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ABOUT SOME PROBLEMS OF IMAGING SENSORS IN AERIAL FIELDS

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Rezumat. *Autorii abordează în lucrare problematica percepţiei imaginii vizuale achiziţionate la limita vizibilităţii atmosferice, cu senzori în IR, cu aplicaţie în specificul de lucru al avioanelor fără pilot. Au fost luate în considerare caracteristicile esenţiale care intervin în achiziţia de imagine în mişcare şi anume: contrastul, strălucirea şi rezoluţia, modul în care acestea sunt perturbate de sursele de zgomot (fluctuaţia fotonică, absorbţia atmosferică, zgomotul de clutter) şi conexiunile cu gradul de percepţie sau probabilitatea de observare. Au fost evidenţiate unele soluţii de creştere a probabilităţii de observare în vederea depăşirii pragului limită de observabilitate.*

Abstract. *The authors tackle in this paper the issues of perception of acquired visual image, at the limit of atmospheric visibility, with IR sensors, with applications in the field of aircrafts without pilot (Unmanned Aerials Vehicles). The paper takes into account the essential characteristics that take part in the acquisition of moving images, namely: the contrast, the brightness, the resolution, the way in which these are perturbed by noise sources (photonic fluctuation, atmospheric absorption and clutter noise) and the connections with the perceptivity factor or observation probabilities. Some solutions have been highlighted, which refer to the increase in the observation probability aiming at overtaking the observability limit threshold.*

Keywords: aerial field**,** thermal sensor, clutter, detection probability

1. Introduction

At the present, the evaluation of orientation probability at mobile robotic systems, especially of those removable in the high (UAV- unmanned aerial vehicles types) is an important concern. The performance is essential when the sensors work in environment conditions very close to their noise level (atmosphere turbulence, fog, dust, gases, etc.). In these conditions, the minimal information waited from sensors refer to the detection probability, some details of the scene (quantified by resolution), at signal to noise level, and the image luminosity. Problems are various, but this paper intends to approach some acquisition image aspects of thermal sensors, on display. In this case, the thermal sensor is in relative movement towards a fixed object on the ground.

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Visual image is the most reach in information. The minimal interesting characteristics which are used for the perception and apperception process are the contrast, the brightness and the geometrical and thermal resolutions. An object may be perceptible by a principal parameter, as the observation function or by its detection probability. In principle, the variation of this parameters or functions may be realized hereby obtain the minimal value for the perception process (fig.1 and fig.2).

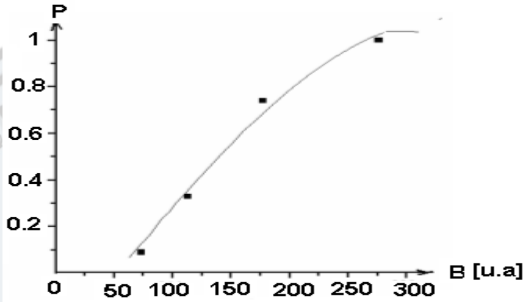
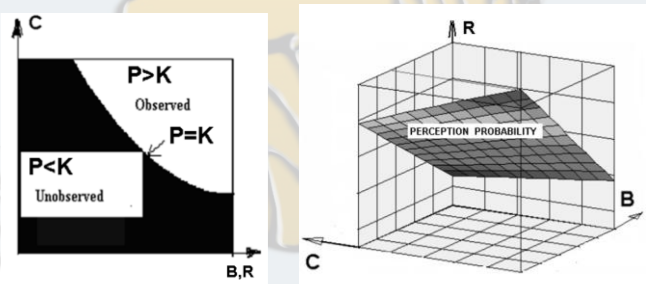


Fig. 1. The cumulative distribution function concerning the probability for an object detection of a weak bright stimulus B by looking a display

In these figures, P is the perception probability or observation function, u.a - arbitrary units.

It is known that the environment (the atmosphere with aerosols or thermal perturbations) continuously deteriorates the final image. Thereby, the resolution and the contrast decrease very much with the luminosity scene (figure 3 and figure 4).



a) b)

Fig. 2. The observation possibilities of a weak bright stimulus by an image sensor in bidimensional (a) and tridimensional space (b) for *L*=constant

Any object in a scene that is placed on a distance L, with a certain minimal dimension H (that is mean a resolution R), can be characterised with its temperature (T_1) and contrast (ΔT_1) variables. Such an object can be observable or non-observable. In consequence, any point with (B_i, C_i, R_i) or (T_i, ΔT_i, R_i) coordinates belongs alone to a domain by the two complementary ones: the observation domain or the non-observation domain.

