MS

Systems for testing multi-sensor surveillance systems

Fig. 1. Types of multi-sensor surveillance systems

Fig. 2. Photo of the most advanced version of MS300 test system

1 Basic information

Multi-sensor surveillance systems are becoming increasingly popular as both large gimbal type systems for long range surveillance and portable systems for short range surveillance. The multi-sensor surveillance systems that combine thermal imager (or two thermal imagers, color VIS camera, low light VIS-NIR camera, SWIR camera, laser range finder, laser designator, laser pointer, illuminator located on a stabilized platform can be considered as most advanced systems that can be tested. Systems built as as set of thermal imager, VIS-NIR camera, and laser range finder are the most typical case.

MS systems are quasi universal test systems optimized for task of extensive testing and boresighting of multi-sensor surveillance systems in all versions met on market. The MS systems are one of the most technically sophisticated test systems offered by Inframet. They are recommended for testing high value multi-sensor surveillance systems (payloads) used for long range surveillance in air, naval and ground applications. However simpler, smaller versions can be used also for testing portable, multi-sensor surveillance systems.

MS systems are the most popular Inframet products and are used in hundreds of laboratories worldwide including top world manufacturers or scientific institutions – see reference list on Inframet website: http://inframet.com/references.htm.

2 Test concept

MS can be considered as a system that combines several subsystems:

1. *Variable target projector* – multi spectral system that project reference images in several spectral bands (used for testing and boresight imaging systems like thermal imagers, VIS-NIR cameras, SWIR cameras);
2. *Laser detector* – cards sensitive to laser light beams that can create image of laser spot (used for boresight to reference optical axis and measurement of divergence angle of LRFs/designators/pointers);
3. *Laser meter* – meter of radiometric / temporal parameters of pulsed lasers (used to test transmitters of LRFs / designators);
4. *Power meter* – of laser pointers / illuminators power;
5. *Optical pulse generator* – to test receivers of LRFs;
6. *Boresight station* – for boresight to a reference mechanical axis,
7. *Electronic image acquisition system* – that enables capturing video image generated by tested imagers in many different analog and digital formats,
8. *Control software* – for controls radiation sources and rotary wheel
9. *Measurement software* – for analysis of acquired data and calculation of parameters of tested multi-sensor system.

3 Test capabilities

Test capabilities of MS depends on version. MS system in the most expanded version can be used to measure following parameters:

1. **Thermal imagers:**
   MRTD, MTF, SiTF, NETD, FPN, non-uniformity, FOV, distortion, magnification, Response function, 3DNoise, NPSD, Bad pixels, PVF, SRF, ATF, SNR, MDTD, AutoMRTD, TOD, NER, NEI, NEFD, NEP, D*
2. **VIS-NIR cameras:**
   resolution, MTF, Sensitivity, NEI (noise equivalent illuminance), SiTF, FOV, MRC, 3D Noise, Uniformity, magnification, NPSD, Bad pixels, Distortion, SNR, Responsivity function
3. **SWIR cameras:**
   resolution, MTF, Sensitivity, NEI (noise equivalent illuminance), SiTF, FOV, MRC, 3D Noise, Uniformity, magnification, NPSD, Bad pixels, Distortion, SNR, Responsivity function
4. **Laser range finders:**
   Pulse energy, pulse peak power, PRF, pulse width, and coding, missing pulses, receiver sensitivity, Extinction Ratio, maximal operational range
5. **Laser designators:**
   Pulse energy, pulse peak power, PRF, pulse width, and coding, missing pulses
6. **Laser pointers:**
   power, uniformity, divergence angle
7. **Boresight capabilities:** alignment errors between
   - optical axis of thermal imager at several FOVs,
   - optical axis of VIS/SWIR camera at different magnification of zoom objective,
   - optical axis of thermal imager relative to optical axis of VIS-NIR/SWIR camera,
   - optical axis of LRF/designator and optical axis of a reference imaging system,
   - reference optical of laser system/imaging system and reference mechanical axis of the tested system.

As can be seen the list of parameters measured by MS systems is very long. It can be said that MS in general enables measurement of all important parameters of thermal imagers, VIS-NIR cameras, SWIR cameras, laser range finders, laser designators, laser pointers, laser illuminators and all boresight errors of multi-sensor systems.

4 MS system structure

MS test system is a modular system built in most advanced version using a long series of blocks. Some of these blocks are offered in different design depending on systems version. The list of main blocks of MS system is as below:

1. CDT off axis reflective collimator (collimators of different aperture, focal length and optical quality are available for different applications)
   (technical details as in https://www.inframet.com/Data_sheets/CDT.pdf)
2. TCB blackbody (typical blackbody for testing thermal imagers)
   (technical details as in https://www.inframet.com/Data_sheets/TCB.pdf)
3. DCB color blackbody (blackbody integrated with a light source – for tests both thermal imagers or VIS-NIR cameras).
   (technical details as in https://www.inframet.com/Data_sheets/DCB.pdf)
4. Visible/NIR light sources to be integrated as blocks of DCB color blackbodies: a)SEM light source based on improved white LED, b)SEM2 multi LED broadband light, c)HAL light source based on halogen bulb
   (technical details as in https://www.inframet.com/Data_sheets/DCB.pdf)
5. Stand alone VIS-NIR light sources: ultra high performance multi-channel LS-DAL light source
   (technical details as in https://www.inframet.com/Data_sheets/LS-DAL.pdf)
6. LS-SAL – SWIR radiation source (SIR (LED light source for SWIR), SAL (version of DAL light source of expanded spectral range into SWIR range), or/and MTB medium temperature blackbody)
   (technical details as in https://www.inframet.com/Data_sheets/LS-SAL.pdf)
7. MRW-8 motorized rotary wheel (optimized for cooperation with a sets of IR targets and visible targets)
   (technical details as in https://www.inframet.com/Data_sheets/MRW8.pdf)
8. MTB-2D medium temperature blackbody for testing cooled long-wave SWIR imagers

