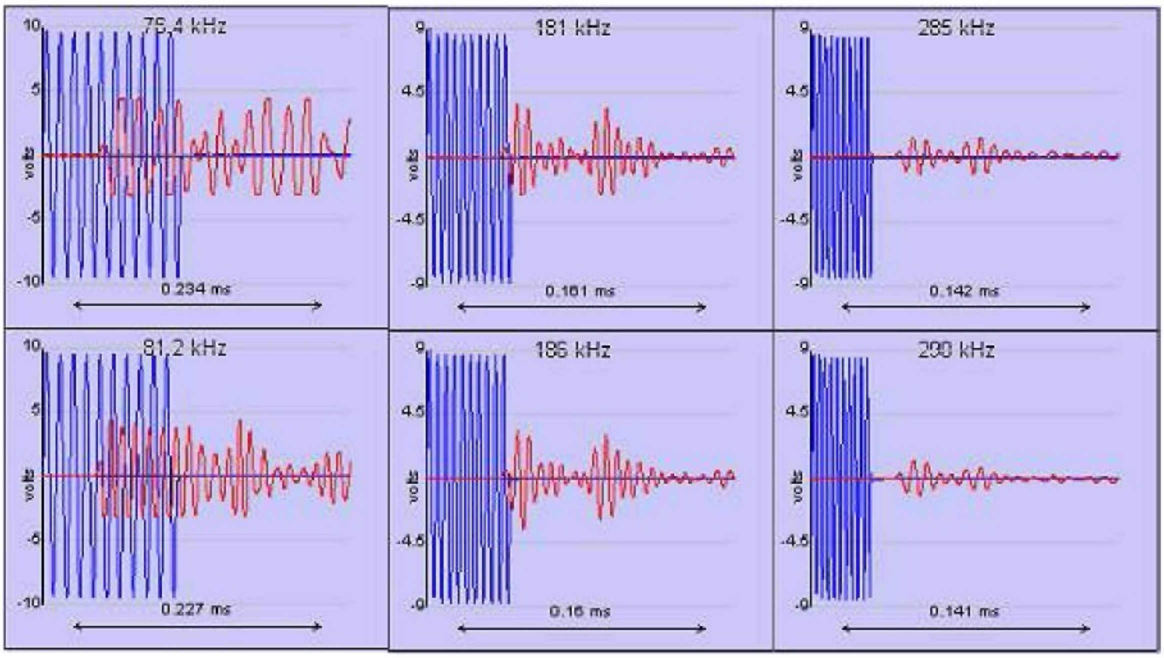
Při řešení rovnic mohou nastat problémy s definováním určitých mezikroků výpočtu. Nejčastěji se problém týká rozložení bodů při dělení intervalu pro řešení. Pak mohou vznikat nestability řešení. Existují ale i další problémy, například s omezujícími počátečními podmínkami (rovnice platí do určitého objemového zlomku, oscilace bublin jsou sférické, …) nutnými pro existenci vůbec nějakého řešení. Proto je vhodné provést vždy různá kalibrační měření a na jejich základě rozhodnout o pravdivosti skutečného měření.

Na obrazovce počítače v aplikaci ABS je při každém měření zobrazen průběh všech vysílaných a jím odpovídajících přijímaných signálů. Vysílaný signál je modrý a přijímaný signál je červený. Na následujícím obrázku 5.2 je obrazovka softwaru ABS a na obrázku 5.3. jsou průběhy několika vybraných signálu pro různé frekvence.

Průběh vysílaného a přijímaného signálu pro danou frekvenci

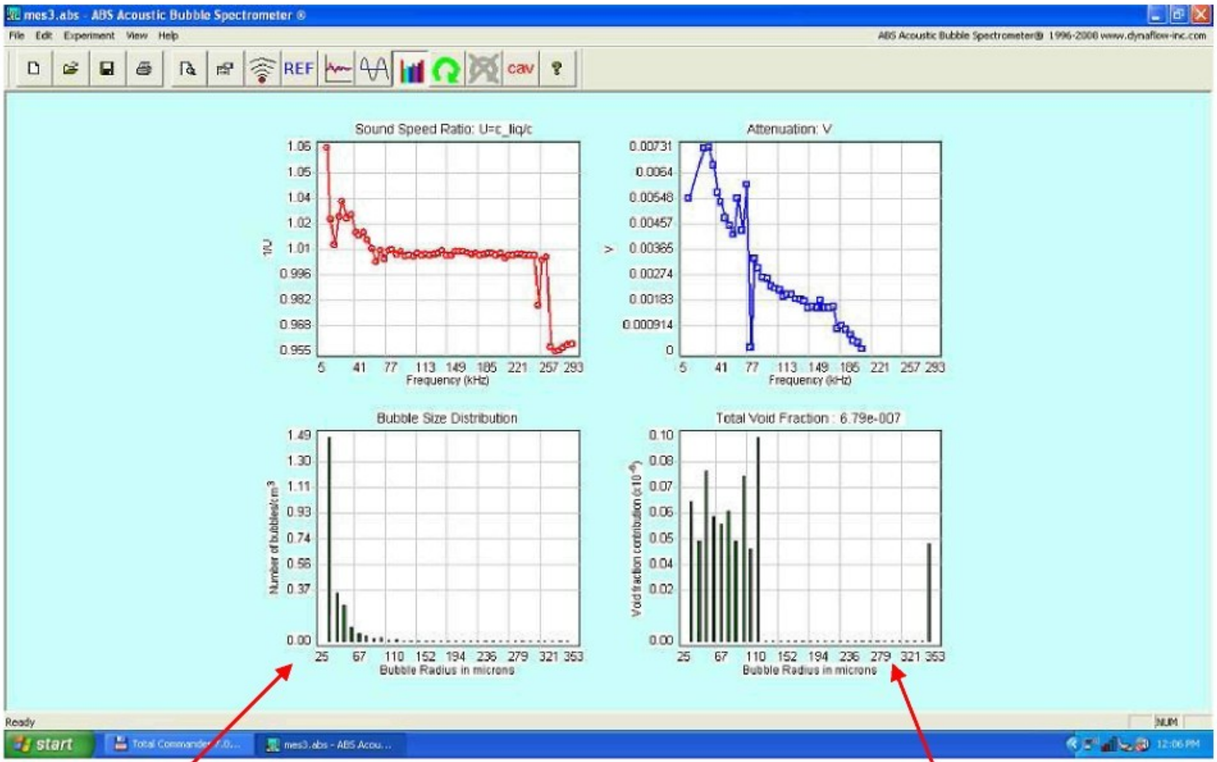


Obr. 5.2: Obrazovka softwaru ABS



Obr. 5.3: Průběhy vybraných signálů různých frekvencí

Po zpracování signálu software vypočte metodou zmíněnou v této kapitole spektrum bublin v 1 mm^3 v daném okamžiku. Na obrázku 5.4 je obrazovka softwaru ABS s dílčím výsledkem. Ve spodní části je grafické vyobrazení spektra bublin a objemového podílu bublin v daném okamžiku. Vrchní grafy zobrazují data o zeslabení signálu.



Spektrum bublin Objemový podíl bublin

Obr. 5.4: Výsledek dílčího měření ABS

Grafických zpracování dílčích výsledků jako na obr. 5.4 je na základě požadavků na měření (vzorkování, rozdělení intervalu na poloměry bublin, …) mnoho. Všechny výstupy jsou ukládány jako textový soubor, který lze převést do programu Excel a v něm provést výsledné grafické zpracování.

Výrobcem měřicího zařízení ABS je americká firma Dynaflow Inc. Akustický bublinkový spektrometr je patentovaný výrobek a v současné době existuje na celém světě pouze několik kusů v několika vývojových variantách.

5.3 Stínová metoda

Stínová metoda je jednou ze základních a nejjednodušších optických metod pro zobrazování nehomogenit (kavitačních bublin) v transparentních tekutinách. Kavitační bubliny se vhodným způsobem prosvětlují laserem, halogenovou lampou nebo xenonovou lampou. Za měřený objekt se vkládá stínítko nebo zařízení pro záznam obrazu, takzvaného stínogramu. Fyzikálním principem je zakřivení trajektorie paprsků světla při průchodu bublinou. Tyto paprsky mají v různých místech různou hustotu, což se projeví na stínítku stíny a obrysy. Na stínogramu bude kavitační bublinka tmavší, protože světlo se v bublince rozptýlí o hodně více než při průchodu pouze tekutinou. Princip této metody si lze jednoduše představit na školním pokusu, kdy se sklo ponoří do kapaliny o stejném indexu lomu, např. dětského oleje a zmizí. Je to důsledkem toho, že rozhraní mezi nemísitelnými látkami je našemu oku, které je v tomto pokusu stínítkem, viditelné pouze při různém indexu lomu obou látek. Stínové metody jsou vhodné pro diagnostiku v prostředích velkých změn indexu lomu.

V našem případě používáme pro osvětlování paralelní svazek paprsků, který je vytvořen studiovým bleskem na obrázku 5.5 FOMEI Digital PRO 1200 s výkonem záblesku 1200Ws a pilotní halogenovou žárovkou o výkonu 1000W. Paprsky pilotní žárovky se po průchodu prostředím zaznamenávají vysokorychlostní CCD kamerou. CCD kamera je digitální kamera připojitelná k počítači. Základem je CCD snímač, což je elektrotechnická součástka. Princip je založen na fotoelektrickém jevu u polovodičů, kdy se kvanta fotonů přemění na elektrický náboj na elementární jednotce CCD snímače, takzvaném pixelu. Tento náboj se působením elektrostatického pole posouvá přes celou pixelovou mříž, zesílí se a převede na datový kód. Jestliže se jedná o rychlokameru, je tento proces velmi rychlý v řádu statisíců za sekundu. Tím je vytvořen obrazový digitální záznam. Ve školní laboratoři používáme CCD rychlokameru značky Integrated Design Tools, Inc., Redlake, typu MotionPro X3 s možným záznamem až 64000 snímků za sekundu, viz obrázek 5.6.

Obr. 5.5: Studiový blesk [16]

Obr. 5.6: CCD rychlokamera [14]

Touto CCD rychlokamerou získáme stínogram v digitálním formátu, který lze na počítači v programu Matlab ve speciální aplikaci zpracovat. Tato aplikace má slangový název „počítání rýže“. Aplikace sama obrázek zpracuje. Principem je ztmavení pozadí a vyřazení objektů, které nemají nic společného s definovanými objekty pro počítání a zesvětlení sledovaných bublin. Princip úprav je zobrazen na obrázku 5.7. Aplikace následně provede součet bublin, které odpovídají zadání. Matlab podpora na internetu uvádí, že spolehlivost výpočtu je 95%.

Obr. 5.7: Postup zpracování obrázku při metodě „počítání rýže“ [18]

5.4 Detekce kolapsů kavitačních bublin pomocí hydrofonů PVDF

Hydrofon je snímač tlaku šířícího se v kapalině. Pro detekci kolapsů kavitačních bublin se PVDF (Polyvinylidenfluorid) vysokofrekvenční hydrofony používají pro své obecně dobré vlastnosti pro tento typ měření. Hydrofony PVDF jsou založené na piezoleketrickém jevu, kdy tlaková síla mechanicky deformuje piezoelektrický element. Deformací se element polarizuje na určitý elektrický náboj. Elektrický náboj o určitém napětí je zesilovači zesílen a změřen. Změřená hodnota napětí odpovídá tlaku v kapalině. Hydrofony jsou speciálně kalibrovány a tlak měří velmi přesně.

Při výzkumu kavitace se hydrofony používají pro měření kolapsů kavitačních bublin. Kolaps s sebou nese tlakový pulz, který měříme. Výstupem je velké množství tlakových signálů, které se při zpracování od sebe oddělují a analyzují. Ve školní laboratoři používáme vysokofrekvenčního PVDF hydrofonu RP Acoustic RP 19 s. Signál je zesílen a veden do oscilografické karty National Instruments NI PXI 5105, 8-CH, 60 MS/s. Z oscilografické karty je veden přes sběrnici do National instrument NI PXI 1033 Chassis a z této sběrnice do počítače. Následně se signál vyhodnocuje a zpracovává v počítači.

Obr. 5.8: Hydrofon PVDF [17]

6 MĚŘENÍ

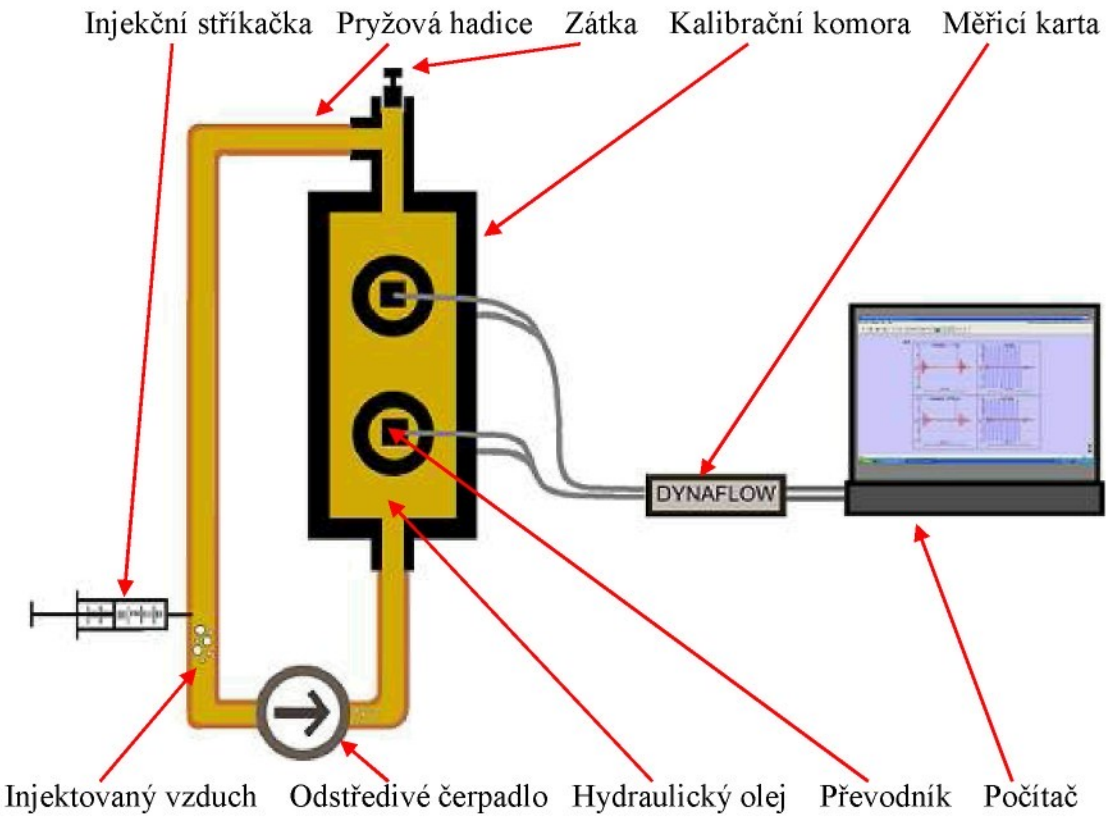
6.1 Kalibrační měření ABS

6.1.1 Kalibrační trať

Kalibrační trať slouží pro kalibrační měření. Kalibračním měřením v našem případě označujeme měření, které je vůbec prvním takového druhu ve školní laboratoři KEZ TUL a slouží nám pro obecné posouzení vhodnosti metodiky ABS pro další, již skutečné měření na modelu hydraulického tlumiče v Hydrodynamické laboratoři KST TUL.

6.1.2 Popis principu kalibračního měření na kalibrační trati pomocí ABS

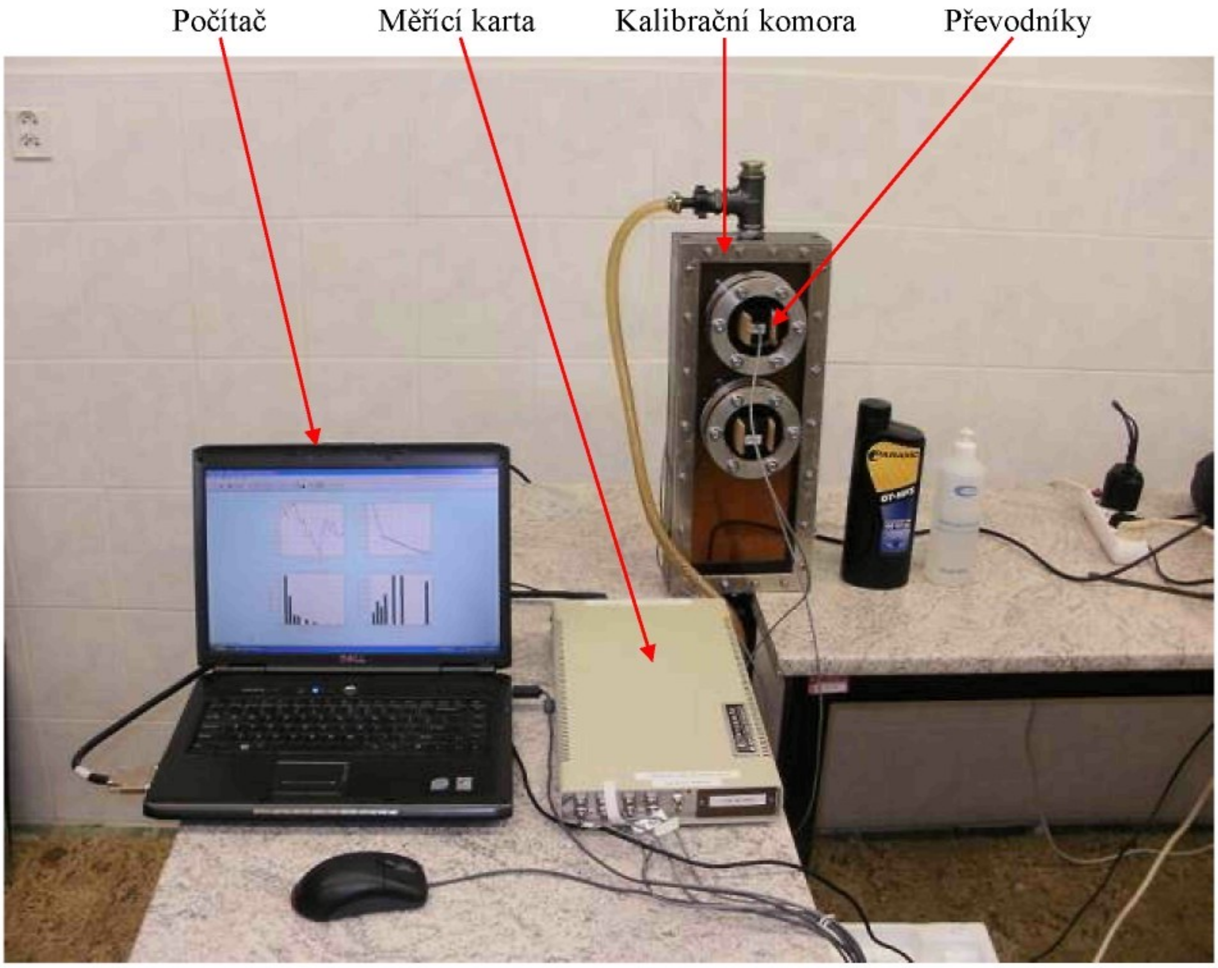
Úkolem bylo otestovat měření spektra bublin pomocí ABS v hydraulickém oleji. Základní myšlenka byla opakovaně dopovat oběh hydraulického oleje určitým objemem vzduchu pomocí injekční stříkačky a sledovat změnu spektra bublin. Po průchodu vzduchu čerpadlem se vzduch rozmísí v oleji a vzniknou bubliny. Tato směs se nechá určitý čas obíhat a bubliny tak budou homogenně rozprostřeny v celém objemu systému. Pak se provede měření pomocí ABS. Tento postup se několikrát opakuje. Princip měření a základní sestava je znázorněna na obrázku 6.1.



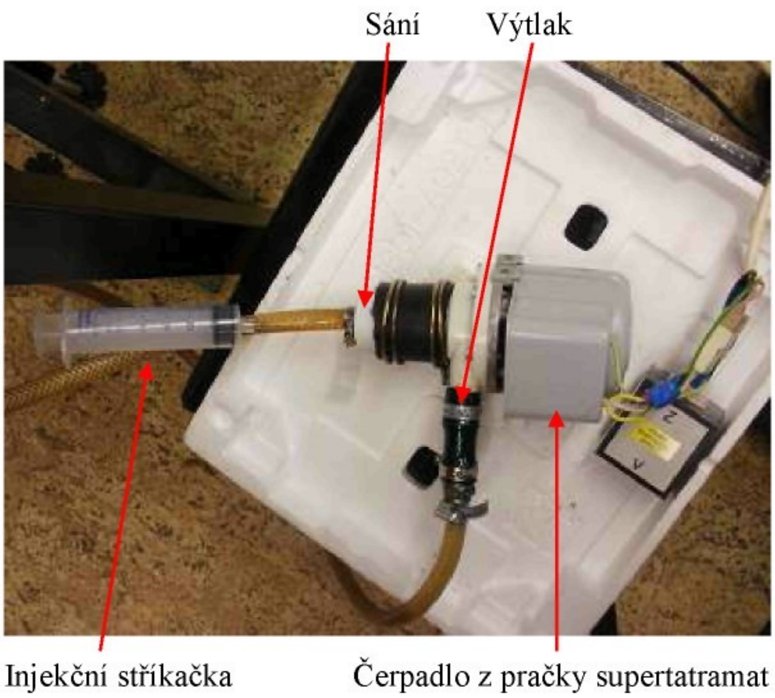
Obr. 6.1: Sestava kalibrační trati

Vedoucí práce navrhl zkonstruovat kalibrační trať z komory, která je k dispozici z dřívější výzkumné činnosti. Komora je sešroubovaná z hliníkových profilů, čelní stěny jsou z plexiskla a mají na sobě připevněna hliníková mezikruží. Na tato mezikruží se přes korkové těsnění připevňují speciální příruby s okénky pro převodníky. Korkové těsnění má v tomto případě funkci izolantu přenosu zvukového signálu mezi přírubou s převodníky a mezikružím. Tento zvukový signál by se přenesl přes hliníkovou konstrukci na přijímač přímo bez průchodu tekutinou. Konstrukce je tedy vytvořena speciálně pro metodu ABS.

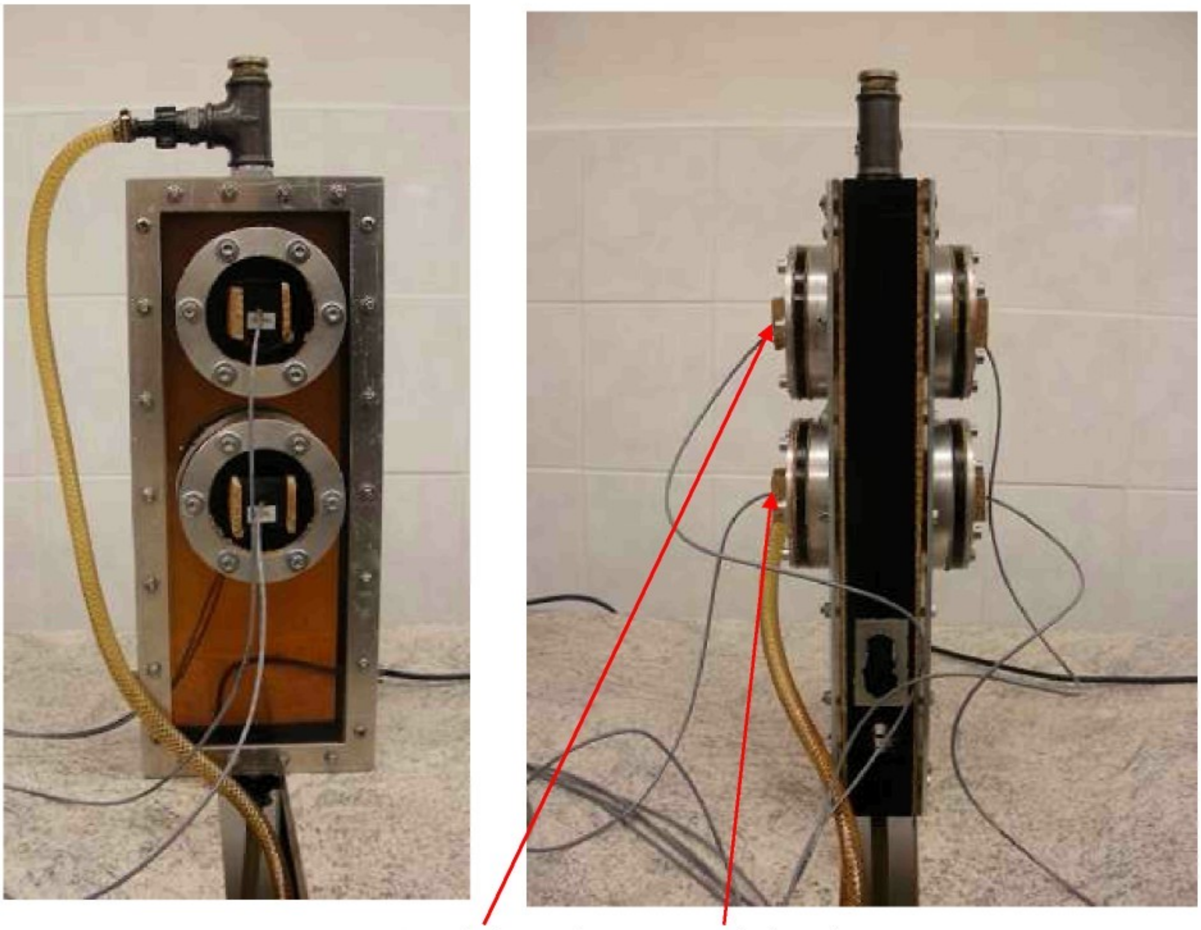
Před sestrojením kalibračního zařízení bylo nutné komoru natřít speciální černou barvou pro zabránění koroze od hydraulického oleje a pro možnost osvětlování laserem se zamezením nekontrolovatelnosti odrazu od hliníkového povrchu komory. Bylo nutné sehnat několik topenářských a hydraulických armatur, pryžové hadice a čerpadlo. Komora pak byla smontována následně popsaným způsobem a byla vyměněna těsnění. Komoru lze odstraněním zátek ve spodní a vrchní části vytvořit jako průtočnou komoru. Místo zátky ve vrchní části komory se zašroubovala dvouvsuvka a na ni T kus. Na T kus je v horizontálním směru přišroubována redukce na pryžovou hadici a ve vertikálním směru zátka, kterou se v systému za provozu vytvoří mírný přetlak. Pryžová hadice pokračuje k odstředivému čerpadlu z pračky supertatramat. Z čerpadla pokračuje druhá pryžová hadice, která vede k redukci a k dvouvsuvce a tím je připojena ke spodní části komory. Po smontování se systém přes T kus ve vrchní části komory naplní hydraulickým olejem. Uzavře se a mírně přetlakuje zátkou. Poslední nedílnou částí je plastová injekční stříkačka se závitem, do kterého se zašroubuje jehla. Tato injekční stříkačka dodává do oběhu předem dané množství vzduchu. Proto musí být připojena na okruh. Vyřešilo se to jednoduchým způsobem. Stříkačka s jehlou byla napíchnuta na pryžovou hadici. Předepjatost pryže jehlu nepropustně obepnula a z místa napíchnutí pryžové hadice neunikal žádný hydraulický olej. Na následujících obrázcích je kalibrační trať.



Obr. 6.2: Kalibrační trať



Obr. 6.3: Detail čerpadla a injekční stříkačky



Převodník 150 kHz   Převodník 50 kHz

Obr. 6.4: Detail kalibrační komory

6.1.3 Měření na kalibrační trati

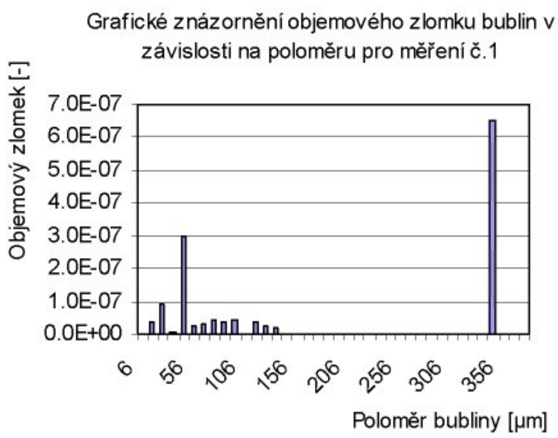
Postup měření na kalibrační trati je popsán v následujícím odstavci. Komora s hydraulickým olejem byla několik dní ponechána v klidu. V tomto období byly z komory vyvedeny všechny bublinky ulpívající na stěnách a v čerpadle.

Vlastní měření začalo základním nastavením softwaru ABS. Nejdůležitější částí bylo nastavit vstupní vlastnosti hydraulického oleje a okolního prostředí, dále pak vlastnosti signálu a jiná omezení. V příloze P5 jsou obrázky z tohoto nastavení ve čtyřech krocích. V prvním kroku se měření pojmenovalo, nastavil čas a datum. Ve druhém kroku byly za pomoci vedoucího bakalářské práce nastaveny parametry signálu dle jeho zkušeností. Důležité bylo správně změřit vzdálenost převodníků, ze které se stanoví objem měřené oblasti. Ve třetím kroku byly zadány parametry tekutiny a okolního prostředí. Byl změřen aktuální atmosférický tlak a teplota vzduchu v laboratoři. Parametry tekutiny byly zjištěny z měření viskozity, měření kapilárního napětí, atd. Tlak nasycených par nebyl měřen, ale dle telefonického rozhovoru se specialistou na oleje firmy Paramo, a.s. je tlak nasycených par hydraulických olejů pro tuto skupinu olejů přibližně stejný. K dispozici byly údaje z rešerše olejů z tabulky 3.1 této bakalářské práce. Byla k dispozici rychlost zvuku 1535ms^{-1} v hydraulickém oleji. V posledním, čtvrtém kroku, bylo nastaveno omezení výstupu. Byl určen interval měřených poloměrů a také rozdělení tohoto intervalu na jmenovité poloměry, kterými se bude přiřazovat počet bublin v daném objemu. Nastavení se uložilo.

Po nastavení bylo nutné provést referenční měření. K tomuto referenčnímu měření se vztahují všechna následující vlastní měření. Při referenčním měření byl oběh hydraulického oleje zastaven. Toto měření bylo uloženo a software ABS z něho při výpočtech odebírá potřebná data pro vyhodnocení vlastních měření.

Následovalo měření na kalibrační trati. Čerpadlo bylo spuštěno a po 5 minutách bylo do oběhu před čerpadlem injekční stříkačkou vpraveno 0,2 cm^3 vzduchu. V čerpadle se vzduch s olejem promísil. Tato směs se nechala 15 minut obíhat a potom se provedlo první měření po dobu 5 minut. Po měření se čerpadlo na 5 minut vypnulo a nechalo vychladnout. Celý tento postup se pětkrát opakoval. Do oběhu bylo vpraveno celkem 1 cm^3 vzduchu po částech o objemu 0,2 cm^3 vzduchu.

V probíhajícím měření se za pět minut vytvořilo okolo 15ti takovýchto dílčích výstupů ve formě textového souboru ukázkou v příloze P6. Textový soubor se převedl do tabulkové formy programu Excel. V Excelu bylo provedeno grafické vyhodnocení, které je kompletně v příloze P7 a ukázkou viz. obrázek 6.5. Jedná se o grafické vyhodnocení počtu bublin v závislosti na poloměru bubliny a objemového zlomku bublin v závislosti na poloměru bubliny. Začíná se od prvního měření po první injektáži. Celkové grafické vyhodnocení je v příloze P8 a P9. Slovní hodnocení výsledků v přílohách je v odstavci 6.1.4.



Obr. 6.5: Ukázka vyhodnocení výsledků měření ABS

6.1.4 Zhodnocení měření na kalibrační trati

Většina dějů v přírodě je nějak podobná se základními matematickými funkcemi. V našem případě to byl předpoklad exponenciálního rozdělení spektra bublin v hydraulickém oleji. Grafy spektra bublin ve všech přílohách jsou klesající přibližně dle exponenciálního rozdělení. Nejvíce je nejmenších bublin a čím větší bubliny jsou, tím je jich méně. Komplexně to platí u druhého měření. Pro další měření už předpoklad komplexně neplatí. Průběh grafu je u prvního poloměru třetího a čtvrtého měření porušen, množství pro nejmenší poloměr je menší než množství pro větší poloměr. Pro páté měření je situace obdobná, ale u prvního poloměru vykazuje enormní nárůst množství bublin. Tyto neobvyklé úkazy mohou být způsobeny předem definovanými podmínkami pro výpočetní algoritmus výrobce nebo tím, že nemáme vhodný rozsah převodníků a v krajních intervalech je správnost řešení omezena.

Všechna měření vykazují u poloměru přes 30 mikrometrů propad množství. Může to být chyba metody, nebo fyzikální jev.

Vyskytuje se proluka mezi bublinami poloměru nad 100 mikrometrů a bublinami okolo 350 mikrometru. Počet bublin okolo poloměru 350 mikrometrů se téměř nemění. Předpokládá se, že je to dáno opět rozsahem převodníků a v daném případě horní mezí, nebo se jedná o chybu jiného charakteru a to bublinou v indiferentním gelu vzniklou při nanášení na převodník.

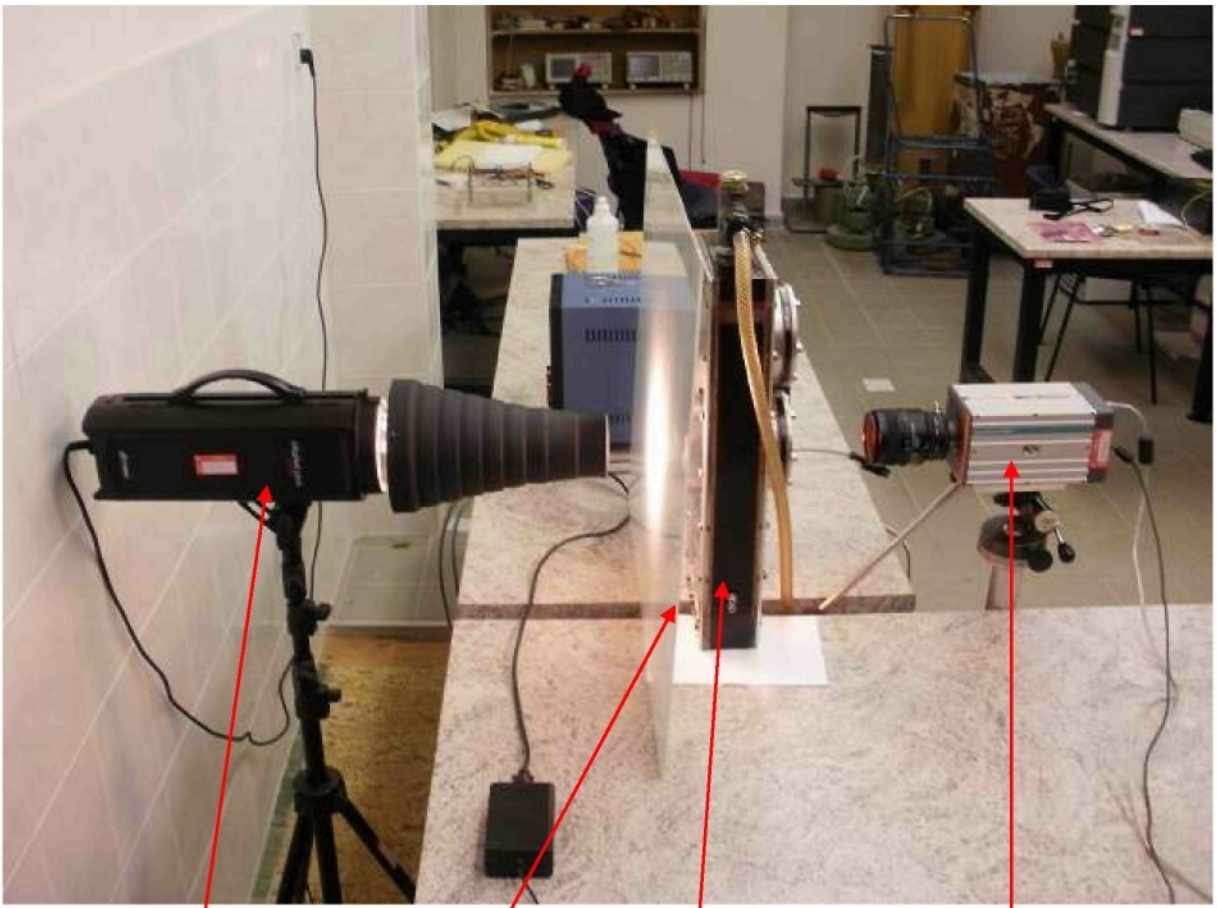
V příloze P8 je do jednoho grafu vynesena závislost spektra bublin všech měření na injektovaném vzduchu. Počet bublin s rostoucím množstvím injektovaného vzduchu roste. Podobně v příloze P9 roste s větším množstvím injektovaného vzduchu objemový podíl bublin na celku. V grafech v P8 a P9 nevynáším bubliny s poloměrem okolo 350 mikrometrů, protože je to nejspíše nepravdivý údaj, daný rozsahem převodníku nebo bublinami v indiferentním gelu.

Měření spektra bublin ve vodě pomocí ABS je nejčastější. Měření spektra bublin pomocí ABS v hydraulickém oleji tak známé není a proto není žádná možnost srovnání a konzultace. Výsledky tedy mohou mít širší význam, který prozatím nelze specifikovat.

6.2 Stínová metoda

6.2.1 Popis měřicí sestavy

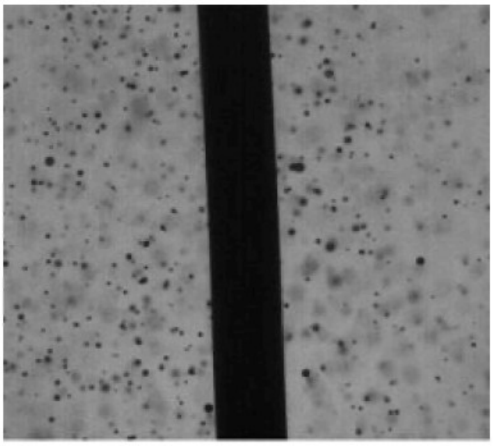
Měření stínovou metodou na kalibrační trati bylo doplňkovým měřením k metodě ABS a bylo charakteru seznámení s touto metodou. Snímky proto nebyly v Matlabu zpracovány a provedlo se pouze vizuální hodnocení. Pro osvětlování tekutiny v kalibrační komoře byla použita halogenová pilotní žárovku studiového blesku a světlo se soustředilo kuželovým nástavcem do prostoru snímaného kamerou. Světlo od lampy mělo obrovskou intenzitu, která nebyla pro osvětlení vhodná. Proto se mezi komoru a lampu vložilo pískované sklo. Pískované sklo rozptýlilo paprsek takovým způsobem, že přímé světlo do objektivu už nemělo takovou intenzitu. Proti osvětlení se na stativu umístila CCD kamera, spojená s ovládacím panelem na počítači. Kalibrační komora a její příslušenství je stejné konstrukce jako v případě měření ABS. Na obrázku 6.6 je měřicí sestava stínové metody. Na tomto obrázku není zachycen počítač. Datové kabely v pravém dolním rohu vedou k počítači.



Obr. 6.6: Měřicí sestava stínové metody

6.2.2 Snímkování stínovou metodou a vizuální hodnocení snímků

Po ustavení kamery se provedla kalibrace CCD kamery bez osvětlení halogenovou lampou. Kamera byla zaostřena na místo v rovině vedené prostředkem komory a nastavila se doba expozice. Následovalo několik snímání při dvojí injektáži asi 0,5cm^3 vzduchu. Nebyl stanoven přesný postup měření, protože se jednalo, jak již bylo zmíněno, pouze o metodické měření. Výsledkem byly řady snímků (stenogramů) tekutiny s bublinami, viz. obrázek 6.7. Výběr vždy jednoho snímku z řady ze všech měření je v příloze P10. V této příloze jsou seřazeny snímky v časovém sledu po první a druhé injektáži s několikaminutovým odstupem. Obrázky v příloze P10 popíšeme. Všechny snímky obsahují černou svislou čáru, což je stín drátu průměru 1,5mm, vloženého do komory pro snadnější zaměření místa středu komory. Z vizuálního hodnocení prvního snímku, kde je na levé straně primární proud po první injektáži, je zřejmé, že v kapalině bylo před první injektáži téměř nulové množství bublin. Po „homogenizaci", rovnoměrném rozptýlení bublin pomocí několikaminutového oběhu čerpadla, je na druhém snímku poznat zmenšení množství bublin touto „homogenizací" oproti primárnímu proudu na prvním snímku. Po několika minutách byl získám třetí snímek a z něho lze vyhodnotit, že došlo ke snížení počtu bublin v tekutině. Následovala druhá injektáž a na čtvrtém snímku je situace po „homogenizaci" druhé injektáže. Vizuálně je poznat, že došlo k velkému nárůstu množství bublin a také vznikly bubliny větších poloměrů. Poslední pátý snímek je získán krátce po čtvrtém snímku a nedošlo téměř k žádné změně.



Obr: 6.7: Ukázka snímku (stínogramu) z měření

6.3 Model hydraulického tlumiče

6.3.1 Účel zařízení

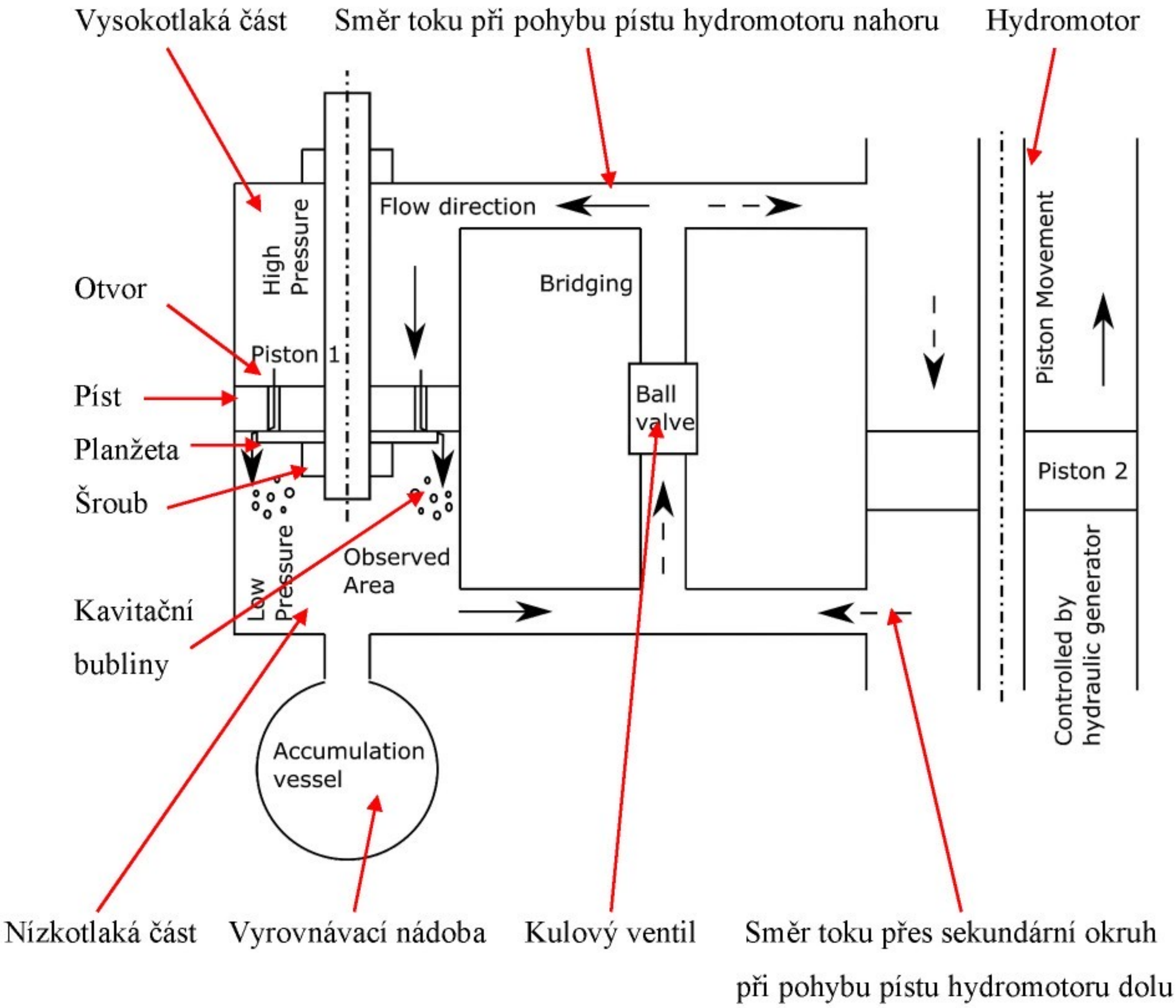
Model hydraulického tlumiče Hydrodynamické laboratoře KST TUL je speciální testovací zařízení, které simuluje skutečné děje v hydraulických tlumičích. Na tomto zařízení probíhalo několik experimentů, například výzkum charakteristiky ventilů hydraulického tlumiče.

V současné době probíhá příprava experimentu, který se bude zabývat vznikem kavitace za škrtícím elementem hydraulického tlumiče. Jedná se hlavně o optimalizaci škrtících elementů pro co největší zamezení vzniku kavitace.

Kompletní příprava experimentu sestává z konstrukce zařízení, ovládání zařízení a mnoha dalších kroků. Dnes je vědeckými pracovníky zkonstruován model tlumiče. Pracuje se na jeho ovládání a regulaci. Další přípravnou částí je vytvoření vhodných podmínek pro měření. Na tomto modelu tlumiče se bude měřit metodou ABS a optickými metodami.

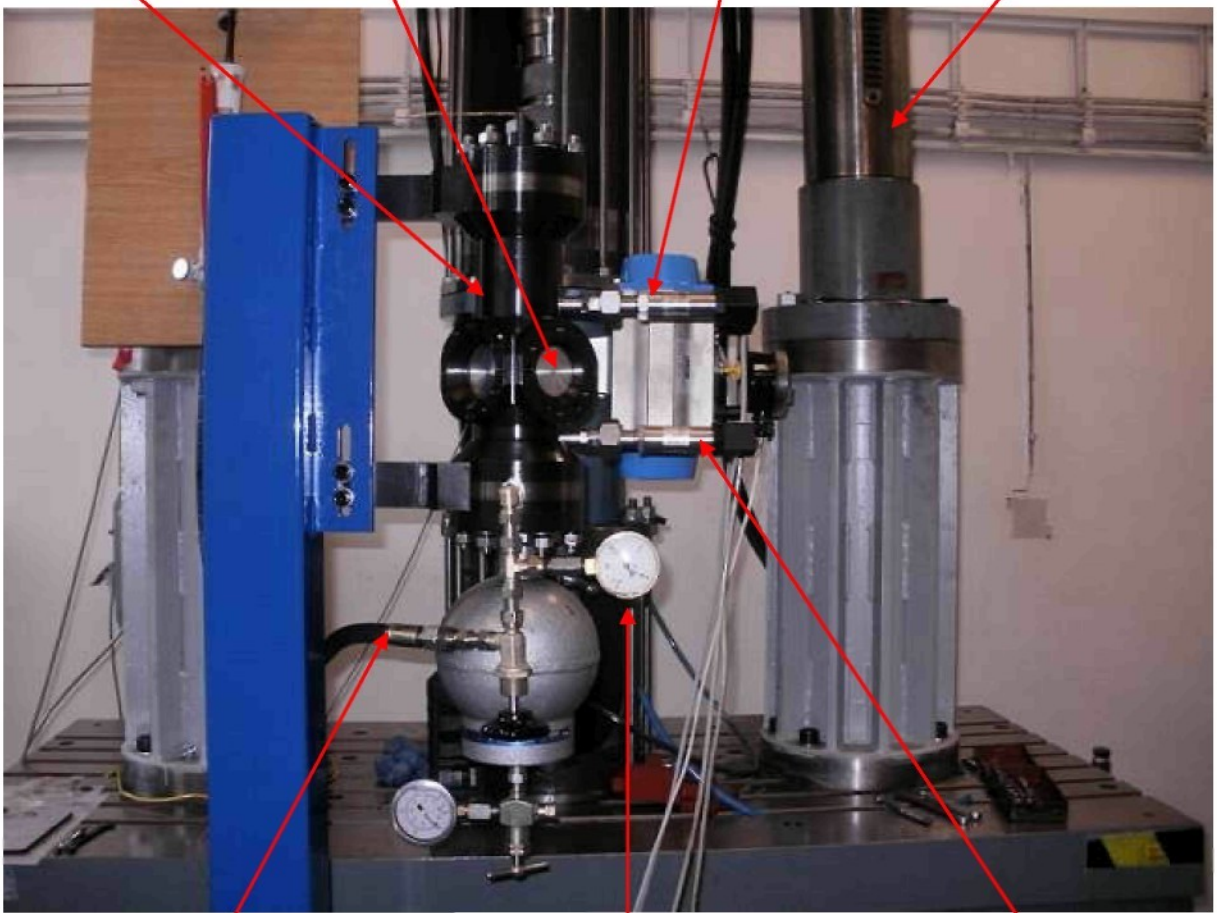
6.3.2 Popis zařízení

Model hydraulického tlumiče je průtočné zařízení velmi se přibližující skutečnému hydraulickému tlumiči. Velikostně se jedná o model tlumiče většího rozměru, podobnému tlumiči v nákladních automobilech a vozech v kolejové dopravě. Na následujícím obrázku 6.8 je schéma modelu, které bude popsáno.

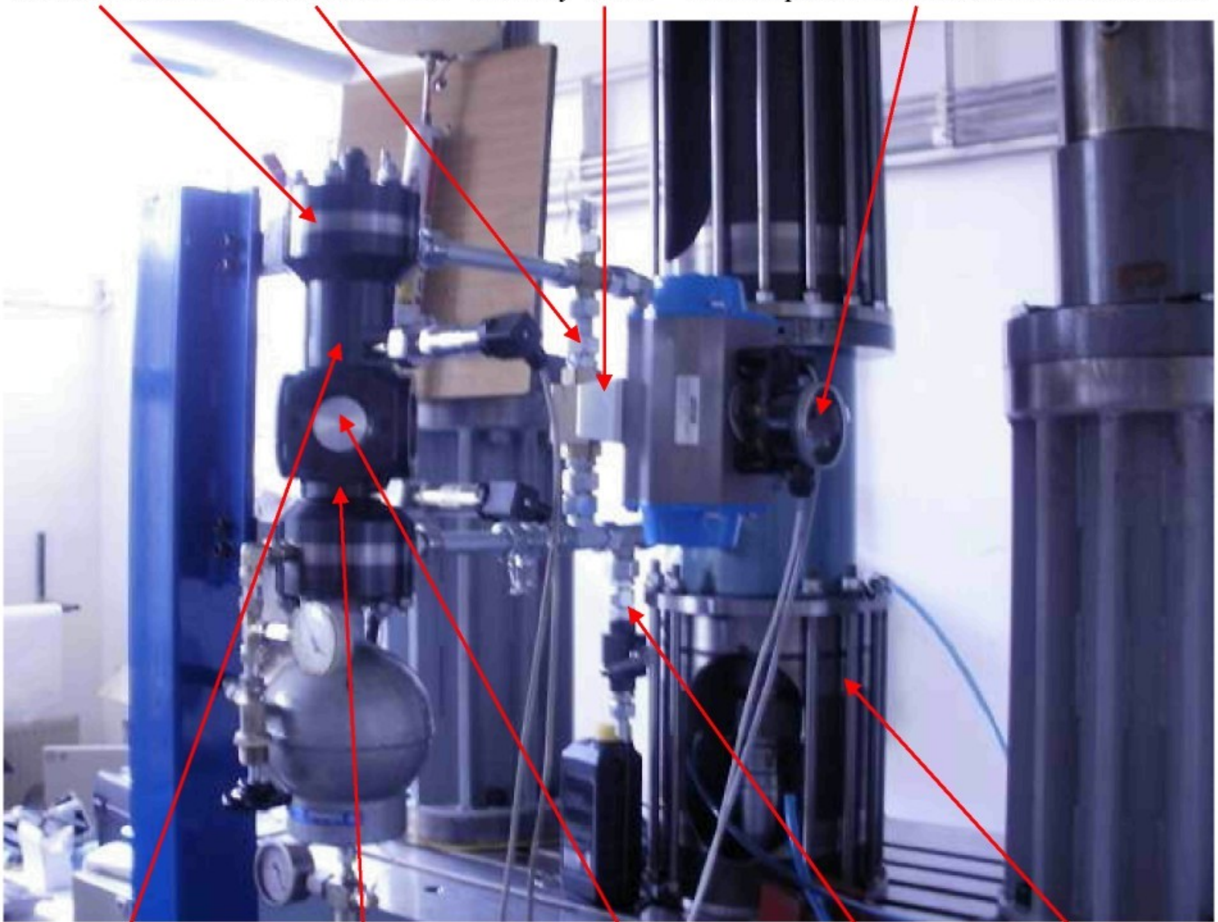


Obr. 6.8: Schéma modelu hydraulického tlumiče [19]

Model se skládá z komory a pístu se škrtícími elementy. Komora má nízkotlakou a vysokotlakou část. Obě tyto části mají tlakové snímače hydrofony, které slouží pro řízení hydromotoru a pro diagnostiku změny tlaku při „proběhnutí tlumiče" při různém kavitačním zpěnění hydraulického oleje. Nízkotlaká část má otvory pro umístění oken, na které se přitisknou převodníky ABS, nebo pro prosvětlování a snímání optickými metodami. Nízkotlaká a vysokotlaká část je oddělena pístem tlumiče. Píst má dvě sady otvorů, na kterých jsou pomocí pružin přitisknuty kruhové planžety a je tak vytvořen druh škrtícího elementu - ventil. V případě modelu tlumiče je píst nepohyblivý a nechává se skrz jeho škrtící elementy protékat hydraulický olej. Je to tedy přesný opak reálného tlumiče, kde se naopak píst pohybuje. Proud hydraulického oleje je vytvořen lineárním hydromotorem. Při pohybu pístu směrem vzhůru se olej nechává protékat skrz škrtící elementy pístu do nízkotlaké části. To je stav, kdy je tlumič ve funkci. Naopak, když jde píst směrem dolu, olej by se protlačoval skrz nízkotlakou část. Nízkotlaká část má okna z materiálu, který by velký tlak od hydromotoru, simulující hmotnosti několika tun, nemusel pevnostně zvládnout. Proto byla konstrukce vytvořena se sekundárním okruhem, přes který se hydraulický olej převádí při pohybu pístu dolu do prostoru nad píst. V tomto sekundárním okruhu je pneumaticky řízený kulový ventil. Otevírá a uzavírá okruh dle fáze ve které se model nachází. Z těchto důvodů je na nízkotlakou část připojen vyrovnávací zásobník, který vyrovnává mírné změny tlaku. Další součástí modelu je několik doplňujicích prvků, jako například ventil pro plnění modelu, na který je připojena hadice a pumpa, dále vypouštěcí a pojišťovací ventil. Obrázek 6.9 a 6.10 ukazuje skutečný model hydraulického tlumiče v Hydrodynamické laboratoři KST TUL na Doubí. V popředí je komora tlumiče a v zadní části je stojan hydromotoru.



Obr. 6.9: Model hydraulického tlumiče (pohled zepředu)



Obr. 6.10: Model hydraulického tlumiče (pohled z boku)

6.3.3 Metodika měření na modelu hydraulického tlumiče

Během zpracovávání bakalářské práce byla několikrát navštívena laboratoř modelu hydraulického tlumiče, kde došlo k seznámení s konstrukcí a funkcí. Model je těsně před dokončením. Při jeho dokončování před prvním spuštěním se vyskytlo několik problémů, které byly v průběhu času odstraněny. Jedním z problémů bylo řízení činnosti modelu. Model je řízen počítačovým programem, který je ve vývoji. Program je závislý na několika senzorech z komory a celého zařízení. Senzory tlaku - hydrofony nízkotlaké a vysokotlaké části způsobovaly problémy, protože snímaly namísto tlaku signál z jiných zařízení, přenášející se přes konstrukci. Tento problém byl odstraněn speciální přechodkou s teflonovým odstíněním hydrofonů.

Dokončovací proces je téměř u konce. Do této doby proběhlo několik testovacích zkoušek. Při posledním bylo provedeno měření tlaku hydrofony na nízkotlaké a vysokotlaké části.

Po dokončení testovacích měření bude prováděno měření metodami popsanými v kapitole 5. První měření bude metodou ABS se stejným postupem jako v při měření na kalibrační komoře. Provede se referenční měření a pak se pro různé průtoky hydraulického oleje vytvořené hydromotorem změří spektrum bublin. Současně s měřením ABS bude měřit tlak na tlakových snímačích a teploty na termočláncích na ventilu, který se škrcením při průtoku zahřívá. Po tomto měření se nechá olej několik hodin ustálit. Následně se stejné měření provede optickými metodami. Buď metodou stínovou se zadním osvitem stejným způsobem jako na kalibrační komoře, nebo laserem s bočním osvitem. Po měření se olej nechá opět několik hodin ustálit. Pak proběhne třetí měření, kdy se pro průtoky stejné jako v předchozích měřeních bude detekovat kavitační šum pomocí hydrofonu. Výsledky budou zpracovány. Výstupem bude vyhodnocení vzniku kavitace v širších souvislostech. Následně bude možné pomocí simulačních metod vytvořit vhodný geometrický tvar škrtících elementů hydraulického tlumiče, který kavitaci eliminuje a stejným způsobem správnost návrhu ze simulačního programu otestovat měřením.

7 ZÁVĚR

Práce obsahuje popis konstrukce a funkčních principů hydraulických tlumičů. V souvislosti s konstrukcí jsou zde uvedeny poznatky týkající se problematiky kavitace v hydraulickém tlumiči. Další část obsahuje seznámení s hydraulickými oleji. Je zde uveden výběr několika používaných olejů a jejich vlastností, popis praktického měření hustoty, povrchového napětí a viskozity. V závěru této části je provedena rešerše literatury zabývající se výzkumem kavitace v oleji. Bakalářská práce obsahuje teoretický úvod do jevu kavitace. Jsou zde vytvořeny grafy závislosti rovnovážného tlaku v kapalině, kritického poloměru a kritického tlaku na počátečním poloměru bubliny pro olej používaný v kavitační komoře ve školní laboratoři. Další část je zaměřena na metodiku diagnostiky kavitace v hydraulickém tlumiči. Jezde uveden popis a vysvětlení principů metod a zařízení s důrazem na vybavení laboratoří Technické univerzity v Liberci. Po uvedení do problematiky diagnostiky následuje kapitola o měření. Z důvodu posouzení vhodnosti metody ABS pro měření kavitace v oleji bylo provedeno kalibrační měření na kalibrační komoře. Kalibrační komora byla navržena a sestavena speciálně pro toto kalibrační měření. Měření bylo zpracováno a vyhodnoceno, jak je uvedeno v kapitole o měření a přílohách bakalářské práce. Na kalibrační komoru byla aplikována i stínová metoda. Pro stínovou metodu bylo provedeno pouze vizuální hodnocení, taktéž uvedené v kapitole o měření a přílohách. Poslední část této kapitoly uvádí popis a metodiku měření na modelu hydraulického tlumiče v laboratoři na Doubí.

Poznatky získané ze zpracování bakalářské práce jsou podkladem pro hlubší studium kavitačních dějů v hydraulickém tlumiči. Bylo by žádoucí důkladně se zaměřit na neobjasněné jevy při měření ABS, na které bylo poukázáno při popisu výsledků. Potom bude možné měřit spektrum kavitačních bublin na komoře modelu hydraulického tlumiče v laboratoři na Doubí. V současné době je k dispozici pro model tlumiče jeden píst bez úprav na škrtících elementech. Snahou by mělo být provádět různé geometrické úpravy škrtících elementů tlumiče tak, aby se kavitace co nejvíce eliminovala. Předpokladem pro tyto úpravy je proměnlivost průřezu, kdy nebude docházet ke snížení tlaků naráz, ale postupně. Tyto úpravy by bylo vhodné modelovat v simulačních programech. Následně by se píst vyrobil a na modelu tlumiče by se proměřila správnost návrhu. Výsledkem by mohla být co nejvhodnější optimalizace geometrie hydraulického tlumiče pro zamezení kavitace.

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Příloha P10 - Obrázky ze stínové metody

Příloha P1 - Tabulka hodnot měření povrchového napětí a hustoty hydraulického oleje

MĚŘENÍ POVRCHOVÉHO NAPĚTÍ A HUSTOTY HYDRAULICKÉHO OLEJE

Podmínky měření a poznámky

Datum 13.4.2010
Teplota laboratorního vzduchu 21°C
Tlak 96.7 kPa

Měřicí zařízení: Skleněný hustoměr, Torzní dynamometr
Konstanta platinového prstence 0.061m
Statistické zpracování provedeno pomocí kapesního kalkulátoru CASIO

Měření hustoty

Změřená hustota (opakovaně při 20°C) 848 kgm^{-3}

Měření povrchového napětí

Teplota vodní lázně	21°C										
Teplota oleje	20°C										
Měření číslo	č.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Naměřená hodnota síly	[mN]	4.100	4.100	4.125	4.100	4.100	4.100	4.125	4.100	4.100	4.125
Výsledná hodnota síly	4.11±0.01 mN										
Povrchové napětí	33.69±0.08 mNm^{-1}										

Teplota vodní lázně	26.5°C										
Teplota oleje	25°C										
Měření číslo	č.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Naměřená hodnota síly	[mN]	4.075	4.050	4.100	4.075	4.075	4.050	4.050	4.050	4.075	4.100
Výsledná hodnota síly	4.07±0.02 mN										
Povrchové napětí	33.36±0.16 mNm^{-1}										

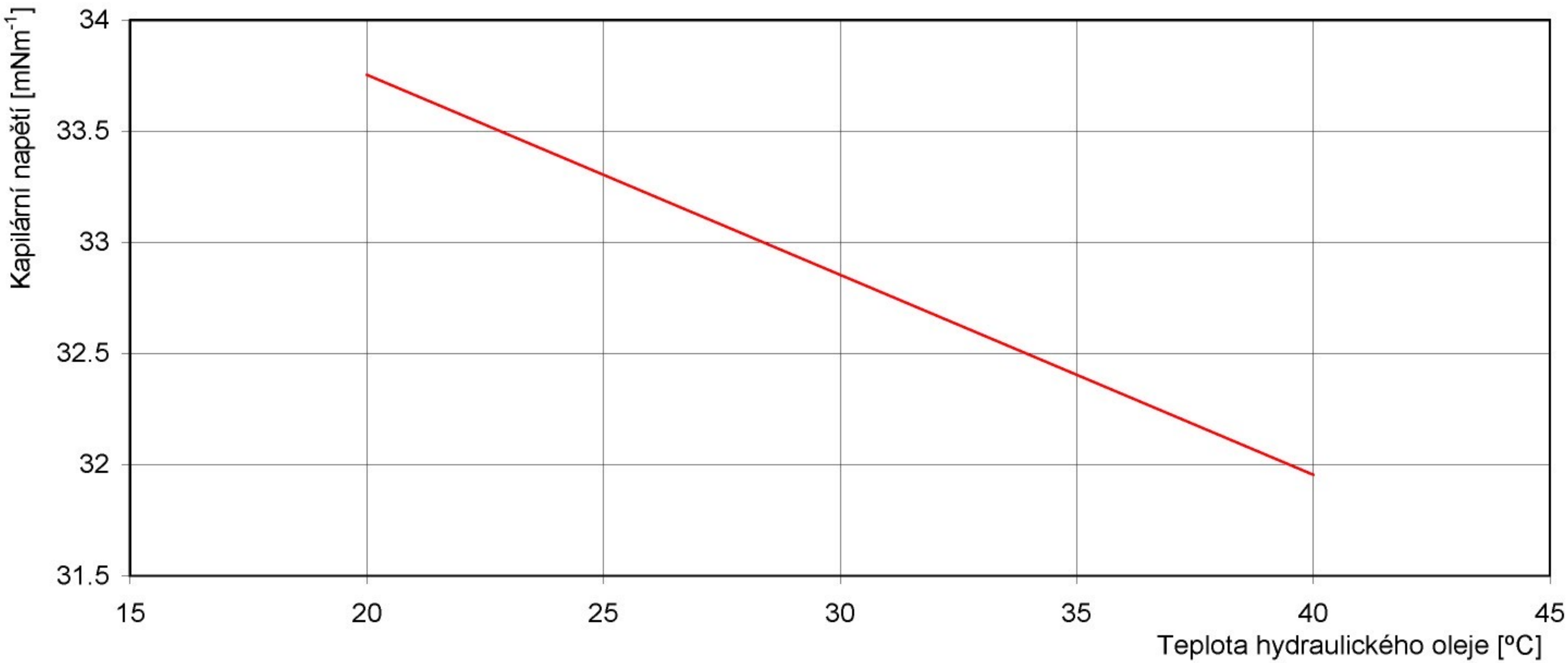
Teplota vodní lázně	33°C										
Teplota oleje	30°C										
Měření číslo	č.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Naměřená hodnota síly	[mN]	4.025	4.000	4.000	4.000	4.000	4.025	4.025	4.000	4.025	4.000
Výsledná hodnota síly	4.01±0.01 mN										
Povrchové napětí	32.87±0.08 mNm^{-1}										

Teplota vodní lázně	37.5°C										
Teplota oleje	35°C										
Měření číslo	č.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Naměřená hodnota síly	[mN]	3.975	3.950	3.950	3.950	3.950	3.950	3.975	3.975	3.950	3.975
Výsledná hodnota síly	3.96±0.01 mN										
Povrchové napětí	32.46±0.08 mNm^{-1}										

Teplota vodní lázně	42°C										
Teplota oleje	40°C										
Měření číslo	č.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Naměřená hodnota síly	[mN]	3.900	3.900	3.900	3.875	3.900	3.875	3.900	3.900	3.900	3.875
Výsledná hodnota síly	3.89±0.01 mN										
Povrchové napětí	31.89±0.08 mNm^{-1}										

Příloha P2 - Graf závisloti kapilárního napětí na teplotě hydraulického oleje

ZÁVISLOST KAPILÁRNÍHO NAPĚTÍ NA TEPLOTĚ HYDRAULICKÉHO OLEJE



Příloha P3 - Tabulka hodnot měření viskozity hydraulického oleje

MĚŘENÍ VISKOZITY HYDRAULICKÉHO OLEJE

Podmínky měření a poznámky

Datum 15.4.2010

Teplota laboratorního vzduchu 23°C

Tlak 100.9 kPa

Měřicí zařízení: Rheotest 2

Typ měření: S pro střední viskozity

Měřicí válec: S 1

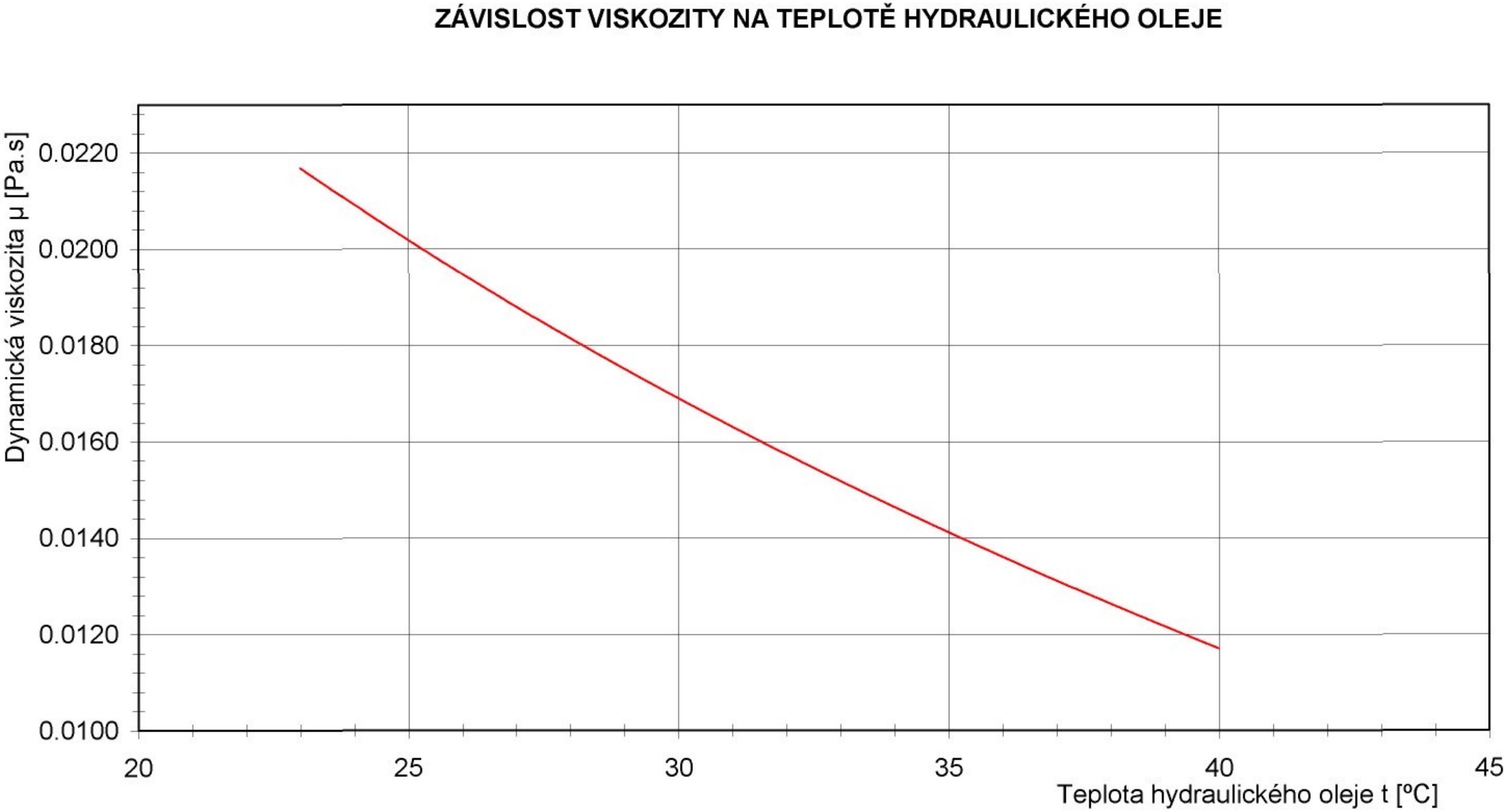
Konstanta válce Z=0.51

Smykový spád D_r=729 s-1

Hustota oleje ρ=848 $kg.m^{-3}$

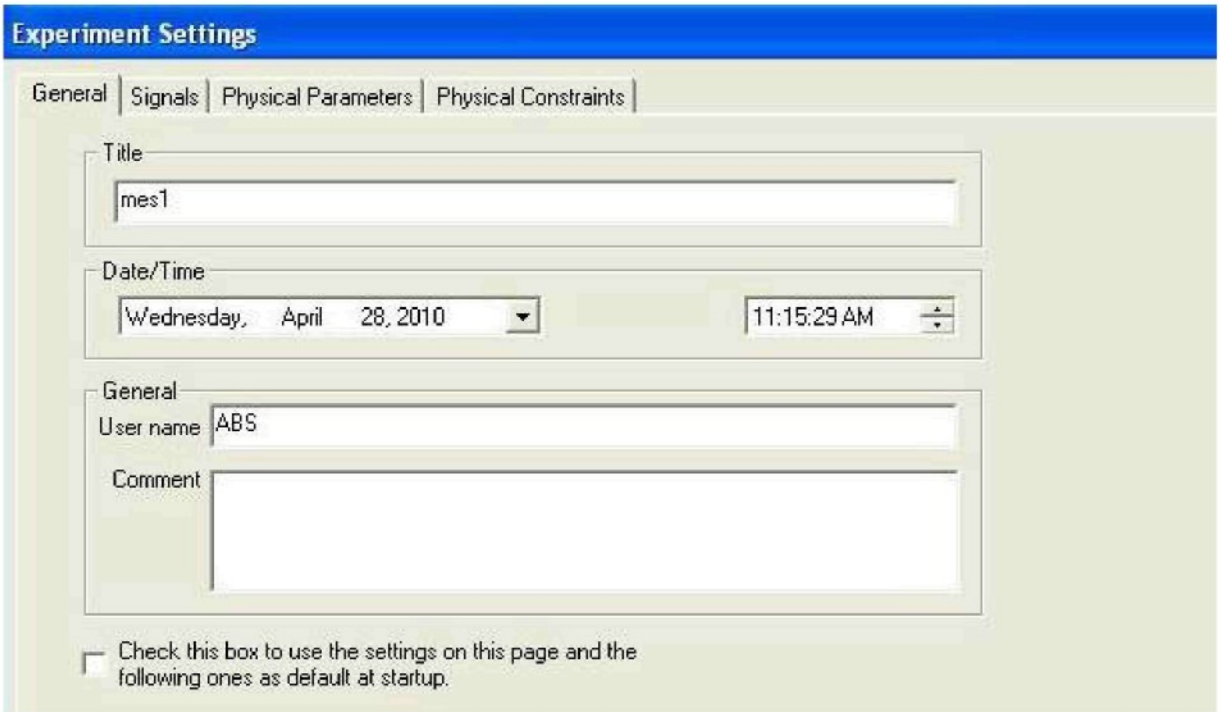
Teplota t [ºC]	Dílky α [-]	Dynamická viskozita μ [Pa.s]	Kinematická viskozita ν [m^2s^{-1}]
23	31	0.0217	$25.6 \cdot 10^{-6}$
24	30	0.0210	$24.7 \cdot 10^{-6}$
25	29	0.0203	$23.9 \cdot 10^{-6}$
26	28	0.0196	$23.1 \cdot 10^{-6}$
27	27	0.0189	$22.3 \cdot 10^{-6}$
28	26	0.0182	$21.4 \cdot 10^{-6}$
29	25	0.0175	$20.6 \cdot 10^{-6}$
30	24	0.0168	$19.8 \cdot 10^{-6}$
31	23	0.0161	$19.0 \cdot 10^{-6}$
32	22	0.0154	$18.1 \cdot 10^{-6}$
33	21.5	0.0150	$17.7 \cdot 10^{-6}$
34	21	0.0147	$17.3 \cdot 10^{-6}$
35	20	0.0140	$16.5 \cdot 10^{-6}$
36	19.5	0.0136	$16.1 \cdot 10^{-6}$
37	19	0.0133	$15.7 \cdot 10^{-6}$
38	18	0.0126	$14.8 \cdot 10^{-6}$
39	17.5	0.0122	$14.4 \cdot 10^{-6}$
40	17	0.0119	$14.0 \cdot 10^{-6}$

Příloha P4 - Graf závislosti viskozity na teplotě hydraulického oleje

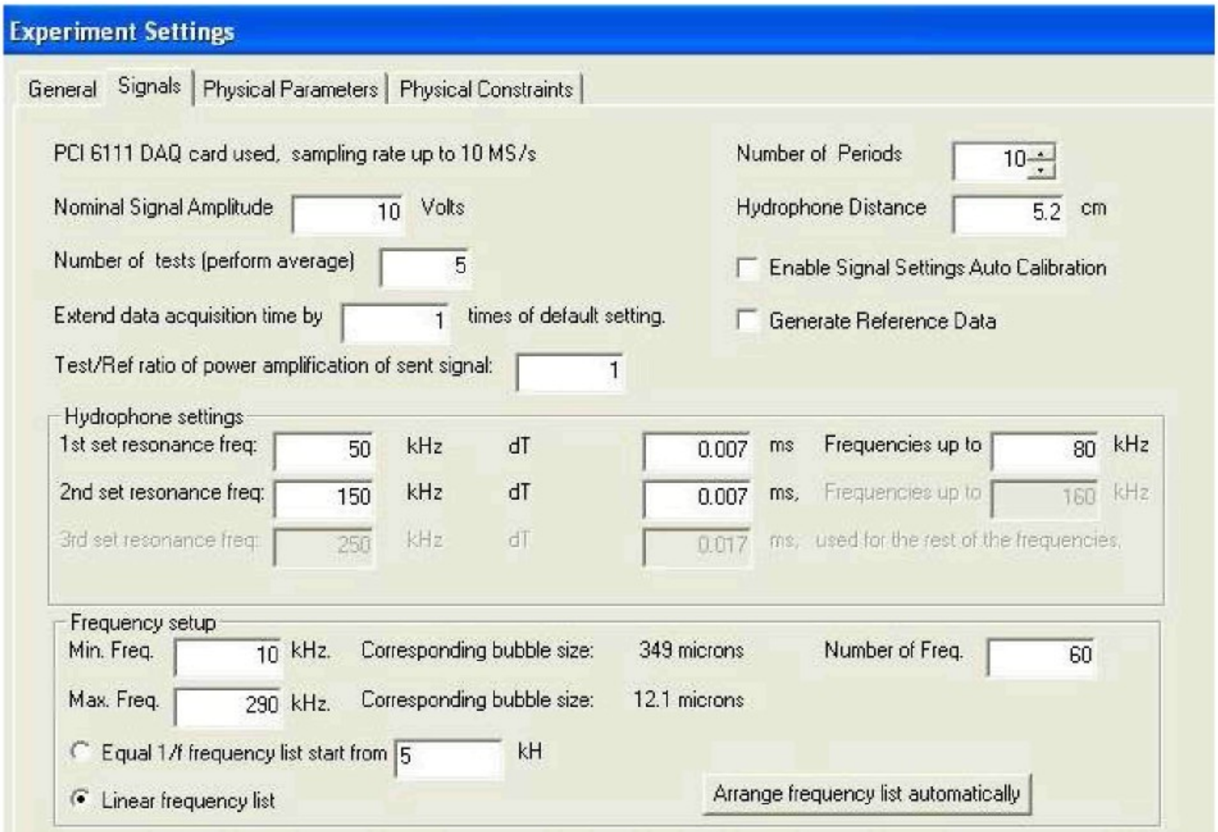


Příloha P5 – Nastavení programu ABS

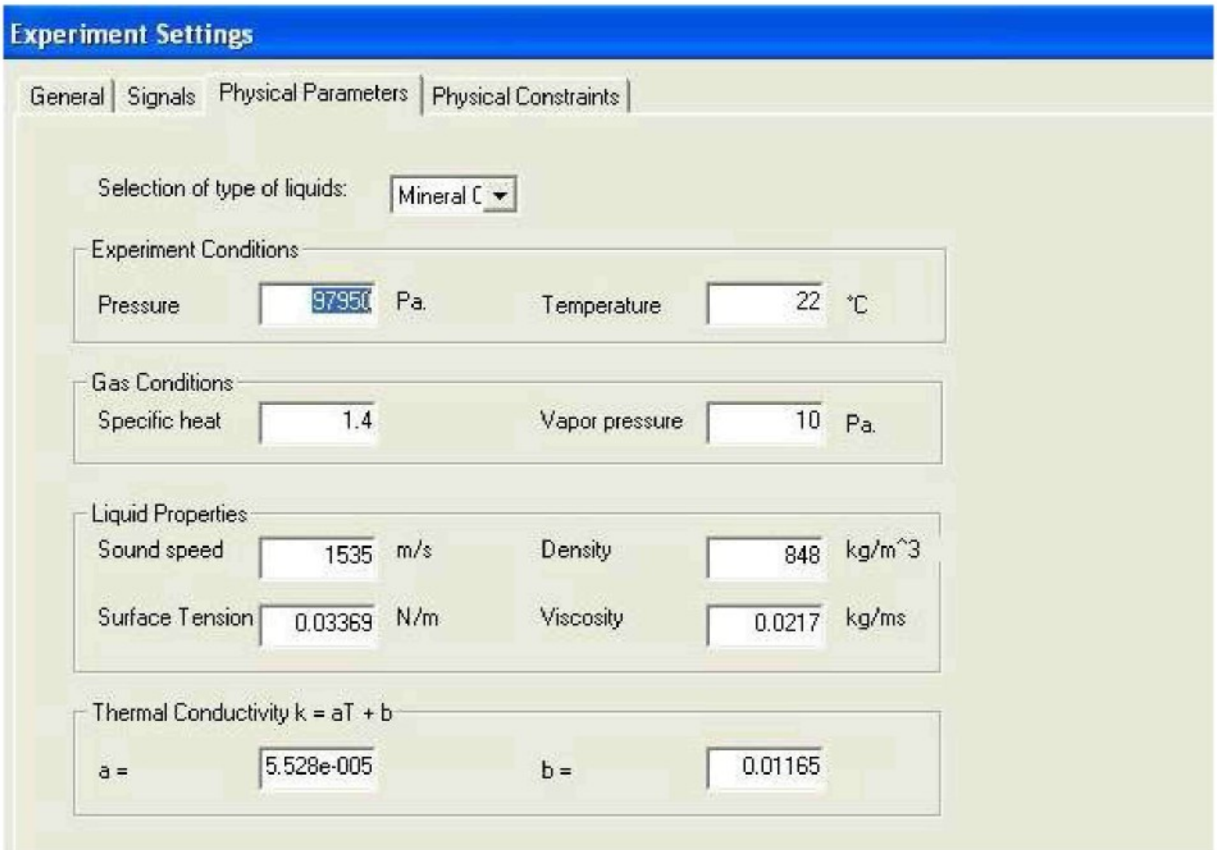
1.Krok - Nastavení názvu a času měření



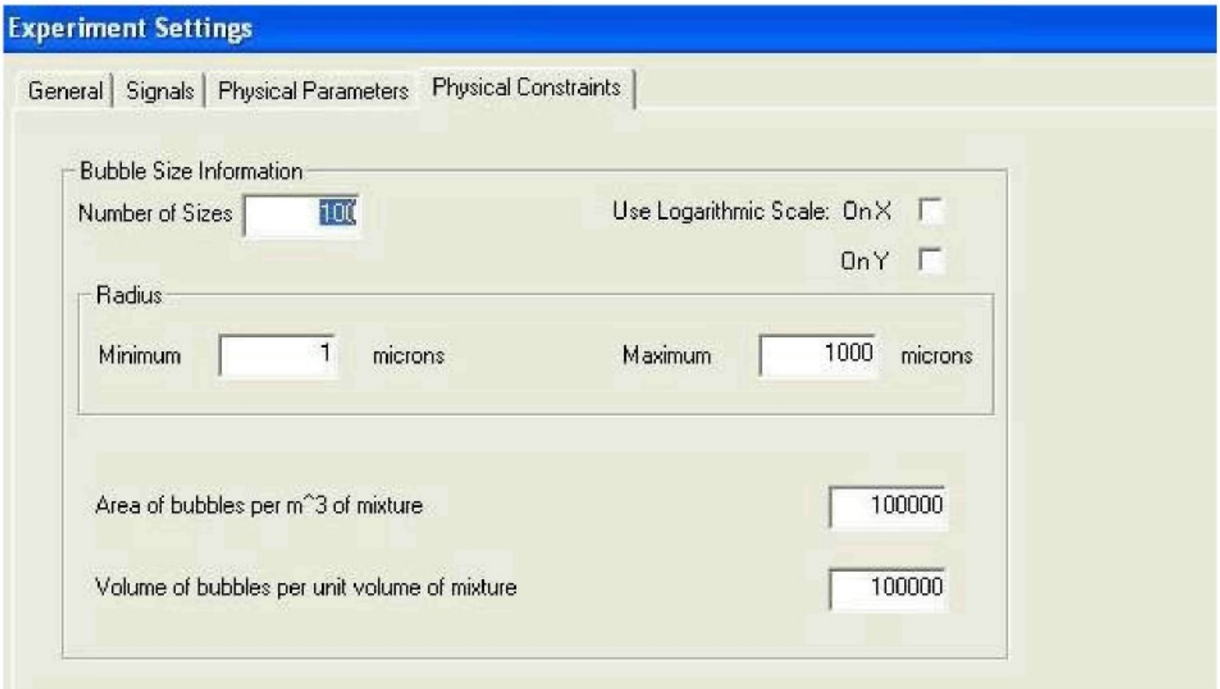
2.Krok – Nastavení parametrů signálu



3.Krok – Nastavení fyzikálních parametrů tekutiny a okolního prostředí



4.Krok – Nastavení parametrů omezení výstupu

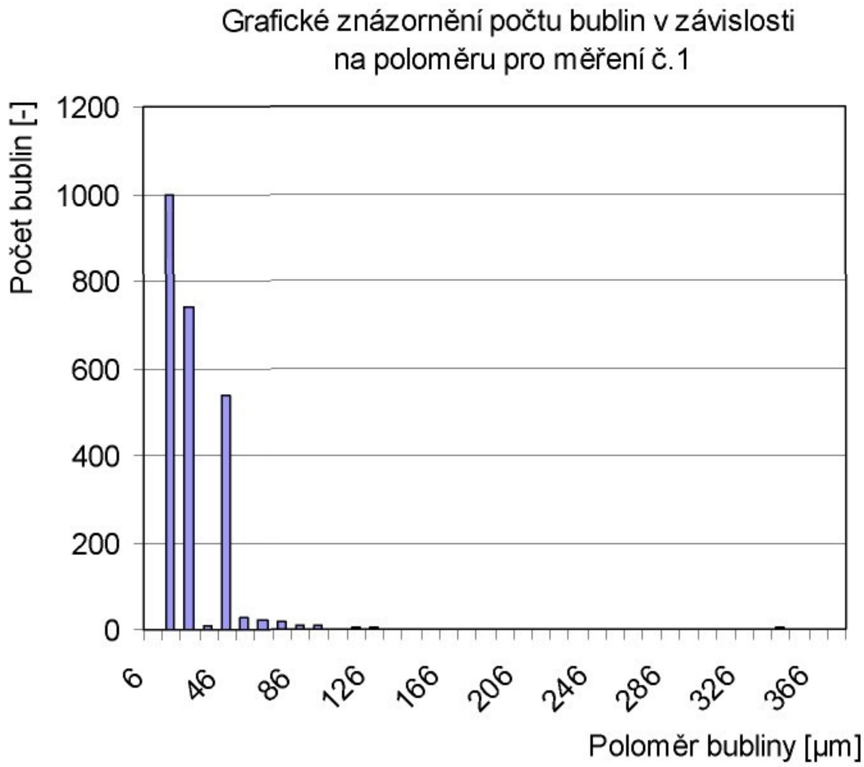


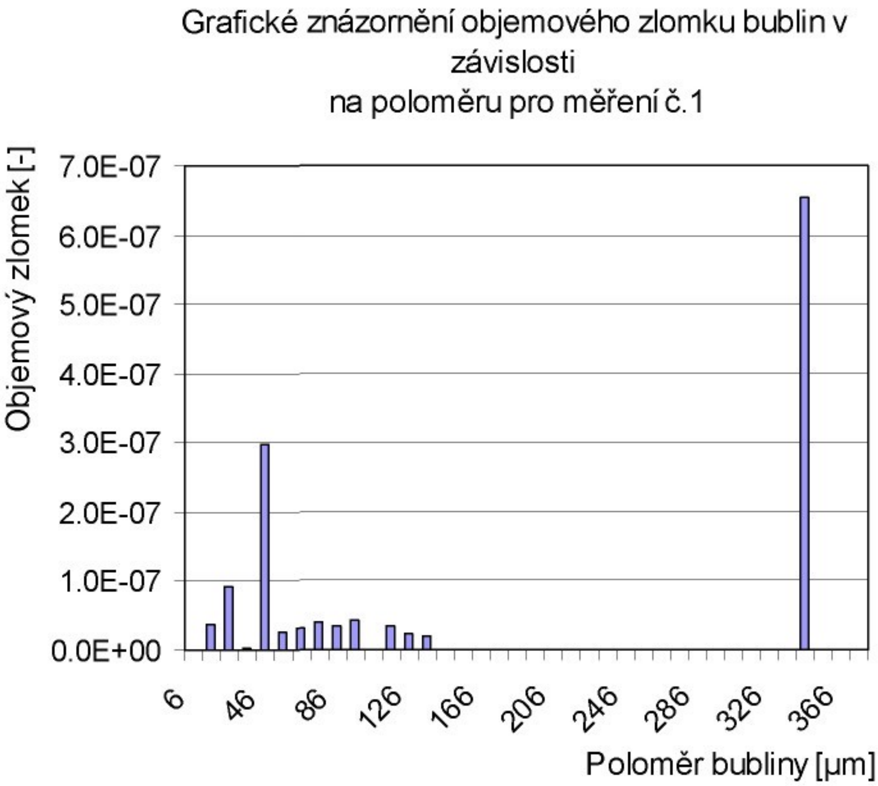
```
*********************************************
*          BUBBLE SIZE DISTRIBUTION         *
*                        *
*                        *
* ABS Acoustic Bubble Spectrometer          *
* Version 5.0                    *
* Copyright (C) Dynaflow, Inc. 1998-2008.   *
*                        *
*********************************************
```

Output run 1 was printed at 11:10:48 428 2010
Total Void Fraction: 0.0000013938

Bubble_radius (micron)	Number_of_bubbles (thousand/m^3)	Void_fraction_contribution
5.99500	0.000	0.000000000000
15.98500	1686.451	0.000000065235
25.97500	618.283	0.000000076931
35.96500	0.000	0.000000000000
45.95500	564.750	0.000000312880
55.94500	16.503	0.000000015645
65.93500	18.756	0.000000028036
75.92500	19.097	0.000000042387
85.91500	12.982	0.000000040856
95.90500	15.312	0.000000065886
105.89500	3.440	0.000000019649
115.88500	0.130	0.000000000960
125.87500	0.000	0.000000000000
135.86500	15.296	0.000000179069
145.85500	0.000	0.000000000000
155.84500	0.000	0.000000000000
165.83500	0.000	0.000000000000
175.82500	0.000	0.000000000000
...	...	...
...	...	...
...	...	...

