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INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2013
Brasov, 23-25 May 2013

COMPATIBILITY ANALYSIS OF THE OPTICAL SYSTEMS CHARACTERISTICS USED IN IMAGE FUSION

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Abstract: *Development of optoelectronic observation systems based on obtaining image fusion includes, inter alia, adequately solve geometrical compatibility of individual images. The paper presents the characteristics of the optical system defining these images formats geometrically and qualitatively, and assumptions about ways to harmonize these features from perspective of obtaining image fusion.*

Keywords: *Fused images, field of view, image size, resolution, distorsion*

1. INTRODUCTION

A new direction for the development of optoelectronic systems used for night vision is based on fusion images from different spectral sensitivity sensors. When these images are combined in an optimal way, the resulting image is a powerful tool, and can provide more details of the scene than any of the constituent monospectral imaging. With such systems, can achieve a significant increase in the performance of scene in conditions of limited visibility, so combining images from different spectral ranges is lately used mostly in military applications.

Below are described some ways for obtaining fusion images and constructive considerations to optimize the benefits of the fusion multispectral images.

2. IMAGE FUSION METHODS

Image fusion methods are divided, generally, in two major categories: direct fusion and digital fusion.

2.1 Direct image fusion. The most basic form of direct image fusion is *physiological fusion* in which one eye is using, for example, a 1x night vision monocular, other eye is capturing directly the image of the scene.

Fig.1 Physiological direct image fusion

Advantage of simple construction, is attenuated by fusion physiological limitations and constraints that may be accompanied by undesired effects, such as binocular rivalry. [1]

The optical direct fusion is one in which to the same eye of the observer they are simultaneously presented two images overlaid on optical path. A form already widely used is the HMD transparent displays mainly used in aviation, where the pilot can see, superimposed on the direct image of the scene, a virtual image from an optoelectronic system projected through a semi reflective visor.[2]

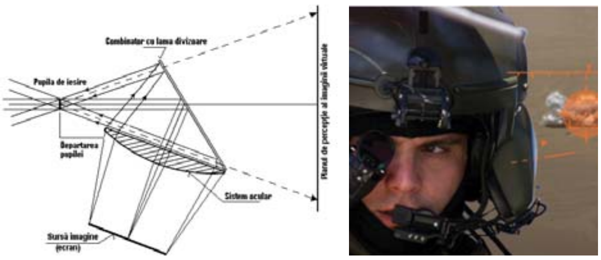


Fig. 2 The optical direct fusion imaging system

A more complex form of the optical direct fusion is that performing simultaneous display of two images formed with different optoelectronic systems and in different spectral ranges, without any further processing of these images. These may come, for example, from a night vision scope –VIS, and from an infrared camera –IR. So, as illustrated in Fig.3, images taken by the two optoelectronic systems is each one displayed on screen and simultaneously presented of the observer eye, are overlapping via an combiner eyepiece equipped with a optical beam splitter.

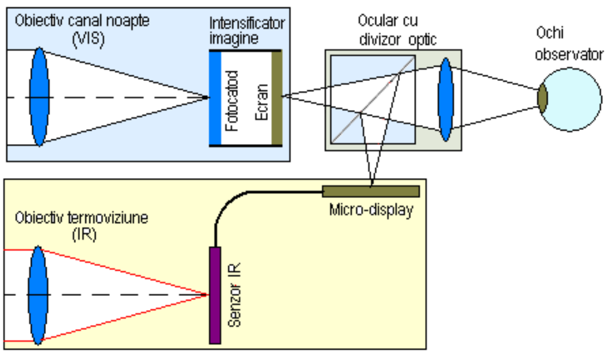


Fig. 3 The direct fusion imaging VIS / IR system

2.2 Digital image fusion.

For night vision equipments, an important direction of development is the digital image fusion. This is achieved using sophisticated fusing algorithms by video signal from two distinct pathways, equipped with image intensifier as VIS sensor and micro bolometer as IR sensor. The figure below shows block diagram of such a system that makes image fusion in VIS and IR ranges by processing of appropriate video signals in the electronic module. In some applications, fused image display mode contains a display of dimensions such that it allowing direct observation, without eyepiece.