(*technical details as in https://www.inframet.com/Data_sheets/MTB.pdf*)

9. Set of IR targets for testing thermal imagers (4-bar targets, edge target, square target, dot-cross target, pinhole target, cross target – different configurations are possible)
10. Set of visible/NIR/SWIR targets (set of five variable contrast USAF 1951 targets, edge target, dot cross target, pinhole target)
11. Laser beam profiler LSR10 – SWIR camera for accurate measurement of divergence angle of LRFs / designators
12. OSA optical signal analyzer (for testing LRFs/laser designators)
13. Optical pulse generator OPG10 – to simulate target irradiated by LRF - for testing receivers of LRFs
14. LVIL illuminator - illumination of LSC sensing cards
15. LSC set of laser sensing cards (TEG – high sensitivity converter of SWIR laser pulsed light into thermal radiation, TEP – medium sensitivity converter of SWIR laser pulsed light into thermal radiation, MON – low sensitivity absorber of SWIR laser pulsed light that permanently change color when irradiated, MOG – medium sensitivity absorber of SWIR laser pulsed light that permanently change color when irradiated, FOS – high sensitivity converter of SWIR laser pulsed light into visible light)
16. Set of optical attenuators SOA and holders (three OA attenuators and AH1 Holder integrated with collimator and AH2 External mount) - to protect collimator mirrors against ultra high power LRFs/designators
17. LCOE pulse energy meter - measurement of pulse energy of monopulse LRFs/designators
18. LCOP power meter - measurement of power of laser pointers
19. BORIM set for boresight to a reference mechanical axis
20. PC - typical PC working under Windows 10 operating system (laptop or desktop PC are delivered)
21. Analog video frame grabber (for capturing video images in popular PAL/NTSC video standard)
22. Digital video frame grabber: Camera Link, GigE, LVDS, HD-SDI, DVI, HDMI, HD-TVI, HD-CVI, CoaXPress, USB2.0/3.0, Ethernet (for capturing video images in digital video standards)
23. TCB Control program - computer program used for control of TCB blackbody and MRW wheel.
24. MTB Control program – computer program used for control of MTB blackbody and MRW wheel.
25. LS Control program - computer program used for control of light sources (SEM, SIR, HAL, LS-DAL, LS-SAL) and MRW wheel.
26. SUB-T program - computer program that delivers software support during measurement of subjective parameters like MRTD, MDTD (TOD - option) of thermal imagers.
27. SUB-V -
28. TAS-T-program for semi-automatic measurement of of parameters of thermal imagers. Program is delivered in form of different versions of different test capabilities.
29. TAS-V: computer program for semi-automatic measurement of parameters of VIS-NIR cameras
30. OSA Browser program - control of OSA optical analyser
31. MET Control -computer control of optical pulse generator OPG10
32. BOR computer program (enables calculation of aligning errors of thermal imagers, VIS-NIR cameras, SWIR imagers, laser systems)

5 Versions of MS test system

MS test systems are modular test systems that can be delivered in form of different versions of different configurations, test capabilities and price. The latter parameter can vary several times depending on version.
The basic division of MS series system is based on output aperture of the collimator. The three digit number after “MS” code means the collimator output aperture in [mm] unit. For example:

System code MS300 means that the collimator output aperture is 300 mm.

There are many typical apertures of MS collimator available. The most typical are: 100, 150, 200, 250, 300, 320, 350, 400, 450, 500, 600mm. Other diameters are also possible on request.

Attention: price of MS system rises quickly with collimator aperture over 300mm. To select optimal collimator aperture please see point 8 – Recommendations.

Collimator aperture is only one of a series of technical parameters that should be determined to choose optimal MS system for required applications. We need also to determine:

1. Test range of thermal imagers (number of parameters to be measured)
2. Number and type of frame grabbers (acceptable electronic image formats of tested imagers)
3. Type of source of light in VIS-NIR band
4. Light intensity range (day, night or day/night)
5. Test range of VIS-NIR cameras (number of parameters to be measured)
6. Type of SWIR radiation source
7. Test range of SWIR imagers (number of parameters to be measured)
8. Test range of LRFs (number of parameters to be measured)
9. Test range of laser pointers
10. Boresight capabilities (types of boresight errors to be measured).

Therefore collimator aperture code and additional code composed from ten letters are used to describe precisely version of MS series systems. Definitions of 10 letter code are shown in Table 1. The columns 1-10 present what letters are to be chosen to define precisely required version of MS test system.

The ten letter coding at first looks complicated and difficult to be used. However, the code is necessary to show precisely what configuration of MS is truly needed. Next, detail know how on details of design of test system is not needed to determine code of needed test system. The user is expected mostly to know the requirements on system test capabilities (number of parameters to be measured).

Letter A means simplest criterion of interest. Letter E the most sophisticated case of criterion of interest. Therefore there is a very big difference in design and price between simple MS300-AAAAA-AAAAA test system and MS300- DEECD- EEEBD test system. Both systems are based on the same collimator of 300mm aperture but the first offers only measurement of MRTD of thermal imagers and resolution of VIS-NIR cameras and the second offers measurement of dozens of parameters and boresight errors of thermal imagers, VIS-NIR cameras, SWIR cameras, LRFs, laser designators, laser pointers.

