• INFRAMET

INFRAMET
Graniczna 24, Kwirynow
05-082 Stare Babice, Poland
tel: 048 604061817, fax 48 22 6668780
email: info@inframet.com www.inframet.com

Report B01/19

Introduction to boresight of electro-optical surveillance systems

Author: Krzysztof Chrzanowski

1 Inframet situation

Inframet is a manufacturer of equipment for testing electro-optical imaging and laser systems. Customers typically ask for systems to measure parameters of tested systems related to image quality or system noise or sensitivity. However, sometimes they ask about tools to do boresight.

Boresight is probably the most ambiguous term in electro-optical metrology. It is often used by many people who understand it in different way or do not know at all its precise interpretation. There are hundred of scientific papers having the word boresight in tittle or abstract but this term is understood in myriad of ways.

Next, it is quite common for Inframet as a manufacturer of test equipment to get a request for delivery of a test system capable to do boresight of an electro-optical imaging/laser system without any precise information what is exactly to be done. Next, some of potential customers ask for delivery of test systems capable to check proper boresight of itself. Finally, there are customers who want to be able to check relative boresight of the collimator of the test system relative to external reference mechanical/optical block. In all cases it is a typical situation that the boresight task is not precisely defined. It occurs also that some customers order some boresight capabilities of a test system in situation when they do not need it. The main reason for such a confusing situation is that the term boresight in modern EO metrology differ significantly from classical definition.

2 Definitions of boresight

According to traditional definition boresight can be defined in three ways [1]:

1. Antenna boresight, the axis of maximum gain (maximum radiated power) of a directional antenna,
2. Boresight (firearm), adjustments made to an optical or mechanical sight, to align the barrel of a firearm with the sights,
3. Boresight point, also known as gun harmonization, the alignment of weapons in an aircraft.

The first definition refer to radio or microwave technology and will not be discussed here.

According to the second definition the boresight is a process to bring into proper alignment (the bore and sights of a gun) by sighting on a distant point through the bore and adjusting the sights on that same point [2].

Fig. 1. Classical concept of boresight

The alignment is typically defined as parallel alignment of the bore and sight of a gun [3] but practically the aim of boresight is to achieve situation when mechanical axis of the bore converge with the optical axis of the sight because gravity effect on bullet trajectory must be taken into account if the bullet can hit the targeting point. For each gun there is usually a correction table, where shooter can find proper angle and corresponding distance. Therefore classical parallel alignment of the bore and sight of a gun should be treated as a reference position of the sight relative to the bore.

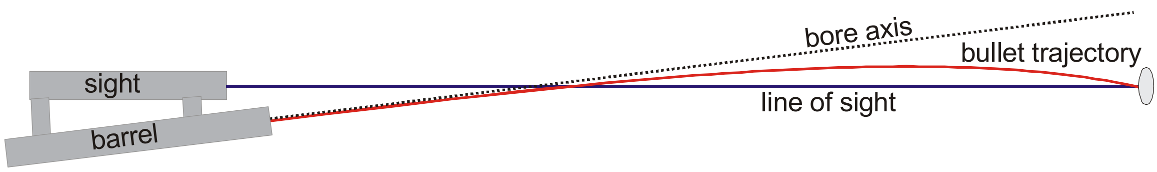

Fig. 2. Effect of gravity of bullet trajectory

The third definition originally referred to the aiming of fixed guns or cannon carried in the wings of a fighter aircraft. The wing guns in fighters were typically not bore-sighted to point straight ahead; instead they were aimed slightly inward so that the projectiles met at one or more areas several hundred yards or meters in front of the fighter's nose. The intent was either to spread the fire of multiple weapons to increase the chance of a hit, called "pattern harmonization", or to concentrate the fire to deliver greater damage at one point, called "point harmonization"[1].