The curve between these two domains is in fact the limit of the sight performance (fig.2), it is similar to Ricco`s lay ($\frac{C \cdot B}{R^2} = ct$) and it is described by the equation:

$$P(T_i, \Delta T_i, R_i) - K = O \qquad (1)$$

where P- the observation (perception) probability. If P ≥ K, the object is observable.

2. Phenomenological considerations

The atmospheric haziness depends by the atmospheric turbulence and by the aerosols diffusion and absorption (figure 4).

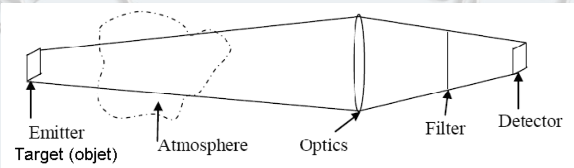


Fig. 3. The block diagram of the thermal sensor and its input

The fog has a major influence in thermal visibility perturbation [2]. The main perturbation factors on the quality of a thermal displayed image are given by the scene thermal photons fluctuation (quantified by the low temperature of object and scene), by the atmosphere absorption and clutter fluctuations done by the detector matrix, especially at a small object acquisition in relative movement towards the sensor. These factors may be quantified by SNR- the signal to noise ratio, σ- the average atmospheric extinction coefficient over path length *L* and the SCR- the signal to clutter ratio.

Perception of display image, which, depending on these characteristics, may look like in fig. 4.

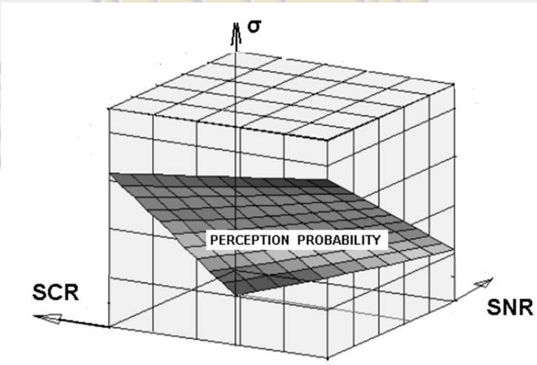


Fig. 4. Any variation of set {SNR, σ, SCR} leads to the variation {C, B, R}, through the appreciation or depreciation of the image quality. It is important to define the conversion of surface P(SNR, σ, SCR)=0, highlighted in surface P(C,B,R)=0

The trajectory of information (and perception modification) from the object emitting thermal irradiation towards the observer's display, is suggested in fig. 5, and its correspondent in thermal irradiation is shown in fig. 6.

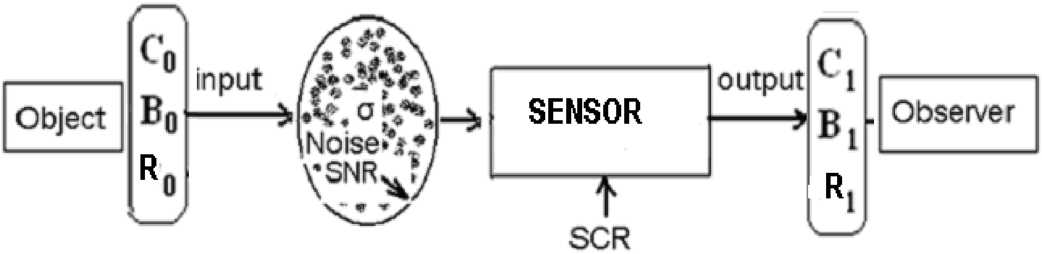
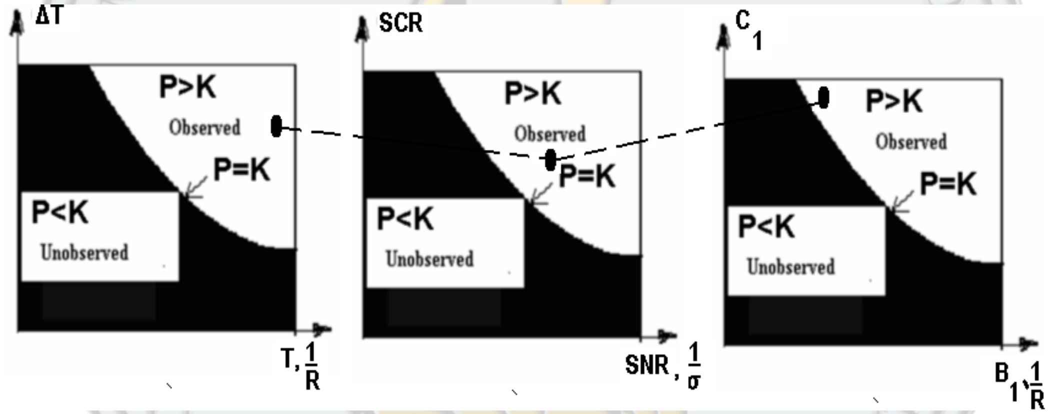