Table 1. Definition of the ten letter code used to describe versions of MS test system

	1	2	3	4	5	6	7	8	9	10
Code	Test range of thermal imagers	Frame grabbers	VIS-NIR light source	Light intensity	Test range of VIS-NIR cameras	SWIR light source	Tests of SWIR cameras	Test range of LRF/designato rs	Tests laser pointers	Boresight capabilities
A	Basic: MRTD	No frame grabber	SEM1 – improved white LED source	Day:0.1-10000cd/m^2 (SEM/HAL: 0.1-1000cd/m^2)	resolution at regulated light intensity	No source	No	No	No	No
B	Typical: MRTD, MTF, SiTF, NETD, FPN, non-uniformity, distortion, FOV	Analog video frame grabber	SEM2 – broadband LED light source for VIS-NIR band	Night: 0.00001 – 1cd/m^2	Minimal Resolvable Contrast (resolution included)	SEM2-SW broadband LED source	resolution	pulse energy (monopulse LRFs), beam divergence (rough meaure-ment)	power, divergen-ce angle,	Imagers to a reference optical axis
C	Expanded: as in 1B but also: Auto MRTD, MDTD	One analog and one digital frame grabber	HAL – halogen light source for VIS-NIR band	Day/Night 0.0001 – 10000 cd/ m^2 (SEM/HAL: up 1000 cd/m^2)	MRC, resolution, MTF, Sensitivity, NEI, distortion, FOV	HAL-SW – broadband halogen light source for VIS-SWIR band	resolution, MTF, Sensitivity, NEI, distortion, FOV	As in 8B but also distance simulation		Imagers and monopulse LRFs/designat ors to a reference optical axis
D	Ultra: as in 1C but also PVF, SRF, ATF, NPSD, 3D noise, bad pixels	One analog and two digital frame grabbers	LS-DAL multi-channel VIS-NIR light source (ultra high performance)		as 5C but also parameters: 3D Noise, Uniformity, NPSD, Bad pixels, SNR, Responsivity function	LS-SAL: modified LS-DAL source for VIS-SWIR band	MRC, 3D Noise, Uniformity, NPSD, Bad pixels, SNR, Responsivity function	Beam diver-gence (accu-rate), pulse en-ergy, pulse peak power, PRF, pulse width, coding, missing pulses		Imagers and all LRFs/ designators to a reference optical axis
E		Custom set of frame grabbers	both SEM2 and LS-DAL sources			MTB-2D blackbody and LS-SAL light source	As in 7c and MRT, MTD	As in 8d but also distance accuracy, ER, max range, receiver sensitivity		Additionally boresight to a reference mechanical axis (plane)

6 Detail interpretation of ten letter code of MS systems

Column no 1. Test range of thermal imagers

Test range of thermal imagers is described by a number of parameters that are to be measured using MS test system. Test range can vary from a measurement of only MRTD to measurement of a long series of parameters: MRTD, MTF, SiTF, NETD, FPN, non uniformity, distortion, FOV, AutoMRTD, MDTD, PVF, SRF, ATF, NPSD, 3D noise.

Test range of thermal imagers is determined by two factors:

1. types and number of IR targets to be delivered,
2. number of test modules in TAS-T computer program or in TCB Control program.

Detail description of codes used in column no 1 of Table 1 is presented below:

1A IR targets: set of eight 4-bar targets; software test modules: TCB Control program and SUB-T program to support MRTD test are delivered.

1B IR targets: set of eight 4-bar targets, edge target, dot-cross target, cross target. Software test modules: as in 1A but additionally TAS-T/S program (MTF, SiTF, noise parameters, distortion, FOV modules) is delivered.

1C Set of eight pinhole targets is additionally delivered. Computer program TAS-T is delivered in version TAS-T/E1 having additional test modules capable to carry out measurement of the following parameters: AutoMRTD. SUB-T supports MDTD measurement.

1D Computer program TAS-T is delivered in version TAS-T/E2 having additional test modules capable to carry out measurement PVF, SRF, ATF, NPSD, 3D noise, bad pixels.

Column no 2. Frame grabbers

Tested multi-sensor imaging systems typically generate output image to be analyzed by humans or by software in electronic forms using different video standards. This video image must be captured and analyzed to measure parameters of imagers (thermal imagers, VIS-NIR cameras, SWIR cameras).

Majority of imagers used in surveillance applications generate video image in standard analog video formats: PAL or NTSC. Therefore analog video frame grabber is a standard module of MS test system.

However, increasing number of imagers that generate video images in different digital standards: Camera Link, GigE, LVDS, HD-SDI, DVI, HDMI, HD-TVI, HD-CVI, CoaXPress, USB2.0/3.0, Ethernet. Therefore Inframet offer optional digital frame grabbers to enable acquisition of video from any imager available on market.

Detail description of codes used in column no 2 is presented below:

2A No frame grabber is delivered. This option is optimal for situation when tested system is equipped with its internal/external display and only subjective parameters (MRTD of thermal imagers and resolution/MRC of VIS-NIR cameras are to be measured. This option is not acceptable when more extensive testing of thermal imagers/VIS-NIR cameras (measurement of objective parameters like MTF, NETD and so on) is to be done.

2B Frame grabber accepting images in standard analog video format (PAL/NTSC) is delivered.

2C As in 2B but one additional digital video grabber is delivered. Customer is to specify video standard. TAS computer program is modified to accept images acquired by the frame grabber.

2D As in 2B but two additional digital video grabbers are delivered. Customer is to specify video standard. TAS computer program is modified to accept images acquired by the frame grabbers.