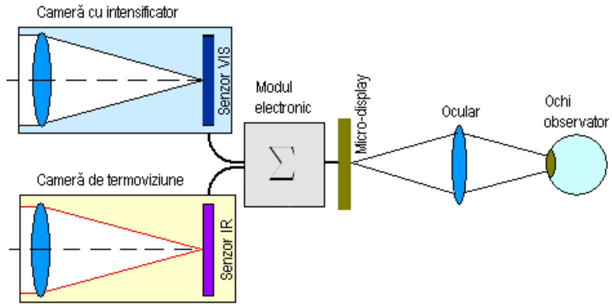


Fig. 3 The digital fusion imaging VIS / IR system

This means of fusing two pathways with complementary spectral ranges and specific sensors combines the advantages of both systems, namely the detection capability in low atmospheric transparency conditions or complete darkness, specific for thermo vision systems, respectively higher resolution even in low light conditions and reduced thermal contrast of the scene, specific in the case of image intensification system.

Towards direct fusion systems, by using the digital fusion algorithms of video signals, images can be produced showing all the advantages of direct fusion to which is added:

- possibility of emphasis by increasing local brightness or coloring of details on targets of interest that are highlighted by IR channel, thus facilitating their rapid detection;
- harmonization by electronic means, easier to achieve, optical-geometrical characteristics of the two images to increase fused image clarity;

3. BASIC CHARACTERISTICS OF OPTICAL SYSTEMS USED FOR IMAGE FUSION

In the following we propose to analyze the main features of optical imaging systems, exclusively prepared for optoelectronic devices that use telephoto lenses to capture images, military-specific applications, in which case working distance is virtually infinite, and the image plane in which the sensor is positioned virtually coincides with the focal plane of the lens.

3.1. Angular field of view FOV is the maximum angle in object space that can be seen. The field of view of an optical system is limited by the diameter of the lens aperture of that system. Dimensional, the diaphragm field is defined by the inside diameter of the mount existing in the focus image plane.

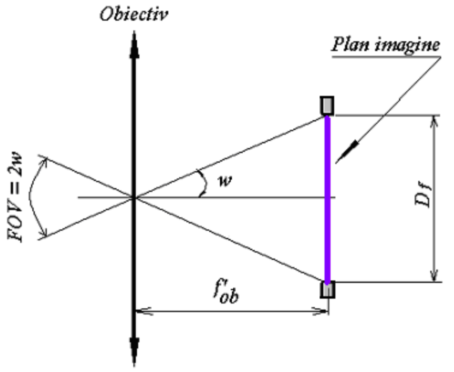


Fig. 4 Explanatory diagram of FOV

According to Fig.4, visual field subtends angle *2w* and is given by the relation (1):

$$FOV = 2w = 2arctg\left(\frac{D_f}{2 \cdot f'_{ob}}\right) \quad (1)$$

If the sensor shape is circular, relation (1) is directly used, but usually the sensor shape is rectangular. A camera's field of view is so limited on the sensor matrix dimensions *a, b*. Therefore, field of view has different values in the two directions, horizontal and vertical, corresponding at the two dimensions *a, b* of the sensor matrix, according to the relation:

$$FOV = 2arctg\frac{a}{2f'_{ob}} \quad (2)$$

In addition, the field of view can be expressed in terms of pixel size *p* and the number of pixels *N* in that direction. Therefore, equation (2) becomes:

$$FOV = 2arctg\frac{N * p}{2f'_{ob}} \quad (2)'$$

3.2. The image size in sensor plane *Y′* in the focus plane depends, as illustrated in Fig.5 and relationship (3) on the angular size of the object *u* and on the focal length f'_{ob} of the camera lens.

$$Y' = tg(u) * f'_{ob} \quad (3)$$

Where: - *u*, is the angle that subtends an object Y size of the scene.