Příloha P7 - Grafické znázornění počtu bublin v závislosti na poloměru pro měření č.1,2,3,4,5 a grafické znázornění objemového zlomku bublin v závislosti na poloměru pro měření č.1,2,3,4,5

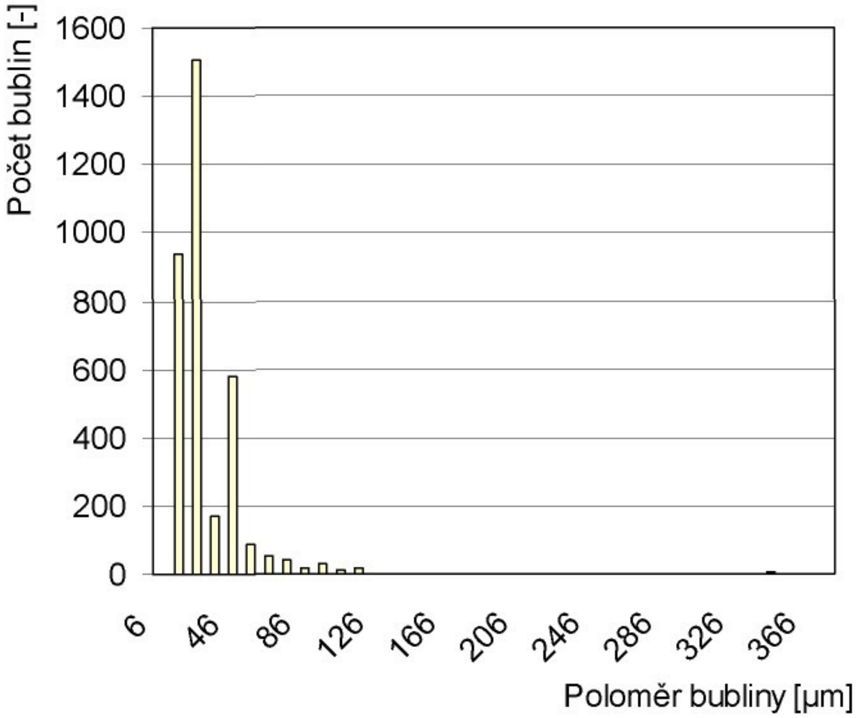




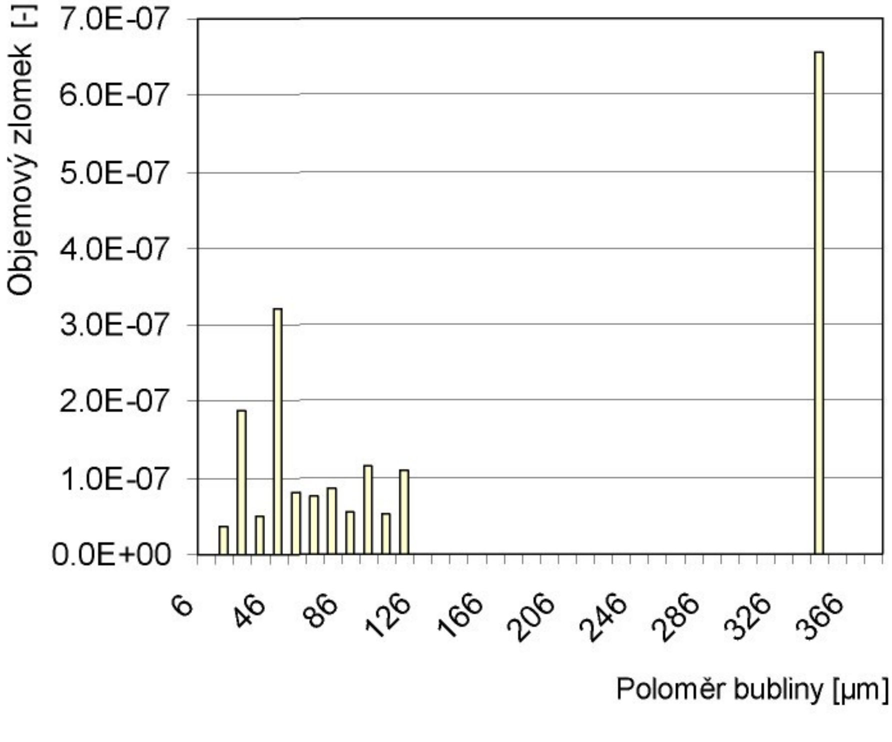

Grafické znázornění počtu bublin v závislosti
na poloměru pro měření č.2
Počet bublin [-]
1200
1000
800
600
400
200
0
6
46
86
126
166
206
246
286
326
366
Poloměr bubliny [μm]


Grafické znázornění objemového zlomku bublin v závislosti
na poloměru pro měření č.2
Objemový zlomek [-]
7.0E-07
6.0E-07
5.0E-07
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
6
46
86
126
166
206
246
286
326
366
Poloměr bubliny [μm]

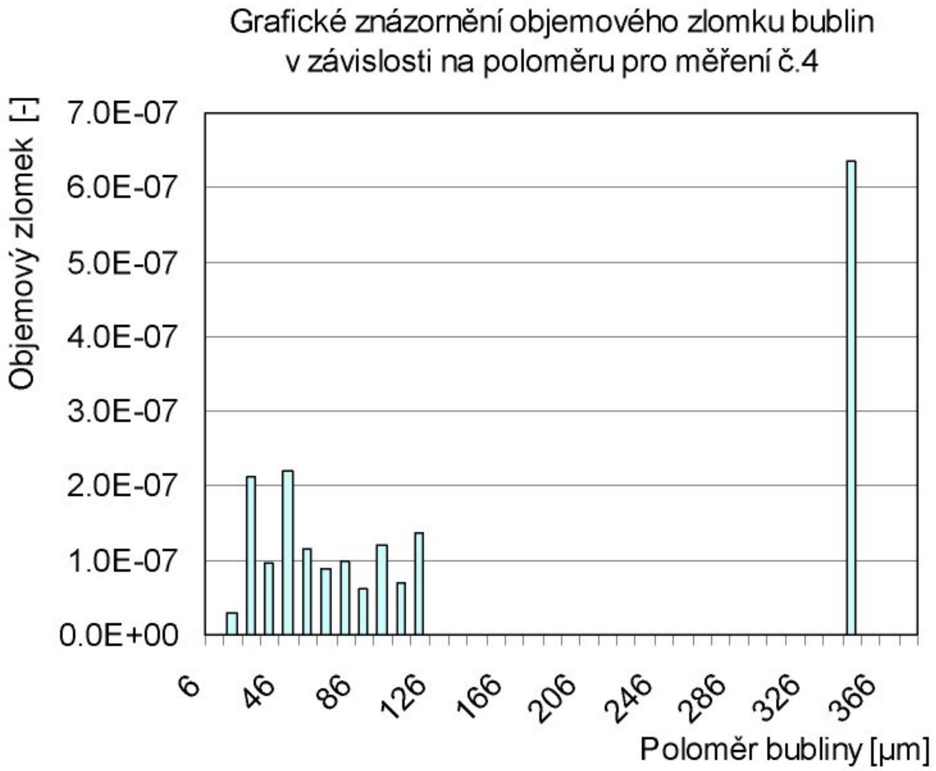
Grafické znázornění počtu bublin v závislosti na poloměru pro měření č.3



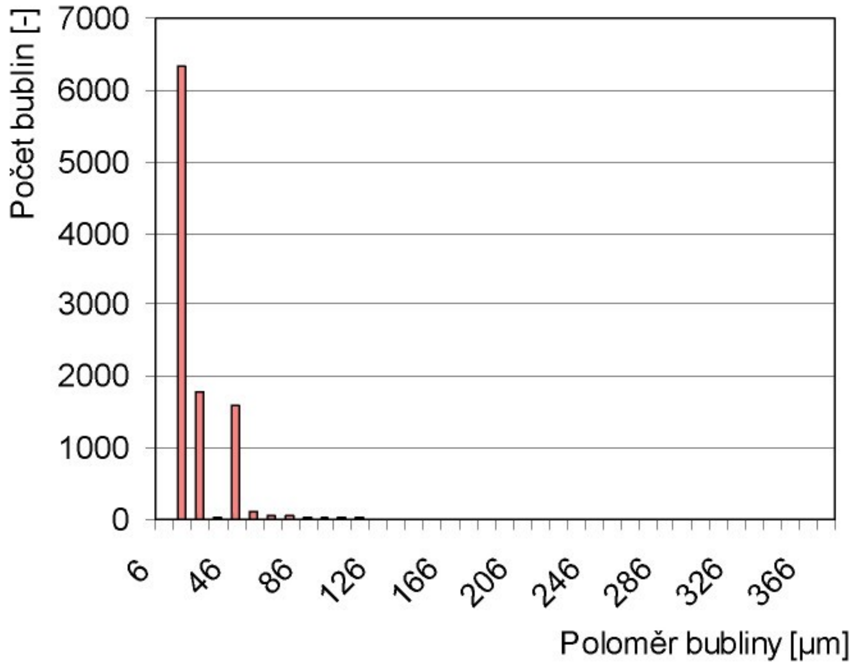
Grafické znázornění objemového zlomku bublin v závislosti na poloměru pro měření č.3



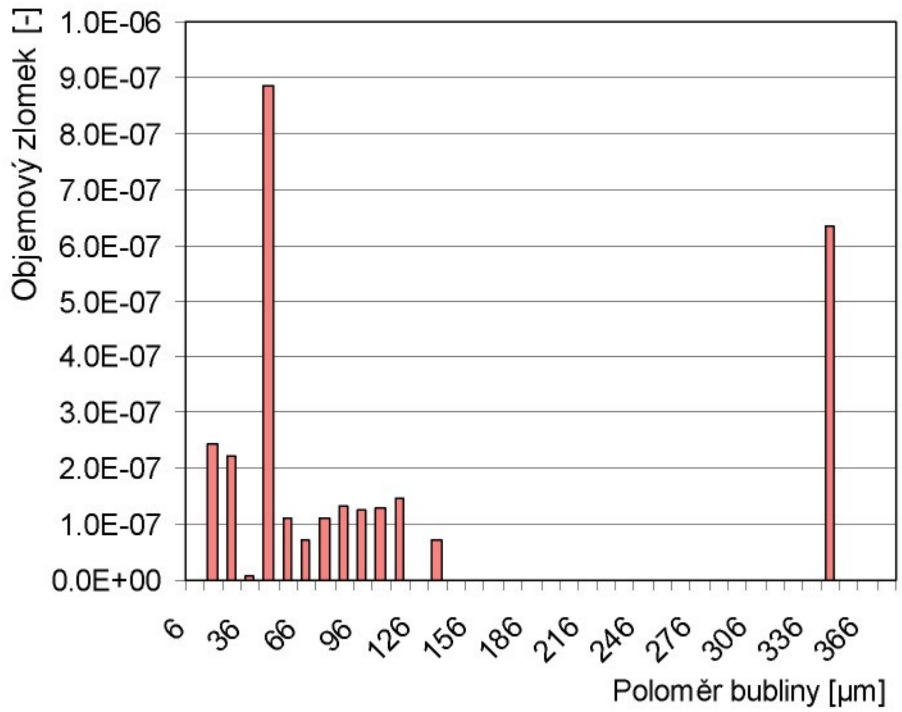

Grafické znázoznění počtu bublin v závislosti
na poloměru pro měření č.4
Počet bublin [-]
1800
1600
1400
1200
1000
800
600
400
200
0
6
46
86
126
166
206
246
286
326
366
Poloměr bubliny [μm]


Grafické znázornění objemového zlomku bublin
v závislosti na poloměru pro měření č.4
Objemový zlomek [-]
7.0E-07
6.0E-07
5.0E-07
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
6
46
86
126
166
206
246
286
326
366
Poloměr bubliny [μm]

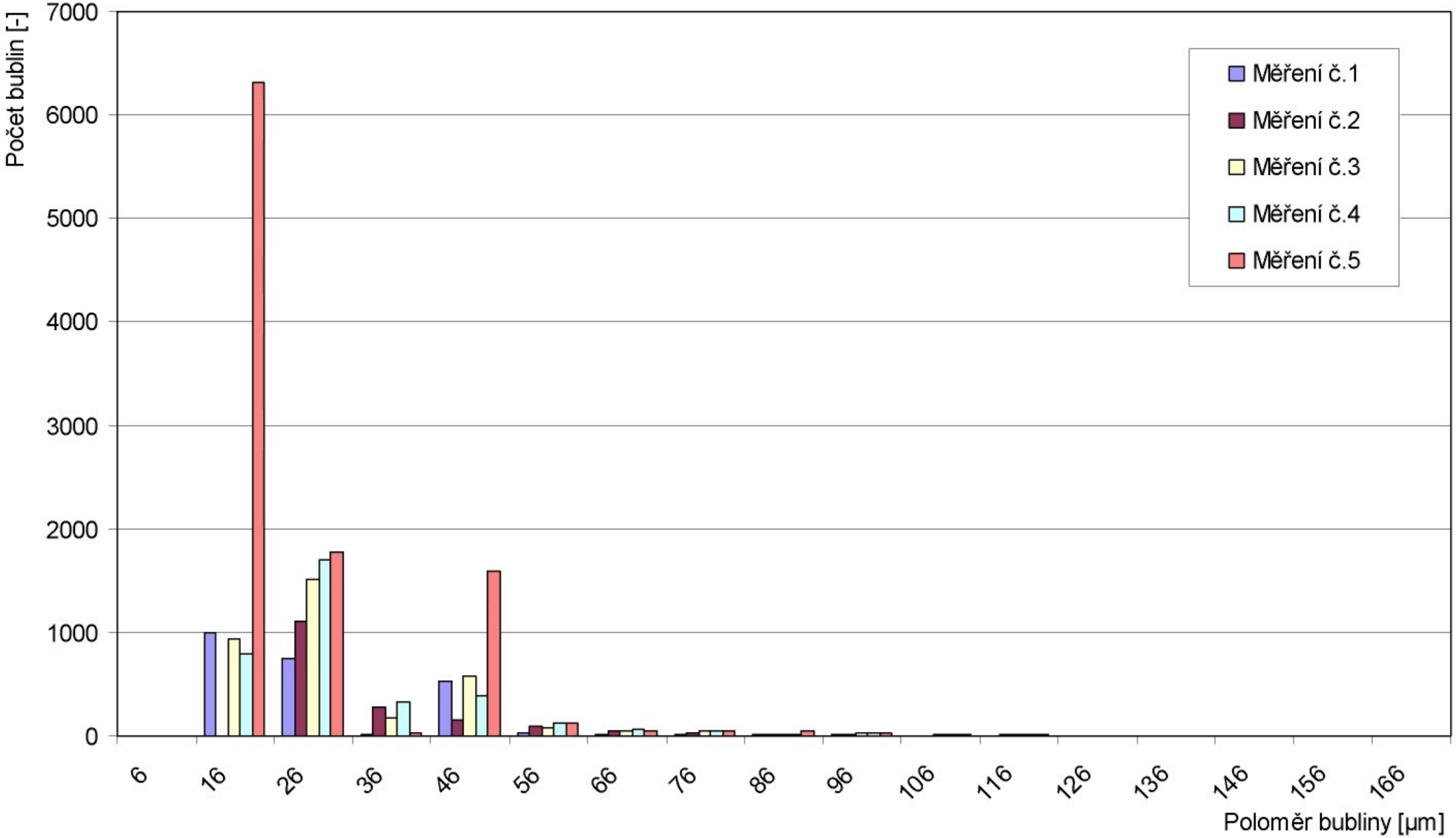
Grafické znázornění počtu bublin v závislosti na poloměru pro měření č.5



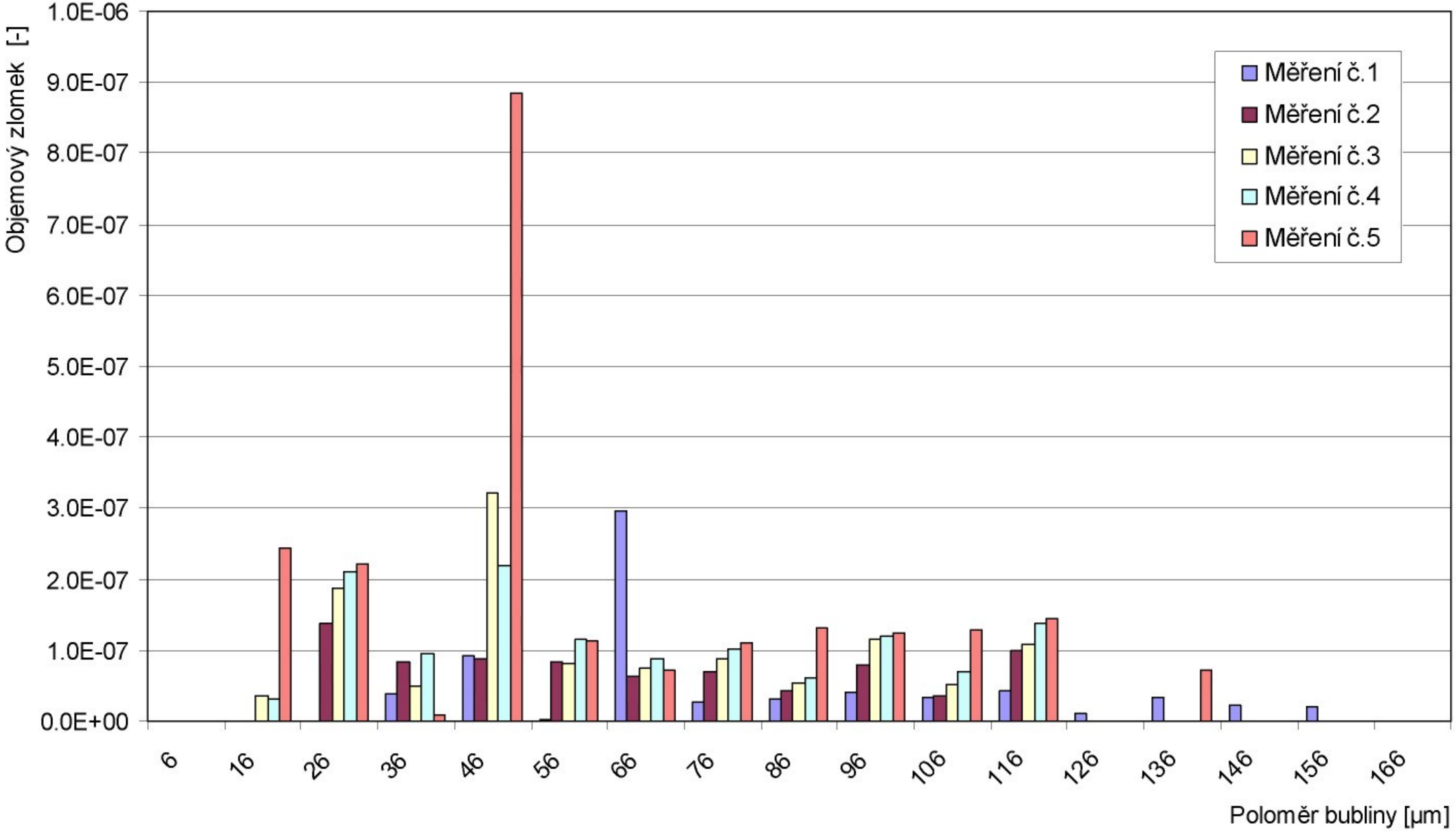
Grafické znázornění objemového zlomku bublin v závislosti na poloměru pro měřeni č.5



Příloha P8 - Grafické znázornění růstu množství bublin spektra poloměrů na injektovaném vzduchu
(pozn. injektáž před prvním měřením a mezi měřeními 0.2 cm^3 vzduchu)



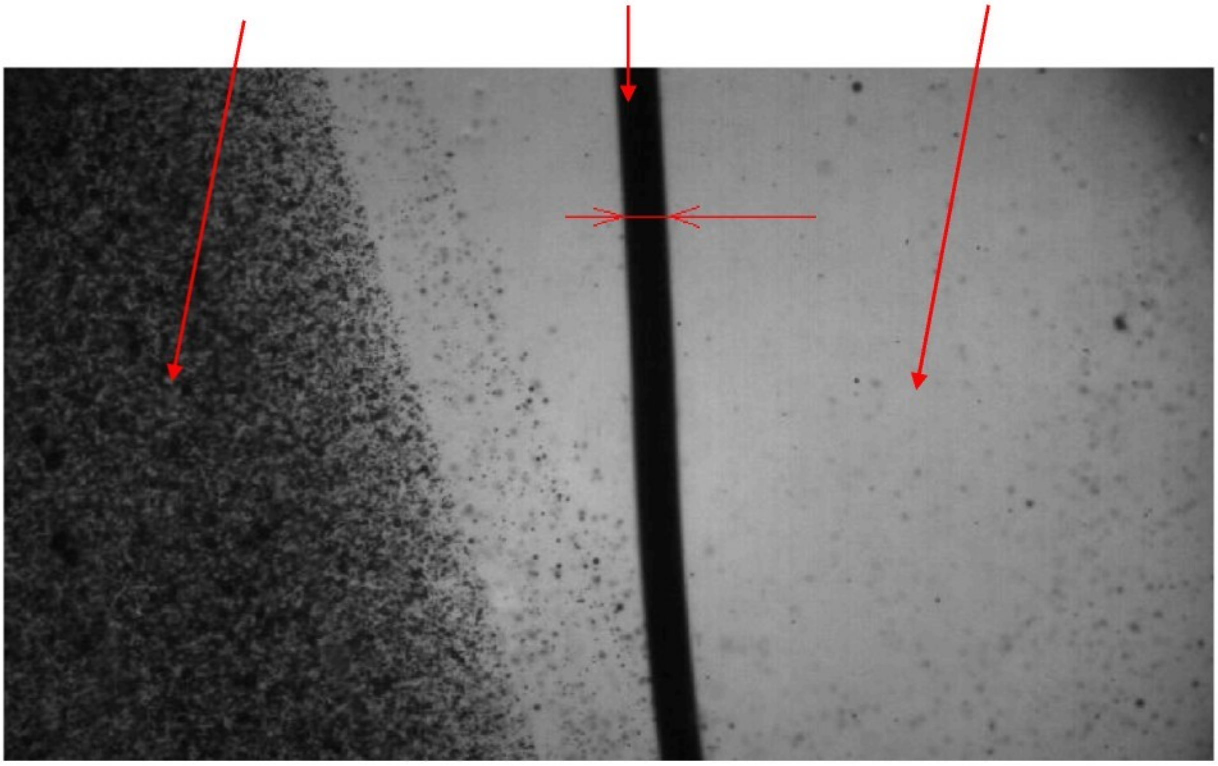
Příloha P9 - Grafické znázornění objemového podílu bublin spektra poloměrů na injektovaném vzduchu
(pozn. injektáž před prvním měřením a mezi měřeními 0.2 cm^3 vzduchu)



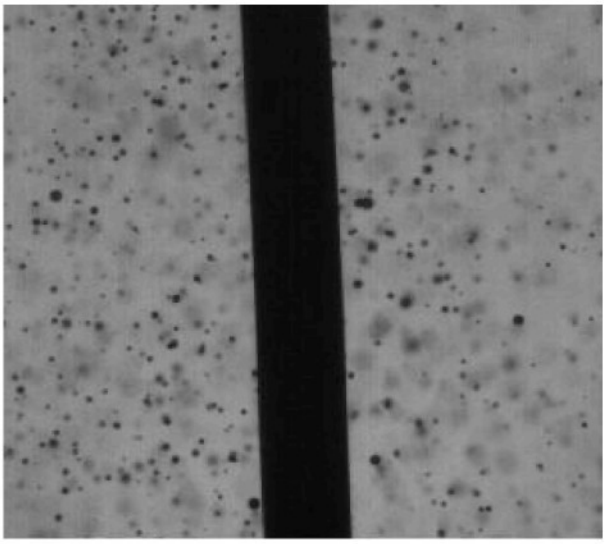
P10 – Stínová metoda

Obrázek snímku 1 krátce po první injektáži.

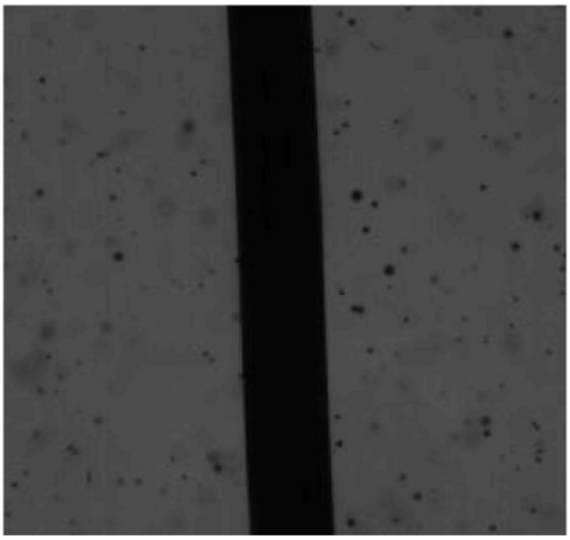
Proud rozptýleného injektovaného vzduchu Drát Tekutina ve stavu před injektáží



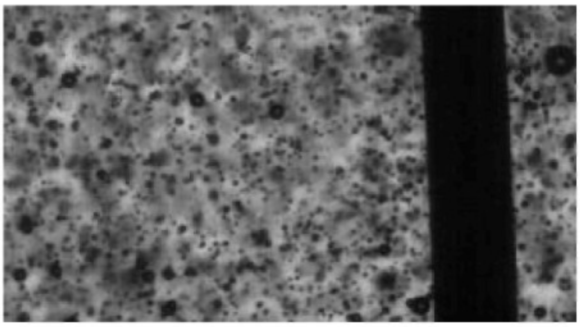
Obrázek snímku 2 po „homogenizaci“ tekutiny a injektovaného vzduchu oběhem čerpadla.



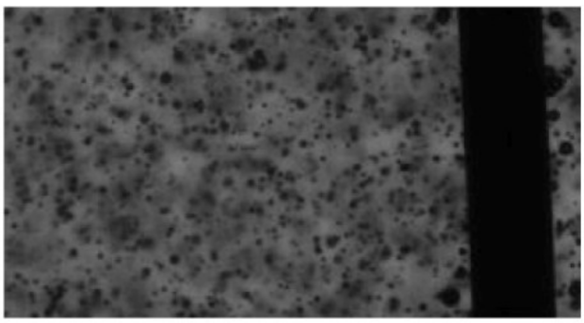
Obrázek snímku 3 po dalších několika minutách od snímání předchozího snímku.

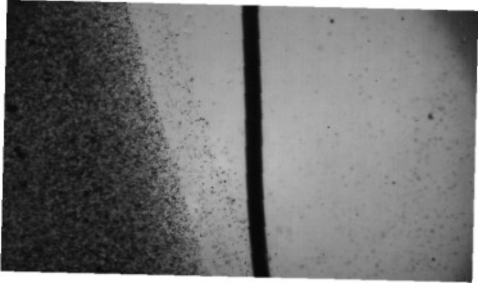


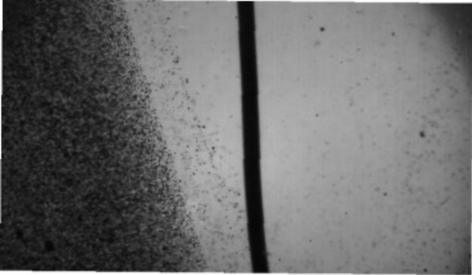
Obrázek snímku 4 po druhé injektáži a „homogenizaci“.

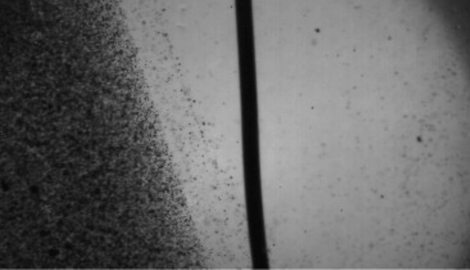


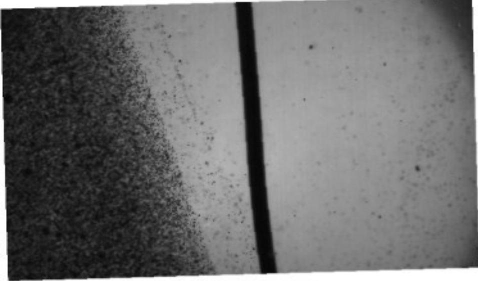
Obrázek snímku 5 po několika minutách od prvního snímku od druhé injektáže.

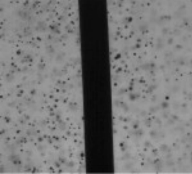


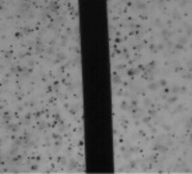


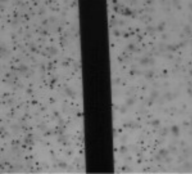


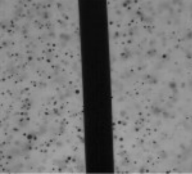


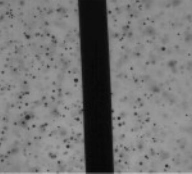


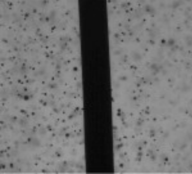


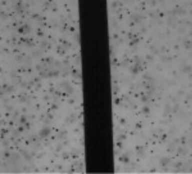


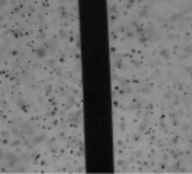


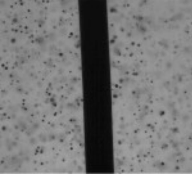


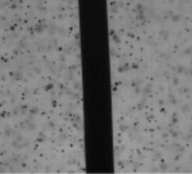












ABS Acoustic Bubble Spectrometer®©

User Manual

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Version 5.0

June 2008

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Abstract

This manual provides a brief description of the ABS Acoustic Bubble Spectrometer®© an acoustics based device that measures bubble size distributions and void fractions in liquids and measures cavitation susceptibility. It explains in detail the procedures for setting up and operating the system including support for a multiple-set hydrophone. A step-by-step operation example is also provided to help the user get started.

Intellectual Property and Software License Agreement

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1. Introduction

The **ABS Acoustic Bubble Spectrometer®©**, is an acoustics based device that measures bubble size distributions and void fractions in liquids. Compared to optical based devices, the ABS Acoustic Bubble Spectrometer®© is more affordable and easier to setup and use. The underlying acoustic technique is very sensitive to bubbles but practically insensitive to particulate matter unlike optical techniques that cannot readily distinguish between these. The ABS Acoustic Bubble Spectrometer®© can be used in a wide variety of two-phase flow applications where knowledge of the bubble size distribution and the volume fraction and/or area of contact between the gas and the liquid are important. These areas include oceanography, cavitation tunnels, controlled laboratory testing, industrial flows, and biomedical instrumentation. The instrument can provide the data in near real time, thus making it suitable for process or time varying applications. The initial efforts to develop the device were funded by National Science Foundation Small Business Innovation Research *(SBIR)* awards [1-2].

The device extracts the bubble population from acoustic measurements made at several frequencies. It consists of a pair of hydrophones or transducers connected to a signal generation / data acquisition system resident on a personal computer. A data board controls signal generation by the first hydrophone and signal reception by the second hydrophone. Short monochromatic bursts of sound at different frequencies are generated by the transmitting hydrophone and received by the second hydrophone after passage through the bubbly liquid. These signals are processed and analyzed utilizing specialized copyrighted software algorithms developed by DYNAFLOW, INC. to obtain the attenuation and phase velocities of the acoustic waves, and, from these, the bubble size distribution.

All the measurements and analyses can be easily and rapidly conducted through a user-friendly Graphical User Interface (GUI). All physical, experimental, and analytical parameters can be modified by the user interactively. Both raw and processed experimental data from experiments

can be saved for future use. The results are displayed graphically in real time on the screen and can also be exported or printed.
As an option, the conventional ABS Acoustic Bubble Spectrometer®© can be upgraded and used to determine the liquid susceptibility to cavitation. In order to do so, a hydrophone projects acoustic power in the liquid with an increasing intensity. A sensitive transducer measures the resulting pressure field. The signals of this transducer are then analyzed and any high frequency emission from cavitation bubble is detected. Cavitation is "called" when a threshold of the *rms* of the emitted signals is crossed.

2. Technical Basis

2.1 Theoretical Foundation

Bubble size distribution measurements using the ABS Acoustic Bubble Spectrometer®© are based on a dispersion relation for sound wave propagation through a bubbly liquid. A multiphase fluid model for sound propagation through bubbly liquids is combined with a model for the bubble oscillations, including various damping modes. The combined model relates the attenuation and phase velocity of a sound wave to the bubble population or size distribution. These relations produce two Fredholm integral equations of the first kind that are ill-posed and require special treatment for solution, particularly in the presence of noise. Novel algorithms developed by DYNAFLOW [1-3] are able to accurately solve these equations using a constrained optimization technique that imposes a number of physical constraints on the solution. This renders the equations well posed and the solution more accurate. A detailed presentation of the underlying physics and mathematics employed in the ABS Acoustic Bubble Spectrometer®© can be found in our JASA paper [3].

2.2 Validation

The complete procedure was initially tested on analytical data with varying amounts of artificial noise added. It was found that to successfully recover the bubble distribution, and to perform much better than previous solution techniques. The bubble distributions obtained from the ABS Acoustic Bubble Spectrometer®© were then validated by comparison with microphotography. Bubble populations were generated using electrolysis and air injection through porous tubes. The bubble population obtained using the ABS Acoustic Bubble Spectrometer®© compared favorably with the results of microphotography. Details can be found in [1-8].

3. System Requirements and Setup

3.1 Hardware

The ABS Acoustic Bubble Spectrometer®© system can operate on a PC that has Windows 2000/XP/Vista installed. For a desktop based system, one spare PCI slot is required. For a notebook based system, one spare PCMCIA slot (CardBus or ExpressCard type) is needed. Sufficient hard disk space is required to store the data acquired, which depends upon the parameters set by the user.

The basic system also utilizes two hydrophones – one for transmission and one for reception of acoustic wave bursts. Different sets of hydrophones can be employed with the ABS Acoustic Bubble Spectrometer®© as long as they have suitable performance characteristics over the frequency and distance ranges of the application and their characteristics are known and specified to the system. For an ABS Acoustic Bubble Spectrometer®© system with optional multiple-set hydrophone support, multiple pairs of hydrophones with different resonance frequencies can be connected to the system at the same time to enhance the performance through coverage of a larger frequency band and to expand the available measurement range.

For the upgraded system with the capability to measure cavitation susceptibility, a low frequency emitting hydrophone and a high sensitivity receiving transducer for cavitation detection are also provided

3.2 Software

The ABS Acoustic Bubble Spectrometer®© software runs on a Windows 2000/XP/Vista operating system or above. It enables the user to conduct the measurements and analyses through a user-friendly Graphical User Interface (GUI) from which the user can easily input the control and operating parameters for the experiment, specify analysis options, and view analysis results. The detailed steps required for control of the various boards, data acquisition, signal analysis, inverse problem solution, and data output are thus transparent to the user. The various options and tasks are accessed through a series of menus and dialog boxes.

3.3 Setup and Cabling for a Desktop Based System

The following hardware is provided as part of a desktop based ABS Acoustic Bubble Spectrometer®© system:

- Signal Generation / Data Acquisition Boards (Installed in PC)
- External BNC Connector Box with integrated amplifier
- BNC Cables
- Optional programmable multiplexer switch with accompanied USB cable and terminal block

Perform the following steps to set up the desktop based ABS Acoustic Bubble Spectrometer®© Generation II system hardware:

For the basic single-set hydrophone system:

- Connect the External BNC Connector Box with the attached Signal Generation / Data Acquisition Board using the 68 Pin Shielded Cable.
- Connect the sending hydrophone to the BNC connection on the Connector Box marked as "***Transmitter***".
- Connect the Receiving hydrophone to the BNC connector on the Connector Box marked as "***Receiver***".
- Turn on the computer
- Turn on the amplifier switch on the BNC Connector Box

For the optional multiple-set system:

- Connect the External BNC Connector Box with the attached Signal Generation / Data Acquisition Board using the 68 Pin Shielded Cable.
- Connect the programmable multiplexer switch to the computer using the accompanied USB cable
- If not attached, attach the accompanying terminal block for the programmable multiplexer switch to the switch, tightly secure the attachment with the screws on the terminal block.
- Connect the BNC connector on the Connector Box marked as "**Transmitter**" to the BNC connector marked as "**AO IN**" on the terminal block of the switch using a BNC cable.
- Connect the sending hydrophones to the BNC connects on the terminal block of the switch marked as "**AO 1**", "**AO 2**", …, in order.
- Connect the Receiving hydrophones to the BNC connector on the Connector Box marked as "**Receiver 1**", "**Receiver 2**", …, in order.
- Power up the programmable multiplexer switch first and then turn on the computer
- Turn on the amplifier switch on the BNC Connector Box

Note:

Make sure the amplifier is turned on and that it has a fresh battery. (When not in use, it should be turned off. Otherwise, the battery will drain.) Also make sure the 68 pin cable connection is good on both ends and pushed in all the way.

3.4 Setup and Cabling for a Notebook Based System

The following hardware is provided as part of a notebook based ABS Acoustic Bubble Spectrometer®© system:

- ❑ Integrated ABS Acoustic Bubble Spectrometer®© System box
- ❑ PCMCIA Expansion Cable (CardBus or ExpressCard type)
- ❑ BNC Cables
- ❑ Optional programmable Multiplexer Switch

Perform the following steps to set up the notebook based ABS Acoustic Bubble Spectrometer®© system hardware:

For the basic single-set hydrophone system:

Figure 1 shows the setup diagram of the basic single set system. The analog input and output as well as the signal amplifier are integrated into one ABS System Box. Follow the following steps to set up the system:

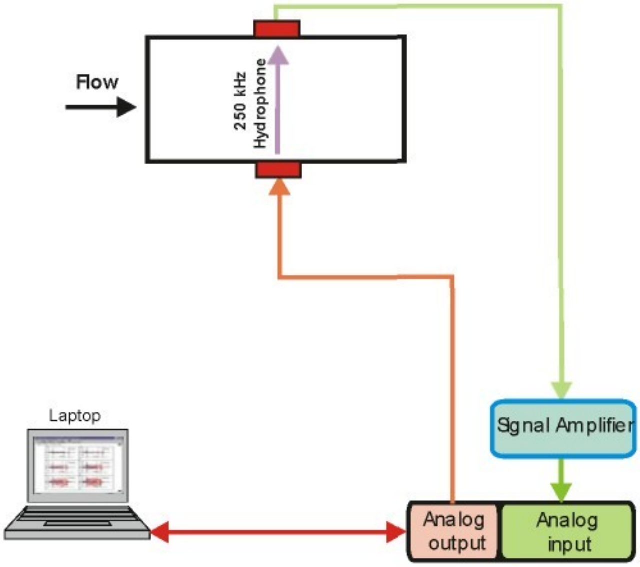

Figure 1. Setup of the basic single-set system.

- Connect the Integrated System Box with one end of the PCMCIA Expansion Cable, and insert the other end into PCMCIA slot of the notebook.
- Connect the sending hydrophone to the ***Transmitter*** of the Integrated System Box.
- Connect the Receiving hydrophone to the ***Receiver*** of the Integrated System Box.
- Power up the interface box first and then power up the laptop.
- Select "***Insert Mobility Express Card and press enter"*** option to continue booting up the computer.
- After the system has completely booted up, using the ***Measurement & Automation*** application to check whether the

DAQ card has been detected by expanding the ***Traditional NI-DAQ Devices***. A device name such as "**PCI-6115**" should appear.

- If the DAQ card is not detected, close the ***Measurement & Automation*** application and unplug the Express Card from the laptop.
- Wait for a few seconds and plug the Express Card back into the laptop.
- Launch the ***Measurement & Automation*** application again, the DAQ card should be detected now. Click the device name to activate the device.
- Use test panel of the ***Measurement & Automation*** application to test the DAQ card to ensure that the analog inputs and outputs are working properly.
- If the above procedures have been performed successfully, the ABS system is ready for measurement.

For the twin-set hydrophone system:

2 shows the setup diagram of the twin-set system. It can drive up to two sets of hydrophones. The system set-up procedures are similar to the single-set system except for connecting the hydrophones to the ABS System Box as described below:

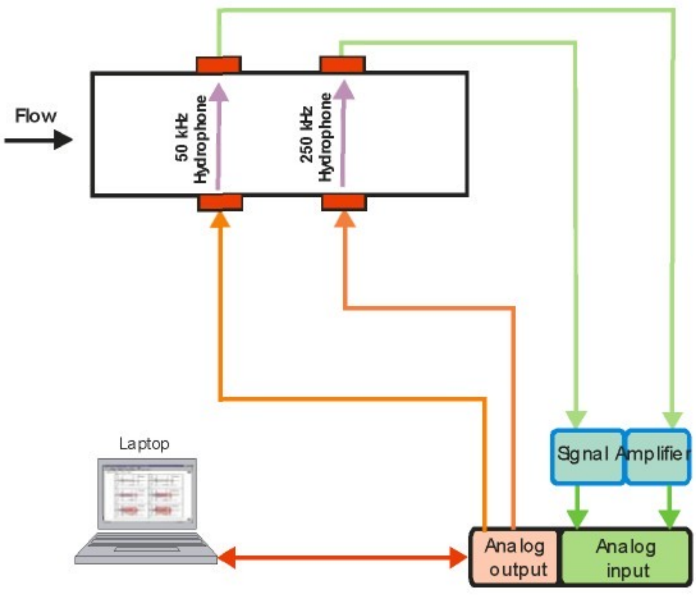

Figure 2. Set up of the twin-set system.

- Connect the two sending hydrophones in the order of ascending resonance frequency to the ***Transmitter 1*** and ***Transmitter 2*** of the Integrated System Box.
- Connect the two receiving hydrophones in the order of ascending resonance frequency to the ***Receiver 1*** and ***Receiver 2*** of the Integrated System Box.

For the optional multiplexer-controlled multiple-set hydrophone system:
Figure 3 shows the setup diagram of the multiplexer controlled triple-set system. A multiplexer is used to route the sent signal to desired hydrophones. As the basic and twin-set system, the analog inputs and outputs as well as the signal amplifier are integrated into the Integrated System Box. Follow the following steps to set up the system:

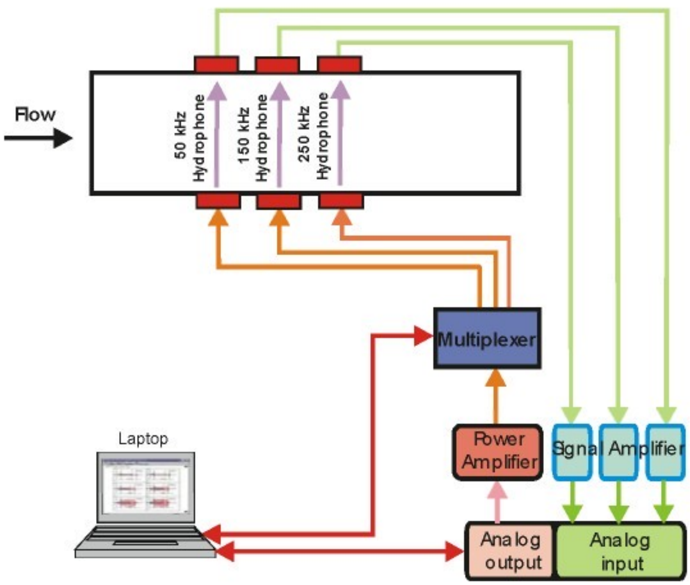

Figure 3. Set up of the multiplexer controlled triple-set system.

- Connect the Integrated System Box with one end of the PCMCIA Expansion Cable, and insert the other end into PCMCIA slot of the notebook.

- Connect the programmable multiplexer switch to the notebook using the accompanied USB cable.
- If not attached, attach the accompanying terminal block for the programmable multiplexer to the chassis, tightly secure the attachment with the screws on the terminal block.
- Connect the BNC connector on the Integrated System Box marked as "***Transmitter***" to the BNC connector marked as "**AO IN**" on the terminal block of the switch using a BNC cable.
- Connect the sending hydrophones to the BNC connectors on the terminal block of the switch marked as "*AO 1*", "*AO 2*", …, in order.
- Connect the Receiving hydrophones to the BNC connectors on Integrated System Box marked as "***Receiver* 1**", "***Receiver* 2**", …, in order.
- Power up the interface box and programmable switch first and then power up the laptop.
- Select "***Insert Mobility Express Card and press enter***" option to continue booting up the computer.
- After the system has completely booted up, using the ***Measurement & Automation*** application to check whether the programmable switch has been detected by expanding the ***Devices and Interfaces***. A device similar like "*NI SCXI-1127*" should appear under the *NI-DAQmx Devices*
- Using the ***Measurement & Automation*** application to check whether the DAQ card has been detected by expanding the ***Traditional NI-DAQ Devices***. A device name such as "**PCI-6115**" should appear.
- If the DAQ card is not detected, close the ***Measurement & Automation*** application and unplug the Express Card from the laptop.
- Wait for a few seconds and plug the Express Card back into the laptop.
- Launch the ***Measurement & Automation*** application again, the DAQ card should be detected now. Click the device name to activate the device.

- Use test panel of the ***Measurement & Automation*** application to test the DAQ card to ensure that the analog inputs and outputs are working properly.
- If the above procedures have been performed successfully, turn on the amplifier switch on the BNC Connector Box, the ABS system is ready for measurement.

For the optional multiplexer-controlled multiple-set hydrophone system with cavitation susceptibility measurement:

Figure 4 shows the set-up sketch of the multiplexer controlled triple-set system with cavitation susceptibility measurement. Compared to the regular triple-set system, this system has an extra hydrophone to generate cavitation and an extra high-sensitivity pressure transducer to detect the cavitation events. As other systems, all the analog inputs and outputs and the signal amplifiers for the regular ABS receiving hydrophones are integrated into the ABS System Box. The pressure transducer has its dedicated unit for power supply and signal amplification. The signals from the pressure transducer and the 1st receiving ABS hydrophone share the same analog input channel, as shown in Figure 4, these two signals are sent to the multiplexer and then are routed to the analog input based on operation mode. The set-up procedures are similar to the multiplexer controlled triple-set system except for the cable connections are more complicated, follow the procedures as described below:

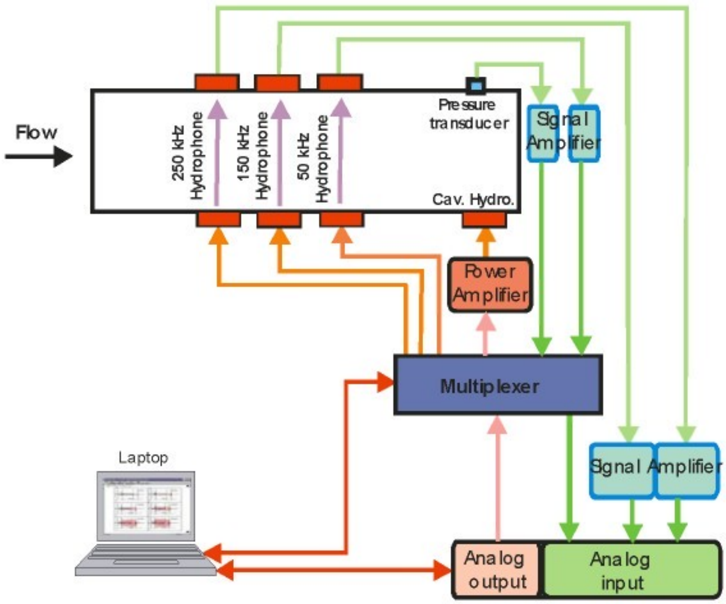

Figure 4. System setup of the multiplexer controller triple-set system with cavitation susceptibility measurement.

- Connect the BNC connector on the ABS System Box marked as "***Transmitter***" to the BNC connector marked as "**AO IN**" on the terminal block of the switch using a BNC cable.
- Connect the sending hydrophones to the BNC connectors on the terminal block of the switch marked as "***AO 1***", "***AO 2***", …, in order. Make sure the hydrophones are connected in ascending order of the resonance frequency
- Connect the cavitation hydrophones to the BNC connectors on the terminal block of the switch marked as "***Cav. AO***",
- Connect the Receiving hydrophones to the BNC connectors on Integrated System Box marked as "***Receiver* 1**", "***Receiver* 2**", …, in order matched with the sending hydrophones.
- Connect the pressure transducer to the BNC input connector of the standalone power supply unit for the pressure transducer. Connect the output connector of the power supply unit and the BNC connector on the terminal block marked as "***Rec.* 2**",
- Connect the port "***To Multiplexer***" on the Integrated System Box to "***Rcv. 1***"

- Connect the port "***AI***" on the terminal block to the port marked as "***From Multiplexer***" on the Integrated System Box.

Notes :

a. Insert the PCMCIA card into the notebook computer, plug in the 12 V power supply to the ABS System Box, and turn on the power to the multiplexer.

b. Before turning on the laptop computer, make sure that the green LED lights on the chassis of the multiplexer and the ABS System Box are on.

*c. If the ABS application fails to acquire data properly, close the ABS application and use the **Measurement & Automation** application to ensure that the DAQ card can be detected. Also use the test panel to test the DAQ card to ensure that the analog inputs and outputs are working properly.*

d. Make sure the amplifier is turned on and that it has a fresh battery. (When not in use, it should be turned off. Otherwise, the battery will drain.) Also make sure the expansion cable connection is good on both ends and pushed all the way in.

4. Operating the ABS Acoustic Bubble Spectrometer®©

Double clicking the ABS icon starts the ABS Acoustic Bubble Spectrometer®© Generation II software. This invokes the Graphical User Interface. It includes the menu, the tool bar and a plotting area. The contents displayed in the plotting area depend on the operation performed; they can be the transmitted and received signals (either reference signals or those from an actual measurement) or the analysis results.

4.1 Tool Bar

The tool bar is located just under the main frame menu at the top of the window. It contains several shortcut buttons that are used to invoke different functions. These shortcut buttons are listed here and described in detail below.

 Print Preview

 Experiment Settings

 Reference Signals

 Acquire

 Analyze

 View Signals

 View Results

 Start Continuous Mode

 Stop Continuous Mode

Cavitation susceptibility measurement Mode

4.2 Experiment Settings

 This button invokes the Experiment Settings property sheet that enables the user to input the various environmental and operating conditions for the experiment. The property sheet can also be invoked from the menu by clicking ***Experiment / Settings*** or by pressing the ***F7*** key. There are four separate property pages as described below and shown in Figure 5 through Figure 9.

- **General:** This page has entries for title, date, time, user's name, and comments on the experiment (Figure 5).

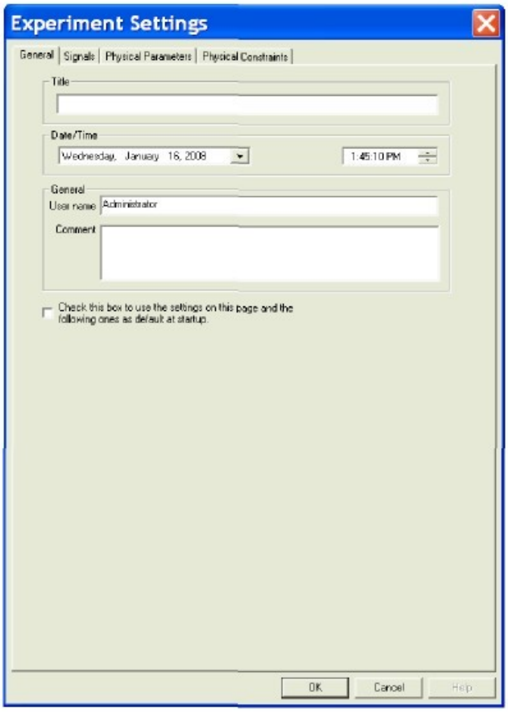

Figure 5. Experimental Settings: General Information Page.

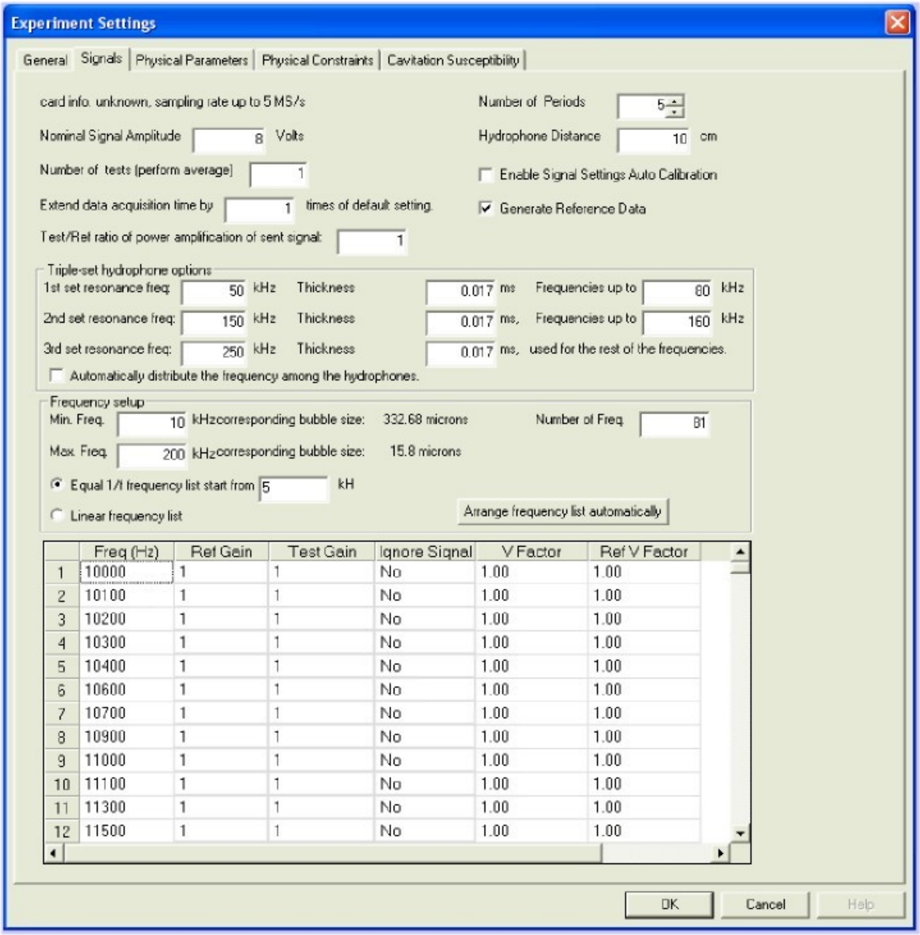

Figure 6. Experimental Settings: Signals Page.

- **Signals:** The signals property page is shown in Figure 6. The user can specify the number of periods and the nominal peak signal amplitudes (in volts; maximum signal amplitude is *10* volts) of the sent signals for test and reference signals respectively, enter the distance between the two hydrophones in the experiment, and build a table that lists signal properties.
  ***Note**: The "burst" duration for each transmitted signal is then equal to the ratio of the number of periods to the signal frequency.*

HARDWARE INFORMATION: The DAQ card information and its maximum sampling rate is automatically detected and used by the system. Information such as ***PCI 6111 DAQ card used, sampling rate up to 5 MS/s*** will be displayed, the system will automatically determine the sampling rate to use based on the signal characteristics under consideration.

DATA ACQUISITION DURATION EXTENSION FACTOR: The default time duration for data acquisition is set to be four times the time of flight between hydrophones in the liquid. This equals the hydrophone distance divided by the sound speed in pure liquid, plus the duration of emission. This default setting is good in normal cases. If this default duration is not optimal for the particular experiment, e.g. the duration is too short to obtain the complete response signal; the user can adjust the time duration by changing the value of *N* of the user input in ***Extend data acquisition time by N times of default setting***, which sets the duration for acquisition to be a multiple of the default acquisition time by the specified factor.

ENABLE SIGNAL SETTINGS AUTO CALIBRATION: Since the gain and voltage settings can be different for each frequency as well as for test and reference signal. It is tedious to manually set up the gain and voltage setting manually. The user can check ***Enable Signal Settings Auto Calibration*** to let the system figure out the best gain and voltage settings for each frequency in both test and reference condition. After checking this option, when acquiring reference signal, the system will continuously adjust the gain and voltage settings until optimal settings have been found for all frequencies, then the real reference signals will be acquired at the settings optimized. When measuring the first time under the test conditions, the system will similarly adjust the gain and voltage settings until optimal settings have been found for all frequencies, then the real test signals will be acquired at the settings optimized. After the calibration for the test signal is finished, the check before ***Enable Signal Settings Auto Calibration*** will be automatically unchecked by the system, and all the subsequent tests will be conducted using the setting found in the calibration process until the user checks the selection again to re-conduct the calibration process. The user can examine the optimized settings from the table. ***Ref Gain***

and ***Test Gain*** are the gain settings for the reference and test signals respectively. ***V Factor*** and ***Ref V Factor*** are the voltage factor settings for the reference and test signals respectively. The actual sent signal voltage is the product of the voltage factor and the specified nominal sent signal amplitude.

FREQ (HZ): This table includes the list of selected insonification frequencies and the corresponding gains to be applied to the transmitted and received signals at each frequency. The frequency list should be arranged in ascending order. These should be set based on the hydrophone characteristics to attain sufficient resolution for the particular configuration without saturating the received signal. Trial and error may be required. The table also includes a column labeled as ***Ignore Signal*** which enables removal of any signal that is erroneous such that it will not be taken into consideration in the analysis for the bubble populations. The software automatically removes any signals that give unreasonable sound speeds or bad signal to noise ratio and sets their values of ***Ignore Signal*** to ***Yes***. Users can also manually ignore any signal that they believe is problematic by setting the value of ***Ignore Signal*** to ***Yes*** at the corresponding frequency.

AUTOMATIC FREQUENCY SETUP: To manually set up a long frequency list can be time consuming. To speed up the process, the GUI can arrange the frequency automatically. What the user needs to do is to specify the ***Min. Freq.*** (minimum frequency), the ***Max. Freq.*** (maximum frequency), and the ***Number of Freq.*** (number of frequencies), and choose how to generate the frequency list. Please notice that when the user changes the ***Min. Freq.*** and the ***Max. Freq.*** the corresponding bubble sizes will be automatically calculated and displayed as a guideline about the optimal bubble size measurement ranges. Two options are available, one is to linearly arrange the frequency list with equal frequency interval (choose ***Linear frequency list***), the other one is base on equal bubble size interval, which corresponding to the equal 1/f interval (choose ***Equal 1/f frequency list)***. If the equal 1/f interval is selected, the user can also specify when to start the equal 1/f interval arrangement. Between the minimum frequency and this frequency, equal frequency interval of 1000 Hz will be used.

TRIPLE-SET HYDROPHONE OPTIONS: If it is a multiple-set hydrophone system, the user can use this option to control how to distribute the frequency list among the three sets of hydrophones. The order of the hydrophone arrangement is that the 1st set is for lower range of frequencies, the 2nd set is for the middle range of frequencies, and the 3rd set is for the higher range frequencies. What the user needs to do is to specify two cut-of frequencies, the first frequency is specified after the text ***Use 1st set of hydrophones for the frequency up to***, frequencies below this one are handled by the 1st hydrophone set. The second frequency is specified after the text ***Use 2nd set of hydrophones for frequencies up to***. Frequencies above this one are handled by the 3rd set of hydrophones. The system will route automatically a given frequency signal to the corresponding hydrophone according to the specification. Please make sure the order of the hydrophone connections matches among the receiving and transmitting hydrophones.

HYDROPHONE RESPONSE CHARACTERISTICS: When a system is delivered, the resonance frequency and response time of the hydrophones are given. They are used for analysis for improved accuracy.

AUTOMATIC FREQUENCY DISTRIBUTION AMONG HYDROPHONES: Except for the basic single set ABS system, the user needs to specify the frequency range for each set of hydrophones. Since the hydrophone performance might change at different conditions, an automatic frequency distribution scheme has been implemented to remove the user guess work in specifying the frequency range for each hydrophone. To do so, the user needs to check the check box of ***Automatically distribute the frequency among the hydrophones.*** Close the signal setup page, and click ***Acquire*** to start the acquisition of the auto frequency distribution process, which examines the frequency response characteristics of each hydrophone set and then assign the optimal frequency range to each set of hydrophones. (This option is presently not active)

AMPLIFICATION RATIO: The system can be coupled with an external amplifier, however usually the amplifier is needed only during the actual tests and not in the reference condition. If this is the case, the user needs to specify the power amplification ratio after the text ***Test/Ref ratio of power amplification of sent signal***, such that the difference will be taking account for in analysis.

GENERATE REFERENCE DATA: Also on this page is a check box ***Generate Reference Data*** which is used to indicate whether the experiment is to be conducted as a reference with a pure liquid (with no bubbles). The pure liquid in the same experimental configuration provides a background reference state and is used in calculating the bubble size distribution in the liquid "with bubbles". This reference data set is obtained by conducting an experiment where bubbles have been removed as much as possible from the liquid under conditions and settings otherwise identical to those to be employed in determining the desired bubble size distribution. Check the box to generate this reference data set. The reference data set can be saved to disk for later use or stored in memory. *This procedure is recommended because it frees the user from errors associated with calibration of the hydrophones in the specific configuration of the experimental setup.*

NUMBER OF TESTS: The user can specify the number of test runs, *n*, desired to obtain the averaged results by entering a number between *1* and *20* in the ***Number of Tests*** box. Sets of signals are generated and acquired as many times as specified. The average of these signals is used to obtain the bubble distribution for $n > 1$. In this case, the signals of the last run are displayed (see ***4.4 View Signals*** below). The sound speed ratio and attenuation vs. frequency displayed are the average values (see ***4.6 View Results*** below). It should be noted that this option does not work with the external trigger mode (section 4.7).

- **Physical Parameters:** The **Physical Parameters** page (Figure 7) specifies the operating conditions of the experimental environment. These data are to be entered in *SI* units as noted on this page and should be specified *for the temperature and pressure at the measurement location*. Values to be specified include:

- ***Pressure*** (static) of the liquid at the measurement location (*Pascal*)
- ***Temperature*** of the liquid at the measurement location (*°C*)
- ***Specific heat ratio*** (c_p/c_v) of the gas comprising the bubbles
- ***Vapor pressure*** of the liquid (*Pascal*)
- ***Sound speed*** in the pure liquid (no bubbles) (*m/s*)
- ***Liquid density*** (kg/m^3)
- Liquid ***surface tension*** (*N/m*)
- Liquid dynamic ***viscosity*** (*kg/m-s*)
- Gas ***thermal conductivity***, *k*, given as a linear function of temperature, *T*, (*°K*) with parameters *a* and *b* (*W/m- °K*):

$$k = aT + b.$$

A database of the frequently used liquids, such as ***water***, ***mercury***, ***mineral oil***, ***corn syrup***, etc. are listed for convenience. If the liquid of interest is not listed in the database, select ***user specified***, and enters the customized physical parameters as required.

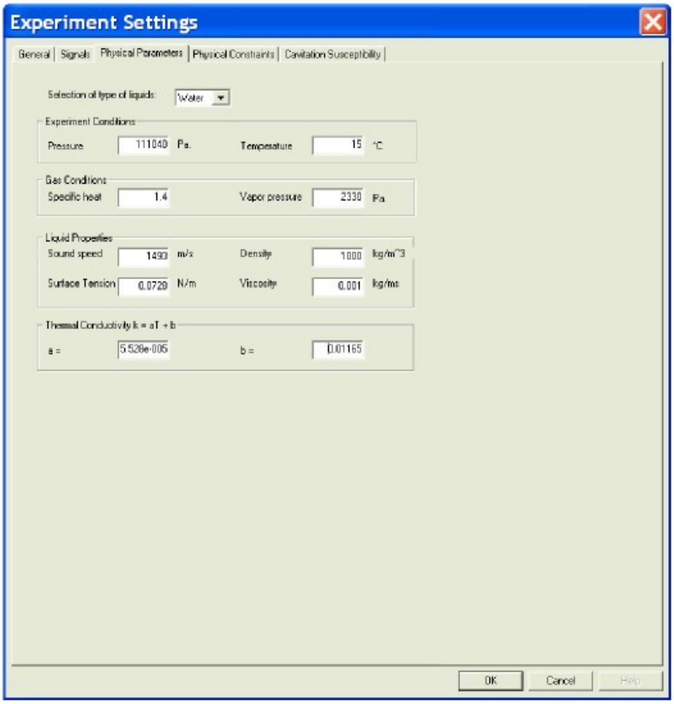

Figure 7. Experimental Settings: Physical Parameters Page.

- **Physical Constraints:** On this page (Figure 8), physical constraints are imposed in order to enable solution of the ill-posed problem, and the parameters of the computed distribution are specified. These include the minimum and maximum of the computed bubble sizes (radii) and the number of discrete sizes to compute. Two options are available for calculation (and subsequent display) of the bubble sizes. The sizes can either be linearly or logarithmically distributed between the minimum and maximum sizes. In addition, the vertical scale (***y***) – bubble number per unit volume – can be displayed with either a linear or logarithmic scale. The logarithmic scale is selected if the appropriate box on this page is checked. Upper bounds on both the total bubble surface area and the total bubble volume per unit volume (m^3) of the measurement region are also specified here. These are utilized as constraints in solving the inverse problem and need only be very approximate. They are usually set to large positive values.

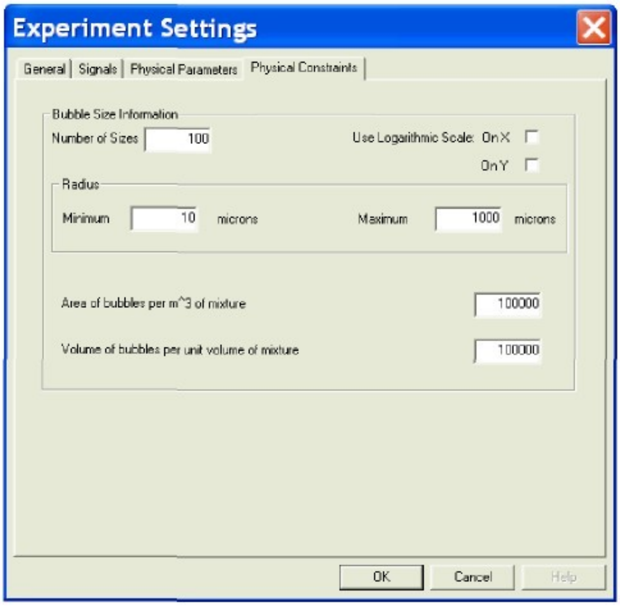

Figure 8. Experimental Settings: Physical Constraints Page.

- **Cavitation Susceptibility:** This page (Figure 9) provides information for the system to measure the cavitation susceptibility.

  AMPLIFICATION OF POWER AMPLIFIER: specifies the amplification of the power amplifier that drives the cavitation hydrophone. ***Please make sure that the actual amplification factor you set on the amplifier matches with the value specified.*** To do so, use a constant input signal amplitude and adjust the amplification of the amplifier until the ratio of the output signal to the input signal of the amplifier reaches the amplification value you require and enter the same in the ABS Cavitation Susceptibility Page.

  MAXIMUM SIGNAL VOLTAGE: gives the maximum signal voltage that will be applied to the cavitation hydrophone, it should not exceed the maximum output voltage of the power amplifier, for the Krohn-Hite wide band power amplifier, the maximum output voltage is 160 v (RMS).

SENT SIGNAL FREQUENCY: specifies the signal frequency used to test the cavitation susceptibility, which usually is around 50 – 70 kHz and corresponds to the best response frequency range of the hydrophone provided for cavitation susceptibility measurement.

SIGNAL CYCLES TO BE ACQUIRED: specifies the number of cycles to be acquired during the data acquisition process, it should be long enough to enable the detection of the cavitation events if the cavitation phenomenon exists.

For the signal analysis, the low frequency signals should be removed from the received signal:

RANGE OF BLOCKED FREQUENCY: specifies the range of frequency to be filtered out during the signal analysis. This purpose of this filtering process is to remove background and excitation noise and keep only high frequency signals of cavitation events.

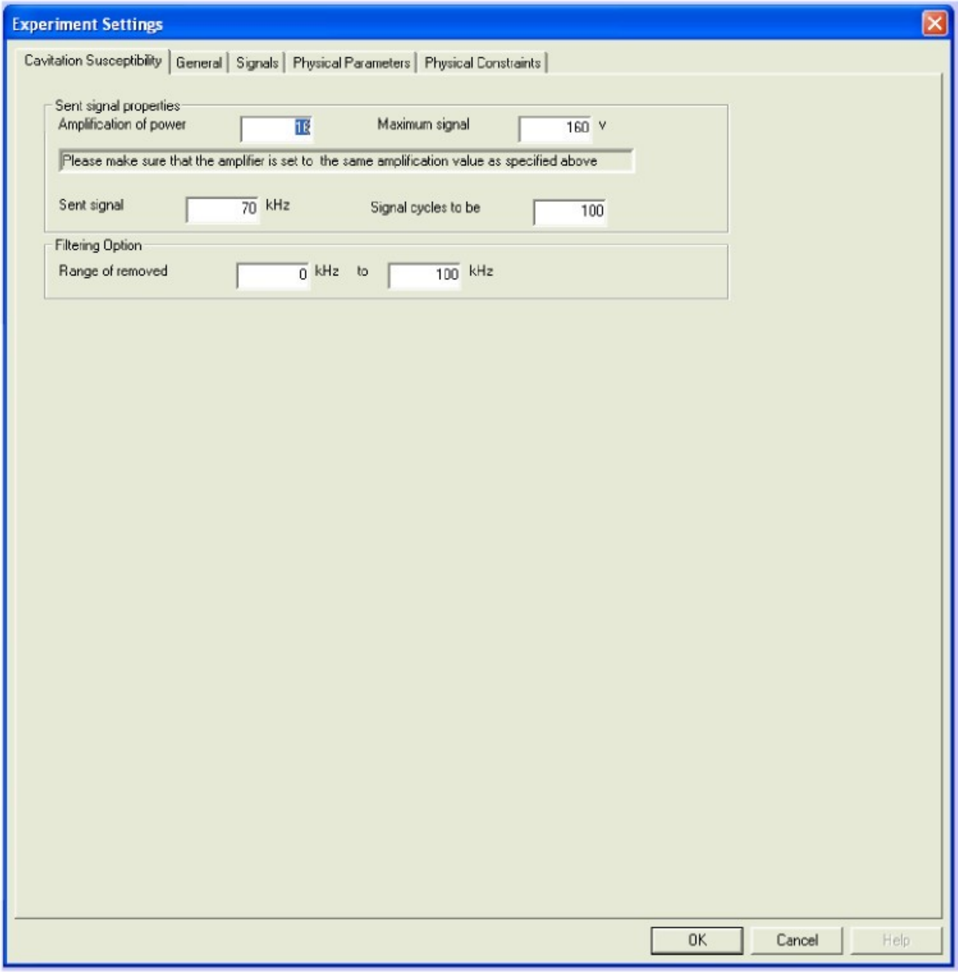

Figure 9. Experimental Settings: Cavitation Susceptibility Page.

4.3 Acquire

 This button initiates acquisition of signal in the ABS hardware version and re-processing of the raw signals in the ABS no-hardware version if the data file loaded is a regular ABS data.

For the hardware version, under regular ABS operation mode, a set of acoustic signals of characteristics specified in the ***Experiment***

Settings/Signals page are sent by the transmitting hydrophone and acquired by the receiving hydrophone. In order to improve the signal analysis a rectangular wave with the same duration as that of the matching sine wave is also added. The ***Acquire*** function can also be invoked from the menu by clicking ***Experiment/ Acquiring Signals*** or by pressing the ***F8*** key. The screen is automatically refreshed after the data acquisition is completed and processed. The raw or analyzed "sent" and "received" signals are displayed (Figure 10) based on the user selection if set in ***View Signals*** mode originally. The analysis results are displayed (Figure 15) if the ***View Results*** mode is originally set.

For the hardware version operating under the cavitation susceptibility measurement mode, a set of acoustic signals of characteristics determined in the ***Experiment Settings/Cavitation Susceptibility*** page are sent by the transmitting hydrophone and acquired by the high sensitivity pressure transducer. Similar as the regular ABS mode, the raw or analyzed "sent" and "received" signals are displayed (Figure 14) based on the user selection if set in ***View Signals*** mode originally. The analysis results are displayed (Figure 18) if the ***View Results*** mode is set originally.

4.4 View Signals

This button activates the ***View Signals*** mode to show the raw or analyzed "sent" and "received" signals most recently acquired (Figure 10). When clicked on while the Ctr key is pressured, a dialog box appears (Figure 12) to let the user specify the scale or magnification factors to be applied to the vertical axes of the signals for display. This enables zooming in on signal details that may be too small to see well with normal magnification. Another way to view the sent/received signals or reference signals is by selecting the ***Test Signals*** or ***Reference Signals*** under either ***Original Signals*** or ***Analyzed Signals*** type on the ***View*** pull down menu. If it is the ***Original Signals*** type, the acquired raw signal is displayed. If it is the ***Analyzed Signals*** type, the processed signals will be displayed.

The following descriptions apply to regular ABS mode.
As shown in Figure 10, the corresponding responses to sinusoidal and rectangular wave are displayed side by side. The duration of the

rectangular wave is also output on top of the signal. Also on the upper left corner of the display window, either "**Ref**" or "**Test**" is marked to indicate that the signal displayed is the reference signal or test signal.

Another feature in the signal display window of Version 5.0 is that the signals that have been dropped (e.g. small signal to noise ratio) from bubble distribution calculations during the signal analysis process are crossed out and marked as "Dropped Signal". This gives the user a direct indication of which signals are used during the analysis. Figure 11 shows a sample screen shot of the signals that have been dropped during the signal analysis.

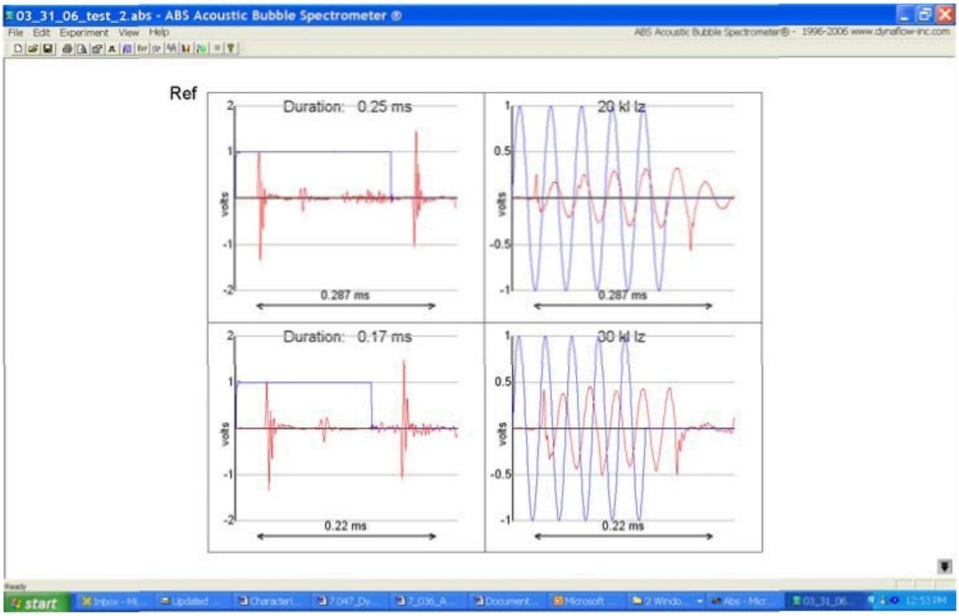

Figure 10. Display of the Raw Sent (blue) and Received (red) Signals.

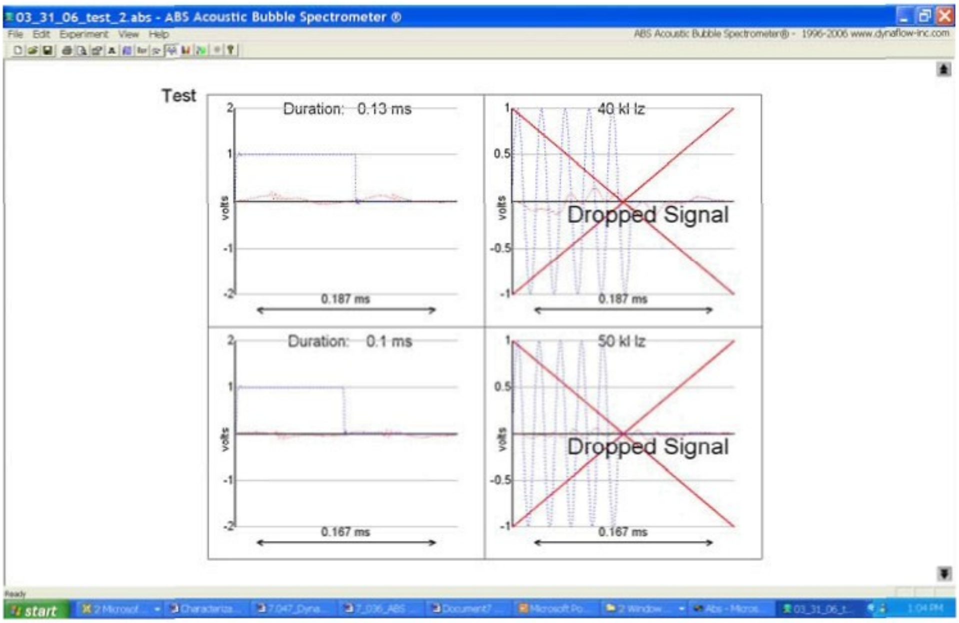

Figure 11. Dropped signals during the analysis are crossed out in signal display window.

If the ***Number of Tests*** specified in the ***Signals*** property page (Figure 7) is greater than 1, another dialog box (Figure 13) appears to enable the user to specify the option to view the signals of an individual test or to view the averaged signals of the tests. The user can select a test of interest by clicking the selection buttons. If the check box ***Used for average*** is checked, that individual test will be used for signal averaging otherwise that specific test will be excluded from the signal average process.

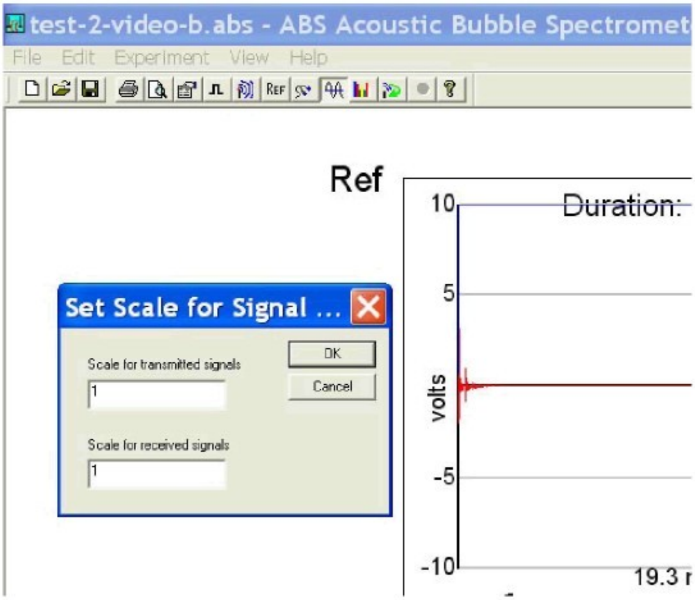

Figure 12. Dialog Box for Setting Display Scale of the Raw Signals.

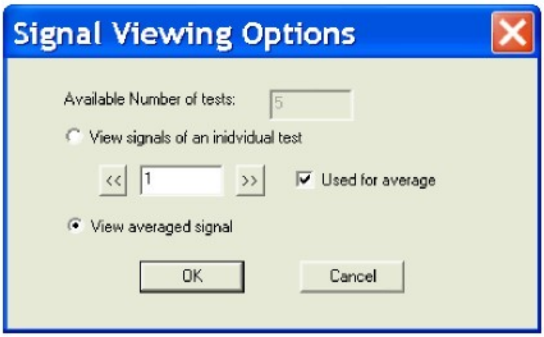

Figure 13. Dialog Box for Selecting Viewing Option for Multiple Tests.

Under the Cavitation Susceptibility mode, not all signals for all voltages tested are displayed, only signals at 4 selected voltages are displayed, covering the typical signals with and without cavitation in the test. When ***raw signal*** is displayed, the ***Sent*** signal is scaled down before the amplification while the ***Received*** signal is displayed in the original scale. If the ***Analyzed signal*** is displayed, the graph scale is based on the analyzed ***Received*** signal, which is displayed in its original scale, while the ***Sent*** signal is scaled down by a varying scale to fit in the graph scale determined by the analyzed ***Received*** signal.

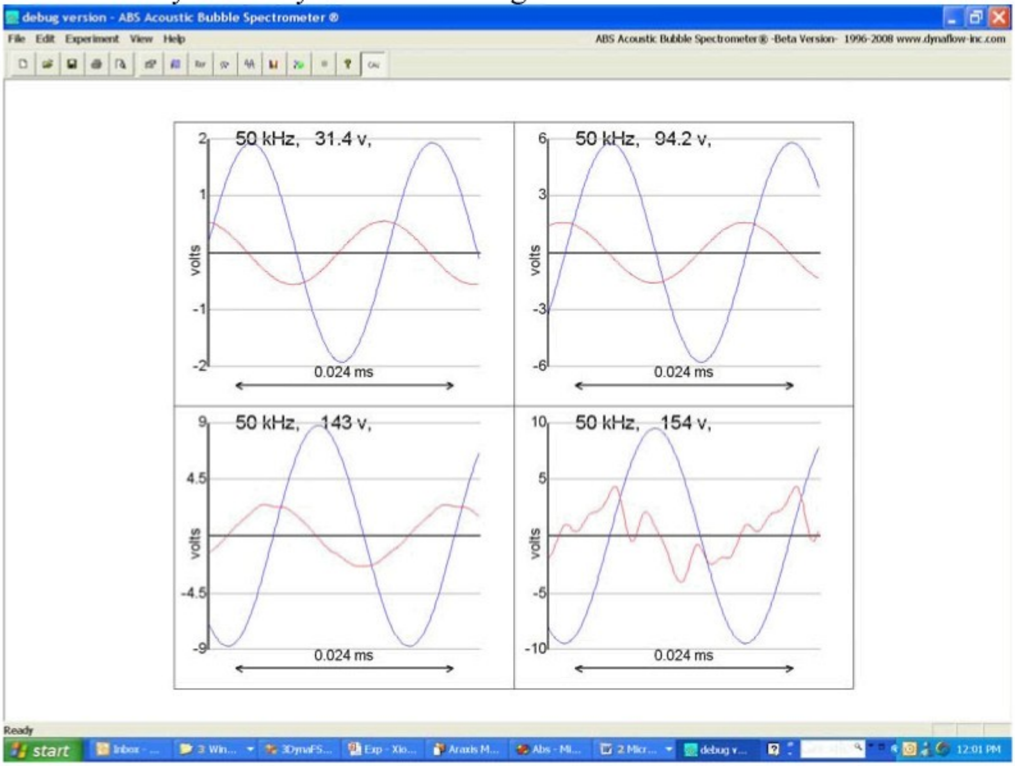

Figure 14. Display of sent and received signals under Cavitation Susceptibility mode.

4.5 Analyze

Under the regular ABS mode, this button invokes the analysis algorithms that processes the analyzed acoustic signals to obtain the measured bubble populations. The results are automatically displayed on the screen based on user selected display option (Figure 15, described below under ***4.6 View Results***). This function can also be invoked by selecting ***Experiment /Analyze Signals*** or pressing the ***F9*** key. Under Cavitation Susceptibility mode, this button invokes the algorithms that process the acoustic signals to obtain variation of the filtered received signal with voltage and the determined threshold of cavitation.

4.6 View Results

 This button activates the ***View Results*** mode to display the analysis results of the experiment (Figure 15). It is automatically enabled after clicking the ***Analyze***  button or can be activated by clicking the ***View Results***  button at any time.

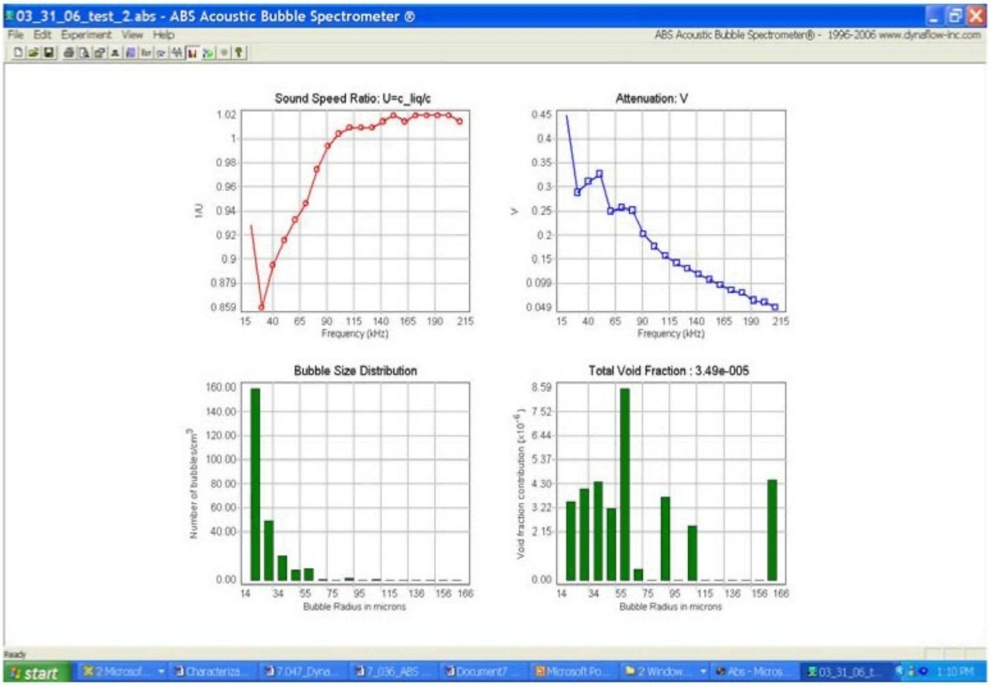

Figure 15. **Display of the Analyzed Results.**

The following descriptions applied to the regular ABS mode:

Four plots are displayed in this mode:

- ***Sound speed ratio*** ($u = c/c_{ref}$) vs. ***frequency***.
- ***Attenuation ratio*** (v) vs. ***frequency***.

- ***Bubble size distribution*** in the form of the *number of bubbles per cubic centimeter* vs. bubble *radius in microns*.
- ***Void fraction contribution*** in the form of the void fraction contribution vs. bubble *radius in microns*. The total void fraction of all bubbles are also displayed above the graph, it is simply the total measured void fraction in the range of bubble size detected.

Note*: The number of bubbles per cubic centimeter is plotted on the vertical axis of the bubble size distribution. To obtain the number of bubbles within the measuring volume, this must be multiplied by the size of the measuring volume in cubic centimeters.*

After the ***View Results***  button is clicked while the Ctrl key is pressed down, a dialog box (Figure 16) appears to enable the user to select the display option for viewing the analyzed results. If the ***Use Previous/Default Display Settings*** button is clicked, the default ranges or the ranges used in the previous display are used for displaying the analyzed results. If the ***Specify Results Display Settings*** button is clicked, a new dialog window (Figure 17) appears to let the user specify the desired ranges for sound speed ratio, attenuation ratio, and bubble size distribution. In addition, the user can also select to display the attenuation ratio in either power spectrum or RMS form.

The user can also show the analysis results of the experiment by clicking on ***Analyzed Results*** in the menu item ***View***.

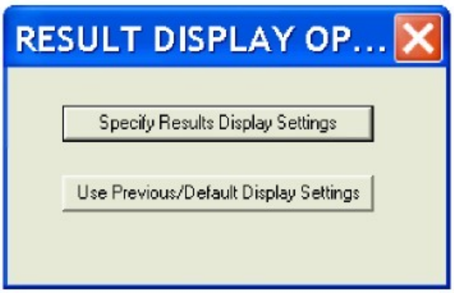

Figure 16. Dialog Box for Selecting Display Option of the Analyzed Results.

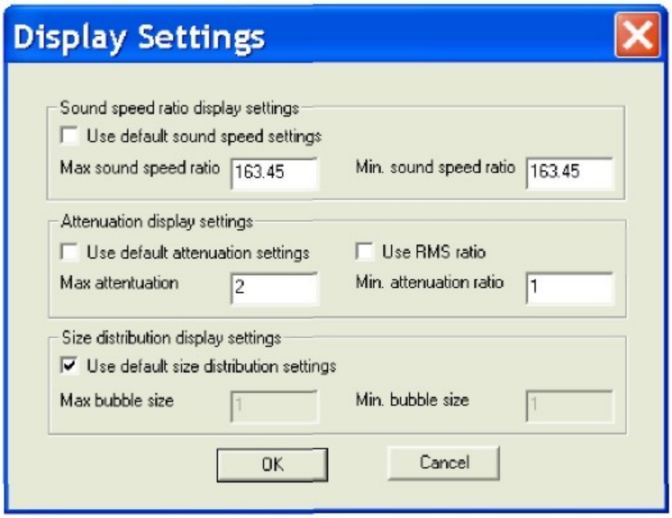

Figure 17. Dialog Box for Specifying Display Range of the Analyzed Results.

In the Cavitation Susceptibility mode, only one graph (Figure 18) is displayed:

- ***Filtered Received Signal Amplitude*** vs. ***Applied Voltagerequency***.