2E Customer can define set of frame grabbers.

Column no 3. VIS-NIR light source

Light source emitting in VIS-NIR spectral band is needed for testing VIS-NIR cameras. The light sources that can be used in MS systems can be divided into two groups:

1. Modules to be integrated with DCB color blackbody (SEM1, SEM2, HAL,
2. Stand alone devices (LS-DAL).

Color blackbody is a radiation source that at the same time work as a typical blackbody in MWIR-LWIR band and a light source in VIS-SWIR band. Technical specifications of DCB color blackbody can be found under the link https://www.inframet.com/Data_sheets/DCB.pdf.

LS-DAL light source is independent from blackbody stand alone light source. Technical specifications of LS-DAL color blackbody can be found under the link https://www.inframet.com/Data_sheets/LS-DAL.pdf.

The advantage of solution when light source is a part of DCB color is elimination of mechanical change of light source on blackbody when switching from testing VIS-NIR cameras to testing thermal imagers. All typical parameters of VIS-NIR cameras can be measured. However, stand alone light source (LS-DAL) offers much higher dynamic and variation of light spectrum. In this way stand alone light source LS-DAL enables better simulation of illumination at real work conditions that can vary from very dark nights to very bright days.

Detail description of codes used in column no 3 is presented below:

- 3A SEM1 – improved white LED source integrated with DCB color blackbody. Light intensity is electronically controlled from PC. Emits white light in spectral band 450-700nm.
- 3B SEM2- broadband LED light source for VIS-NIR band integrated with DCB color blackbody. Emits spectral uniform light in band 450-850nm of color temperature about 5000K. Light intensity is electronically controlled from PC.
- 3C HAL – broadband halogen light source for VIS-NIR band to be integrated with DCB color blackbody. Light intensity is electronically controlled from PC. Emits light of color temperature 2850K in spectral band 400-1000nm.
- 3D LS-DAL multi-channel light source – ultra high performance multi channel light source of very high dynamic and variable spectrum. This light source can simulate illumination scenarios met in any geographical regions (very dark nights in Afghanistan mountains and very bright days in Arabian desert)
- 3E Both SEM2 and LS-DAL sources are delivered. This solution combine advantages of SEM2 and LS-DAL. SEM2 is used for typical testing. LS-DAL is used only for most demanding tests that require simulation of extreme illumination conditions.

Column no 4. Light level

All the light sources (SEM, HAL and LS-DAL) can be delivered in different versions capable to simulate:

- 4A day conditions,
- 4B night conditions
- 4C both day conditions and night conditions.

However, only LS-DAL light source can offer simulation of both very dark nights and very bright days (dynamic of regulation over 100 000 000 times up to 10 kcd/m). Max luminance of SEM and HAL light sources is limited to 1 kcd/$m^{2.}$ (simulation of illumination up to about 10000 lx for targets of 33% reflectance). It should be noted that light intensity range of SEM / HAL light source is sufficient to simulate typical light conditions met on Earth.

Column no 5. Test range of VIS-NIR cameras

Test range of VIS-NIR cameras is described by a number of parameters that are to be measured. Test range can vary from a measurement of only resolution parameter (simplified tests by final users) to measurement of a long series of parameters(resolution, MTF, Distortion, FOV, Sensitivity, SNR, NEI, FPN, Non Uniformity, Responsivity function, MRC, 3D Noise, Number of bad pixels and bad pixel localization).

Test range of VIS-NIR cameras is determined by two factors:

1. number of VIS/NIR targets to be delivered,
2. number of test modules in TAS-V computer program.

Detail description of codes used in Table 1 column no 5 is presented below:

- 5A USAF1951 100% contrast target and software modules: LS Control program and SUB-V program to support resolution at regulated light intensity measurement;
- 5B 5A and additionally set of 4 variable contrast USAF 1951 targets is delivered (total contrast in range at least 5% to 100%). SUB-T program support of MRC (minimal resolvable contrast) Measurement. This is the most important parameter of surveillance VIS-NIR cameras. Its measurement enables calculation of detection, recognition and identification of so called NATO target (or other reference targets) according rules presented in a NATO standard.
- 5C 5B and additional edge target, dot-cross target, square target. Software test modules: as in 5B but additionally TAS-V program (MTF, sensitivity, NEI, distortion, FOV modules) is delivered.
- 5D 5C and additional modules in TAS-V program: 3D Noise, Uniformity, NPSD, Bad pixels, SNR, Responsivity function. This version useful for design teams working on development of new VIS-NIR cameras.

Column no 6. Source of SWIR light

Light source emitting in SWIR spectral band is needed for testing SWIR cameras. The SWIR light sources used in MS systems can be divided into two groups:

1. modified VIS-NIR light sources (SEM2-SW, HAL-SW, LS-DAL) typically used for testing VIS-NIR cameras (see column no 4),
2. special radiation sources like MTB medium temperature blackbody.

Light sources from the first group emits most light in spectral band from visible to half of SWIR band (about 1500nm) and are fully sufficient for testing typical non cooled SWIR cameras sensitive up to 1700nm. Radiation source from the second group is recommended to test cooled SWIR cameras sensitive up to about 2200nm for ability to detect medium temperature targets: measurement of MRT (minimal resolvable temperature) and MDT (minimal detectable temperature) parameters.