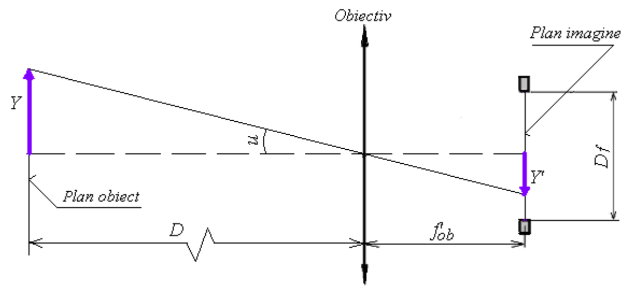


Fig. 5 Explanatory diagram image formation by a telephoto lens system

Relation (3) can be written also in the form:

$$Y' = \frac{Y}{D} * f'_{ob} \quad (3)'$$

Where: - *Y*, is the object size;

- *D*, is the distance to the object plane (> practical infinite).

Image size can be expressed in number of pixels N_p that it takes on the corresponding direction according to pixel size *p*, according to relations (4):

$$N_p = \frac{1}{p} * \frac{Y}{D} * f'_{ob} \quad (4)$$

3.3. Image distortion. From relation (3)' it follows that image size *Y '* depends linearly on the object size *Y*. The *Y '/Y* report is defined as an transversal magnification *β* of an objective optical system, so with the expression:

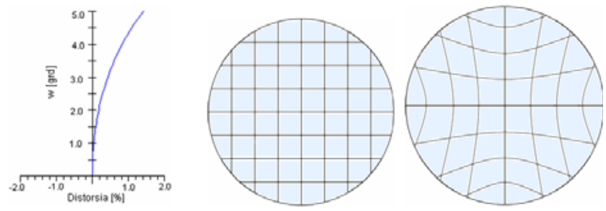
$$\beta = -\frac{Y'}{Y} = -\frac{f'_{ob}}{D} = const. \quad (5)$$

An optical system, whose transversal magnification *β* is not constant, possesses geometric *image distortion* aberration, thus manifested by transversal magnification in field changes. Distortion D is expressed as a percentage and has the form:

$$D[\%] = \frac{\Delta Y'}{Y'} * 100 \quad (6)$$

Where: *ΔY′* is the deviation from the nominal image size *Y′* that result from the relationship (3)'.

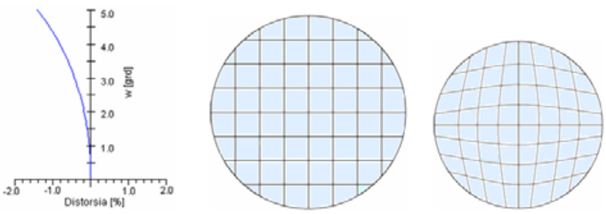
Distortion increases in absolute value with increasing angle of beam emerging, therefore with increasing object size. Image distorsion increase from zero, on optical axis, up to a maximum value at the edge of field, is nonlinear, and may have a "+" or "-" sign. Fig.6 show the positive distorsion diagram (a) and the "pillow" deformation of a grid image specific to this type of distortion (b).



a) b)

Fig. 6 Positive image distortion

Fig.7 show the negative distorsion diagram (a) and the "barrel" deformation of a grid image specific to this type of distortion (b).



a) b)

Fig. 7 Negative image distortion

If optical lens system would not cause image distortion, ratio of any image element y' and object element conjugate y would be constant in the entire field of vision. An optical system that satisfies the condition β = *constant* is called *orthoscopic*.