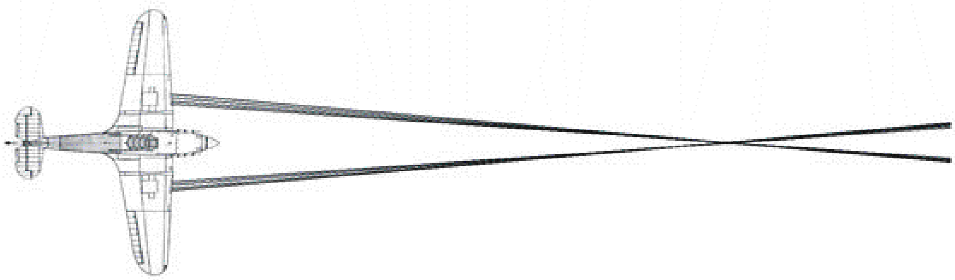

Fig. 3. Concept of harmonization of wing guns

Military aircraft from the 1960s onward generally did not carry guns in the wings and basically original concept of harmonization understood as converging of two wing guns has expired. However, the term harmonization/boresight is still used in modern literature on aircraft technology but this term refer to a process of harmonization of weapons having any location with electro-optical imaging or laser system and/or with navigation systems.

To summarize, classical definitions present boresight as a process to align a barrel with optical sight or one barrel with the second barrel. Practical experience of the author of this paper shows that the term boresight used nowadays in electro-optical technology has much wider meaning than presented by these classical definitions discussed earlier. At the same time there is no standard that regulates boresight of EO systems.

In such situation it is proposed to define boresight as a process of adjustment of modules or complete electro-optical systems carried out with aim to align at least two reference axis (optical or mechanical) of these EO systems or to keep the same axis non dependent on system settings or work conditions.

Now, let us define in detail the terms optical axis, and mechanical axis used in the definition of the boresight process.

The term optical axis is frequently used in literature on optical technology but in no consistent way. The optical axis is defined in different way for single thin lens, mirror, thick lens, or multi lens optical system. However, generally optical axis of optical imaging system is defined as a line along which there is some degree of rotational symmetry in an optical system [4]. In more detail optical axis can be defined as a line passing through the cardinal points of symmetrical optical systems (the focal points, the principal points, and the nodal points).

The term optical axis is also frequently used in literature on electro-optical technology but it is surprisingly difficult to find a precision definition of optical axis of electro-optical system. In detail, the author has not found even a single precision definition of optical axis of EO system that could fit to both imaging and laser systems. In such situation let us define optical axis of electro-optical system as a line along which there is some degree of rotational symmetry in such EO system.

This general definition of optical axis of EO system is very similar to classical definition of optical axis of optical system. However, EO systems differ much from typical optical systems (thin lens, thick lens, multi lens objective, multi lens afocal system) and optical axis of EO system differs much from such axis of optical system.

The optical axis of EO system can be precisely defined as:

1. Optical axis of imaging EO system (thermal imager, night vision device, VIS-NIR camera, SWIR camera, UV camera) is a line that connect center of the imaging sensor, center of thin lens equivalent to system optics and a point in target plane is the center of FOV of such imaging system.
2. Optical axis active laser systems (laser transmitter in laser range finder, laser pointer, laser illuminator, laser designator) is an imaginary line that connects centers of profiles of the emitted

laser beam,

3. Optical axis of non-imaging EO system (IR seeker, receiver of laser seeker, receiver of laser range finder, receiver of laser communication system) is a line that connect center of the discrete optical detector, center of thin lens equivalent to system optics and a point in target plane that is the center of FOV of such a system.

It should be noted that optical axis of EO system can be the same line as optical axis of optics used to built the EO system but both axis typically differs because it is difficult to locate imaging sensor, discrete detector or laser diode exactly on optical axis of the optical objective of the EO system (Fig. 4).

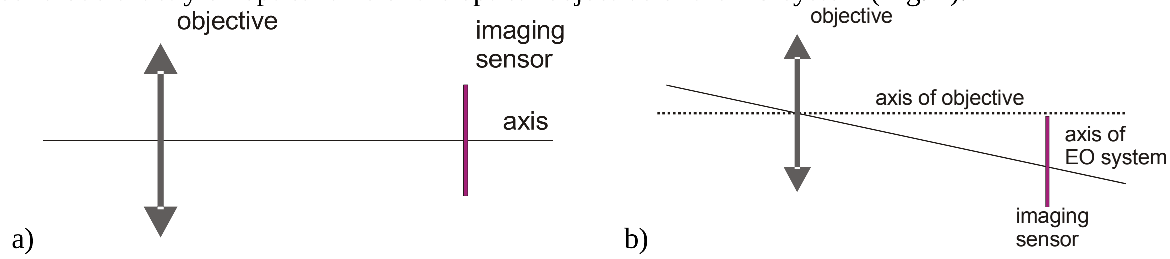

Fig. 4. Optical axis of EO system: a)perfect aligning of imaging sensor and objecive, b)very bad aligning of imaging sensor and objecive