Detail description of codes used in column no 6 is presented below:

- 6A No SWIR light source
- 6B SEM2-SW – modified SEM2 light source: expanded spectral band. Emits light in spectral band 450-1100nm. Light intensity is electronically controlled from PC.
- 6C HAL–SW – modified HAL halogen light source. Increased light intensity in SWIR band.
- 6D LS-SAL light source – special version of LS-DAL light source of expanded spectral band into SWIR
- 6E both LS-SAL and MTB medium temperature blackbody are delivered. This solution combines advantages of LS-SAL and MTB. LS-SAL is used for testing typical non cooled SWIR cameras. MTB is used only for special tests of cooled long wave SWIR cameras.

Technical specifications:

LS-SAL light source https://www.inframet.com/Data_sheets/LS-SAL.pdf

MTB-2D blackbody https://www.inframet.com/Data_sheets/MTB.pdf

Column no 7.Test range of SWIR imagers

Test range of SWIR cameras is described by a number of parameters that are to be measured. Typical non-cooled SWIR cameras sensitive up to about 1700nm can be characterized by the same parameters as VIS-NIR cameras. Cooled SWIR cameras sensitive up to about 2200nm can be additionally characterized by some parameters (MRT, MTD) that describe sensitivity to thermal radiation of medium temperature targets.

Test range of VIS-NIR cameras is determined by three factors:

1. number of VIS-SWIR targets (modified VIS-NIR targets) to be delivered, when test range of VIS/NIR imagers is selected then there is one set of targets delivered for VIS/SWIR range.
2. number of test modules in TAS-S computer program,
3. type of SWIR light source (MTB blackbody is needed for MRT and MDT tests).

Detail description of codes used in Table 1 column no 7 is presented below:

- 7A No testing SWIR imagers
- 7B USAF1951 100% contrast target and software modules: LS Control program and SUB-V program to support resolution measurement;
- 7C resolution, MTF, Sensitivity, NEI, distortion, FOV
- 7D As in 7C but also MRC, 3D Noise, Uniformity, NPSD, Bad pixels, SNR, Responsivity function. Measurement of MRC is particularly recommended to estimate detection, recognition, identification ranges of target of interest.
- 7E As in 7D but also measurement of MRT (minimal resolvable temperature), MDT (minimal detectable temperature). Option recommended when testing cooled SWIR imager of sensitivity up to about 2200nm.

Column 8. Test range of LRFs/laser designators

Tests of LRFs can be divided into three groups main: transmitter tests (beam divergence, pulse energy, pulse peak power, PRF, pulse width, and boresight of transmitter to the line of sight), total performance tests (distance measurement, Extinction Ratio, maximal operational range), internal boresight tests (boresight error between transmitter and emitter).

Inframet generally recommends to limit tests of LRF/designators to transmitter tests due to a series of reasons. First, properly done performance/internal boresight tests require precision aligning of tested LRF module relative to the test system. This aligning can be relatively easily done testing stand alone LRF as a small module that can be located at collimator output but is difficult to be done when LRF is a part of a big system and is located at some distance from the collimator. Therefore it is recommended to do performance tests and internal boresight tests of LRFs before installation of LRF to a big multi-sensor system. Second, parameters of receiver of LRF (receiver sensitivity and boresight error relative to transmitter) rarely deteriorate with time. Typically the main problem is deterioration of transmitter parameters.

However, it should be noted that Inframet can offer both transmitter tests and total performance tests of LRFs/designators at much higher level comparing to other systems offered on the market.

Most of test systems offered by competitors enable measurement of pulse energy. Some of them enable measurement of beam divergence angle and so called distance simulation. Practically such test systems are of very limited use for testing modern LRFs for following reasons.

First, typical pulse energy meters enable measurement of pulse energy only in case of monopulse LRFs/designators that emit low frequency ultra high power pulses. They are practically useless in case of multipulse LRFs that emit a series of high frequency of low power pulses. The latter LRFs are increasingly popular and are manufactured by a series of big companies.

Second, divergence angle of LRFs/designators is typically measured using laser sensing cards, scanning beam profiler, or typical SWIR camera. None of these solutions enables accurate measurement of beam divergence angle of high power pulses of monopulse LRFs/designators. Laser sensing cards (used also by Inframet for boresight tests) enable only rough measurement. Scanning profilers are a good solution but only for spatially static LRFs/designators- they are useless in case of gyroscopic gimbal based systems when there is always some angular movement of tested system and measurement must be done after a single laser shot. Typical SWIR cameras generate overinflated results due to image blurring generated when shooting ultra high power ultra short pulses. Because of these reasons Inframet uses special LSR10 laser beam profiler based on a special ultra high dynamic SWIR camera.

Third, some of competing test systems offer so called distance simulation. This means that tested LRF will indicated simulated distance. However, practically such tests are of very limited value because of lack of any calibration of incoming pulses. The same high power pulses are used to simulate both short distance and long distance targets. Therefore such tests generate typically positive results for measuring distance to long distance targets even when in real life the LRF will not generate any measurement result at all. In contrast Inframet uses professional OPG10 optical pulse generator block that generate calibrated optical pulses. Receiver sensitivity can be measured and later maximal operational range can be calculated. Direct tests against long distance targets can be carries out, too.

To summarize, Inframet offers very expanded tests of LRFs using MS test systems. User can choose optimal version. Detail description of codes used column no 8 of Table 1 is presented below:

8A No tests of LRFs/designators

8B Pulse energy (monopulse LRFs) and beam divergence (rough measurement) can be measured. Measurement of pulse energy is gone using COE meter. Rough measurement of beam divergence angle is done using laser sensing cards.

8C As in 8B but also distance to the target can be simulated. The simulation is done using special non calibrated OPG1 optical pulse generator.

8D Expanded tests of transmitters can be carried out. Following parameters can be measured: beam divergence (accurate), pulse energy, pulse peak power, PRF, pulse width, coding, missing pulses. Beam divergence is measured using LSR10 laser beam profiler. Other parameters are measured using advanced OSA optical signal analyzer system.