A vertical line indicating the determined threshold voltage for cavitation susceptibility is also displayed.

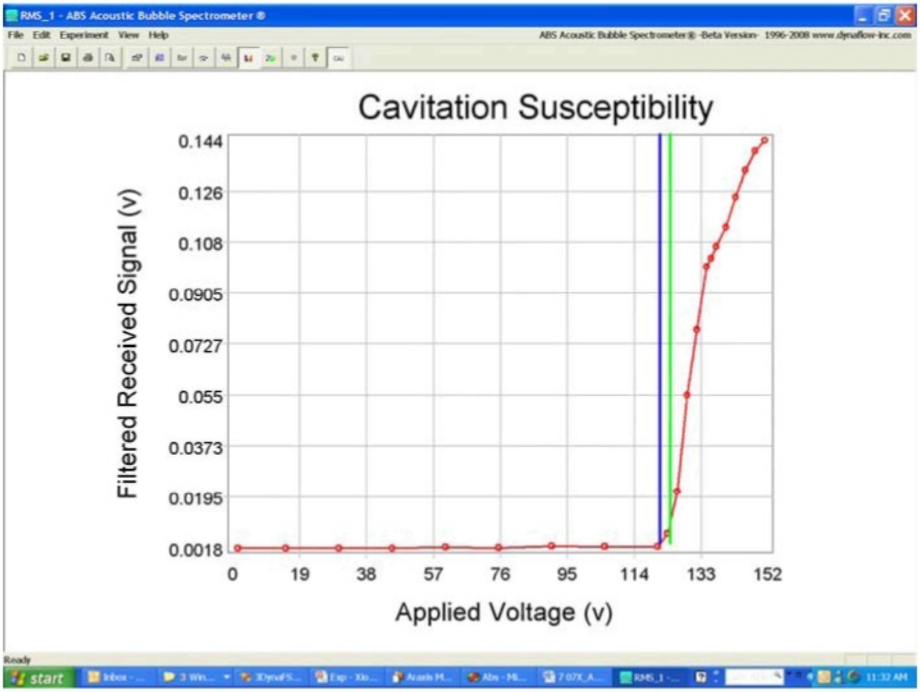

Figure 18. Display of cavitation susceptibility results.

4.8 Reference Signals

 After this button is highlighted, the signals acquired by clicking on the ***Acquire*** button  are designated as reference signals (see ***Generate Reference Data*** in **4.2**). This button is automatically released after the acquisition is finished. Also note that this button has to be clicked to release the Cavitation Susceptibility mode if it is activated.

4.9 Continuous Mode

 In some cases it may be desirable to monitor the bubble characteristics continuously. Click this button to activate the ***Continuous Mode*** which runs the ABS continuously. Before activating the ***Continuous Mode*** the user needs to make sure that the reference data are available. A dialog window (Figure 19) appears after the button is clicked to allow the user to set up the ***Continuous Mode***. The ***Time delay between sequences***

specifies the time delay before one sequence of emission/reception and the next. The ***Output options*** allow the user to choose whether the analyzed results are written to a file. If ***No output*** is selected, the results of the sequences are not output to files, however results for the most current one can be displayed on the screen. If ***Output results*** is selected, the results of the sequences are written to files at the desired frequency (see ***4.10*** for detail). While the ***Continuous Mode*** is activated, the button will be disabled until the ***Continuous Mode*** is deactivated.

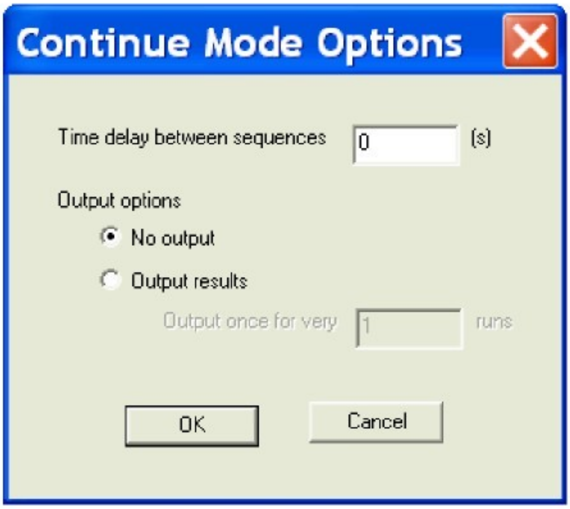

Figure 19. Dialog Box for setting up the Continuous Mode.

One restriction to the ***Continuous Mode*** is that the cursor has to be left on top of the  button to run the ABS continuously if there is no mouse activity, otherwise the ***Continuous Mode*** will be idle unless a mouse activity is detected.

4.10 Stop Continuous Mode

 This button is enabled when the ***Continuous Mode*** is activated. Click this button to deactivate the ***Continuous Mode***. After the ***Continuous Mode*** is deactivated, the button will be disabled.

4.11 Cavitation Susceptibility Measurement Mode

This button activates the Cavitation Susceptibility mode if the system is capable of this functionality. After this button is highlighted, the system is operated under Cavitation Susceptibility mode.

4.11 Files and I/O

Important data are automatically saved to files during the experiment. In both ***Acquire*** and ***Analyze*** processes, the following files are generated:

- *ATTENUATION RATIO VS FREQUENCY.DAT* This file includes the attenuation ratio at each frequency.
- *N_M3VSR1.DAT*. This file includes the number of bubbles at different bubble size bins.
- *N_M4VSR1.DAT*. This file includes the number of bubbles per unit bin size at different bubble sizes, i.e. number of bubbles divided by bin size.
- *NGROUP1.DAT*. This file includes the number of bubbles, the surface area of the bubbles, and their contribution to the void fraction at different bubble size bins.
- *SOLN_PARAM1.DAT*. This file gives the statistics of the analysis.
- *SOUND SPEED SATIO VS FREQUENCY.DAT*. This file includes the sound speed ratio at each frequency.
- *VF.DAT*. This file includes the contributions to the void fraction at each frequency.

The following files are generated only in the ***Acquire*** process:

- *BEST_FIT.DAT*. This file includes the time delay obtained from analysis at each frequency.
- *PEAKS.DAT*. This file includes five time delays between the transmitted and received signal that have the highest correlation values at each frequency.
- *UVF.DAT*. This file includes both the sound speed ratio and the attenuation ratio at each frequency.

The following file is generated only in the ***Analyze*** process:

- *BUBBLE SIZE DISTRIBUTION.DAT*. This file includes the number of bubbles and its contribution to the void fraction at different bubble sizes.

In the ***Continuous Mode***, all the above files are generated for the latest run. In addition, void fraction and bubble size distribution information for selected runs in sequence are also generated.

- *BUBBLE SIZE DISTRIBUTION_CONT_MODE.DAT*. This file includes the number of bubbles and its contribution to the void fraction at different bubble sizes for each selected run in the ***Continuous Mode***. In addition the total void fraction and the time at which output is generated are also included.
- *VOIDFRACTION_VS_TIME.DAT*. This file includes the variation of void fraction with time for the selected runs in ***Continuous Mode***.

Raw data and processed results from an experiment can be saved or reopened by two means.

Save/Open

Clicking on ***File/Save*** will save all the information in a single binary file readable by the software with a name chosen by the user. The extension of the saved file is "*.ABS*". Clicking on ***File/Open*** enables users to open a previously saved *.ABS* file. With this feature, users can view signals and results acquired previously. Users can also re-analyze the signals (solve the inverse problem) differently.

Export/Import

Clicking on ***File/Export*** to export the acquired signals to individual files for each frequency in ASCII format. Two types of data files are available for export, the *.DAT* files contain the transmitted and received signals vs. time, and the *.CPV* files are used by graphic software DF_CONTOUR© developed by DYNAFLOW, INC which is provided with the ABS. Clicking on ***File/Export*** to export the experiment data to current directory, at first a window pops up to let the user decide whether to export the *.CPV* files. Then a series of files are generated with names of the form *XXXKHZ.DAT* and/or *XXXKHZ*.CPV based on the users' choice, where *XXX* is the frequency of the signal (in *kHz*).

In addition to exporting an individual file at each frequency, the following files are also exported:

- *CORRELATION.DAT*. This file includes at each frequency the sound speeds based on time delay between the detected starts of transmitted and received signals and based on correlation as well as the time delay obtained from the correlation.
- *RECAMPLITUDE.DAT*. This file includes the amplitude of the received signal at each frequency.
- *RECPOWER.DAT*. This file includes the power of the received signal at each frequency.
- *TRAAMPLITUDE.DAT*. This file includes the amplitude of the transmitted signal at each frequency.
- *TRAPOWER.DAT*. This file includes the power of the transmitted signal at each frequency.
- *UVF.INP*. This file includes the sound speed ratio and the attenuation ratio at each frequency.

The reference data can be exported individually by clicking on ***File/Export reference results***. A *.REF* file with a name specified by the user will be exported. In addition to the total number of sampling frequencies used, it also exports the corresponding time delay between transmitted and received signal, the power of the signals, and the gains for the transmitted and received signals at each frequency.

Clicking on ***File/Import*** to import the individual ***.DAT*** files for each frequency listed in the property page ***Signals*** in the experiment settings as described in section 4.2. Note that if a corresponding ***.DAT*** file does not exist for a frequency listed an error message pops up to show the information about the missing data file.

5. Example ABS Acoustic bubble Spectrometer®© Experiment

An example of taking a set of measurements with the ABS Acoustic bubble Spectrometer®© is provided in this section. The bubble population in water at an ambient pressure of *110 kPa* and a temperature of *15°C* is determined. The gas in the bubbles is air. The following procedures are performed.

1. Run the ABS Acoustic bubble Spectrometer®© software by double clicking on the ABS icon. A screen with blank plots and a tool bar will appear. If desired, an existing file from a previous session with a *.ABS* extension may be opened as a starting point.
2. Use the **File / Save As** a utility to create a new file.
3. Select the **Experiment Settings** button  from the tool bar.
4. Go to the **General** information page and fill in the information desired (Figure 1).
5. Go to the **Signals** page. Edit the default frequencies to those desired. Edit the default gains (applied to the voltages of the transmitted and received signals by the data acquisition board) such that sufficient resolution is attained for the particular configuration without saturating the received signal (Figure 2).
6. Select the box "***Generate Reference Data***" option to obtain the reference background data set.
7. Go to the **Physical Parameters** page. Edit the default values of these physical conditions to correspond to those of the experiment as required (Figure 3).
8. Click on the **Acquire** button.  A "no-bubble" reference state is generated and the sent and received raw signals are displayed (Similar to Figure 5). It is very useful to inspect the signals to assure that sufficient resolution was obtained and that there are no other problems such as no received signals or no delay between emitted and received signal which usually indicates electric leak problems between the transducers. If these signals are not satisfactory, one should return to the **Signals** page and modify the settings accordingly or inspect the

experimental setup for problems. A new reference state can then be acquired.

9. Experiments in the presence of bubbles will now be conducted having a suitable reference state in memory.
10. Select the **Experiment Settings** button  again and go to the **Signals** page. Turn off the "***Generate Reference Data***" option
11. Click on the **Acquire** button.  The sent and received raw signals in the presence of bubbles are displayed (Figure 5). Again, it is useful to inspect these signals to assure that sufficient resolution was obtained and that there are no other problems.
12. Go to the **Physical Constraints** page and edit these as needed.
13. Select the **Analyze** button  to process the acquired experimental data. The results will be displayed as in Figure 9.
14. If desired, one may alternately view the raw signals and the calculated results by use of the **View Signals**  and **View Results**  buttons.
15. The experimental data (including reference state data) and results may be saved to disk at any time by use of **File/Save**.
16. Based on these results, refine the parameters if desired and repeat the experiment.

6. Advanced Features

6.1 Utilizing the Signal Dropping Option

In version 5.0, the user has the option to actively interfere with the signal processing. This option should only be used by a very educated user and, if not properly used, could result in very erroneous results. With this option the user can define criteria for dropping signal from the analysis. Figure 20 shows the signal drop option page which can be activated by requesting a Key from DYNAFLOW. The user can choose to drop a signal if the signal to noise amplitude ratio is less than a given threshold or if the sound speed ratio from the analysis is outside of the user specified range.

7. Useful Tips for Running Measurements

To maintain the best signal possible, make sure that the battery in the amplifier is powerful enough. Also keep the hydrophone surface clean and bubble free as much as possible.

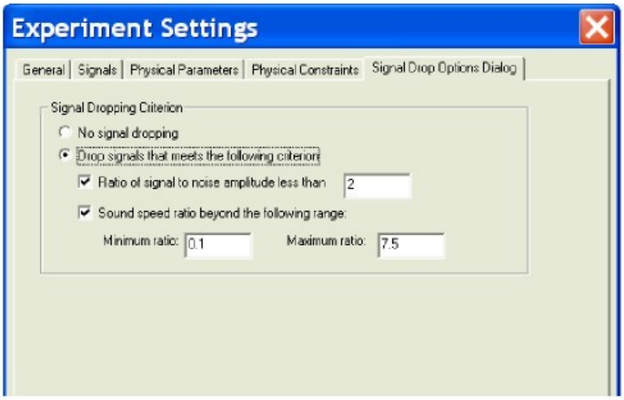

Figure 20. Signal dropping options.

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8. Chahine, G. L., Kalumuck, K. M., "Development of a Near Real-Time Instrument for Nuclei Measurement: the ABS Acoustic bubble Spectrometer®©," FEDSM'03 - 4th ASME_JSME Joint Fluid Engineering Conference, Honolulu, Hawaii, July 2003.

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With the MotionPro® X3 camera integration could not be simpler. Just install the software, connect one or more X Series cameras to USB 2.0 or Ethernet ports (or both), and you are ready to capture high-speed digital imagery. Control the camera with the feature-rich MotionPro® X software or use the LabVIEW™ or MATLAB® plug-in to integrate it into a larger experiment setup. To create your own control software, an SDK is included.

The extensive image processing algorithms include binning (2x2, 3x3, and 4x4), filtering, advanced color control, and programmable LUT enable you to maximize the image quality under various lighting conditions.

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Applications: Microscopy, Ballistics and Munitions esting, Biomechanical research, Fluid dynamics research (PIV), Off-board vehicle impact testing

Features	Benefits
Up to 1280 x 1024 resolution color or mono	High resolution allows fine detail to be captured even at high frame rates
Fast frame rates from 1000 fps at full resolution to over 64,000 fps at reduced resolution	Perfect for capturing movies of fast dynamics of a process or event
Gigabit Ethernet and USB2.0	Operate camera from remote locations via Gigabit Ethernet while using USB 2.0 for local monitoring
100 nanosecond inter-frame time in double exposure mode	perform particle imaging velocimetry (PIV) measurements to study fast moving fluids
iPod and PDA compatibility	Store movies on to iPod (video) for quick review. Control the camera operation remotely and wirelessly via PDA interface

Sample Frame Rates

Vertical Resolution	Max. Horiz. Resolution = 1280
1024	1000
768	>1300
512	2000
256	4000
128	8000
64	16,000
32	32,000
16	64,000

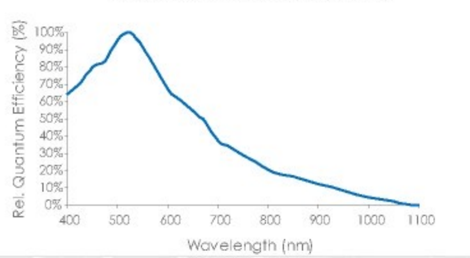
Note: Horizontal resolution does not affect frame rate performance. All X cameras can record at any frame rate at full horizontal resolution.

Accessories

X Timing Hub	USB digital interface, integrated control software with 8 outputs, 2 inputs
USB Repeater	For use up to 15m

Spectral Range

X3 Mono Relative Spectral Response



MotionPro X3 Performance Specifications

CMOS Imager	
Sensor Array	Area Array with 12µm x 12µm pixels, color or monochrome
Image Resolution	Up to 1280 x 1024 at 1000 fps
Dynamic Range	59 dB at sensor
Memory and Record Rates	
On-board Storage	4 GB
Recording Rates	Selectable, up to 64,000 fps
Playback Rates	User selectable
Camera Control	
Shutter	Global Electronic Shutter variable from 1µs, optional 100 nanosecond exposure*
Exposure modes	Single, Double, XDR (extended Dynamic Range)
Trigger Frame	Variable position from start to the maximum available frame capacity
Trigger Mode	CMOS level (3.3v) via BNC connectors
Time Stamp	Each frame
Software	
Control Software	MotionPro X; Windows 2000/XP, Mac OS X** (10.3 or later)
Image Processing Algorithms	Binning, filtering, advance color control, and programmable LUT
Plug-ins	LabVIEW™for PC; MATLAB® for PC and Mac; Twain Driver for PC and Mac
File Formats	TIFF, BMP, PNG, MRF, MCF, AVI, BLD, MPEG, and MOV (Mac only)
Mechanical Description	
Camera Dimensions	3.7 in (95 mm) H x 3.7 in (95 mm) W x 6.4 in (162 mm) L
Camera Weight	4.2 lbs (1.9 kg)
Camera to PC Interface	USB 2.0, USB 2.0&Gigabit Ethernet (optional)
Camera Cable Lengths	5m (USB2.0); Longer cable lengths (not supplied) may be used with GigE
Lens Compatibility	1" C-mount
Lens Mount	C-mount, F-mount adapter (optional)
Synchronization	
Synchronization (USB Hub Optional)	All cameras are synchronized with each other using an external sync pulse on 3.3v CMOS BNC connector
Environmental	
Camera Power	+24 vdc (100-240 VAC, 50-60 Hz ac/dc convertor)
Operating Temperature	+5°C to +40°C Ambient (0°F to 122°F)
Emission/Safety	CE approved, FCC Class B compliant, UL listed
Input/Output	
Trig In (BNC) **Sync In (BNC)** **Sync Out (BNC)** **USB 2.0 (LEMO)** **Gigabit Ethernet** **Live Out (BNC) RS170 (NTSC/PAL)** **DC Power (LEMO)**	

*Enquire with factory
**GigE interface is not supported under Mac.
Specifications are subject to change.

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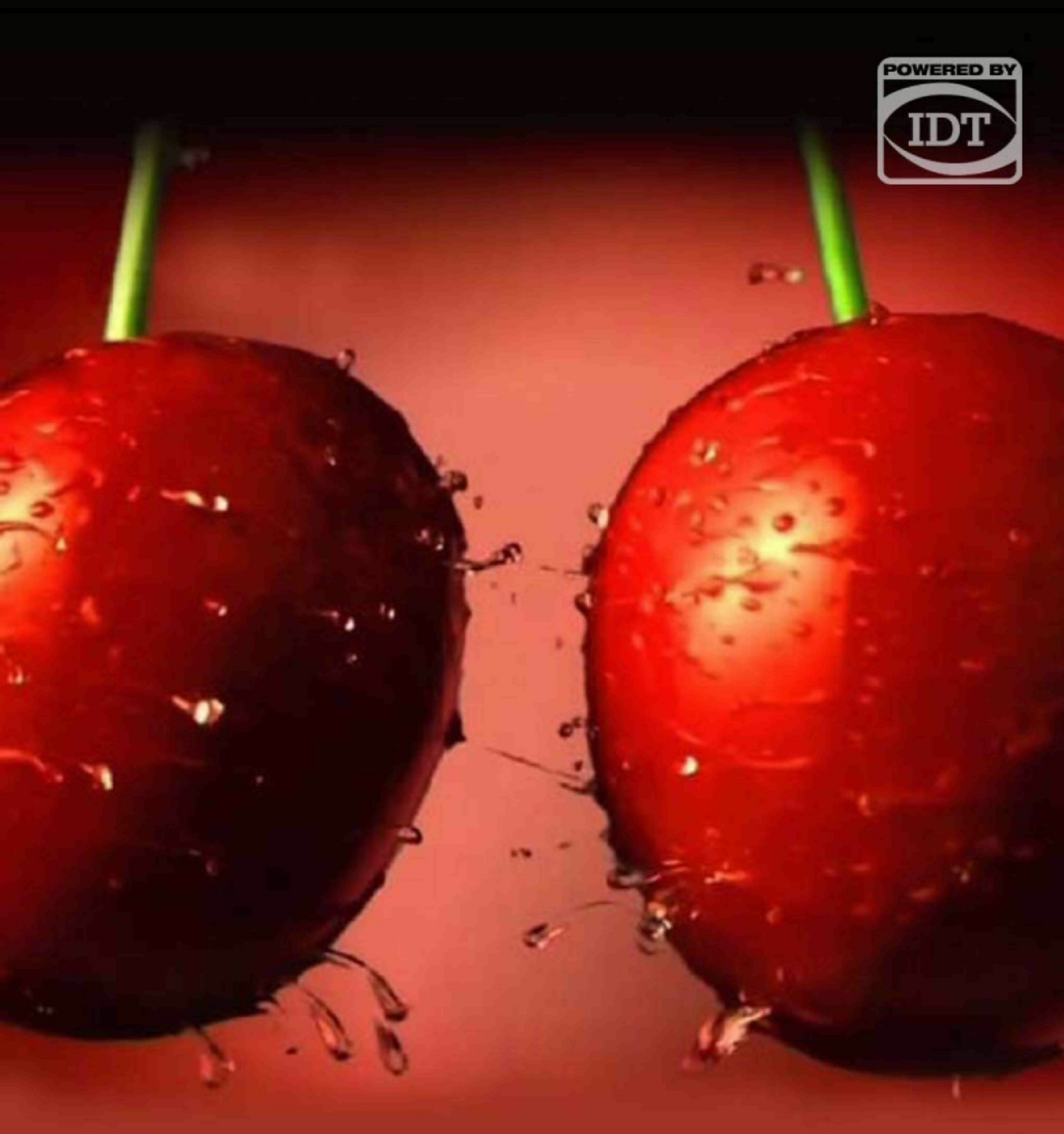

Motion Studio

Cross-platform User Manual

(For Windows™ and MAC™)

Software Release
2.08

Document Revision
March 2010

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1. Precautions

1.1. Cleaning the sensor

Clean the optical surfaces with filtered, compressed air and glass cleaner or distilled water. Use a cotton swab or lens paper. Do not use alcohol or other solvents as these may damage the optical coating and cements.

1.2. Laser

Do not focus a laser beam on the sensor directly or by reflection, it can cause permanent damage to the sensor. Any laser powerful enough to produce localized heating at the surface of the sensor will cause damage, even if the camera power is off. **Laser-damaged sensors are NOT covered by the warranty**.

2. Warranty

IDT, Inc. provides warrants to the original purchaser that, from the date of delivery, the hardware components of the **MotionPro X™ System** or the **MotionScope M™ System** or the **MotionPro Y™ System**, the **MotionXtra™ N System** or the **MotionXtra™ HG System** (the "Product") will be in good working condition for a period of one (1) year on all parts. Should any of the components of this Product fail to be in good working order at any time during this warranty period, IDT, Inc. will either repair or replace those components at its factory at no additional cost. This warranty does not include service to repair damage to the Product caused by accident, disaster, misuse, abuse, or non-IDT modification of the Product. All service shipments to IDT must be sent pre-paid. Warranty service may be obtained by contacting IDT in writing during the warranty period.

Integrated Design Tools, Inc.
1202 E Park Ave
TALLAHASSE FL 32301 - USA
Attn.: Service Department
T: (850) 222-5939
F: (850) 222-4591

Note: It is requested that the product be returned to INTEGRATED DESIGN TOOLS, Incorporated for warranty service in its original packaging.

3. System Overview

3.1. Introduction to the cameras

A “state-of-the-art” CMOS sensor combined with the most advanced features we and our customers could think of, resulted in a new product line: the **Y-series**.

The Y3 captures the 1280 x 1024 images with a speed of 1000 fps. Up to 2000 fps in Plus™ mode and frame rates up to 100.000 fps possible at lower vertical resolution. A large internal RAM memory, up to 16 GB accommodates long recording time.

Two interfaces (Gigabit Ethernet and USB 2.0) accommodate easy communication with multiple cameras (a mix of Y, X, M, and MotionXtra cameras).

The new design offers a high refresh rate during recording and playback through the digital HDMI output. The use of composite materials and a smart mechanical design results in a shock resistant camera up to 100G.

The optional battery pack offers the backup of the images in case of power surge but also an autonomous use up to 60 minutes.

Current MotionPro Y models are **Y3**, **Y4L**, **Y5**, **Y6** and **Y7 HDiablo** (1920x1080 – 1700 fps)

The **MotionXtra N-series** cameras include the capabilities of the Y-series in a small camera package.

The N3 captures the 1280 x 1024 images with a speed of 1000 fps. Up to 2000 fps in Plus™ mode and frame rates up to 100.000 fps possible at lower vertical resolution. The internal RAM memory, up to 2.5 GB accommodates compressed images.

The Gigabit Ethernet accommodates easy communication with multiple cameras (a mix of Y, X, M, and HG cameras).

The optional battery pack offers the backup of the images in case of power surge but also an autonomous use up to 60 minutes.

Current MotionXtra N models are **N3**, **N4L**, **N4** and **N5**.

The **MotionScope M-series** comprises two configurations of area scan cameras which are designed for use in industrial and research environments. The **M-3** features a 1.3 Million pixel sensor delivering over 500 fps via a standard Camera Link® interface, whereas the **M-5** provides a very high resolution image with 4 Million pixels and sustained rates over 150 fps. The camera electronics are packaged in a very compact and rugged housing capable of withstanding high-G forces and vibration.

Image capture to a computer system is done via a full **Camera Link™ frame grabber**. To ensure the best possible performance and ease of use the M-series have seamlessly integrated to operate with the Motion Studio software suite. The Motion Studio suite and SDK integrates the M-series in a single software platform with IDT X-series, Y-series and Redlake MotionXtra camera systems.

The camera benefits of such features such as pre and post triggering for event capture, circular buffering, external synchronization and flexible choice of ROI. When very long record times are required this compact camera system is configured with a dedicated disk array system.

This flexible and compact camera system is well suited for a variety of vision inspection applications as well as for R&D laboratory usage.

Current MotionScope M-series models are **M3** and **M5**.

The **X-Series** is the first high-speed camera featuring a CMOS sensor that can support a **double-exposure** mode. This mode advance allows two consecutive exposures within a 100-nanosecond interval, a revolution for capturing the motion of objects at ultra-high speeds, as in Particle Image Velocimetry. High framing rates are achieved using the partial windowing capability. **The X-Series** cameras are designed for use in industrial and scientific applications that include machine vision, microscopy, and flow and spray analysis.

The camera is supplied in one basic memory configuration: 4 GB.

The cameras feature a **USB 2.0** digital interface and **Giga-Ethernet (1000 Mbps**) that provides true and easy plug-and-play installation and capabilities at a high-speed rate of transfer to a desktop or laptop computer with a single cable. Also, the readily accessible sync input and output signals quickly integrate the camera with illumination sources, such as laser or strobe light. A video output signal (PAL/NTSC) and IRIG-B are also available.

Current MotionPro X models are: **X3**, **X4**, **X5** (2352x1728 – 250 fps).

HG systems are rugged cameras that can withstand violent forces up to 100 G. They come equipped with an internal battery for memory backup, and feature a synchronization scheme via a hub that has become the standard among many automotive manufacturers.

HG camera designs are ideal for Range, Aerospace, and Ballistics applications due to their rugged build, and their ability to perform in a wide range of environments. Accurate phase synchronization between cameras is easy using GPS signals, even when the cameras are miles apart.

The unique ability to process images via look-up tables (LUTs) on the fly allows the system to acquire and download 10 bit dynamic range images at the same fast rate as downloading 8 bit images. Custom LUTs can also be created for the specific needs of any application.

Current HG models supported by Motion Studio and the SDK are:

- Legacy Redlake cameras (**HG-2000**, **CR-2000**, **HG-TX**).
- **HG-100K**, **HG-LE**, **HG-TH**.
- New **HG-XR**, **HG-XL** and **HG-CH**.

3.2. System components

The systems components are listed below.

- **Camera**: it is the first high-speed camera featuring a CMOS sensor capable of supporting a double-exposure mode. The camera body accepts standard C-mount lenses.
- **MotionPro X/Y and MotionXtra N Digital Interface**: The USB 2.0 (480 Mbps) cable or Giga-Ethernet (1000 Mbps) provides data and control signals to and from the camera as well as it connects the camera to any USB 2.0 or Ethernet port on your personal computer or laptop. N cameras do not have any USB interface.
- **MotionScope M Digital Interface**: the camera interfaces to a computer system via a Full Camera Link™ frame grabber. Currently supported frame grabbers are the Dalsa-Coreco X64 Xcelera-CL PX4 and the National Instruments PCIe-1429.
- **Power Source**: The power source provides external power to the camera
- **Trigger and Synchronization Connectors**: The camera has three BNC connectors for input and output of synchronization signals and triggering. These signals are CMOS level, and provide a means to synchronize the camera with an external clock or triggered it with relationship to a given event. The synchronization signals are generated for every image frame produced.
- **Software and SDK**: operates in Windows 2000, XP, Vista and MAC OS X (10.2 and later) environment.
- **Optical Interface**: The standard interface is C-mount. C-to F and Canon mount converters are available upon request.

3.3. System accessories

- **MotionPro Timing Hub**: USB 2.0 digital interface, integrated control software with 8 outputs and 2 inputs.
- **MotionPro Data Acquisition (DAS)**: USB 2.0 digital interface, integrated control software with 16 analog inputs, 4 analog outputs and 16 digital I/O channels.
- **Galileo Wireless Sync/Trigger system**.
- **USB repeater**: for up to 15 m.

3.4. Note on cross-platform manual

The cross-platform manual provides instructions on using the camera on the Windows and MAC OS/X platforms. The Windows and MAC icons below denote differences in setup, procedures and commands between Windows and MAC users.

3.5. Software Development Kit

Upon the installation of the Motion Studio software package several options are available to the user. These options are easily accessed via the Program menu under the Windows Start button. The programs and associated files are organized under the **IDT/MotionProX** folder (**IDT/MStudio64** for the 64 bit version and **/Applications/MotionProX** for the MAC version). The folder includes the example programs and the associated documentation. The software components included in the Software Development Kit are:

- SDK modules with example source code in MSVC++ and VB.
- TWAIN driver.
- Plug-in for LabVIEW™ (Windows only).
- Plug-in for MATLAB™.

The SDK modules provide an API interface to develop applications to operate the camera and access all the camera capabilities using a programming language such as C++ and Java. A C/C++ header file is included in the SDK (**XStrmAPI.h** file in the Include sub-directory).

Most compiled languages can call functions; you will need to write your own header/import/unit equivalent based on the C header file.

A Visual Basic module is included in the SDK (**XStrmAPI.bas** file in the Include sub-directory). VB cannot use **XsQueueOneFrame** or **XsQueueCameraSettings** or related functions, because these functions have callbacks which occur on a different thread. If you want to use VB, you might need to write some C code depending on your application's requirements. The same issue with asynchronous callbacks, above, also applies to Java.

The Windows driver is a DLL (XStreamDrv.dll) that resides in the system32 directory. It may be found also in the Bin sub-directory.

MS Visual C++™: A Visual C++ 6.0 stub COFF library is provided (**XStreamDrv.lib** in the Lib sub-directory); if you are using Visual C++, link to XStreamDrv.lib. The DLL uses Windows standard calling conventions (_stdcall).

Borland C++ Builder™: the XStreamDrv.lib file is in COFF format. Borland C++ Builder requires the OMF format. To convert the library into to OMF format, use the IMPLIB Borland tool with the following syntax: “IMPLIB XStreamDrv.lib XStreamDrv.dll”.

Other compilers: the Most other compilers can create a stub library for DLLs. The DLL uses Windows standard calling conventions (_stdcall).

MS Visual C#: the **XsCamera.cs** file has been added to the include folder. It wraps the APIs into a C# class. Just include the file into your C# project and call the “**XsCamera**” class members.

MAC OS Project Builder™: the driver is a Framework that resides in the **/Library/Frameworks** folder. If you use Apple Project Builder 2.1, add the XStream.framework file to your project.

For a more detailed description of the SDK please refer to the **Motion Studio SDK Reference**.

4. Installing the System

This section specifies the minimum recommended computer requirements and gives the procedures needed to install the Camera Head, Camera Cable, Power Supply, I/O Cable, and software.

4.1. Minimum computer requirements

MotionPro X/Y – MotionXtra N		
	PC (Win32 and x64)	**MAC**
Operating System	Windows XP, Vista and 7	MAC OS X 10.3 (Panther) or higher
Processor	Pentium III or equivalent with 500 MHz processor.	G4 MAC OS X compatible
RAM	2 GB	512 MB
USB 2.0 Port	USB 2.0 port that is NOT shared with other devices (X and Y)	high speed USB port that is NOT shared with other devices (X and Y)
Network adapter	Giga-Ethernet (recommended) or 10/100 Mbps.	Giga-Ethernet (recommended) or 10/100 Mbps (Y and N).
Hard Drive	60GB or greater hard drive (recommended).	60GB or greater hard drive (recommended).

NOTE: Use an USB 2.0 port on the computer or a Giga-Ethernet port. USB 1.1 DOES NOT support camera operation.

MotionScope M™			
	PC Win32	**PC x64**	**MAC**
Operating System	Windows XP, Vista and 7 @ 32-bit	Windows XP, Vista and 7 @ 64-bit	Not supported
Processor	Intel CORE 2 at 2 GHz	Intel CORE 2 at 2 GHz.	Not supported
RAM	2 GB	4 GB	Not supported
Frame Grabber	Coreco X64 Xcelera-CL PX4 NI PCIe-1429 EPIX PIXCI E4 Bitflow Karbon	Coreco X64 Xcelera-CL PX4 EPIX PIXCI E4 Bitflow Karbon	Not supported
Computer Slots	One available x4 or larger PCI Express slot	One available x4 or larger PCI Express slot	Not supported
Hard Drive	100GB or greater hard drive	100GB or greater hard drive	Not supported

4.2. Package contents

Before beginning the installation process, check that the following items are present in the package. If you are missing any of the items listed below, please contact IDT, Inc. or your sales representative.

- Camera.
- I/O USB 2.0 Cable (MotionPro X and Y camera).
- CD-ROM of Motion Studio software suite and documentation.
- Power supply.
- Cross-platform Quick Start Guide.

4.3. MotionPro X/Y and MotionXtra N camera Installation

4.3.1. Software Installation

Windows 2000/XP/Vista

Before installing the software make sure that the computer has Windows 2000, XP or Vista installed as operating system.

1. Log into Windows with a username and password that has **ADMINISTRATIVE PRIVILEGES**.
2. Insert the Motion Studio CD in the CD drive. If the computer is configured to AUTORUN, the installer will run automatically. If not, click on the Windows **Start** button. Select **Run** from the menu. Use the **Browse** button to locate the SETUP.EXE file on the CD and click the **OK** button.
3. Select the “Install” option and follow the on-screen instructions.
4. EXIT when the installation is complete and restart your computer.

MAC OS/X

Before installing software make sure that your MAC has MAC OS X 10.2 (Jaguar) or higher, installed as operating system.

1. Log into Mac OS/X with a username and password that has **ADMINISTRATIVE PRIVILEGES**.
2. Insert the Motion Studio CD in the CD drive.
3. Locate the **mstudio.dmg** file in the MAC sub-directory of the CD.
4. Double click on the **mstudio.dmg** to run installation program and follow the on-screen instructions.
5. EXIT when the installation is complete and restart your computer.

4.3.2. Hardware installation (USB 2.0)

A 24 VDC, 1 Amp supplies the camera with the necessary power. This power supply unit is included with the camera system package. All communication and data transfer with the host computer is done via the USB 2.0 or the Giga-Ethernet interface. The USB 2.0 interface requires a single cable, which is also supplied with the camera package. External triggering and synchronization are done via the two connectors (BNC type). Triggering is expected to be done with a TTL pulse. The synchronization signal is also TTL level.

NOTE: Connect the camera to the computer before connecting the camera to the power source.

Windows 2000/XP/Vista

1. Connect the USB 2.0 cable to an available USB 2.0 port on your computer.
2. Connect the other end of the USB 2.0 cable to the back of the camera.
3. Connect the camera to the power source.
4. Turn the camera ON/OFF switch to the ON position and wait a few seconds for the camera to initialize it self.
5. Follow the on-screen instructions. Click on the **YES** or **Continue Anyway** button when prompted by the Windows 2000 or XP Operating system to proceed with the installation.

MAC OS/X

1. Connect the USB 2.0 cable to an available USB 2.0 port on your computer.
2. Connect the other end of the USB 2.0 cable to the back of the camera.
3. Connect the camera to the power source.
4. Turn the camera ON/OFF switch to the ON position and wait a few seconds for the camera to initialize it self.

NOTE: Use an USB 2.0 port on your computer. USB 1.0 does NOT support camera operation.

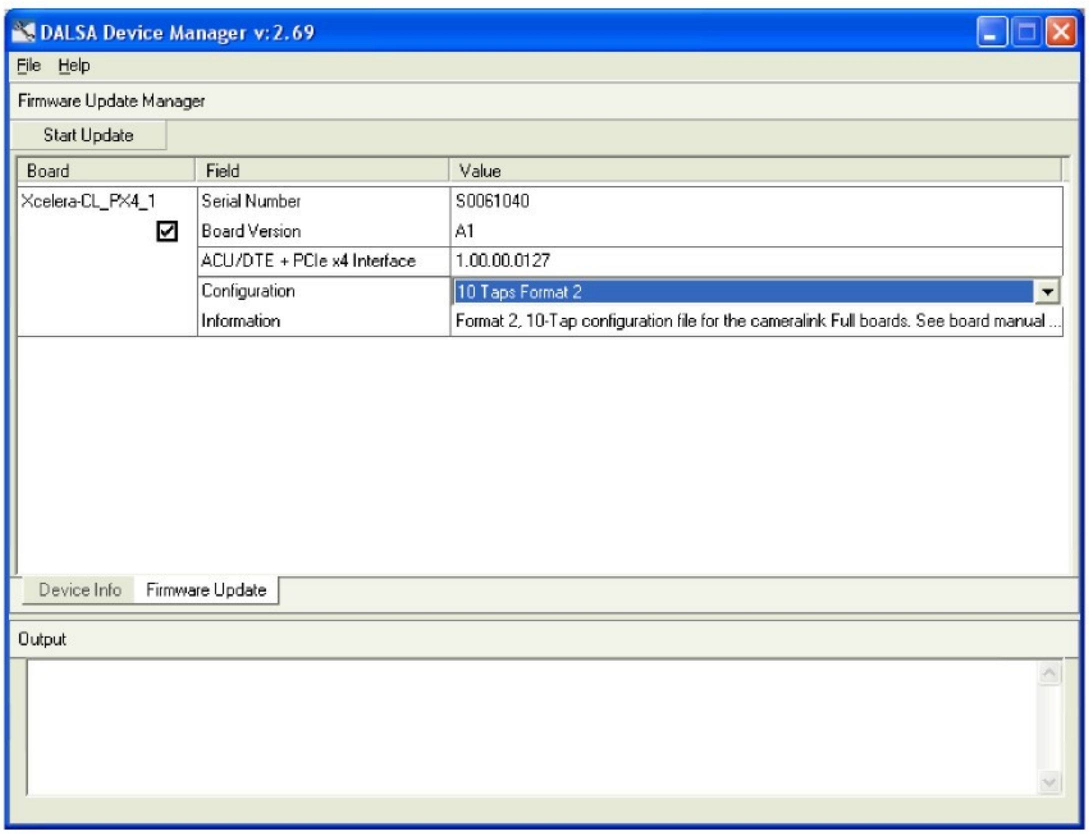
4.4. MotionScope M camera installation

4.4.1. Installing the Dalsa-Coreco X64 Xcelera-CL PX4 frame grabber

Install the frame grabber in a PCIe x4 slot and power up your computer.

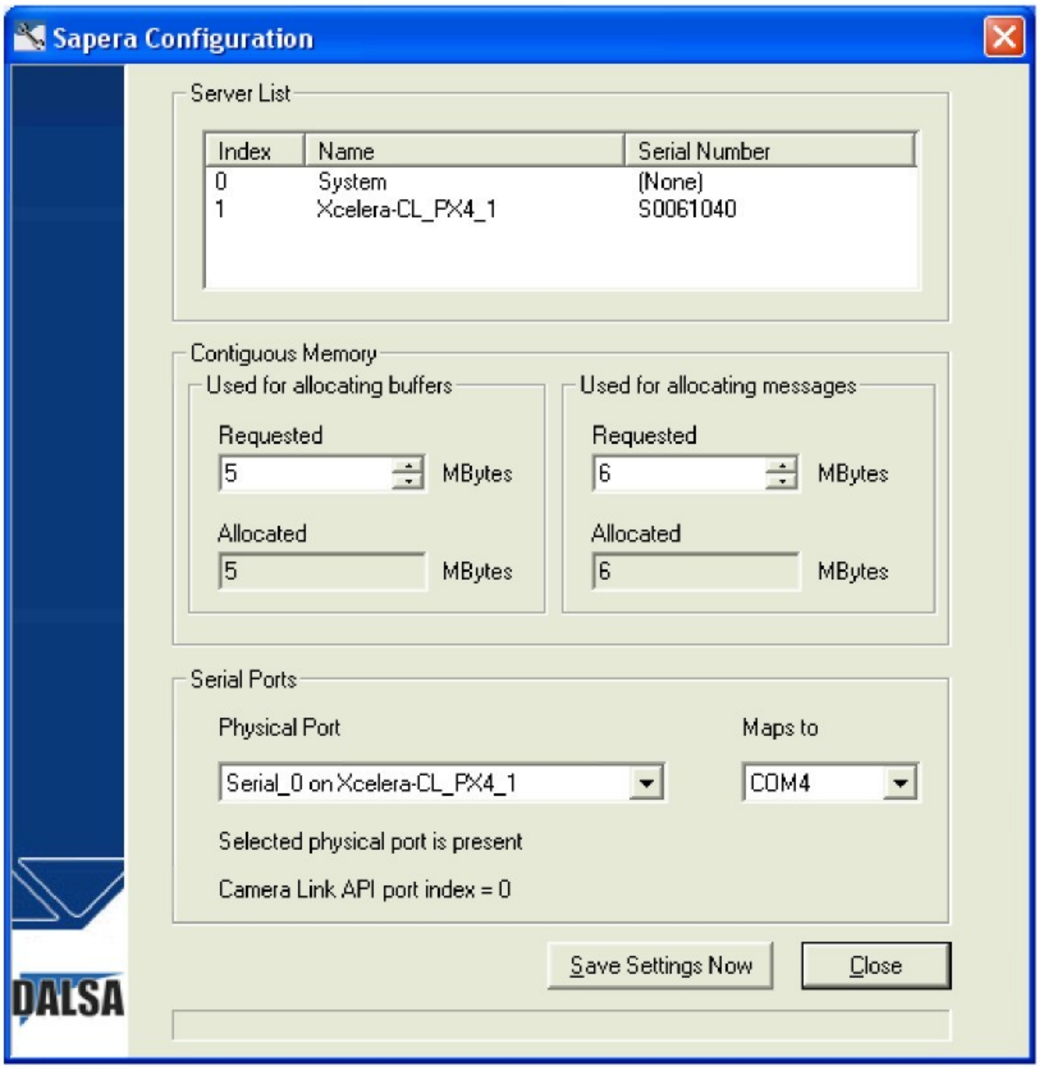
Install the "**X64 Xcelera-CL PX4 driver for Sapera LT Image Library**" and follow the procedure below to update the firmware.

1. From the "All Programs -> DALSA -> X64 Xcelera-CL PX4 Driver" menu, select the "CorDeviceManager" item.
2. Select the Firmware Update Tab.
3. From the Configuration combo, select the "10 Taps Format 2" option.
4. Click the Start Update button.
5. Restart the computer.



Install the “**Sapera LT Image Library**” version 6.04. Then follow the procedure below to edit the camera serial port. The configuration is necessary to correctly operate the camera.

1. From the DALSA -> Sapera LT menu, select the Sapera Configuration item.
2. From the Maps to combo-box in the “Serial Ports” group, select the “COM 4” option.
3. Exit the program and restart the computer.



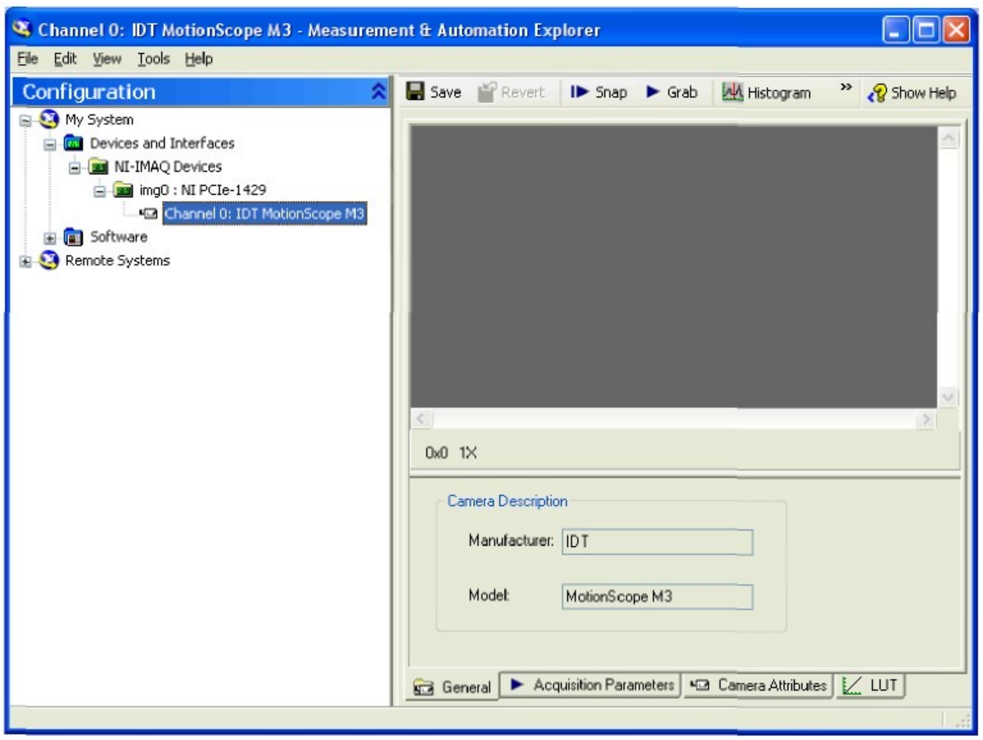
NOTE: if more than 1 frame grabber is installed, you have to select a different COM port for each frame grabber (COM4 for FG1, COM5 for FG2, etc.).

4.4.2. Installing the National Instruments PCIe-1429 frame grabber

- Install the software by following the instructions below.

1. Install the "NI VISION Acquisition software" version 8 or later, which includes the NI-IMAQ driver software.
2. Install the Motion Studio software suite (see the following topics).

- Install the frame grabber in a PCIe x4 slot and power up your computer.
- Connect the camera (see the following topics).
- Run the NI "Measurement and Automation" utility and follow the instructions below.



1. From the left pane, expand the "Devices and Interfaces" branch of the configuration tree
2. Expand the "NI-IMAQ Devices" branch.
3. Expand the "NI PCI2-1429" branch.
4. Right click "Channel 0" and select "Camera".
5. From the menu, locate IDT, then "MotionScope M3" or "MotionScope M5" and select it.
6. Exit the measurement and Automation utility.

4.4.3. Installing and configuring the EPIX PIXCI™ E4 Frame Grabber

Install the software by following the instructions below:

1. Install the "XCAP Imaging Application for Windows 95/98/ME/NT/2000/XP/Vista" software.

2. Install the Motion Studio software suite (see the following topics).

Then power off the computer, install the frame grabber in a PCI Express x4 available slot and power up the computer.

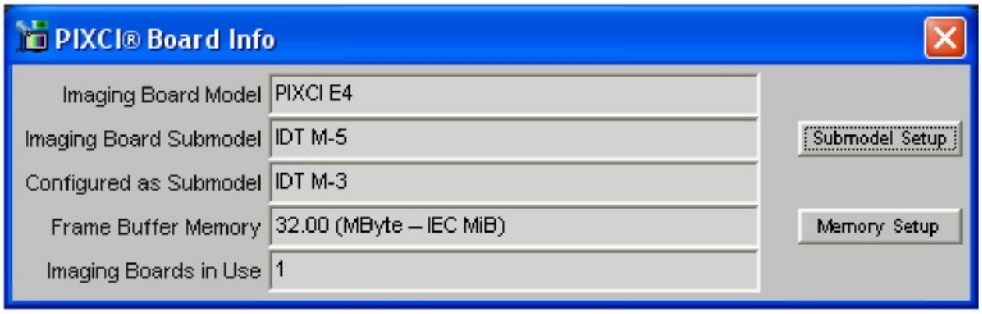
Install the drivers for the frame grabber form the location where XCAP has installed them. The default is C:\Program Files\EPIX\XCAP\Drivers\WinXP.

Run "XCAP for Windows". Enter the activation code and restart the application.

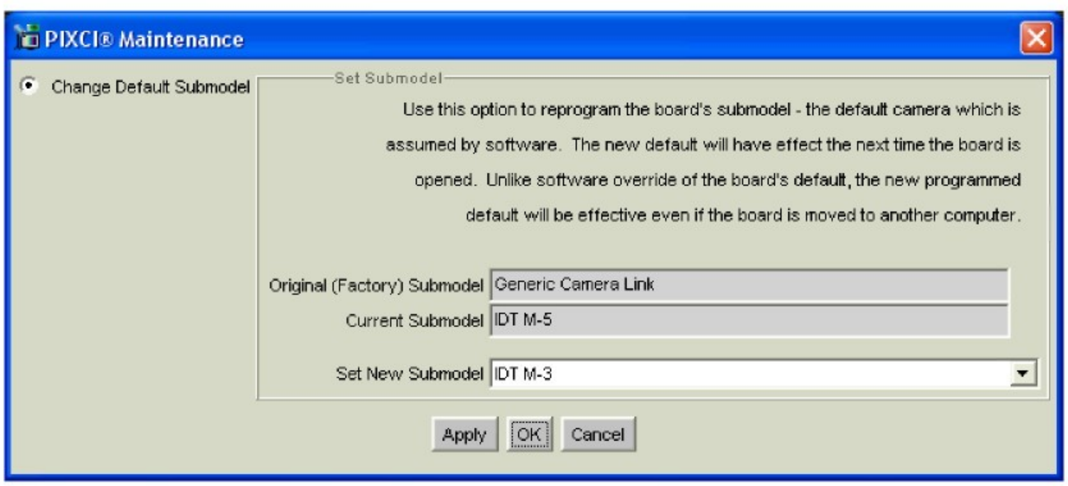
4.4.3.1. How to set the M3 or M5 camera as default

To set M3 or M5 as default, the board sub-model must be changed.

1. From the PIXCI menu item, select “PIXCI Open/Close”.
2. If the Close button is grayed out, click Open. A window with a pre-configured camera model will be open.
3. From the PIXCI Open/Close window, click “Board Info”. The dialog box below will appear.



4. Click “Submodel Setup”. The PIXCI Maintenance dialog box will appear, like in the picture below.
5. From the Set new submodel list” select IDT M-3 or M-5.
6. Click OK.

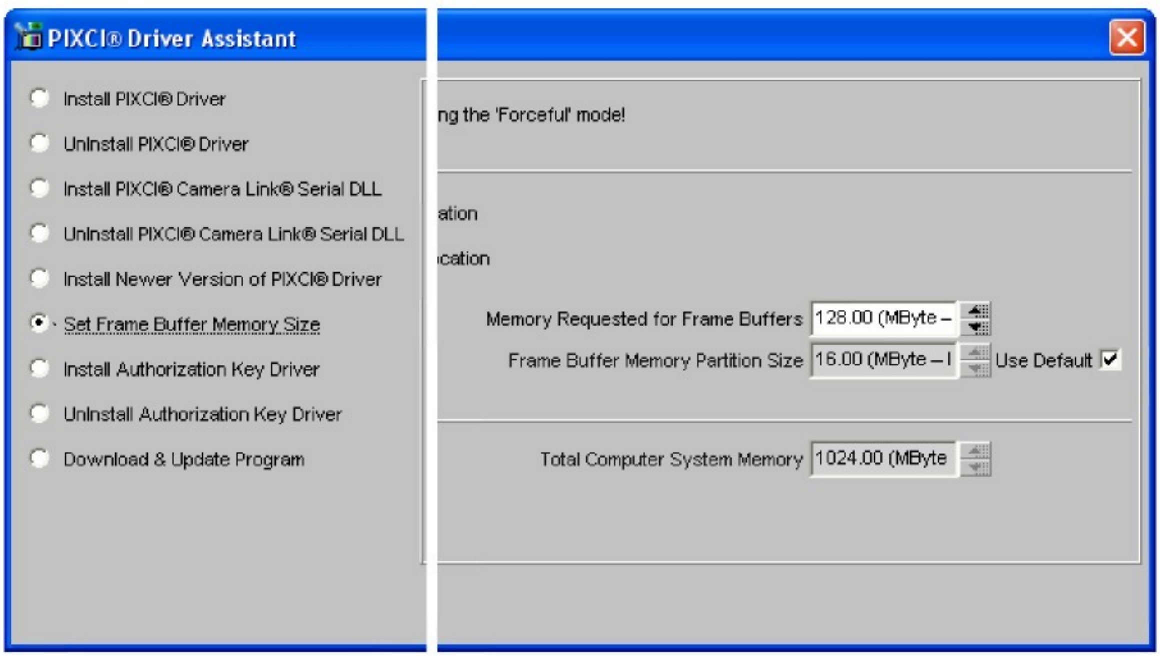


4.4.3.2. How to increase the amount of memory allocated for the acquisitions

The PIXCI E4 drivers do not allow increasing the number of buffers to acquire via the XCLIB library. It may be done only via the XCAP Imaging application.

The PIXCI driver allocates the memory when Windows starts up, then each change is followed by a computer reboot.

1. From the PIXCI menu item, select “PIXCI Open/Close”.
2. If the Close button is active, click Close.
3. Click the “Driver Assistant” button and select the “Set Frame Buffer Memory Size” item.
4. Change the memory size in the “Memory requested for Frame Buffers” control.



4.4.4. Installing and configuring the Bitflow Karbon-CL Frame Grabber

First install the software by following the instructions below.

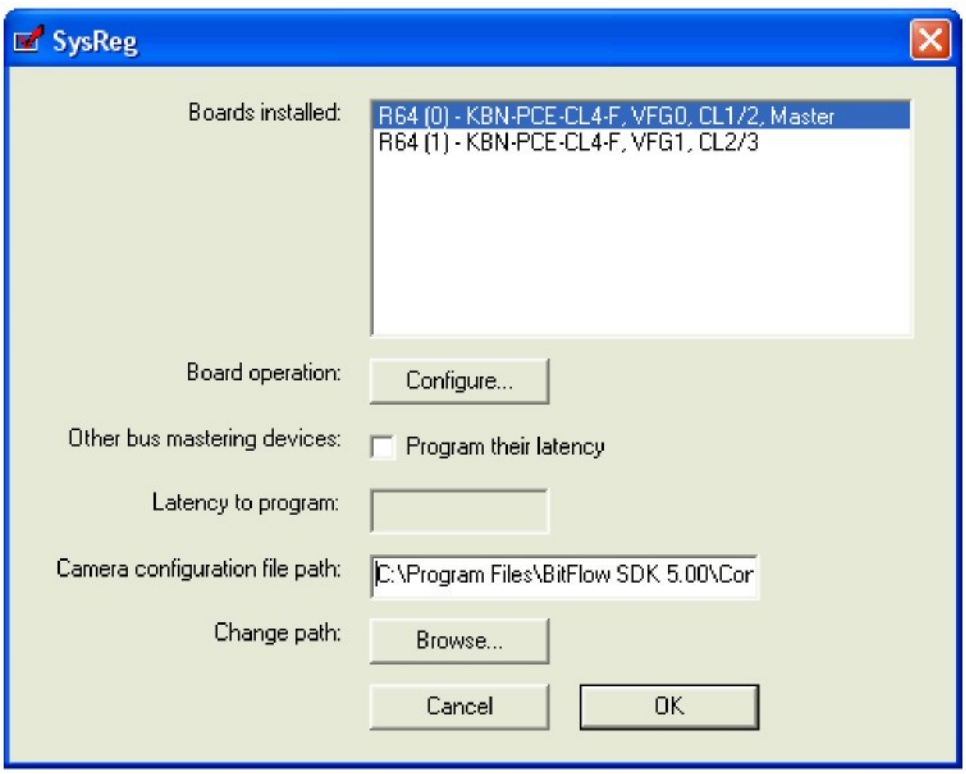
1. Install the “Bitflow SDK. When the setup asks for serial number, enter the value “0”. It will install all the binary modules necessary to operate the camera.

2. Install the Motion Studio software suite (see the following topics).

Then power off the computer, install the frame grabber in a PCI Express x4 available slot and power up the computer.

Follow the instructions on video when Windows detects the frame grabber. When Windows asks to verify the driver, click “Install anyways”.

Run the “**SysReg**” application from the desktop link. When the utility starts, it will show the frame grabber information.



4.4.4.1. How to attach the correct camera file to the frame grabber

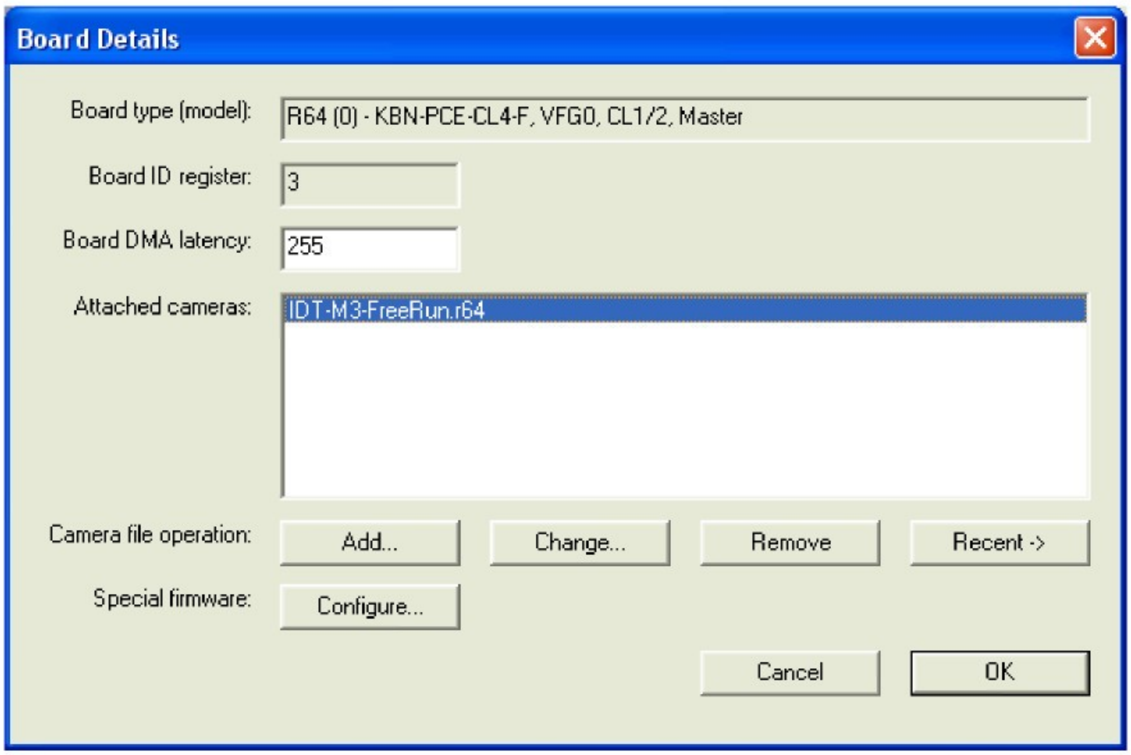
From "**SysReg**" utility, click on the "Configure…" button next to "Board Operation".

From the "Board Details" window that appears, click the "Add…" button.

In the "Choose camera file" dialog box that opens, locate the "Make: IDT, Inc." tree item.

Expand the tree to the bottom and select M3 or M5 camera file.

Select OK.



4.4.4.2. How to install the correct firmware on the frame grabber

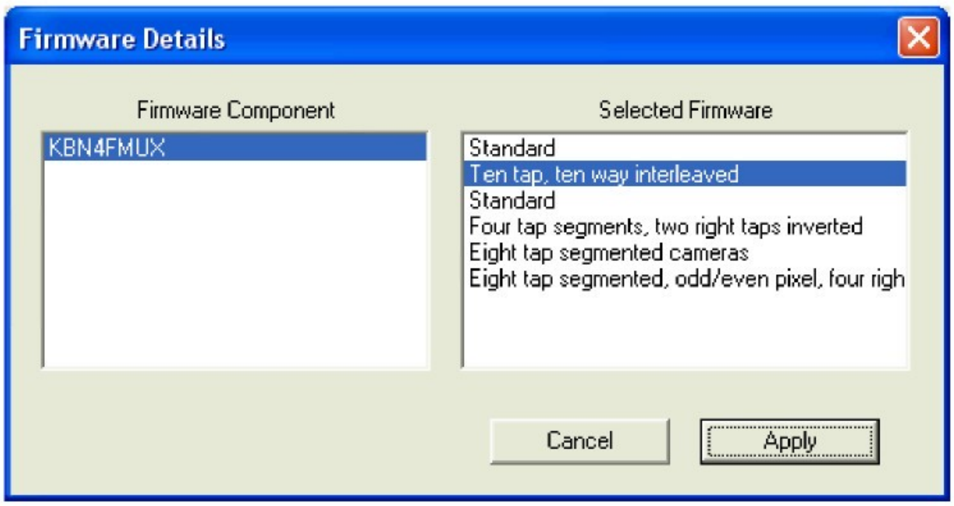
From the “Board details” window, click on the “Configure…” button next to “Special firmware”.

In the right pane of the window that appears, select “**Ten tap, ten way interleaved**”.

Click Apply and wait until the firmware is updated.

Click OK to close the “Board details” window.

Click OK to close SysReg.



4.4.5. Installing the Motion Studio software suite

Before installing the software make sure that the computer has Windows XP or Vista installed as operating system.

1. Log into Windows with a username and password that has **ADMINISTRATIVE PRIVILEGES**.
2. Insert the Motion Studio CD in the CD drive. If the computer is configured to AUTORUN, the installer will run automatically. If not, click on the Windows **Start** button. Select **Run** from the menu. Use the **Browse** button to locate the SETUP.EXE file on the CD and click the **OK** button.
3. Select the "Install" option and follow the on-screen instructions.
4. EXIT when the installation is complete and restart your computer.

4.4.6. Connecting the camera

A 12 VDC, 1 Amp supplies the camera with the necessary power. This power supply unit is included with the camera system package. All communication and data transfer with the host computer is done via the Camera Link interface. The Camera Link interface requires two cables. External triggering and synchronization are done via the three SMA connectors. Triggering is expected to be done with a TTL pulse. The synchronization signal is also TTL level.

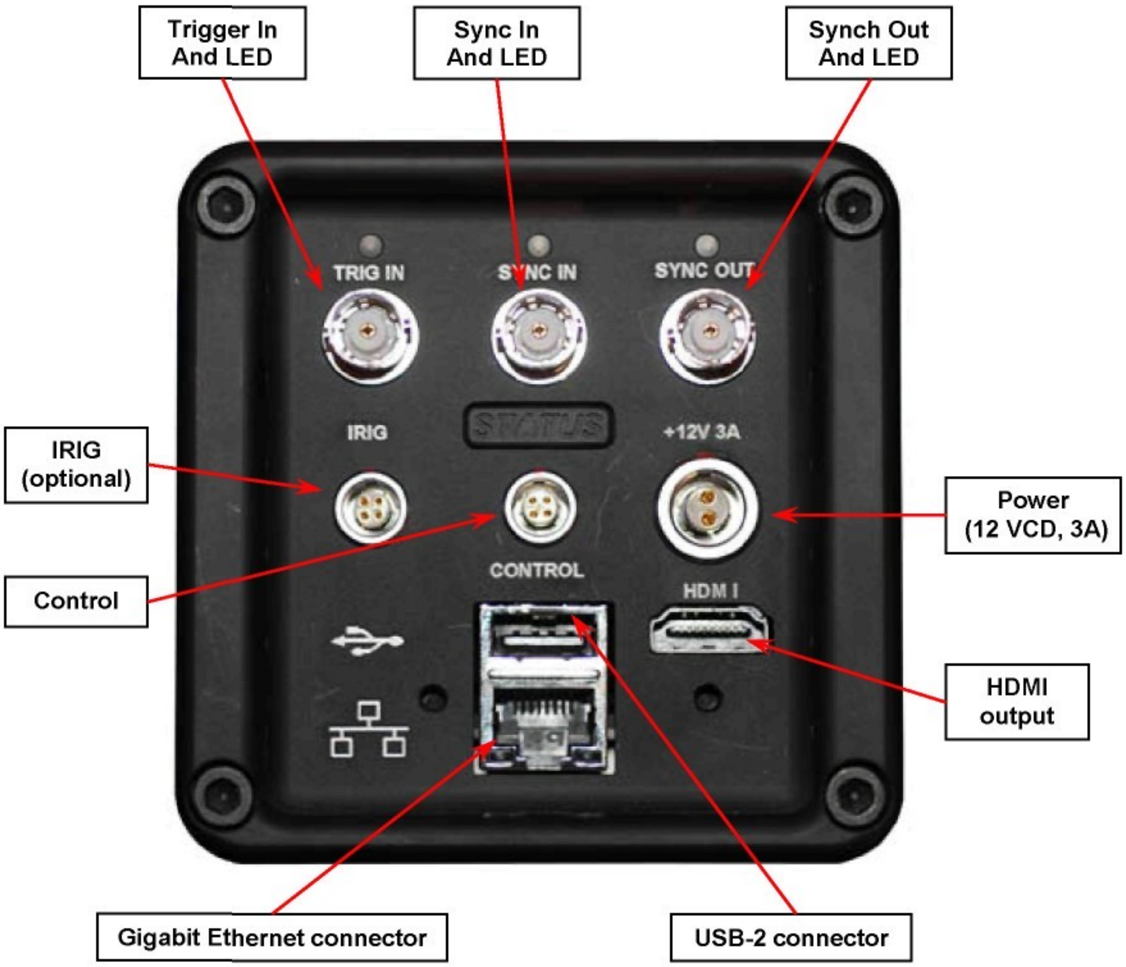
NOTE: Connect the camera to the computer before connecting the camera to the power source.

1. Connect the Camera Link cables to the frame grabber on your computer. Connect the lower connector on the camera side to the connector on the computer that is near the PCI slot.
2. Connect the camera to the power source.

4.5. Camera back panel

4.5.1. MotionPro Y

The MotionPro Y-series camera back panel (revision 5) is shown below.



Control pins (Rev 5 and below)

The Sync/Trigger signals are available through the pins of the Control LEMO Connector. The connector is located in the central part of the back panel. The signals mapping is listed in the table below:

PIN #	Position	Type	Signal
1	Upper-Left	INPUT	Trigger In
2	Lower-Left	INPUT	Sync In
3	Lower-Right	OUTPUT	Sync Out
4	Upper-Right	-	Ground

Control Pins (Rev 7 and above)

In hardware revision 7 (H) cameras, the control connector is an 8 PIN size 1 LEMO and it's located in the left side of the back panel. The pins indexes are listed below:

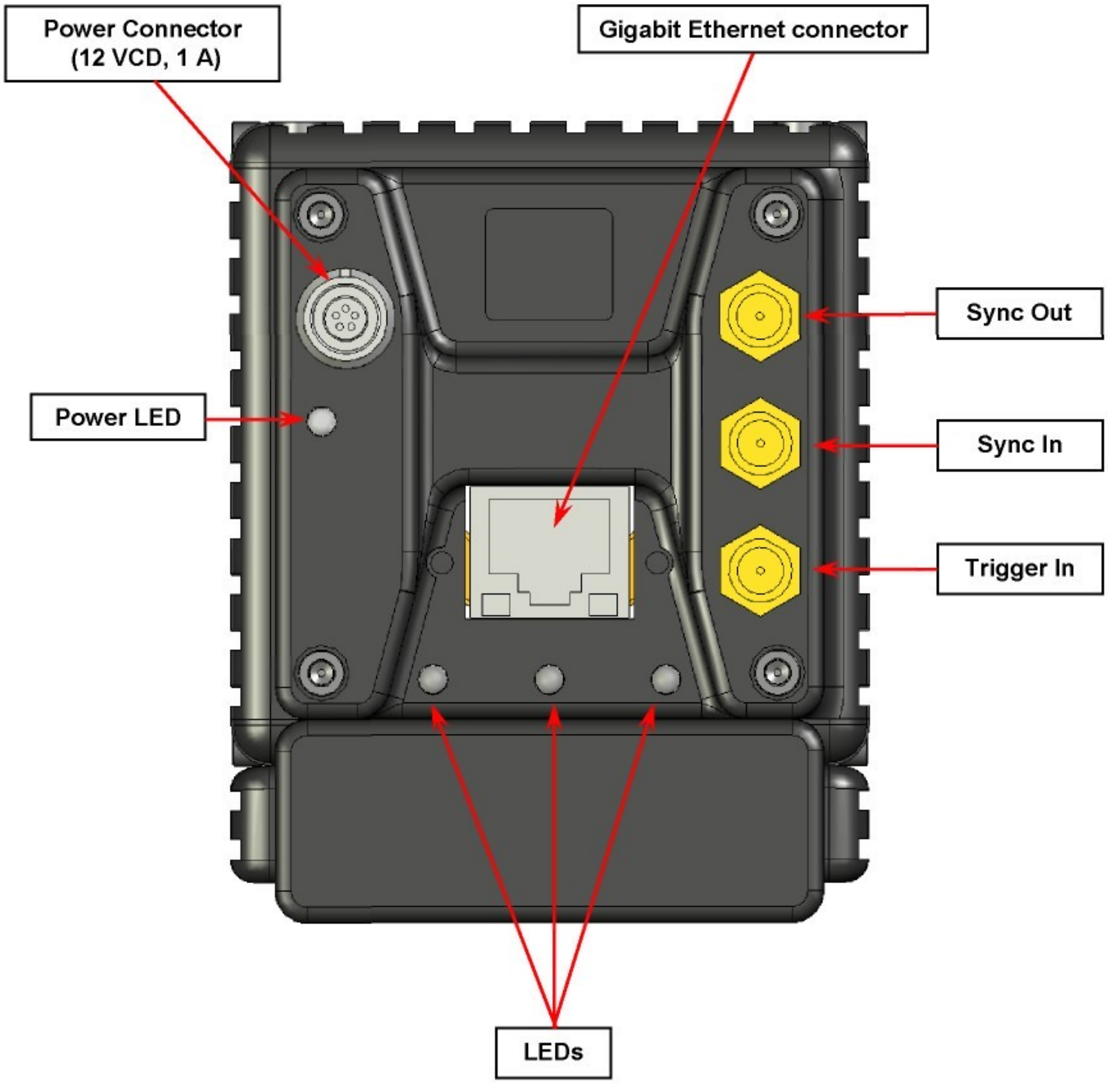
- **PIN 1**: upper position close to the red dot.
- **PIN 2 to 7**: counter clockwise from PIN1.
- **PIN 8**: central position.

The pin-out is in the table below.

PIN #	Type	Signal
1	-	+12 V
2	-	Ground
3	IN	Trigger In
4	IN	Sync In
5	OUT	Sync Out
6	IN	RX
7	OUT	TX
8	IN	GPS

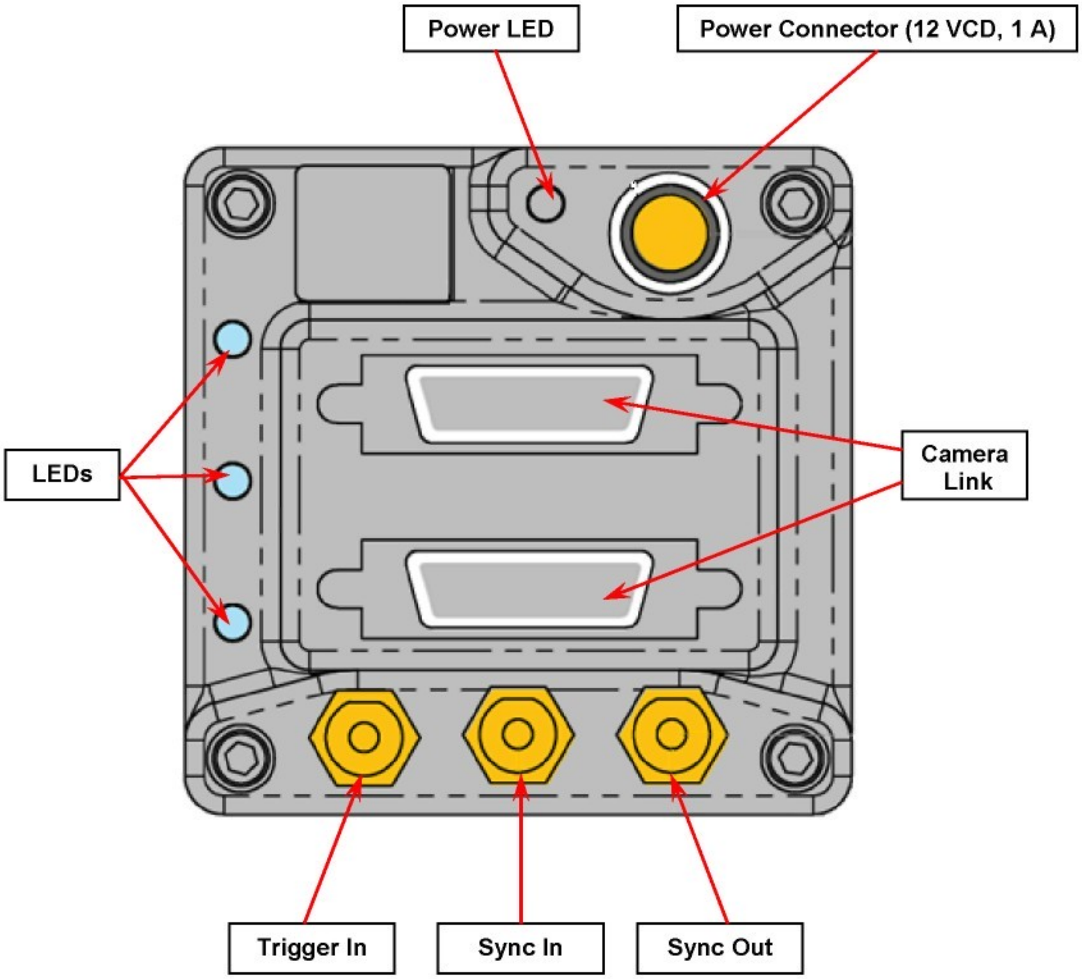
RX and TX are "receive" and "transmit" signals of the new internal serial interface.

4.5.2. MotionXtra N



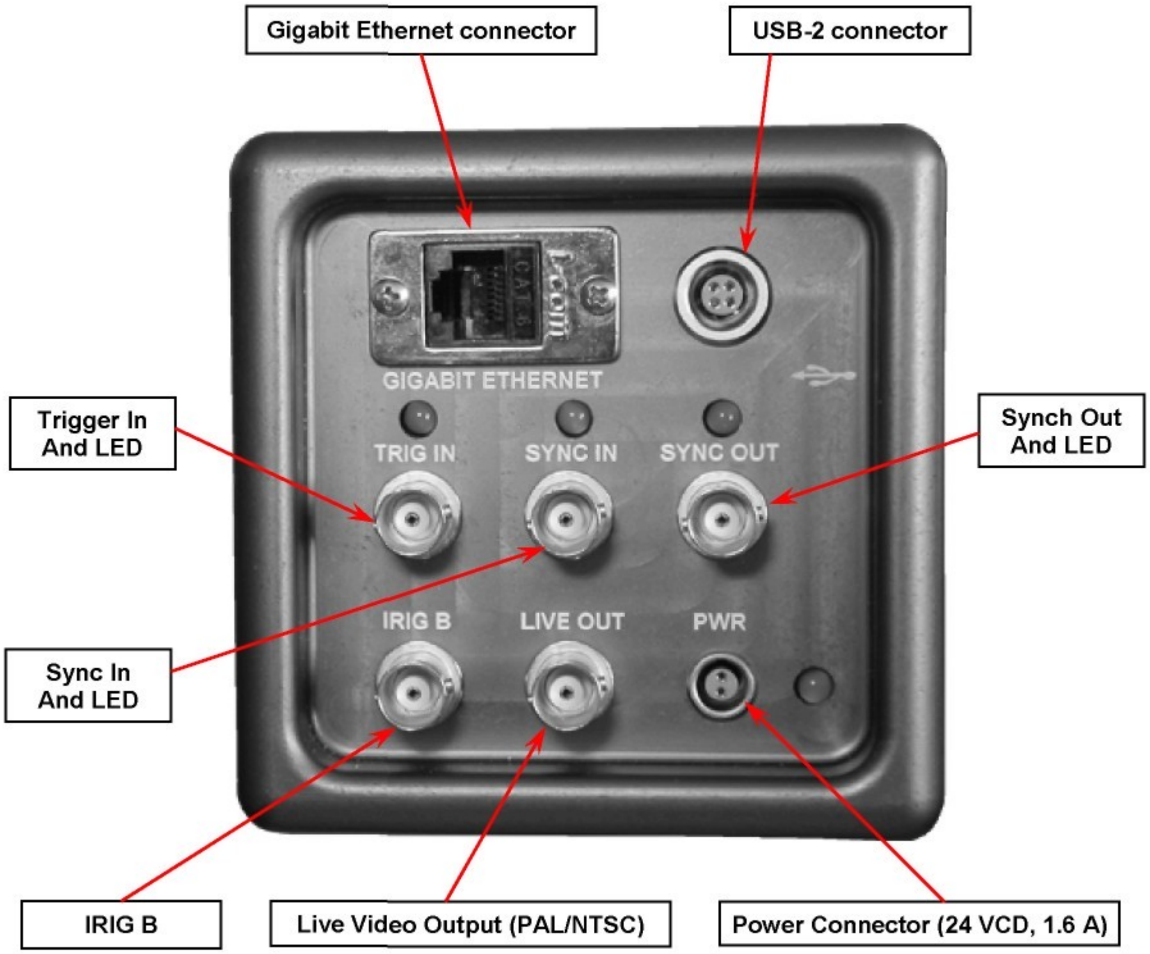
4.5.3. MotionScope M

The MotionScope M-series camera back panel is shown below.



4.5.4. MotionPro X

The MotionPro X USB 2.0/Gigabit-Ethernet camera back panel is shown below.



4.6. IRIG Support

X cameras support IRIG B-120. The signal should be connected to the Trigger In connector.

Y cameras support the IRIG modes listed below.

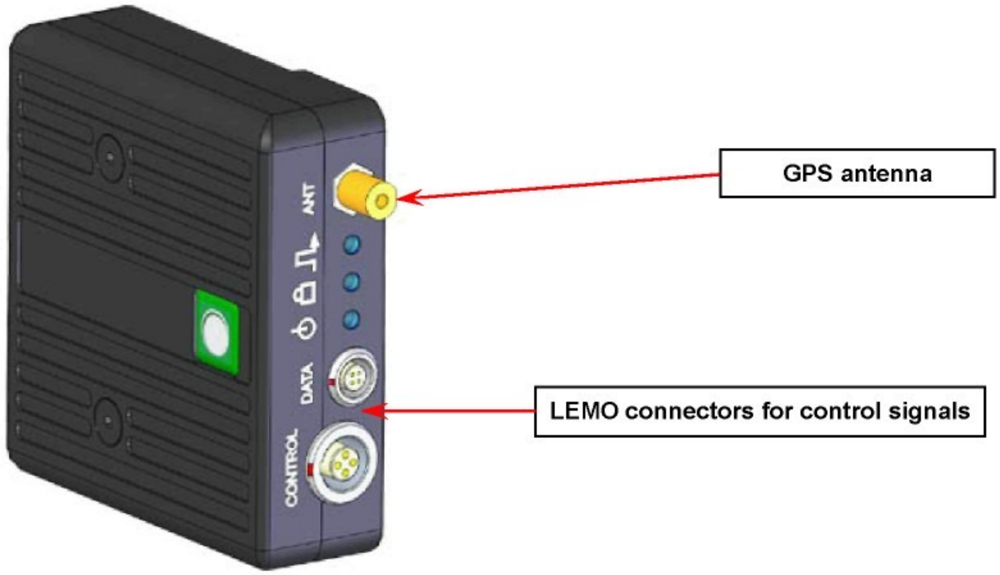
- Modulated IRIG: A, B, D, E, G, H
- Level Shift IRIG: B simple and B differential.

The IRIG signal is detected by an external box docked to the camera and connected to the "Control" 8-pin control LEMO connector.

The module has three LED:

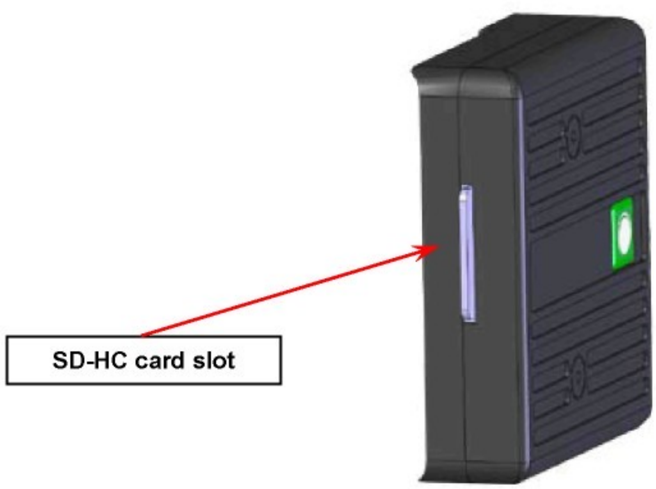
- **Red**: power.
- **Yellow**: IRIG signal is locked
- **Green**: 1 PPS reference signal sent to the camera.

4.7. IRIG-Flash Device



The IRIG flash device is an external box that can be connected to the Y cameras via the external 8-pin and 4-pin control LEMO connectors. The device can be easily hooked to the camera. It is provided with a connector for a GPS antenna and it is fully compatible with the Motion Studio software.

Also, it is provided with a smart card slot that can contain a 16 GB SD card (SD-HC), for a direct download of the acquired images.



WARNING: DO NOT CONNECT the control cables between the module and the camera when the camera is powering up. Connect the cables BEFORE powering up the camera or AFTER the power up cycle is completed and the back "Status" light is turned into green.

4.8. Camera lens adapter

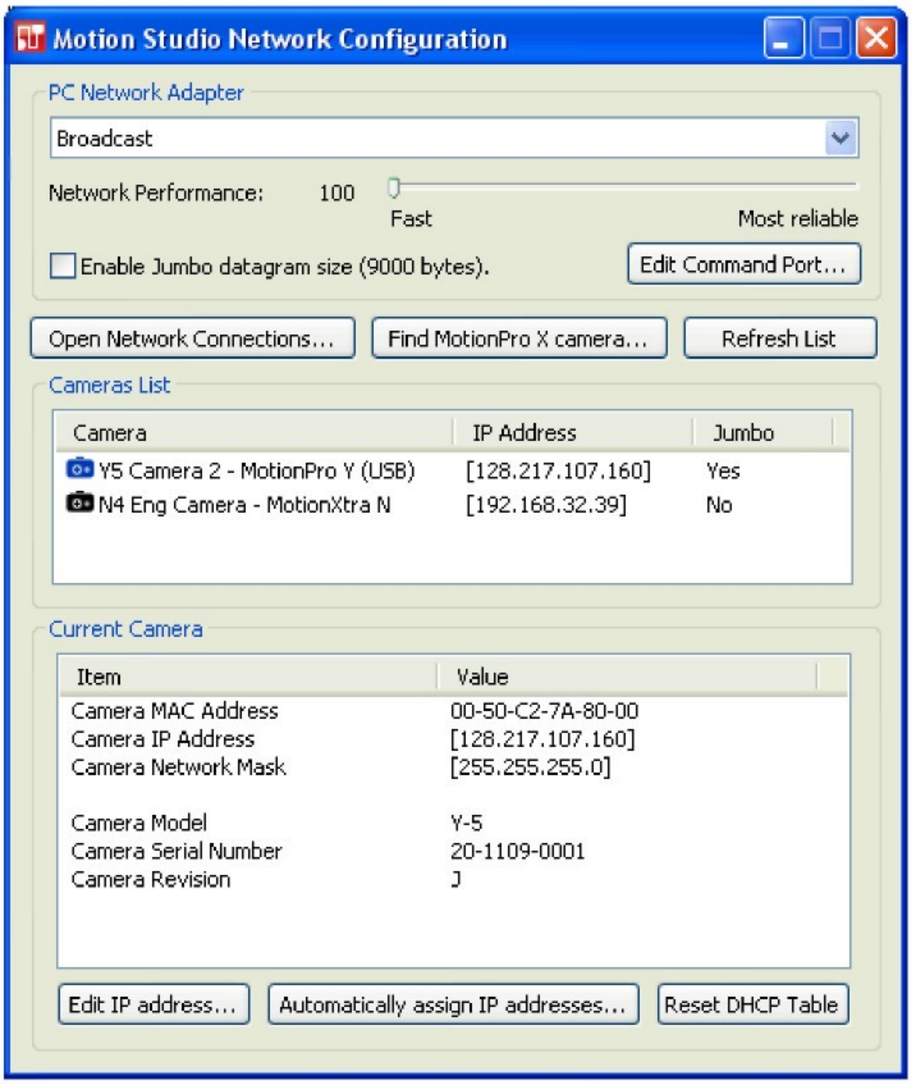
The cameras are supplied with a standard C-mount. Alternatively, a C to F mount adapter is available to interface with F-mount (Nikon type) lenses. Use Nikon lenses with a tilt/shift capability when imaging at an angle. As an option, mounting hardware for tilt/shift lenses by Canon is also available. Contact your IDT sales representative for ordering information.

5. Configuration of Giga-Ethernet cameras

5.1. Motion Studio Network Configuration Utility

The network configuration utility is an external application that allows the user to configure the IP addresses of the cameras.

From Windows "Start" menu, select All Programs, then IDT, then Motion Studio, then Tools and then "Network Configuration"



Some of the parameters that can be configured are the same for all the camera models.

Network adapter: the default value is broadcast, i.e. the driver searches for cameras through each enabled network adapter. If a specific adapter is selected, the driver searches for cameras only through it.

Network performance: it's a delay added to the data exchange between the cameras and the computer. If there is traffic on your local network, then move the slider to "More reliable" to avoid loss of data during the communication

Network Connections: click this button to open the "Network Connections" control panel applet and configure the network adapter's IP address.

Enable Jumbo datagram size: see one of the topics below.

5.2. Configuring the Y camera IP address

Y cameras are delivered with a specific IP address. If the address is not compatible with your network parameters, the camera is not able to establish a communication with the computer through the network. To set the IP address for the first time, please follow the instructions below.

- Connect the Y camera to the computer through the USB 2.0 cable.
- From the Motion Studio program group, select Tools and run the "**Network Configuration**".
- The Y camera will be listed as "Camera Name – MotionPro Y (USB)". Select it, and click the "Edit IP Address…" button.
- Enter the IP address and the subnet mask. Then click OK and exit the configuration utility.
- Turn off the camera and turn it on. The new IP address is stored and will be used by the camera in Giga Ethernet communication.

NOTE #1: the computer network adapter may not have a specific IP address because it's assigned by the DHCP. If there is any problem for the software to detect the camera, it's better to assign a specific IP address also to the computer adapter. To do that, open the "Network Connections" window and select the Properties of the network adapter. Select the "Internet Protocol (TCP/IP)" and click the "Properties…" button. Select the "Use the following IP address" option and set the IP address and subnet mask values.

NOTE #2: if the camera IP address is not compatible with the adapter's IP address, the camera will be listed with a yellow exclamation mark. If you try to open a session the software will not be able to grab images from the camera and an error message will appear.

5.3. Configuring the N camera IP address

N cameras are delivered with a specific IP address. If the address is not compatible with your network parameters, the camera is not able to establish a full communication with the computer through the network. To set the IP address for the first time, please follow the instructions below.

- Connect the Y camera to the computer through the Ethernet cable.
- From the Motion Studio program group, select Tools and run the “**Network Configuration**”.
- The N camera will be listed as “Camera Name – MotionXtra N”. Select it, and click the “Edit IP Address…” button.
- Enter the IP address and the subnet mask. Then click OK and exit the configuration utility.
- Turn off the camera and turn it on. The new IP address is stored and will be used by the camera in Giga Ethernet communication.

NOTE: if the camera IP address is not compatible with the adapter’s IP address, the camera will be listed with a yellow exclamation mark. If you try to open a session in this condition the software will not be able to grab images from the camera and an error message will appear.

5.4. Large datagram size (Jumbo packets)

Some Giga-Ethernet network adapters are able to send and receive large data packets. The usual datagram size is 1500 bytes. Large datagram packets, called Jumbo packets, are up to 9000 bytes.

If both the camera and the adapter can use jumbo packets, the transfer speed is increased. To activate jumbo packets, do the following.