It is often not clear where is precisely located center of the thin lens equivalent to optical objective of the imaging/non imaging EO system. However, the optical axis of the EO system can be always determine a line between center of imaging sensor/discrete detector and center of system FOV at target plane. Next, if target plane is at long distance from the EO system (typical case) then optical axis can be also determined with good accuracy as a line between the center of imaging sensor/discrete detector and center of system FOV at target plane because potential error of detemination of the center of the optics has little itfluence on position of the calculated optical axis.

`The proposed definition of the optical axis is clear and simple to use. It is actually easier to determine optical axis of EO system than optical axis of classical optical system. However, before practical use of proposed definition it is necessary to clarify difference between line of sight (LOS) of EO system and optical axis of EO system.

Line of sight of imaging EO system is a line that connect a point of target plane indicated by aiming mark and and real/virtual aiming mark at image plane (typically electronic imaging sensor plane). Line of sight can be potentially the same as optical axis but often these lines differ. However, in practical applications line of sight is often used a reference axis of EO system and can be treated as a special case of optical axis.

Now it can be concluded that the term optical axis of EO system is sufficiently defined and let us concentrate on the term reference mechanical axis of EO system.

There are cases of mechanically symmetrical EO systems (some monoculars/sights) when the reference mechanical axis is a line along which there is some degree of rotational symmetry in such EO system. However, in general the reference mechanical axis can be any line chosen by designer of EO system to be used as a reference when calculating coordinates of optical or mechanical modules. Line perpendicular to the front wall of EO targeting systems can be treated as an example reference axis of EO system.

As it was earlier presented, boresight is a process to align at least two optical/mechanical axis of EO system. However, perfect aligning is practically non possible to achieve. Therefore in practical terms boresight of EO systems is a process minimization of boresight errors understood as angles between several optical/mechanical axis tested EO system. The types of axis can vary: optical axis of imaging system often represented as line of sight indicated by an aiming mark, optical axis of laser system (indicated by center of laser beam), optical axis of non-imaging systems, mechanical axis (or mechanical planes) of these systems (typically barrel or mechanical base).

Boresight errors defined above can generate at least following effects:

1. image shift between centers of images generated by two imaging EO systems,
2. laser beam hitting target that differs from target indicated by line of sight of imaging EO system,
3. discrete detector of a non-imaging EO system gets radiation from targets outsize its expected FOV.

Relative rotation of two images generated by two channels of EO imaging system (binocular night vision goggles, thermal binoculars) is not basically boresight error according to the boresight definition presented earlier but minimization of this effect is commonly considered as boresight task and let us assume that in most expanded version boresight also includes aligning of images generated by different channels of EO systems.

As it can be easily noticed new definition of boresight presented in several forms in this section is much wider than the classical definitions due to a series of reasons. First, we can talk about boresight even in case of EO systems that are not used as sights for weapons and no aligning to a gun barrel is requited. Second, aligning of laser systems to imaging systems is included. Third, aligning of images includes not only aligning of centers of two images (aligning of optical axis) but also adjustment needed to achieve the same image rotation or even perfect fusion of two images. Fourth, new definition includes also aligning of EO system with aim to keep its axis non dependent on imager settings or work conditions.

3 Types of boresight

Boresight definition presented in previous section covers a very wide range of activities. Some division of boresight is needed in order to avoid confusion when talking on boresight subject.

Let us divide boresight on some groups using a set of criterion:

A) who is to do boresight,
B) where boresight is to be done,
C) what system is to be aligned,
D) application of system to be aligned,
E) number of optical channels of EO system to be aligned,
F) stage of production cycle.

3.1 Who is to do boresight?

According to this criterion, boresight can be divided into three groups:

1. Manufacturing boresight,
2. Maintenance boresight,
3. Operational boresight.

Manufacturing boresight means aligning processes of blocks of EO systems done by manufacturer to achiever situation when this EO system can be considered as ready to be passed to a final user.