8E As in 8d but also distance accuracy, ER, max range, receiver sensitivity can be measured. The tests are done using advanced fully calibrated OPG10 pulse generator capable to simulate laser pulses reflected by a target irradiated by LRF.

Column 9. Test range of laser pointers/illuminators

Laser pointer/illuminators are much simple comparing to LRFs/designators. The same valid for testing of laser pointer/illuminators that are characterized by only two main parameters: power, divergence angle.

Detail description of codes used column no 9 of Table 1 is presented below:

9A no testing laser pointers/illuminators.
9B measurement of power (any laser pointer/illuminator), and divergence angle (laser pointers and laser illuminators of divergence angle not bigger than 2 deg). These test capabilities are achieved using COP power meter and BRL test camera.

Column 10. Boresight capabilities

Boresight is a process to align optical axis of single system or a series of optical or electro-optical systems with a certain reference optical axis or mechanical axis. Proper boresight is particularly critical in case of multi-sensor electro-optical surveillance systems built from a series of systems like thermal imager, VIS/NIR camera, SWIR camera, laser range finder, laser pointer. Quality of boresight is characterized by a series of boresight errors: angles between some axis.

There are two main types of boresight:

1. boresight to a reference optical axis (typically optical axis of the imagers that is considered as a line of sight),
2. boresight to a reference mechanical axis (typically axis perpendicular to a front wall that works as reference mechanical plane).

Boresight to a reference optical axis is needed practically for any multi-sensor surveillance system. Boresight to a reference mechanical axis is needed only for some targeting systems.

Boresight capabilities are described by a number of boresight errors that can be measured. Detail description of codes used column no 10 of Table 1 is presented below:
10A No boresight tests
10B Imagers to a reference optical axis. Measurement of alignment error between 1)optical axis of thermal imager relative to optical axis of VIS-NIR camera or SWIR imagera), 2)optical axis of thermal imager/VIS-NIR/SWIR camera at several FOVs (zoom magnifications)
10C Imagers and monopulse LRFs/designators to a reference optical axis. Measurement of aligning error between optical axis of laser system (monopulse LRF, laser designator, laser pointer/illuminator) relative to optical axis of a reference imaging system.
10D Imagers and all LRFs/ designators to a reference optical axis. As per option 10C but systems with multipulse LRFs can be tested, too.
10E Additional measurement of aligning error of any of imagers/laser system to a reference mechanical axis. The tests are done using specialized BORIM boresight set.

7 Code of exemplary MS system

The code MS300-BBBAC-AADAC means an MS system of following features:

- 300 - Collimator free aperture: 300mm
  1. B- Test range of thermal imagers: MRTD, MTF, SiTF, NETD, FPN, non-uniformity, distortion, FOV
  2. B - Frame grabbers: standard analog video(PAL/NTSC)
  3. B - Light source: SEM2- broadband LED light source for VIS-NIR band
  4. A - Light level: Day- max 1000 cd/m2
  5. C - Test range of VIS-NIR cameras: resolution, MTF, Sensitivity, NEI, distortion, FOV, MRC
  6. A - SWIR radiation source: No light source
  7. A - Test range of SWIR imagers: No tests
  8. D - Test range of LRF/designators: Beam divergence (accurate), pulse energy, pulse peak power, PRF, pulse width, coding, missing pulses
  9. A - Testing laser pointers: no tests
  10. C - Boresight capabilities: Boresight of imagers and monopulse LRFs/designators to a reference optical axis

8 Recommendations

MS is a sophisticated modular system that can be arranged in myriads of configurations of different design, test capabilities and price. There are also myriads of multi-sensor systems on the market that can be possibly tested. Therefore it is necessary to take great care when choosing MS system to fit well to tested multi-sensor EO system. Below are formulated some recommendations on choosing optimal version of MS system.

These recommendations can be divided into two groups: 1)collimator (the number code), 2)test capabilities (ten letter code).
The rule of thumb for choosing proper aperture of the collimator is following:

1. Recommended situation: the collimator aperture is bigger than diameter of a circle overlapping fully optics of all sensors
2. Barely acceptable situation: the collimator aperture is bigger than diameter of a circle overlapping at least 50% of optics of the sensors (valid only for boresight tests).

In the first case there is no need to move mechanically tested system relative to collimator when switching from testing thermal imager to testing other subsystems. In the second case tested system must be moved relative to collimator to achieve situation that collimator aperture overlaps aperture of tested subsystem.

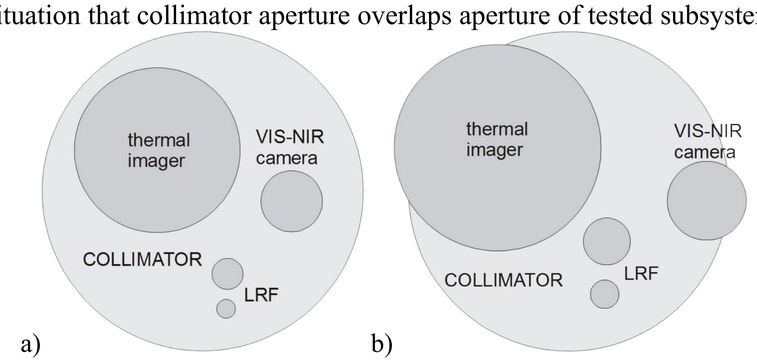

Fig. 3. CDT collimator and tested multi-sensors system: a) collimator overlapping optical apertures of all sensors of the surveillance system; b) collimator only partially overlapping optical apertures of optics of tested system

It is not recommended also to choose collimator of too big aperture (aperture is several times bigger than combined aperture of optics of tested system). The reason is that collimator aperture is related to collimator focal length. The ratio of focal length of Inframet off axis reflective collimators to collimator aperture (F-number) is typically in range from about 6 to 10. For details please see http://www.inframet.com/Data_sheets/CDT.pdf. Too long collimator focal length creates situation when number of available 4-bar targets (see https://www.inframet.com/targets.htm) that can be resolved by tested imager can be too small to measure proper MRTD. It is recommended that spatial frequency of available 4-bar targets should cover at least the range from 0.2 to 1.2 of Nyquest frequency of tested imager (or at least from 0.4 to 1 of Nyquest frequency).