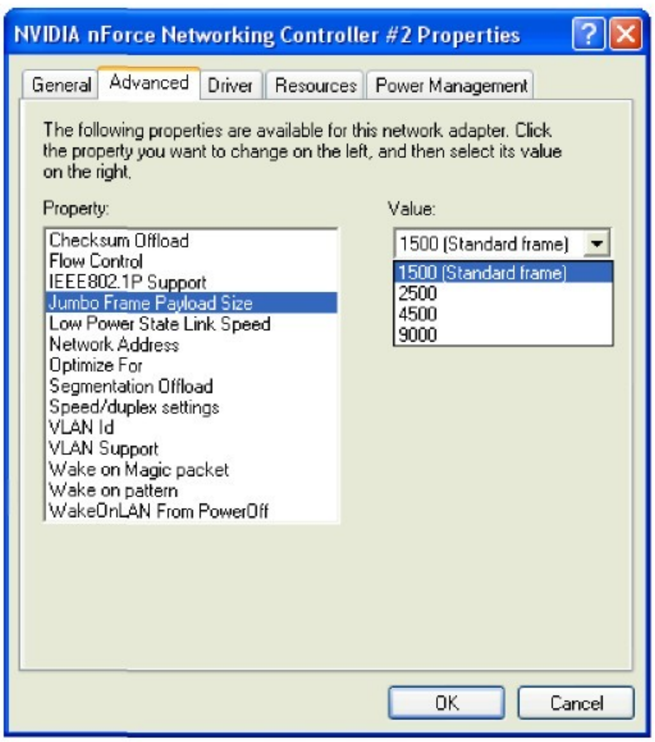
Configuring Jumbo packets on the Network adapter

1. From Windows "Start" menu, open the "Network Connections" window and select the network adapter.

2. Right click and select the Properties menu item.

3. From the Properties dialog box, click the "Configure…" button.

4. From the network adapter configuration dialog, select the "Advanced" tab.



5. From the property list, locate the "Jumbo frame…" item (or anything similar to that) and change the value to 9000.

Configuring Jumbo packets on Network adapter

1. From the Motion Studio program group, select Tools and run the "**Network Configuration**".

2. Make sure that the camera is listed and the "Jumbo" item in the camera list is set to "Yes".

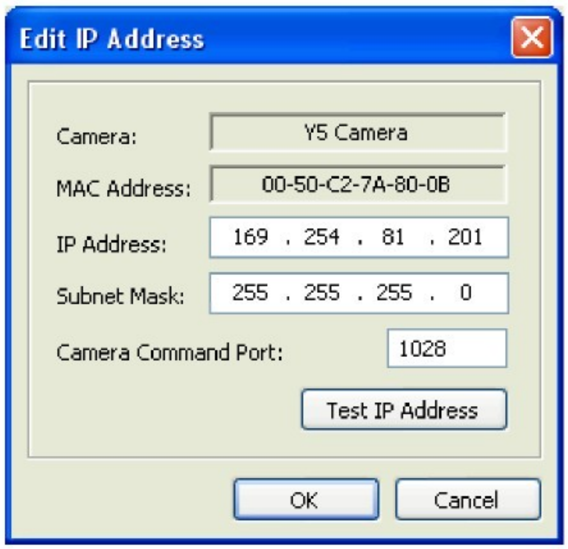
3. Check the "Enable Jumbo datagram size (9000 bytes)" item.

5.5. Configuring the X camera IP address

When a MotionPro X camera is powered up, it does not have an IP address. Without a valid IP address the camera can be enumerated, but some parameters, such as camera model, serial number, etc. cannot be read. The Configuration utility enumerates all the MotionPro/MotionXtra GE cameras and shows each camera's IP address or "none". A camera without a valid IP address is listed with a red spot on the icon.

For each camera the user may:

1. Click the "Edit IP Address…" button. If the camera has an IP address, it may be edited, and otherwise the application "suggests" a value. See the picture below.



   The user may edit and test the camera IP address and subnet mask. By pressing the "Test IP address" button the user sends a PING command to the specified address and checks if it is available.

2. Click the "Automatically assign IP addresses…" button. The utility runs a procedure that automatically sets an IP address to all the enumerated Giga-Ethernet cameras.
3. Reset DHCP Table: the values of the IP addresses are stored in a table that may be reset.

Sometimes a camera is not enumerated and the IP address cannot be configured. If the user knows the camera's MAC address (see glossary), he can try to set the camera IP address by clicking the "Find X Camera…" button.

The user sets the camera MAC address and the desired IP address. Then he clicks OK. If the configuration is successful the camera will be listed in the Network Configuration list.

6. Motion Studio™ stand-alone program

This application allows the user to acquire, save/play-back image records, and control the camera in Single or Double Exposure modes. It also allows the user to retrieve file images from previous acquisitions for display and further manipulation. Upon execution the user can select to use the application to open a file images or to open a camera window.

6.1. Open camera Wizard

A discussion of the program interface as it applies to the live camera window is provided first. Once the camera option is selected from the first menu the Camera Wizard is displayed. This wizard allows the user to select which camera to control and access if more than one camera is attached to the computer system. For each camera, the attribute ‘monochrome’ or ‘color’ is displayed.

Refresh List

Click this button to restart the cameras detection procedure.

Find X camera

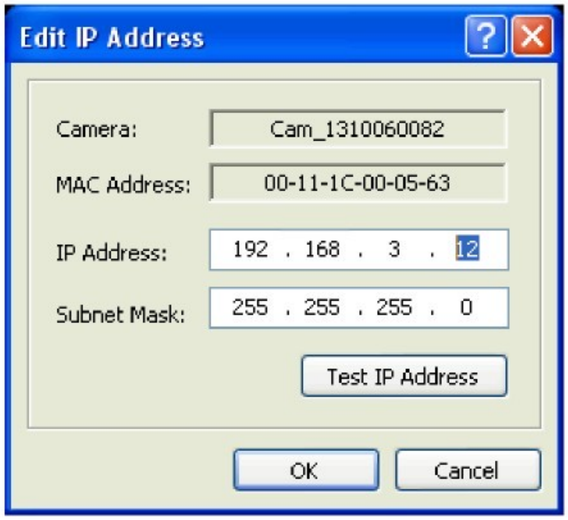
See the previous topic about the configuration of Giga-Ethernet cameras.

Edit camera name

Each camera has a name. If the camera has flash memory, the name is stored into it. Cameras without flash memory have the name stored in a configuration file in the hard disk. To change camera name, click the “Edit name…” button.

Edit IP Address

Click the “Edit IP address” button and manually assign an IP address to the camera.



The user may edit and test the camera IP address and subnet mask (disabled for X cameras). By pressing the “Test IP address” button the user sends a PING command to the specified address and checks if it is available

Enumeration filter

The user can select which camera type is enumerated and listed in the camera wizard window.

1. Click the “Enum Filter…” button.
2. Check or uncheck the camera models.
3. Click OK.

Camera interface

Before opening camera windows the user may select the interface.

- **Standard**: a limited set of controls are displayed in a vertical bar on the right side of the camera window.
- **Digital Cinema**: a limited set of controls for recording and a full set of controls for image processing.
- **Expert**: all the camera controls are displayed.

Activation Key

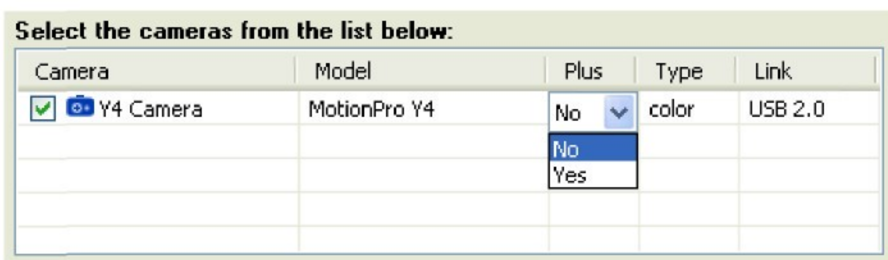
Some cameras have time limited license. If the license has expired and you have a 16 digit activation key, click the button and enter the key.

Activate Camera List

If more than one camera is going to be used, the camera list interface may be activated. For a more detailed description of camera list mode, see the "Multiple Camera Support" topic.

Plus Mode

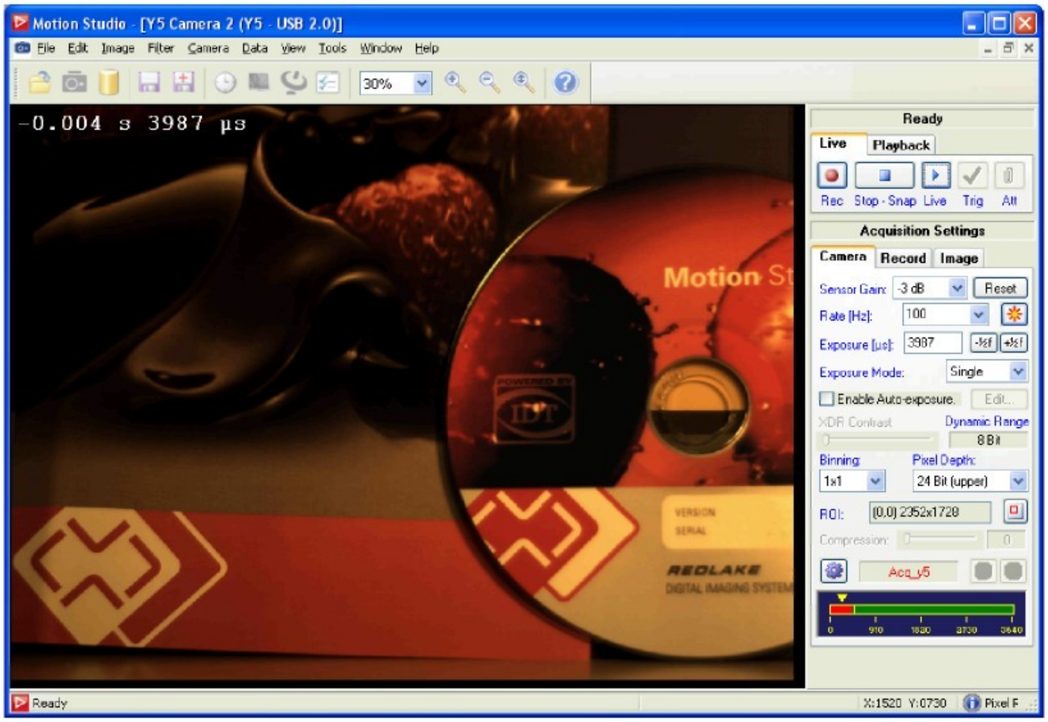
The plus option can be activated on each camera independently. Just click on the Plus cell in the camera list and select Yes or No. The option is disabled if the camera does not support it. In Plus™ mode, the camera is capable of acquiring images at double speed and with double memory space. See below.



Reset camera configuration

If this option is selected, the configuration stored in the camera is reset and the camera is opened with default settings.

Once the Wizard competes the initialization procedure for the camera the application window for the active camera is open as shown below (expert interface).



Along with the usual top bar menu structure the application also includes a docked dialog bar on the right side and a pan tool. In this menu the main operational controls of the camera are grouped by function: Camera Control (Live and Playback), Acquisition Settings (Camera, record and Color). The function of these controls is in great part also accessible from the top menu bar.

6.2. Motion Studio Menu structure

The main menu bar contains the following options:

File

Edit

Image

Filter

Camera

Playback

Tracking

View

Tools

Window

Help

The application also includes a docked dialog bar on the right side. The Docked Dialog Bar has the main operational controls of the camera and they are grouped by function: Camera Configuration, Image Recording Configuration, Color Configuration (for color cameras only) and Playback controls for acquired images.

6.3. FILE Menu

The file menu contains the following options:

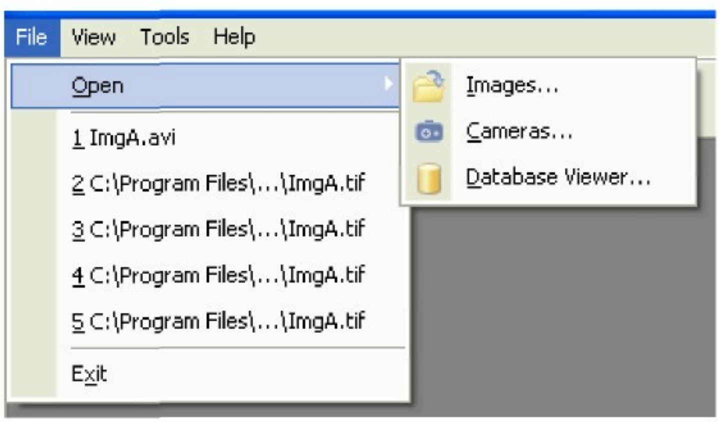
- Open previously acquired and filed images.
- Open the camera window.
- Open the database viewer window.
- Save images on the hard disk and close windows
- Select from a list of the five most recently displayed images.

6.3.1. Initialize a camera window

From the main menu select File > Open > Camera.

6.3.2. Open File Images

From the main menu select File > Open > Images.



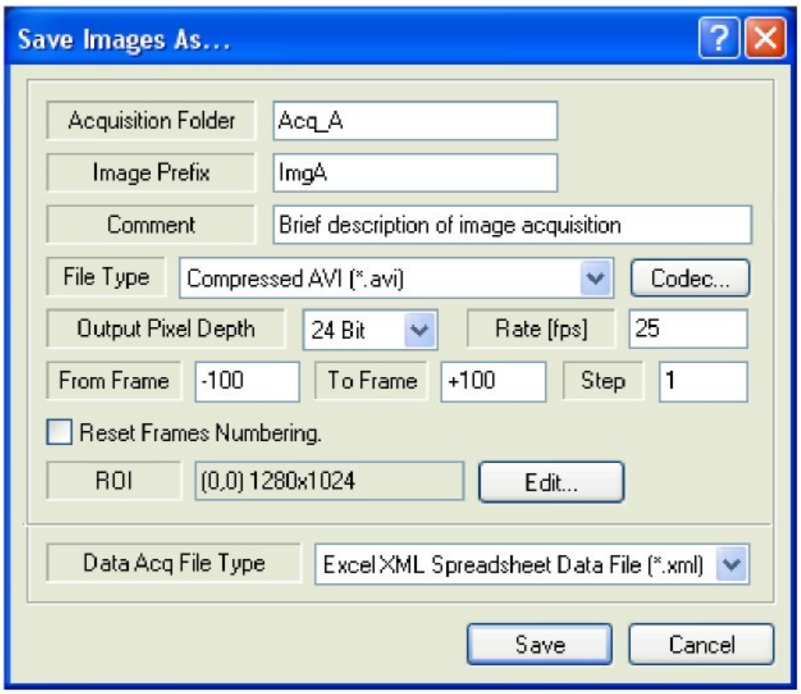
6.4. Save images

Each acquired sequence may be opened and saved in a different format.

1. From the File menu select File >> Save
2. Select one of the options below:
   - Create a new acquisition folder.
   - Simply save the images.

6.4.1. Create a new acquisition folder

The program will create a new acquisition folder in the current database and save the images and the acquisition settings. For further information about the parameters please refer to the paragraph 5.20 (Saving acquired images and data).

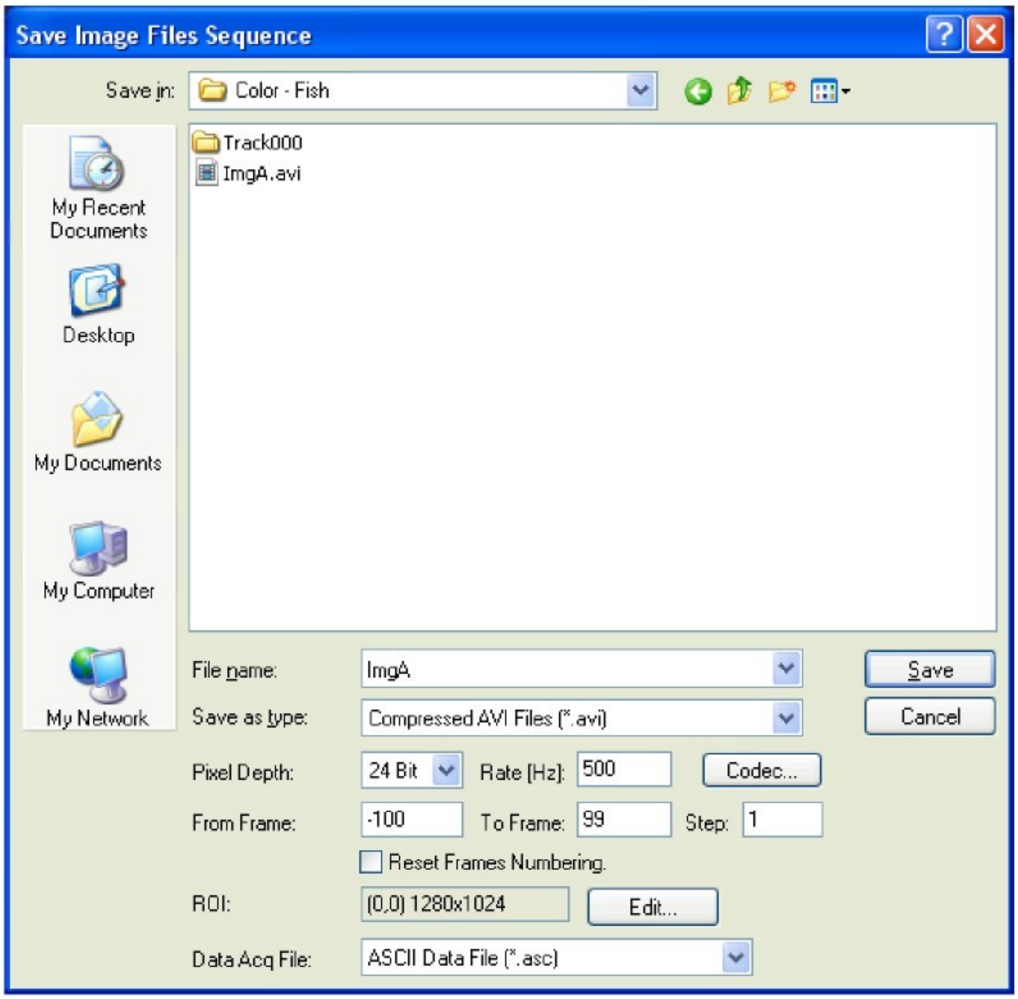


1. Enter the folder name, the image prefix and the comment (optional).
2. Select the file type and the rate. If the file is compressed AVI, select the codec.
3. Select start index, stop index and step.
4. Select the Reset Frames Numbering option to change the start frame index to 0.
5. Also a subset of the sequence can be saved. Select a region of interest by pressing the Edit button.
6. Select the Data Acquisition File Type, if present.

6.4.2. Save the images only

This option saves the images, but not the acquisition settings.

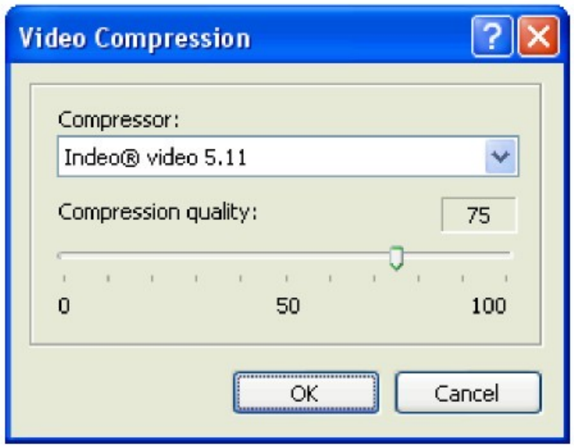
1. Select the desired folder.
2. Type the image name, the image format and the sequence rate. If the file type is compressed AVI, select the codec.
3. Also a subset of the sequence can be saved. Select a region of interest by pressing the Edit button.
4. Select the Reset Frames Numbering option to change the start frame index to positive or change the Image Step.



6.4.3. AVI Codec/JPEG quality selection

The default codec used in Motion Studio to save compressed AVI files is "**Indeo™ Ver. 5.11**". If the codec is not installed on the computer the software automatically asks the user to select a new default codec.

The default codec can be changed each time a new sequence of images is saved in compressed AVI format.



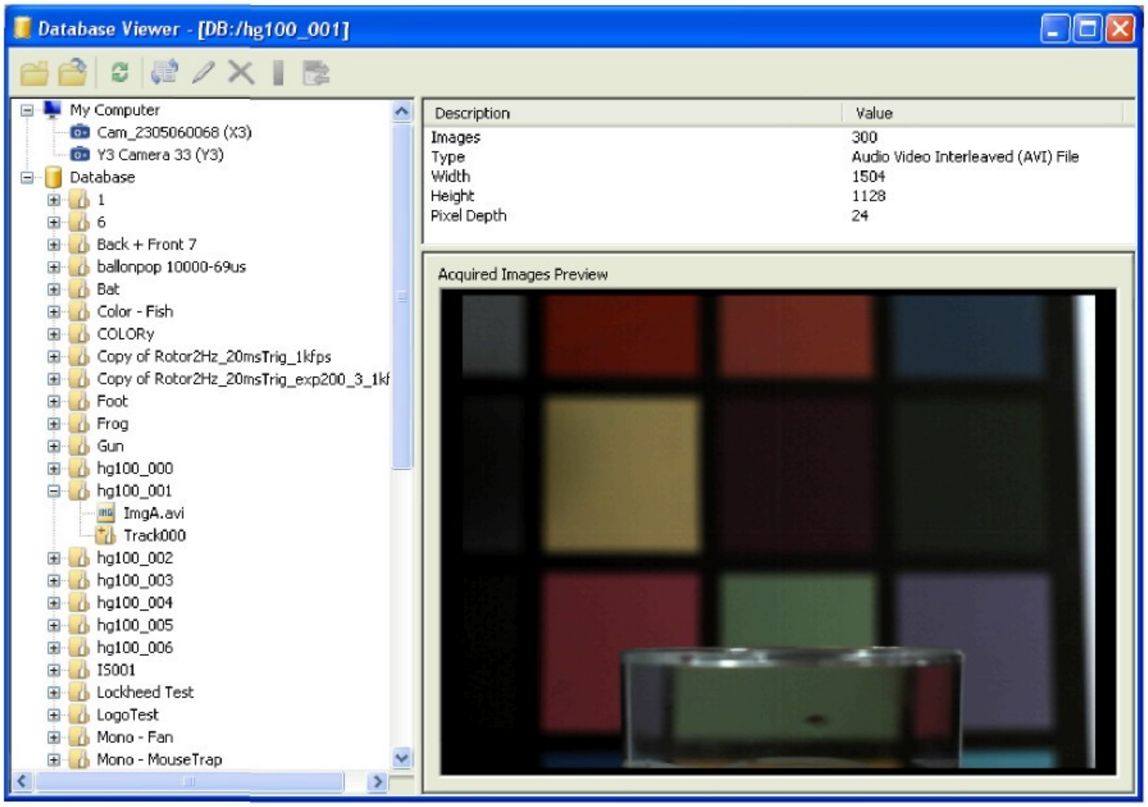
- Select the codec from the list.
- Select the compression quality with the slider (0 to 100).

Also, JPEG compression quality may be selected in the same dialog box. The default is 100.

6.5. Database viewer

The database viewer window browses the current Images folder and enumerates the acquisition folders. It shows also the cameras and devices connected to the computer (Timing Hub/Data Acquisition).

The window has three panes.



Left Pane: the left pane is a tree view and displays the tree structure of the images database. It shows also the detected cameras and devices, such as timing hubs and data acquisition modules.

Right Upper Pane: it's a list view and it shows the main parameters of the selected item. If the item is a device it shows the device ID, serial number, etc. If the item is an acquisition it shows all the acquisition parameters.

Right Lower Pane: the pane is used to preview the first frame of a sequence or the data acquired with the data acquisition module.

6.5.1. The viewer Toolbar

New Database

The selection of this item opens the 'Create New database' dialog box. The user may browse the existing directories in the hard disk or create a new directory. If the OK button is pressed the root database files are copied in the new directory and the user can start saving new sequences in the new folder.

Open Database

Browse the directories in the hard disk and locate a database folder. The program recognizes as valid database locations the directories where the file **xvdb.mdb** is found. Changes to the currently selected database are reflected on the settings.

Refresh

Click this button to refresh the viewer contents.

Open Item

Click this button to open the currently selected item. The button is enabled if the selected item is a sequence or a camera.

Edit Item

Click this button to edit the currently selected item. The button is enabled if the selected item is an acquisition folder. The user may change the folder name, date, time and acquisition comment.

Delete Item

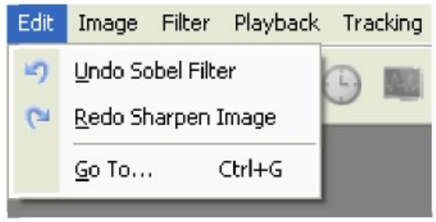
Click this button to delete the currently selected item. The button is enabled if the selected item is an acquisition folder.

iPod Synchronization

If your iPod is connected to the computer, Motion Studio can detect it and allow you to transfer your acquired sequences. You may transfer the sequences from iPod to the current database and vice versa. You may also eject the iPod.

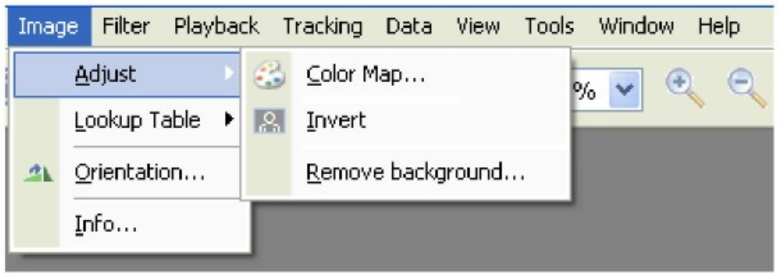
6.6. EDIT menu

The Edit menu contains UNDO and REDO for image operations. It also has a “Go To…” function for jumping to a particular frame in a sequence.



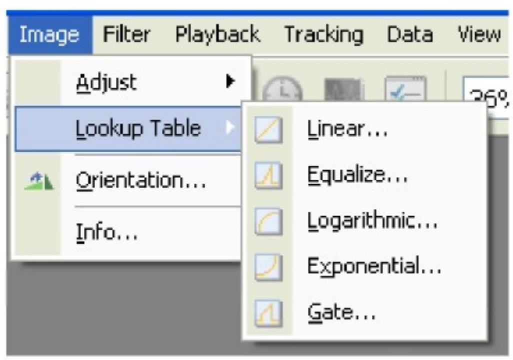
6.7. IMAGE menu

The Image menu contains the LUT operations. It also allows flipping and rotating of the image. If the Camera window is open and the Thumbnails bar is in use, the “Thumbnails Cfg...” option displays for Thumbnail view configuration options. For more information, refer to “View Thumbnails”.



If an image sequence is open, the Image menu has an Image Info option for displaying and editing the acquisition settings. The Adjust sub menu has controls for the following:

- Color Map for colorizing monochrome images
- Inverting.
- Background removing for monochrome images.



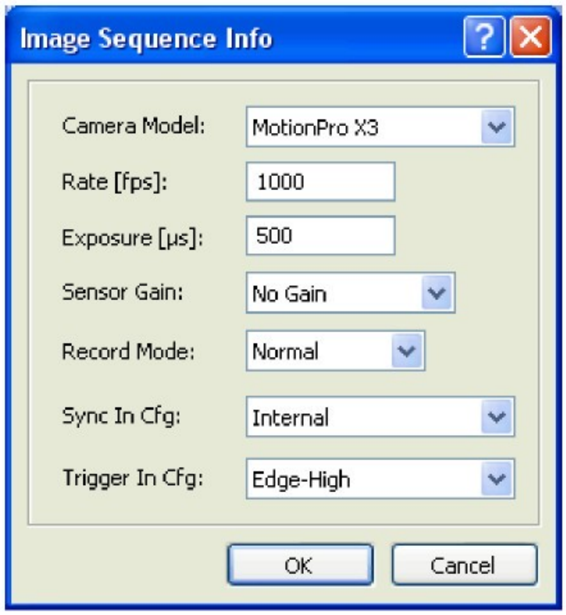
The Lookup Table submenu has controls for the following LUT transformations: **linear**, **equalize**, **logarithmic**, **exponential** and **gate**. For further information on Lookup Tables, please refer to the appendix.

NOTE: Brightness and Contrast, Gamma, LUT, Invert and Histogram Equalize are intensity operations. Any intensity operation can be applied to the image only once. If the user applies a LUT to the current image and then selects “brightness and contrast’, the preview window will show the original image without any LUT modification, and so on.

6.8. Image Info

The main acquisition parameters may be displayed and edited.

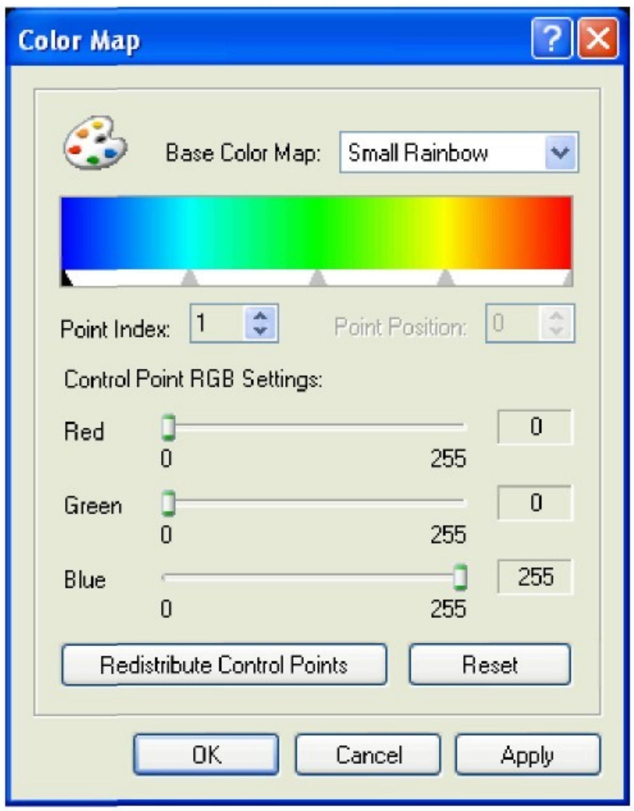
1. Select Image from the main toolbar.
2. Select Info from the drop-down menu.
3. Edit the parameters.
4. Click OK to change the parameters on the acquisition.



6.9. Color Map Adjustment for monochrome images

The Color Map has controls for displaying black and white images in color using a pre-loaded, user-defined color scheme.

1. Select Image from the main toolbar.
2. Select Adjust from the Image drop-down list.
3. Select Color Map.
4. Select Base Color Map from the drop-down list.
5. Change the RGB values and Point Index.
6. Click OK to change the image.



6.10. Sharpen, gamma, brightness, contrast, hue, saturation

Some image adjustment controls have been added to the image vertical bar. The parameters improve the image quality.

Dynamic Noise Reduction: it reduces temporal noise on images. The range is from 0 to 30. The default value is 5.

Sharpen: it sharpens the image edges. The range is from 0.0 to 1.0. the default value is 0.0.

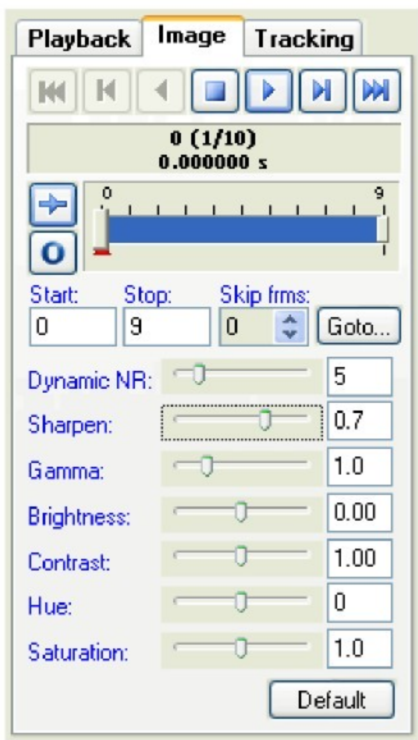
Gamma: introduces a gamma correction to the image. The range is from 0.1 to 4.0. The default value is 1.0.

Brightness: it increases or decreases the image brightness. The range is from -0.25 to 0.25. The default value is 0.0.

Contrast: it increases or decreases the image contrast. The range is from 0.5 to 1.5. The default value is 1.0.

Hue (color images only): it modifies the image hue. The range is from -180 to 180. The default value is 0.

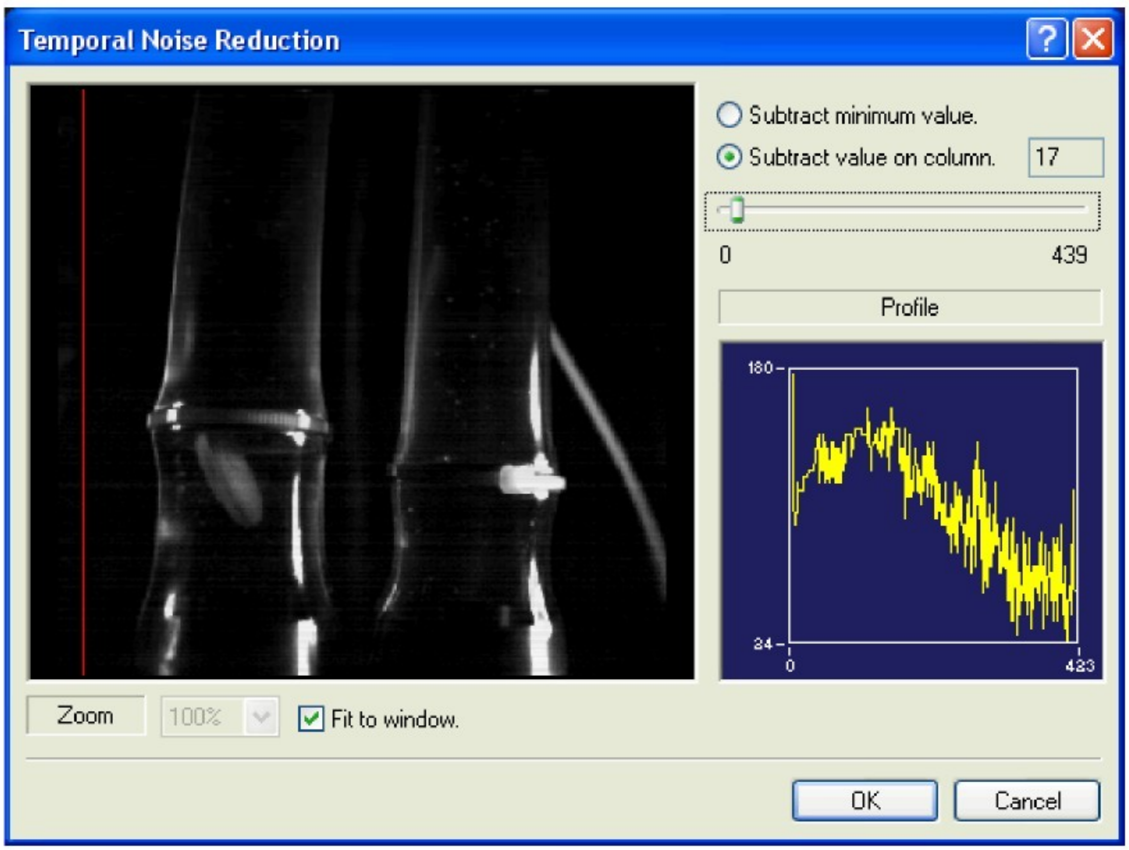
Saturation (color images only): it modifies the color saturation. The range is from 0.0 to 2.0. The default value is 1.0.



6.11. Remove background

This tool is very useful to remove temporal noise background from images taken with the X4 camera. It requires a very dark and uniform background.

1. Select Image from the main toolbar.
2. Select Adjust from the Image drop-down list.
3. Select one of the options.
   - Subtract minimum value: on each row the minimum value will be subtracted.
   - Subtract value on column: on each row the value on a specific column will be subtracted.
4. Use the Zoom drop-down list to inspect the image details.



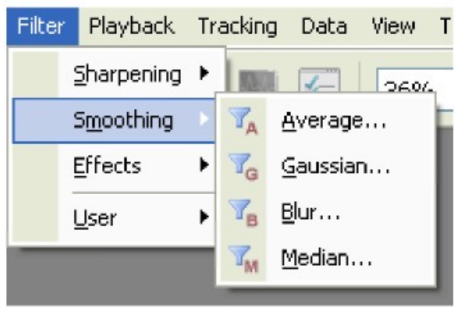
6.12. FILTER menu

The filter menu has several preset filters as well as user defined filters. The filter menu for Windows differs from the Mac filter menu. The Windows version offers two additional Effect filters Uniform Noise and Gaussian Noise. A preview window with an image thumbnail is available and includes the filter kernel display box.

Windows

From the main toolbar select Filter > the desired filter submenu from the following:

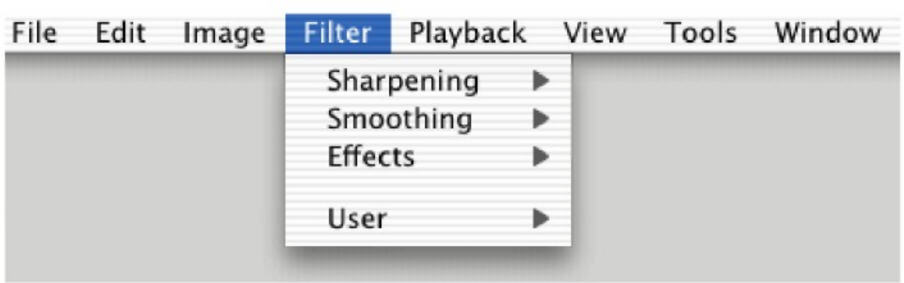
- Sharpening filters: Laplacian, Prewitt and Sobel.
- Smoothing filters: Average, Gaussian, Smooth, and Median.
- Effect filters: Minimum, Maximum, Uniform Noise, Gaussian Noise, Erode, Dilate, Open, Close.

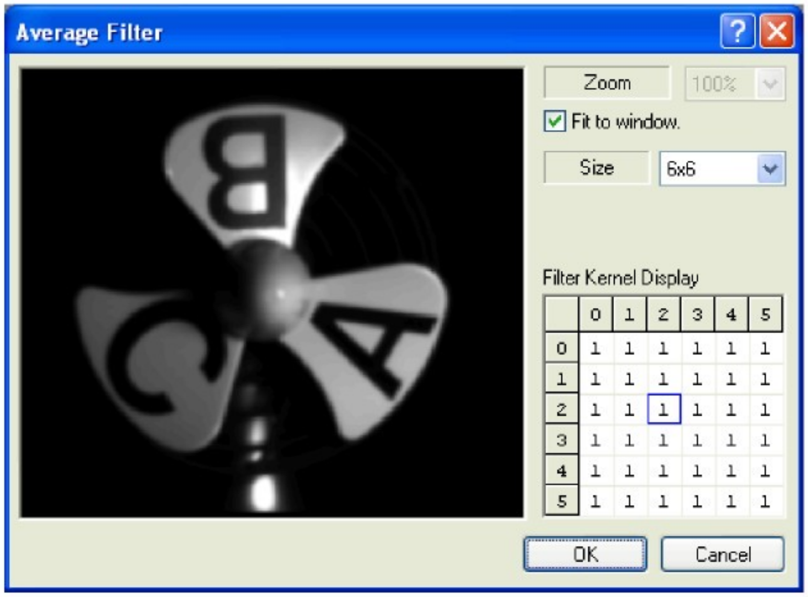


MAC

From the main toolbar select Filter > the desired filter submenu from the following:

- Sharpening filters: Laplacian, Prewitt and Sobel.
- Smoothing filters: Average, Gaussian, Smooth, and Median.
- Effect filters: Minimum, Maximum, Erode, Dilate, Open, Close.



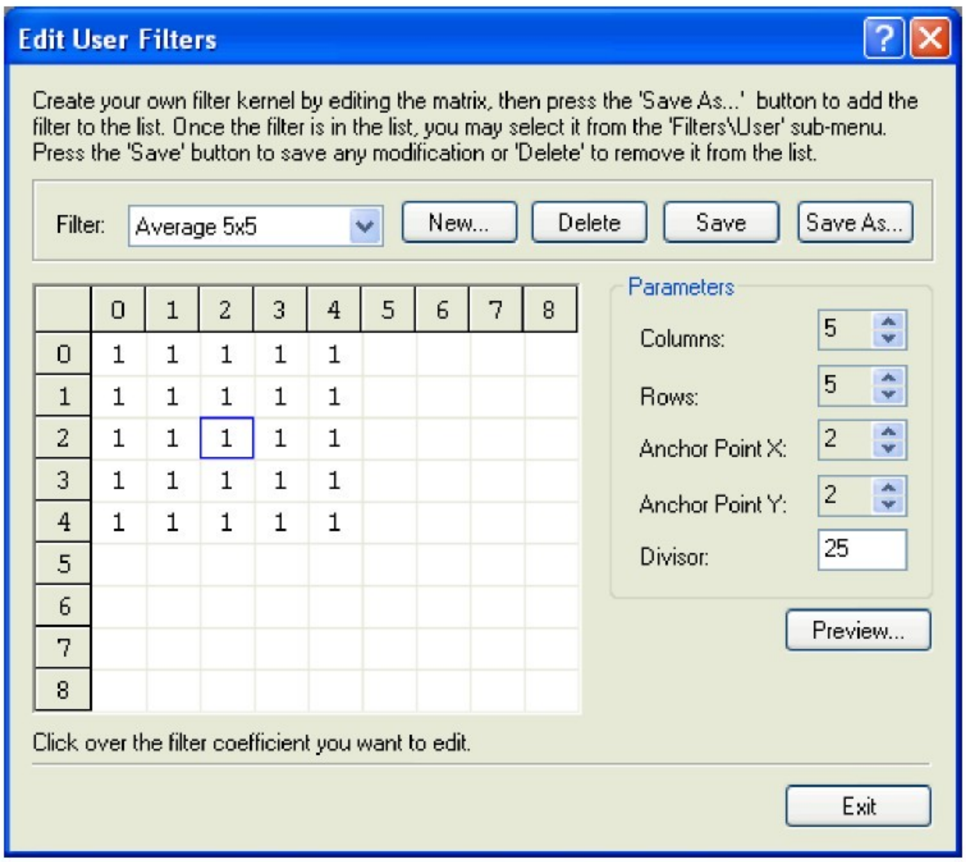

Average Filter
Zoom
100%
Fit to window.
Size
6x6
Filter Kernel Display
0 1 2 3 4 5
0 1 1 1 1 1 1
1 1 1 1 1 1 1
2 1 1 1 1 1 1
3 1 1 1 1 1 1
4 1 1 1 1 1 1
5 1 1 1 1 1 1
OK
Cancel

6.13. Create a User-defined filter

The **User filter** utility has the flexibility to apply a custom filter and save the kernel for future use. The filter kernel size, anchor point and image divisor are custom configurable.

Once a custom filter has been created and saved, the user-defined filter is added to the Filter drop-down list.

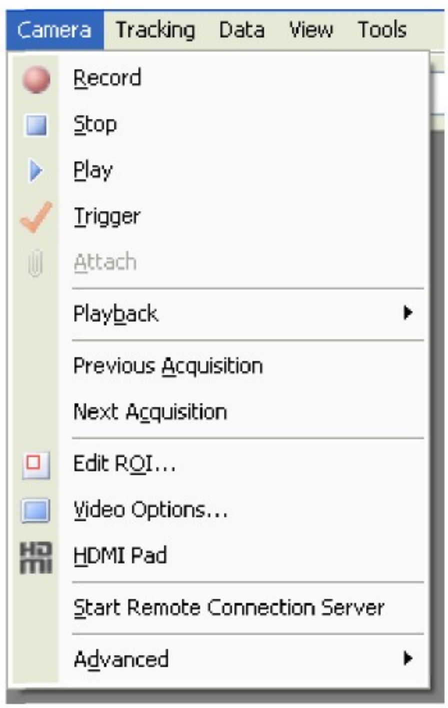
1. Select Filter from the main toolbar.
2. Select User from the drop-down list.



6.14. CAMERA Menu

The Camera Menu on the main toolbar offers an alternative to using the buttons and dialog box provided by the Docked Dialog menu including the following functions:

1. Record
2. Stop
3. Play
4. Playback
5. Select previous and next acquisition settings.
6. Start and Stop the remote connection server (see chapter 7).
7. Edit Region of Interest (ROI).
8. Edit Video Options.
9. Show and Hide the HDMI Pad (new designed Y cameras only).



6.15. Camera Control - Live

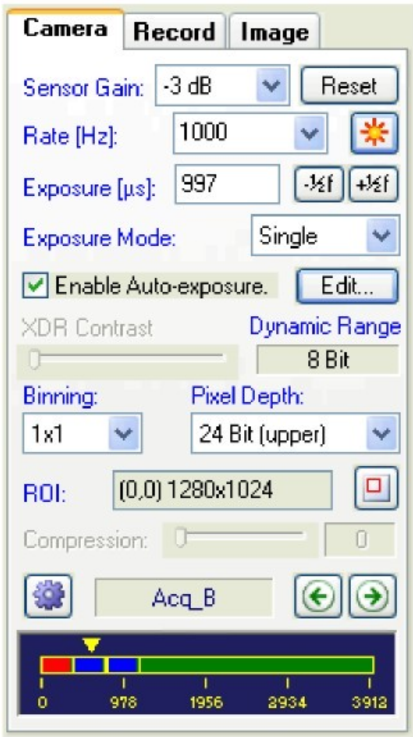
The Camera Control Tab at the top of the Docked Dialog menu has camera control functions including the following:

1. Record.
2. Live play of images (continuous).
3. Trigger.
4. Attach.
5. Stop.

6.16. Camera Configuration

Expert Interface

Use the Camera Tab on the Docked Dialog menu at the right of the image to configure the camera. The configuration options are as follows:



Sensor Gain
Use the sensor gain drop-down list to select a Gain value ranging from "-3 dB" to "+6 dB" ("-6 dB" to "+3 dB" for X4, and "-3 dB" to "+3 dB" for Y5).

Reset
Click the Reset button if a Device IO Control error message appears. The Reset button restores the camera from the error condition.

Rate
Use the Rate drop-down list to select a new Frame Rate value. If the current exposure is too large for the selected rate, the program automatically adjusts it to an acceptable value.

Low Light mode
Click the button to set the rate to 25 Hz and the exposure to four times the current value. If the button is clicked twice or an acquisition is started the original values of exposure and rate are restored. The option is useful for preview in low light conditions.

Exposure
Use the f-stop buttons to select a new exposure value. The value is in microseconds.

Exposure Mode
Use the drop-down list to select either Single, Double or XDR exposure mode (for XDR see the appendix).

Auto-Exposure
Select this option to activate the automatic exposure adjustment.

XDR contrast
Use the slider to select the contrast in XDR mode (see the appendix).

Dynamic range
It shows the image dynamic range in XDR mode. If the image pixel depth is 8, the range may be 9, 10, or 11 bits. If the pixel depth is 10 bit, the range may be 11, 12, or 13 bits.

Binning
Use the Binning drop-down list to select a new value from 1x1 to 4x4. Pixels may be grouped to form a larger pixel, which results in added SNR and sensitivity. When this parameter is changed, the Region of Interest (ROI) is reset. The control is disabled when the camera is in live mode.

Pixel Depth

Use the Pixel Depth drop-down list to select from the following options: 8-bit (Gray 8) or 10-bit (Gray 16) for monochrome cameras, or 24 bit (RGB) for color cameras.

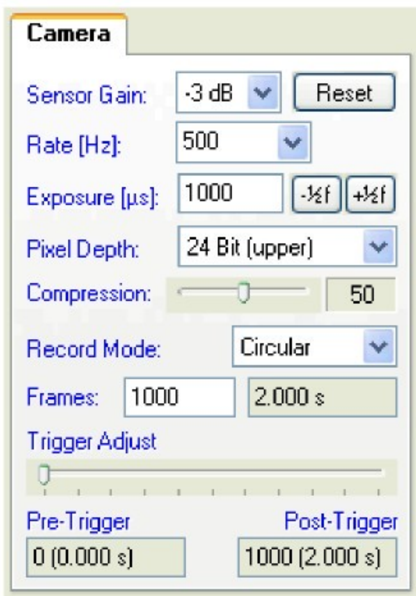
ROI
Click on the ROI button to open the ROI dialog, and change the current settings. For more information, see “Set a Region of Interest (ROI)”.

Live Time Out
If the camera cannot snap a frame during live mode, a time out may occur. Type a new value into the text box to change the duration of the time out. The value is displayed in seconds.

Compression
In N camera models the frames are stored in compressed format. The compression rate can be configured. The values are from 0 (uncompressed) to 100 (fully compressed). The size of a fully compressed frame is about 40% of the original size.

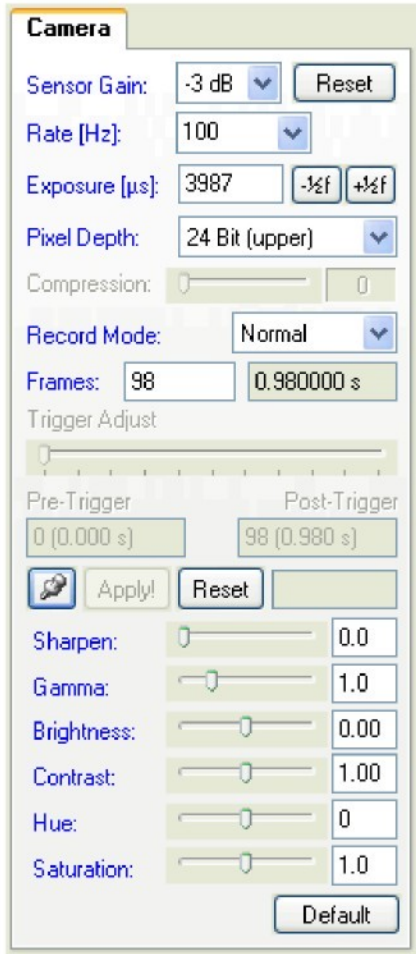
Standard Interface

If the **Standard** interface is selected, only a subset of the controls is shown in the camera Tab (see below).



Digital Cinema interface

If the digital cinema interface is selected, a subset of camera controls and image processing controls are shown in the camera Tab.



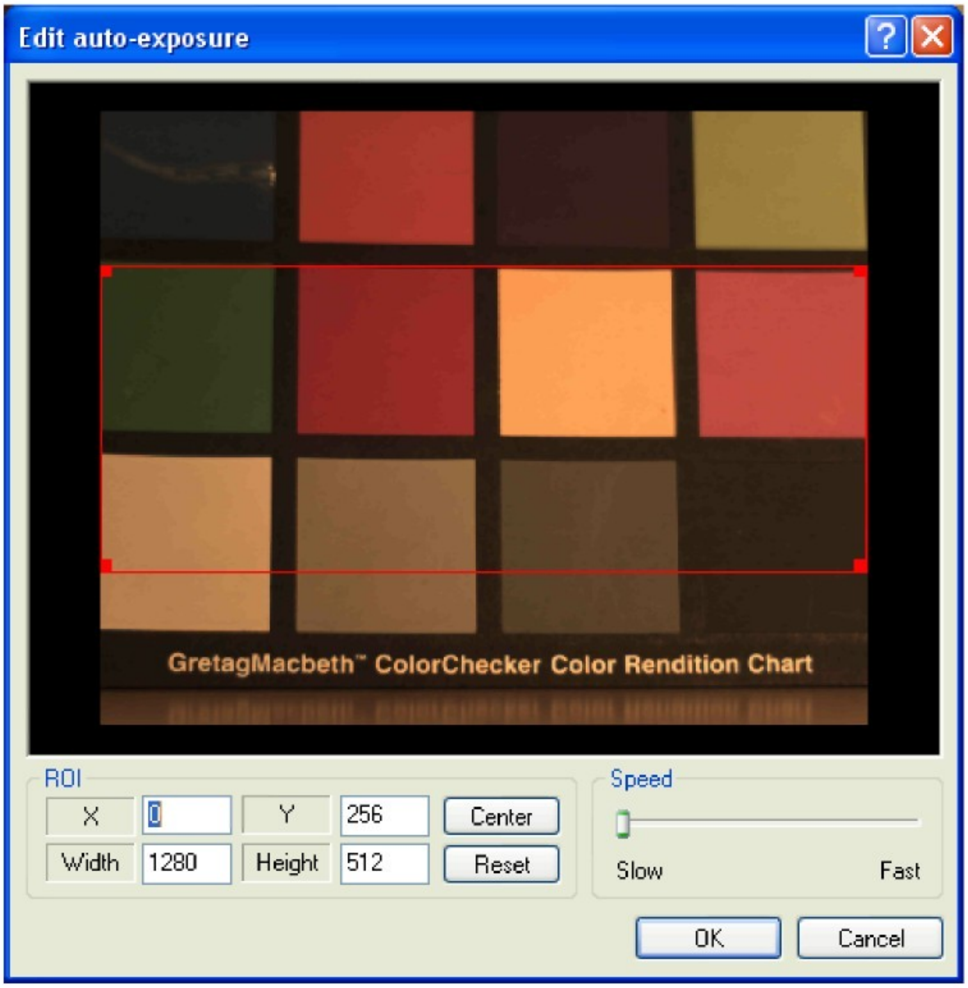
6.16.1. Auto-exposure

When this option is selected, the camera automatically adjusts the exposure to match a specified average luminance value. The camera reacts to any change of external light intensity by changing the current exposure value.

1. With the auto-exposure disabled, click the "Set" button on the camera bar to set the reference luminance value.

2. Enable the auto-exposure.

3. Click the "Edit…" button and change the parameters below.



ROI: the statistics region of interest. It's the area of the image where the average intensity is computed and compared to the reference value to compute the new value of exposure.

Speed: the reaction speed to changes of image intensity. The larger is this parameter, the faster the camera corrects the exposure.

6.16.2. Set a Region of Interest (ROI)

The **MotionPro** camera system has a **Partial Windowing** capability that can be selected and set via the software interface. Using this setting a region of interest for the image that is less than the total available area of the sensor may be selected. This region can be interactively adjusted and can occupy any area of the sensor's active pixels.

1. Click on the ROI button on the Camera Configuration Tab.
2. From the Edit Region of Interest dialog box, select the ROI by setting the numerical values for its origin and dimensions or by dragging the handles of the red box that highlights the ROI within the sensor area.

Once the ROI is configured only the active portion of the image is acquired and displayed. It is important to note that the maximum framing rate of the camera is inversely proportional to the number of rows in the ROI.

Region of Interest options:

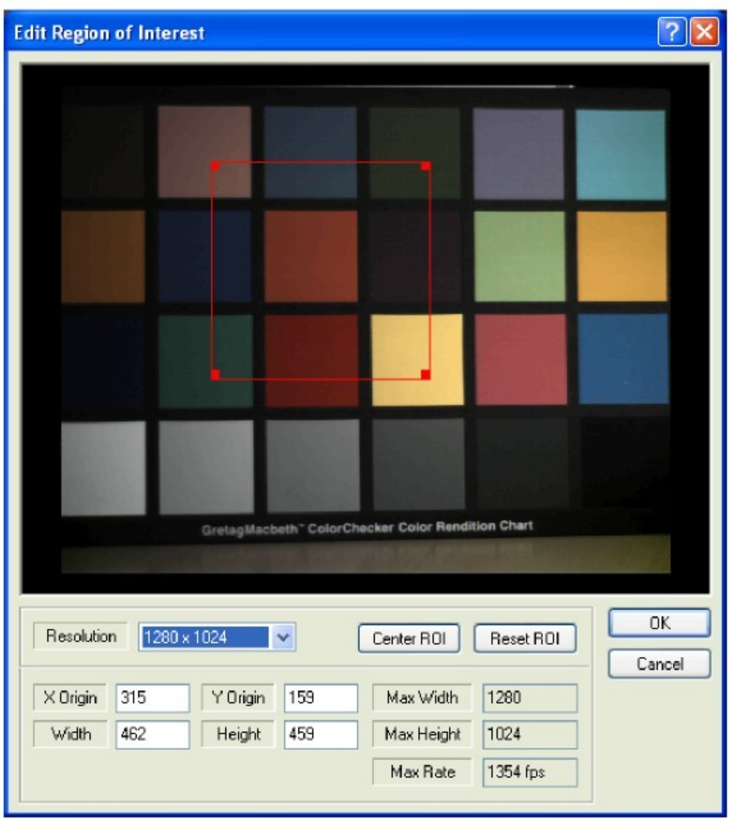
Resolution: select a resolution from the drop-down list or select User and edit the values in the X Origin, Y Origin, and Width and Height text boxes.

Center ROI: click the button to center the current ROI.

Reset ROI: click the button to reset to the maximum value.

Max Rate: displays the maximum acquisition rate for each ROI.

After the ROI is set, the selected region will appear in the main viewing window. To resize the image to the screen area, select the Fit to Window from the main toolbar.



6.16.3. Edit video options

Video Output

This option enables or disables video output in X, Y and MotionXtra Legacy cameras.

Y cameras: the video output modes are listed below:

- **PC only**: images are sent to the computer via GE or USB, no HDMI output is produced.
- **PC and HDMI**: any time an image is sent to the computer (playback or live) the same image is sent also to the HDMI output. The live/playback speed is reduced because a double output is done.
- **HDMI only**: any time an image is read from the camera, the image is sent to the HDMI output. No images are sent to the computer. Live/Playback speed is increased because the images are not sent to the computer via USB or GE.
- **Independent HDMI**: computer and HDMI operations are independent. The user can do live on the computer and playback on HDMI or vice versa autonomously. Live/Playback speeds are independent. This option is active on new design Y cameras only.

Video Format

X and MotionXtra legacy: select NTSC or PAL format.

Y cameras: select two HDMI formats (1280x720p, 1920x1080p or extended 1280x720p)

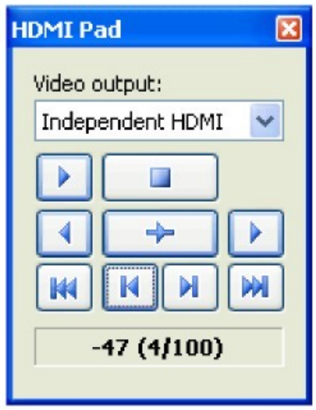
Preview Mode

Y cameras: select full resolution or decimated (on the computer).

6.16.4. HDMI Pad

New design Y cameras support an "Independent HDMI" video output mode. In that fashion, the HDMI output is independent from the computer output. The HDMI output is controlled via the HDMI pad.

From camera menu, select HDMI Pad.



6.17. Record Configuration

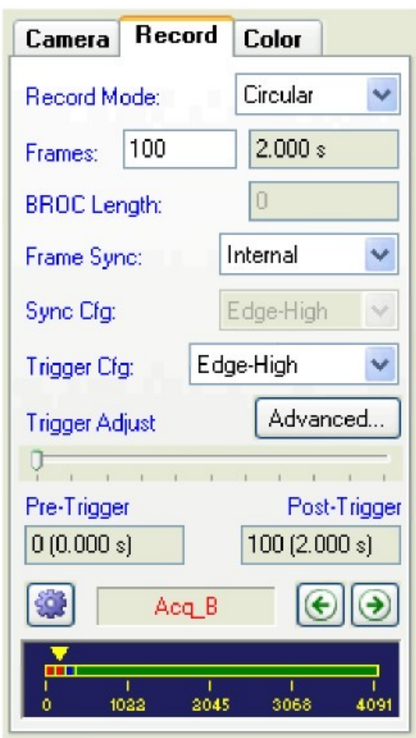
The record configuration Tab may have two layouts according to the camera type: cameras with 2 BNC connectors and cameras with 3 BNC connectors.

X-Stream XS-3 cameras with 2 BNC connectors have a single sync/trigger input and a single sync output. The input may be used to provide a pulse train for sync or a single pulse for triggering in circular mode.

Other Cameras with 3 BNC connectors have one input for the sync signal, one input for the event trigger, and one output for the sync output. The "trigger in" signal may be configured to accept IRIG signals.

Use the Record tab on the Docked Dialog box at the right of the image to set the record options.

6.17.1. Record Configuration (3 BNC cameras)



Record mode

Use the drop-down list and select one of the following options:

- **Normal**: the camera acquires and stops when the memory segment is filled.
- **Circular**: the camera acquires and restarts when the memory segment is filled. The camera waits for an event trigger to complete the acquisition.
- **BROC (Burst Record on Command)**: the memory segment is divided into sub-segments; the camera acquires in circular mode in a sub segment. When the event trigger is issued, the camera completes the acquisition and start acquiring in the following sub-segment until the memory segment is filled.

Frames

In the text box edit the number of frames to be recorded to the camera memory in a single acquisition. The values can be set from 1 up to a maximum number depending on the amount of free memory and the number of rows on each frame. Select the number of rows on each frame with the ROI setting.

BROC Length

If BROC mode is selected, use the text box to type the number of frames of each sub-segment. If the number of frames is 1000 and the BROC length is 100, the camera will acquire 10 sub-segments.

Frame Sync / Sync Cfg

Sync Configuration and Event Trigger configuration are separated. Synchronize the camera with a pulse train and simultaneously issue an event trigger from the "Trigger In" BNC connector. Use the drop-down list to select Internal or External synchronization source. If the "Frame Sync" is external, use the "Sync Cfg" drop-down list to select one of the following options: edge-high, edge-low, pulse-high, and pulse-low.

IRIG Frame Sync

Some Y cameras have the IRIG option, which can be activated from the Frame Sync drop-down menu. When the option is selected, the camera sync source is internal, but it is phase locked with the GPS signal (1 Hz frequency). Also, the camera detects the IRIG time stamp and the software displays it (See Options).

Trigger Cfg

In Circular or BROC mode, select from the following event triggers options:

- Edge High
- Edge Low
- Switch Closure

Trigger Adjust

When the record mode is set to Circular or BROC, the Trigger Adjust controls are active. In this mode the camera acquires the set number of frames before the trigger event (pre-trigger) and the remaining after (post-trigger) the trigger event. Use the slider to adjust the number of pre- and post-trigger frames.

Advanced Sync/Trigger Configuration

Use the Advanced... button to open the Trigger, Sync In and Sync Out configuration dialog.

Acquisitions Configuration

Use the Wheel Icon button to open the Advanced Acquisitions Configuration dialog.

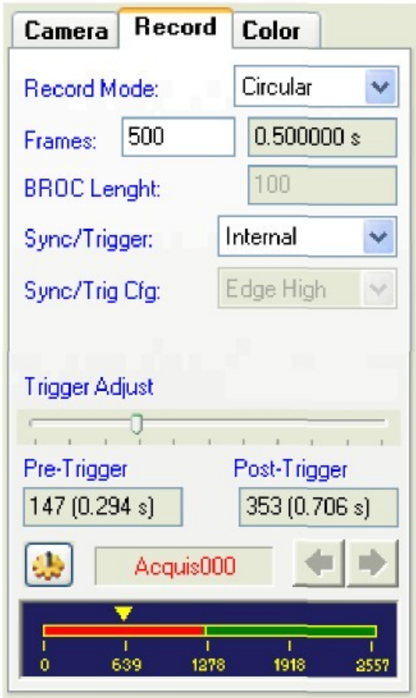
Select Acquisition

Use the arrow buttons to select the previous or next acquisition.

Memory Indicator Bar

The colored bar depicts the available memory.

6.17.2. Record Configuration (2 BNC X-Stream XS-3 cameras)



Sync/Trigger and Sync/Trig Cfg

The external synchronization and the event trigger have a single input and cannot be issued in the same time. The Sync/Trigger parameter controls the source of synchronization. If the source is external, the input may be configured (edge or pulse). If the mode is normal, the parameters control the sync, if the mode is circular or BROC they control the event trigger.

6.17.3. Advanced Sync/Trigger Configuration (Y/N and HG cameras)

Trigger In

The Y camera can enforce a minimum time that the trigger input must remain continuously at its active level before it recognizes a valid trigger. This parameter is called "Debounce" and can be used to reject noise pulses on the trigger input, or to debounce mechanical contacts used as trigger sources.

After it recognizes a valid trigger pulse, the camera can wait for a few microseconds before issuing the trigger. This parameter is called "Delay".

Sync In

The "Debounce" and "Delay" parameters can be applied to the sync in source as well (see above). If an external sync source is connected to the camera, the software is able to detect the rate and the pulse width of the signal. If the user sets the frame sync parameter to external and no signal is active on the sync In, the program displays a warning message.

Sync Out

The sync out mode can be configured:

- **Default**: the sync out signal follows the sync in (internal or external). The signal width is the exposure time.
- **Inverted Default**: the signal follows the sync in as in the default, but it's inverted.
- **Configurable Width**: the user can define the width of the sync out signal.
- **Inverted Configurable Width**: like in the option above, but inverted.
- **Disabled**: the sync out signal is disabled.

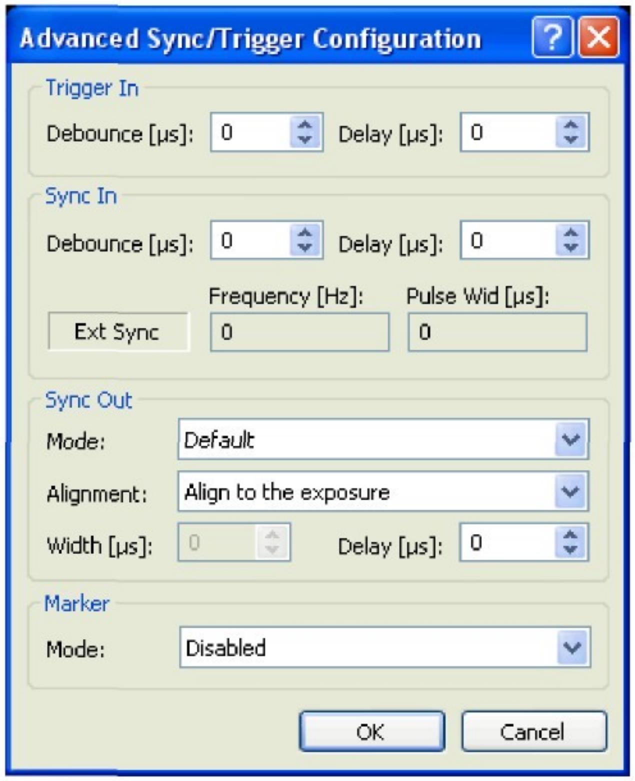
A "Delay" can also be added to the Sync Out signal.

Alignment: when the auto-exposure option is selected the exposure is done at the end of the acquisition period. Then the period and exposure are not aligned. The alignment option is used to decide whether the sync out will be aligned to the period or to the exposure.

Marker

If this option is enabled, the user can send to the camera a pulse that gets recorded in one frame. The recorded pulse is a marker in the frame and lets the user know that something happened at that time. The marker is shown in the frame if the "Marker" Time stamp option is selected.

The pulse can be sent through the "Sync In" connector or the "Trigger In" connector.


Advanced Sync/Trigger Configuration
Trigger In
Debounce [µs]: 0
Delay [µs]: 0
Sync In
Debounce [µs]: 0
Delay [µs]: 0
Frequency [Hz]:
Pulse Wid [µs]:
Ext Sync
0
0
Sync Out
Mode: Default
Alignment: Align to the exposure
Width [µs]: 0
Delay [µs]: 0
Marker
Mode: Disabled
OK
Cancel

6.17.4. Advanced Acquisitions Configuration

Image Folder

Browse to the directory of selections for saving acquired images. This is the parent directory for the saved images. Each time the images are recorded a new sub-directory containing the actual image files is created.

Download images after acquisition and stop

Check this box to automatically save the data to the computer's hard disk after each acquisition.

Download images after acquisition and restart... times

Check this box to automatically restart the process of saving data to the computer's hard disk after each acquisition. Use the corresponding text box to type in the number of times to repeat the process.

Post-recording operation

After the acquisition, the camera can automatically download the images to the IRIG-Flash device. For further information about the device please refer to the appendix.

Overwrite existing folder

If this option is unchecked, any time an acquisition is done, the program checks if the folder is already present and, if yes, it generates a new folder names with decimal digits. Example: if the folder name is A, the program checks if A is present. If yes, it generates A_000, then A_001 and so on.

If the parameter is checked we have two options:

1. The "Download images after acquisition and restart" option is unchecked. In this case the program saves the images in the same folder all the time. Example: the folder name is A. then the program creates the folder A the first time and saves the images. If subsequent acquisitions are done, the program saves the images in the same A folder and overwrites them.
2. The "Download images after acquisition and restart" option is checked. In this case the program creates folder names from the acquisition name with 7 digits. Example: the acquisition name is A, then the program creates A_0000000, then A_0000001, then A_0000002 and so on.

Acquisition Folder name

The first acquisition directory name defaults to Acquis000. Subsequent acquisitions are stored in sequentially numbered directories, (ex. Acquis000, Acquis001, Acquis002...).

Image Prefix

Type the image prefix into the text box.

Comment

Type a comment to the acquisition.

Frames

Use this dialog box to set the number of frames to record.

Time

It displays the acquisition record time.

File Type

Use the drop-down list to set the image type format for archiving files to the hard drive of the computer.

Memory Size Display

The dialog box displays the total memory size in GB and MB. XS-3 models acquire 10 bit images and the pixels are stored in the camera memory in a packed format. Ten pixels are stored in 16 bytes of data, so the size of a frame in full resolution is 2 MB.

New

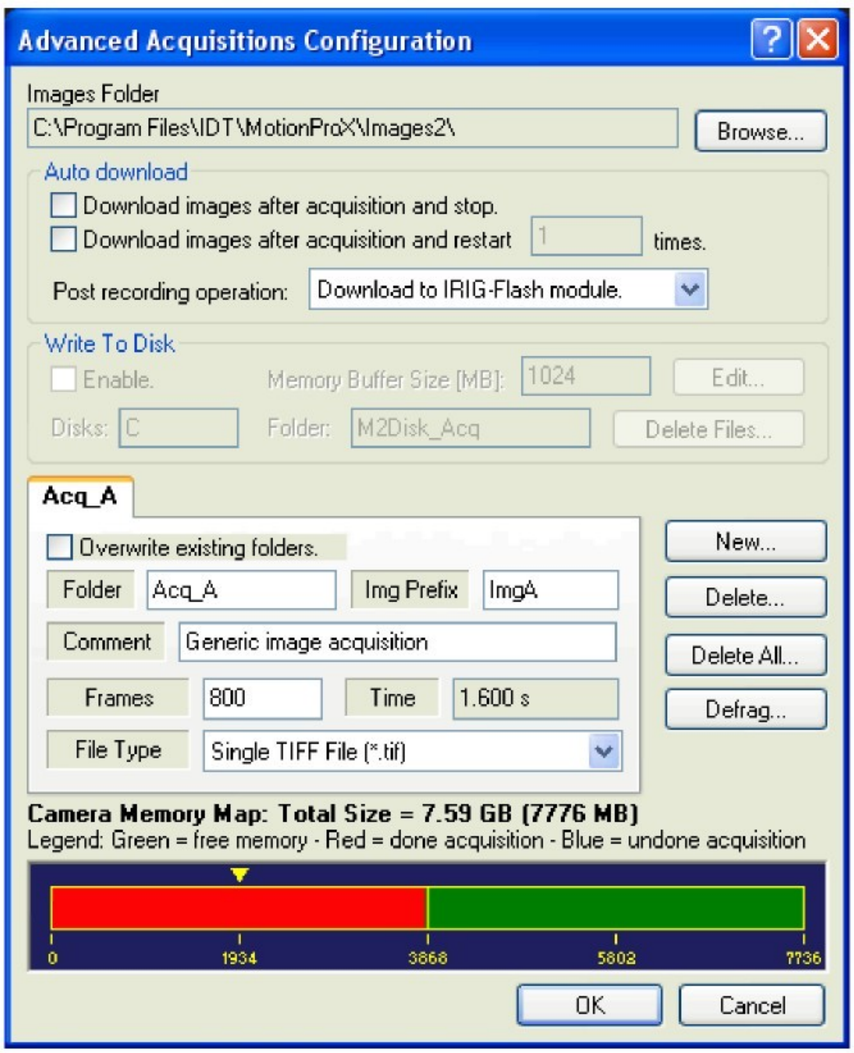
Create new acquisition folders to store a new sequence of images using the. Configure all of the parameters independently for each folder.

Defrag...

Click on the Defrag... button to re-organize the camera memory using the defrag utility.

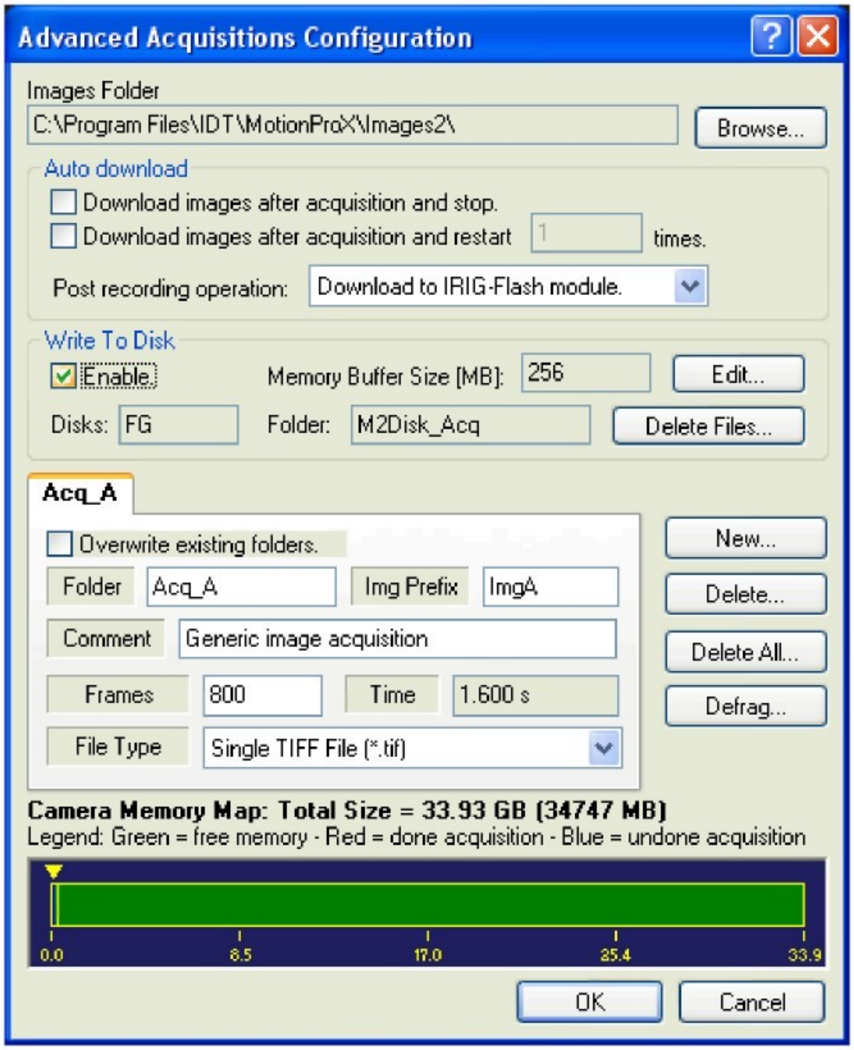
Delete and Delete All

Delete a selected folder or all folders.



6.17.5. Write To Disk Option

M cameras can activate the direct write to disk option.



Enable "Write To Disk"

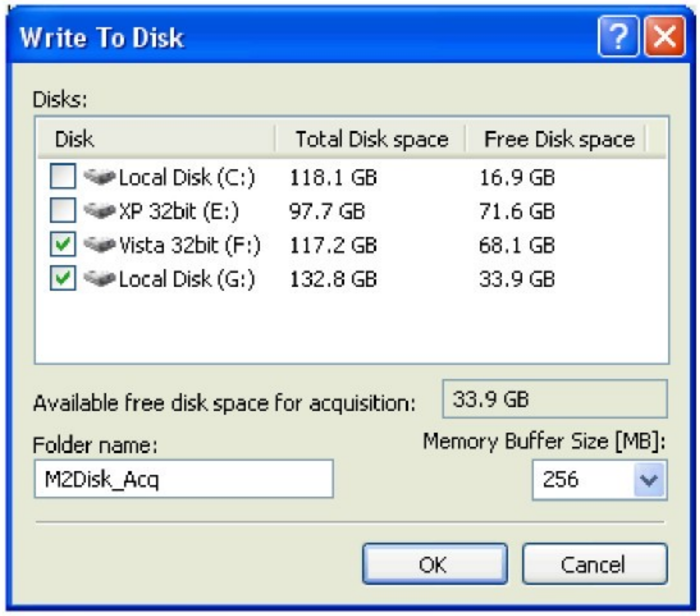
The option is active if the camera is an M-series and the computer has a license file.

Delete Files

Click this button to delete the files stored in the acquisition folder.

Edit

Click this button to change the write to disk settings.



Memory Buffer Size

It indicates the amount of computer memory allocated for the acquisition. The camera acquires images in this memory buffer and the data is automatically saved to the hard disk in real time.

Disks

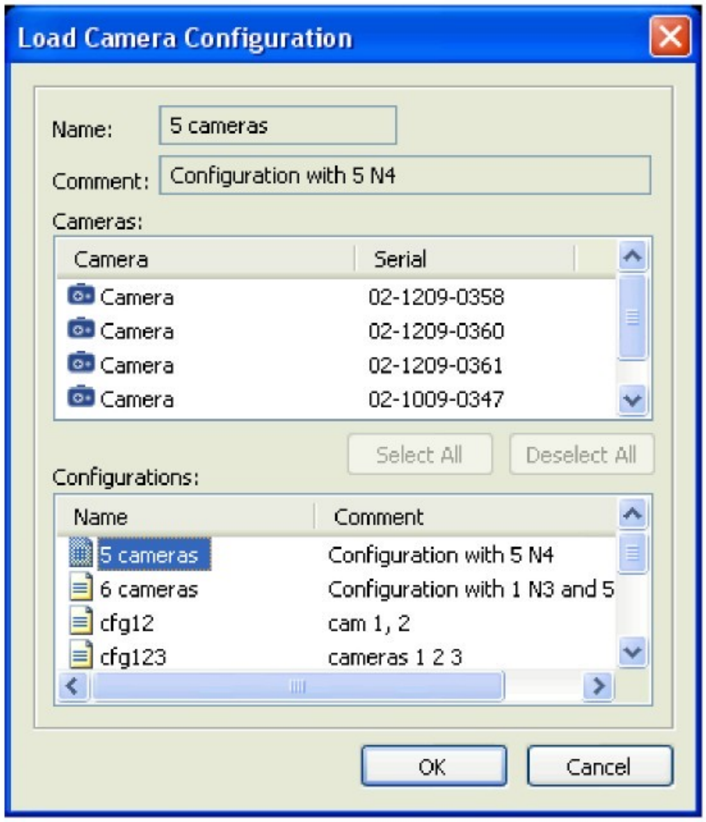
Select the disk drives used for the acquisition.

Folder

Type the name of the folder where the images will be stored.

6.18. Load camera configuration

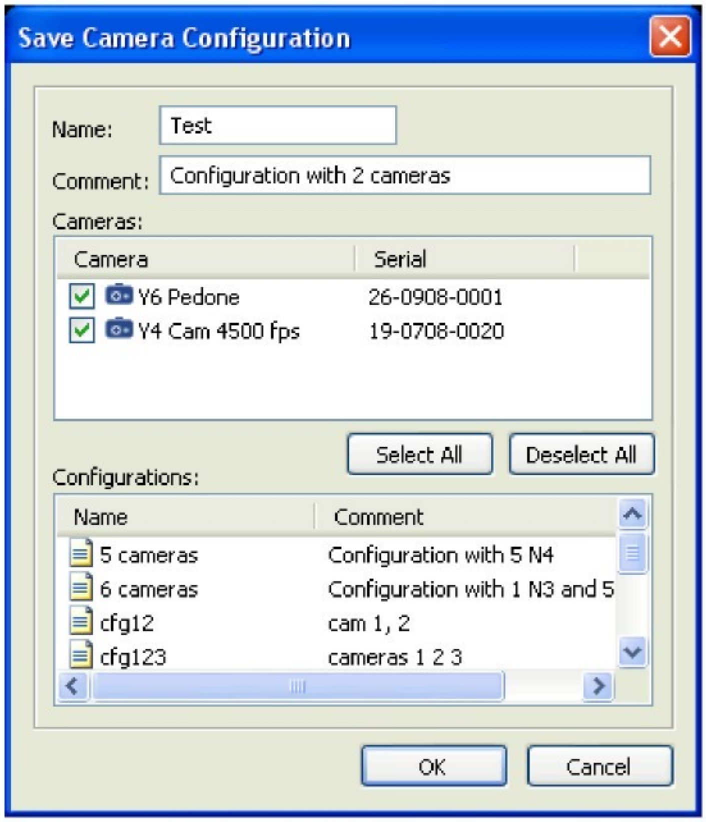
From File menu, select "Load camera Cfg…"



Select one of the available configurations and click OK. The camera settings stored in the configuration will be loaded and any previous setting (included memory segment configuration) will be overwritten.

6.19. Save camera configuration

From File menu, select “Save camera Cfg…”



Select one of the available configurations or type a new name and comment. Then click OK. The current camera configuration (included the memory segments for the acquisitions) will be stored for future use.

In a multi-camera environment you can select the cameras from the list and save only the configuration of the cameras that are selected.

6.20. Saving acquired images and data

The acquired images stored in different areas of the camera memory can be saved to the computer's hard drive.

Click the Save button on the main toolbar or select File from the main toolbar > Save Acquisitions…

The program displays a list of the acquisitions. For each acquisition the program displays the following save options and acquisition file information.

Enable Fast Download and Convert

If this option is enabled, the camera downloads the images in a temporary file, and then a new process is launched. The process converts the temporary file in the selected output format and the user may start a new acquisition. After the fast download the conversion process may be activated right away (Convert after download) or later (Convert later). The conversion option is active only if the fast download item is selected.

Show the download progress in the Status Bar

During the download, the dialog box that shows the progress is not displayed. The download progress is shown in the program status bar.

Save extra data

The program saves extra data to the images file. Extra data may include IRIG time stamp, temperature, image index, exposure, rate and other time stamp information.

Acquisition Folder

The program creates a new folder for each saved acquisition. Type a new name for the folder directly into the text box.

Overwrite folder

Please refer to the Advanced Acquisition configuration topic.

Image Prefix

Type a prefix into the text box to change prefix. If the prefix is ImgA, the images will be saved as "ImgA000000."

Camera name

If this option is selected, the image prefix is created with the camera name.

Comment

Type a brief comment/description of your acquisition.

File Type

Use the drop-down list to select one of the following image formats: TIFF, BMP, PNG, MPT, MRF, MCF, MOV (Mac) and AVI (PC). For more information, see the Appendix.

Output Pixel Depth

The output file pixel depth may be different from the original image's pixel depth in monochrome cameras. Use the drop-down list to select one of the mono or color pixel depths. Bit images with 8 bits can be saved in 8 and 10 bit output files, while 10-bit images can be saved in 8-bit and 10-bit image files. TIFF, PNG, MPT, MCF and MRF support both 8 and 10 bit; BMP, AVI (PC) and MOV (Mac) support 8-bit only. Color images are saved in 24-bit RGB format.

Rate [fps]

If the sequence is saved in AVI format, the playback rate may be configured.

From Frame/To Frame/Step

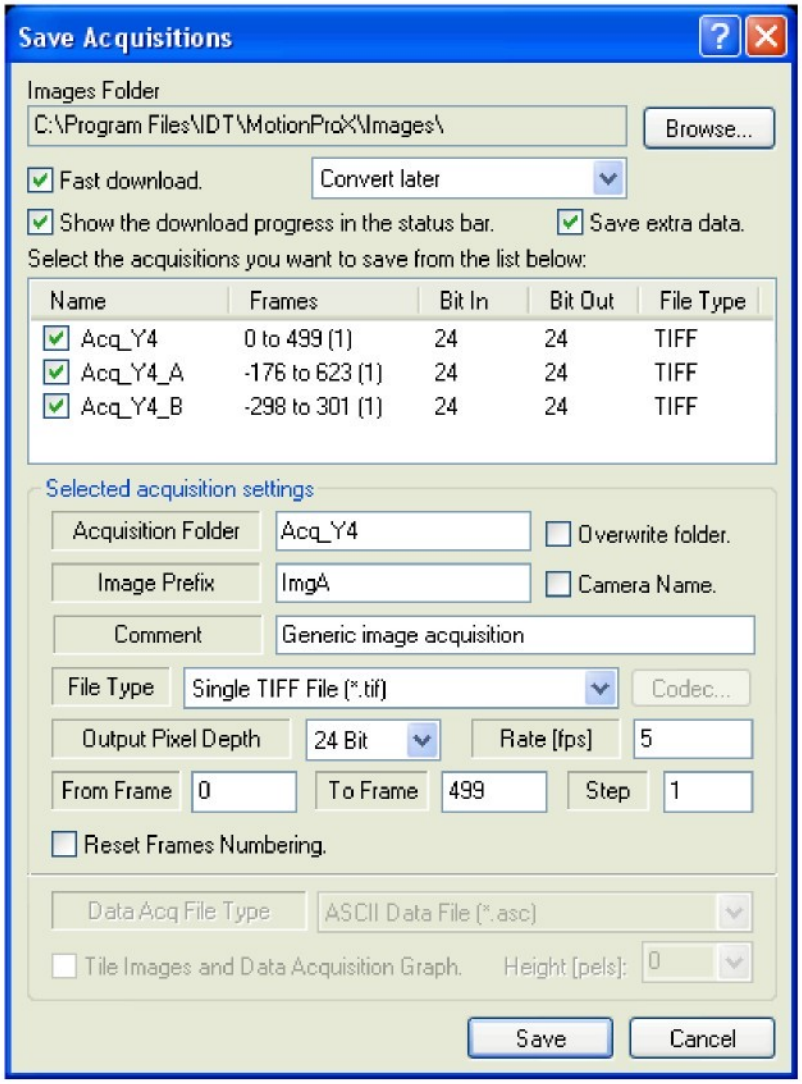
Type the desired Start Frame Index, Stop Frame Index and Step value directly into the text box. For example, if from=2, to=10 and step=2, only the following frames will be saved: 2, 4, 6, 8 and 10.

Reset Numbering

In Circular mode the frame number can be negative; also, the Step may be different from 1. Select the Reset Numbering Option to save images with numbers starting from 0 index and step 1.

Data Acquisition

If data acquisition is connected and some data have been acquired with the images, the user may select the file format. Available formats are: ASCII, Tecplot, LabVIEW, Excel XML spreadsheet and Excel XLS workbook.



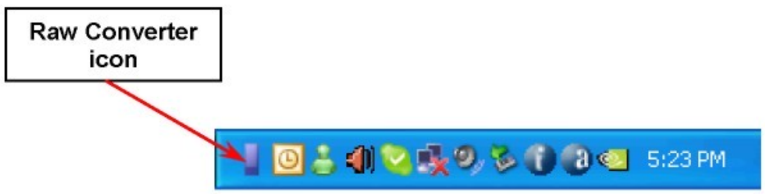
Example: start frame is 10, stop frame is 16 and step is 2. If Reset Numbering is unchecked the output file names will be: Img000010, Img000012, Img000014, and Img000016. If it is checked the image names will be: Img000000, Img000001, Img000002, and Img000003.

6.21. Fast Download and Raw Converter

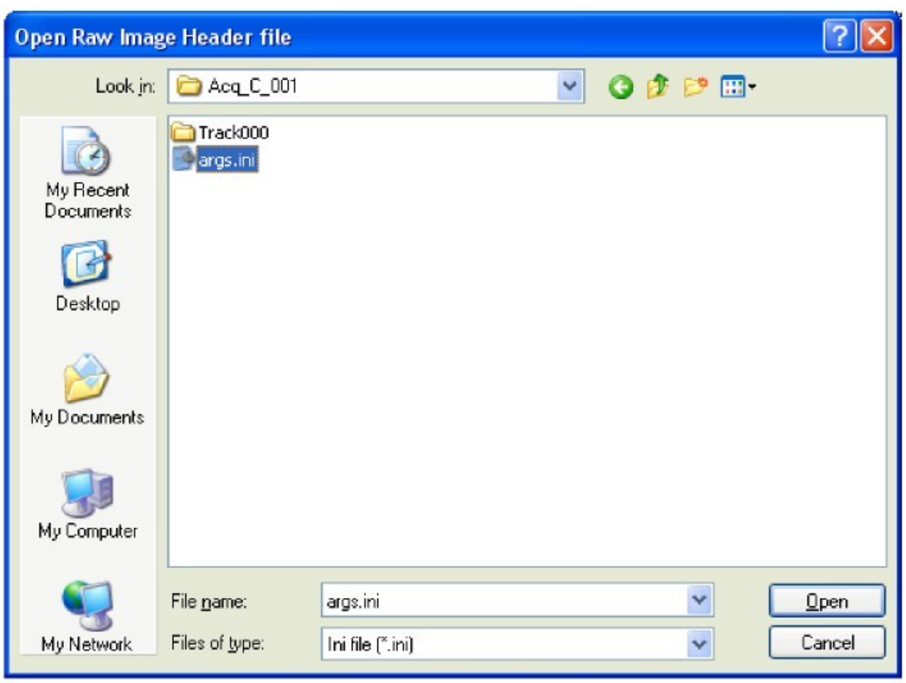
The user may enable the fast download when the images are saved to the hard disk. To do this, select the “Fast Download” option in the “Save Acquisitions” dialog box.

Once the fast download is activated, the program transfers raw data from the camera to a temporary file that must be converted. The conversion may be done automatically (“Convert after download” option) or later (“Convert later” option).