Maintenance boresight means aligning processes of blocks of EO systems done by maintenance team with aim to keep readiness of this system to be used by final users.

Operational boresight includes aligning processes of blocks of EO systems done by users of this system to make system optimized for current operational situation. Regulation of position of aiming mark depending on distance to target of interest can be considered as example of operational boresight.

This paper concentrates on the first two groups of boresight as operational boresight is relatively easy and specialized test equipment is not needed.

3.2 Where boresight is to be done?

According to criterion of place of where boresight is carried out the boresight can be divided into two groups:

1. Laboratory boresight
2. Field boresight.

Laboratory boresight are all aligning processes done at laboratory/manufacturing room/depot conditions. Generally laboratory boresight means all boresight tests done inside buildings.

Field boresight means all aligning processes done at field conditions outside buildings. However it should be emphasized that this type of boresight can be further divided into two subgroups: a)real field boresight tests, b)dry field boresight.

Real field boresight tests means real shooting to targets at field conditions with aim to verify and potentially improve alignment of tested EO system.

Dry field boresight (dry zeroing) means alignment of tested EO system at field conditions without real shooting but using some boresight equipment (often limited to shooting target).

It should be noticed that real field boresight tests are considered as final critical tests and this stage of boresight process can not be fully replaced by laboratory tests or dry field tests. The aim of laboratory tests and dry field tests is only to minimize time and costs of real field tests.

3.3 System is to be aligned

There are many types of electro-optical systems offered on international market. We can list here at least eleven main types:

1. Optical systems (iron sights, telescopic sights, reflex sights, holographic sights, binoculars,

telescopes)
2. Night vision devices (goggles, monoculars, binoculars, sights)
3. Thermal imagers (sights, monoculars, binoculars, electronic cameras)
4. VIS-NIR cameras (cameras, sights)
5. SWIR cameras (electronic cameras, sights)
6. Clip-ons (night vision, thermal, fused)
7. Laser systems (laser sights, laser range finders, laser designators, laser pointers/illuminators, LIDARs)
8. Multi sensor imaging systems (thermal imager, VIS-NIR camera, SWIR camera)
9. Multi sensor imaging/laser systems (thermal imager, VIS-NIR camera, SWIR camera, laser system)
10. Fused imagers (optical fusion, electronic fusion)
11. EO systems integrated with navigation system.

Some boresight (aligning) is needed for proper work of any of types of EO systems listed earlier. Therefore according to criterion of tested system boresight can be divided into at least eleven of groups (list of types of EO system). The latter division is very important because potential users of boresight equipment are typically interested in boresight of one or two types of EO systems. However, this division is confusing due to too high number of listed types of EO systems and additional versions. Therefore let us group the listed EO types into smaller groups.

It is possible to divide these EO systems according to spectral band used by these systems. However, this division is almost useless as great majority of these system use visible and near infrared range. In addition, boresight methods do not depends much on spectral band. More interesting criterion is application of system to be aligned.

3.4 Application of EO system to be aligned

According to criterion of application of system to be aligned the EO systems can be divided into two main groups:
1. Surveillance systems,
2. Sights and targeting systems.

The main task of surveillance imagers is to generate high quality image of scenery of interest.

Sights are in general systems used to support aiming. Most sights generate image of scenery of interest like surveillance imagers but the image includes aiming mark.

Targeting systems can be treated as more advanced version of sights. These systems can not only generate aiming mark on produced images like typical sights but offer at least some of such features: ability to measure distance to target, target indication using laser beam, determination of target coordinates, and target tracking.

Night vision monoculars/goggles can be considered as prime example of surveillance imagers. There is a reference mechanical axis of such imagers determined by plane of an adapter used to attach monocular/goggles to a helmet. However, requirements on aligning optical axis to a reference mechanical axis is low or very low. it is practically acceptable if optical axis of monoculars/goggles agrees with mechanical axis of this adapter with accuracy of several angular degrees.

There is similar situation in case of multi sensor imaging systems used for surveillance mounted on a rotary gimbal. There must be some aligning between optical axis of the imaging sensors and a mechanical axis of the gimbal but accuracy requirements are low.

Laser illuminators are another example of EO systems when boresight accuracy to a mechanical axis is low. If illuminator emits beam of divergence over 10º or more then precision aligning of illuminator with a mechanical axis is not important.