The safest solution to choose ten-letter code that describes system test capabilities is to choose most advanced version (for example MS-X-EEECD-EEEBE) when the highest available letters are used to make the code. However, this is also the most expensive version in situation when there is a risk that some of advanced features are not needed. Therefore careful analysis what test capabilities are truly needed is always recommended.
Example test systems:

1. MS150 ABBAA-AAAAB system for limited testing/boresight of small short range multi sensor system built as thermal imager with VIS-NIR camera
2. MS300 BBBAB-AABAC system for typical testing boresight of long range multi sensor system built as thermal imager, day VIS-NIR camera, monopulse LRF
3. MS300 BDBAC-AADAD system for expanded testing boresight of long range multi sensor system built as thermal imager, day VIS-NIR camera, LRF
4. MS300 BDECC-DCEAD system for ultra expanded testing boresight of long range multi sensor system built as thermal imager, day VIS-NIR camera, SWIR camera, LRF.

9 Comparison to competitors test systems

There is a series of systems for testing multi-sensor surveillance systems offered on international market. However, there is also a series of objective reasons that makes MS systems offered by Inframet the best choice for potential customers.
At first, there are several general advantages of Inframet.

1. High technical level or even technical superiority in all areas of electro-optical technology. Inframet is the only company in the world that can deliver equipment for testing any type of EO system. This feature is important in situation when tested multi-sensor surveillance systems are built by combining a series of

EO sub-systems.

2. Company openness. Inframet in contrast to competing companies presents at website detail technical data sheets. Reference lists and example orders are available on request.
3. Long term cooperation strategy. Inframet treats its customer like partners trying to share its know how, to support them in application of our test equipment and to start long term cooperation. In addition, Inframet offers not only training how to operate test system but much wider educational training that helps in design of new EO systems
4. MS system is offered in form of a long series of versions. It makes possible optimization for specific situation of different customers.
5. Reasonable price policy of Inframet. The MS system are offered at high ration of test capabilities to price.

There is also a series of technical advantages of MS systems that are listed below.

Thermal imagers

1. Blackbody head integrated with electronic controller. This means that the blackbody is a single module in situation when competitors offers blackbodies in form of two modules. The cables between controller and blackbody head are eliminated (improved reliability). Distance between temperate sensors and electronics is very short (higher resistance to EMI). This solution significantly increase blackbody reliability and extend life time.
2. Vertical design configuration. It means that MRW8 rotary wheel is located on CDT collimator and later blackbody is located on a wheel. This solution makes MS system compact (smaller optical table needed) and more resistible to vibrations because all block are fixed to the CDT collimator. Next, this configuration improves also temperature uniformity of blackbody emitter (crucial when testing cooled thermal imagers of very low NETD - see http://www.if.pwr.wroc.pl/~optappl/article.php?lp=834).
3. Blackbody of ultra high emissivity. Inframet is the only manufacture of systems for testing thermal imagers that offer in standard version blackbody of ultra hight emissivity 0.98±0.01 when typical values are below 0.97. The blackbodies are also characterized by excellent temperature uniformity - very useful feature when testing high performance cooled thermal imagers of very low NETD.
4. Virtual MRTD measurement method. Dubterm can deliver computer program that enables to carry out measurement of Virtual MRTD using computer simulation of thermal imagers in order to speed up measurement of MRTD of thermal imagers.

VIS-NIR cameras

1. Ultra advanced VIS-NIR light sources capable to simulate realistically both day conditions and night conditions due to extremely wide range of illumination regulation in range from about 30 μlx to over 30 klx. In other words it can be said that MS system (version with LS-DAL light source) can simulates both ultra dark nights in Afghanistan mountains and very bright day conditions on Arabia desert. *There is on the market no test system that could simulate illumination condition in so wide range.*
2. Dual color blackbody. It is a special version of classical differential area blackbody combined with a light source that emits radiation in both MWIR/LWIR range and VIS-NIR range. It is a patent pending technical solution extremely useful when testing dual imaging systems (thermal imager combined with VIS-NIR camera). Both imaging systems can see a test target at the same time. No mechanical exchange of blackbody for a light source is needed. *There are on market similar fused blackbodies but of much lower performance properties (emissivity and temperature range of the blackbody emitter, spectral range and regulation dynamic of light source).*
3. Set of variable contrast USAF1951 targets. VIS-NIR cameras are typically tested using low cost USAF 1951 targets of 100% contrast. However, these typical targets of 100% contrast poorly simulate low contrast targets commonly met in real life conditions. Therefore tests of VIS-NIR cameras should be done against low contrast USAF1951 targets - lower contrast the better. However, it is difficult to manufacture these targets of very low contrast. Some competitors offers variable contrast targets of contrast over 10%. Inframet offers a set of USAF 1951 targets of contrast from 3% to 100%. It makes possible to measure Minimal Resolvable Contract (MRC) function of tested VIS-NIR camera and calculate detection/recognition/identification ranges according to rules of NATO standards.