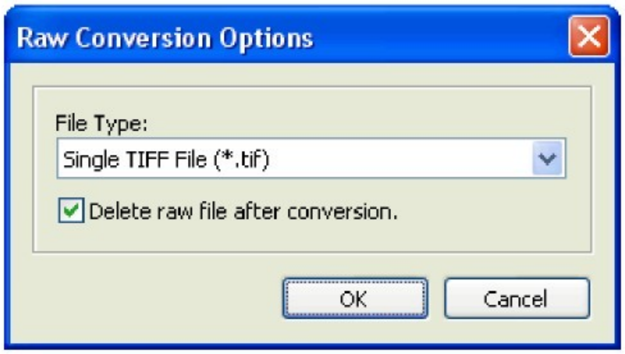
1. **Convert after download**: the file is automatically converted after the download. The raw converter runs in background and converts the file. A progress bar is displayed in the tray notification area of Windows.



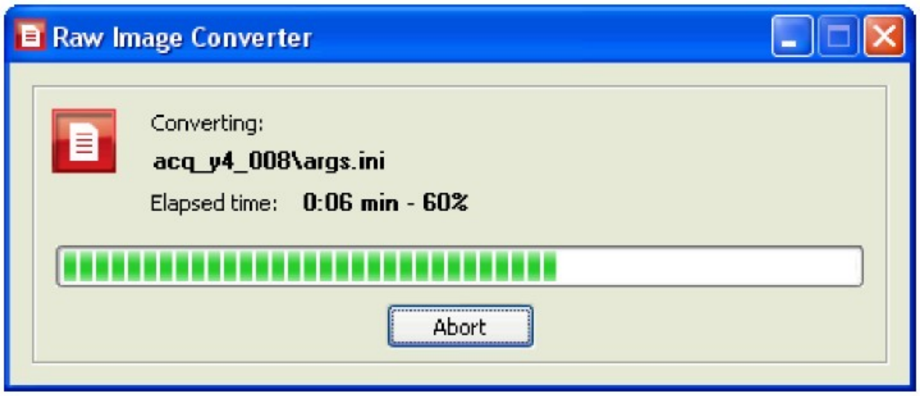
2. **Convert later**: the file is converted manually by the user. From the Start menu select “All Programs”, then “IDT”, then “Motion Studio”, then “Tools” and then run the “Raw Converter”. Locate the args.ini file in the acquisition directory and click OK.



Then select the conversion options. The file format may be changed and the raw file can be kept and converted more than one time.

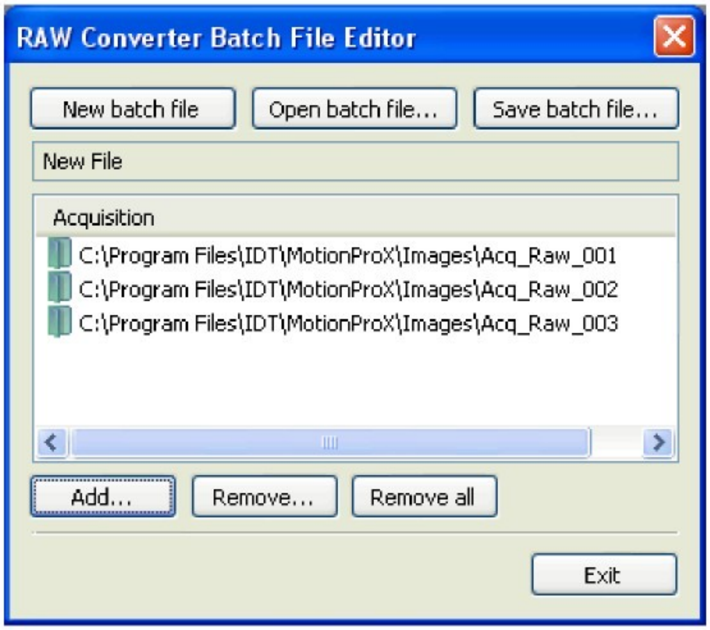


When the OK button is clicked, the raw converter starts the conversion and a progress dialog box appears.



6.21.1. Raw converter batch files

If the amount of raw sequences to convert is large, the user may generate a batch file and run the conversion once. From Tools menu, select “Raw batch editor…”



New batch file: click this button, to reset the current batch configuration and generate a new batch file.

Open batch file: opens a previously generated batch file.

Save batch file: save the changes in the current batch file or in a new file.

Add: adds a sequence to the current batch file (ARGS.INI file)

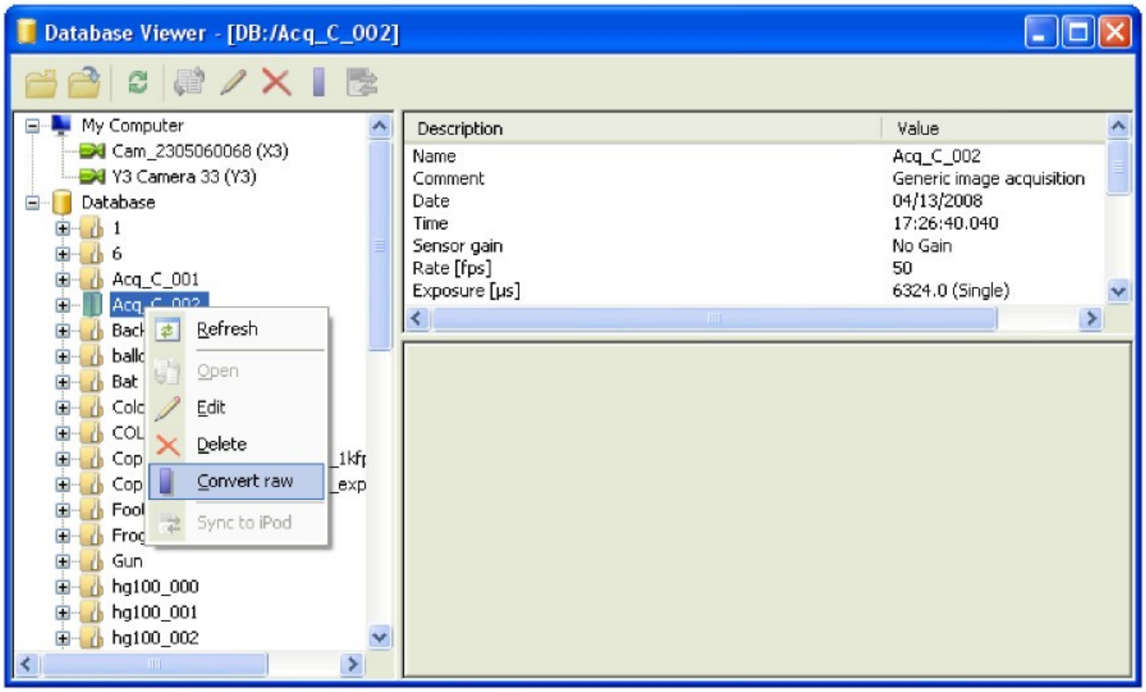
Remove: removes a sequence from the current batch file.

Remove all: removes all the sequences from the list.

Once the batch file is generated and saved, launch the raw converter and open the batch file. All the sequences included in the batch file will be converted.

6.21.2. Raw Sequences and Database Viewer

If the “Convert later” option is selected, the sequence is saved in RAW format. The database viewer shows the folder with a different color (green).



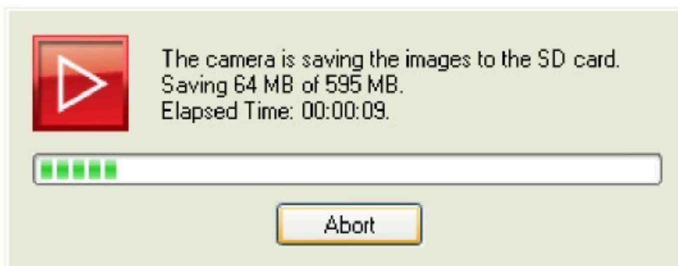
The user may right click on the red folder and select the “Convert Raw” option. The raw converter will be activated and the sequence converted to the image format.

6.22. Download data to SD card and convert

To activate the automatic download of the acquisition to the IRIG-Flash module (SD card), do the following:

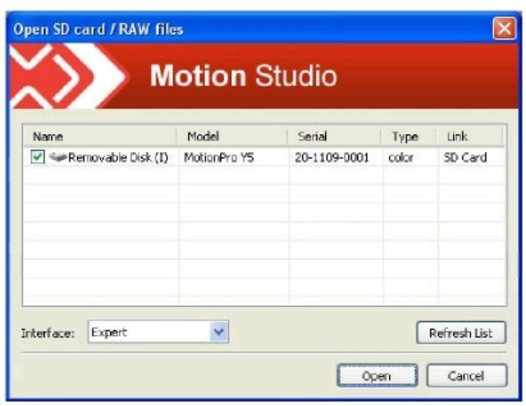
- Open the Advanced Acquisition configuration dialog box.
- Select the "Download to IRIG-Flash module" option in the Post-Recording Operation control.
- Click OK.
- Start the acquisition

When the acquisition is done, the camera automatically starts the download of the memory into the SD card. Motion Studio displays a progress window. If any error occurs, an error message is displayed.



The content of the SD card can be converted into images.

- From the File menu, select Open, then "SD cards/RAW files…".
- Locate the SD card from the list
- Click Open.



The SD card content is enumerated as a "Virtual camera" and will be open in a camera window. Then the user may download images and save them in any file format.

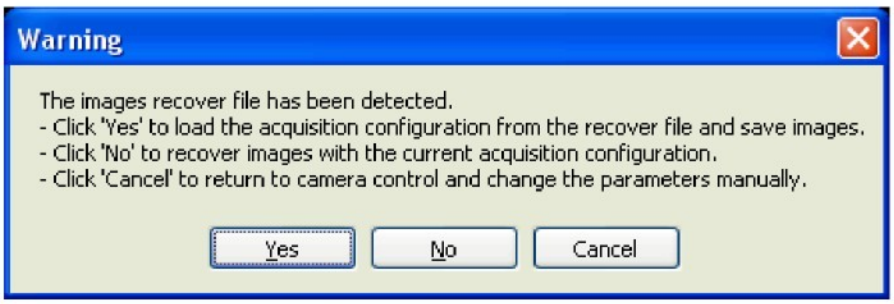
6.23. Images Recover

After each acquisition a local configuration file is saved in the database directory (_nnn_recover.xsv, where “nnn” is the serial number of the camera). The file contains the information about the latest acquisition. If any error has occurred after an acquisition and the program has been restarted before the images have been saved, the acquisition may be recovered.

1. From the main toolbar select the File menu.

2. From the drop-down menu select the “Images Recover” item.

3. Select one of the options.



6.24. Image Configuration

The image tab includes controls for color reconstruction and white balance and controls for image improvement. Dynamic NR, sharpen, gamma, brightness and contrast are active also for monochrome cameras

Interpolation
Use the drop-down list to select the color interpolation algorithm (used to convert color filter array data into RGB data). The available algorithms are Advanced, Nearest and Bilinear.

Light Source
Use the drop-down list to select the light source that best fits the current environment. Select the User option to manually change the color gains or balance the colors with an automatic balance procedure.

RGB Gains
If the User light source is selected, use the Color Gain sliders to increase or decrease the corresponding color component (red, green or blue). The range is from 0.5 to 2.5.

Sharpen
It sharpens the image edges. The range is from 0.0 to 1.0. The default value is 0.0.

Gamma
It introduces a gamma correction to the image. The range is from 0.1 to 4.0. The default value is 1.0.

Brightness
It increases or decreases the image brightness. The range is from -0.25 to 0.25. The default value is 0.0.

Contrast
It increases or decreases the image contrast. The range is from 0.5 to 1.5. The default value is 1.0.

Hue (color images only)
It modifies the image hue. The range is from -180 to 180. The default value is 0.

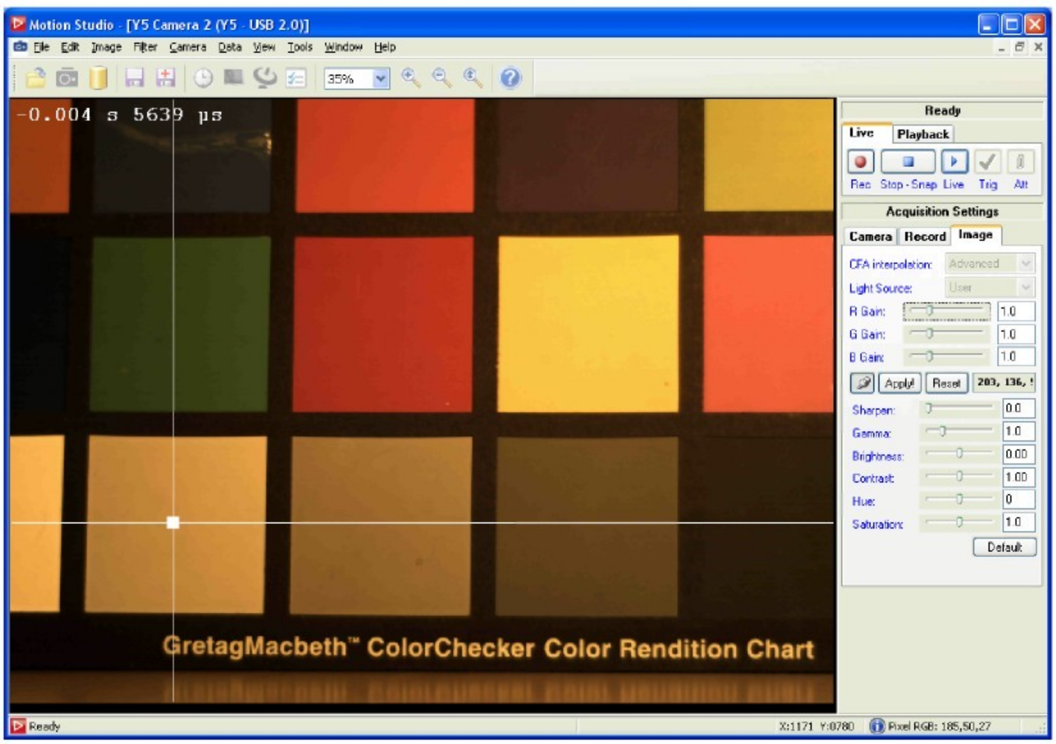
Saturation (color images only)
It modifies the color saturation. The range is from 0.0 to 2.0. The default value is 1.0.

Default
Click on the Default button to reset to the original values.

6.24.1. Automatic White Balance

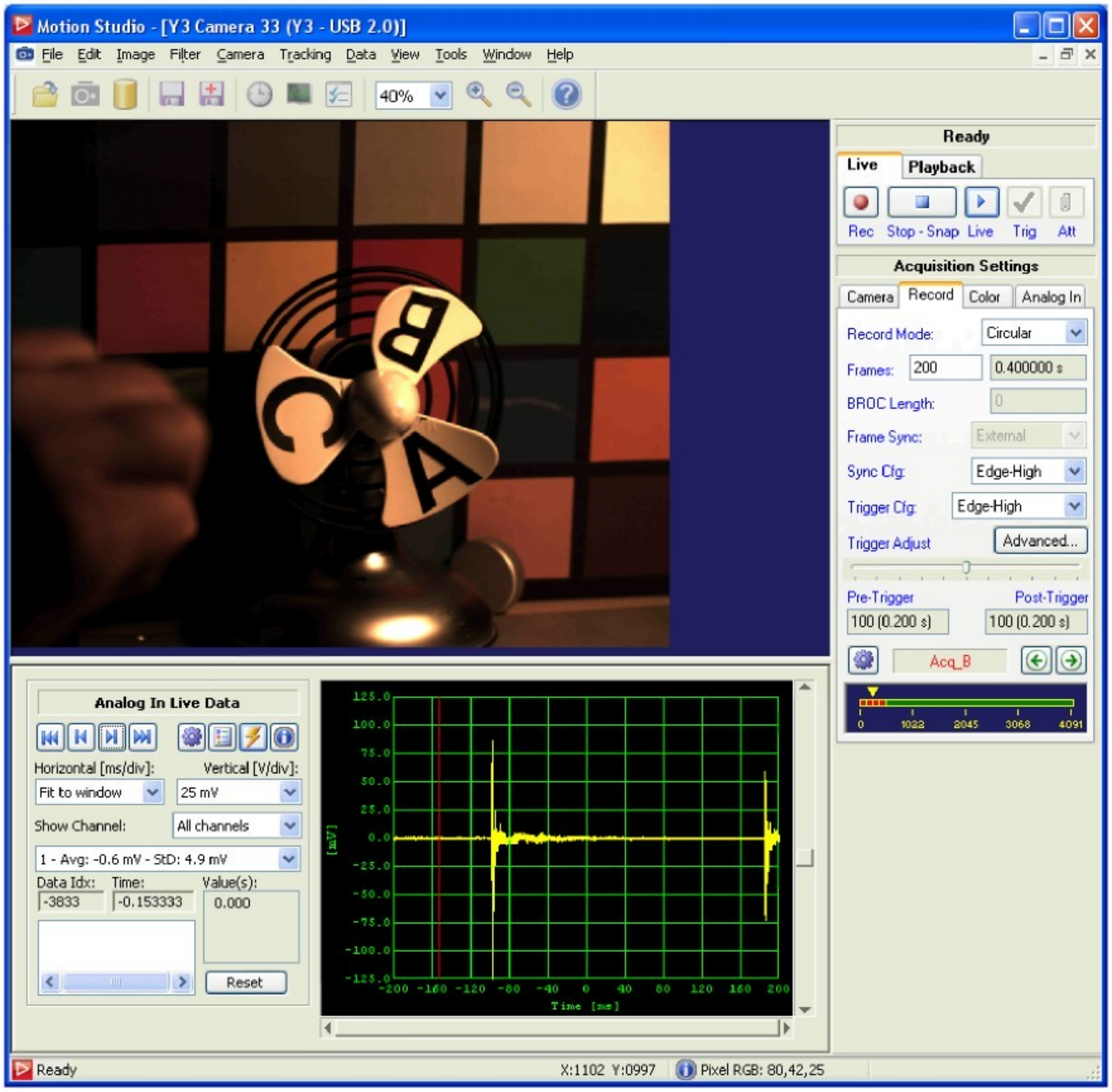
Edit color gains manually or use the automatic balance procedure:

1. Select the Color tab from the Docked Dialog Bar.
2. Select the User option in the Light Source drop-down list.
3. Click Reset and snap an image (Stop button).
4. Press the Target button. A target will appear on the image.
5. Click on the image to move the target. Move the target over a gray, non-saturated area.
6. Click the Apply button.



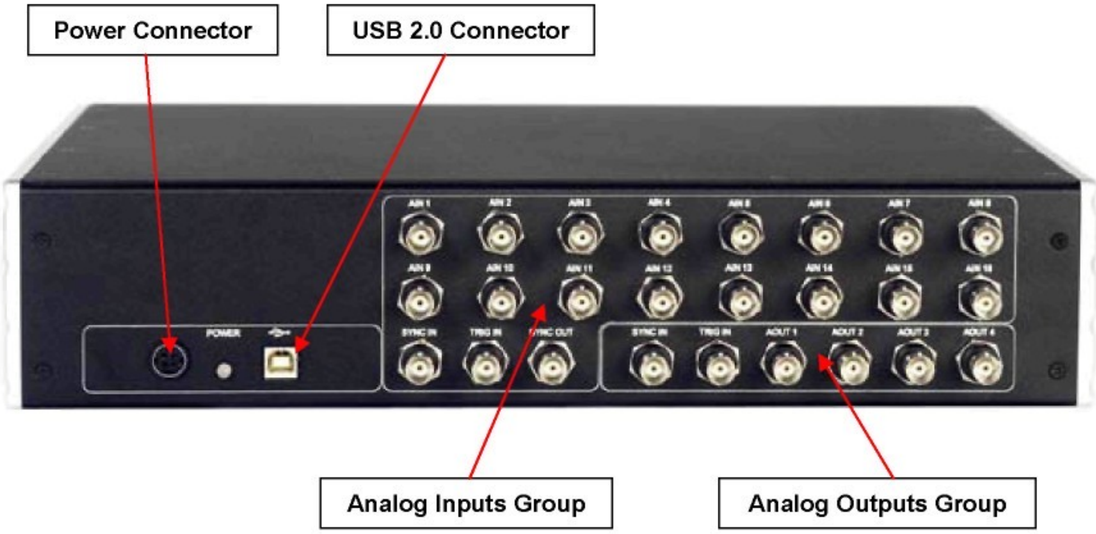
6.25. Data Acquisition module

The MotionPro Data Acquisition System is integrated in Motion Studio. When a Data Acquisition module is detected the camera window is split in two panes and an “Analog In” tab is added to the “Acquisition Settings” Tab. See the picture below.



6.25.1. Data acquisition cables and back panel

The picture below shows the data acquisition module back panel



The BNC connectors are grouped in two groups:

Analog Inputs

- **AIN1 to AIN15**: the analog input channels
- **Sync In**: the analog input external synchronization input
- **Trig In**: the analog input external event trigger input
- **Sync Out**: the analog input output signal.

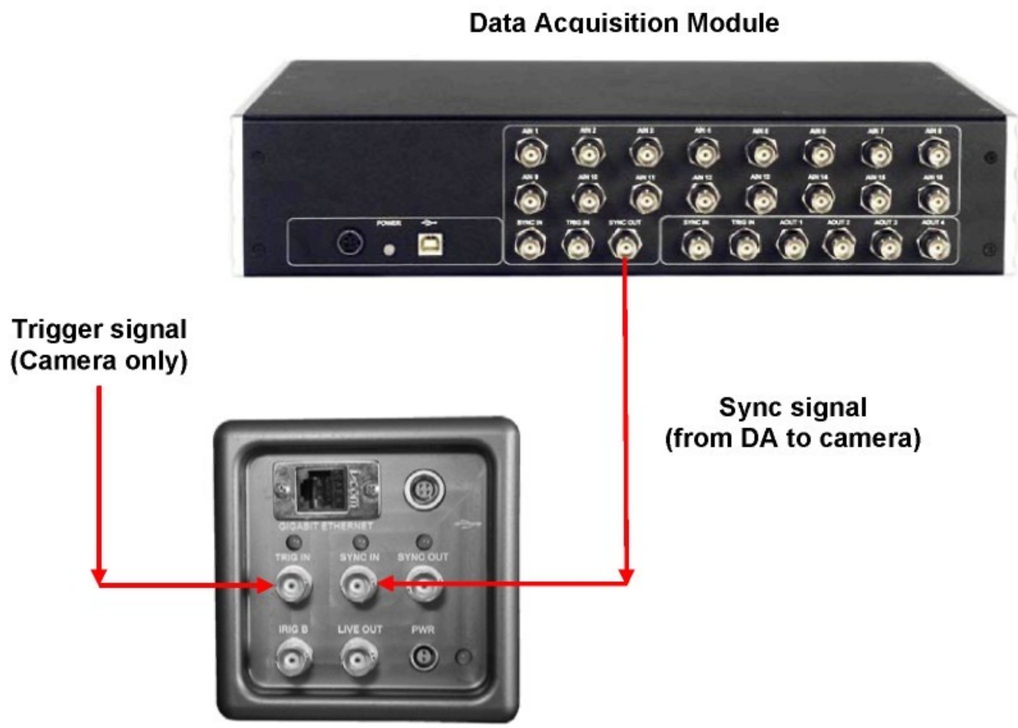
Analog Outputs

- **AOUT1 to AOUT4**: the analog output signals
- **Sync In**: the analog output external synchronization input
- **Trig In**: the analog output external event trigger input

For the connection of the DAS to the camera there are 2 possible scenarios.

6.25.1.1. Simple connection

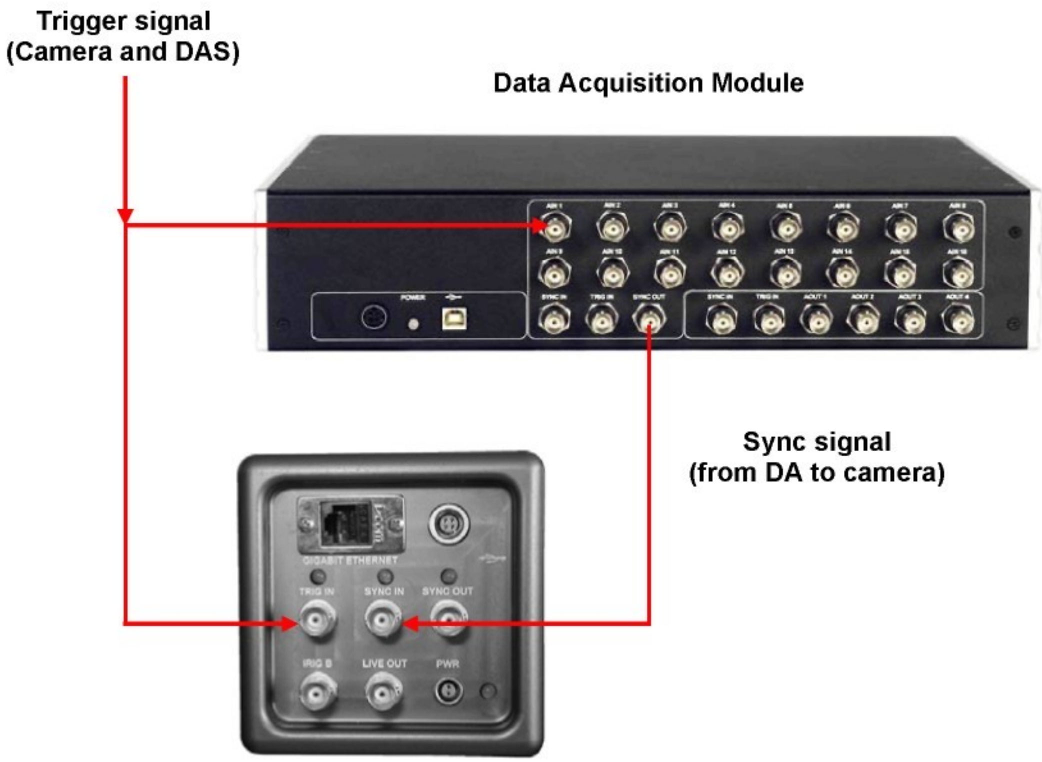
The “Sync Out” connector of the “Analog Input section” of the Data Acquisition back panel is connected to the “Sync In” connector of the camera. The Data Acquisition module generates the camera acquisition rate, the camera acquires in External Sync In configuration.



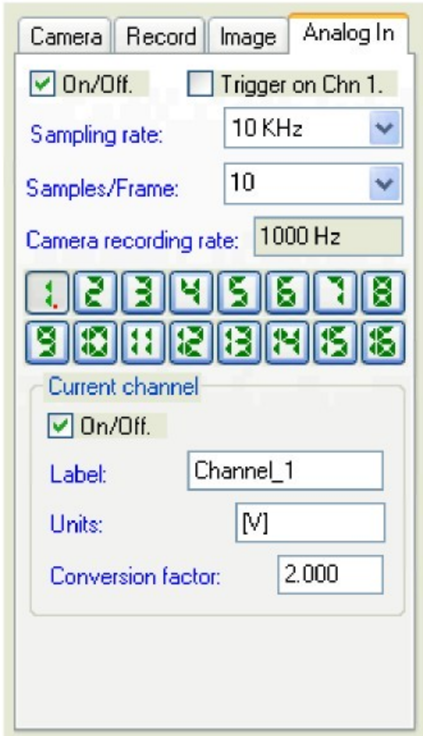
NOTE: The trigger signal must be connected to the camera “Trigger In” connector only, not to the Data Acquisition module

6.25.1.2. Connection with “Trigger In” signal

In some specific conditions it is convenient to connect the Trigger In signal to the Channel 1 of the data acquisition. The “Sync Out” connector of the “Analog Input” section of the DAS back panel is connected to the “Sync In” connector of the camera. The trigger signal is connected to the “Trigger In” connector of the camera and to the “AIN 1” connector of the DAS. In the software, the option “Trigger on Chn 1” must be selected.



6.25.2. Analog Input Configuration



On/Off

The acquisition module may be enabled and disabled. If enabled, the camera rate control is grayed out and the acquisition rate is automatically computed and configured. See below.

Trigger In on Chn 1

Select this option and connect the trigger signal to the channel 1 input. The sampling of the trigger signal will help synchronizing the images with the data.

Sampling Rate

Select the number of samples per second. The max sampling rate is 500 KHz.

Samples per frame

Select the number of data samples per camera frame. The value is used a divider of the acquisition rate to compute the camera acquisition rate. The number is a multiple of the active channels number.

Camera recording rate

The camera rate is automatically computed with the formula below:

Cam Rate = (Data Acq Rate) / (Smp per Frame)

Channels selection

Each channel may be independently enabled and configured.

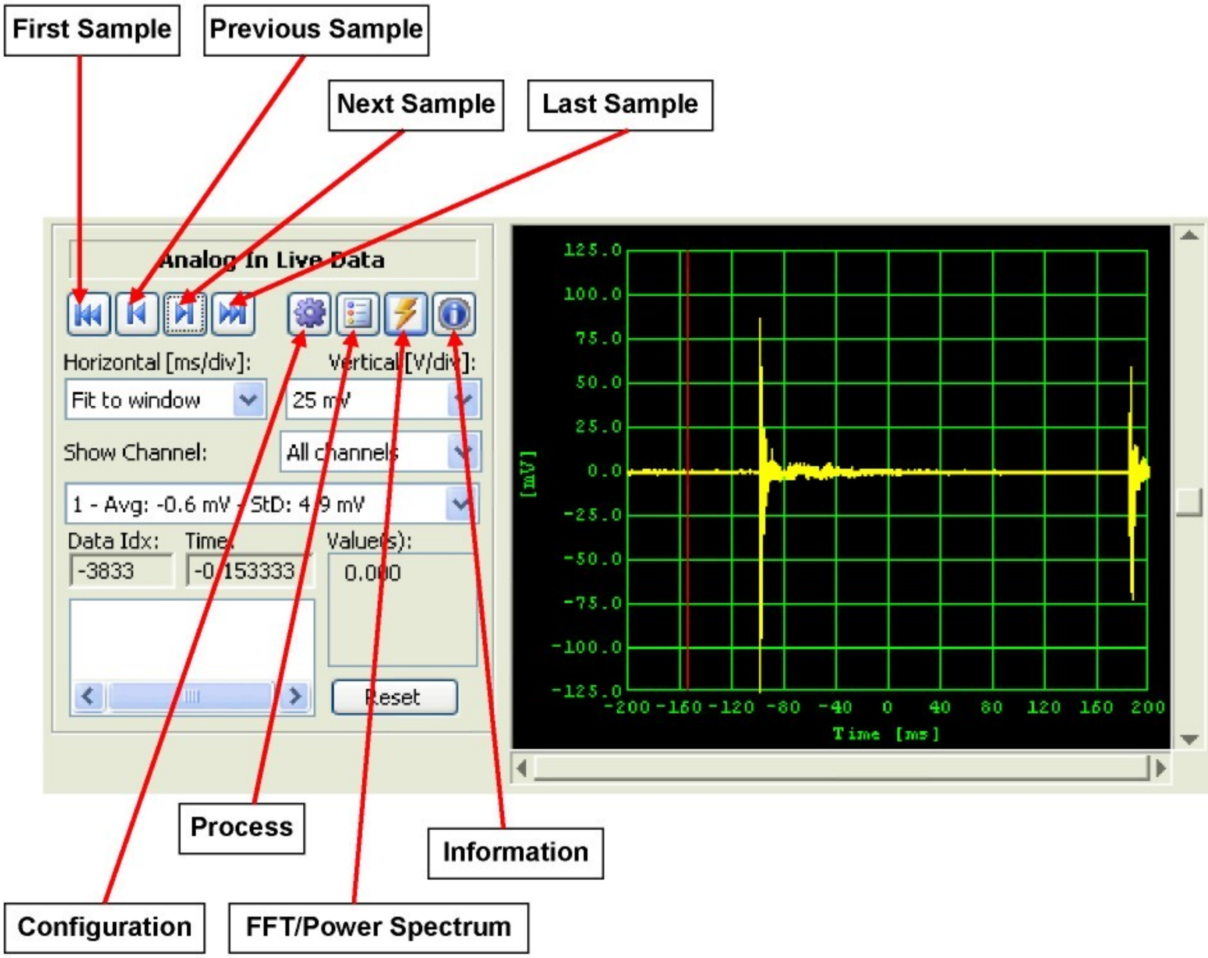
Channel On/Off

Enables and disables the channel

Label, Units, Conversion factor

Enter the channel label, the units and the conversion factor.

6.25.3. Analog Input Data Pane



The acquired data is displayed in a pane of the camera window. The display may be configured.

Navigation buttons: first sample, previous sample, next sample, last sample.

Data graph configuration: see below.

FFT and Power Spectrum: see below.

Data Processing Menu: see below.

Data Information: see below.

Horizontal resolution: select the graph horizontal resolution in milliseconds per division.

Vertical resolution: select the graph vertical resolution in Volts per division.

Show Channel: select if you want to be displayed all the channels or one single channel.

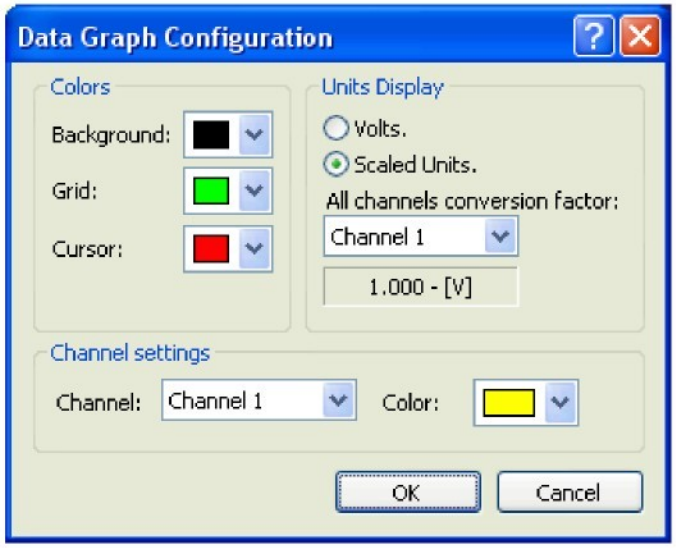
Average and Standard Deviation: for each channel the average and the standard deviation are shown.

Data Index, Time and value: the index, time and value of the currently selected data item.

Operations list: see the Data Processing topic below.

6.25.4. Data Graph Configuration

From the data pane, click the data graph configuration button.



Background color: the data graph background color.

Grid color: the data graph grid color.

Cursor Color: the data graph cursor color (vertical line).

Units Display: the graph may be displayed in Volts or in converted units.

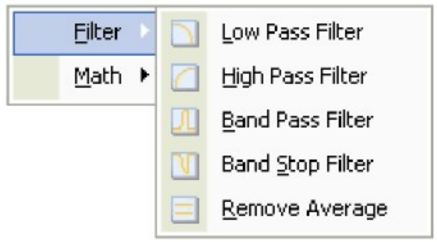
All channels conversion factor: If all the channels are shown in the graph window, select which conversion factor to use for the visualization.

Channel color: select the channel and set the graph color.

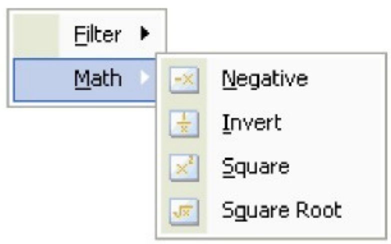
6.25.5. Data Processing Menu

The acquired data may be processed in the current window. To activate the filters or the mathematical operations, click the Data Processing button.

Select the Filter submenu or the Math submenu.



Filter operations: low pass filter, high pass filter, Band Pass filter, Band Stop filter or Remove average.



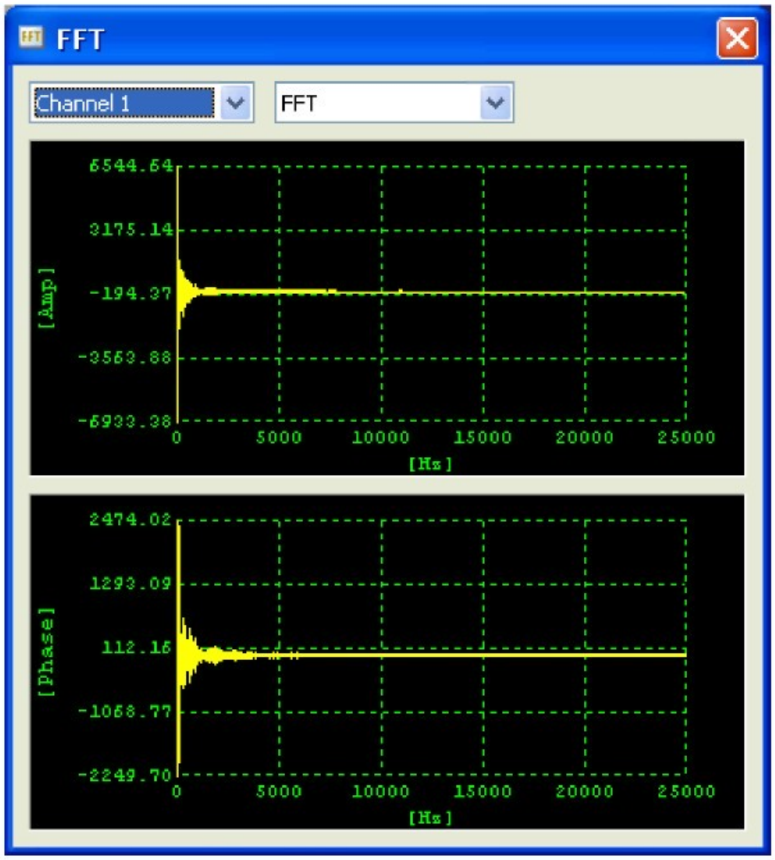
Mathematical operations: Negative, Invert, Square and Square Root.

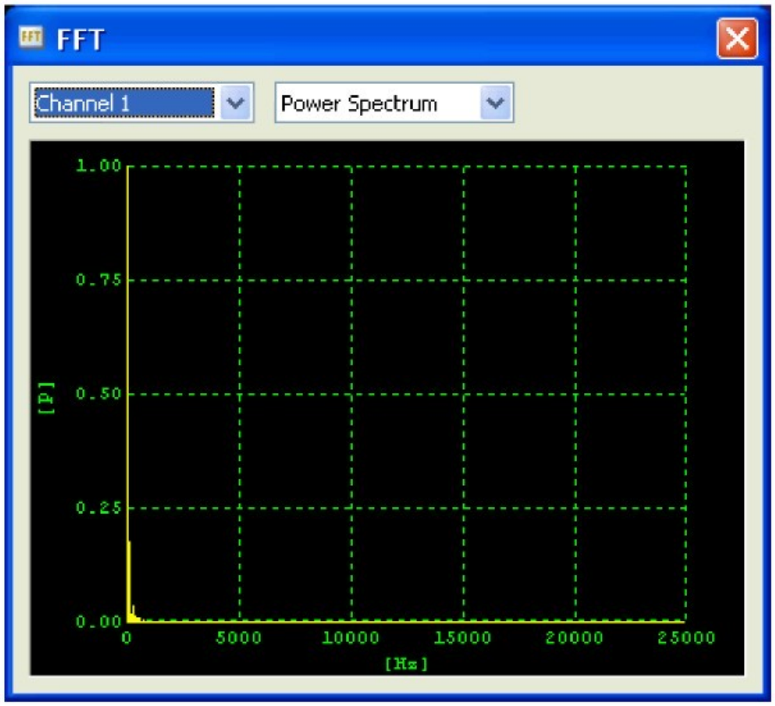
If the filters or the mathematical operations are activated the operations list is filled with those operations. The user may:

- Select the items in the list and activate the single operation.
- Reset the list and delete the operations.

6.25.6. FFT and Power Spectrum

Click the FFT button. The FFT dialog box appears. The user may select the channel to display, the FFT and the power spectrum.

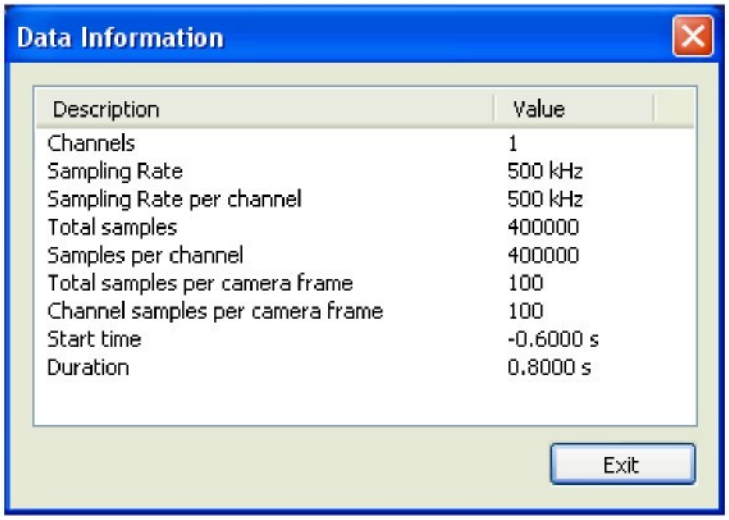



FFT
Channel 1
Power Spectrum
1.00
0.75
0.50
0.25
0.00
[P]
0
5000
10000
15000
20000
25000
[Hz]

6.25.7. Data Information

From the data pane, click the data Info button.

General information about the data acquisition is displayed.

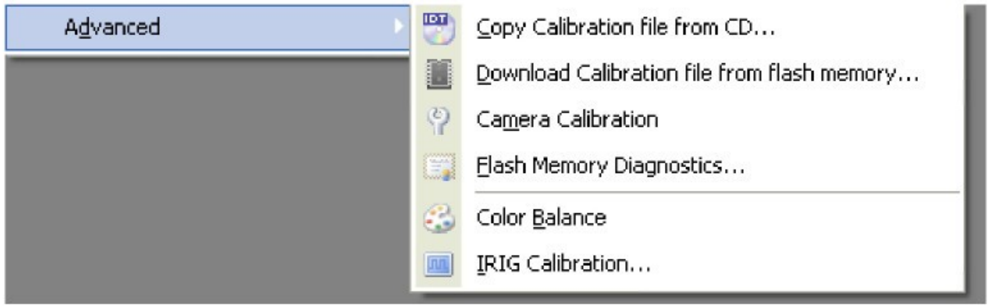


6.25.8. Note about the "Overrun" error

The "Overrun" error appears when the buffers allocated for the data acquisition are not enough and the acquisition is too fast. The error appears more easily when large sampling rates are configured (100 KHz, 250 KHz or 500 KHz). To avoid the error, increase the number of frames to acquire.

6.26. Advanced Camera Configuration in Camera menu

From the main toolbar select Camera > Advanced to access operations for the noise calibration file management and the Advanced Color Balance.



6.26.1. Copy Calibration file from CD

Each camera is shipped with a calibration file. For versions of Motion Studio below 2.07.04, the file is stored in the **WINDOWS\System32** directory (WINNT\System32 for Windows 2000). For versions of Motion Studio above 2.07.04, the file is stored in "**C:\Common Files\IDT\CameraFiles**".

If the file is not stored in the local directory, it may be copied from the camera CD.

6.26.2. Download Calibration file from flash memory

Giga-Ethernet cameras have on-board flash memory. The calibration file is stored in the flash memory and may be downloaded and copied to the hard disk.

6.26.3. Camera Calibration

To reduce the noise associated with CMOS sensors and improve the performance of the default calibration file, Motion Studio offers a Calibration dialog box.

1. Select Camera from the main toolbar.

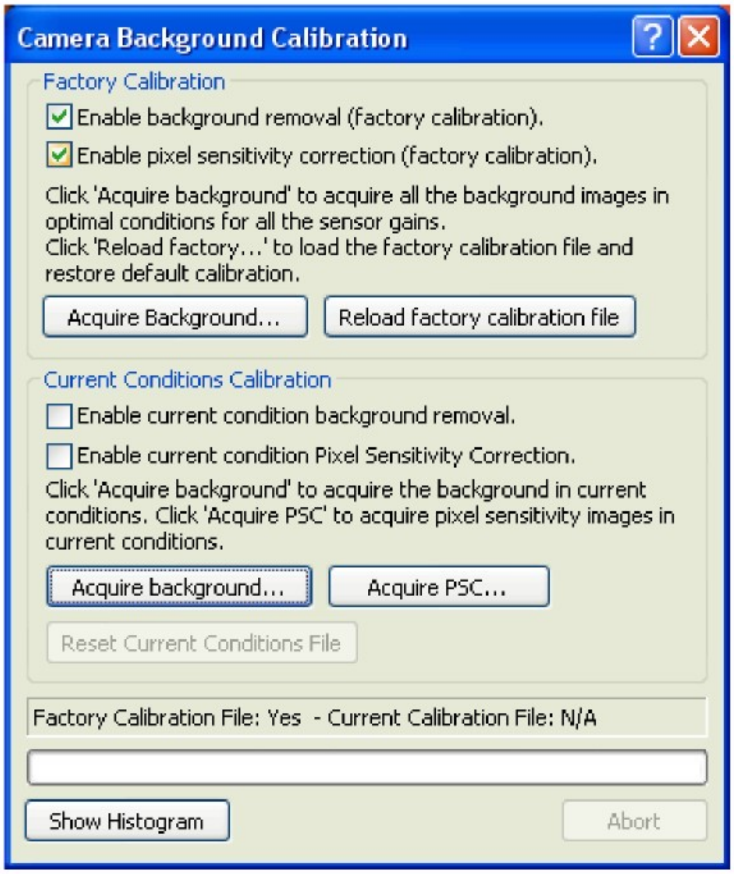
2. Select Advanced > Camera Calibration.

To reduce the noise associated to the CMOS sensor and improve the performance of the default calibration file, select the following options:

- **Enable background removal (factory calibration)**: it removes the background from any acquired images and reduces the noise.
- **Enable pixel sensitivity correction (factory calibration)**: it enables the compensation of differences in pixels sensitivity.
- **Acquire the background images in the optimal conditions**: the camera lens cap must be on. The driver acquires the background images in the optimal conditions for all the parameters (exposure, rate, sensor gain and pixel gain). The background images are not saved into the calibration file.
- **Reload factory calibration file**: the driver loads the default camera calibration file. This option is useful if the user wants to reload the default background images

To reduce the background noise in current conditions, select the following options.

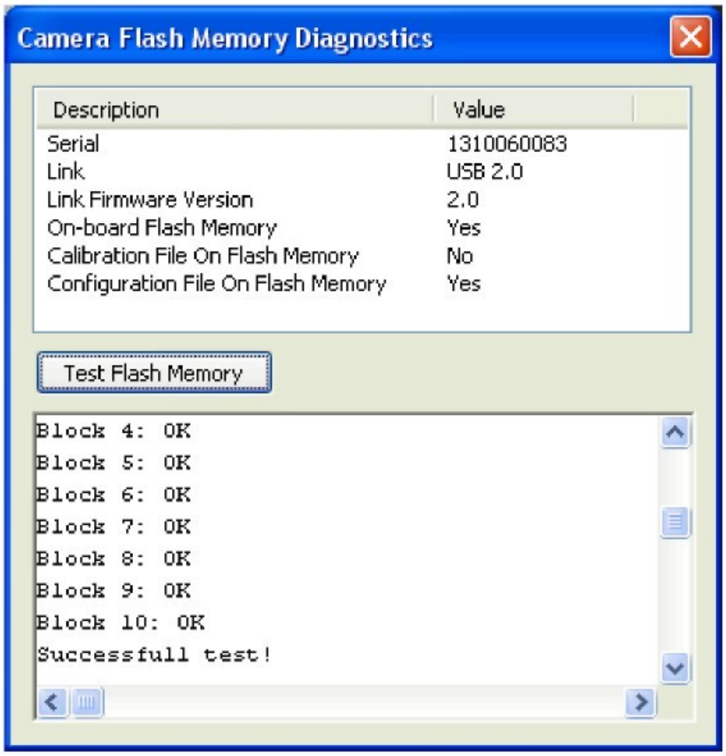
- **Enable current condition background removal**: if this option is selected the driver uses the background images that have been acquired in current conditions and corrects the images. The background calibration data is saved in a file and reloaded when the program is launched.
- **Enable current condition pixel sensitivity correction**: if this option is selected the driver uses the coefficients that have been computed in current conditions and corrects the acquisitions. The coefficients are saved in a file and reloaded when the program is launched.
- **Acquire the background images in current conditions**: the camera lens cap must be on. The driver computes the background images for the current operating conditions. If the sensor gain or the region of interest change after the calibration, the correction may be wrong.
- **Acquire the PSC images in current conditions**: the lens must be removed and a constant light should illuminate the sensor. The driver computes the pixel sensitivity correction coefficients for the current operating conditions. If sensor gain and region of interest change after the calibration, the correction may be wrong.
- **Reset current conditions file**: if this option is selected, the current conditions calibration file is deleted and the current images and coefficients are reset.


Camera Background Calibration
Factory Calibration
Enable background removal (factory calibration).
Enable pixel sensitivity correction (factory calibration).
Click 'Acquire background' to acquire all the background images in optimal conditions for all the sensor gains.
Click 'Reload factory...' to load the factory calibration file and restore default calibration.
Acquire Background...
Reload factory calibration file
Current Conditions Calibration
Enable current condition background removal.
Enable current condition Pixel Sensitivity Correction.
Click 'Acquire background' to acquire the background in current conditions. Click 'Acquire PSC' to acquire pixel sensitivity images in current conditions.
Acquire background...
Acquire PSC...
Reset Current Conditions File
Factory Calibration File: Yes - Current Calibration File: N/A
Show Histogram
Abort

6.26.4. Flash Memory Diagnostics

It's a tool to test the camera flash memory.

1. Select Camera from the main toolbar.
2. Select Advanced > Flash Memory Diagnostics.
3. Click Test Flash Memory to perform a read/write test.



6.26.5. Color Balance Adjustment

Build user-defined color tables with the Color Balance procedure.

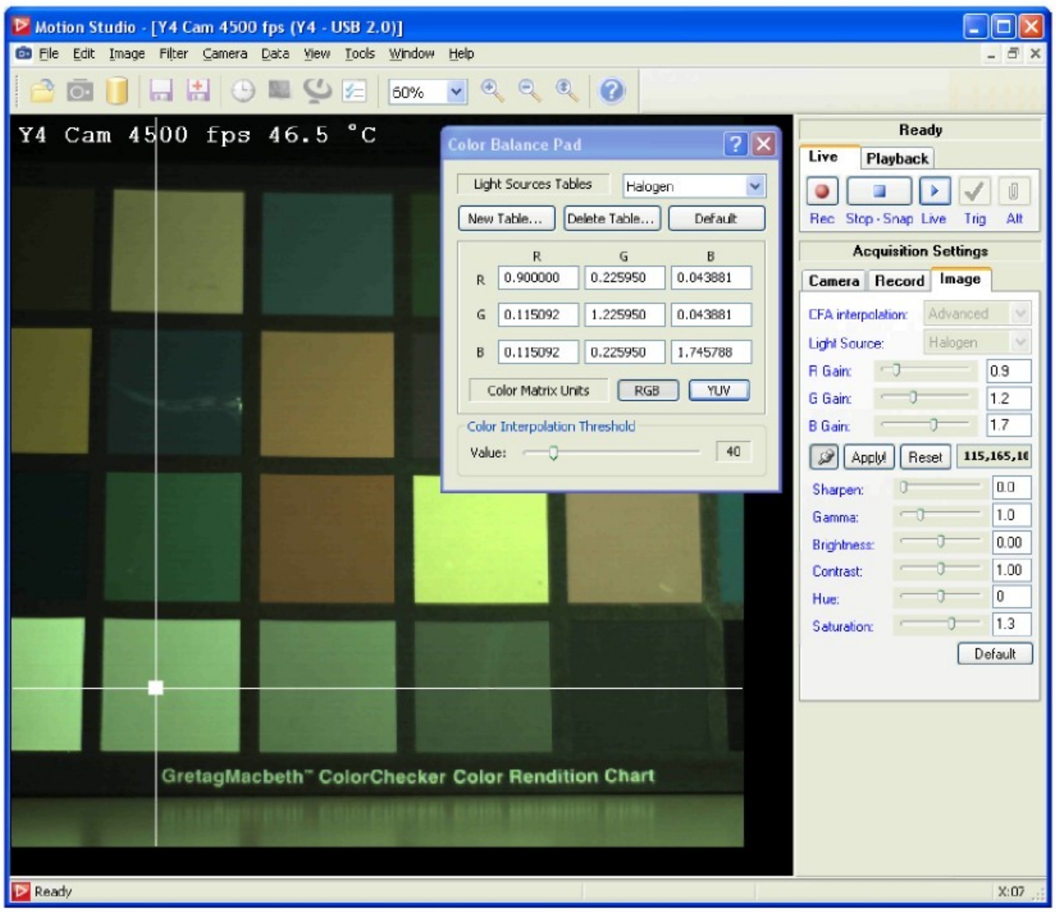
1. Select Camera from the main toolbar.
2. Select Advanced > Color Balance.
3. Use the Color Balance Pad, to create new color schemes (Light Source Tables), edit or delete them.

New Table: Click the button to create a new default diagonal table.

Delete Table: Click the button to delete the currently selected table.

Default: Click the button to load the default configuration.

Color Matrix Units: Click the appropriate button to select either the RGB or YUV color matrix.



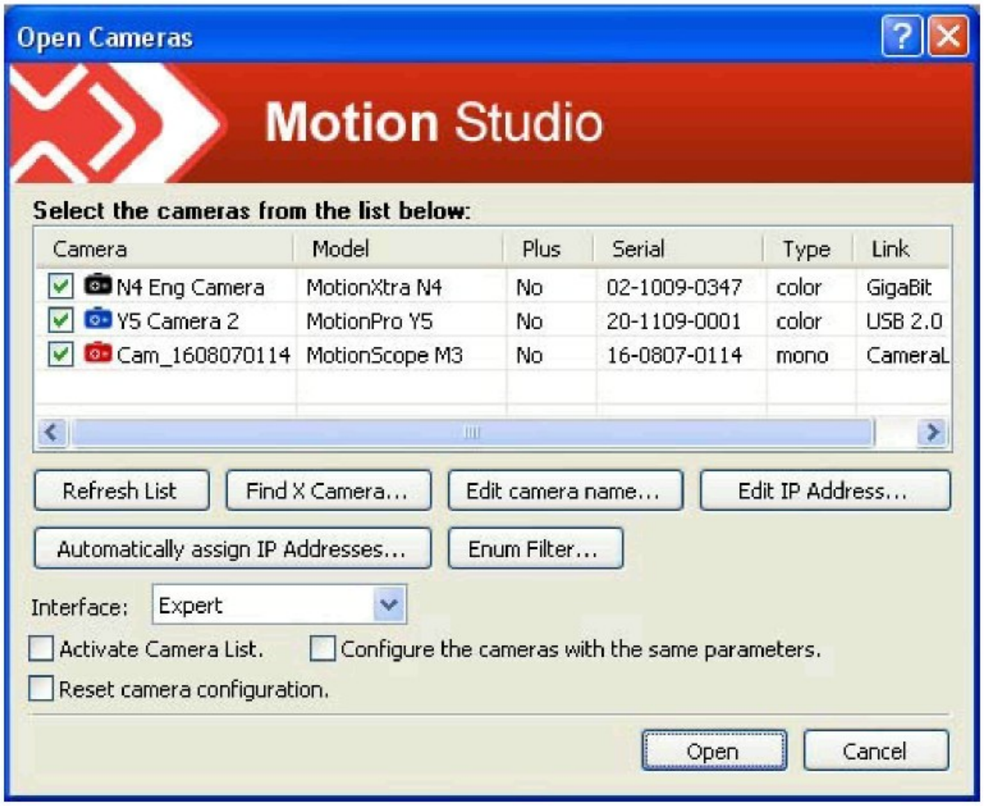
6.26.6. IRIG Calibration (X cameras)

This option is enabled only on X/HS cameras when the IRIG B-120 item is selected in the Time stamp tab of the general options. The calibration is a automatically started after each acquisition if the “Run IRIG calibration after each acquisition” option is enabled.

The IRIG precision is 1 s. The calibration procedure checks the images IRIG flags in order to find a “one second” transition. Once the transition is found, the time precision is increased according to the acquisition rate.

6.27. Multiple cameras support

Motion Studio supports multiple cameras systems.



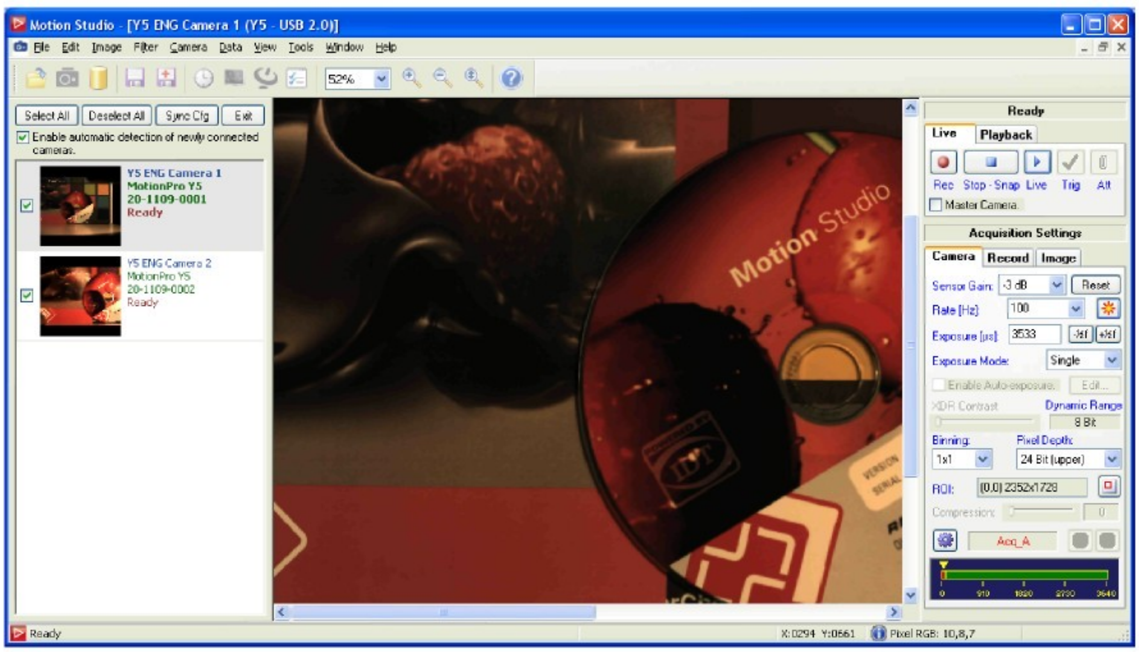
The way the camera views are shown depends on the selected options.

If none of the “Activate camera list” and “Configure the cameras with the same parameters” options is selected, the program opens a separate window for each camera. The windows are tiled and each camera can operate independently from each other. Each camera may have different parameters from other cameras. The cameras may be also configured as master/slave.

Activate camera list

If this option is selected, the program opens a vertical “camera list” bar. From this bar the user may:

- **Select a camera**: do a single click on the camera thumbnail to activate it. Do a double click to activate the camera and start Live.
- **Select a subset of the cameras**: check the check boxes at the left side of the camera thumbnail and operate the camera control bar. Click “Select All” to select all the cameras, click “Deselect All” to deselect all the cameras.
- **Synchronize camera configurations**: click “Sync Cfg” to copy the configuration of the foreground camera to all the selected cameras.
- **See the status of the cameras**: below the camera name, model and serial number, the camera status is displayed (Ready, Live, Recording…).
- **Exit the session**: Click the Exit button to exit the session.



Configure the cameras with the same parameters

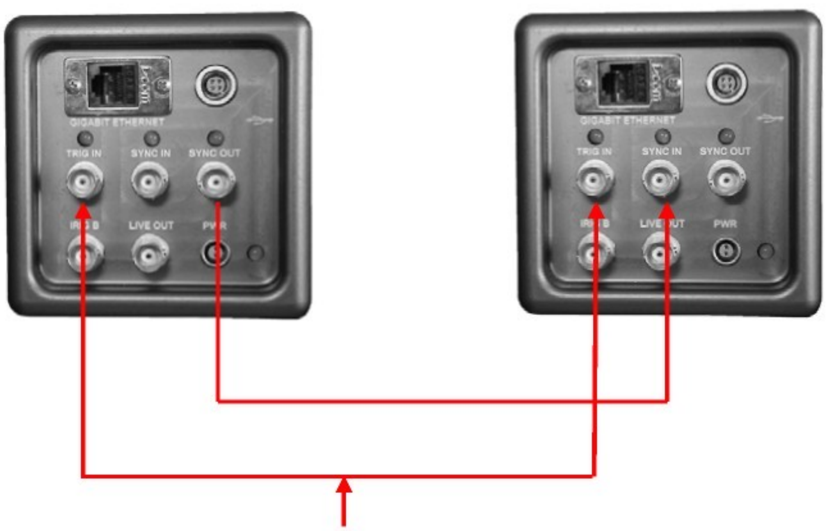
If this option is selected, the program sets the same value to most of the cameras parameters. A separate window for each camera is activated. The values that may be different are exposure, pre-trigger and post-trigger.

6.27.1. Master/Slave operation mode

In this operation mode, one of the cameras acts as the master and the others as slaves. The master camera controls itself and some of the configuration parameters of the slaves, such as record mode, acquisition rate, etc. To set one camera as master, check the "Master Camera" check box on the "Camera Control" group in the camera control bar. The check box is hidden when only one camera is connected.

The master camera drives the slaves' acquisitions via the sync out signal. The slave cameras are automatically configured to operate with external frame sync. The picture below shows how to configure a two cameras master/slave layout.

Master Camera **Slave Camera**



Trigger

Master camera "sync out" signal must be connected to slave's camera "Sync in" connector. To provide simultaneous trigger to cameras (circular and BROC mode), master camera and slave camera should receive the same trigger signal.

6.27.2. Master/Slave vs. Global Configuration

The global configuration is active when the “Configure the cameras with the same parameters” option is selected in the “Open Cameras” wizard. The table below shows the main differences between the two operating modes.

Item	Master/Slave	Global
Preview is synchronized	Yes	No
Recording is synchronized	Yes	No
Playback is synchronized	Yes	Yes
Cameras have the same parameters	No (only rate, record mode and exposure mode are equal)	Yes (only exposure time can be different)
All the images are saved once	Yes	Yes

6.28. Playback Controls

The Playback controls work like other familiar media player controls. The controls include the following:

- Directional play
- Forward or reverse
- Step forward and reverse
- Skip to first or last frame
- Stop play

6.28.1. Frame by frame review

The frame number and corresponding time from the initial frame (or from the event trigger frame, if the mode is Circular or BROC) are displayed in seconds. Use the slider bar to browse through the frames. In Circular or BROC acquisition mode when the pre-trigger and post-trigger have been selected, a red marker shows the position of Frame 0 (the trigger frame). Indexes of frames before the trigger frame display Negative and indexes of frames after the trigger display Positive.

6.28.2. Playback Speed and Playback Settings

Playback slider

Move the slider to select a frame. The red triangle indicates the position of frame 0 (circular mode only).

Loop playback button

Click on the button to continuously loop the acquisition.

Zero button

Click this button to set the frame 0 position (trigger).

Start Frame

Type the number directly into the Start Frame text box.

Stop Frame

Type the number directly into the Stop Frame text box.

Skip frames

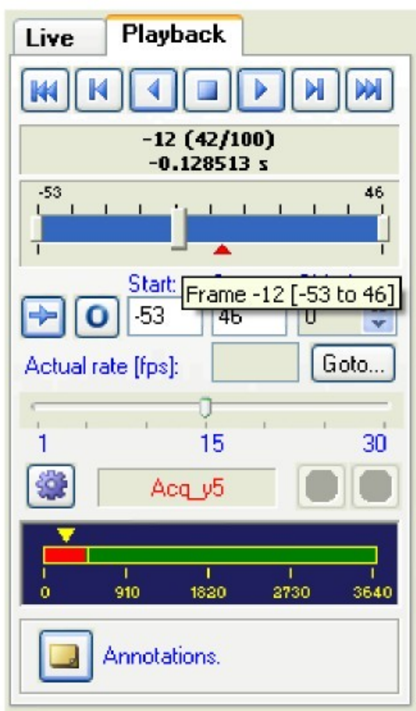
Use to skip frames during playback.

Goto Button

It opens a dialog box. Enter the image index to be displayed.

Playback rate Slider

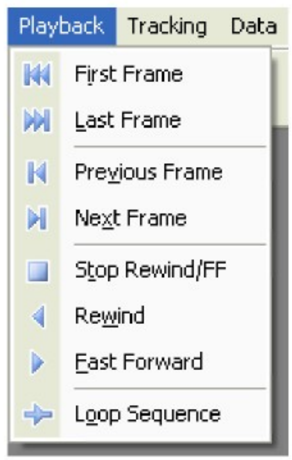
Use to adjust the speed of the playback. The actual playback rate depends on the processor speed and it is shown in box above the slider. If the actual rate is slower than the desired one, use the skip frames control to increase it.



6.29. PLAYBACK Menu

The Playback menu displays when file images are open. When the program is in Camera mode, access the Playback menu through the Camera Option on the main toolbar. Standard operations include the following:

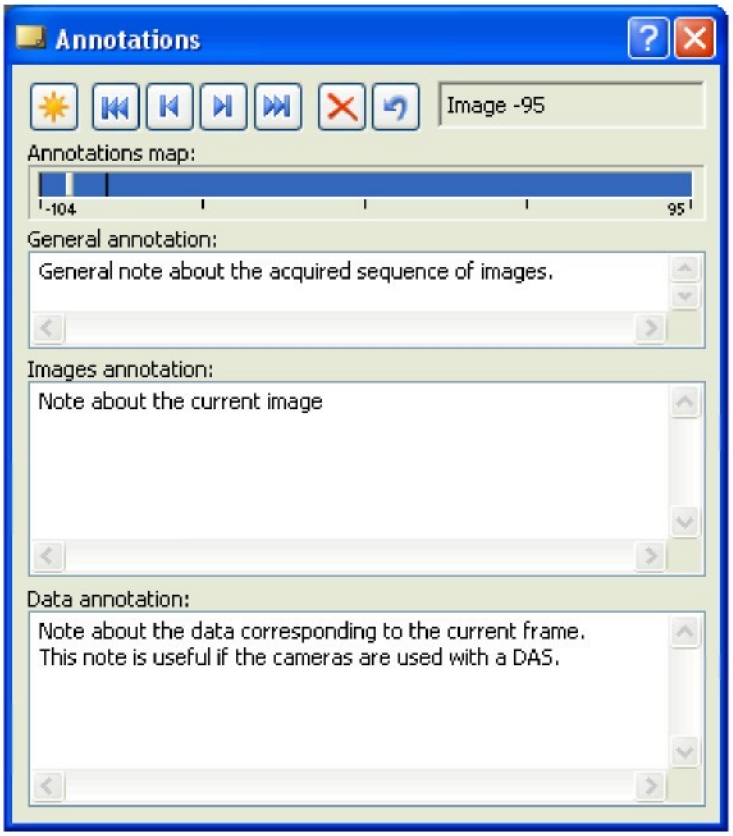
- Play Forward or Backward
- Jump to First or Last frame
- Loop Through
- Playback Speed
- Playback's Start and End frames for loop through.



The items share their functionality with the docked button bar on the right side of the application window.

6.30. Annotations

The Annotation button on the playback tab shows the annotation dialog box.



General annotation

Add a general comment to the acquired sequence.

Images annotation

A note may be added to the current image. Use the playback button to locate an image and add the note.

Data annotation

Add a note about data (for future use).

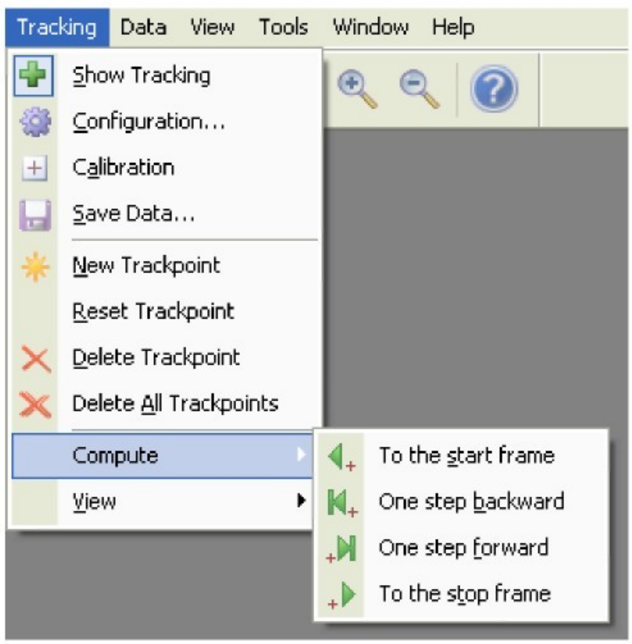
The horizontal bar shows the positions of the notes (black vertical lines) and the position of the currently displayed image (gray handle). Buttons operations include the following.

- Use the arrow controls to locate the annotations.
- Reset all the annotations.
- Delete an annotation.
- Undo the latest edit of an annotation.

6.31. TRACKING menu

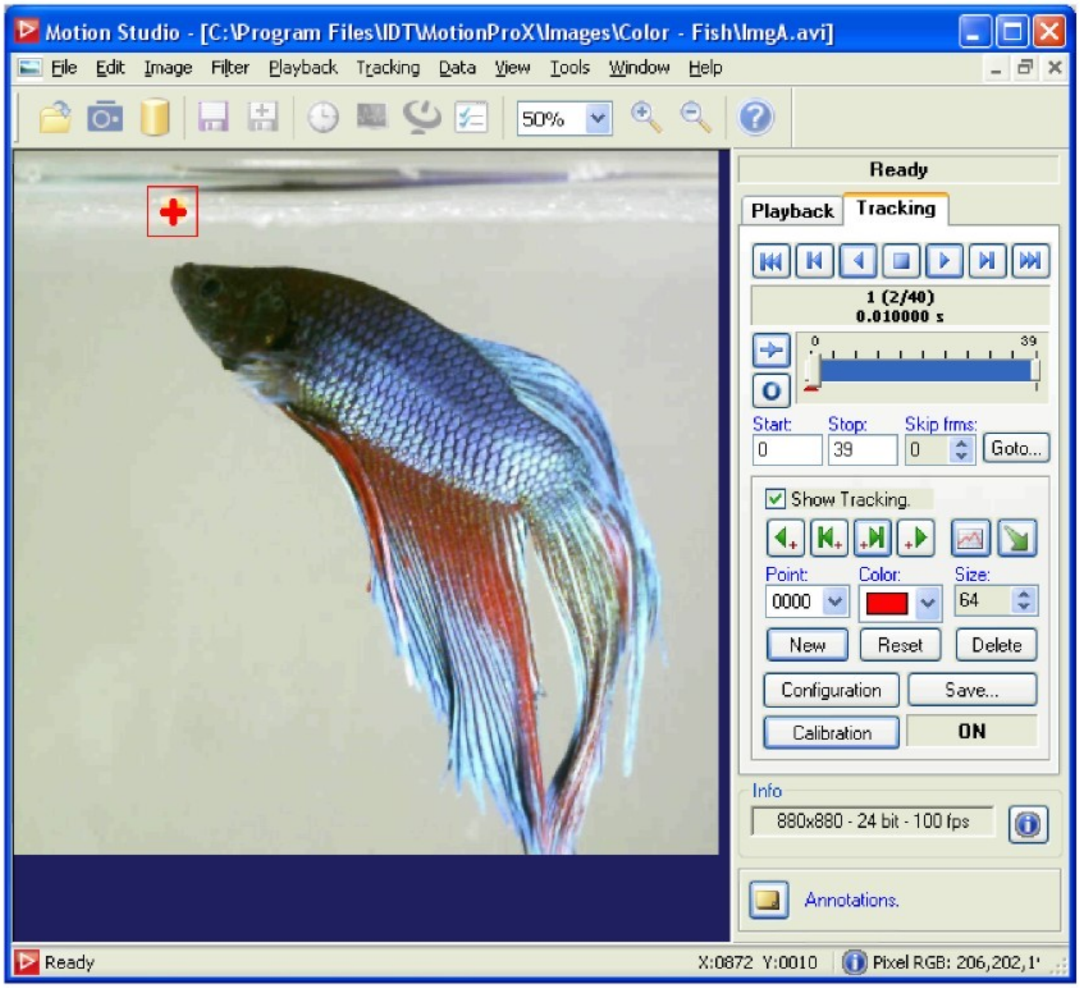
The Tracking Menu on the main toolbar offers an alternative to using the buttons and dialog box provided by the Docked Dialog menu including the following functions:

- Enable and disable tracking.
- Open the tracking configuration dialog.
- Add, remove or reset the track-points.
- Compute tracking.
- Show or hide the vectors, the table/graph dialog box and the correlation windows.

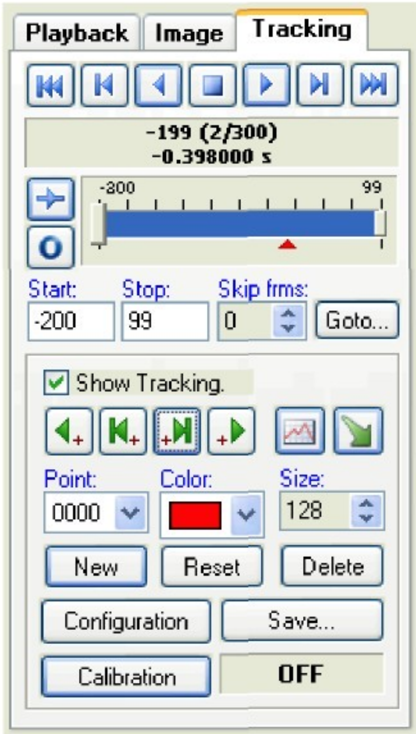


6.32. Tracking control

The tracking control tab appears on the main dialog bar if the "Tracking" option is enabled in the General Options ("Enable Motion tracking" in the Miscellaneous Tab).



Use the tracking tab to enable and configure the tracking points. The options are as follows:



Show tracking: enables or disables the display of the tracking point and trajectory. If this option is unchecked no tracking can be computed.

Track computation buttons: click the track buttons to compute tracking one step forward or backward, to the start frame or to the stop frame.

Table/Graph: shows or hides the table graph window.

Vectors: shows or hides the trajectory vectors.

Point: select the track point to configure

Color: the track point color

Size: the correlation area size in pixels. The area is a square.

New: click the button to add a new track-point.

Reset: click the button to reset all the computed positions.

Delete: click this button to delete the current track point.

Tracking Configuration: click this button to open the configuration dialog box.

Save: click this button to save the tracking results in ASCII, LabVIEW, Tecplot or Excel format.

Calibration: opens and closes the tracking calibration dialog box.

6.33. Tracking procedure

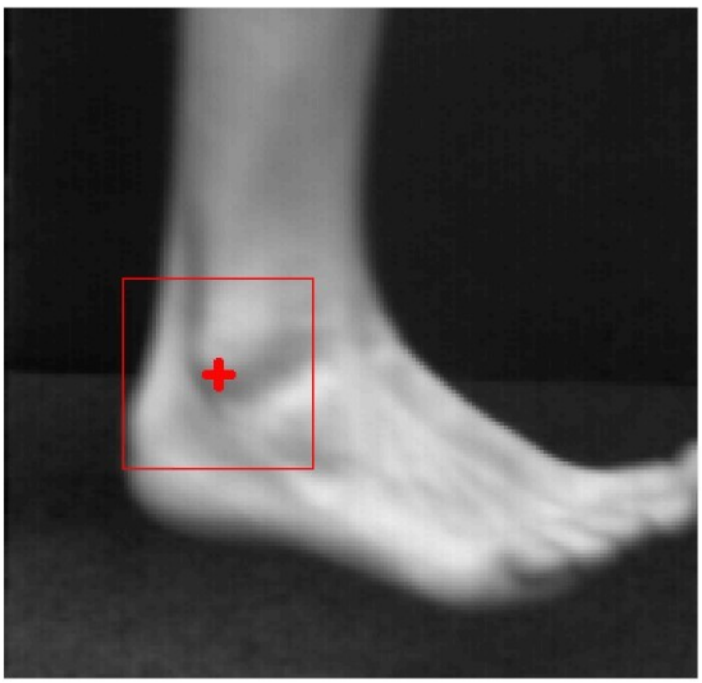
6.33.1. Add a new track-point and compute

To add a new track-point, follow the steps below:

1. Click the New button on the tracking tab. The cursor will change into an arrow with a plus symbol.

2. Move the cursor to the image and click on the position where the track-point needs to be added. The cursor will change to the standard arrow.

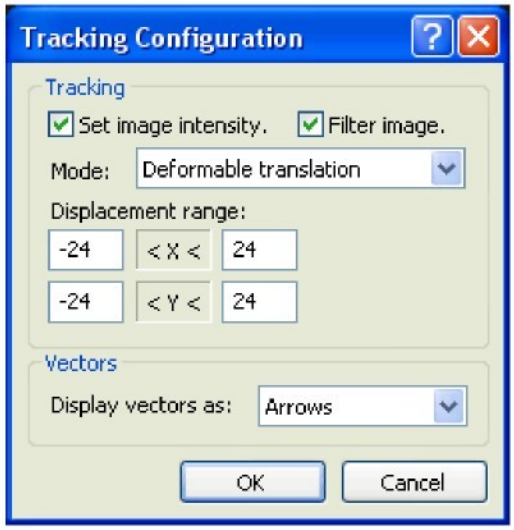
3. The track-point position may be changed by dragging the central cross (see below).



4. Then the point trajectory may be computed by clicking the green arrow buttons on the tracking bar.

6.33.2. Edit the tracking configuration

Click the "Trk Config" button on the tracking bar or select the "Configuration" item from the tracking menu. The options are as follows.



Set Image intensity: when a new track-point is added the program computes the intensity range on the current image. The current image will be considered as a reference image for the computations. If the option is disabled, no intensity is computed.

Filter image: before each computation a set of sharpening filters is applied to the images. The filters reduce the effect of the background on the computation. If the option is disabled no filter is applied before the computations.

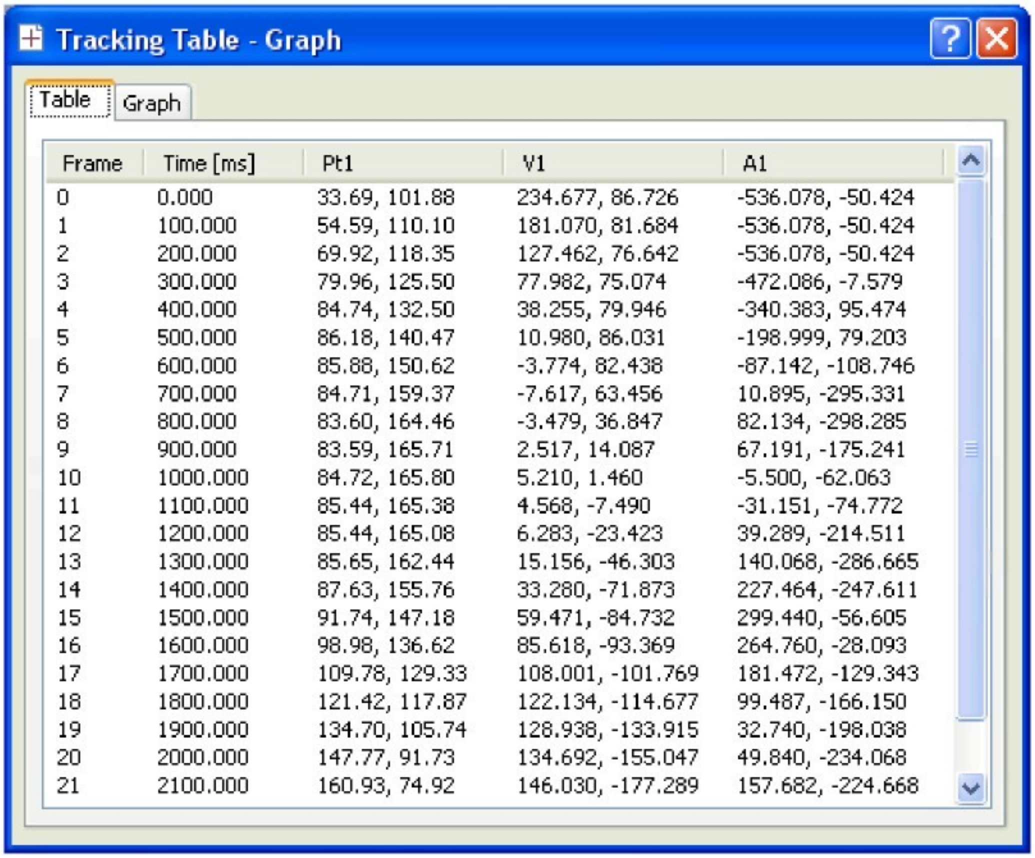
Mode: the tracking algorithm can be adapted to different tracking conditions (deformable translation, rigid translation and rigid translation with rotation).

Displacement range: the displacement from one point to the next may have a limited range. Enter the values to avoid errors.

Display vectors: the track-point trajectory may be displayed as a sequence of arrows, a continuous line or a dotted line. The trajectory is shown is the "Vectors" button in the tracking bar is selected.

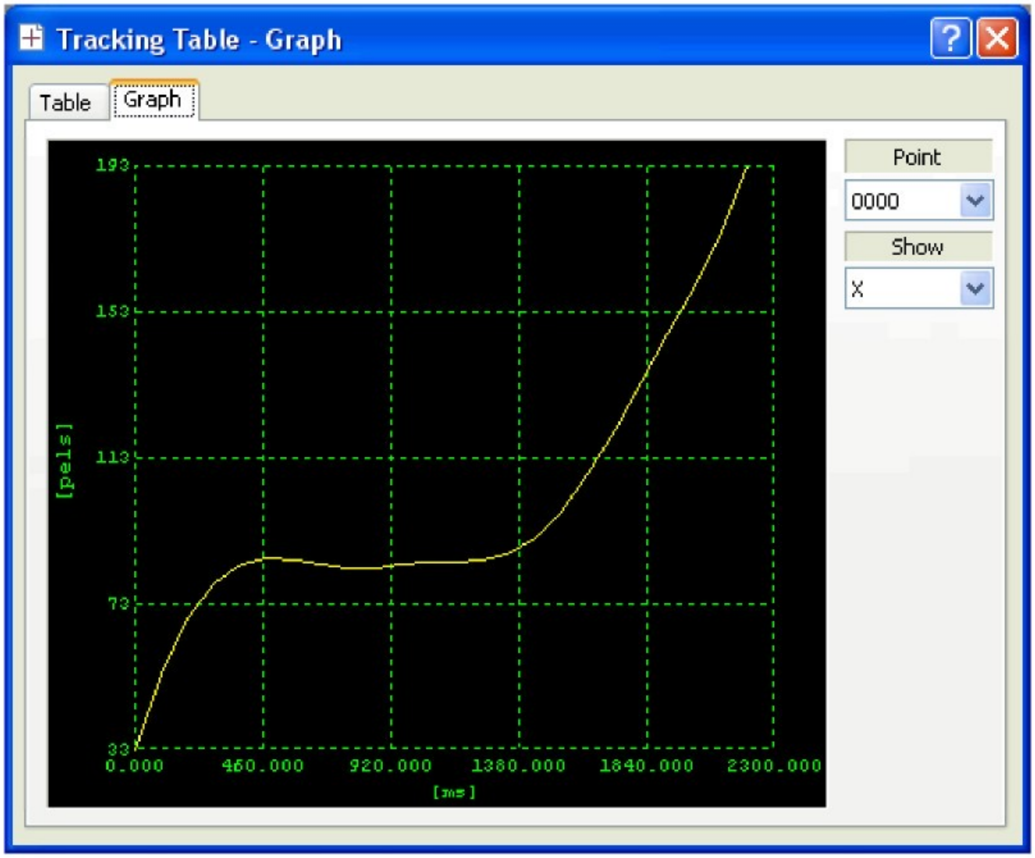
6.33.3. Show the tracking data and the vectors

From the tracking bar, click the Table/Graph button. The same dialog box shows the table with the computed values and the graphs.



Frame	Time [ms]	Pt1	V1	A1
0	0.000	33.69, 101.88	234.677, 86.726	-536.078, -50.424
1	100.000	54.59, 110.10	181.070, 81.684	-536.078, -50.424
2	200.000	69.92, 118.35	127.462, 76.642	-536.078, -50.424
3	300.000	79.96, 125.50	77.982, 75.074	-472.086, -7.579
4	400.000	84.74, 132.50	38.255, 79.946	-340.383, 95.474
5	500.000	86.18, 140.47	10.980, 86.031	-198.999, 79.203
6	600.000	85.88, 150.62	-3.774, 82.438	-87.142, -108.746
7	700.000	84.71, 159.37	-7.617, 63.456	10.895, -295.331
8	800.000	83.60, 164.46	-3.479, 36.847	82.134, -298.285
9	900.000	83.59, 165.71	2.517, 14.087	67.191, -175.241
10	1000.000	84.72, 165.80	5.210, 1.460	-5.500, -62.063
11	1100.000	85.44, 165.38	4.568, -7.490	-31.151, -74.772
12	1200.000	85.44, 165.08	6.283, -23.423	39.289, -214.511
13	1300.000	85.65, 162.44	15.156, -46.303	140.068, -286.665
14	1400.000	87.63, 155.76	33.280, -71.873	227.464, -247.611
15	1500.000	91.74, 147.18	59.471, -84.732	299.440, -56.605
16	1600.000	98.98, 136.62	85.618, -93.369	264.760, -28.093
17	1700.000	109.78, 129.33	108.001, -101.769	181.472, -129.343
18	1800.000	121.42, 117.87	122.134, -114.677	99.487, -166.150
19	1900.000	134.70, 105.74	128.938, -133.915	32.740, -198.038
20	2000.000	147.77, 91.73	134.692, -155.047	49.840, -234.068
21	2100.000	160.93, 74.92	146.030, -177.289	157.682, -224.668

The first column lists the frame number, the second lists the time. Then for each point there are listed the position (in pixels or mm if the calibration is on), the speed and the acceleration.

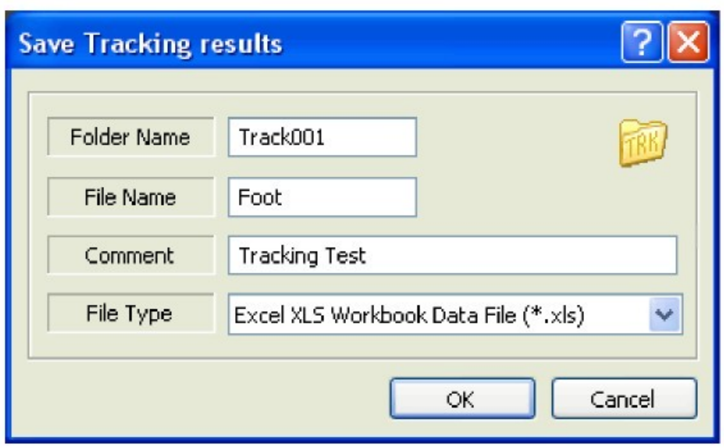


Each component of the data can be separately displayed in a graph. The “Point” combo-box lists the configured points, and the “Show” combo-box lists the components (X, Y, Vx, Vy, Ax, and Ay).

6.33.4. Save the tracking data

The tracking results are always saved in a default binary file and reloaded when the image sequence is open again. The user may save the data in a different format:

1. From the tracking bar, click the “Save…” button.
2. Enter the folder name, the file name and a comment (optional).
3. Select the file format:
   - Binary file (**BIN**).
   - ASCII text file (**ASC**).
   - Tecplot Text file (**PLT**).
   - LabVIEW Measurement file (**LVM**).
   - Excel XML Spreadsheet file (**XML**).
   - Excel XLS Workbook file (**XLS**).
4. Click the OK button.



6.33.5. Calibration

The tracking displacements are computed in pixels and can be converted into mm through a calibration.

Click the calibration button on the tracking tab to open the calibration window.

On/Off: when a calibration is loaded the button allows activating/deactivating the calibration.

Model: select the calibration model (basic, simplified, generic)

Calibrate: click this button to start the calibration.

Save image: click this button to save the current frame as a calibration image and create a new calibration folder.

Browse: click this button to browse for a calibration image and import it in the current acquisition.

Discard: when a calibration is loaded, it may also be discarded.

Show/Hide Image: toggle this button to show or hide the current calibration image.

The calibration procedure may be divided into two steps:

1. Save a calibration image and create a new calibration folder or browse the database and import a calibration image from existing folders.

2. Select the calibration model and calibrate.

6.33.6. Save the calibration image

Select the image from your sequence or snap it from the camera window.

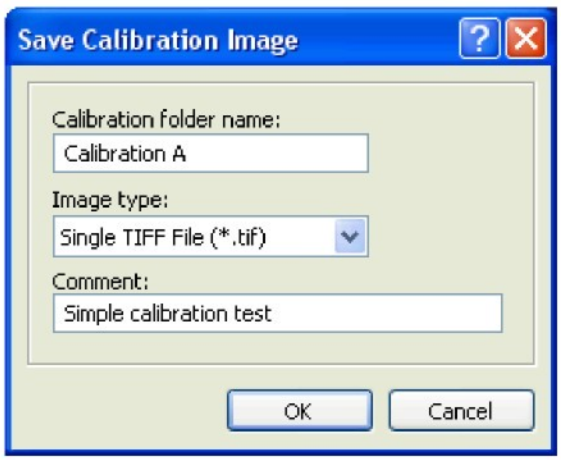
Click the “Save calibration image” button from the calibration configuration window.

Enter the calibration folder name.

Select the calibration file type (TIFF, Bitmap or PNG).