3.4. Image resolution of a system represents the threshold separation angle (minimum), also is the angle under which two adjacent elementary objects can be seen. The resolution characteristics of an image tell us the ability of the optoelectronic system to view small details on an image with high contrast. The resolution of the optoelectronic system is give mainly by the camera resolution, the display resolution being, usually, larger. Generally, the parameters, which represent the ability of the thermal camera to view small details (resolution), can be divided into four categories:

a) Parameters based on the specification for FPA (detectors numbers, pixel size).
b) MTF (Modulation transfer function) and derived parameters.
c) Parameters based on the camera response to point or linear sources.
d) Parameters based on the operators ability to view some details.

Of interest for our subject is the first criterion for the evaluation of the resolution, based on the sensor’s matrix of characteristics. In the case of optoelectronic systems, the number of detectors, lines number or pixel size have influence on the camera’s ability to view small details. The total numbers of detectors is used to describe the resolution of the camera with detector matrix (ex. 320x240 pixels or 640x480 pixels). The resolution can be also given as a inverse of the “separation” in cycles (cy) or lp/mrad. The sensor resolution expressed in lp/mrad is calculated with the relation:

$$R_S = \frac{1}{2*p}[lp/mm] \tag{7}$$

Where: p is the dimension in *mm* of a pixel of the sensor in case of a digital output, or a TV line in case of an analogical output.

The maximal resolution R of a optoelectronic system is given by the *relation*:

$$R = f'_{ob}*Rs*10^{-3}[lp/mrad] \tag{8}$$

In relation (8) R is achieved in lp/mrad, when the focal length of the camera’s lens f'_{ob} is in *mm* and the sensor resolution R_S is given in *lp/mm*.

4. ASSUMPTION REGARDING THE COMPATIBILIZATION OF MAIN CHARACTERISTICS OF OPTICAL SYSTEMS USED IN IMAGE FUSION

As shown in Section 2, fusing two images means to overlap them in one image. In order that the fused image to be as clear as possible and/or to avoid errors given by relative position appreciation of different objects from the scene, it is necessary that before fusing the two images, they must have similar values for the geometrical parameters. For the appreciation of geometrical similitude of the two images, 3 criteria must be taken into account: size, orthoscopic and image alignment.

In the case of direct fusion, the geometrical similitude of the images is done only by the opto-mechanical systems of the two-monospectral cameras. The performances of the fused images depend by the degree of similitude of the two images and their resolution.

In the case of digital fusion, the geometrical similitude of the two images is done electronically, either automatically, which complicates fusion algorithms, either manual calibration, the electronic box having adjustment buttons.

Next, we will discuss about the geometrical harmonization of the images as a final purpose for obtaining optimal images for fusion, unconcerned by the chosen method: direct fusion or digital fusion.

4.1. Fused images visual fields correlation. An accurate superposition of two individual images that make up the image fusion is only possible if both channels displayed the same area of the scene. This means that both images must have the same linear field of view, both horizontally and in the vertical plane. According to the scheme in fig.4 and relation (2) follows that to take the same field of view, if the homologous sizes of the sensor to the two channels are a_1 respectively a_2, then the focal lengths f_1 respectively f_2 of the two subsystems, must be in the report k_0 given by relation:

$$\frac{f_1}{f_2} = \frac{a_1}{a_2} = k_0 \quad (8)$$

Obviously, the matrix homologous sides of the two sensors must meet the same report k_0 in both directions, ie the two sensors must be the same size (for example 4:3).

Of course, there may be situations when the two images are different format, but then we talk about fused image only on area of intersection of the two images. In such circumstances, fully fused image may contain at most one-component images. Partial overlap of two individual images is also possible if the sensors have the same format but have different fields of view values. This fusion possibility can occur when perfect equalization to separate fields of view is not possible or when the equalizer is not an end in itself, image fusion optimization is priority. In this working hypothesis, ratio of the lens focal lengths of the two subsystems will not follow equation (8) them being in a relationship $k \neq k_0$. Closer the value k of the ratio of the focal lengths to k_0, the image for fusion will have a greater part in the displayed image.