Laser range finders

1. Expanded testing (long list of parameters) of transmitters of both monopulse LRFs and multipulse LRFs is possible. Competing systems offers typically only measurement of pulse energy of pulse energy of

monopulse LRFs.

2. Accurate single shot measurement of divergence angle of LRFs using laser beam profiler optimized for testing pulsed lasers. Typical systems cannot measure accurate divergence angle of LRFs on basis of a single shot.
3. Measurement of realistic maximal operational range. Some of competing test systems offers only so called distance simulation. This means that tested LRF will indicated simulated distance. However, practically such tests are of very limited value because of lack of any calibration of incoming pulses. Therefore such tests generate typically positive results for measuring distance to long distance targets even when in real life the LRF will not generate any measurement result.
4. Long life time of collimator even when testing high power LRFs. The secondary mirror is damaged when testing high power LRFs of pulse energy over about 20mJ in typical test systems if user forgets to activate optical attenuator at collimator interior. Collimators in MS systems are protected against such mistake of operators due to special dual port design.

Boresight

1. Boresight of imaging systems based on a concept of DCB dual color blackbody that irradiate target both at MWIR-LWIR band and VIS-NIR band. No mechanically movable parts. Highest boresight accuracy can be achieved. Competitors offers two mechanically switchable radiation sources: blackbody and visible light source.
2. DCB dual color blackbody irradiates the reference target both at MWIR-LWIR band and VIS-NIR band at the same time. It makes possible testing advanced fused imagers that generated fused visible-thermal image.
3. Boresight of imaging systems to LRFs is based on well checked concept of laser sensing cards. Inframet delivered a set of five cards optimized for all types of LRFs. Competitors offers lower number of cards.
4. Software that enables accurate measurement of aligning errors of thermal imagers, VIS-NIR cameras, SWIR imagers, laser systems.
5. Precision method for boresight to a reference mechanical axis based on high dynamic VIS-NIR camera. Typical systems use standard cameras not capable for precision calculation of distance between two light source that differ thousand of time of light intensity (point laser source and reflected image).

Other features

1. Long recalibration intervals. Manufactures of typical test systems recommends recalibration of blackbody once per year or once per two years. Inframet can optionally deliver special blackbody of ultra small temporal drifts and then recalibration interval can be extended to once per four years or even longer period.
2. Recalibration equipment. Inframet can optionally deliver calibration set for MS test system that can be used for recalibration or checking of crucial MS system modules by customer. This unique offer makes MS owner independent from recalibrations in Inframet laboratories and allows to make MS system traceable directly to local metrology institute.
3. Evaluation software. In order to make easier interpretation of test results a set of three computer simulation programs is offered:
   - Simterm - the program generates images that resemble images generated by real thermal imagers. User can insert parameters of tested thermal imager and see images of different real targets at different field conditions generated by tested imager.
   - Mosot - the program calculates detection, recognition and identification ranges of several targets using a thermal imager of known MRTD,
   - Movis - the program calculates detection, recognition and identification ranges of several targets using a VIS-NIR camera of known MRC.
4. Educational support. Inframet is the only manufacturer of equipment for testing thermal imagers that offers free book on testing thermal imagers
   http://www.inframet.pl/Literature/Testing%20thermal%20imagers.pdf.

10 Options

A series of options are offered in addition to standard versions presented in previous sections:

1. Virtual MRTD measurement method
2. Computerized ultra precise focusing platform for regulation of distance simulated by MS system
3. Optical table dedicated to MS system
4. Mobile optical table for UUT of regulated height is delivered. It is recommended

5. Equipment for recalibration of MS system

Ad 1)This option means that Dubterm computer program is delivered. This program enables to carry out measurement of MRTD using so called Virtual MRTD method in order to shorten time of measurement.
Ad 2)Computerized ultra precise focusing platform CFOC12 for regulation of distance simulated by MS system. Simulated distance is regulated from the minimal distance to infinity. The minimal distance depends on focal length of the collimator. In case of focal length equal to 1m the minimal distance is 90m.
Ad 3) AT optical table to be used as a platform for MS test system (and optionally also UUT) is delivered. This option is recommended to eliminate table vibrations that can negatively influence measurement results. Tables of different size are offered. Technical data as in https://www.inframet.com/optical_tables.htm.
Ad 4) MT mobile optical table of regulated height. It is recommended to locate both MS test system and UUT. This solution gives best protection against mechanical vibrations of floor in room test. However, solution when MS system located on a stationary AT optical table and UUT on a MT mobile optical table.
Ad 5)Inframet delivers calibration set that makes possible to recalibrate blackbody, light source, laser meters and to check performance of off axis reflective collimator.

Please add numbers of the chosen options to the code of MS system. MS300 AAAAA-AAAAA-34 means MS300 AAAAA-AAAAA system with options: 3 and 4.

11 Summary

1. MS system is one of most sophisticated Inframet test systems capable to test virtually all multi-sensor electro-optical imaging/laser systems present market.
2. MS test system can be easily configured by potential user to suit for his applications by adding/removing modules
3. If you have problems to choose proper versions of MS test system using proposed code please **describe your application** in words and Inframet staff shall propose an optimal version. Problem to choose proper version is natural - the reason is complexity of testing multi-sensor systems.
4. This data sheet present a list of typical versions of MS test system. Inframet can deliver customized versions.
5. Please contact Inframet if you have any questions. We are happy to serve you and work had to keep our status as leader in field of apparatus for testing electro-optical surveillance systems.

Version 6.1

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