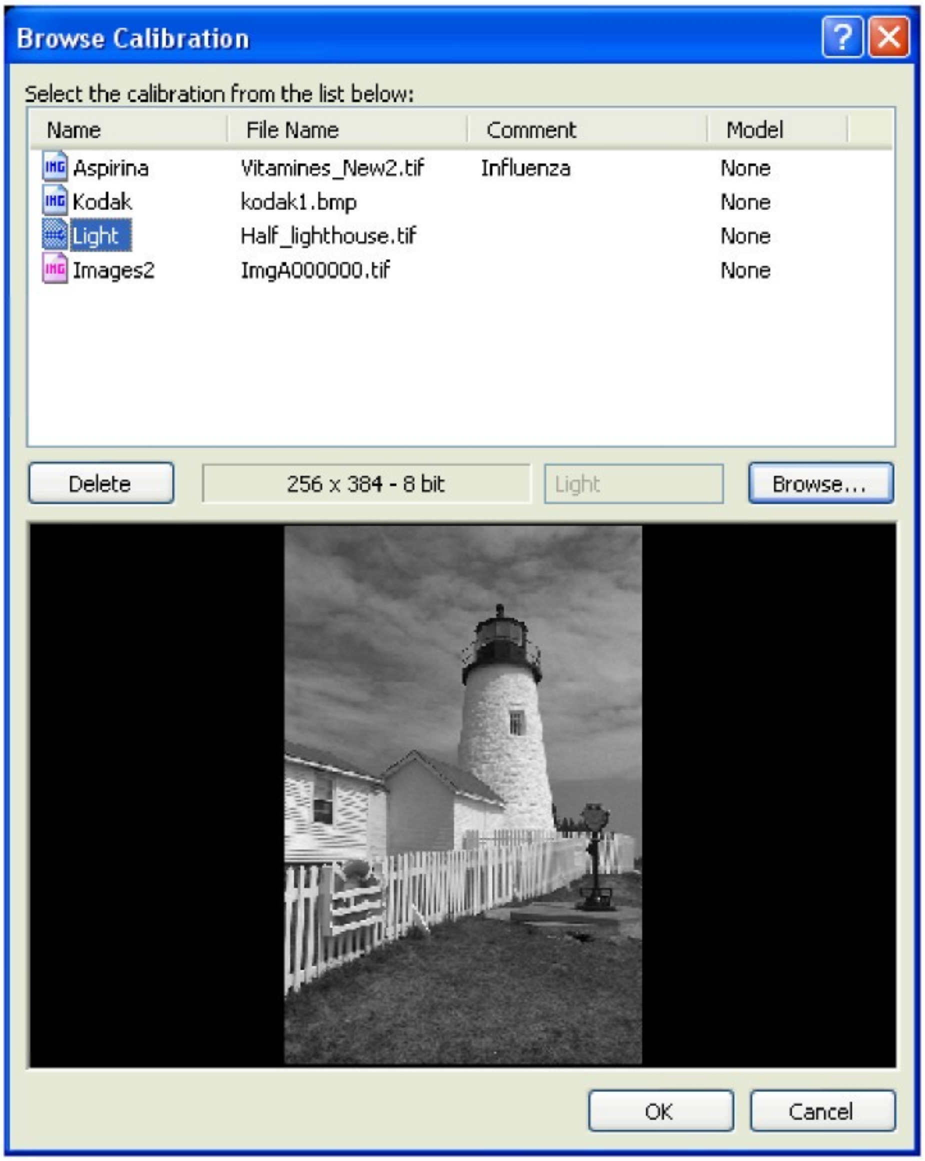
Enter a comment (optional).

Click OK to save the calibration image.



6.33.7. Browse the database for a calibration image

1. Click the "Browse…" button from the calibration configuration window.
2. Select a calibration image form the list.
3. Click OK to import the calibration image and the settings, if any.
4. Click the Browse… button to import a calibration image and/or settings from a directory external to the database. The image will be listed with a pink icon and the name will be editable.

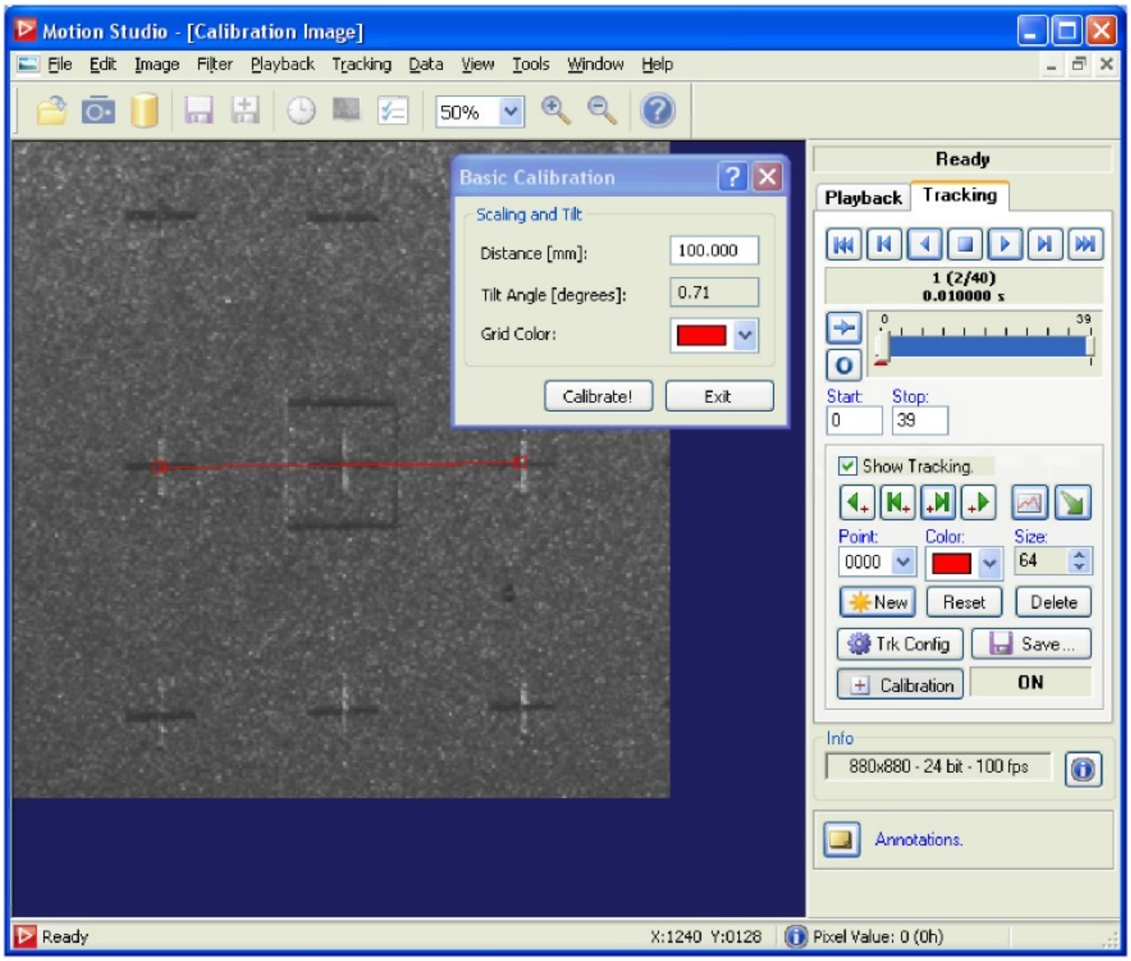


6.33.8. Calibrate

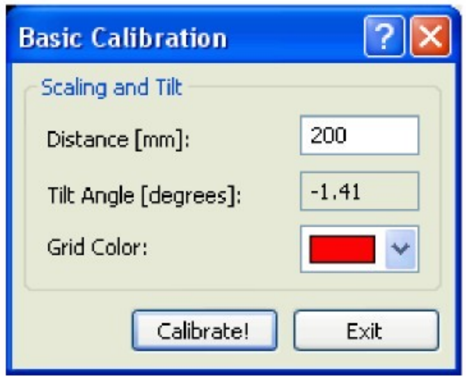
Three calibration models are available: basic, simplified and generic.

6.33.8.1. Basic model

The basic model is the simplest. The user is asked to drag a line on the calibration target and enter a distance in mm.

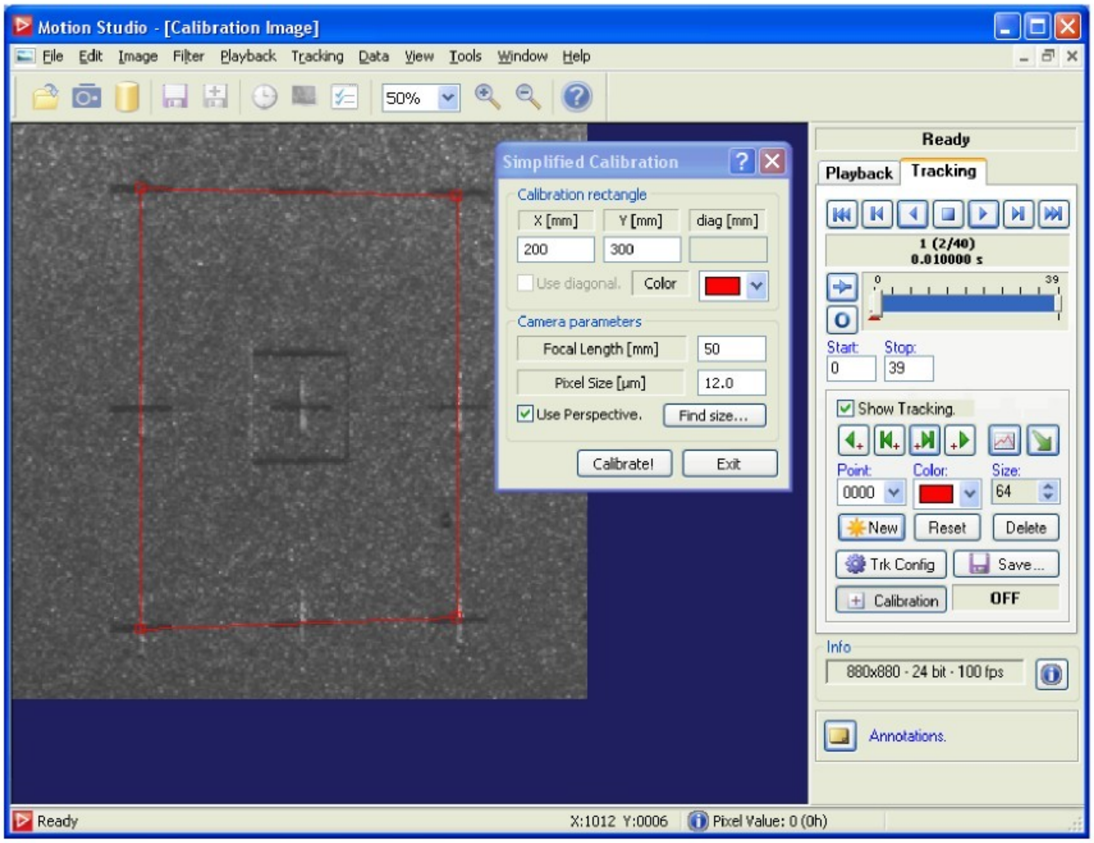


The calibration grid has two handles. The handles may be dragged over two reference points on the calibration image.


Basic Calibration
Scaling and Tilt
Distance [mm]:
200
Tilt Angle [degrees]:
-1.41
Grid Color:
Calibrate!
Exit

6.33.8.2. Simplified model

This method requires that the calibration target is vertically aligned with the camera, i.e. vertical lines in the target correspond to vertical lines on the target image. The rectangular grid has four handles that may be dragged over four reference points of the calibration image.

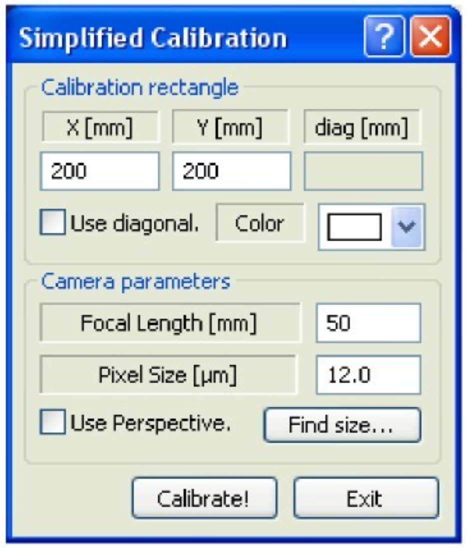


To achieve more precision the zoom factor may be set to 300 or 400 and the handles may be positioned upon the calibration target marks.

With the simplified calibration two options are available:

1. The camera plane is parallel to the target plane and there is no perspective: the calibration is just a way to find a constant value that will be multiplied by the pixel displacements to find the space displacements. Both horizontal and vertical lines of the calibration target are perfectly parallel to the rectangle sides. In the Calibration dialog box, the “Use Perspective” option is OFF, and the rectangle sides are parallel.

2. The camera plane is not parallel to the target plane and there is a perspective effect. The effect is computed only on horizontal lines while vertical line must be parallel to the rectangle vertical sides. In the Calibration dialog box, the “Use Perspective” option is ON.



X/Y Dimensions: the user enters the dimensions in mm of the rectangle. The distance between the points of the calibration target is known. The values are in mm (1 inch = 25.4 mm).

Focal Length: the camera focal length in mm.

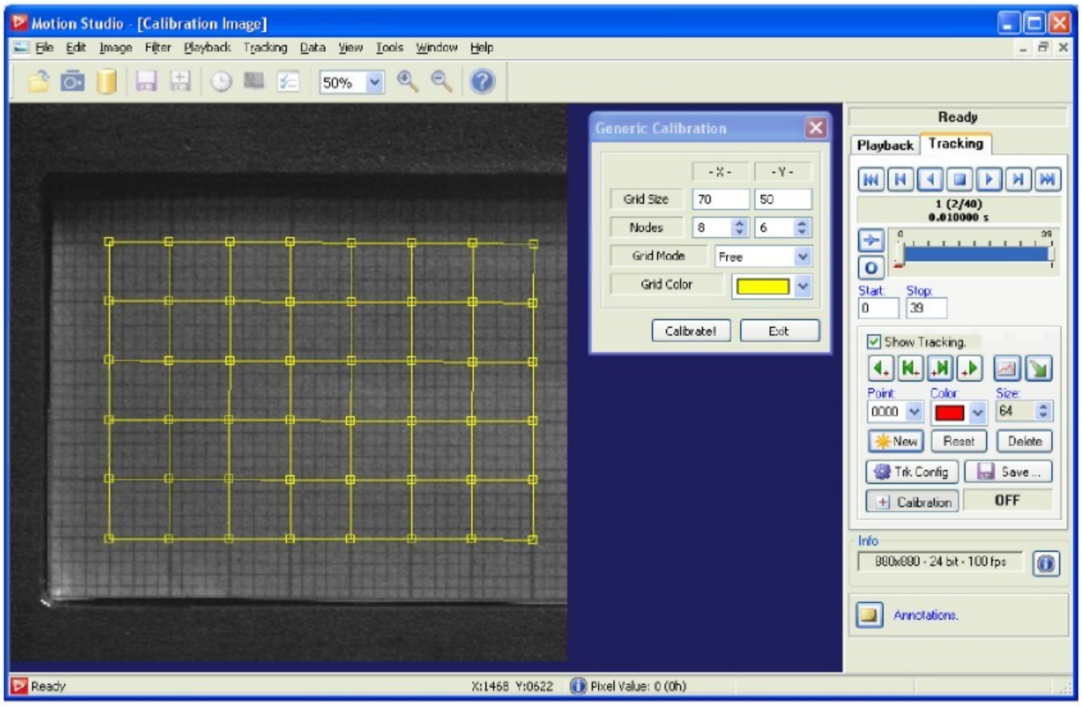
Diagonal: when the “Use perspective” option is off, the user may check the “Use diagonal” check box and enter the rectangle diagonal length instead of Width and height.

Grid Color: the color of the calibration grid may be changed.

Pixel size: the user may edit the pixel size. Click “Find size…” to select the camera model and find the correct size.

6.33.8.3. Generic Model

The generic calibration considers different kind of distortion due to optical and/or perspective issues. The calibration grid is more complex than a rectangle, is a multi-point grid (see below). The points of the grid will be positioned over the marks of the calibration target. Then the program computes the parameters of a third grade polynomial which maps the points of the image (pixels) into the points of the real space (mm).

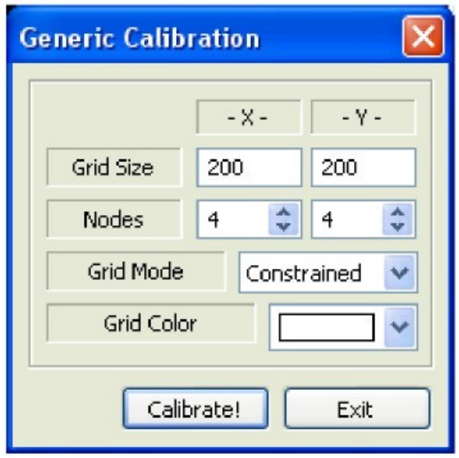


The grid may be moved and resized. The way the grid is resized is controlled by the "**Grid Mode**" in the calibration dialog:

Zoom: in this mode the handles are positioned over the four external corners of the grid. The grid may be zoomed or moved.

Constrained: in this mode the handles are positioned over the four external corners of the grid. The grid can be distorted.

Free: in this mode each point of the grid has its own handle and can be moved independently.



Once the grid handles are in the correct position, the user enters some parameters, and then clicks “Calibrate!”.

Grid Size (X/Y): the user enters the dimensions in mm of the grid (distance between the grid corners). The distance between the points of the calibration target is known. The values are in mm (1 inch = 25.4 mm).

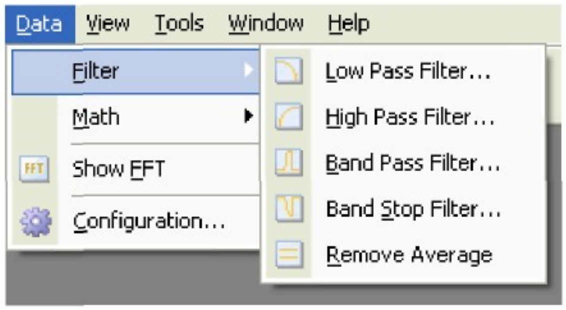
Grid Nodes (X/Y): the user enters the number of nodes in the grid. The minimum is 4, while the maximum is 20. The number of nodes depends on the calibration target.

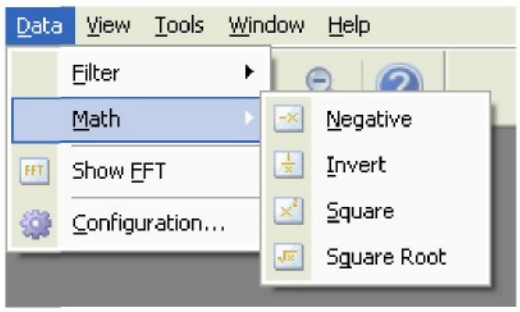
Grid Mode: see above.

6.34. DATA menu

When acquired data pane is visible and some data is displayed the DATA menu is active.

Use the Data menu to apply filters and mathematical operators, to show or hide the FFT/Power Spectrum window and to open the data graph configuration dialog box.

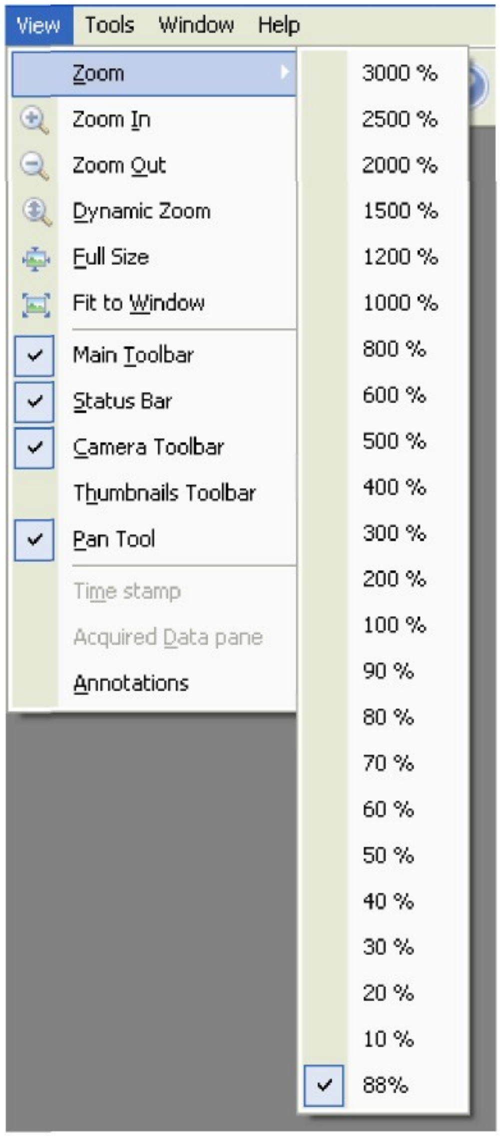




6.35. VIEW menu

Use the View menu to magnify the image, restore the original size (100% zoom) or compute a zoom factor that fits in the window.

Use the View menu to select the toolbar options.



6.35.1. Zoom Tools

The **Zoom In** and **Zoom Out** tools let you change the image magnification.

The **Dynamic Zoom** tool lets you zoom in or our by dragging the mouse or mouse wheel up or down.

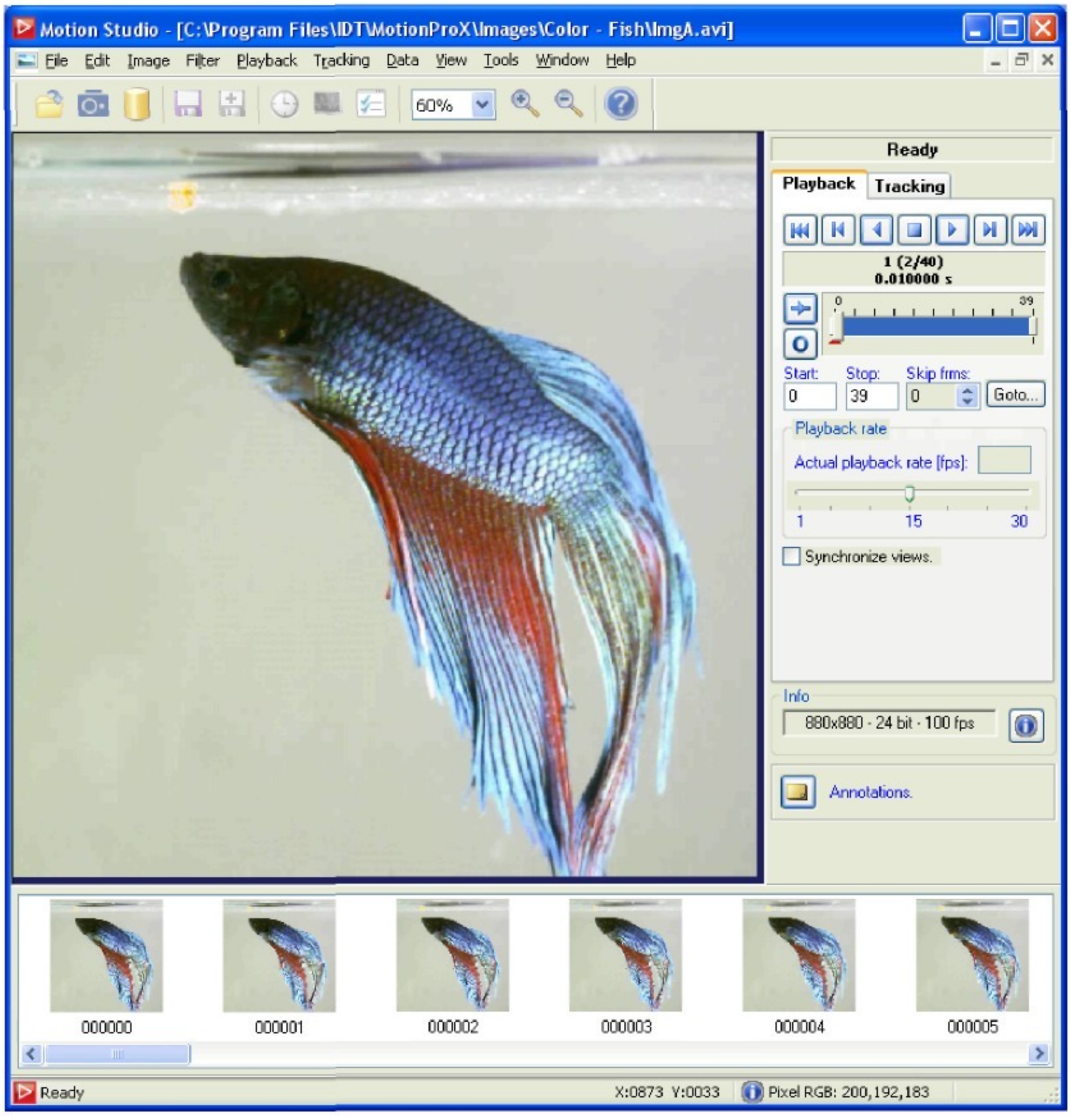
To Increase or decrease magnification, do one of the following:

- Select a magnification percentage from the toolbar Zoom menu.
- From the View menu, select the Zoom In or the Zoom Out tool, and then click the image. To zoom in on a specific area, use the Zoom In tool and draw a rectangle.
- From the View menu, select the Dynamic Zoom tool and then drag up to zoom in to the area where you begin dragging, or drag down to zoom out from that location.

To deselect one of the Zoom tools, press the ESC key on the keyboard.

6.35.2. View Thumbnails

1. Select View menu > Thumbnails Toolbar. Once an image sequence is opened or acquired, the Thumbnail Toolbar is populated with images.
2. Use the arrow buttons on the Playback Control tab to scroll through the images.
3. Click on a Thumbnail in the sequence to select a frame for display. The selected image is highlighted in the sequence.



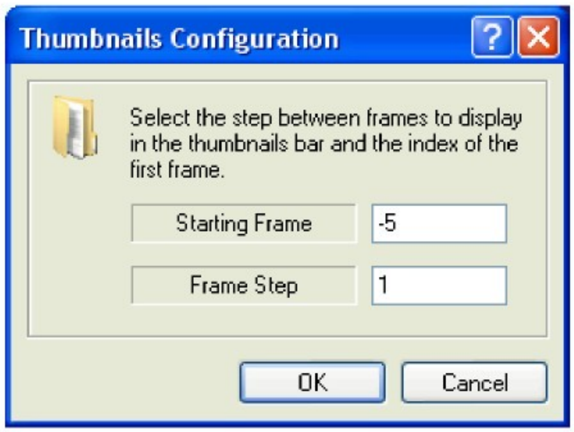
6.35.3. Configure the Thumbnail Parameter

1. From the main toolbar, select Image > Thumbnails Cfg… to configure the thumbnail viewing parameters.

2. Type the number of the start frame in the Start Frame text box.

3. Type a number of frames to skip in the Frame Step text box.

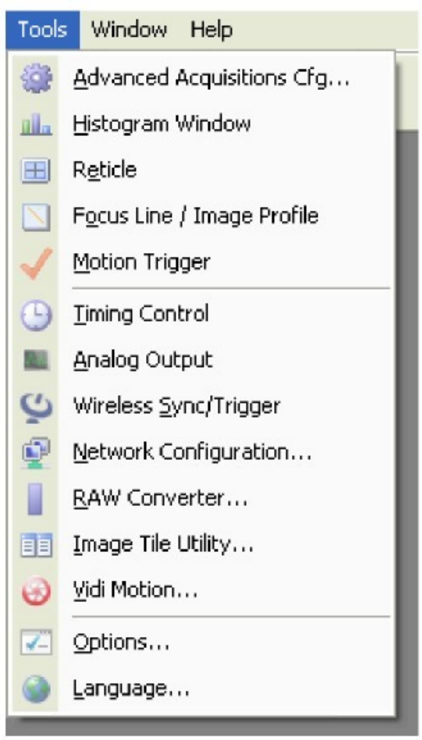
4. For example, if you select Frame Step 2 and Start Frame 2, the thumbnails will have the index 2, 4, 6, 8.



6.36. TOOLS menu

The Tools menu has the General Options for the program and the Timing Hub control dialog. If a Camera window is open, the Tools menu contains the following options:

- Advanced Acquisition Configuration dialog box (see Advanced Acquisitions Cfg on the Record tab).
- Histogram window.
- Focus Line tool for help focusing the image.
- Motion Trigger configuration.
- Timing Control for the generation of timing signals with the MotionPro Timing Hub.
- Analog output for the generation of analog waveforms with the MotionPro Data Acquisition System (DAS).
- Wireless Sync/Trigger for the use of Galileo™ Wireless System.
- Giga-Ethernet cameras network configuration.
- Raw Image converter.
- Vidi Motion (Lens Calculator).
- Image tile utility.
- Options dialog box.
- Language selection.



6.36.1. Options

The General Options provide the option defaults for the program.

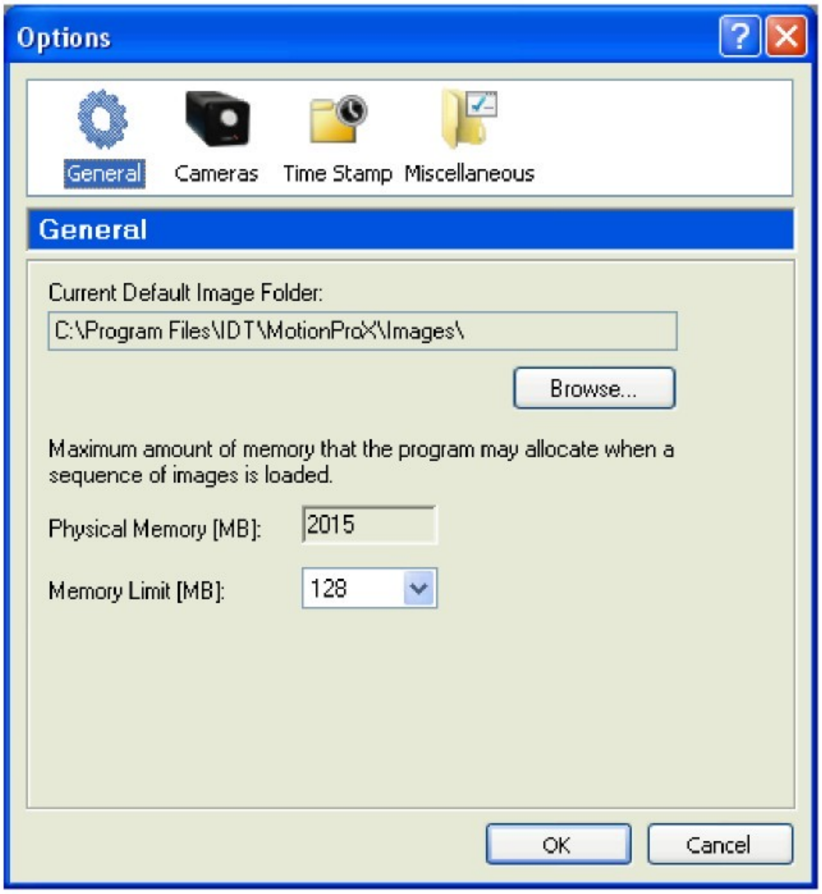
Select Tools from the main toolbar > General options.

Image Folder

It shows the directory where the images will be stored after each acquisition. Click the Browse button to change this setting.

Memory Limit

Sets the maximum amount of memory the program allocates when opening a saved sequence.



6.36.2. Camera Options

Enable double exposure

Select single or double exposure.

Live While Record

During a recording session the preview can be enabled on all cameras, fully disabled or activated only on the camera window that has the focus.

Trigger Hot Key

The software trigger can be sent to the cameras by clicking the Trigger button on the camera toolbar or by pressing a keyboard key. The user can configure that key.

Get raw gray data from color cameras

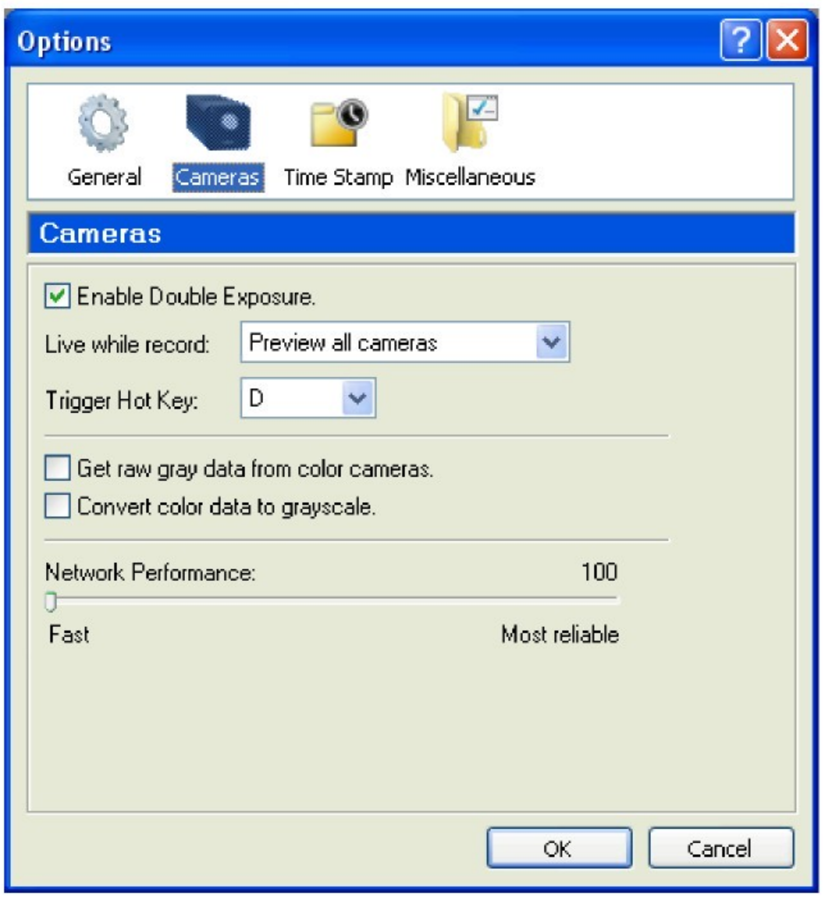
Grayscale images coming from the sensor are not converted into RGB format. The frames are acquired and displayed as black and white images.

Convert color data to grayscale

Converts color RGB images into 8-bit grayscale images.

Network performance

The network performance is a delay added to the data exchange between the cameras and the computer. If there is traffic on your local network, then move the slider to “More reliable” to avoid loss of data during the communication.



6.36.3. Time Stamp Options

To display frame information directly on the images, check the corresponding boxes:

Comment

The acquisition comment.

Date

The acquisition date.

Marker

Display the frame marker.

Time

The acquisition time (or current time during live).

Frame Number

The frame index.

Rate and Exposure

The values of rate and exposure during the acquisition.

IRIG

IRIG information in B-120 format (date, time, CF and SBS).

Acquired data value

The data acquired with the Data Acquisition module.

Time from acquisition start

If the record mode is BROC it shows the time elapsed from the start of acquisition.

File Name

The name of the file where the image is stored.

Temperature and units

The camera board temperature and the units (degrees Celsius or Fahrenheit).

Time from trigger and precision

The elapsed time from the trigger frame. The number of digits is configurable. You may either display in seconds with up to 6 decimal digits or in milliseconds with up to 3 decimal digits.

Add Logo

A bitmap can be displayed on the acquired frames and saved to the image files. Click the browse button to locate a TIFF, BMP or PNG file.

Run IRIG Calibration

When this option is selected, the program automatically starts an IRIG calibration after each acquisition.

Add vertical offset...

If this option is selected the time stamp is not printed on the image, but on a horizontal black stripe set above or below the image. The stripe is saved on the images when the frames are saved.

Font

Select the font for the time stamp.

Position

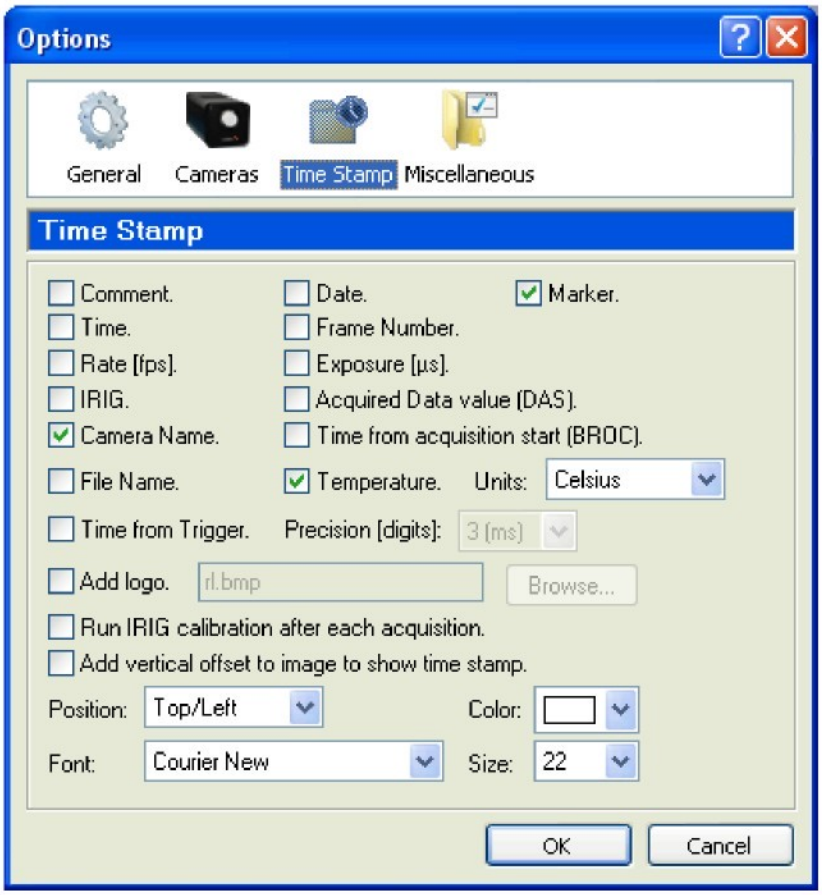
Select the display position Top/left (default), top/right, bottom/left or bottom/right.

Color

Select the time stamp color. If the image is monochrome, the color will be converted into grayscale when the images will be saved.

Size

Select the font size.



6.36.4. Miscellaneous Options

Show Main Menu dialog at start-up

It displays the main menu dialog box when Motion Studio is initialized.

Prompt before closing camera windows

The program will prompt the user before closing any camera window.

Show cameras enumeration filter at start-up

If the option is checked the camera enumeration filter dialog is displayed when the camera wizard is started.

Check Calibration file at start up

If this option is selected the program checks the calibration file when the camera is open. If the camera does not have a calibration file, the option may be unchecked.

Enable motion tracking

This option enables and disables the motion tracking.

Save Tracking data with IRIG time

If this option is selected, the tracking data is saved with the IRIG time information.

Enable Camera Diagnostic Trace

It logs each camera operation in a text file in the program directory for diagnostic purposes.

Enable Remote Diagnostic Trace

It logs the communication between the cameras and the client Palm when the remote connection server is active.

Enable Remote Connection server

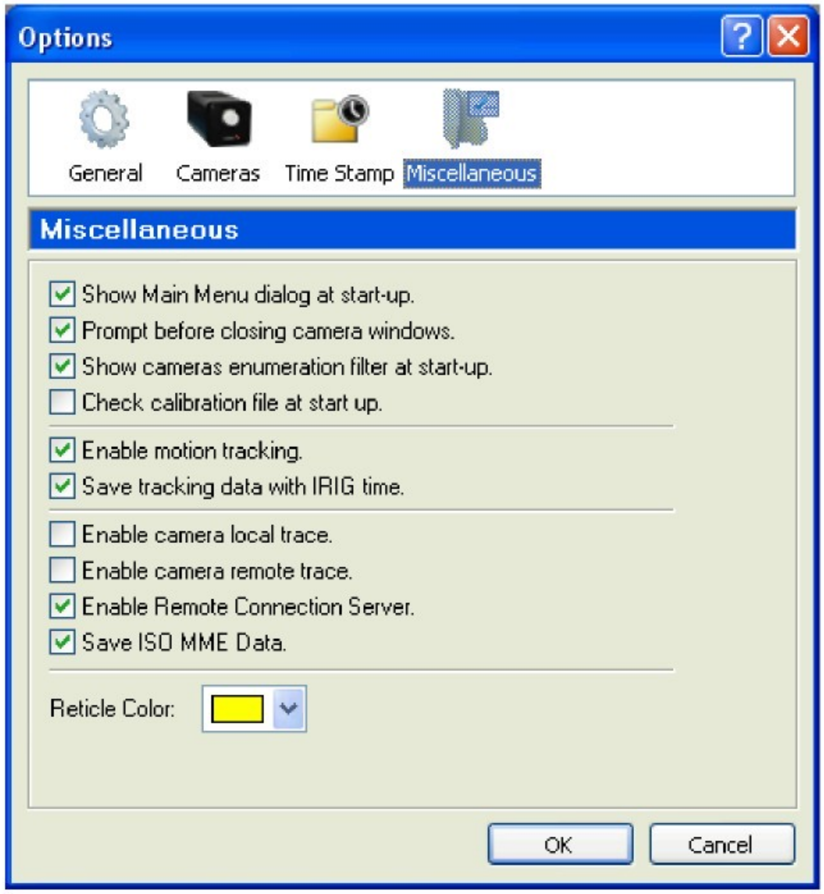
If this option is selected the remote connection server may be started and the camera may be remotely controlled by a Pocket PC via the wireless LAN. For more info, see the "Motion Studio Remote Control" paragraph.

Save ISO MME data

ISO MME data is generated and saved in the acquisition folder. The files are _config.mii and _config.mme.

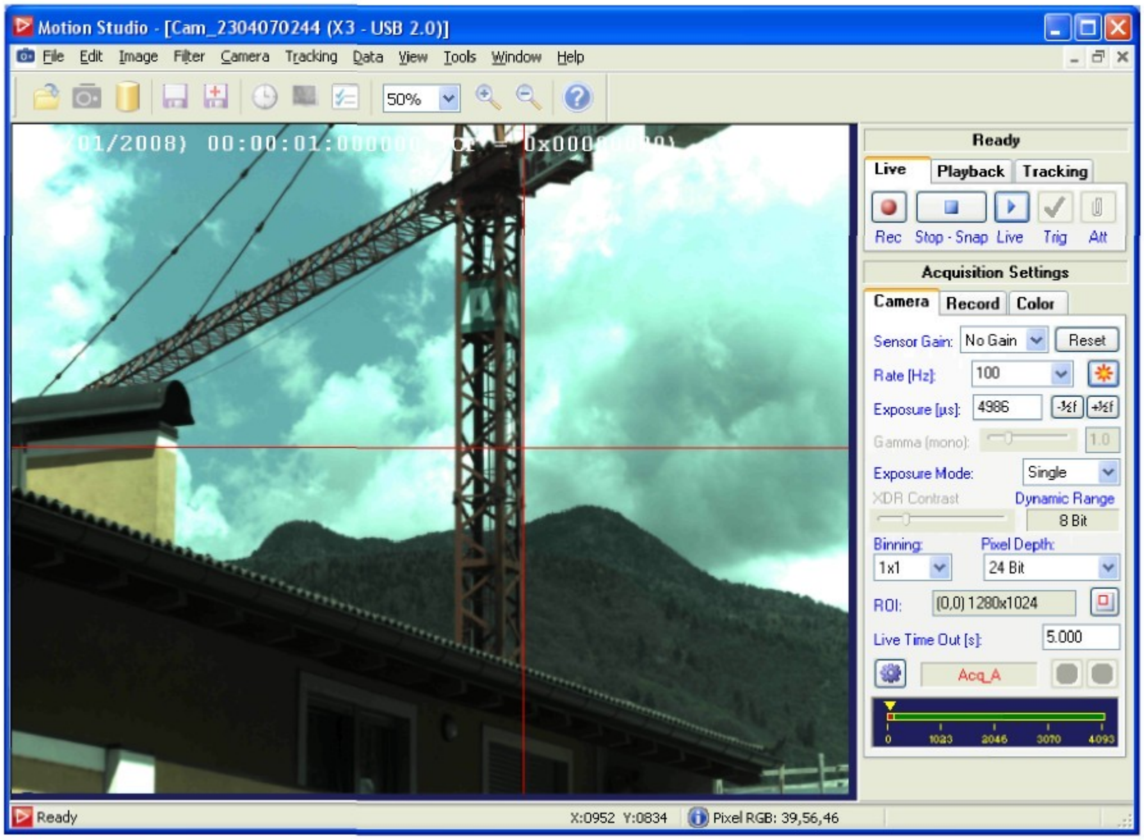
Reticle Color

Select the color of the reticle in the tools.


Options
General
Cameras
Time Stamp
Miscellaneous
Miscellaneous
Show Main Menu dialog at start-up.
Prompt before closing camera windows.
Show cameras enumeration filter at start-up.
Check calibration file at start up.
Enable motion tracking.
Save tracking data with IRIG time.
Enable camera local trace.
Enable camera remote trace.
Enable Remote Connection Server.
Save ISO MME Data.
Reticle Color:
OK
Cancel

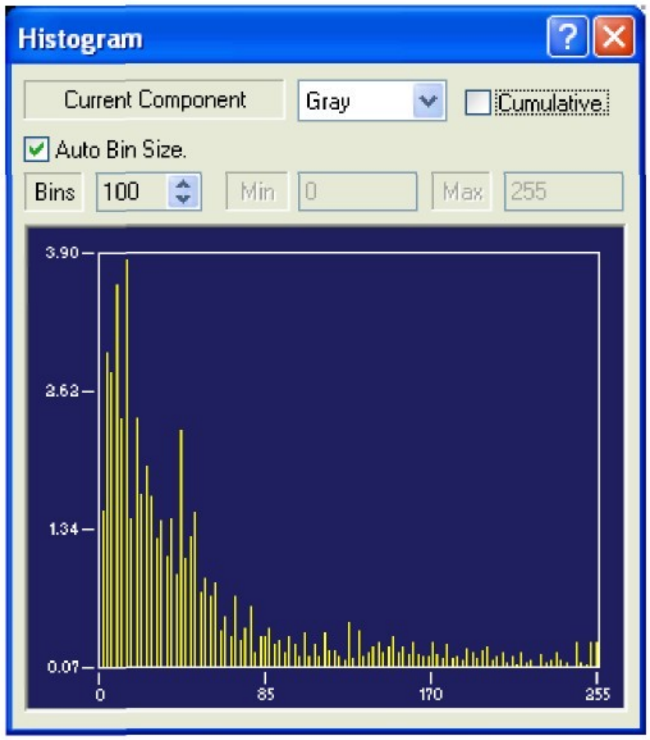
6.36.5. Reticle

The reticle is a pair of crossed lines drawn over the image. It may be used to vertically or horizontally align the camera. The color of the cross may be edited in the general options. To move the cross just click on the image.



6.36.6. Histogram

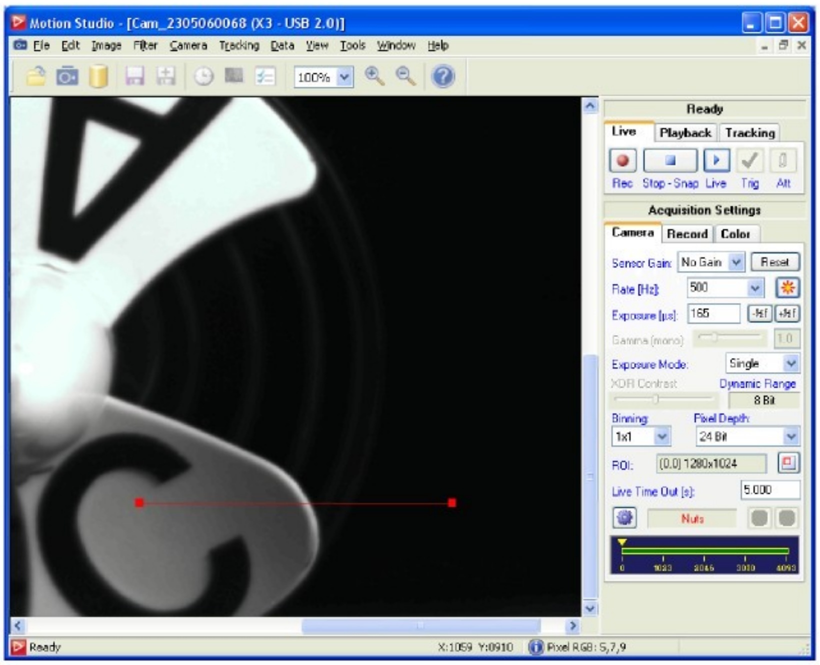
The image intensity Histogram is used to set the camera exposure parameters and with the camera focusing to optimize the dynamic range. Color cameras have three color components, red, green and blue. The histogram is computed for each of these components separately. For monochrome cameras the histogram is computed on the grayscale pixel values.

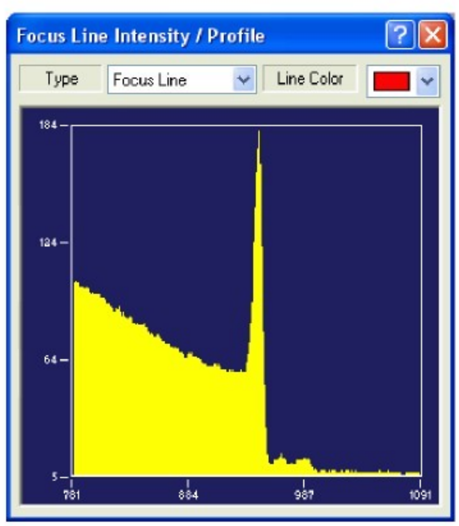


6.36.7. Focus Line / Image Profile

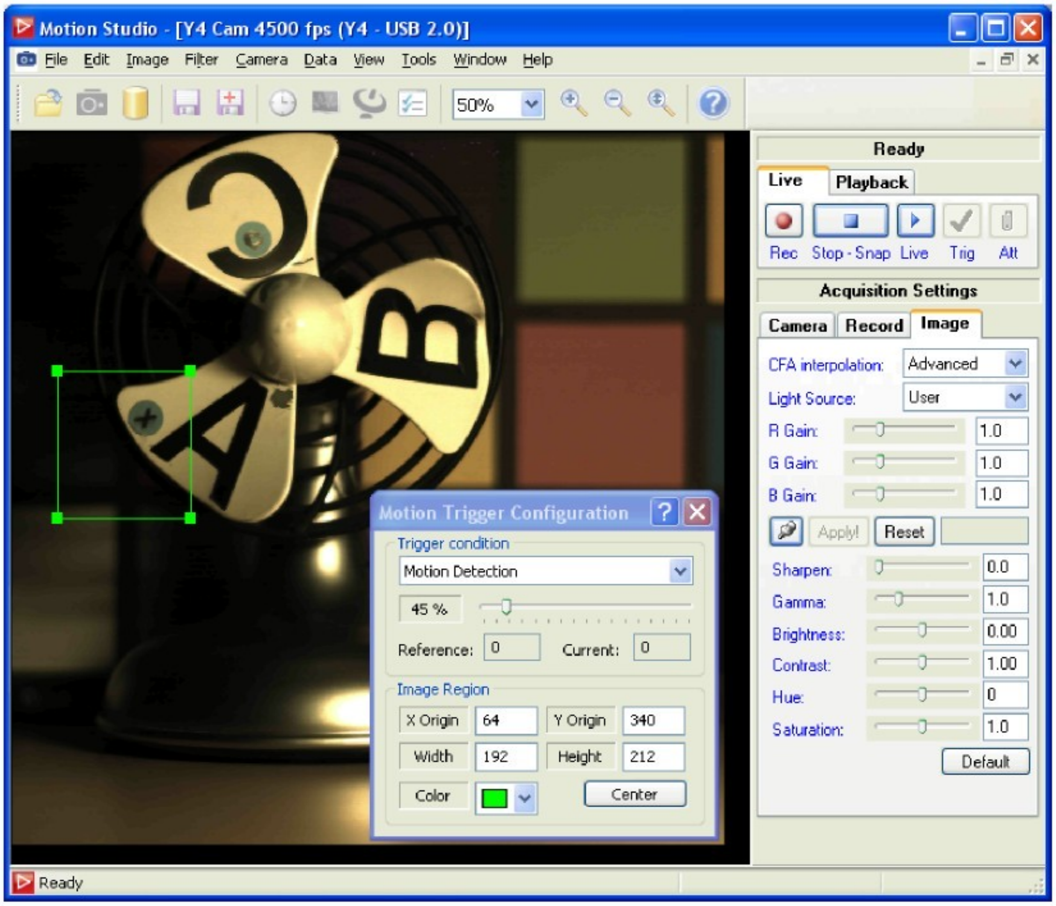
The Focus Line Intensity dialog box displays the values of image intensity (levels of gray in monochrome images and levels of green on color images) along the points of the focus line. If the image is well focused, you will see the intensity changing when the line crosses an edge of the image.

1. From the main toolbar select Tools > Focus Line/Image Profile.
2. Use the "Type" drop-down list to select Focus Line or Image Profile.
3. Use the "Color" drop-down list to select the Focus Line color.
4. To position the focus line, drag the line handles and position them across the image edges.





6.36.8. Motion Trigger



The Motion Trigger automatically generates a trigger when a condition becomes true in a region of the image. The ROI is set by a rectangular grid that may be dragged and positioned anywhere in the image. The option is valid if the camera acquires in circular mode.

The Trigger condition is configurable. Four options are available.

- The average intensity in the ROI changes by a configurable amount.
- The average intensity in the ROI decreases by a configurable amount.
- The average intensity in the ROI increases by a configurable amount.
- A general motion is detected in the ROI.

In new design (pipeline) Y cameras, the motion trigger is implemented in the firmware and the trigger condition can be detected in real time during the acquisition.

Trigger condition

Select the condition that generates the trigger and the levels.

Reference/Current

The Start average is the value of average computed when the acquisition starts, the Current Average is the value computed on the current preview image.

Threshold slider

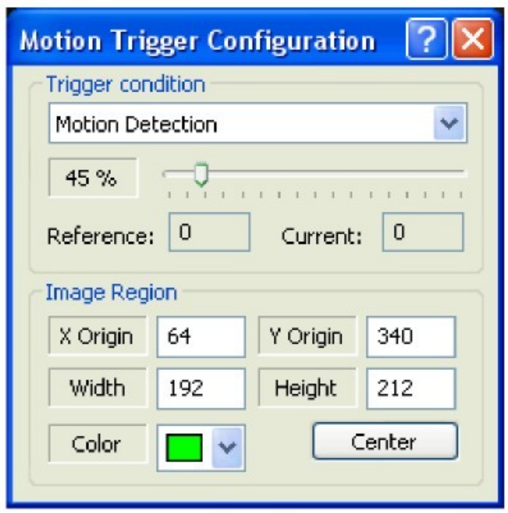
The range is from 1 to 400. It indicates a percentage of the reference intensity of the image.

X, Y, Width and Height

The position and size of the trigger ROI. The user may also drag the handles of the grid to change the size or the entire grid to change position.

Center

Click this button to center the position of the trigger ROI.

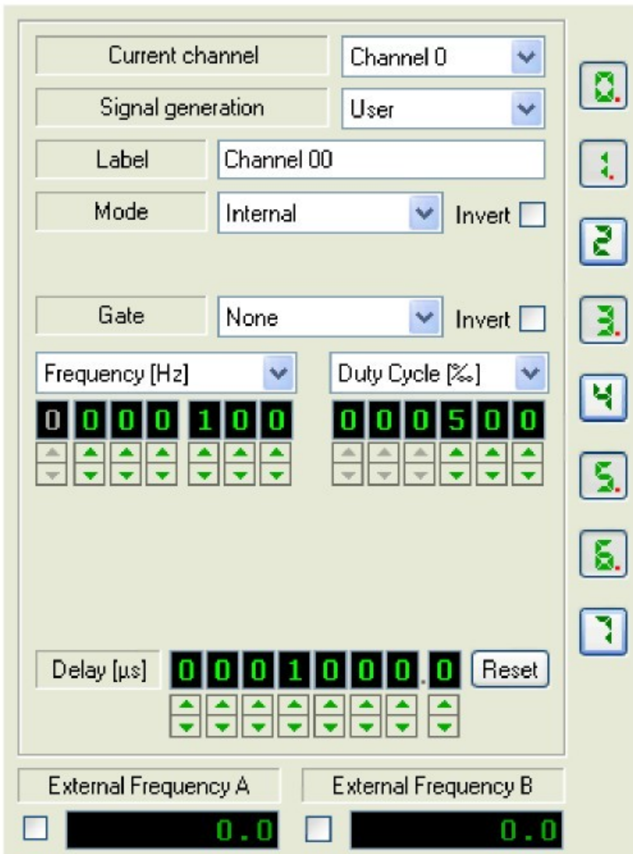


6.36.9. Timing Hub Control

Motion Studio provides the controls for the MotionPro Timing Hub. If a Timing Hub is detected, the Timing Control menu item is displayed in the Tools menu.

From the main toolbar select Tools > Timing Control.

6.36.9.1. Channels selection and controls



Current channel: select the channel you want to configure.

Signal generation: see the “Signal generation” topic below.

Label: The user may change the label of the output channel.

Mode: The operating mode may be selected. For a more detailed description of the modes, refer to the topics below.

External In: when the selected mode is “external”, the user may select the external input channel (0 or 1).

Gate: each channel may be gated. The gate channel may be one of the two external inputs (0 or 1) or one of the other output channels. The gate selection is disabled if the mode is “Start/Stop” or “Rate Switch”.

Invert: the output signal, the input signal (external mode only) and the gate signal may be inverted.

Frequency/Period: the user may select the frequency in Hz or the period in us of the selected channel.

Duty cycle: the user may select the channel duty cycle in percentage (1 to 999) or duration of the high value of the channel in us.

Pulses: if the mode is burst the user may select the number of pulses generated by the trigger.

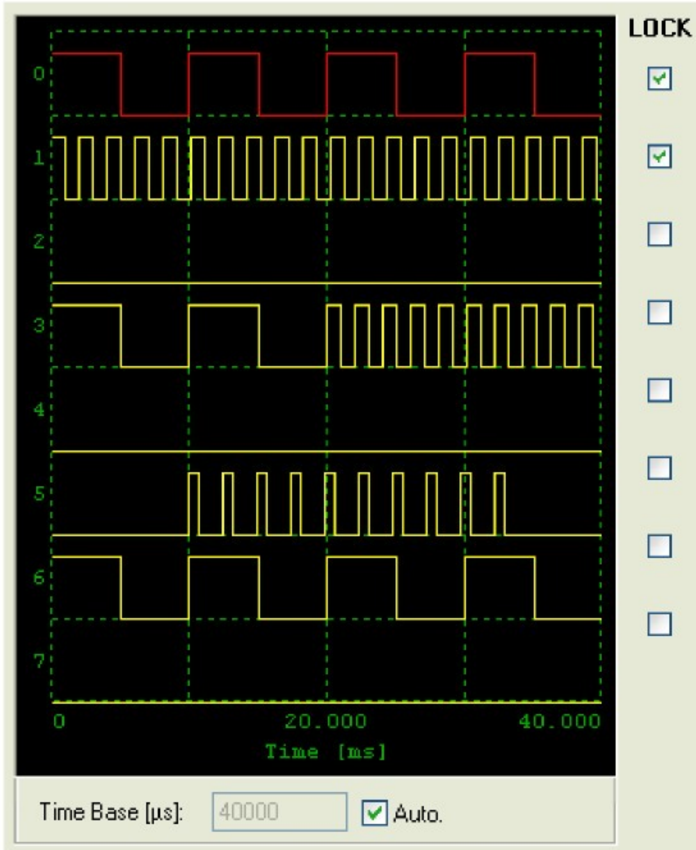
Delay: the output delay may be adjusted. The range is from 0 to 9 s (steps of 100 ns). If the mode is external the delay steps are in external signal clocks.

Reset: the delay may be reset to the default value (0).

External Frequencies: the external input channels frequency may be displayed by selecting the check box.

Signals buttons: each channel may be turned on and off by clicking the corresponding button.

6.36.9.2. Signal Display and lock



The output channels signals are shown in the black window. The user may select the Time base period. If auto is selected, the application shows four periods.

Lock: two or more output channels may be locked by checking the “lock” check boxes. If two or more channels are locked, they are simultaneously turned on and off when one of the locked buttons is clicked.

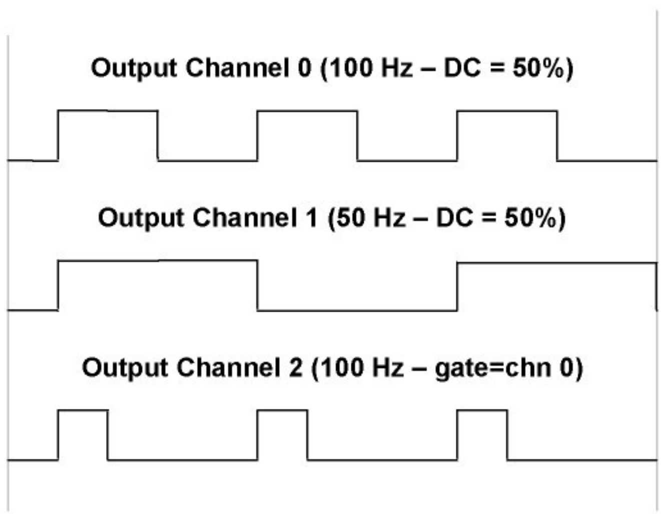
6.36.9.3. Internal Mode

Output waveforms are generated by the internal clock. The user may adjust the internal frequency or period and the duty cycle. The channel may be inverted and gated by another signal. The gate can be selected among the external inputs (0 or 1) or among one of the other output channels.

The diagram below shows an example with the following configuration:

- **Output channel 0**: F = 100 Hz, duty cycle 50%, no gate.
- **Output channel 1**: F = 50 Hz, duty cycle 50%, no gate.
- **Output channel 2**: F = 100 Hz, duty cycle 50%, gate = output channel 0.

The output channel 0 frequency is 100 Hz. The output channel 1 frequency is 50 Hz. The output channel 2 frequency is 100 Hz but the channel is gated by the output 0, so the result is a signal which has 100 Hz frequency and a duty cycle of 25%.



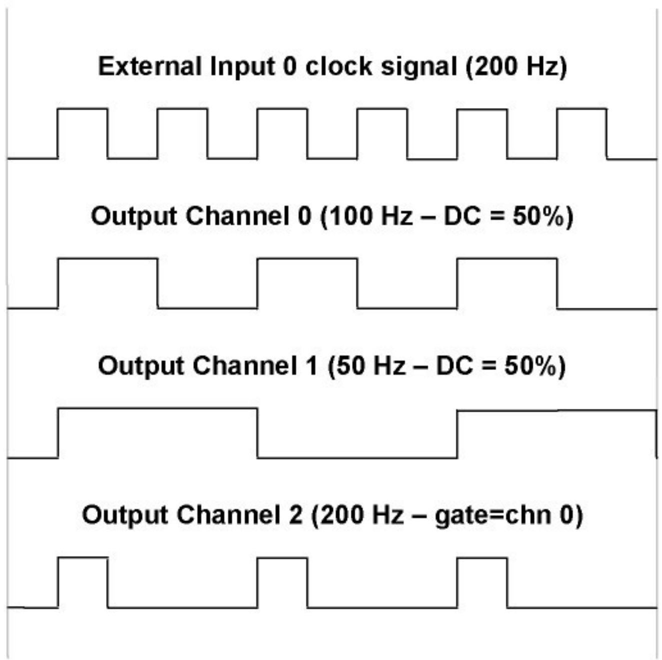
6.36.9.4. External Mode

Output waveforms are generated by an external signal. The user may adjust the output channel divider and duty cycle. The output channel may be inverted and gated by another signal. The gate can be selected among the external inputs (0 or 1) or among one of the other output channels.

Let's assume that the external frequency is 200 Hz. The diagram below shows an example with the following configuration:

- **Output channel 0**: F = 100 Hz, duty cycle 50%, external input 0, no gate.
- **Output channel 1**: F = 50 Hz, duty cycle 50%, external input 0, no gate.
- **Output channel 2**: F = 100 Hz, duty cycle 50%, external input 0, gate = output channel 0.

The output channel 0 frequency is half the external frequency. The output channel 1 frequency is one fourth the external frequency. The output channel 2 frequency is equal to the external frequency but the channel is gated by the output 0, so the result is a signal which has half the external frequency and a duty cycle of 25%.

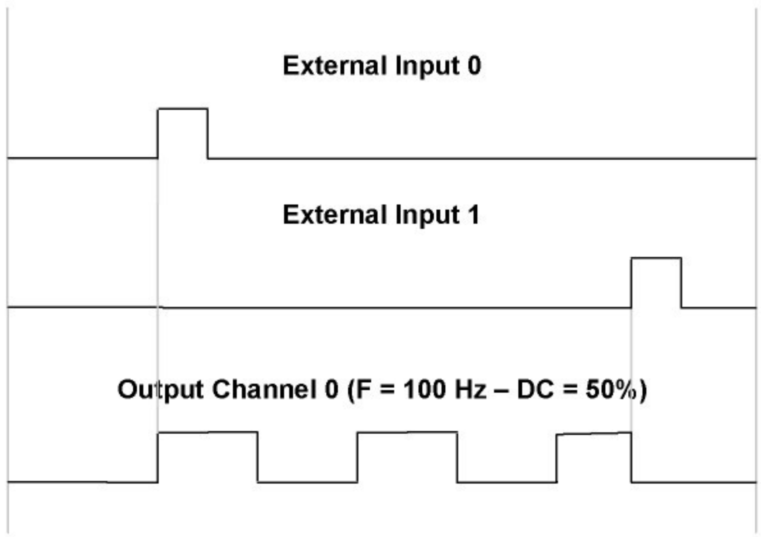


6.36.9.5. Start/Stop Mode

The two external signals drive the output signals generation. The input 0 starts the output, while input 1 stops it. The frequency and delay of the output are configured as in “internal” mode. No gate is allowed. When the stop signal level is high, the output signal is truncated.

The diagram below shows an example with the following configuration:

- **Output channel 0**: mode = Start/Stop, F = 100 Hz, duty cycle = 50%.

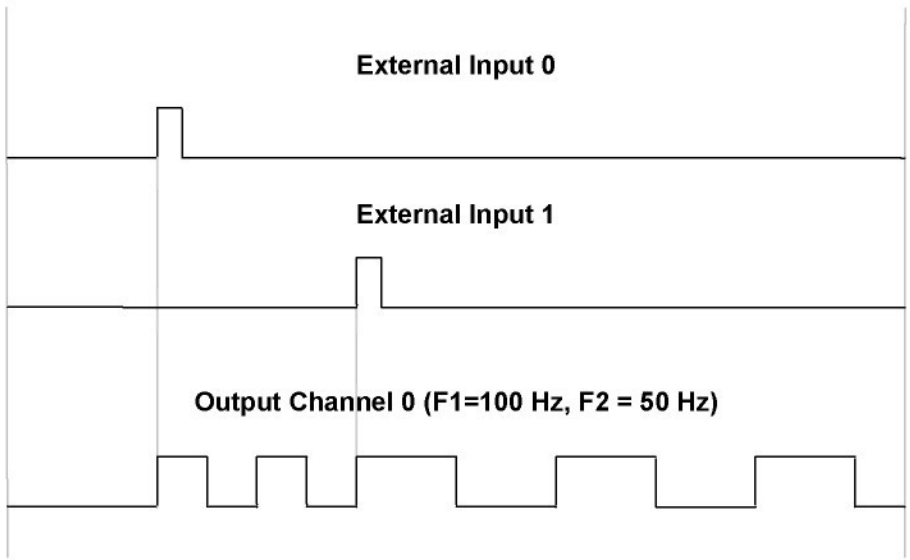


6.36.9.6. Rate Switch Mode

The two external signals drive the output signals generation at two different frequencies. Input 0 starts the outputs at the frequency 1, while input 1 switches the frequency to the Frequency 2 value.

The diagram below shows an example with the following configuration:

- **Output channel 0**: mode = Rate Switch, F1 = 100 Hz, duty cycle1 = 50%, F2 = 50 Hz, duty cycle1 = 50%. When the input 0 level goes high, the output signal starts at 100 Hz. When the input 1 level goes high, the output 0 frequency switches to 50 Hz.

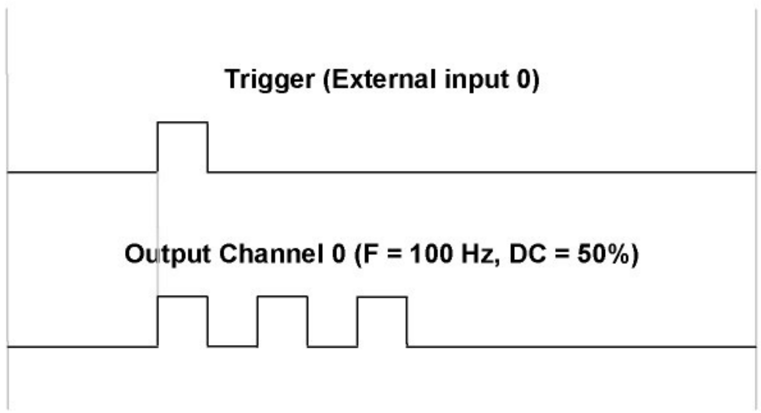


6.36.9.7. “Burst Single” Mode

In burst (single) mode, one of the external inputs or one of the output channels is used as trigger to generate one or more pulses. The frequency and the Duty cycle controls are used to determine the duration of the pulse. The generation of the pulses may be also delayed. Both the output signal and the trigger may be also inverted.

The diagram below shows an example with the following configuration:

- **Output channel 0**: mode = Burst (single), Trigger = External Input 0, F = 100 Hz, duty cycle = 50%, pulses = 3. The external Input 0 serves as a trigger. When the trigger goes high, three pulses are generated by the output channel 0. The duration of the pulses is about 5 ms (50 % of 100 Hz). The pulses are generated once.

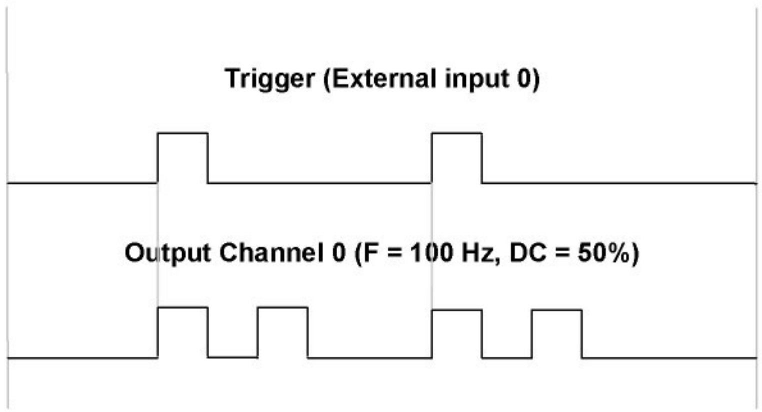


6.36.9.8. "Burst retriggered" mode

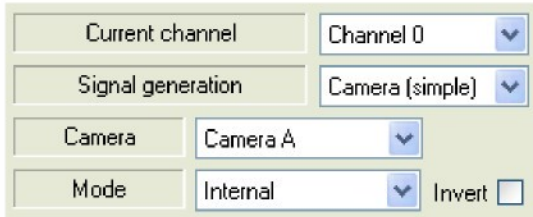
The Burst retriggered mode is equivalent to the burst single mode. The pulses are generated any time the trigger signal goes high and not only once.

The diagram below shows an example with the following configuration:

Output channel 0: mode = Burst (retriggered), Trigger = External Input 0, F = 100 Hz, duty cycle = 50%, pulses = 2. The external Input 0 serves as a trigger. When the trigger goes high, three pulses are generated by the output channel 0. The duration of the pulses is about 5 ms (50 % of 100 Hz). The pulses are generated each time the trigger goes high.



6.36.9.9. Signal generation (Camera synchronization)



The MotionPro Timing Hub may be used to synchronize a camera or other devices. The signal generation options are:

- User: the output signal synchronizes an external device. No internal control is done by the program.

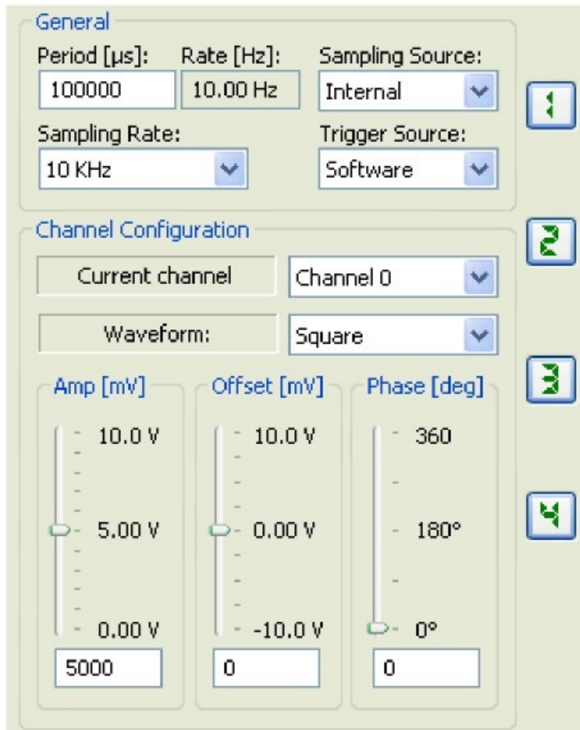
- **Camera (simple)**: the label edit box will be converted into a list of open cameras. In the camera dialog bar the "Rate" control will be disabled, the "Rate Sync" control will be set to "External" and the camera operation frequency will be configured directly from the timing panel. If the "Sync Cfg" value is set to "Pulse High" or to "Pulse Low", the camera exposure is controlled by the duty cycle of the external square wave. In this condition the exposure edit box is grayed out and the value is automatically computed.
  1. If the "Sync Cfg" value is set to Pulse High, the exposure is equal to the inverse of the output channel frequency multiplied by the duty cycle.
  2. If the "Sync Cfg" value is set to Pulse Low, the exposure is equal to the inverse of the output channel frequency multiplied by (100 - duty cycle).
- **Camera (XDR)**: the signals are generated to have the best results from the XDR mode.

6.36.10. Analog Data Output

Motion Studio provides the controls for the generation of analog output with the MotionPro Data Acquisition System (DAS). The available analog output channels in the module are four.

From the main toolbar select Tools > Analog Out.

6.36.10.1. General parameters and channels configuration



Period and Rate: select the period of the generated waveform. The corresponding rate in Hertz is displayed.

Sampling Source: the sampling source may be the internal module clock or an external digital signal.

Sampling Rate: select the sampling rate in Hz. If the sampling source is external, enter the external signal frequency.

Trigger Source: the event trigger starts the waveforms output. It may be software, external edge high, or external edge low.

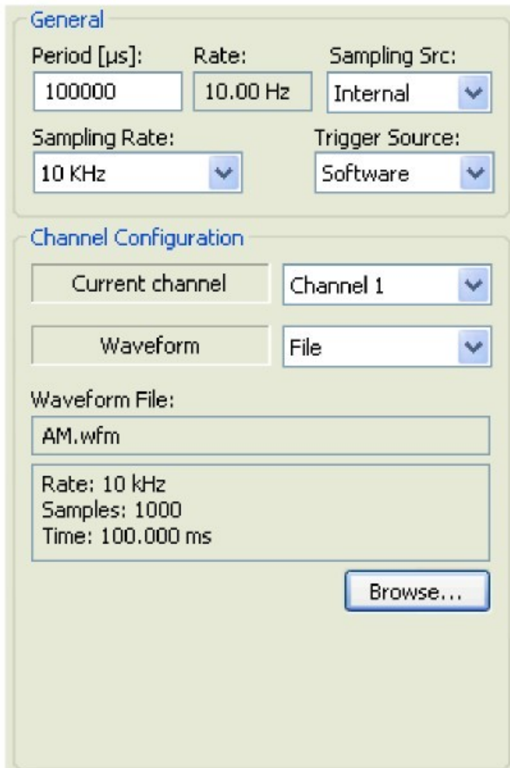
Current channel: select the channel you want to configure.

Waveform: select the channel waveform: square, sine, triangle, saw tooth, or waveform file.

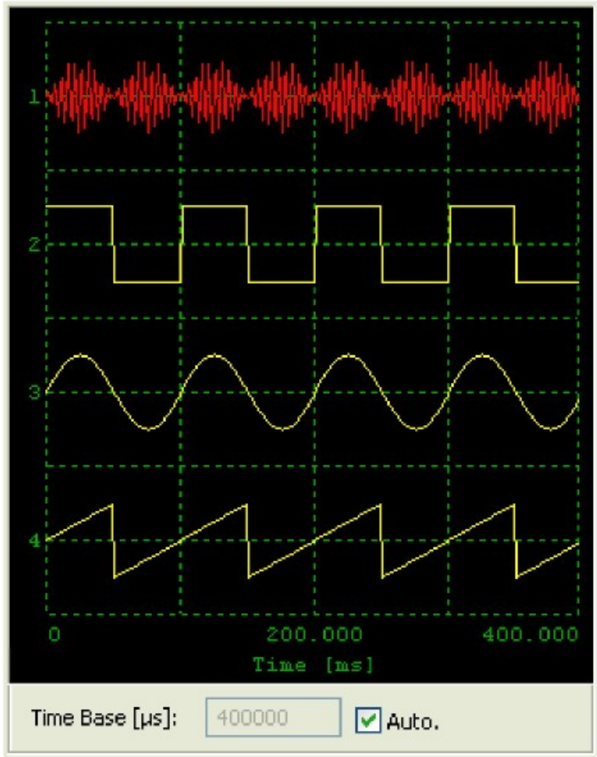
Amplitude, Offset and Phase: if a waveform is selected, edit the amplitude, the offset and the phase.

Browse: if the "File" option is selected, click the "Browse" button to open a data file. The file will be played back.

Signals buttons: each channel may be turned on and off by clicking the corresponding button.



6.36.10.2. Data display and lock



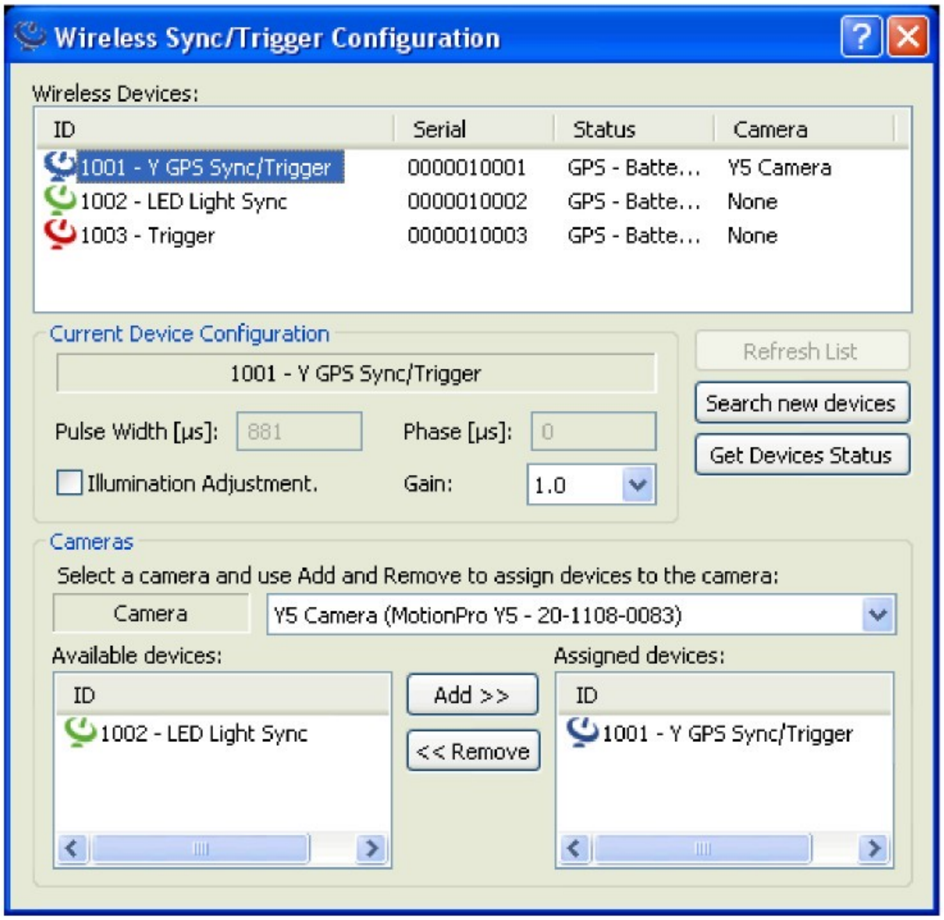
The output channels signals are shown in the black window. The user may select the Time Base period in μs. If auto is selected, the application shows four periods.

Lock: two or more output channels may be locked by checking the “Lock” options. If two or more channels are locked, they are synchronously turned on and off when one of the channel buttons is pressed.

6.36.11. Galileo Wireless Sync/Trigger

Cameras and light sources can be synchronized with the Galileo Wireless System. For more information about Galileo, please refer to the documentation.

From "Tools" menu, select "Wireless Sync/Trigger".



Refresh List: click this button to enumerate all the wireless devices available in the ZigBee network. Make sure that the coordinator USB key is correctly installed. The button is disabled if one or more devices are listed in the "Assigned Devices" list.

Get Device Status: click this button to retrieve the current status of the wireless devices. The status shows if the GPS signal is detected and the level of the battery (0 to 5).

Illumination adjustment and gain: select this option on a sync device to activate the light sensor.

Camera: select a camera from a list of all the available cameras. Once a camera is selected, you may connect one or more wireless devices to that camera.

Add/Remove: click Add to connect a device to a camera. Click Remove to disconnect it.

Once a device is connected to a camera, the devices parameters can be configured from wireless dialog box or from the camera control bar.

Sync/Trigger Device: each camera can have only one camera device connected. The camera frame sync is automatically set to "External" and the "Sync Cfg" is set to "GPS". The user can set the rate and the exposure from the camera control bar and automatically the Period and Pulse width of the wireless device will be set to the same values.

LED Light Device: each camera can have more than one light devices assigned. The period is set to the inverse of the camera rate and the pulse width can be configured from the wireless dialog box. The phase can also be configured.

6.36.12. Giga-Ethernet cameras Network Configuration

See the "Configuration of Giga-Ethernet cameras" topic.

6.36.13. Image Tile Utility

The Image Tile Utility is an external application that may be invoked by Motion Studio. It allows the user to horizontally or vertically tile image sequences.

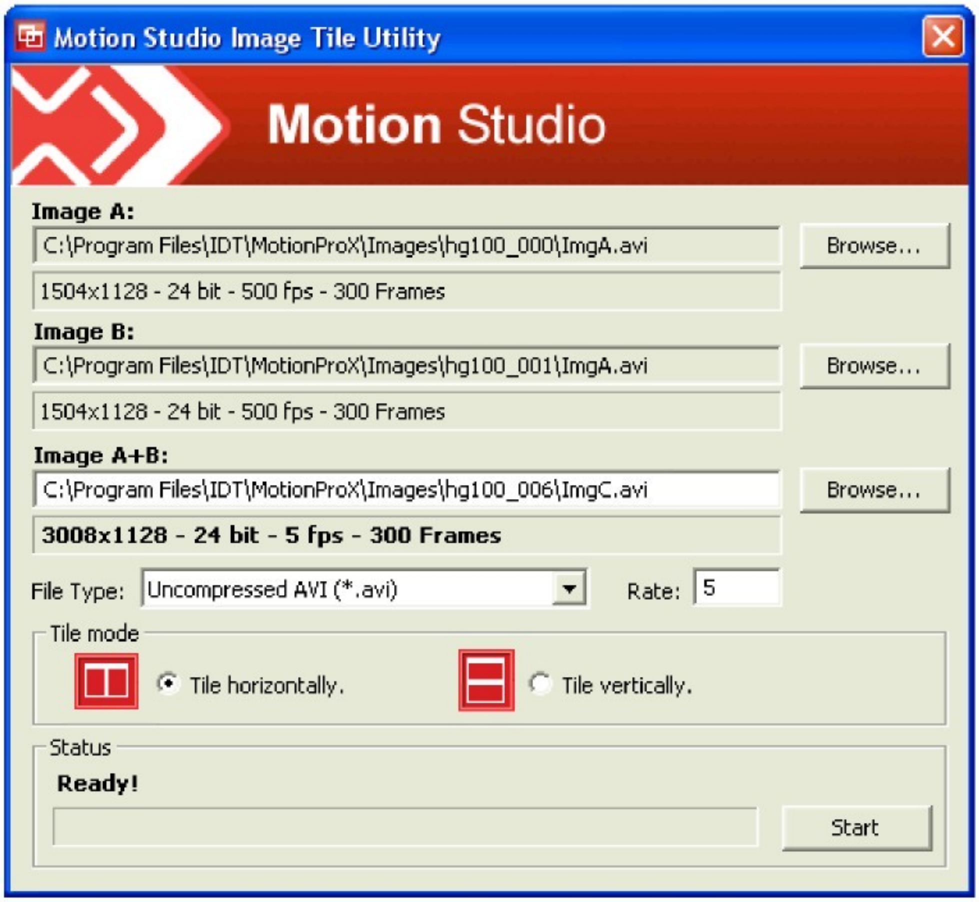


Image A and Image B

Click the Browse button to select the sequences that will be tiled.

Image A+B

Click the browse button to select the name of the output image sequence.

File Type

Select the output image sequence type.

Rate

Edit the output file rate

Tile mode

The images may be tile horizontally or vertically tiled.

Start

Click this button to start the tile process.

The image tile utility can be used with command line parameters. The syntax is below.

To display the help message:

XImgTile /H

To tile images:

XImgTile /A ImgA /B ImgB /O ImgAB /T OutType /V TileV /R Rate

where:

- **ImgA**: full path of Image A (ex: *C:\Program Files\IDT\MotionProX\Imgs\ImgA.tif*).
- **ImgB**: full path of Image B (ex: *C:\Program Files\IDT\MotionProX\Imgs\ImgB.tif*).
- **ImgAB**: full path of output image (ex: *C:\Program Files\IDT\MotionProX\Imgs\ImgAB.tif*).
- **OutType**: output file type (1:TIF, 2:BMP, 3:JPG, 4:PNG, 11:MPT, 12:MRF, 13:AVI, 16:MPG).
- **TileV**: 0 for horizontal tile, 1 for vertical tile.
- **Rate**: output file rate, only for file image formats that support the parameter (ex: AVI).

6.36.14. Language Selection

1. From the Tools menu, select “Language…”
2. Select the language from the list and click OK.

Currently the supported languages are English, German, Italian, Japanese and Chinese.

6.36.15. Vidi Motion

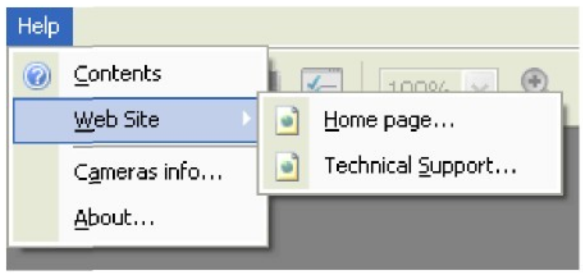
For a detailed description of the Vidi Motion tool, please refer to the Vidi Motion topic.

6.37. WINDOW menu

If more than a window is open in the Motion Studio program, use the window menu to cascade, tile horizontally, tile vertically or select one of the windows.

6.38. HELP menu

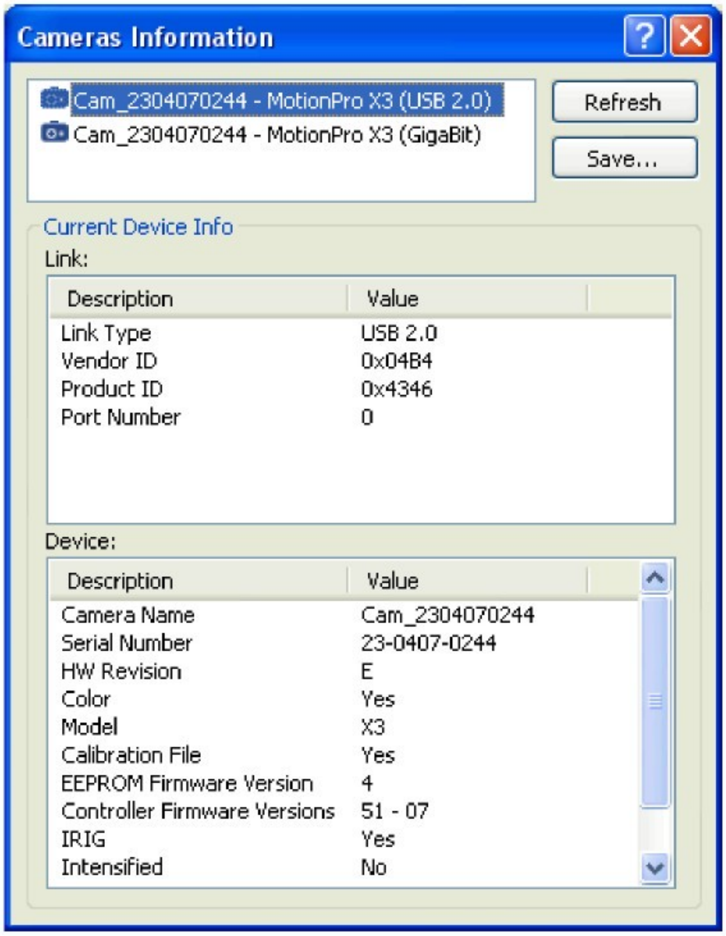
This menu contains support options and information including: e-mail tech support and software and manual updates.