Situation is totally different in case of sights or targeting systems. Here boresight to a mechanical axis with accuracy of a fraction of milliradian becomes a typical requirement. Therefore boresight to a mechanical axis becomes critical in case of these group of EO systems.

However, it should be noted that border between imaging surveillance systems and sights/targeting systems is sometimes unclear. In fact sights/targeting systems can be considered as modified EO imaging systems. Anyway we are concentrate on sights/targeting systems and laser system of narrow beams as only in this case boresight is really important.

Next, EO systems as LIDARs or different imagers are commonly combined with global navigation systems and inertial navigation systems to create photogrammetry systems capable to deliver 3D geo-spatial information on scenery of interest. Precise boresight of axis of imagers and/or laser systems with axis of inertial navigation system is of critical importance for accuracy of photogrammetry systems.

3.5 Number of optical channels of EO system to be aligned

Criterion of number of optical channel of EO system to be aligned is another criterion that can help to EO systems on groups that require different methods. According to this criterion EO systems can be divided into:

1. single channel imaging systems (optical sights, mono night vision devices, thermal sights, clip ons, and many others)
2. single channel laser systems (laser sights, pointers, illuminators, designators)
3. dual channel imaging systems (binoculars, binocular night vision goggles, thermal binoculars)
4. dual channel laser systems (laser range finders)
5. multi channel imaging systems (multi-sensor imaging system: thermal imager, VIS-NIR camera, SWIR camera)
6. multi channel imaging/laser system (multi-sensor imaging/laser system: thermal imager, VIS-NIR camera, SWIR camera, laser range finder, laser pointer, laser designator).

It is logical that different number of optical channels means that different boresight methods must be used to carry out boresight of different EO systems.

3.6 Stage of production cycle

The criterion discussed so far allowed us to create some logical division of EO systems from point of view of boresight of these systems. However, the most elegant criterion to divide EO systems from point of view of boresight of these systems can be stage of production cycle.

It can be commonly agreed that dual channel or multi channel EO systems can be built by combining of several single channel systems. It is also logical that single channel EO system must be internally well aligned before boresight of this system to an external reference axis can be done.

Therefore boresight of EO systems according to criterion of period of production cycle can be dived into following groups:

1. Internal boresight of single channel EO system
2. Boresight of of channels of dual/multi channel EO systems,
3. Boresight EO systems to an reference external mechanical axis.

These three types of boresight can be in described as below:

1. Internal boresight of single channel EO systems can be defined as adjustment of modules of this system in order to achieve properly operational EO system. In practical terms, in case of imaging EO systems it is regulation of relative position of typical modules like optical objective, image sensor, display, ocular. The aim of this regulation in case of imaging EO is to achieve situation when optical axis of the system is properly set and does not depend on system settings that can be regulated during normal operation (optical magnification, focus, ocular diopter power) and does not depend on working conditions (ambient temperature, pressure, humidity). In case of laser systems or non-imaging EO systems that modules are different but but the aim of the boresight is the same.
2. Boresight of multichannel EO systems can be defined as adjustment of two or more single channels of imaging/laser EO systems in order to achieve situation when optical axis, images or laser beams of these channels are aligned. Practically it means that case of imaging channels it required that all imaging channels generate images of the same angular orientation and sometimes of the same magnification and distortion. In case of laser channels it is required that laser beam is parallel to optical axis (or line of sight) of an imaging system.
3. Boresight of EO system to a mechanical axis can be defined as aligning of optical axis of an EO imaging/laser system with a reference mechanical axis of an external system or a mechanical axis of the same EO system. Classical boresight understood as aligning line of sight of optical sight to a mechanical axis of a barrel belongs to this type of boresight. This type of boresight is also often called weapon zeroing.

Next, it should be noted that type B and C boresight are optional. Type B boresight is used only in case of multi-channel EO systems. Type C boresight is practically often not done in case of surveillance EO systems because boresight accuracy for these systems are very low.

4 Literature

1.https://en.wikipedia.org/wiki/Boresight_(firearm)
2. https://www.merriam-webster.com/dictionary/boresight
3. http://www.ktgunsmith.com/boresight.htm
4. https://en.wikipedia.org/wiki/Optical_axis