4.2. Possibilities for linking the size of fusionable images. The main difference between the errors image size introduced by deviations of focal length and distortion, is that in the first case image deformation is constant in field, whereas distortion causes nonlinear image deformation in field. A deviation from the nominal value of the focal lengths ratio of the two constituent imaging systems can be compensated by optical or digital zoom applied to one of the two images. Distortion deviation is more difficult to compensate due to nonlinearity of this lens geometric aberration. Therefore, the compensation of the effect on image size cannot be achieved by changing the focal length (zoom function) for the entire visual field, but only for a single field value. Diagrams of Fig.7 show the situation offsetting a -1.6% negative distorsion at the edge of a lens field with a deviation of -1.6% of the other lens focal length. According to the chart, at the edge of the field sizes of the two images are equal but at 0.65 of the field, the maximum size difference between them is 0.45%, which leads to a maximum difference of 1.8 pixels for a sensor with 640x480 pixels.

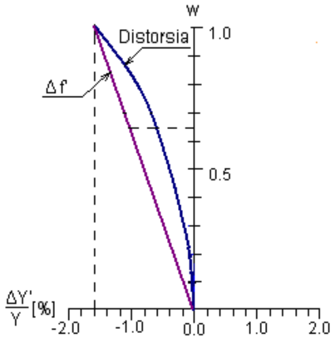


Fig.7 Distortion – Δf' compensation at the limits of the field of view

A higher minimization of displacement caused by distortion can be realized by zoom, only if dimensional compression for fusion images is made at a value of the field determined, considering that displacement between the two images is minimum in the interest area of the field and maximum in image corners. Using data from previous example, for a distortion of -1,6% optimal compensation using zoom is made by focal length variation with -1,15%. Furthermore, total compensation for distortion is made at approximately 0.8 from the field of view, which causes a displacement of 0.75 pixels at 0.4 and 0.9 of field and of maximum 1.8 pixels on the extremities of the field, as show Fig.8.

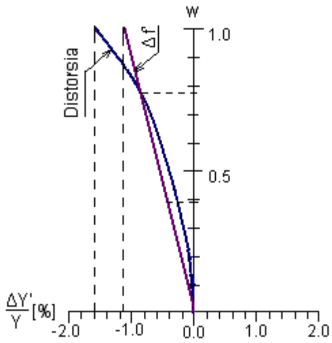


Fig. 8 Distorsion – Δf' compensation at 0,8 of the field of view

4.5. The tradeoff between field of view and resolution. Some combinations of wavelengths have the potential to produce images whit high differences for field of view and resolution. For example, VIS sensors are easy to obtain in large format and with small dimensions for pixels (< 5μm). By contrast, IR technology, despite that it increased thermal images popularity, offers sensors with low dimensions and high dimensions for pixels (> 15μm). Despite the fact that technological advances are determined for reducing pixel dimension and increasing sensor resolution, the rice remains constantly high. By comparison, if it considered a fusion between a image from a VIS sensor an a image for IR micro bolometer and if it admitted that both paths have the same focal length, then the resolution ration of both images can be equal with 3÷5 for VIS sensors. If the images are superimposed, high differences between resolutions can cause low quality images [1]. An acceptable compromise in this sort of situations is to reduce field of view of the IR path up to 1/3.

5. CONCLUSIONS & ACKNOWLEDGMENT

In order to benefit from fusion complete advantages of two images fusion, it must be take in to consideration a series of relations and constraints. Therefore, if a high quality of the two overlapping images cannot be achieved, the result will have a low quality. Many factor of influence must be taking into consideration by the system designer for the development of a system based on image fusion, from which correct superimpose, differences between sizes and distortion, and the level of performance imposed. In addition, a special importance must be accorded to entire field of view and for the resolution of each optical path, between the must not exist high differences. Sure, digital fusion, despite it can assure high performance, allows by using high complexity fusion algorithms electronic compensation for imperfection produced by optical systems.

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