6.38.1. Camera Information

Cameras Info displays a dialog box with the information about the cameras, such as model, type (color or black and white), ID and serial number. The information may be saved in a text file by clicking the "Save…" button.

From the main toolbar, select Help > Cameras Info.



7. Vidi-Motion (Lens calculator)

7.1. Overview

Vidi-Motion contains the most important specifications of the Redlake Motion cameras, a lens calculator and an overview of the current lenses available from Redlake. With Vid-Motion you may:

- Calculate resolutions, amount of motion blur, correct exposure time, depth of field, hyper focal distance etc.
- Find compatible lenses, based on the selected amount of pixels, pixel size, the field width and focal length.
- Review lens specifications such as: f-stop, size, weight, minimum object distance.
- Calculate the speed at impact, of a free falling object. It is assumed that the object falls in vacuum, thus no compensation for air resistance is included.
- Calculate the circumference speed of a spinning object.

7.2. Camera information

Select the camera Family first, then the camera model.

MotionPro HS: HS-1, HS-2, HS-3, HS-4, SI-3, SI-4.

MotionPro X: X3, X4, X5

MotionPro Y: Y3, Y4L, Y5, Y6, Y7-HDiablo

MotionXtra N: N3, N4, N4L, N5

MotionScope M CameraLink: M3, M5

MotionPro: 500, 2000, 10000.

MotionScope M (old): M1, M2, M3.

MotionXtra: HG-2000, HG-TX, HG-SE, HG-LE, HG-TH, HG-100K, HG-XE, HG-XR, HG-N.

MotionScope: 1000, 2000, 8000.

MotionCorder: SR-500, SR-1000, SR-3000, SR-ultra.

MotionMeter: 250, 1000

Once you have selected the Camera **Model**, several textboxes will be updated with the camera specifications. The default values are:

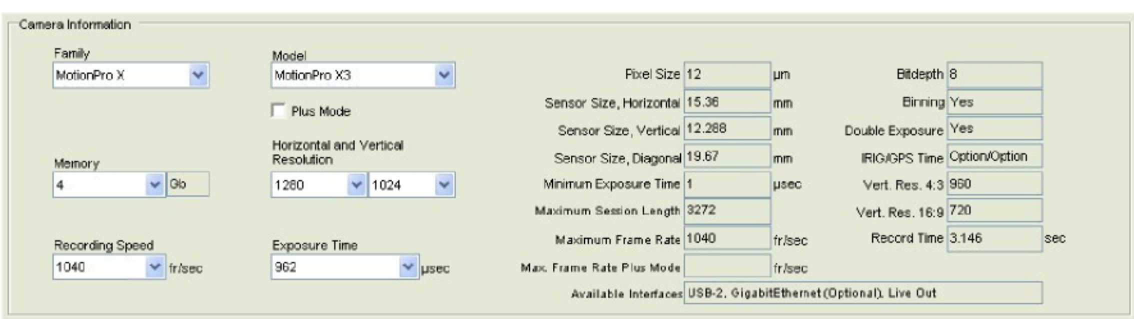
- Maximum **Memory** configuration.
- Maximum **Recording Speed** at maximum **Horizontal and Vertical Resolution**.
- **Exposure Time** of 1 divided by Recording Speed.

Select the **Memory** configuration: **Maximum Session Length** and **Record Time** will be recalculated.

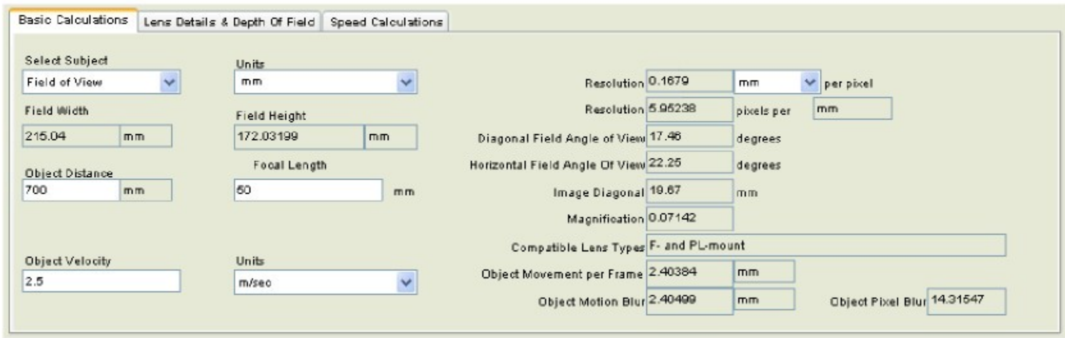
Select the **Horizontal and Vertical Resolution**: **Maximum Session Length, Record Time** and **Recording Speed** will be recalculated.

Adjust the **Recording Speed** to the frame rate you want to capture images at. The **Record Time** and the **Exposure Time** are recalculated.

Adjust the **Exposure Time** at the correct time, if it is known or leave it as it is and calculate it later.



7.3. Basic Calculations



7.3.1. Lens calculations

Several calculations are combined here.

Select the calculation of **Focal length**, **Field of View** or **Object Distance.** Later you need to input the remaining parameters.

Choose the measurement unit

Input the two remaining values

The result will be displayed including: **Field Height**, **Resolution**, **Angle of View**, **Image Diagonal**, **Magnification** factor and the **compatible lenses types.**

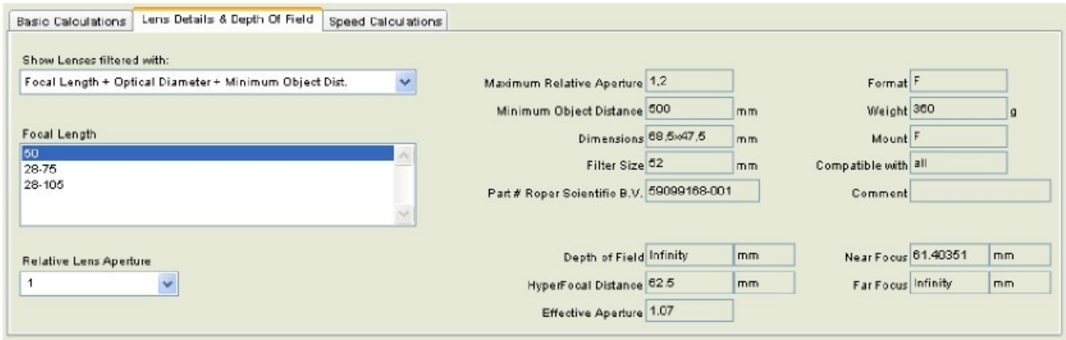
If the lens specifications shown are not compatible with your lens, you need to lower the **Horizontal and Vertical Resolution** to avoid “vignetting”.

The units of the results can be independently chosen, in the drop down box “Resolution”.

7.3.2. Fast moving objects

- Input the **object velocity** here and choose the correct unit (m/sec, km/h, feet/s, and inches/s).
- The **Object movement per frame**, the **object motion blur** and the **object pixel blur** are calculated.
- The units are equal to the choice made in the drop down box “**Resolution**”.
- If the object movement is too big: increase the recording speed.
- If the motion blur is too high: lower the exposure time.

7.4. Lens details and depth of field



According to the lens calculation results, compatible **lenses** are listed here. The list can be filtered to include the following specifications:

- Focal length + optical diameter + minimum object distance
- Lens type + minimum object distance
- Lens type
- No filter

Select a lens in the "**focal length**" box to display the product details and part number.

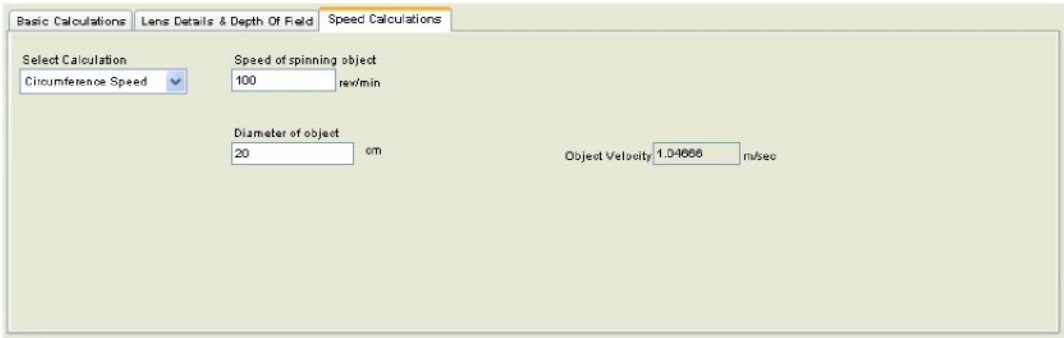
7.4.1. Depth of field and hyper-focal distance

Select the relative lens aperture. The following parameters will be calculated.

- Depth of Field.
- Near focus.
- Far focus.
- Hyper focal distance.
- Effective aperture.

7.5. Speed calculations

Speed calculations include circumference speed and falling objects speed.



7.5.1. Circumference speed

The **object circumference speed** can be calculated if the following is known:

- The **speed of the spinning object** (rev/min).
- The **diameter of the object** (cm).

The result is shown in m/sec.

7.5.2. Falling objects

The theoretical speed at impact of a falling object can be calculated here. The speed at 0 meter is assumed to be equal to 0.

- Input the distance form object to the impact point with the correct unit (m or ft)
- The speed at impact units are in m/sec or km/hr.

Note: Decimal signs are shown according to the “decimal setting” of the Operating System.

8. Frame Synchronization and Event Triggering

8.1. Overview

The camera and software enable external sync and triggering capabilities. The camera is synchronized externally via a trigger source in the form of a TTL pulse. The synchronization INPUT signals as well as a synchronization OUTPUT signal are handled through BNC connectors. The synchronization signal is output for every frame that is acquired and can supply the time reference for other pieces of hardware, for example a strobe for illumination.

Two options are available:

1. **Cameras with 2 BNC connectors**: 1 input connector is used for synchronization and event triggering. The output connector is used for sync out.

2. **Cameras with 3 BNC connectors**: a "Trig In" connector is used for event triggering, a "Sync in" connector is used for external synchronization. The output connector is used for sync out.

8.2. Record Modes and Trigger Configuration

On the Record tab, the default Frame Sync source of the camera is set to Internal. If in External, the camera must have an external Sync signal.

TRIG IN: use the Trigger in connector at the back of the camera for event triggering.

SYNC IN: use the Sync In for external synchronization.

SYNC OUT: use the Sync Out for sync out.

Record Mode	Sync In Configuration	Trigger In Configuration
Normal	Internal or external (the BNC is used to provide a sync signal)	Ignored (the camera does not require event trigger)
Circular/BROC	Internal or external (the BNC is used to provide a sync signal)	All values (the camera requires an event trigger)

8.3. Change the Sync and the Trigger

1. Select the Record tab.

2. Use the Frame Sync drop-down list to select from the following options:

   - Select Internal to acquire frames continuously at a rate that is dependent on the frame read-out time and the exposure.

   - Select External to wait for an external trigger input to acquire frames. An external signal must be provided.

3. In external mode, the camera waits for an external sync input to acquire a frame. Use the Sync Cfg drop-down list to select from the following options.

   - Select Edge-High to trigger on the positive going slope of the signal.

   - Select Edge-Low to trigger on the negative slope of the signal.

   - Select Pulse High mode to set the duration of the exposure to equal the trigger signal duration (High state).

   - Select Pulse Low mode to set the duration of the exposure to equal the trigger signal duration (Low state).

   The time delay between the trigger signal and the acquisition of the image is less than 20 ns.

   If the record mode is set to “Circular” or “BROC” each acquisition requires an event trigger. To set a trigger, click on the Trigger button on the Camera Control tab for a software trigger, or use an external trigger source.

   1. Select the Record tab.

   2. Use the Record Mode drop-down list to select BROC or Circular.

   3. Use the Trig Cfg drop-down to select from the following options: Edge High, Edge Low, and Switch Closure.

8.4. Exposure Modes

To set the Exposure mode, Camera tab > Exposure Mode pull-down list indicate **Single** frame, **Double** (two frames consecutively) or **Extended Dynamic Range (XDR)**. In the timing of these acquisitions, the first frame is acquired each time the internal clock of the camera or an external trigger is present. The exposure for this first frame is equal to the exposure setting parameter. The second frame with an exposure that is equal to the frame read-out time (the value depends on camera model and Region of Interest) is acquired within 100 ns from the first one. The exposure ratio control shows the ratio between the first exposure and the second.

Extended Dynamic Range (XDR): in this mode the camera operates in double exposure and the image pairs are combined to increase the camera dynamic range. If this mode is enabled the exposure control contains the sum of first (configurable) and second (fixed) exposures.

8.5. Triggering the camera and synchronizing with strobe illumination

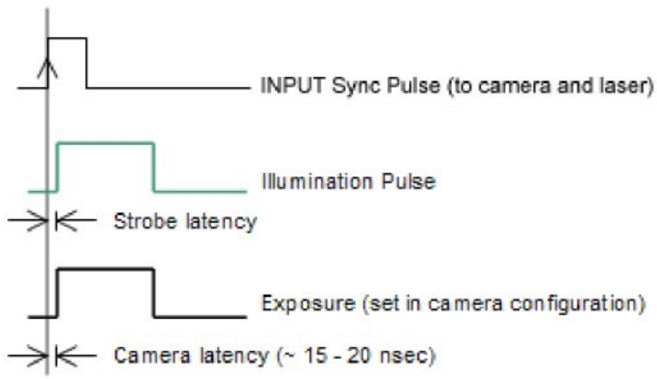
The camera cab is used together with a strobe for illumination. In this case it is necessary to synchronize the illumination pulse event with the camera exposure. Examples of methods that can be employed are presented in the following. The schematics of various timing diagrams are included. This diagram assumes the use of an externally pulse(s) (TTL) to synchronize both the camera and the strobe.

8.5.1. Synchronizing via the leading edge of a pulse event (Single exposure)

The figure shows the timing signals in a single exposure configuration. In the Record Tab the frame sync is set to “External Edge-High” and the exposure mode is set to “single”. The camera exposure is started by the leading edge of the pulse signal and the exposure duration is set in the “Exposure” control of the camera software panel.

Definitions:

- Input sync pulse is **TTL level**.
- Illumination pulse duration: typical 7-10 ns for flash lamp and 100-150 ns for diode pumped lasers respectively).
- **Camera exposure > Illumination latency + Illumination pulse duration**.

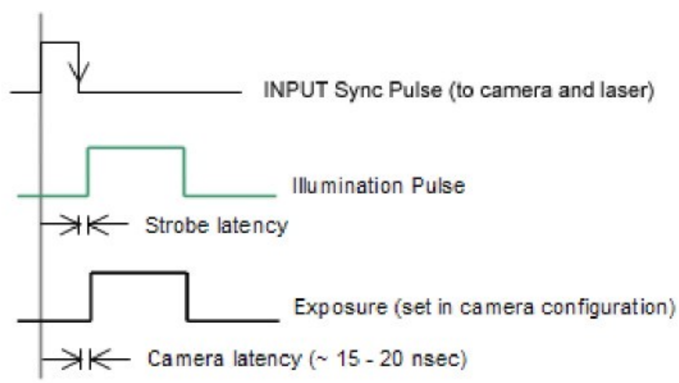


8.5.2. Synchronizing via the trailing edge of a pulse event (Single exposure)

The figure shows the timing signals in a single exposure configuration. In the Record Tab the frame sync is set to “External Edge-Low” and the exposure mode is set to “single”. The camera exposure is started by the trailing edge of the pulse signal and the exposure duration is set in the “Exposure” control of the camera software panel.

Definitions:

- Input sync pulse is **TTL level**.
- Illumination pulse duration: typical 7-10 ns for flash lamp and 100-150 ns for diode pumped lasers respectively).
- **Camera exposure > Illumination latency + Illumination pulse duration**.

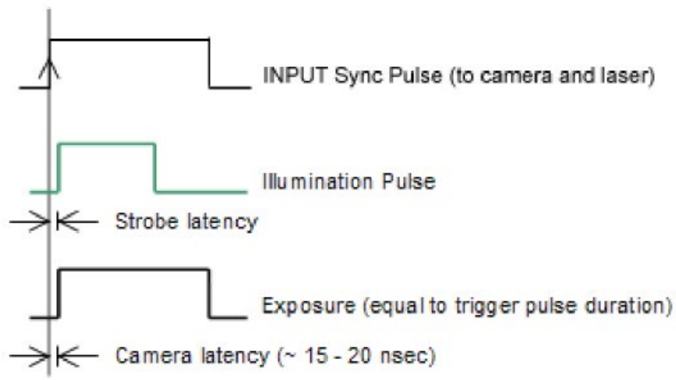


8.5.3. Synchronizing and controlling the exposure with an input pulse

The figure shows the timing signals in a single exposure configuration. In the camera panel the frame sync is set to “External Pulse-High” and the exposure mode is set to “single”. The camera exposure is integrated over the high part of the input pulse and the camera ignores the exposure value set in the “Exposure” control of the camera software panel.

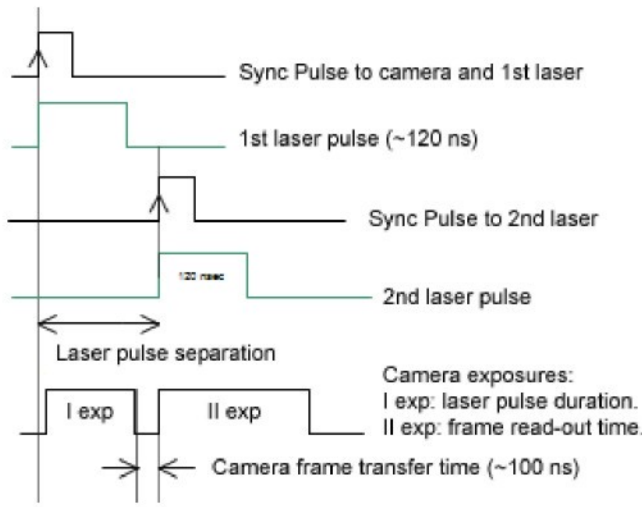
Definitions:

- Input sync pulse is **TTL level**.
- Illumination pulse duration: typical 7-10 ns for flash lamp and 100-150 ns for diode pumped lasers respectively).
- **Camera exposure > Illumination latency + Illumination pulse duration**.



8.5.4. Synchronizing in dual exposure mode

The figure below shows the timing signal in a typical double exposure PIV configuration. In the camera panel the sync mode is set to “External Edge-High” and the exposure mode is set to “double”. The time between the two laser pulses must be larger than the sum of the first laser pulse duration and the camera frame transfer time. The second exposure duration cannot be set and depends from the camera frame readout, so the second laser pulse duration must be configured to the desired exposure time.



9. Motion Studio Remote Control

9.1. Overview

The camera may be remotely controlled by a Pocket PC. The requirements are:

1. A Windows 2000/XP personal computer (the "**host**") with the following items: the camera and software, a 10/100/1000 Ethernet network card or an 802.11b (wireless) network card.

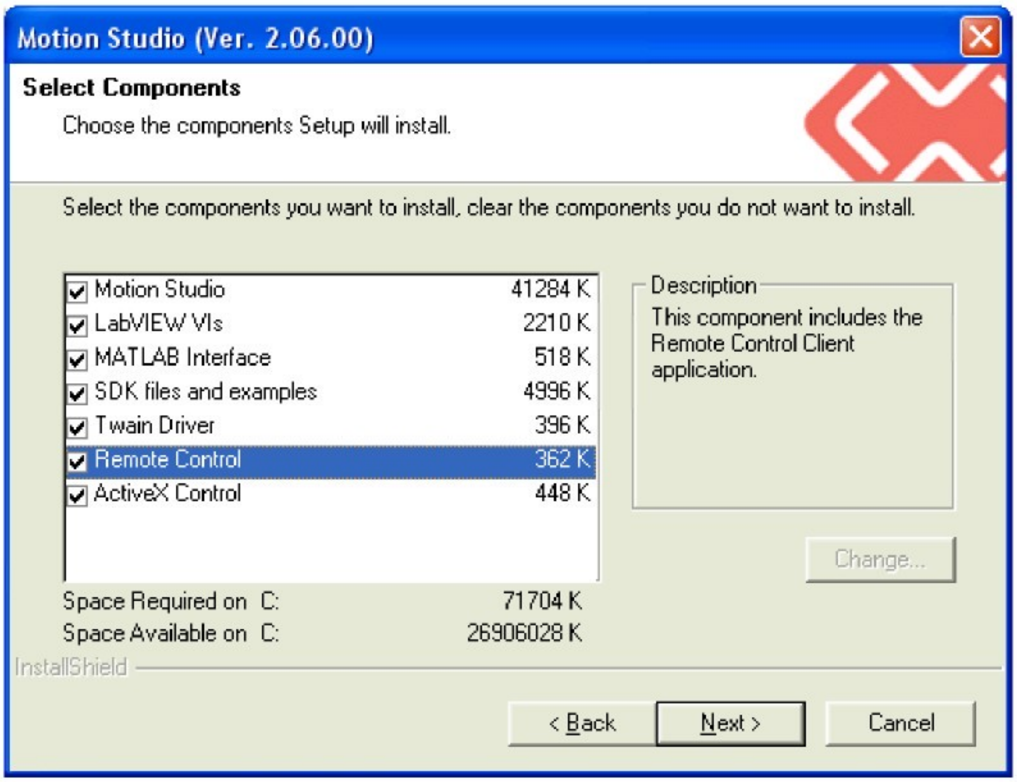
2. A pocket PC (the "**client**") with the following items: Windows Mobile 2003 Second Edition, the Motion Studio Remote Control software, and an 802.11b (wireless) network card.

9.2. Software installation

To install Motion Studio on the host, follow the instructions on the Quick Start Guide.

To install the “Motion Studio Remote Control” on the Pocket PC, you need Microsoft ActiveSync installed on your computer. There are two ways to install the Remote Control.

1. When installing Motion Studio, the setup asks for the Setup type among Typical, Full and Custom. Select custom and check the Remote Control Option. Then follow the on-screen instructions.



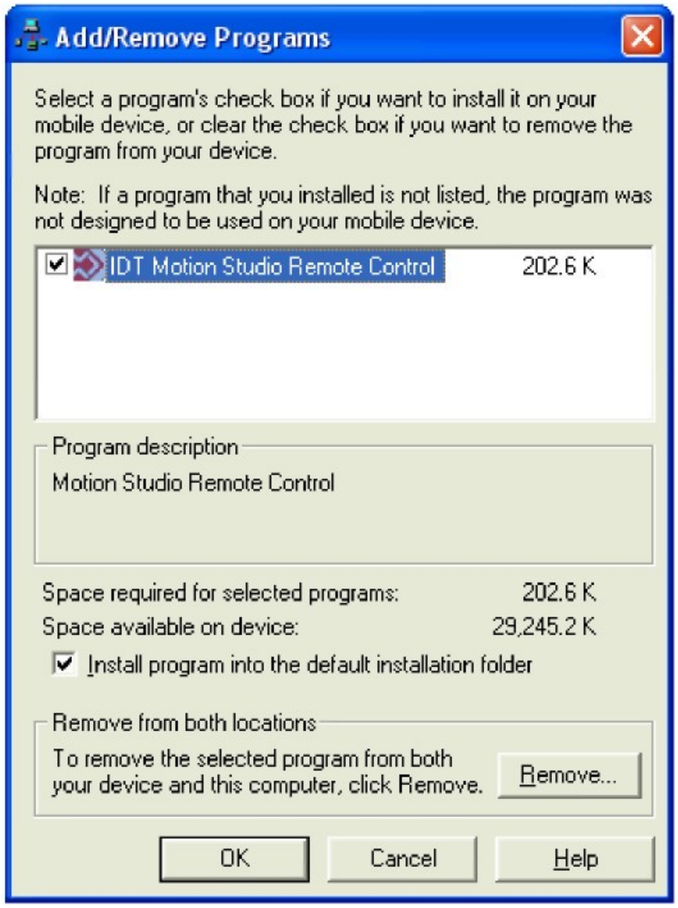
2. Run the xstream_rem.exe self-extracting file from the Remote subdirectory of the Motion Studio CD and follow the on-screen instructions.

Both the install options copy the remote Control Install files to the **XRemote** sub-directory of the Microsoft ActiveSync application.

To install the Remote Control to the Pocket PC:

1. Locate the XRemote subdirectory in the Microsoft ActiveSync folder.

2. Run the CEInstall.exe application and follow the on-screen instructions.



9.3. Configuring the wireless connection

In order to remotely control the camera from the client, the wireless connection requires to be configured.

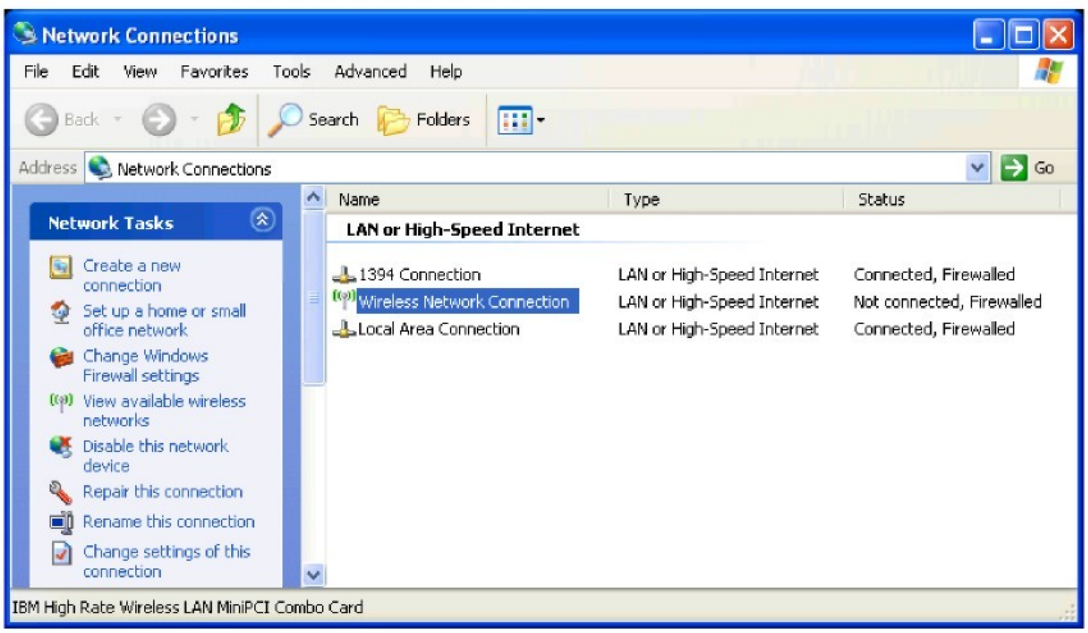
A wireless network may be of two types: “**infrastructure”** (usually used when a wireless router is present on a LAN) and “**ad-hoc**” (computer to computer connection, usually used when no wireless router is present on a LAN).

Both types of wireless connection may be used to remotely control the camera.

9.3.1. Configuring the host

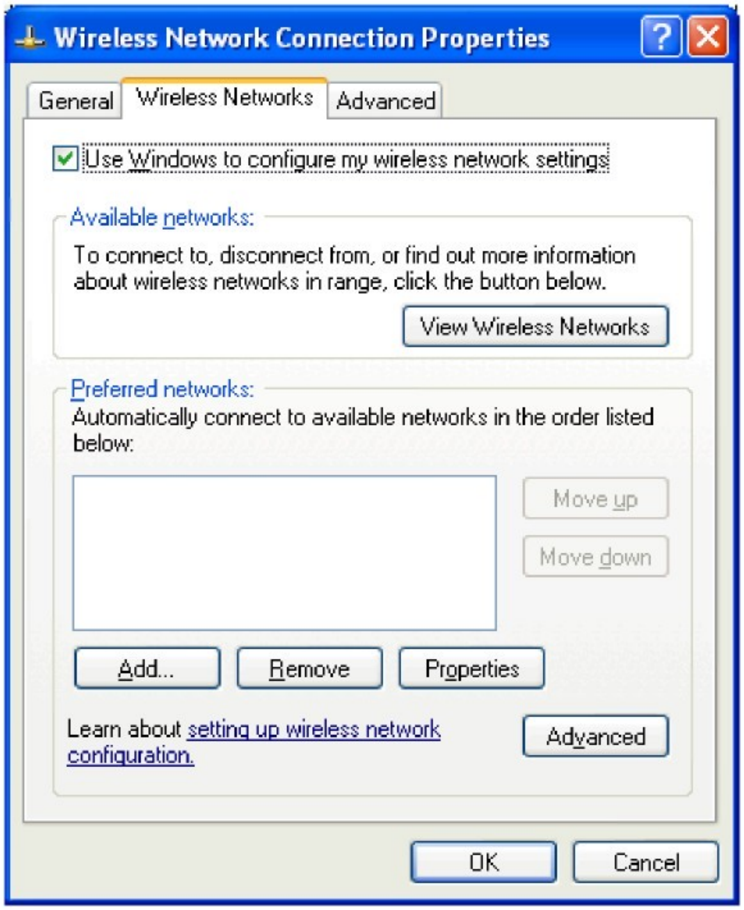
The computer running Motion Studio can have more than one network card. In this section, we show the configuration of the wireless card in a computer to computer (ad how) connection. We suppose that the host computer is connected to the corporate LAN via the Ethernet card and the wireless card will be used in a dedicated connection to the Pocket PC.

From the Start Menu, select All Programs, Accessories, Communications, and Network Connections. The window below will appear.

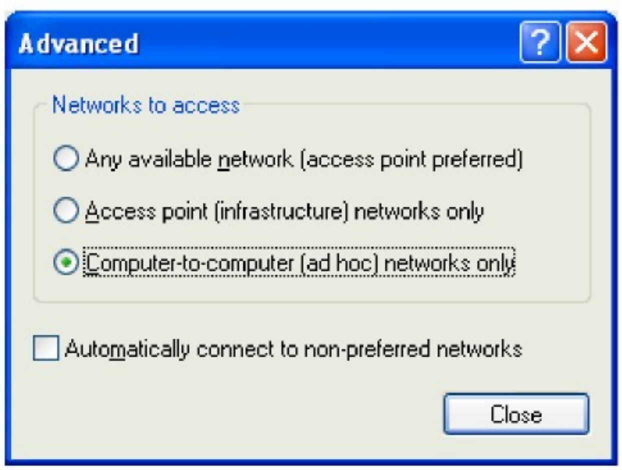


If the wireless card is not connected to any wireless connection, the wireless connection status is shown as “disconnected”.

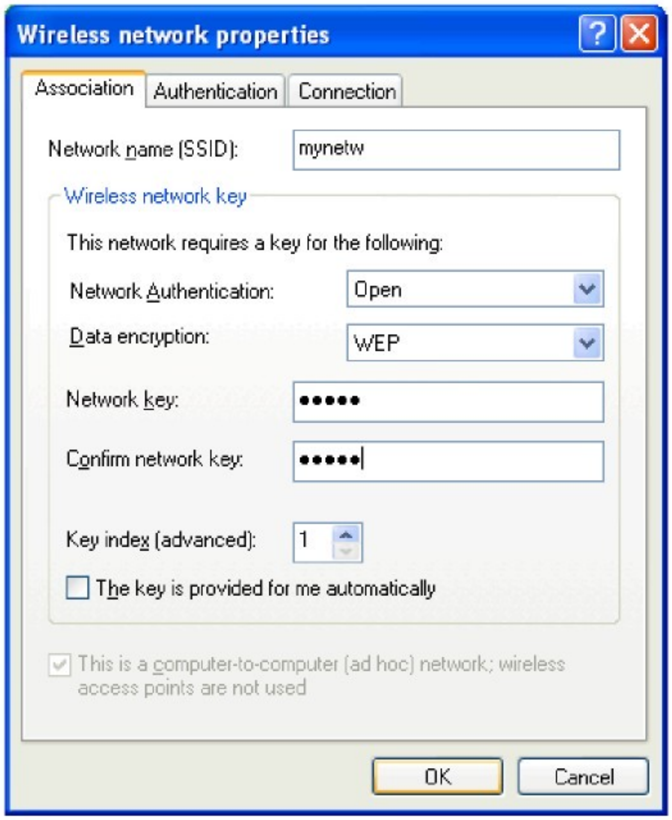
Right click on the “Wireless Network Connection” item and select Properties. Then select the Wireless Networks Tab.



The dialog box shows the available wireless network. Click the Advanced button. The following dialog box appears.

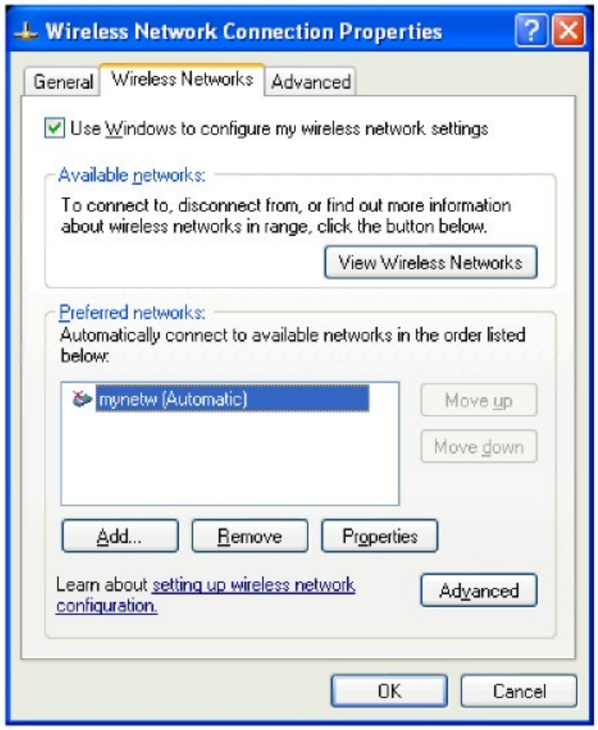


Select the "Compute-to-computer (ad hoc) networks only" option, to display only the dedicated connections. The click Close and then click the Add button. The following dialog box appears.

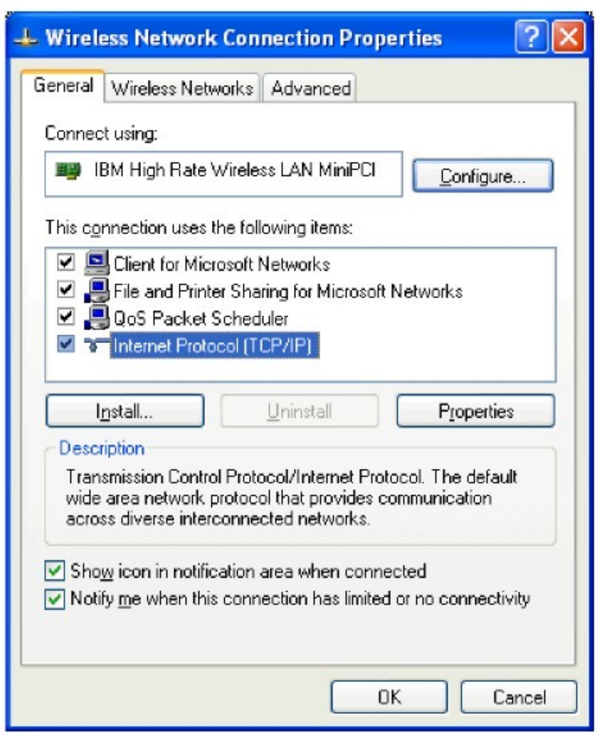


Edit the network name (SSID), uncheck the “The key is provided for me automatically” option, enter the Network Key and then confirm it. The network key is a password which is required to authenticate the connection. You will be required to enter the same key when you will configure the Pocket PC wireless connection.

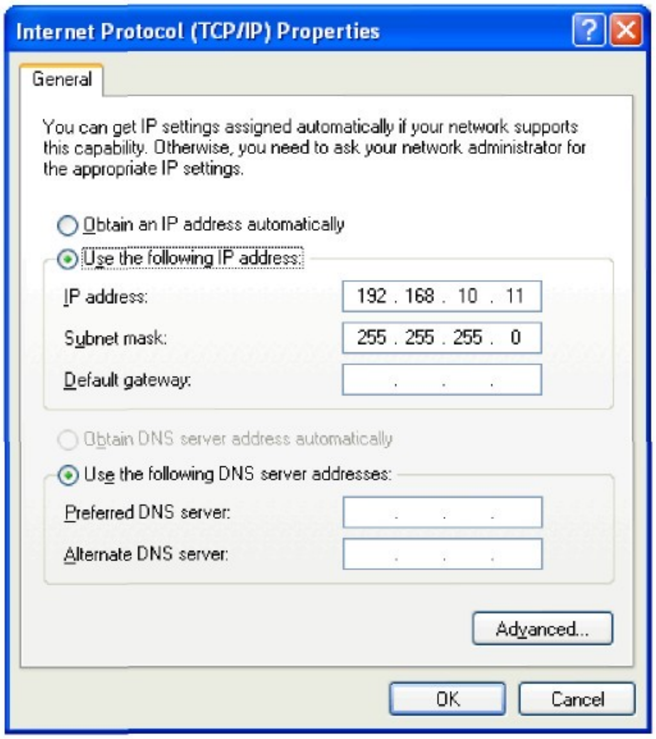
Then click OK. The new network appears in the preferred networks list, but it’s still not active.



From the Wireless Network connection Properties dialog box, select the General Tab as shown below.

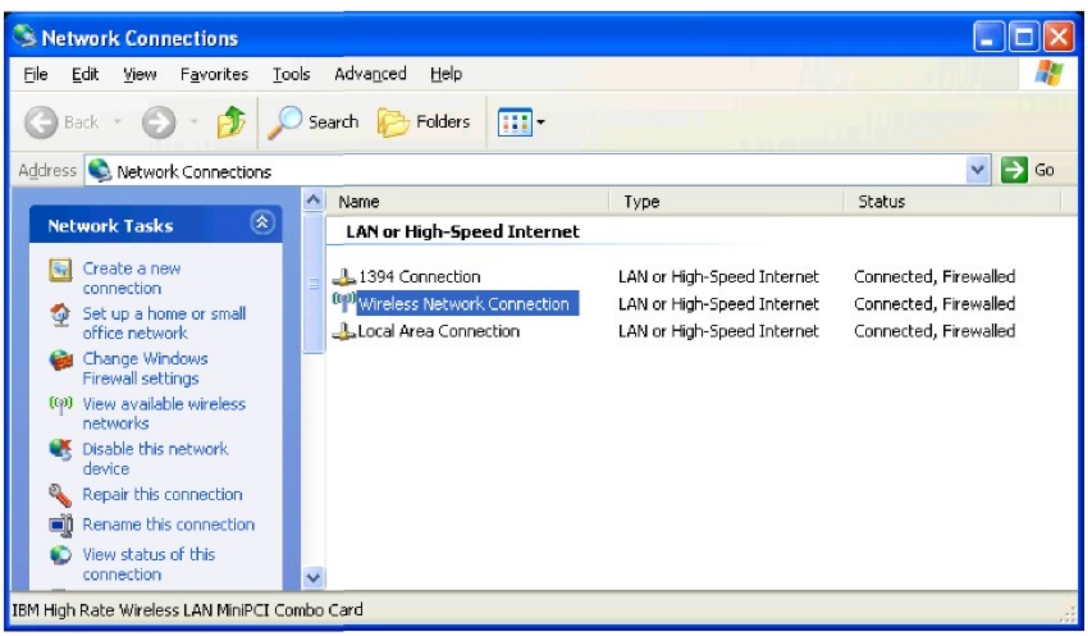


Select the Internet Protocol (TCP/IP) item, and click Properties. The following dialog box appears:



Select the “Use the following IP Address” option and enter the IP address and the subnet mask. Make sure that your IP address is not duplicated in the network. Otherwise the connection would be refused.

Click OK, then OK again and wait a few seconds until the wireless connection shows its status as “Connected” (see the picture below).

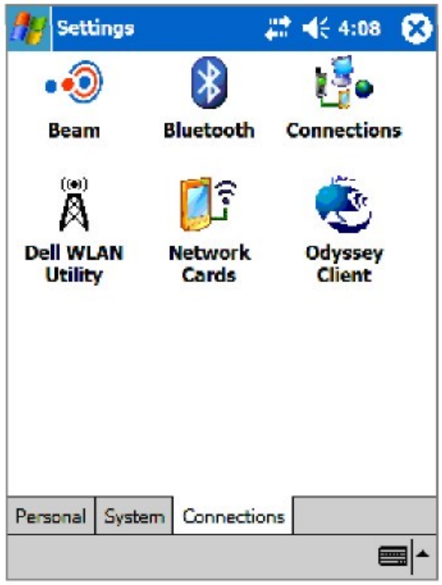


The message below will appear from the status bar.

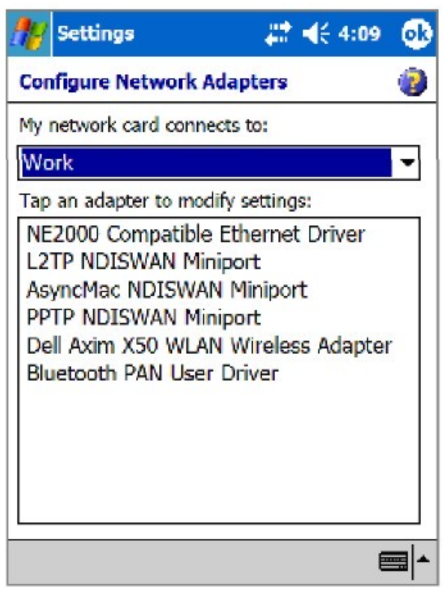
NOTE: if the wireless network connection is protected by a firewall, make sure that the port 8164 is open to the TCP and UDP traffic.

9.3.2. Configuring the client (Pocket PC)

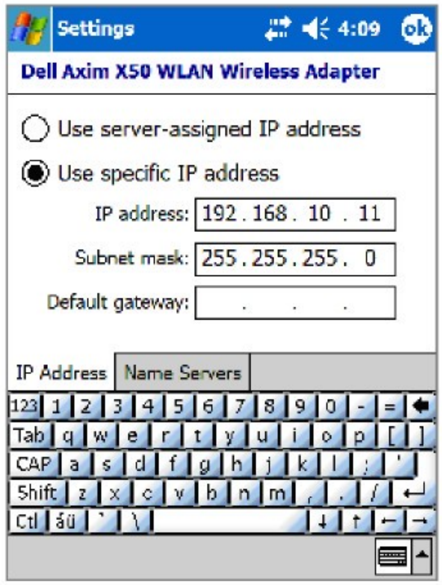
From the Windows Mobile Start menu, select the Settings item. Then select the Connection Tabs as shown below.



Select the Connections item. The screen below appears:



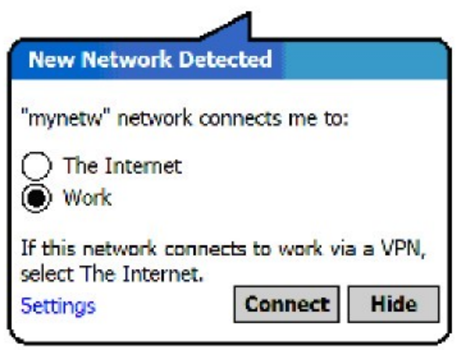
Make sure that the “My network card connects to:” option is “Work”. Then from the list of network adapters (you may have different models on your Pocket PC) select your wireless Adapter.



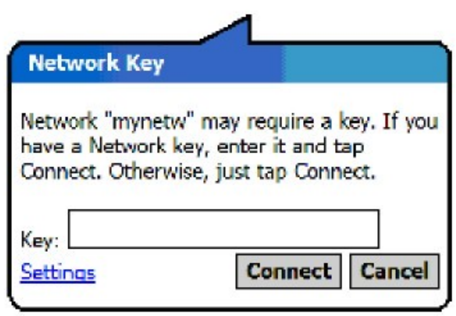
Select the "Use specific IP address" option and enter the address and the subnet mask. The subnet mask must be the same as the one entered in the host TCP/IP configuration. The IP address must be different from the host's.

Then click OK and disable/enable the wireless card to let the configuration changes take effect.

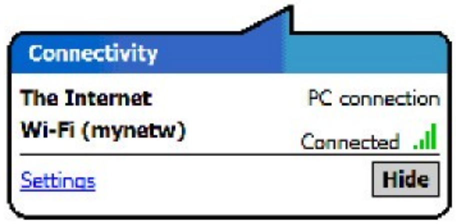
When the new changes take effect, the wireless connection starts and the message box below shows up:



Select the "Work" option and click connect. You will be asked to enter the network key as shown below



Enter the network key you entered in the host connection configuration (see above) and click connect. If the connection starts the dialog box below appears.



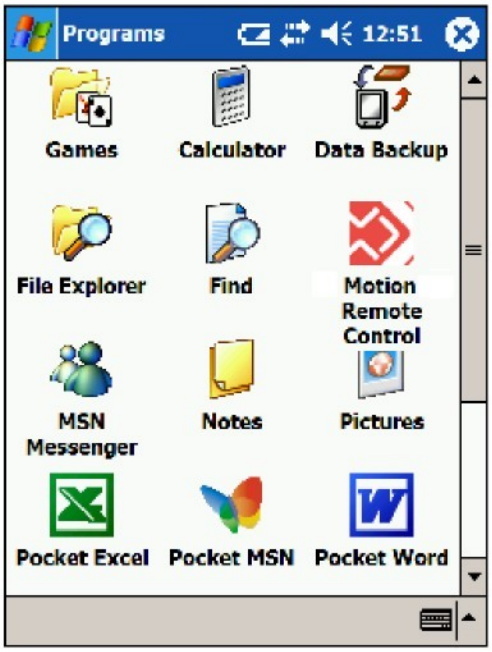
9.4. Using the Motion Studio Remote Control

9.4.1. Starting the remote server on the Host

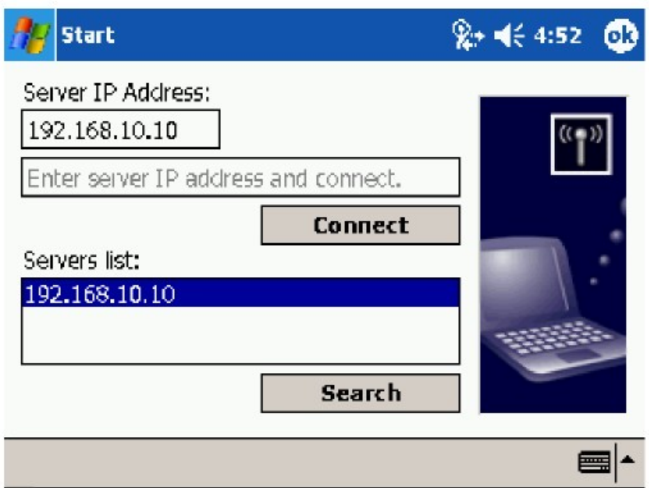
1. Run Motion Studio.
2. From the main menu select Options.
3. From the General Options dialog box, select the Camera Tab and check the “Enable Remote Connection server” option. Then click OK.
4. Open a camera window.
5. From the Camera menu, select the “Start remote Connection Server” item.

9.4.2. Running the Remote control on the Pocket PC

1. From the Pocket PC Start menu, select Programs.
2. From the Programs window, select the "Motion Studio Remote Control" application and start it.

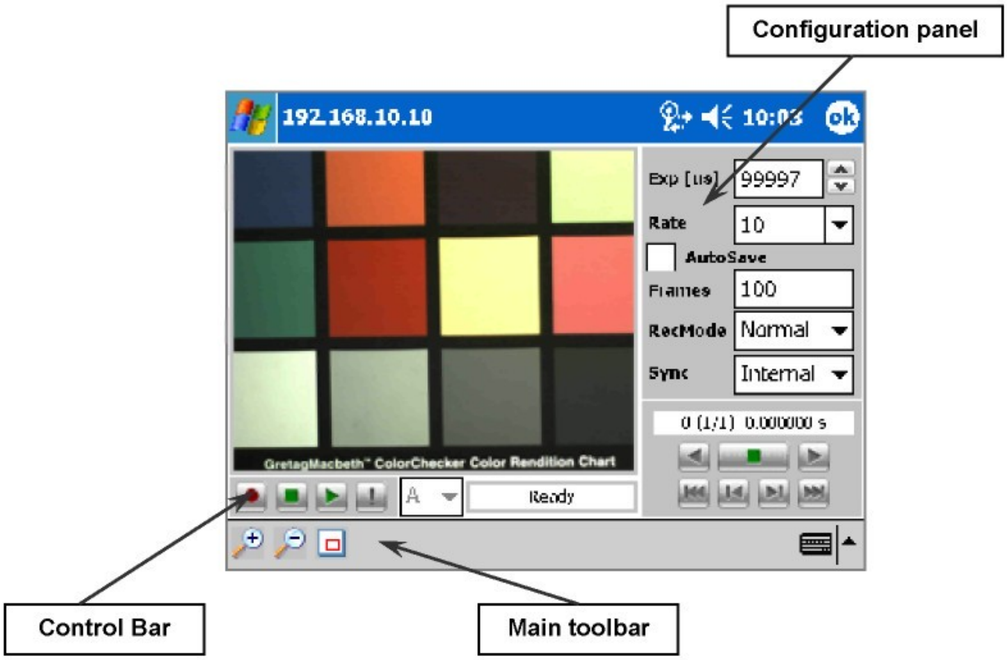


The program will set the Pocket PC landscape view and show the following screen.



To start the connection to the host, a valid IP address needs to be entered. If the host connection is active and the server has been activated in Motion Studio, the IP address is shown in the Servers list. Otherwise, click the Search button. If no IP address appears in the servers list, enter the address manually. Then click connect and start the remote control.

The application includes a configuration panel on the right, a control bar on the bottom and a main toolbar.



The **Control Bar** has camera control functions including the following:

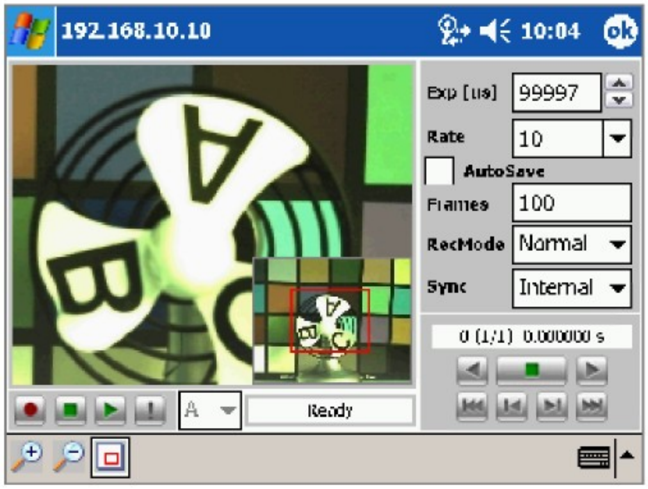
- Record.
- Stop/Snap a single image.
- Live play of images.
- Trigger.
- Camera selection: if more than one camera is active on the host, you may select which camera to operate.

The **Configuration Panel** allows configuring the main camera parameters, such as:

- Exposure.
- Acquisition rate.
- Automatic save on images after acquisition (auto-save flag).
- Number of frames to record.
- Record mode.
- Sync mode.
- The Playback controls work like other familiar media player controls. The controls include the following:
  - Directional play
  - Forward or reverse
  - Step forward and reverse
  - Skip to first or last frame
  - Stop play

The **Main Toolbar** has controls for zoom and pan the image, including the following:

- Zoom In.
- Zoom Out.
- Toggle the pan window.

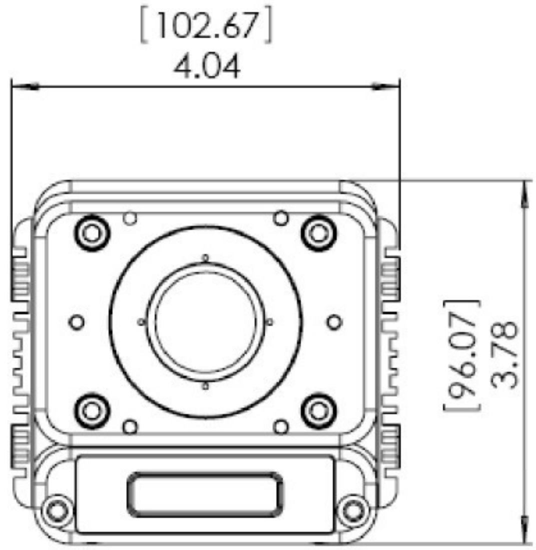


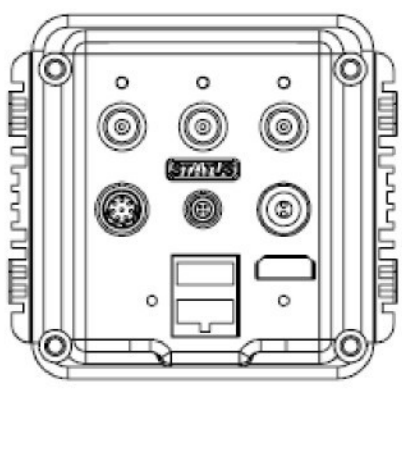
When the pan window is enabled, the user may drag the red rectangle and locate the area of the image to display.

10. Appendix A Product Specifications

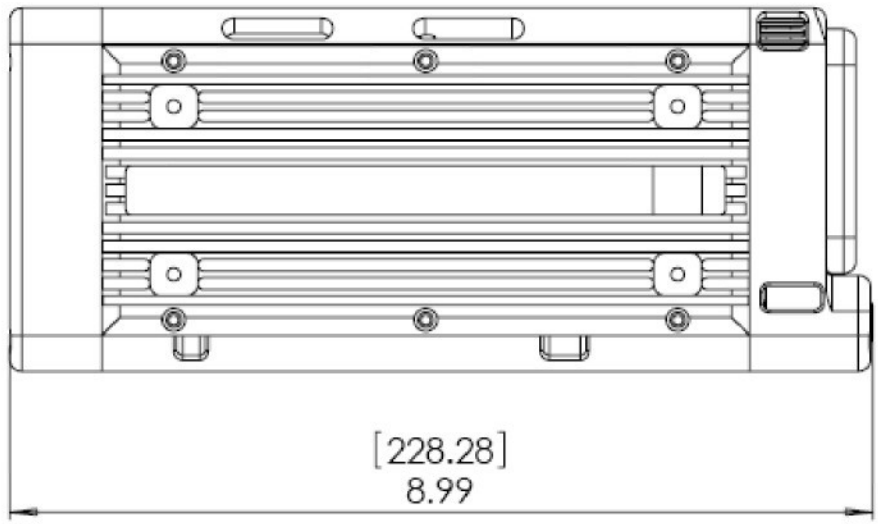
10.1. Mechanical and hole mounts (MotionPro Y)

10.1.1. Front and back views

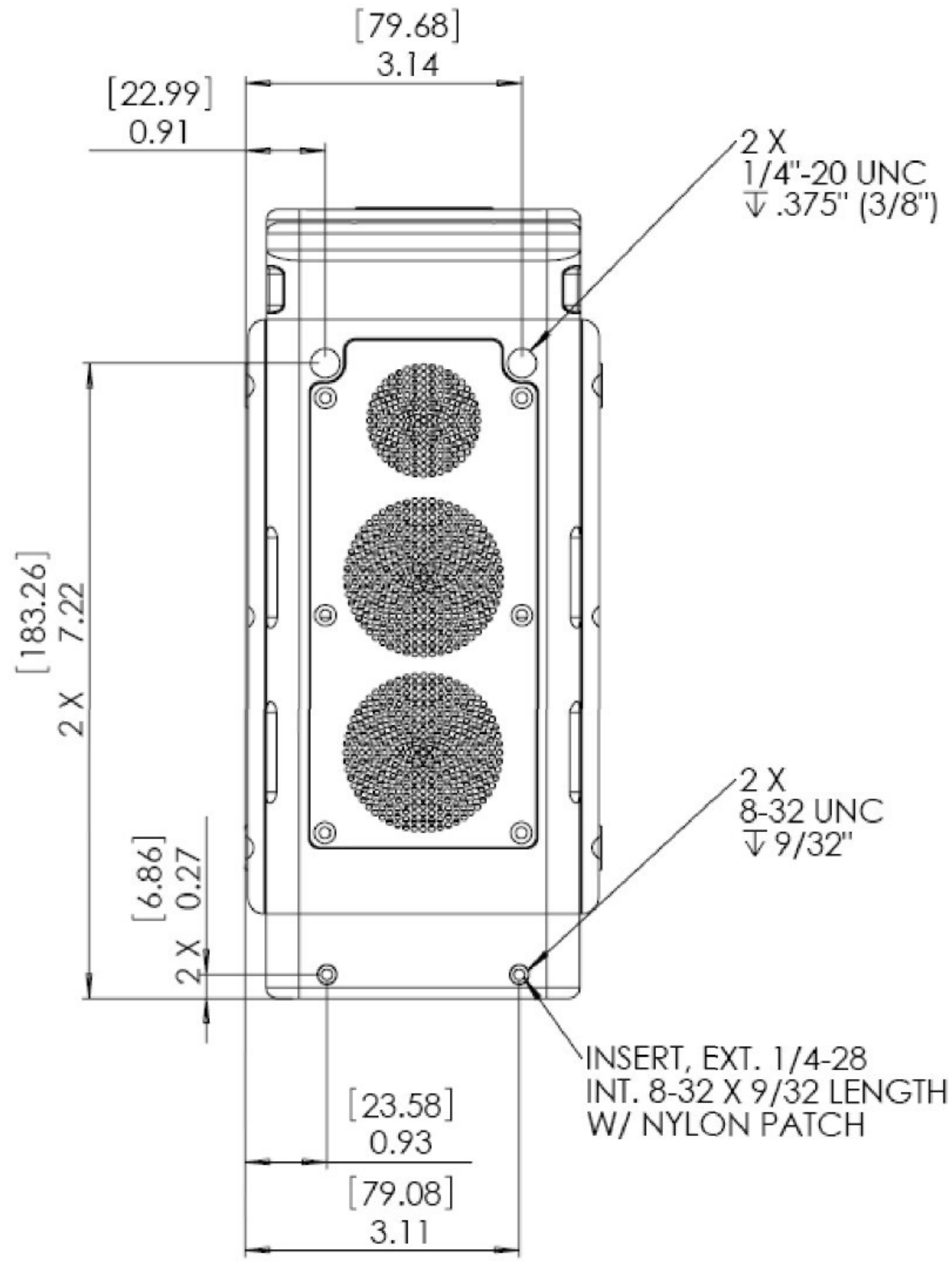




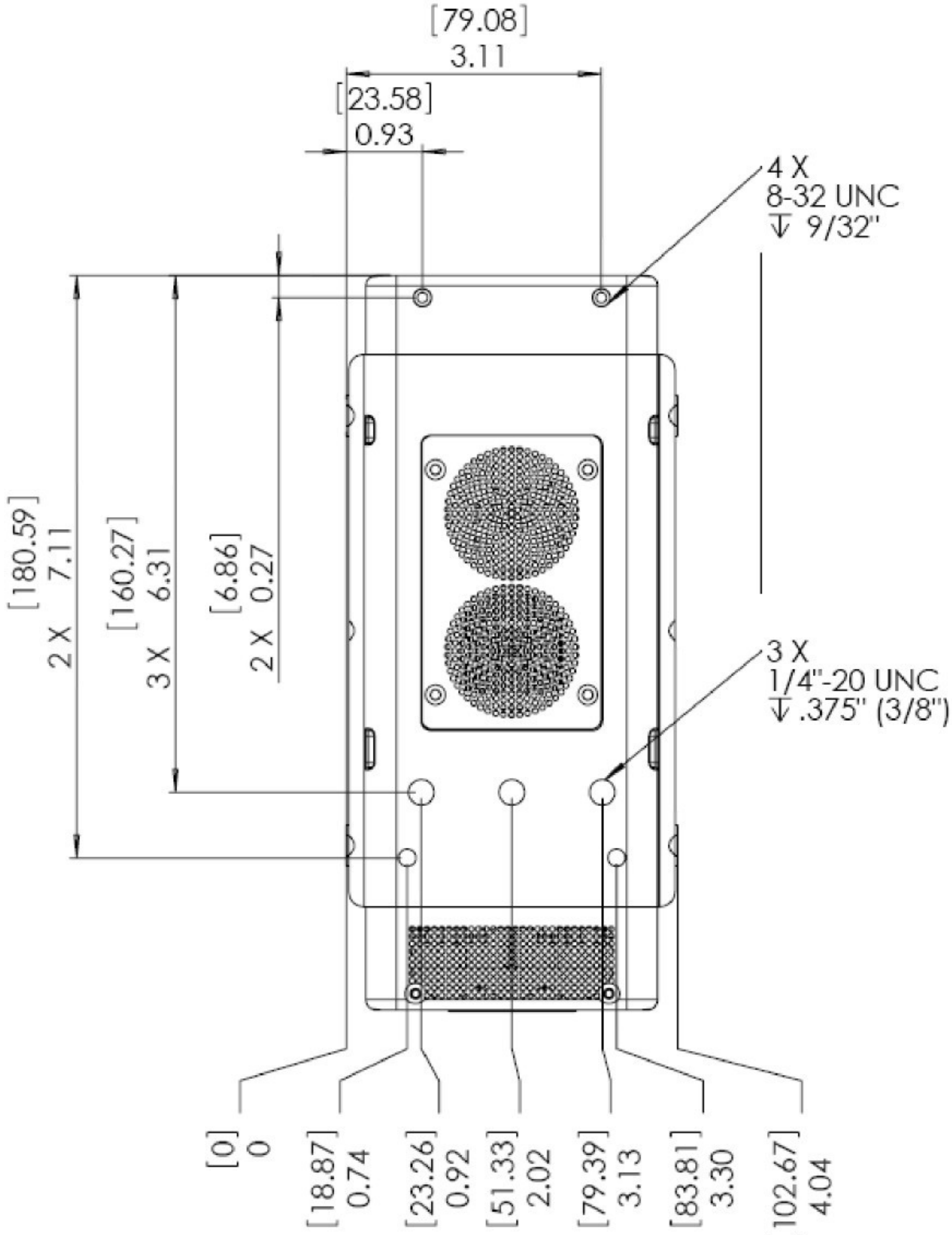
10.1.2. Side view



10.1.3. Top View

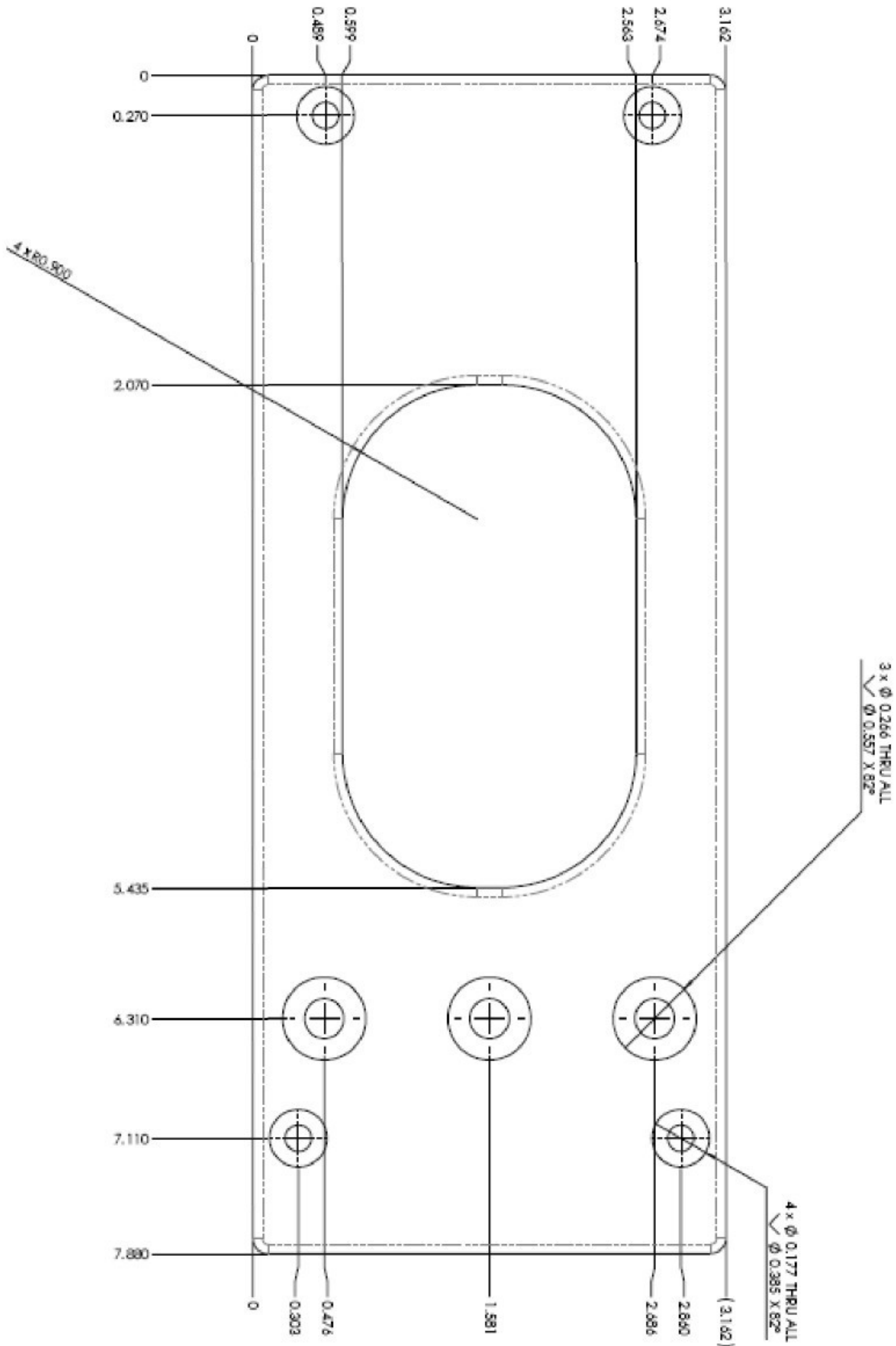


10.1.4. Bottom view

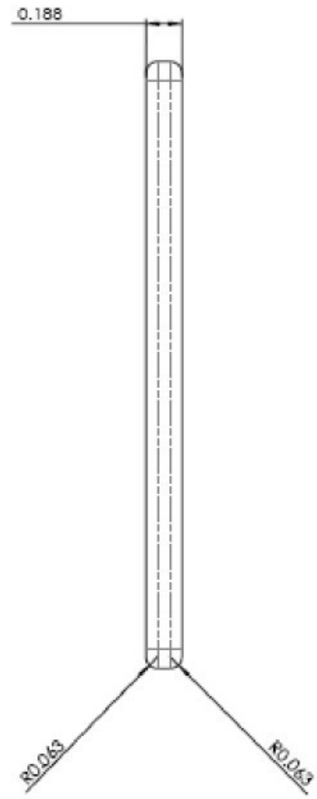


10.1.5. Mounting plate

Front View

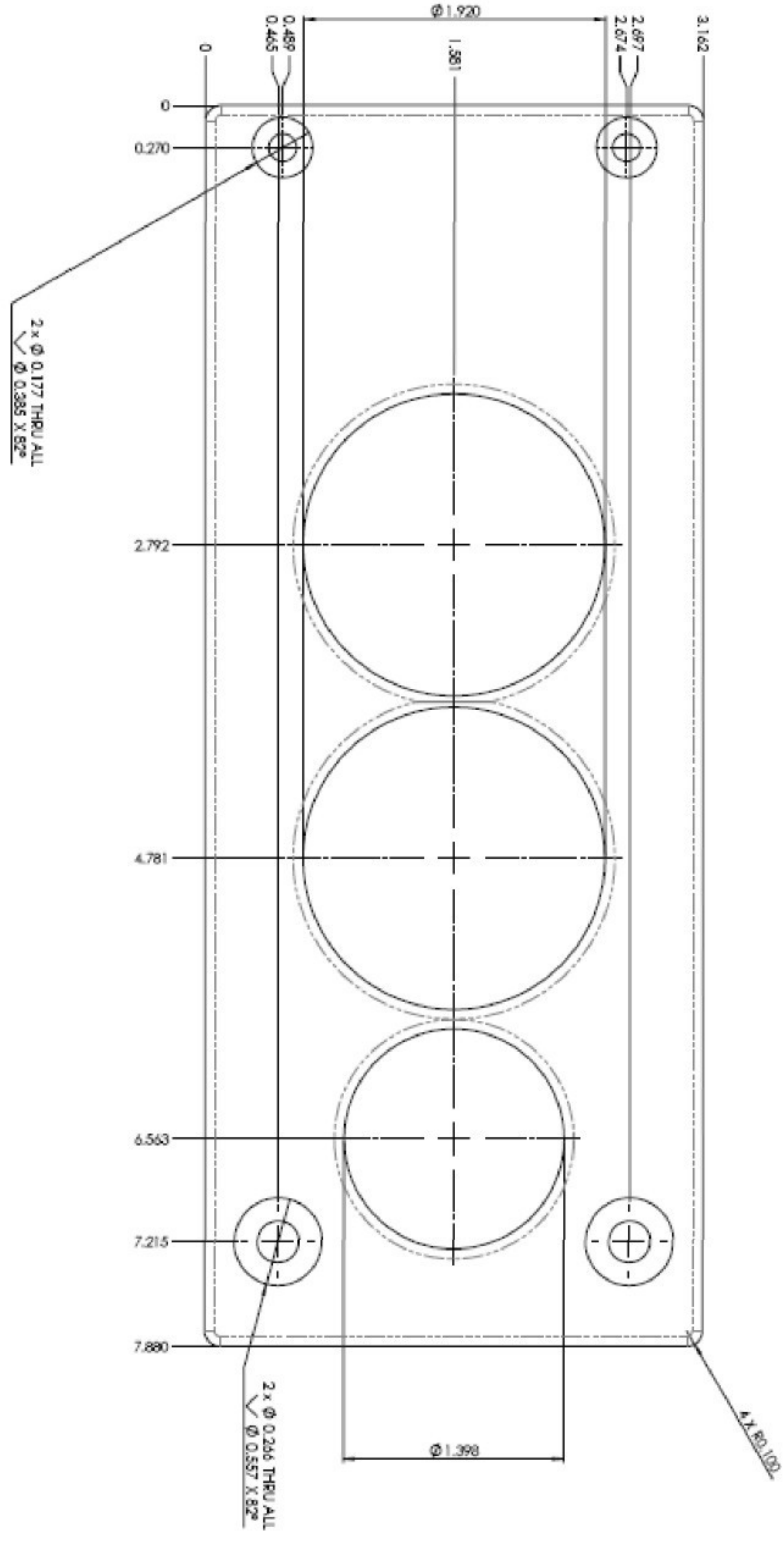


Side view



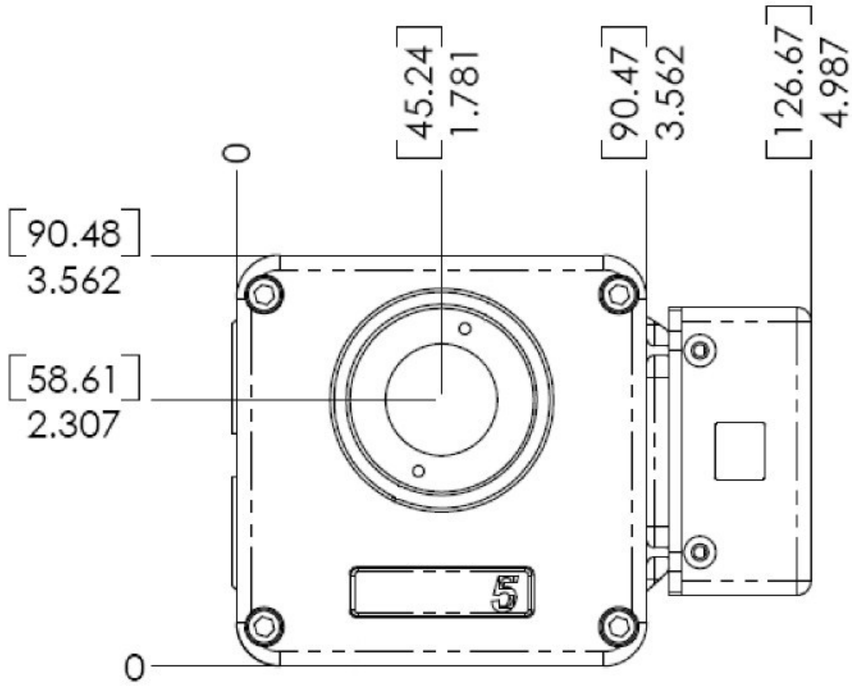
10.1.6. Top mounting plate

Front view

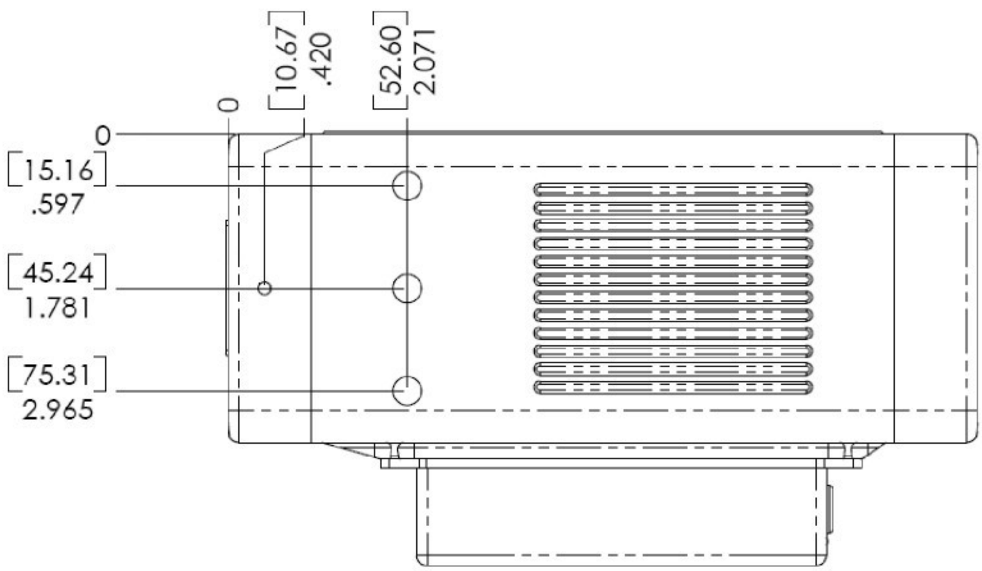


Side view

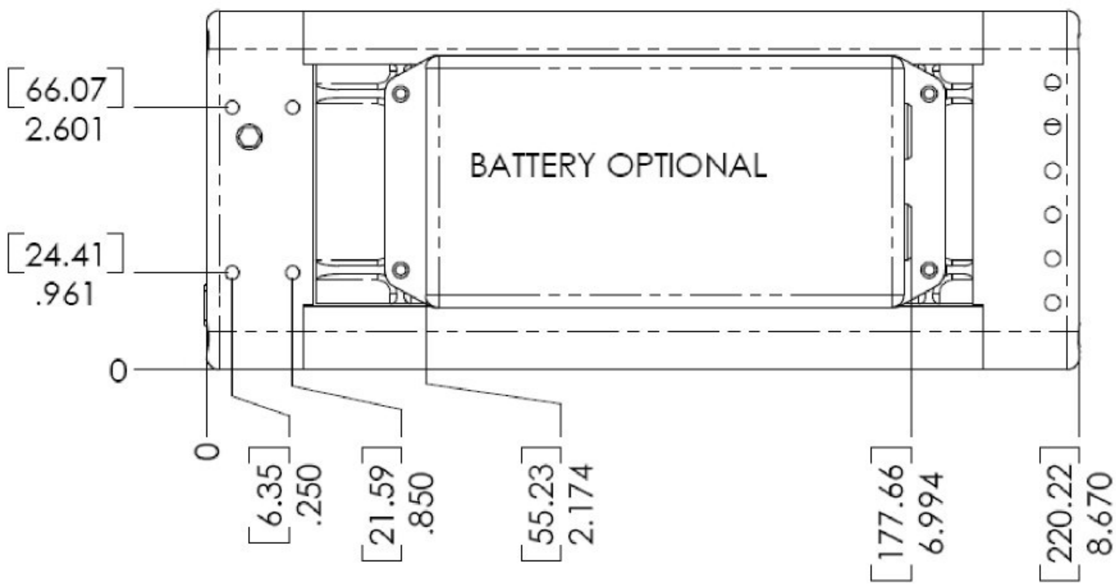
10.1.7. First revision camera front view



10.1.8. First Revision camera top view

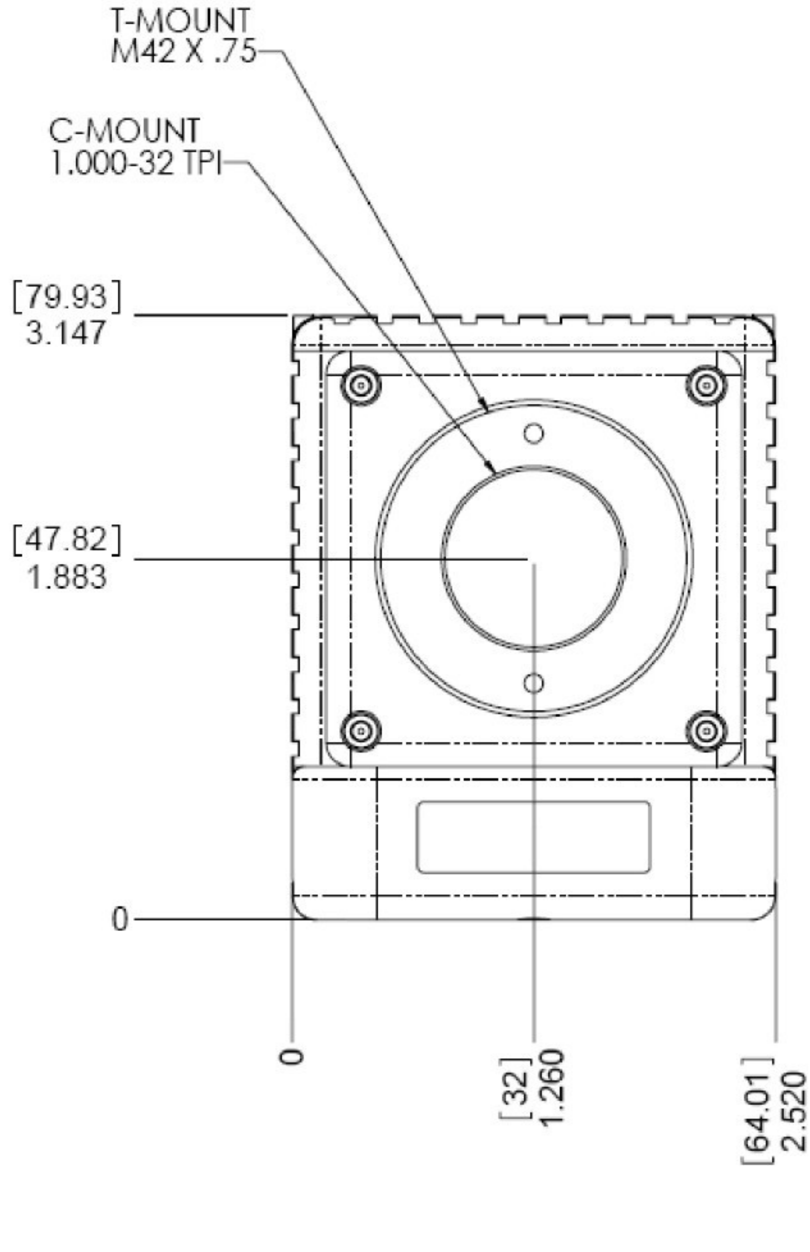


10.1.9. First revision camera side view

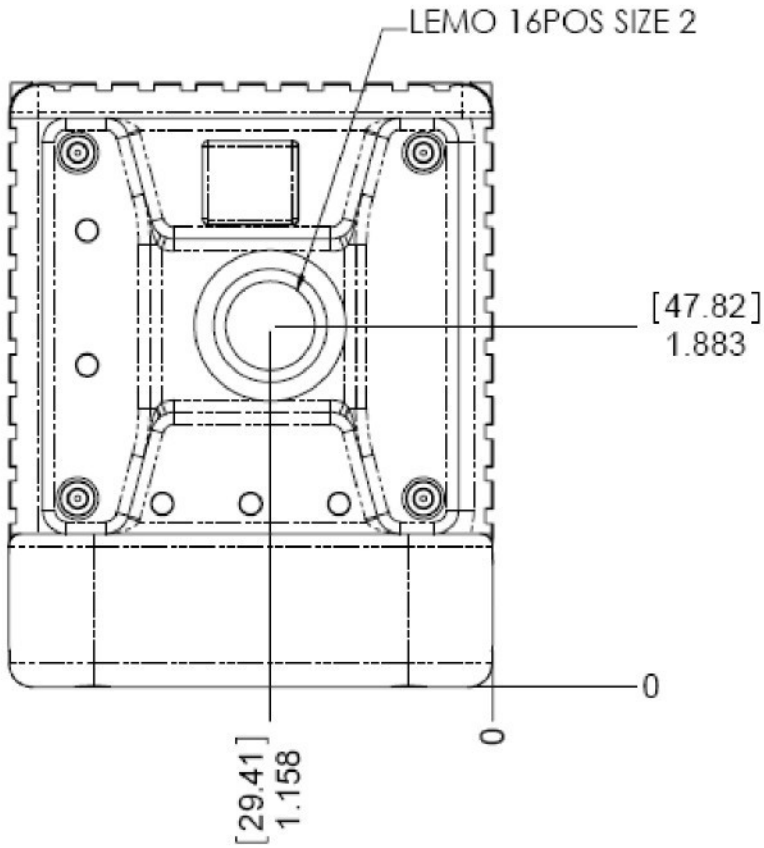


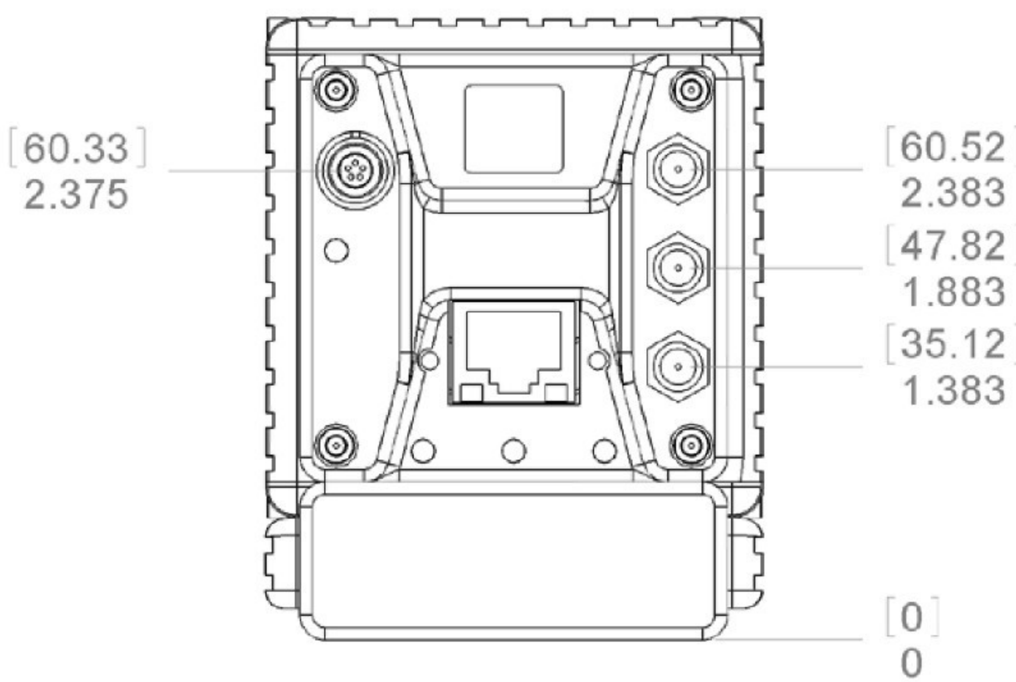
10.2. Mechanical and hole mounts (MotionXtra N)

10.2.1. Front View

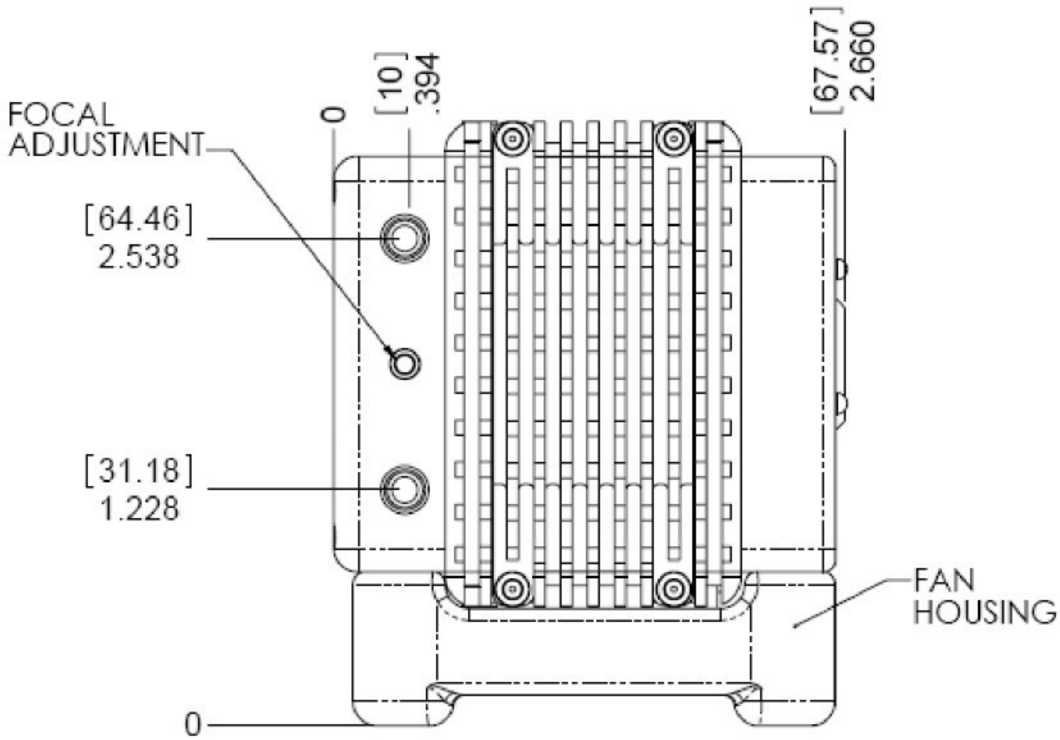


10.2.2. Back Views

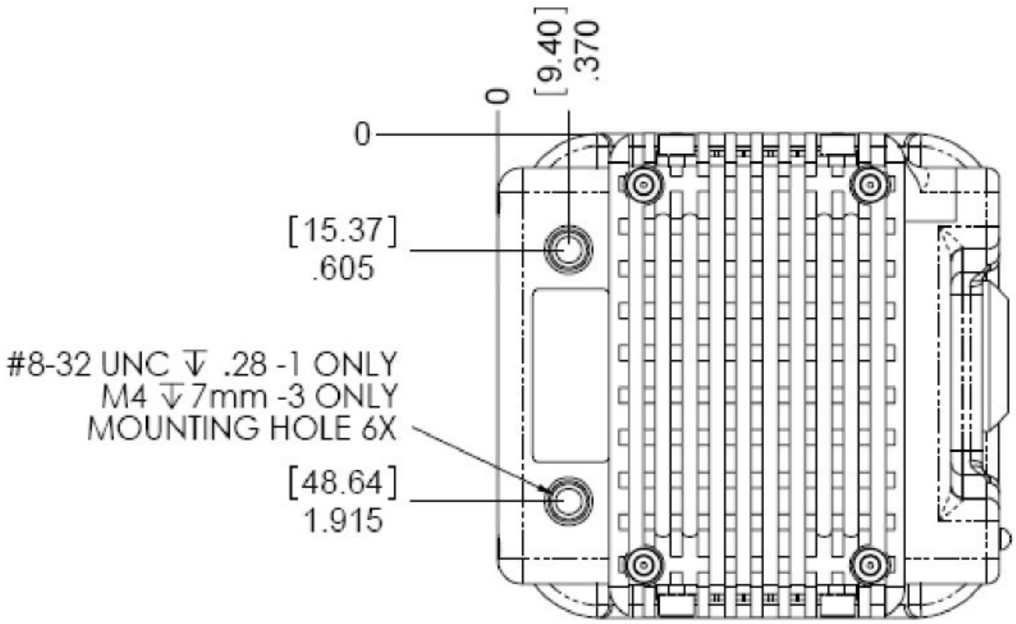




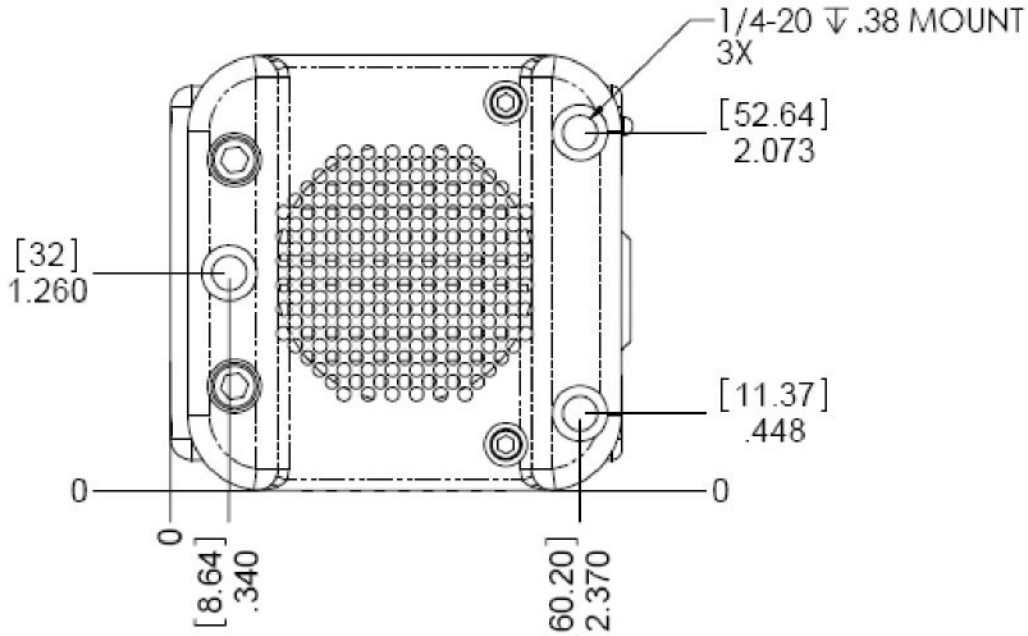
10.2.3. Side View



10.2.4. Top View

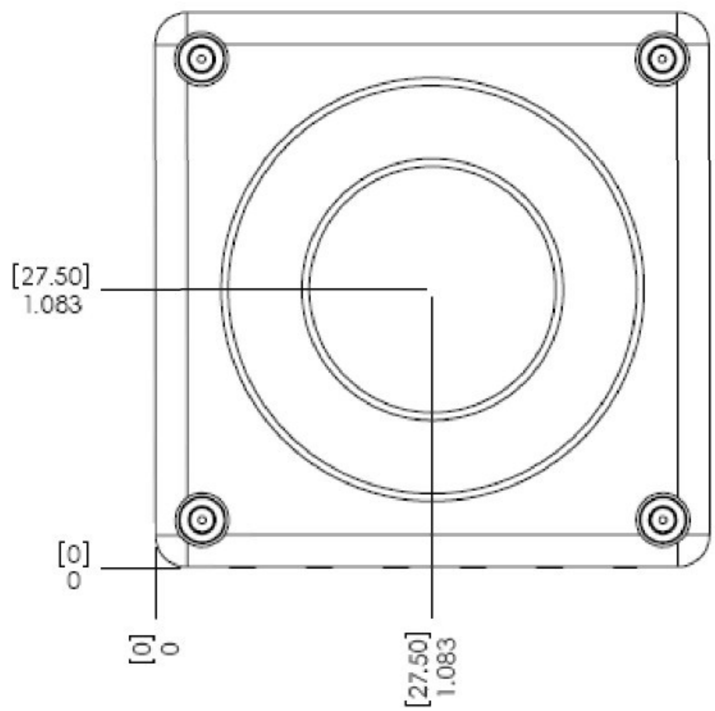


10.2.5. Bottom View

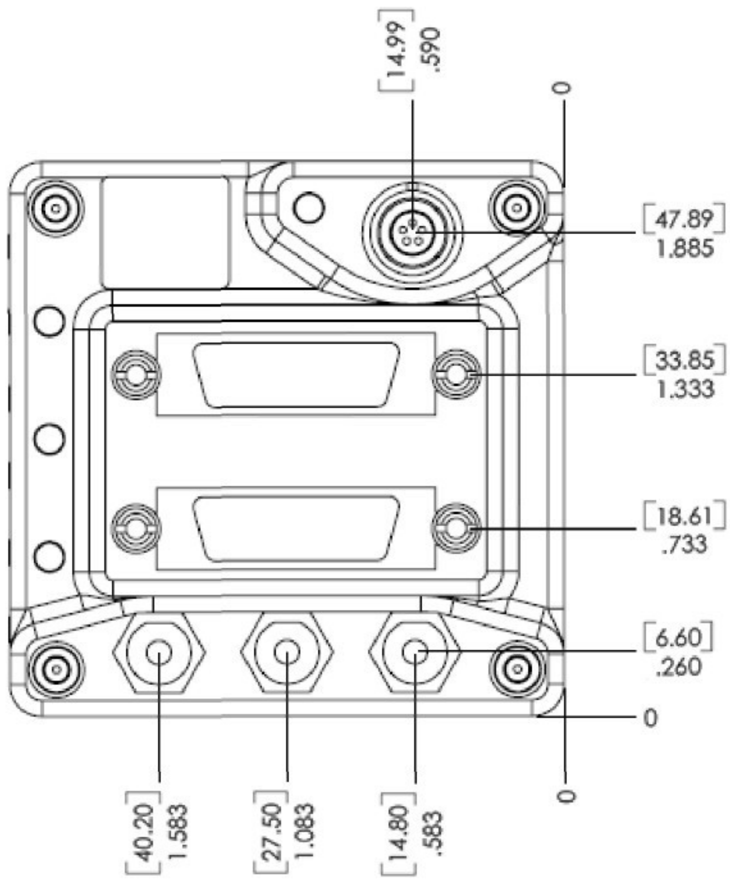


10.3. Mechanical and hole mounts (MotionScope M)

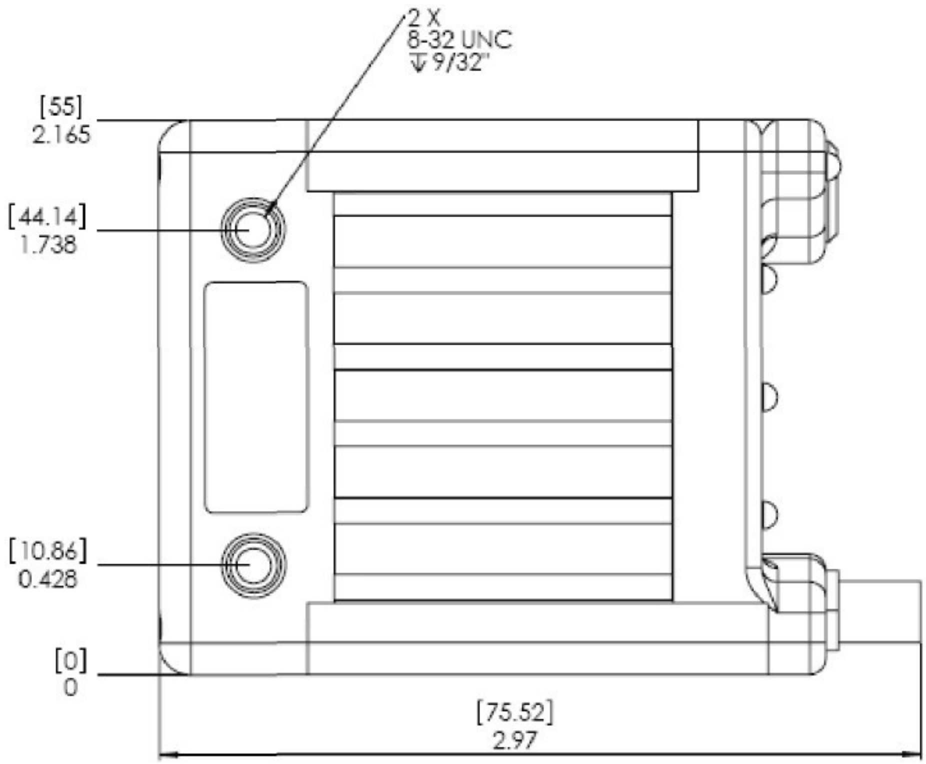
10.3.1. Front View



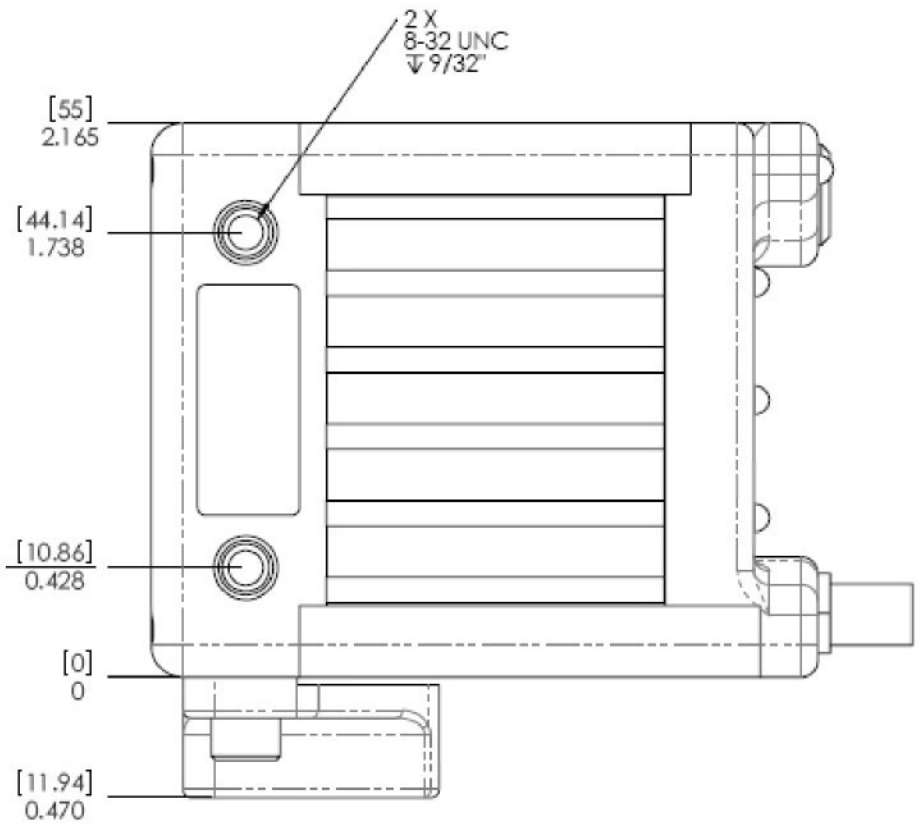
10.3.2. Back View



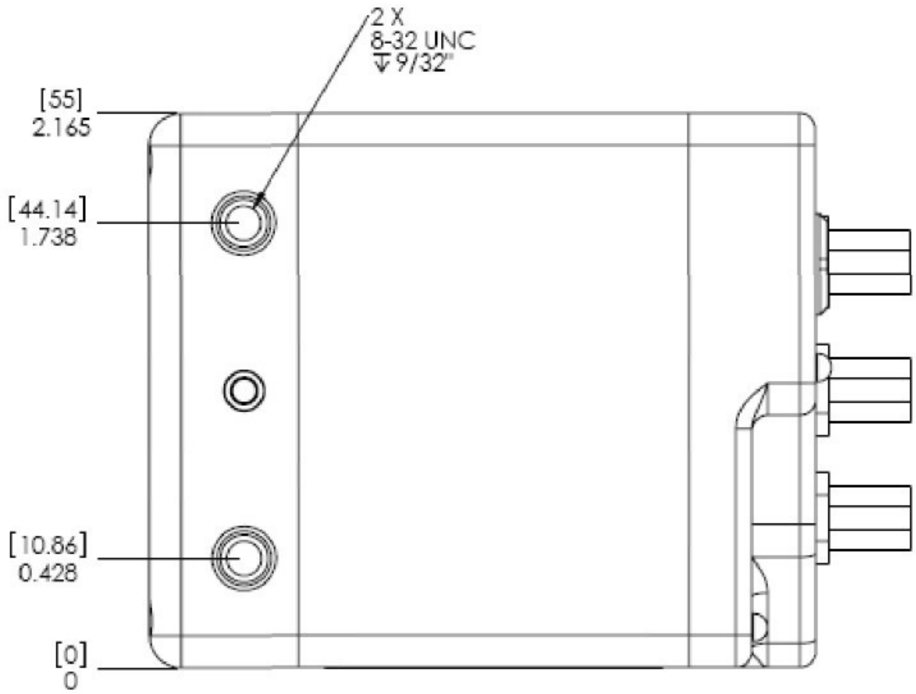
10.3.3. Side View



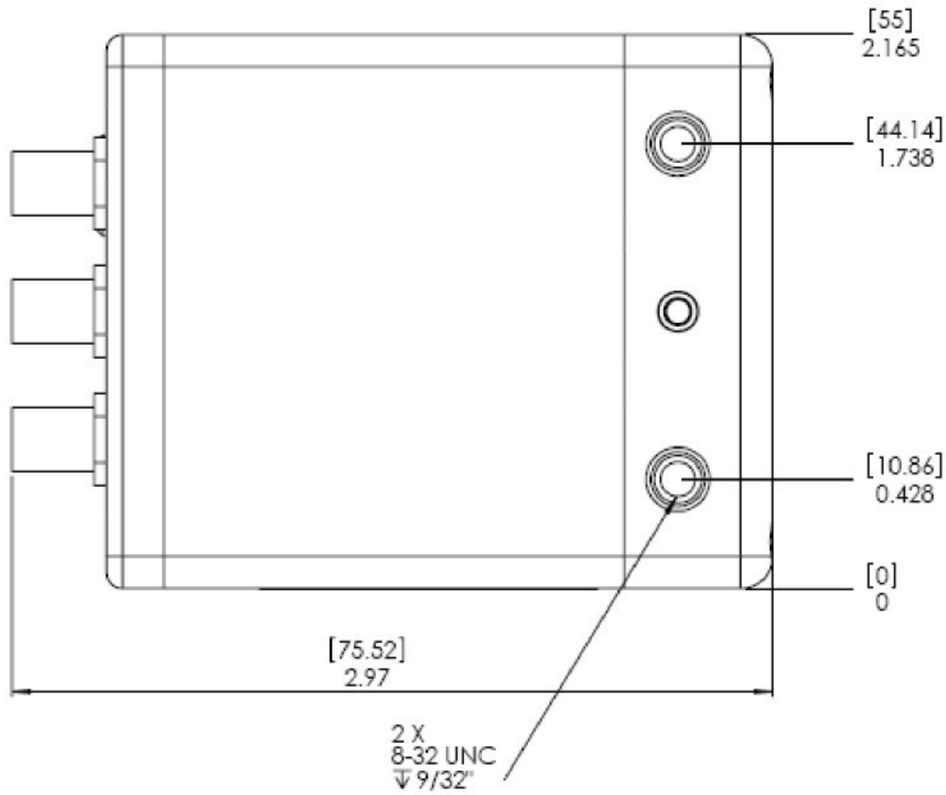
10.3.4. Side View with mount



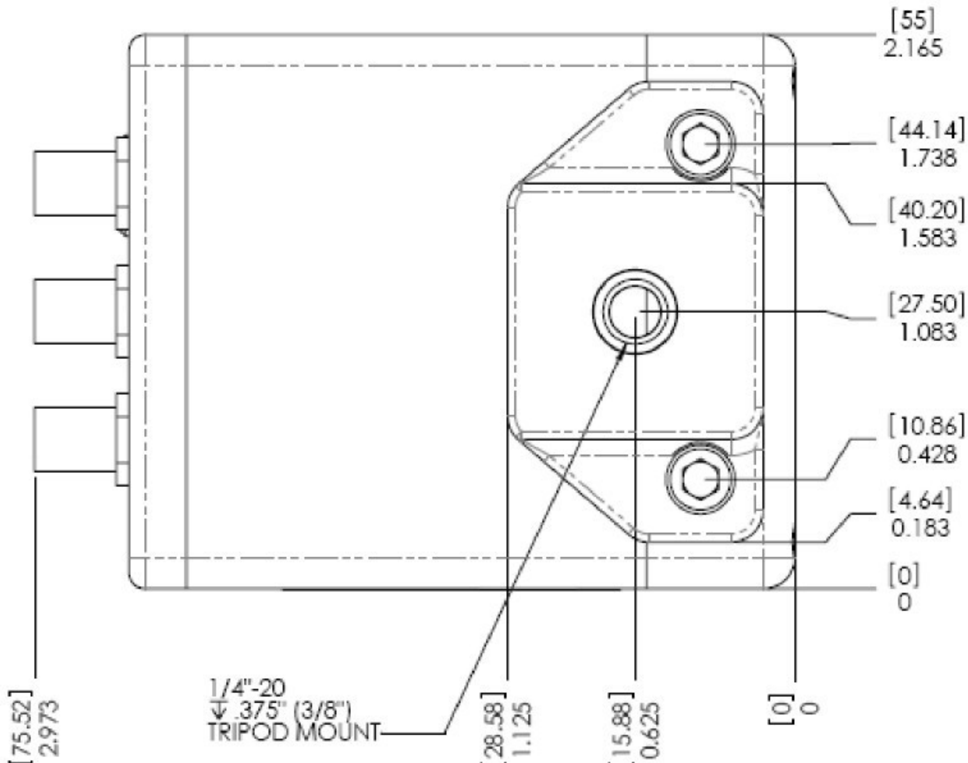
10.3.5. Top View



10.3.6. Bottom View

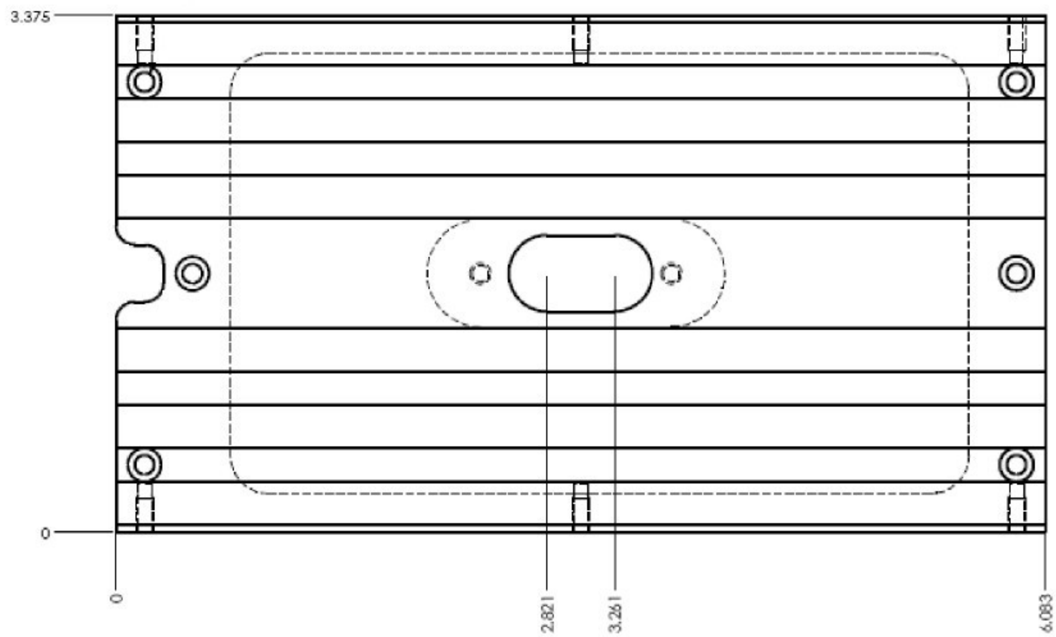


10.3.7. Bottom View with Mount

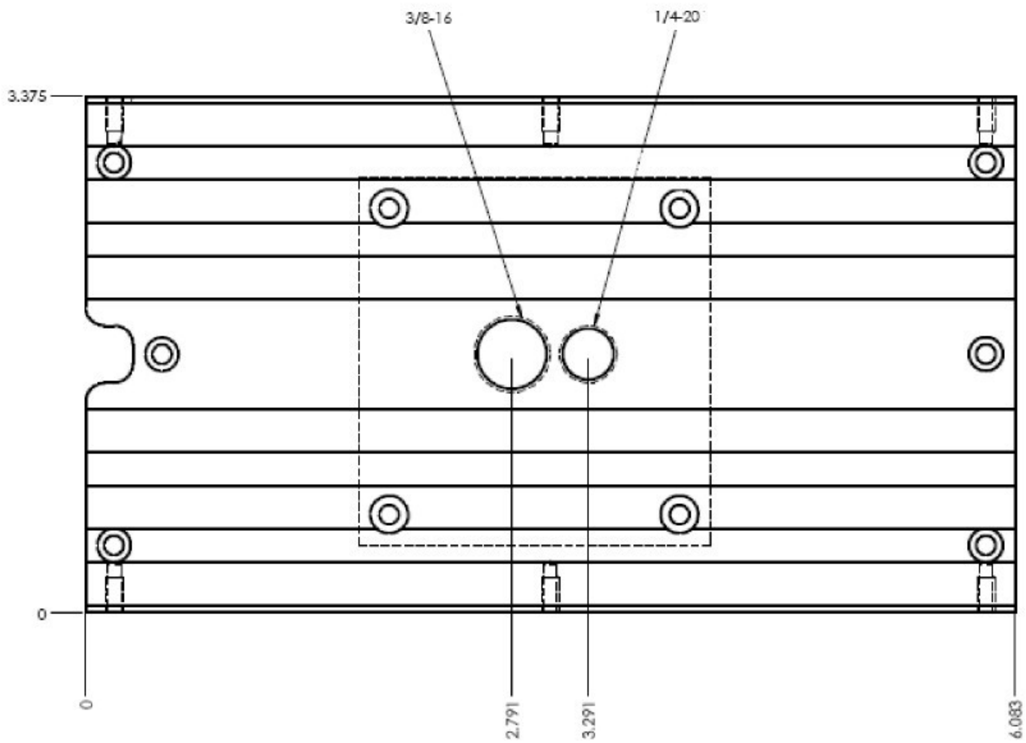


10.4. Mechanical and hole mounts (MotionPro X)

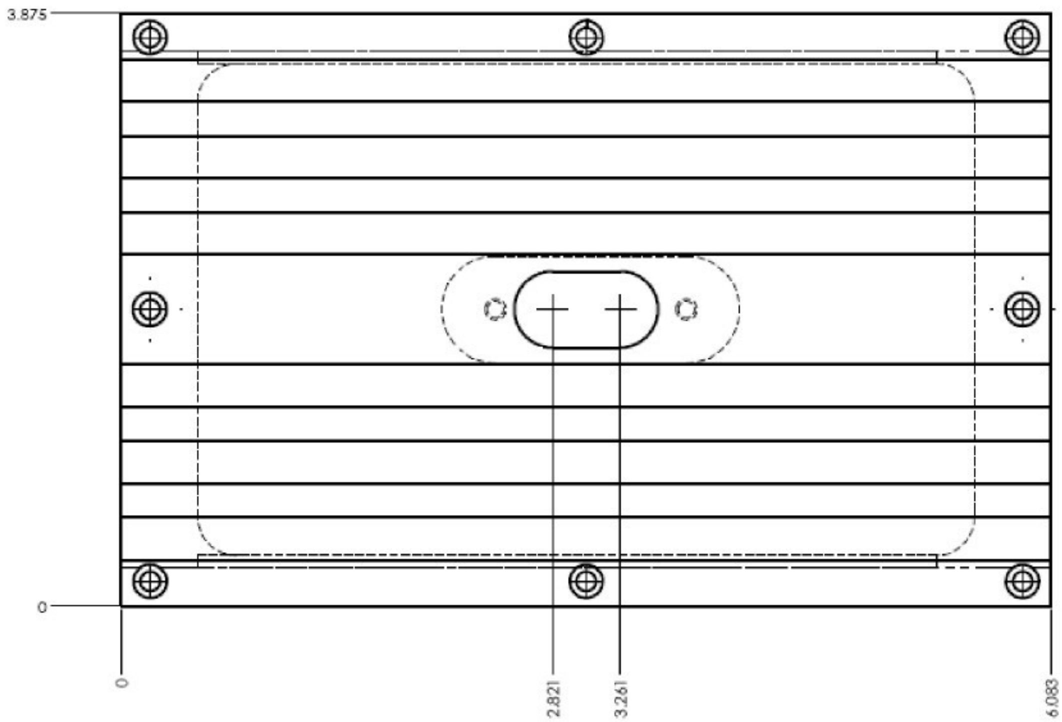
10.4.1. Top view



10.4.2. Bottom view



10.4.3. Side view



10.5. Camera specifications

10.5.1. Y-Series

MotionPro Y					
	Y3	**Y4L**	**Y5**	**Y6**	**Y7 HD**
Sensor Array	1280 x 1024	1016 x 1016	2352 x 1728	1504 x 1128	1920 x 1080
Pixel Size	12 µ	13.7 µ	7 µ	16 µ	12.5 µ
Sensor Bit Depth	10	10	10	12	12
Image Bit Depth (mono)	8/10-bit	8-bit	8/10-bit	8/12-bit	8/12-bit
Image Bit Depth (color)	24/30-bit	24-bit	24/30-bit	24/36-bit	24/36-bit
Sensor Dynamic Range	59 dB	60 dB	60 dB	66 dB	66 dB
Analog to Digital conversion	10-bit	10-bit	10-bit	12-bit	12-bit
Sensor aspect ratio	5:4	1:1	4:3	4:3	16:9
Pixel Fill factor	40 %	40 %	55 %	67%	67%
Center to center spacing	12 µm	14 µm	7 µm		
Sensitivity (mono)	3,000 ASA	6,000 ASA	2,000 ASA	9,000 ASA	9,000 ASA
Sensitivity (color)	1,000 ASA	2,000 ASA	800 ASA	3,000 ASA	3,000 ASA
Internal clock	90 MHz	140 MHz	90 MHz	66 MHz	66 MHz
Memory Configuration	4GB, 8GB, 16GB				
Configurable binning	1x1, 2x2, 3x3, 4x4				
Shutter	Global, 1 µs min exp, efficiency>99				
Synchronization	BNC 3.3 V CMOS				
Cable	Standard USB 2.0 to 5 m, 15 m with optical repeater CAT. 5 or CAT. 6 Ethernet cable				
Operating system	Windows 2000, XP, Vista, MAC OS X				
Gain	Programmable gains and high/middle/low 8-bit selection				
Size and weight	90.5 x 90.5 x 320 mm, 2.0 kg (2.45 kg with optional battery)				
Lens Mount	C-mount, F-mount (Nikon and Canon)				
Tripod Mount	Standard ¼-20 photo mounts				

10.5.2. N-Series

MotionXtra N			
	N3 / N3L	N4/ N4L	N5
Sensor Array	1280 x 1024	1016 x 1016	2352 x 1728
Pixel Size	12 µm	13.7 µm	7 µm
Bit Depth	10	10	10
Image Bit Depth	8, 9, 10-bit mono 24, 27, 30-bit color	8, 9, 10-bit mono 24, 27, 30-bit color	8,9,10-bit mono 24,27,30-bit color
Sensor Dynamic Range	59 dB	60 dB	60 dB
Analog to Digital conversion	10-bit	10-bit	10-bit
Sensor aspect ratio	5:4	1:1	4:3
Pixel Fill factor	40 %	40 %	55 %
Center to center spacing	12 µm	14 µm	7 µm
Sensitivity (mono)	3,000 ASA	6,000 ASA	2,000 ASA
Sensitivity (color)	1,000 ASA	2,000 ASA	800 ASA
Internal clock	90 MHz	70 MHz	90 MHz
Compression	Yes	No	Yes
Memory Configuration	1.25 GB, 2.5 GB	1.25 GB	1.25 GB, 2.5 GB
Configurable binning	1x1, 2x2, 3x3, 4x4		
Shutter	Global, 1 µs min exp, efficiency>99		
Synchronization	SMA 3.3 V CMOS		
Cable	CAT. 5 or CAT. 6 Ethernet cable		
Operating system	Windows 2000, XP, Vista, MAC OS X		
Gain	Programmable gains and high/middle/low 8-bit selection		
Size and weight	75 x 55 x 55 mm, 320 g		
Lens Mount	C-mount, F-mount (Nikon and Canon)		
Tripod Mount	Standard ¼-20 photo mounts		

10.5.3. M-Series

MotionScope M		
	M3	M5
Sensor Array	1280 x 1024	2320 x 1728
Pixel Size	12 µ	7 µ
Bit Depth	10	10
Image Bit Depth	8-bit mono 24-bit color	8-bit mono 24-bit color
Sensor Dynamic Range	59 dB	60 dB
Analog to Digital conversion	10-bit	10-bit
Sensor aspect ratio	5:4	4:3
Pixel Fill factor	40 %	55 %
Center to center spacing	12 µ	7 µ
Sensitivity (mono)	3,000 ASA	2,000 ASA
Sensitivity (color)	1,000 ASA	800 ASA
Internal clock	72 MHz	40 MHz
Memory configuration	Computer memory	
Video Output Type	Full camera Link	
Video Data Output Mode	10 taps 8 bit each	
Configurable binning	1x1, 2x2, 3x3, 4x4	
Shutter	Global, 1 µs min exp, efficiency>99	
Synchronization	SMA 3.3 V CMOS	
Cables	2 MDR 26-pin Camera Link Cables	
Operating system	Windows XP, Vista	
Gain	Programmable gains	
Size and weight	75 x 55 x 55 mm, 320 g	
Lens Mount	`C-mount, F-mount (Nikon and Canon)	

10.5.4. X-Series

X-Stream XS - MotionPro HS/X				
	XS-3 / HS1	**HS3 / X3**	**X4**	**X5**
Sensor Array	1280 x 1024	1280 x 1024	512 x 512	2352 x 1728
Pixel Size	12 µ	12 µ	16 µ	7 µ
Bit Depth	10	10	10	10
Image Bit Depth	8/10-bit mono 24/30-bit color	8-bit mono 24-bit color	8-bit mono 24-bit color	8-bit mono 24-bit color
Sensor Dynamic Range	59 dB	59 dB	57 dB	60 dB
Analog to Digital conversion	10-bit	10-bit	10-bit	10-bit
Sensor aspect ratio	5:4	5:4	1:1	4:3
Pixel Fill factor	40 %	40 %	62 %	55 %
Center to center spacing	12 µ	12 µ	16 µ	7 µ
Internal clock	85/90 MHz	90 MHz	90 MHz	66 MHz
Memory Configuration	1GB,2GB,4GB			
Configurable binning	1x1, 2x2, 3x3, 4x4			
Shutter	Global, 1 µs min exp, efficiency>99			
Synchronization	BNC 3.3 V CMOS			
Cable	Standard USB 2.0 to 5 m, 15 m with optical repeater CAT. 5 or CAT. 6 Ethernet cable			
Operating system	Windows 2000, XP, MAC OS X			
Gain	Programmable gains and high/middle/low 8-bit selection			
Size and weight	95 x 95 x 162 mm, 1.9 kg			
Lens Mount	C-mount, F-mount (Nikon and Canon)			
Tripod Mount	Standard ¼-20 photo mounts			

10.6. Frame Rates

In the tables below, the max frame rates for some camera resolutions.

MotionPro Y3 / MotionXtra N3		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1280 x1024	1,040	2,080
1280 x 864	1,230	2,470
1280 x 768	1,380	2,770
1280 x 512	2,080	4,160
1280 x 384	2,770	5,540
1280 x 256	4,160	8,290
1280 x 128	8,290	16,400
1280 x 64	16,400	32,200
1280 x 32	32,200	62,300
1280 x 16	62,300	116,500

MotionPro Y4L		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1016 x 1016	4,500	9,000
1016 x 768	6,000	11,800
1016 x 512	8,950	17,200
1016 x 256	17,200	32,200
1016 x 128	32,200	56,000
1016 x 64	56,000	92,000
1016 x 32	92,000	132,000
1016 x 16	132,000	

MotionPro Y5 / MotionXtra N5		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
2352 x1728	500	999
2352 x 1128	765	1,530
2352 x 1024	840	1,685
2352 x 512	1,685	3,360
2352 x 256	3,360	6,700
2352 x 128	6,700	13,280
2352 x 64	13,280	26,125

MotionPro Y6		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1504 x 1128	1,200	N/A
1280 x 1024	1,500	N/A
1024 x 768	2,400	N/A
800 x 600	4,100	N/A
640 x 480	5,900	N/A
512 x 512	6,750	N/A
480 x 320	11,200	N/A

256 x 256	21,500	N/A
128 x 128	65,000	N/A

MotionPro Y7 HDiablo		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1920 x 1080	1,500	N/A
1280 x 720	3,300	N/A
768 x 432	8,000	N/A

MotionXtra N3L		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1280 x1024	500	N/A
1280 x 768	665	N/A
1280 x 512	1000	N/A
1280 x 256	2000	N/A
1280 x 128	4000	N/A
1280 x 64	8000	N/A
1280 x 32	16000	N/A
1280 x 16	32000	N/A

MotionXtra N4L		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1016 x 1016	2,000	N/A
1016 x 768	2,660	N/A
1016 x 512	3,970	N/A
1016 x 256	7,775	N/A
1016 x 128	14,900	N/A
1016 x 64	27,500	N/A
1016 x 32	48,000	N/A
1016 x 16	75,000	N/A

MotionXtra N4		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1016 x 1016	3,000	6,000
1016 x 768	4,040	7,950
1016 x 512	6,000	11,800
1016 x 256	11,800	22,500
1016 x 128	22,500	42,000
1016 x 64	42,000	70,000
1016 x 32	70,000	100,000
1016 x 16	100,000	200,000

MotionScope M3		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1280 x1024	520	1,040
1280 x 768	690	1,380
1280 x 512	1,040	2,080

1280 x 256	2,080	4,140
1280 x 128	4,140	8,200
1280 x 64	8,200	16,100
1280 x 32	16,100	31,100
1280 x 16	31,100	58,200

MotionScope M5		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
2320 x1728	170	N/A
2320 x 1376	215	N/A
2320 x 1024	285	N/A
2320 x 768	380	N/A
2320 x 512	570	N/A
2320 x 256	1,135	N/A
2320 x 128	2,240	N/A
2320 x 64	4,370	N/A
2320 x 32	8,350	N/A
2320 x 16	15,350	N/A

X-Stream XS3 / MotionPro HS1	
Resolution	**Max Rate [fps]**
1280 x 1024	660
1280 x 768	880
1280 x 512	1,320
1280 x 256	2,640
1280 x 128	5,270
1280 x 64	10,400
1280 x 32	20,500
1280 x 16	39,800

MotionPro X3 / HS3		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
1280 x1024	1,040	2,080
1280 x 768	1,380	2,770
1280 x 512	2,080	4,160
1280 x 256	4,160	8,290
1280 x 128	8,290	16,400
1280 x 64	16,400	32,200
1280 x 32	32,200	62,300
1280 x 16	62,300	116,500

MotionPro X4 / HS4		
Resolution	**Rate [fps]**	**Plus™ Rate [fps]**
512 x 512	5,130	10,100
512 x 256	10,100	20,100
512 x 128	20,100	38,500
512 x 64	38,500	73,500
512 x 32	73,500	132,000

512 x 16	132,000	200,000

MotionPro X5		
Resolution	Rate [fps]	Plus™ Rate [fps]
2352 x 1728	250	500
2352 x 1376	314	628
2352 x 1024	422	842
2352 x 768	563	1120
2352 x 512	842	1,675
2352 x 256	1,675	3,310
2352 x 128	3,310	6,470
2352 x 64	6,470	12,360
2352 x 32	12,360	22,720
2352 x 16	22,720	39,100

10.7. Intensified X cameras

In the table below, you may find the optical specifications at 20 C and nominal operating conditions.

Parameter	Value
Input diameter	17.5 mm min
Input window	Glass (AVG)
Cathode sensitivity for white light	500 µA/lm min
at 800 nm	43 mA/lm min
at 850 nm	33 mA/lm min
Phosphor	P46
Output window	Fiber-optic
Luminance gain	1590 cd/m²/lx min
E.B.I.	0.25 µlx max
Shading	45 % max
Resolution	36 lp/mm min
Gate-able	Yes (down to 50 ns)
Iris delay	16.6 ns max

11. Appendix B - Image Formats

Motion Studio supports the image formats listed in the table below:

Format	Ext	Pixel Depth	Notes
Tagged Image File Format - TIFF™	**TIF**	8/16/24/48	Gray/Color
Windows™ Bitmap	**BMP**	8/24	Gray/Color
JPEG File	**JPG**	8/24	Gray/Color
Portable network Graphics – PNG	**PNG**	8/16/24/48	Gray/Color
Type 2 Bayer	**TP2**	8	Gray/Bayer
Falcon eXtra RAW	**FBA**	8/24	Gray/Color
Multi-Page TIFF	**MPT**	8/16/24/48	Gray/Color
Multi-page Raw	**MPR**	8/16/24/48	Gray/Color (IDT proprietary)
Multi-page Compressed	**MCF**	8/16/24/48	Gray/Color (IDT proprietary)
Audio Video Interleaved (AVI)	**AVI**	8/24	Gray/Color
Apple Quick Time (MOV)	**MOV**	8/24	Gray/Color
Weinberger Sequence (BLD)	**BLD**	8/24	Gray/Color
Moving Picture Experts Group (MPEG)	**MPG**	8/24	Gray/Color (MPEG-1)
MPEG H.264 (Advanced Video Coding)	**MP4**	8/24	Gray/Color (MPEG-4)

11.1. Formats Overview

11.1.1. TIFF Format

TIFF pictures store a single raster image at any color depth. TIFF is arguably the most widely supported graphic file format in the printing industry. It supports optional compression, and is not suitable for viewing in Web browsers.

The TIFF format is an extensible format, which means that a programmer can modify the original specification to add functionality or meet specific needs. This can lead to incompatibilities between different types of TIFF pictures.

11.1.2. Bitmap Format

Windows bitmap files are stored in a device-independent bitmap (DIB) format that allows Windows to display the bitmap on any type of display device. The term "device independent" means that the bitmap specifies pixel color in a form independent of the method used by a display to represent color. The default filename extension of a Windows DIB file is .BMP.

For further information, refer to the Microsoft™ documentation.

11.1.3. JPEG Format

The name "JPEG" stands for Joint Photographic Experts Group, the name of the committee that created the standard. The JPEG standard specifies both the codec, which defines how an image is compressed into a stream of bytes and decompressed back into an image, and the file format used to contain that stream. The compression method is usually lossy, meaning that some visual quality is lost in the process and cannot be restored. However there are variations on the standard baseline JPEG that are lossless.

11.1.4. PNG Format

PNG is an extensible file format for the lossless, portable, well-compressed storage of raster images. PNG provides a patent-free replacement for GIF and can also replace many common uses of TIFF. Indexed-color, grayscale, and true-color images are supported, plus an optional alpha channel. Sample depths range from 1 to 16 bits.

PNG is designed to work well in online viewing applications, such as the World Wide Web, so it is fully stream-able with a progressive display option. PNG is robust, providing both full file integrity checking and simple detection of common transmission errors. Also, PNG can store gamma and chromaticity data for improved color matching on heterogeneous platforms.

PNG is a platform-independent format that supports a high level of lossless compression, alpha channel transparency, gamma correction, and interlacing. It is supported by more recent Web browsers.

11.1.5. TP2 format

Type-2 format is the Redlake raw data format. It’s the format used to save raw image data.

11.1.6. FBA format

The FBA format is the Falcon eXtra raw data format. It’s the format used by Falcon eXtra software to save raw image data. For further information, please refer to falcon documentation.

11.1.7. AVI Format

The Microsoft AVI file format is a Resource Interchange File Format (RIFF) file specification used with applications that capture, edit, and play back audio-video sequences. In general, AVI files contain multiple streams of different types of data. Most AVI sequences use both audio and video streams. A simple variation for an AVI sequence uses video data and does not require an audio stream. The program supports uncompressed (raw) and compressed AVI. The INDEO 5.11 codec is installed on 32-bit Windows. The format is not supported in MAC OS.

11.1.8. MOV Format

The Apple Quick Time MOV file format is used with applications that capture, edit, and play back audio-video sequences. In general, MOV files contain multiple streams of different types of data. Most MOV sequences use both audio and video streams. A simple variation for an MOV sequence uses video data and does not require an audio stream. The format is not supported on Windows OS.

11.1.9. BLD Format

The BLD format corresponds to the file format RAW, which is known from several applications. Each BLD file needs a corresponding descriptor file in the DSC format. In a BLD file all single frames of an image sequence are stored successively uncompressed in the block format. The data is in binary raw data format (e.g. for grayscale pictures 1 Byte per Pixel). The descriptor file (DSC) belonging to the BLD file is a line-orientated ASCII file, in which values like e.g. resolution, frames or date are stored. The DSC file can be created with any text editor.

11.1.10. MPEG Format

MPEG, which stands for “Moving Picture Experts Group”, is a name of family standards used for coding audio-visual in a digital compressed format. MPEG is a generic means of compactly representing digital video and audio signals for consumer distribution. The basic idea is to transform a stream of discrete samples into a bit-stream of tokens which takes less space, but is just as filling to the eye. The graphic library implements the MPEG-1 format, the standard on which such products as video CD and MP3 are based. The compression/decompression technique implemented in MPEG is “**lossy**”, e.g. some amount of data information is lost.

11.1.11. MPEG H.264 (Advanced Video Coding)

It is also known as MPEG-4 Part 10 or MPEG-4 AVC (Advanced Video Coding). The intent of the H.264 project was to create a standard capable of providing good video quality at substantially lower bit rates than previous standards without increasing the complexity of design so much that it would be impractical or excessively expensive to implement. An additional goal was to provide enough flexibility to allow the standard to be applied to a wide variety of applications on a wide variety of networks and systems, including low and high bit rates, low and high resolution video and broadcast. *The MPEG H.264 format is supported only on a 32 bit Windows OS with installed QuickTime™.*

11.1.12. Multi-page Raw Format (MRF)

Multi-page Raw Format (MRF) is an uncompressed IDT proprietary file format. Multiple raster images are stored in a single file. The format is described below.

Each MRF file contains a file header, an image header and an array of bytes that defines the image data bits. The image raster data is not compressed and stored in the file “as it is”. Both 8 bit and 16 bit data are supported. The file structures are the following:

11.1.12.1. File header

A MRF file begins with a file header structure containing the IDT raw file signature.

```
typedef struct _RCFILE_HEADER
{
    char szSign[8];             // IDT raw file signature
    unsigned long nReserved;    // reserved
} RCFILE_HEADER, *PRCFILE_HEADER;
```

Members

szSign[8]: a 8 char buffer which contains the signature "IDT-MRF". It indicates that the remainder of the file contains a Multiple Raw File.

nReserved: this field is reserved for future use.

11.1.12.2. Image header

The file header is followed by the image header which contains general information about the data stream.

```
typedef struct _RCIMG_HEADER
{
    unsigned long nSize;           // size of this header
    unsigned long nPages;          // number of pages/frames
    unsigned long nWidth;          // image width
    unsigned long nHeight;         // image height
    unsigned long nBPP;            // bits per pixel
    unsigned long userData[64];    // user data array
} RCIMG_HEADER, *PRCIMG_HEADER;
```

Members

nSize: size of the structure in bytes. It should be 84.

nPages: number of images contained in the file

nWidth: width of each image in pixels.

nHeight: height of each image in pixels.

nBPP: number of bits per pixels (8, 10 or12)

userData: an array of 64 unsigned long that may be user by the user to store other information.

11.1.12.3. Data arrays

The image header is followed by the images data. Images are stored contiguously in uncompressed format.

11.1.13. Multi-page Compressed Format (MCF)

Multi-page Compressed Format (MCF) is a compressed IDT proprietary file format. Multiple raster images are stored in a single file. The format is described below.

Each MCF file contains a file header, an image header and an array of bytes that defines the image data bits. The image raster data is compressed and stored in the file. Both 8 bit and 16 bit data are supported. The file structures are the following:

11.1.13.1. File header

A MRF file begins with a file header structure containing the IDT raw file signature.

```
typedef struct _RCFILE_HEADER
{
    char szSign[8];              // IDT raw file signature
    unsigned long nReserved;     // reserved
} RCFILE_HEADER, *PRCFILE_HEADER;
```

Members

szSign[8]: a 8 char buffer which contains the signature "IDT-MCF". It indicates that the remainder of the file contains a Multiple Compressed File.

nReserved: this field is reserved for future use.

11.1.13.2. Image header

The file header is followed by the image header which contains general information about the data stream.

```
typedef struct _RCIMG_HEADER
{
    unsigned long nSize;          // size of this header
    unsigned long nPages;         // number of pages/frames
    unsigned long nWidth;         // image width
    unsigned long nHeight;        // image height
    unsigned long nBPP;           // bits per pixel
    unsigned long userData[64];   // user data array
} RCIMG_HEADER, *PRCIMG_HEADER;
```

Members

nSize: size of the structure in bytes. It should be 84.

nPages: number of images contained in the file

nWidth: width of each image in pixels.

nHeight: height of each image in pixels.

nBPP: number of bits per pixels (8, 10 or12)

userData: an array of 64 unsigned long that may be user by the user to store other information.

11.1.13.3. Data arrays

The image header is followed by the images data. Images are stored contiguously in compressed format. The first four bytes contains the size of the compressed buffer, followed by image data.

Data compression is done using ZLIB library version 1.1.4, which is free and available for download at the URL http://www.zlib.org.

The compression algorithm used by ZLIB is a variation of LZ77 (Lempel-Ziv 1977). It finds duplicated strings in the input data. The second occurrence of a string is replaced by a pointer to the previous string, in the form of a pair (distance, length). Distances are limited to 32K bytes, and lengths are limited to 258 bytes. When a string does not occur anywhere in the previous 32K bytes, it is emitted as a sequence of literal bytes.

11.1.14. Note on 16 bit grayscale formats

10-bit images acquired from the camera may be saved in different 16 bit formats. These formats include TIF, PNG, MPT, MRF and MCF. Since 16 bit grayscale format is not a standard, not all the applications for image processing may correctly display the saved images.

12. Appendix C – Error codes

Below a list of the Motion Studio error codes with a brief description.

ERR001: Internal error. The program has generated a severe internal error and must be restarted.

ERR005: Invalid database path. The program is trying to open a database from a wrong directory.

ERR011: Error opening file. The program failed opening an image file because it is damaged or the format is not supported.

ERR012: Error opening image sequence. The program failed opening an image sequence because it is damaged or the format is not supported.

ERR023: Camera generic error. Unspecified camera error.

ERR027: Camera play time out. The camera cannot snap images and a time out occurred. Check if the camera sync configuration is set to external and the external sync signal is available.

ERR028: Camera acquisition time out. The camera cannot acquire images and a time out occurs.

ERR033: Unable to open camera. The program cannot start the communication with the camera. Check the hardware and the cables.

ERR034: Unable to create a folder. The program cannot create a new folder in the database for the storage of the acquired images. Check your administrator privileges.

ERR035: not enough camera memory to add a new acquisition. All the camera memory is filled with acquisitions. A new acquisition cannot be added.

ERR036: Unable to delete the current acquisition. The program cannot delete the current acquisition from the camera memory configuration.

ERR037: Camera hardware generic error. An error occurred in the communication through the USB or the Ethernet cable.

ERR038: The buffer is too small. The buffer allocated for the image snap is too small.

ERR039: Camera device I/O error. An error occurred in the communication through the USB cable. Check the cables and the USB board.

ERR040: Camera I/O read error. An error occurred while the program was reading an image from the camera. Check the cables and the USB board.

ERR041: Cannot complete the operation because the camera is busy. The camera is busy and cannot perform the requested operation. Wait and try again.

ERR042: An error occurred during the calibration procedure. The error can occur during the camera background calibration or during the tracking calibration. Restart the program and try again.

ERR045: Invalid range value. The error occurs when the user tries to configure a parameter which is out of the allowed range. Correct the value and try again.

ERR048: An error occurred during the color balance and/or white balance procedure because one of the circular targets is outside the image. Move the targets and try again.

ERR049: An error occurred during the color balance and/or white balance procedure. Move the targets and try again.

ERR055: Unable to create a new database. The error occurs when the program tries to create a new database. Check your administrator privileges and try again on a different folder.

ERR056: Unable to delete folder. The error occurs when the program tries to delete a folder (acquisition, calibration or tracking) from the current database. Check your administrator privileges.

ERR059: Unable to create calibration folder. The error occurs when the program tries to create a new calibration folder and save the calibration image.

ERR061: Unable to copy file. The error occurs when the program tries to copy the camera calibration file from the distribution CD. Check your administrator privileges and the CD integrity.

ERR065: Invalid camera calibration file. The error occurs when the program tries to copy a camera calibration file that is not valid. Check if the file is damaged.

ERR067: Camera I/O write error. An error occurred while the program was trying to write a parameter to the camera. Check the cables and the USB board.

ERR068: Unable to open camera driver. The program cannot start the communication with the camera. Check the hardware and the cables.

ERR070: Invalid iTunes version. The error occurs because the program is trying to communicate with the iPod through iTunes and the version is not valid. Install a newer version of iTunes.

ERR071: iTunes Type library is not compatible. The error occurs because the program is trying to communicate with the iPod through iTunes and the version is not valid. Install a newer version of iTunes.

ERR072: Unable to connect to iPod through iTunes. There is a communication error between the program and the iPod. Try again.

ERR073: More than one iPod found. The computer is connected to more than one iPod. Disconnect one of them and try again.

ERR074: Unable to connect to iTunes. There is a communication error between the program and iTunes.

ERR075: Not enough space on the destination database. The error occurs because the program tries to synchronize with the iPod, but the iPod disk has not enough space to store the database.

ERR076: Unable to delete the iPod acquisition list. The error occurs because the program is trying to synchronize with the iPod but it's not able to delete the previous acquisition list.

ERR077: Unable to delete the acquisition folder. The error occurs because the program is trying to synchronize with the iPod but it's not able to delete one of the acquisition folders.

ERR078: Unable to create the acquisition folder. The error occurs because the program is trying to synchronize with the iPod but it's not able to create a new acquisition folder.

ERR079: Unable to copy the database system files. The error occurs because the program is trying to synchronize with the iPod but it's not able to copy the database system files.

ERR080: Unable to find images. The error occurs because the program is trying to synchronize with the iPod but it cannot find images in the source database.

ERR081: Unable to add files to the iPod acquisition list. The error occurs because the program is trying to synchronize with the iPod but it cannot add a sequence to the iPod list.

ERR082: Unable to add files to the iPod acquisition list. The error occurs because the program is trying to synchronize with the iPod but it cannot add a sequence to the iPod folders.

ERR083: Unable to convert the acquisition to the iPod format. The error occurs because the program is trying to add a sequence to the iPod list but it cannot convert it to the proper iPod format.

ERR084: Multiple camera snap time out. The error occurs because the program is trying to snap an image from a multiple camera setup. One or more cameras failed, check the cables. If the system is in Master/Slave configuration check that the sync in connector of the slave camera is connected to the sync out connector of the master.

ERR086: Unable to save calibration image. The error occurs because the program tries to save a tracking calibration image. Check your administrator privileges and try again.

ERR087: Unable to download the camera calibration file from flash memory. Check the cables and try again.

ERR088: The command line passed to the raw converter to convert a file is not correct.

ERR089: Unable to find acquisition directory. This error occurs when the Raw Converter tries to open an INI files but is not able to find it. Check the command line path and try again.

ERR090: Invalid configuration file. This error occurs when the Raw Converter tries to convert a sequence but the configuration file is not valid.

ERR091: Unable to read the RAW file. This error occurs when the Raw Converter tries to convert a sequence but the raw file is not valid or damaged.

ERR092: the raw file and the converter have different versions. This error occurs when the Raw Converter tries to convert a sequence generated by an older version of the software.

ERR093: Unable to set the IP address. This error occurs when the program tries to change the camera IP address and it fails. Check that the selected IP address is compatible with the network adapter subnet mask and disconnect the USB cable if it's connected.

ERR094: Unable to assign a specific IP address to the camera. The automatic assignment of the IP addresses has failed. Try with the manual configuration.

ERR095: Data acquisition module over-run. A data acquisition module internal error has occurred.

ERR096: Data acquisition module under-run. A data acquisition module internal error has occurred.

ERR097: Unable to download the camera calibration file from flash memory because the camera calibration file is not stored in the flash. Contact the technical support.

ERR098: The calibration file download has been aborted. The user has clicked the Abort button during the download.

ERR099: Unable to set the IP address. An error occurred in the procedure of setting the IP address starting from the camera MAC address. Make sure that the MAC address is correct and the camera is connected to the network.

ERR100: Unable to save tracking data. The error occurs because the program tries to save the tracking results to a file and it fails.

ERR101: Invalid file format. The error occurs when a waveform file is not valid. The file may be damaged or have invalid data.

ERR102: Unable to save to a file. The error occurs when the program cannot save an image to the specified file format.

ERR103: Unable to save to a file. The error occurs because the file is too large and the file format does not support that size.

ERR104: Unable to allocate enough computer memory for the acquisition. This error occurs when M cameras try to acquire a large number of images in computer memory.

ERR105: The camera cable has been disconnected.

ERR106: The program is unable to attach to the camera. The program instance has been detached from the camera because the control has been taken by someone else.

ERR107: Unable to configure the camera for first use. The procedure of setting up the camera for the first time failed.

ERR108: Aborted operation. The error message occurs when the user aborts the raw conversion procedure.

ERR109: The selected region of interest is not supported by this file format.

ERR110: the application is not able to open a device in the Galileo network.

ERR111: the HG100K camera memory cannot be erased.

ERR112: a Galileo wireless device cannot be configured.

ERR113: a frame cannot be read from the camera during a procedure of sequence save.

ERR114: the compressed AVI codec is not valid and the sequence cannot be saved.

ERR115: memory allocation error. The program cannot allocate enough memory to open and display a sequence of images.

ERR116: write to disk overrun. When the program acquires in direct write to disk mode with M camera, the memory allocated for buffering is not enough and it is overwritten.

ERR117: SD card download error. The camera cannot download the images to the SD card.

ERR118: the time limited license has expired. Contact IDT for a new activation code.

ERR119: The activation key cannot be sent to the camera. Reboot the camera, restart Motion Studio and try again.

ERR120: Read EEPROM error. The camera cannot be initialized because the EEPROM data cannot be read.

ERR121: The HDMI output cannot be initialized.

ERR122: SD card download error. Some cameras were not able to save the images to their SD card devices.

13. Appendix D - Spatial filtering

Spatial filters alter pixel values with respect to variations in light intensity in their neighborhood. The neighborhood of a pixel is defined by the size of a matrix, or mask, centered in the pixel itself. These filters can be sensitive to the presence or the absence of light intensity variations. Spatial filters can serve a variety of purposes, such as detecting edges along a specific direction, contouring patterns, reducing noise and detail outlining and smoothing.

Spatial filters fall in two categories:

High-pass filters emphasize significant variations of the light intensity usually found at the boundary of object. They are also called **sharpening** filters.

Low-pass filters attenuate variations of the light intensity. They have the tendency to smooth images by eliminating details and blurring edges. They are also called **smoothing** filters.

In the case of a 3x3 matrix, the value of the central pixel derives from the values of its eight surrounding neighbors. A 5x5 matrix specifies 24 neighbors; a 7x7 matrix specifies 48 neighbors and so forth.

If $\mathbf{P}_{(i,j)}$ specifies the intensity of the pixel P with the coordinates (i,j), the pixels surrounding $P_{(i,j)}$ can be indexed as follows (in the case of a 3x3 matrix):

$P_{(i-1,j-1)}$	$P_{(i,j-1)}$	$P_{(i+1,j-1)}$
$P_{(i-1,j)}$	$P_{(i,j)}$	$P_{(i+1,j)}$
$P_{(i-1,j+1)}$	$P_{(i,j+1)}$	$P_{(i+1,j+1)}$

A **linear filter** assigns to $\mathbf{P}_{(i,j)}$ a value which is a linear combination of its surrounding values. For example:

$$P_{(i,j)} = P_{(i-1,j-1)} + P_{(i,j-1)} + P_{(i+1,\, j-1)} - P_{(i-1,j+1)} - P_{(i,j+1)} - P_{(i+1,j+1)}$$

A **nonlinear filter** assigns to $\mathbf{P}_{(i,j)}$ a value that is not a linear combination of the surrounding values. For example:

$$P_{(i,j)} = \max(P_{(i-1,j-1)}, P_{(i+1,\, j-1)}, P_{(i-1,j+1)}, P_{(i+1,j+1)})$$

13.1. Linear filters (Convolution filters)

A *convolution* is a mathematical function that replaces each pixel by a weighted sum of its neighbors. The matrix defining the neighborhood of the pixel also specifies the weight assigned to each neighbor. This matrix is called the *convolution kernel*.

For each pixel $P_{(i,j)}$ in an image, the convolution kernel is centered on $P_{(i,j)}$. Each pixel masked by the kernel is multiplied by the coefficient placed on top of it. $P_{(i,j)}$ becomes the sum of these products.

In the case of 3x3 neighborhood, the coefficients of the kernel matrix can be indexed as follows.

$K_{(i-1,j-1)}$	$K_{(i,j-1)}$	$K_{(i+1,j-1)}$
$K_{(i-1,j)}$	$K_{(i,j)}$	$K_{(i+1,j)}$
$K_{(i-1,j+1)}$	$K_{(i,j+1)}$	$K_{(i+1,j+1)}$

The grater the absolute value of a coefficient $K_{(a,b)}$, the more the pixel $P_{(a,b)}$ contributes to the new value of $P_{(i,j)}$. If a coefficient $K_{(a,b)}$ is 0, the neighbor $P_{(a,b)}$ does not contribute to the new value of $P_{(i,j)}$.

0	1	0
1	**0**	1
0	1	0

then

$$P_{(i,j)} = P_{(i,j-1)} + P_{(i-1,j)} + P_{(i+1,\ j)} + P_{(i,j+1)}$$

If the kernel contains both negative and positive coefficients, the transfer function is equivalent to a weighted differentiation and produces a sharpening or high-pass filter (like **Laplacian**, **Prewitt** and **Sobel** filters).

If all coefficients in the kernel are positive, the transfer function is equivalent to a weighted summation and produces a smoothing o low-pass filer (like **Average** and **Gaussian** filters).

13.2. Linear sharpening filters

Typical smoothing filters are:

Gradient filters

A gradient filter highlights the variation of light intensity along a specific direction, which has the effect of outlining edges and revealing texture.

A gradient convolution filter is a first-order derivative. Its kernel uses the following matrix:

a	-b	c
b	**x**	-d

c	d	-a

Where a, b, c and d are integer coefficients and x=0 or x=1.

This kernel has an axis of symmetry that runs between the positive and negative coefficients of the kernel and through the central element. This axis of symmetry gives the orientation of the edges to outline.

There are two sets of pre-defined gradient filters used in Motion Studio. They are listed below.

The **Prewitt filters** have the following kernels. The notations N (north) NE(north-east) E (east) SE (south-east) S (south) SW (south-west) W (west) NW (north-west) indicate which edges of bright regions they outline.

The **Sobel filters** are very similar to the Prewitt filters except that they highlight light intensity variations along a particular axis that is assigned a stronger weight. They have the following kernels.

Laplacian filters

A Laplacian filter highlights the variation of the light intensity surrounding a pixel. The filter extracts the contour of objects and outline details. Unlike the gradient filter, it is omni directional.

The Laplacian filter is a second-order derivative. Its kernel uses the following matrix:

a	d	c
b	**x**	b
c	d	A

where a, b, c and d are integers.

The Laplacian filter has two different effects, depending on whether the central coefficient x is equal or greater than the sum of the absolute values of the outer coefficients.

If x is equal to that sum, the filter extracts the pixels where significant variations of light intensity are found. The presence of sharp edges, boundaries between objects, modification in the texture of a background, noise, and other effects can cause these variations. The transformed image contains white contours on a black background.

If x is greater than that sum, the filter detects the same variations as mentioned above, but superimposes them over the source image. The transformed image looks like the source image, with all significant variations of the light intensity highlighted.

13.3. Linear Smoothing filters

A **smoothing filter** attenuates the variations of light intensity in the neighborhood of a pixel. It smoothes the overall shape of objects, blurs edges, and removes details.

It is an averaging filters and its kernel uses the following matrix:

a	d	c
b	**x**	b
c	d	a

where a, b, c and d are positive integers, and x=0 or x=1.

Because all the coefficients are positive, each central pixel becomes a weighted average of its neighbors. The stronger the weight of a neighbor is. The more influence it has on the new value of the central pixel.

A list of average smoothing kernels is shown below

A **Gaussian filter** attenuates the variations of light intensity in the neighborhood of a pixel. It smoothes the overall shape of objects and attenuates details. It is similar to a smoothing filter, but its blurring effect is more subdued.

Its kernel uses the following matrix.

a	d	c
b	**x**	b
c	d	a

where a, b, c and d are positive integers, and x=0 or x=1.

Because all the coefficients are positive, each central pixel becomes a weighted average of its neighbors. The stronger the weight of a neighbor is. The more influence it has on the new value of the central pixel.

Unlike a smoothing kernel, the central coefficient of a Gaussian filter is greater than 1. Therefore the original value of a pixel is multiplied by a value greater than the weight of any of its neighbors. As a result, a greater central coefficient corresponds to a more subtle smoothing effect. A larger kernel size corresponds to a stronger smoothing effect.

13.4. Nonlinear filters

A nonlinear filter replaces each pixel with a nonlinear function of its surrounding pixels. Like the convolution filters the nonlinear filters operate on a neighborhood.

A **Median filter** is a nonlinear low pass filter that assigns to each pixel the median value of its neighborhood, effectively reducing isolated pixels and reducing details. However, the median filter does not blur the contour of objects.

A **Maximum Filter** is a nonlinear filter that assigns to each pixel the maximum value of pixels in its neighborhood. This has the effect to increase the contrast of the image.

A **Dilation** of an image is a particular case of max filter. The output pixel is set to the maximum of the corresponding input pixel and its 8 neighbors. The effect of dilation is to fill up holes and to thicken boundaries of objects on a dark background (that is, objects whose pixel values are greater than those of the background).

A **Minimum Filter** is a nonlinear filter that assigns to each pixel the minimum value of pixels in its neighborhood. This has the effect to decrease the contrast of the image.

An **Erosion** of an image is a particular case of min filter. The output pixel is set to the minimum of the corresponding input pixel and its 8 neighbors. The effect of erosion is to remove spurious pixels (such as noise) and to thin boundaries of objects on a dark background (that is, objects whose pixel values are greater than those of the background).

Opening an image is a sequence of erosions followed by dilations. The process of opening has the effect of eliminating small and thin objects, breaking objects at thin points, and generally smoothing the boundaries of larger objects without significantly changing their area.

Closing an image is a sequence of dilations followed by erosions. The process of closing has the effect of filling small and thin holes in objects, connecting nearby objects, and generally smoothing the boundaries of objects without significantly changing their area.

13.5. Adding noise to images

A random noise signal may be generated and added to an image. Two different noise signals may be generated.

Uniform noise: a noise signal with uniform distribution over a range [low, high].

Gaussian noise: a noise signal with Gaussian distribution that has a specified mean value and a specified standard deviation.

NOTE: Uniform noise and Gaussian noise are not available in the MAC version of the software.

14. Appendix E - Look-up Table Transformations

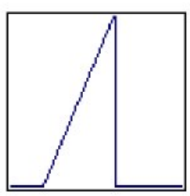
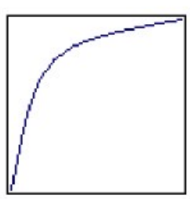
The *look-up table* (LUT) transformations are basic image-processing functions that you can use to improve the contrast and the brightness of an image by modifying the dynamic intensity of region with poor contrast. LUT transformations can highlight details in areas containing significant information, at the expense of other areas.

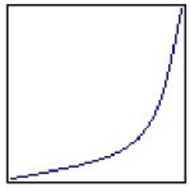
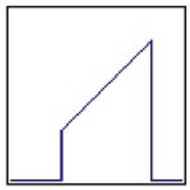
A LUT transformation convert input gray-level values (8 or 16 bit) into other gray-level values. The transfer function has an intended effect on the brightness and contrast of the image. Each input value is transformed into a new value by a *transfer function*

Output value = F (input value)

Where F is a linear or nonlinear, continuous or discontinuous transfer function defined over the interval [0, max]. In case of an 8-bit image, a LUT is a table of 256 elements. Each element of the array represents an input value. Its content indicates the output value.

Five different LUT types are available in Motion Studio: linear, equalize, logarithmic, exponential and gate. The table below shows the transfer function for each LUT type.

Resolution	Transfer Function	Description
Linear		A linear transfer function (y = ax + b) affects both the brightness and contrast of the image. The parameter b (offset) increase or decrease the image brightness, while the parameter s (gain) influences the image contrast.
Equalize		The equalize function alters the gray-level value of pixels so they become distributed evenly in the defined grayscale range (0 to 155 for an 8 bit image) The function associates an equal amount of pixels per constant gray-level interval and takes full advantage of the available shades of gray.
Logarithmic		The logarithmic function expands low gray-level ranges while compressing high level ranges. These transformations increase the overall brightness of an image and increase the contrast in dark areas at the expense of the contrast in bright areas.

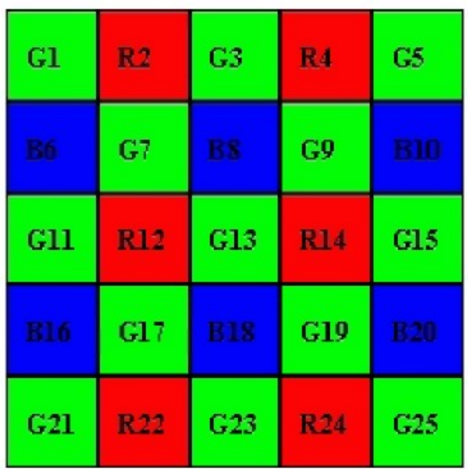
Exponential		The exponential function expands high gray-level ranges while compressing low level ranges. These transformations decrease the overall brightness of an image and increase the contrast in bright areas at the expense of the contrast in dark areas.
Gate		The gate function sets to zero all the gray-level values that are below a certain value and above another one. The other gray-level values remain unaltered.

15. Appendix F - Color Filter Arrays (CFA)

The Color camera uses a single image sensor. Color imaging with a single sensor requires the use of a **Color Filter Array** (CFA) which covers the sensor array. In this fashion each pixel in the detector samples the intensity of just one of the three color components, i.e. red, green or blue. The recovery of full-color images from a CFA-based sensor requires a method of calculating values of the other color separations at each pixel. These methods are commonly referred as color interpolation or color “demosaicing” algorithms.

In a single-sensor camera, varying intensities of light are measured at a rectangular grid of image sensors. To construct a color image, a CFA must be placed between the lens and the sensors. A CFA typically has one color filter element for each sensor. Obviously, the color interpolation algorithms depend on the CFA configuration. Many different CFA configurations have been proposed. The one used in IDT cameras is the **Bayer pattern**.

A Bayer pattern consists of pixels on your sensor tinted green, red or blue and set in a mosaic pattern. Consider the figure below: moving from left to right and then down, you see that you have a GR-BG pattern. This is your Bayer pattern, and is then placed all over the sensor to form the Bayer Mosaic Pattern. This means that you have half of your pixels tinted with a Green sensitive element, a quarter tinted with a Red sensitive element, and a quarter tinted with a Blue sensitive element.



The MotionPro/MotionScope camera models have different Bayer patterns:

- **X3**, **Y3**, **N3** and **M3** have **BG-GR** pattern.
- **X4**, **X5, Y5, M5** and **N5** have **GR-BG** pattern.
- **Y4, N4, Y6 and Y7 HDiablo have GB-RG pattern.**

The camera driver may perform six different interpolation algorithms (demosaicing):

▪

- **Advanced**: a new advanced method for high quality reconstruction.
- **Nearest**: the algorithm is based on nearest neighbor reconstruction.
- **Bilinear**: for each missing pixel, a weighted value of the surrounding four pixels is computed. It's the simplest method and is non-adaptive. The indiscriminate averaging of neighboring pixel causes a blur effect ("Zipper").
- **Gradient A**: the interpolation is done using chrominance gradients in two steps. First the luminance channel is interpolated (green). Then the color differences (red minus green and blue minus green) are interpolated.
- **Gradient B**: the interpolation is done using luminance gradients in a more adaptive way than algorithm B.
- **Gradient C**: the interpolation is done using a threshold based variable number of gradients.
- **Hue Transition A**: the algorithm is based on the assumption that the hue of the image cannot change abruptly and in an unnatural manner. The term hue refers to the relation between luminance (green) and chrominance (red, blue).
- **Hue Transition B**: based on the same principles of "A" method, but more precise
- **Pixel Grouping**: the algorithm is based on the observation that natural scene images are usually composed of numerous groups of pixels, and have approximately the same brightness and color.

16. Appendix G – XDR

The **eXtended Dynamic Range (XDR)** is an IDT-proprietary implementation that uses a of the MotionPro Y4 camera. In XDR mode the camera dynamic range may be enhanced to 9, 10 or 11 bit depth.

Imagine that we are taking a picture of a high contrast scene. In the picture we may have a very bright portion (almost saturated) and a very dark portion that is almost black.

How can we change our exposure to have a good image? If we try to increase the exposure to improve the dark part, we saturate the bright one. On the other side, if we decrease to improve the bright part, we reduce the light to the dark portion and we loose information.

The solution is XDR.

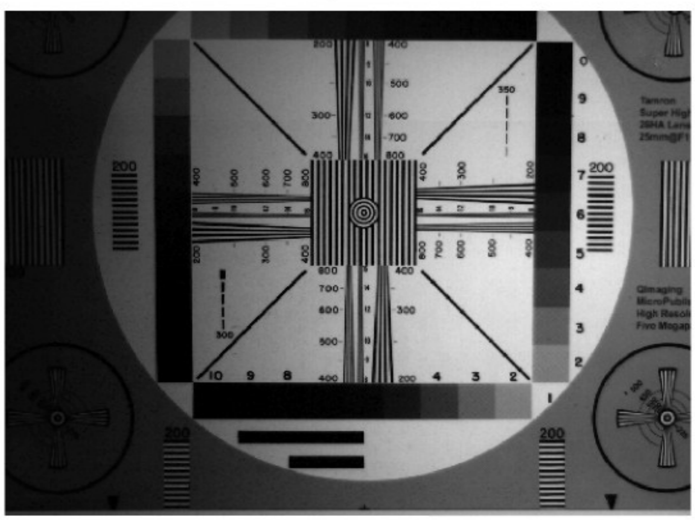
With XDR the Y4 camera uses a capability of the sensor that can acquire at two different exposures at the same time: one of the pictures at lower exposure and one at higher exposure.

Then the pictures are linearly combined to obtain a third picture with increased sensitivity. The ratio between higher exposure and lower exposure gives the new pixel depth, which can be 8, 10 or 11 bits for 8 bit images or 10, 11 and 12 bits for 10 bit images.

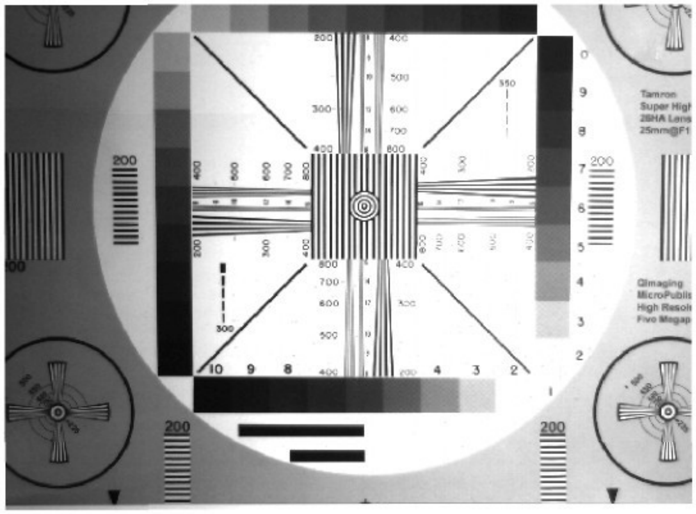
Last but not least, the resulting image may be converted back to 8 bits (or 10 bits) with a look up table.

See the example below.

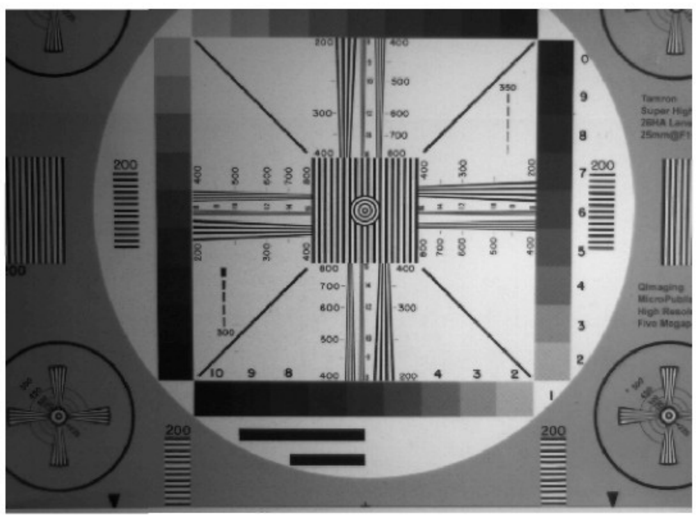
The image below shows a dark area at the top left side.



If we increase the exposure, the top left side becomes visible but the image saturates at the right side. See below.



With XDR the two images are combined and the result is a uniform image without dark or saturated zones.



17. Appendix H – Glossary

A

Ambient Light
It's the available natural light completely surrounding a subject. It's tight already existing in an indoor or outdoor setting that is not caused by any illumination supplied by artificial light source.

Aperture
It's the lens opening. The hole or opening formed by the metal leaf diaphragm inside the lens or the opening in a camera lens through which light passes to expose the sensor. The size of aperture is either fixed or adjustable. Aperture size is usually calibrated in f- numbers-the larger the number, the smaller the lens opening. Aperture affects depth of field, the smaller the aperture, the greater is the zone of sharpness, the bigger the aperture, the zone of sharpness is reduced. The size of the aperture is indicated by its f-number.

ASCII
American Standard Code for Information Interchange, an encoding system for converting keyboard characters and instructions into the binary number code that the computer understands.

Aspect ratio
It's the ratio between the width and height of an image or image sensor.

Auto focus
It's a system that automatically focuses the camera lens.

AVI (Audio Video Interleaved)
It's a file format used to store video and audio. For further information, refer to the Microsoft™ documentation.

B

Bandwidth
It's the capacity of a networked connection and determines how much data can be sent along the networked wires. The bandwidth is particularly important for Internet connections, since greater bandwidth also means faster downloads.

Bayer pattern
A Bayer pattern consists of pixels on the sensor tinted green, red or blue and set in a mosaic pattern. Moving from left to right and then down, the pattern may be GR-BG. This is the sensor's Bayer pattern, and is then placed all over the sensor to form the Bayer Mosaic Pattern. This means that half of the pixels are tinted with a Green sensitive element, a quarter tinted with a Red sensitive element, and a quarter tinted with a Blue sensitive element.

Binning
Binning is a method of increasing camera speed and sensitivity to boost low signals. Binning causes the acquired image to be brighter and smaller, but the resolution will be lower as a result. Because the image is smaller, the image transfer time is reduced significantly. When you select a binning setting in your imaging software, the camera combines data from several pixels in the camera's CCD into a single super pixel. For example, a 2x2 bin means that 2 pixels in the horizontal direction and 2 pixels in the vertical direction are combined to form one super pixel.

Bit Depth
It's the color or gray scale of an individual pixel. A pixel with 8 bits per color gives a 24 bit image. (8 Bits x 3 colors are 24 bits.) 24 bit color resolution is 16.7 million colors.

BMP (Bitmap)
It's a file format used to store images. For further information, refer to the Microsoft™ documentation.

BNC
BNC is the acronym for Bayonet Neill-Concelman (for the inventors Paul Neill and Carl Concelman). It's a twist-and-lock connector for coaxial cables, used for electronic equipment and for wiring LANs.

Brightness
It's the value of a pixel in an electronic image, representing its lightness value from black to white. It's usually defined as brightness levels ranging in value from 0 (black) to 255 (white).

BROC (Burst Record on Command)
It's one of the operating modes of a camera with on board memory. The memory is divided into segments; the camera acquires in circular mode in a segment. When the event trigger is issued, the camera completes the acquisition and start acquiring in the following segment until the memory is filled.

C

C-Mount
A standard threaded lens mount used to attach a camera to a microscope, or a separate lens to a camera.

CCD (Charge Coupled Device)
It's the light sensitive silicon chip near the optical interface of the camera that converts light intensities into electrical signals. Every pixel's charge is transferred through a very limited number of output nodes (often just one) to be converted to voltage, buffered, and sent off-chip as an analog signal. All of the pixel can be devoted to light capture, and the output's uniformity (a key factor in image quality) is high.

Circular Mode
It's one of the operating modes of a camera with on board memory. The camera acquires and restarts when the memory is filled. The camera waits for an event trigger to complete the acquisition.

CFA (Color Filter Array)
The filter dyes placed directly over each pixel on the chip surface.

CMOS (Complementary Metal-Oxide Semiconductor)
It's the light sensitive silicon chip near the optical interface of the camera that converts light intensities into electrical signals. Each pixel has its own charge-to-voltage conversion, and the sensor often also includes amplifiers, noise-correction, and digitization circuits, so that the chip outputs digital bits. These other functions increase the design complexity and reduce the area available for light capture. With each pixel doing its own conversion, uniformity is lower. But the chip can be built to require less off-chip circuitry for basic operation.

Contrast
It's a measure of rate of change of brightness in an image.

D

Dark Current
The charge accumulated by pixels while not exposed to light. Normally, this charge is reduced or eliminated prior to capturing a picture.

Depth of Field
The distance between the nearest and farthest points that appears in acceptably sharp focus in a photograph. Depth of field varies with lens aperture, focal length, and camera-to-subject distance.

Diaphragm
An adjustable device inside the lens which is similar to the iris in the human eye, it's comprised of six or seven overlapping metal blades; continuously adjustable from "wide open" to "stopped down"; controls the amount of light allowed to pass through the lens and expose the sensor when a picture is taken. It also controls the amount of depth of field the photograph will have. Openings are usually calibrated in f-numbers. The more blades used will have a more natural and rounded spots.

Digitization
It's the process of converting analog information into digital format.

Digital Camera
It's an electronic device used to capture and store photographs electronically instead of using photographic film like conventional cameras. Modern compact digital cameras are typically multifunctional, with some devices capable of recording sound and/or video as well as photographs.

Double Exposure
It's a capability of CCD and CMOS cameras to acquire two images within a 100 ns interval. The first camera exposure may be controlled while the second exposure doesn't.

DLL (Dynamic Linking Library)
A dynamic link library (DLL) is a collection of small programs, any of which can be called when needed by a larger program that is running in the computer. The small program that lets the larger program communicate with a specific device such as a printer or scanner is often packaged as a DLL program (usually referred to as a DLL file). The advantage of DLL files is that, because they don't get loaded into RAM together with the main program, space is saved in RAM.

Dynamic Range
It's the ratio of the saturation level of the CCD to the readout noise of the CCD camera system. Dynamic range is a measure of the ability of the camera to capture both bright and dark features in a single image. In general, the higher the camera's dynamic range, the more information per pixel it can capture. It's usually expressed in dB.

E

Ethernet (10Base-T)
It's a local area network (LAN) architecture developed by Xerox Corporation in cooperation with DEC and Intel in 1976. Ethernet uses a bus or star topology and supports data transfer rates of 10 Mbps.

Exposure
The amount of time that light reaches the image sensor.

F

F-Number
The ratio of the diameter of the opening to the focal length of the lens; a large aperture is indicated by a small numerical f-number. The f-number series is a geometric progression based on changes in the size of the lens aperture, as it is opened and closed. As the scale rises, each number is multiplied by a factor of 1.4. The standard numbers for Calibration are 1.0, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, etc., and each change results in a doubling or halving of the amount of light transmitted by the lens to the film plane.

Fast Ethernet (100Base-T)
A newer version of Ethernet, called also 100Base-T, which supports data transfer rates of 100 Mbps.

Field of View
It's the area visible through the camera's optics.

Fill Factor
The fill factor indicates the size of the light sensitive photodiode relative to the surface of the pixel. Because of the extra electronics required around each pixel the "fill factor" tends to be quite small, especially for Active Pixel Sensors which have more per pixel circuitry. To overcome this limitation, often an array of micro-lenses is placed on top of the sensor.

FireWire (IEEE 1394)
High bandwidth (40 megabytes/second - 1394a; 80 megabytes/second - 1394b) interface for connecting digital imaging, storage, and other devices to host computers.

Focal Length
The distance from the optical center of the lens to the image sensor when the lens is focused on infinity, usually expressed in millimeters.

Focus
It's the process of bringing one plane of the scene into sharp focus on the image sensor.

Fps (Frames per second)
It's used to describe how many frames a camera can acquire per second.

Frame
One of the still pictures that make up a video.

Frame Grabber
It's a device that lets you capture individual frames out of a video camera or off a video tape.

Frame Rate
It's the number of frames that are shown or sent each second. Live action relates to a frame rate of 30 frames per second.

G

Gigabit Ethernet
A version of Ethernet, which supports data transfer rates of 1 Gigabit (1,000 megabits) per second. The first Gigabit Ethernet standard (802.3z) was ratified by the IEEE 802.3 Committee in 1998.

Gray Level
It's the brightness of a pixel.

Gray Scale
It's an image containing shades of gray as well as black and white.

GUI (Graphical User Interface)
A system that simplifies selecting computer commands by enabling the user to point to symbols or illustrations (called icons) on the computer screen with a mouse.

H

High-G
It refers to the Vehicle Impact Test or similar environment that includes up to 100-G shock and 5-G vibration stress. Generally indicates ability to withstand extreme shock and vibration forces.

I

Image Intensifier
It's an electro-optical vacuum tube which intensifies or amplifies on low light level images.

Integration
It's the active collection of photons as done by an image sensor.

Interpolation
Method used to increase the resolution of an image map by adding pixels to an image based on the value of surrounding pixels. This method can cause artifacts.

IP Address
The Internet Protocol Address is a unique set of numbers used to locate another computer on a network. The format of an IP address is a 32-bit string of four numbers separated by periods. Each number can be from 0 to 255 (i.e., 1.154.10.266). Within a closed network IP addresses may be assigned at random, however, IP addresses of web servers must be registered to avoid duplicates.

IRIG (Inter-Range Instrumentation Group)
Time code signals of various formats defined by the IRIG 200-98 standard/time derived from GPS satellites. Both require an optional receiver/decoder/generator module.

Iris
It's a diaphragm in the lens that opens or closes to set the aperture (the amount of light that passes through the lens to the CCD).

J

K

L

Laser
Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. A laser is a cavity, with mirrors at the ends, filled with material such as crystal, glass, liquid, gas or dye. It's a device which produces an intense beam of light with the unique properties of coherence, collimation and mono-chromaticity.

LED (Light Emitting Diode)
Light producing transistor used to display dots, numeric and text, slowly replacing by LCD display.

Lens
One or more pieces of optical glass or similar material designed to collect and focus rays of light to form a sharp image on the sensor.

Lossless
It's an image format which stores the image in a non-compressed format, or in a compressed format that don't loose information.

Lossy
It's an image format that sacrifices a certain amount of image information in order to create a smaller compressed file.

Low-G
It refers to a general industrial environment with less than 10-G shock and 2.5-G vibration stresses.

M

MAC Address
The Media Access Control address is a hardware address that uniquely identifies each node of a network. A MAC address is 48 bits long and is commonly written as a sequence of 12 hexadecimal digits (for instance, 48-3F-0A-91-00-BC). MAC addresses are uniquely set by the network adapter manufacturer and are sometimes called "physical addresses" for this reason.

MCF (Multi-page Compressed Format)
Multi-page Compressed Format (MRF) is a compressed IDT proprietary file format. Multiple raster images are stored in a single file.

Micro-lens
To overcome the limitations of a low fill factor, on certain sensors an array of micro-lenses is placed on top of the pixel array in order to funnel the photons of a larger area into the smaller area of the light sensitive photodiode.

Megapixel
It means having a resolution of one million pixels.

MOV
It's a file format used to store images. The Apple Quick Time MOV file format is used with applications that capture, edit, and play back audio-video sequences.

MPEG (Moving Picture Experts Group)
It's a file format used to store videos. MPEG is a name of family standards used for coding audio-visual in a digital compressed format. MPEG is a generic means of compactly representing digital video and audio signals for consumer distribution.

MRF (Multi-page Raw Format)
Multi-page Raw Format (MRF) is an uncompressed IDT proprietary file format. Multiple raster images are stored in a single file.

N

NTSC (National Television Standards Committee)
It's a standard for video broadcasting and recording in the US and Japan.

O

Offset
It's the offset value adjusts the CCD black level relative to the analog-to-digital converter zero. It is factory-optimized for the camera's maximum dynamic range.

Optical Zoom
It indicates that the camera has a real multi-focal length lens, as opposed to a digital zoom, which magnifies the center portion of the picture.

P

PAL (Phase Alternation Line)
It's a standard for video broadcasting and recording in Europe.

Palette
It's a thumbnail of all available colors to a computer or devices. The palette allows the user to choose which colors are available for the computer to display. The greater the number of colors, the larger the data file becomes and more processing time is required to display your images. If the system uses 24-bit color, then over 16.7 million colors are included in the palette.

Peltier Cooler
Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. This effect is commonly used in electronic components and small instruments. There are no moving parts and such a device is maintenance free.

Pixel
It's an individual element of either a sensor or a digital image.

PIV (Particle Image Velocimetry)
Particle Image Velocimetry is an optical method used to measure velocities and related properties in fluids. The fluid is seeded with particles, which, for the purposes of PIV, are generally assumed to faithfully follow the flow dynamics. It is the motion of these seeding particles that is used to calculate velocity information.

Plug-in
A file containing data used to alter, enhance, or extend the operation of a parent application program. Plug-ins, both commercially and independently authored, can usually be downloaded for free and are stored locally. Plug-ins come in different versions specific to particular operating systems.

PNG (Portable Network Graphics)
It's a file format used to store images. PNG is an extensible file format for the lossless, portable, well-compressed storage of raster images. PNG provides a patent-free replacement for GIF and can also replace many common uses of TIFF. Indexed-color, grayscale, and true-color images are supported, plus an optional alpha channel. Sample depths range from 1 to 16 bits.

Pulse
It's a signal whose amplitude deviates from zero for a short period of time. A pulse may be periodic (pulse train) and not periodic (single pulse). The **Pulse Width** is the time between the rising edge and the falling edge of a pulse. If the pulse is periodic it has a period and a duty cycle.

Q

Quantum Efficiency
It's a quantity defined for a photosensitive device such as photographic film or a sensor (CCD or CMOS) as the percentage of photons hitting the photo reactive surface that will produce an electron-hole pair. It is an accurate measurement of the device's sensitivity. It is often measured over a range of different wavelengths to characterize a device's efficiency at different energies.

R

Resolution
Resolution is expressed as either the number of pixels counted horizontally by the number of pixels counted vertically or by the number of mega pixels. It can be expressed as one of the following formats: QVGA (320 x 240), VGA (640 x 480), SVGA (800 x 600), XGA (1024 x 768) UXGA (1600 x 1200).

RGB (Red, Green and Blue)
The color system used in most digital cameras in which the image is separated by capturing the red, green, and blue light separately and then are re-combined to create a full color image.

S

Sensor
It's an electronic device that converts the light allowed in by the shutter to an electrical signal.

Sensor Gain
It's the amount of analog signal amplification. The gain is factory-optimized for the camera's maximum dynamic range.

Sharpness
The clarity of detail in a photo

Shutter
It's the device in the camera that opens and closes to let light from the scene strike the image sensor and expose the image. The three primary types used in digital photography are digital shutters, iris shutters and focal plane shutter.

SDK (Software Development Kit)
It's a programming package that enables a programmer to develop applications for a specific platform. An SDK typically includes one or more APIs programming tools and documentation.

Spike
It's a short pulse of voltage or current, usually undesirable.

Square wave
It's a periodic signal which changes instantaneously between two fixed levels. The values are usually 0 and 5 V (TTL) or 0 to 3.3 V (CMOS).

Switch Closure
It's a type of external event trigger. The trigger is detected when the poles of the trigger connector are shorted by a switch.

Synchronous
Synchronous events occur at the same time or at the same rate or with a regular or predictable time relationship or sequence.

T

TIFF (Tagged Image File Format)
It's a file format used to store images. TIFF pictures store a single raster image at any color depth. TIFF is arguably the most widely supported graphic file format in the printing industry. It supports optional compression, and is not suitable for viewing in Web browsers.

Thumbnail
It's a small, low-resolution version of a larger image file that is used for quick identification.

Trigger
A trigger is something that causes a data acquisition system to start collecting data or a camera to start acquiring images. It may be as simple as pressing a software button or a set of conditions which when met trigger data capture (internal triggers), or an externally generated, hardware signal (an external trigger).

Tripod
A tripod is a three-legged supporting stand used to hold the camera steady, especially useful when using slow shutter speeds. Another is the monopod, single leg tripod.

TTL (Transistor-Transistor Logic)
A common semiconductor technology for building discrete digital logic integrated circuits. For digital circuits, logic 1 is obtained for inputs of 2.0 to 5.5 V and logic 0 for inputs of 0 to 0.8 V.

TWAIN
It's a protocol for exchanging information between applications and devices such as scanners and digital cameras. TWAIN makes it possible for digital cameras and software to "talk" with one another on PCs.

U

Underexposure
A picture that appears too dark because not enough light got to the imaging system.

USB (Universal Serial Bus)
It's a serial bus standard for connecting devices. It was designed for computers such as PCs and the Apple Macintosh, but its popularity has prompted it to also become commonplace on video game consoles, PDA, cell phones. It has a slow version (USB 1.1 – 12 Mbps) and a high speed version (USB 2.0 – 480 Mbps).

USB 2.0
Finalized in 2001, Universal Serial Bus (USB) 2.0 is a complete overhaul of the Universal Serial Bus input/output bus protocol which allows much higher speeds than the older USB 1.1 standard did. The goal of the new serial bus is to broaden the range of external peripherals that can be used on a computer. A hard drive can easily hit the USB 1.1 bottleneck whereas it now becomes more 'usable' under USB 2.0 conditions. USB 2.0 maximum speed is 480 Mbps.

V

W

White balance
It's a function to compensate for different colors of light being emitted by different light sources.

X

XDR (Extended Dynamic Range)
It's an IDT-proprietary implementation that uses the double exposure capability of the MotionPro series cameras.

Y

Z