Fig. 5. Information flow in spatial domain. The degradation of information flow



a) b) c)

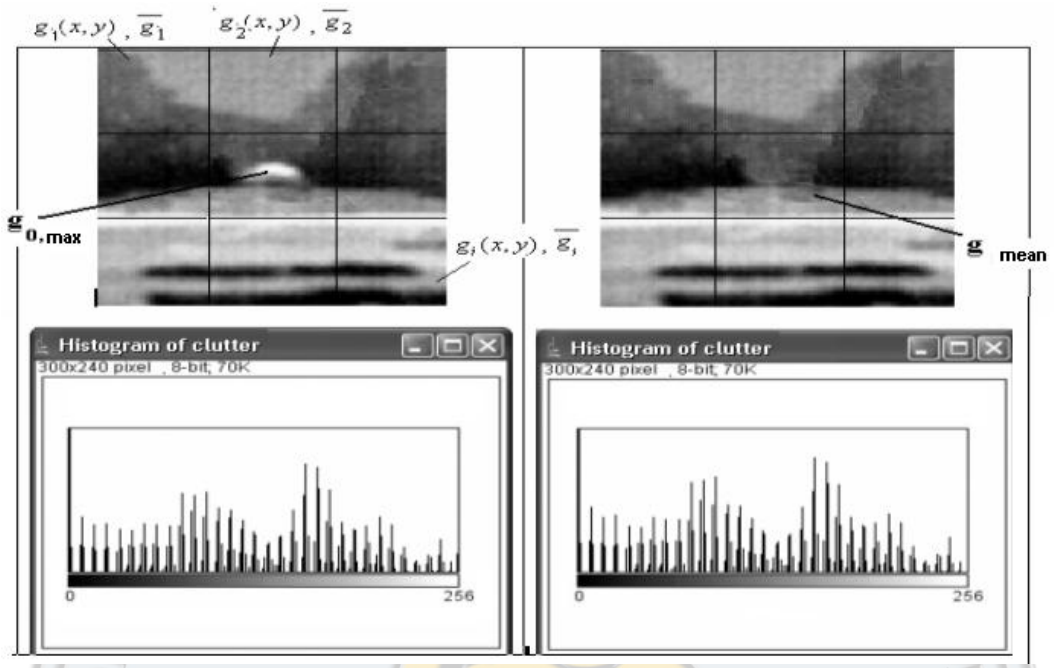
Fig. 6. The modification of the initial observation probability (a) due to the degradation of ambient (b) and clutter noise (c)

The clutter noise, as a stochastic process, tends to cover the useful signal emitted by the object, leading to erasing of image points and the creation of other, false ones.

Thus, at the visibility limit, several zones of pixel (radiant) intensities, similar to the object image, can appear in the image field.

This makes its detection prediction much more difficult.

The calculation of the clutter type noise is realised by the segmentation in surface units of the interest scene (Figure 7).



a) b)

Fig. 7. Example of calculation, based on hystograms, of the ratio signal clutter, in the case of a scene where an object of detecting interest appears (a) and, in the case of the same scene, without the object (b)

3. **Analytical considerations**

The function of thermal transfer usually expresses the evolution of image quality as a function of resolution and contrast. In the thermal image at the visibility limit, these latter parameters are insufficient, taking into account the existence of clutter noise. It is, therefore, important to introduce a new function (named observability function *P*) similar in properties and significance to the function of thermal transfer, but, in addition, dependent on brightness, even though, by definition, contrast is defined as difference in brightness.

At low levels of brightness, a higher contrast may prevent the visibility of an object, as it was shown in Figure 2. The function *P* is linked to the probability of observation *K* and increases as MRT decreases, so that one can evaluate a relationship of inverse proportionality of the form:

$$P = \frac{k}{MRT} \tag{2}$$

As, by definition:

$$MRT_1 = MRT_0 \cdot MRT_A \tag{3}$$

where 0 refers to the scene, 1 to display, and A to atmosphere.

Then, taking into account relationship (2), one can write:

$$P_1 = P_0 \cdot P_A \tag{4}$$

Relationship (3) can be expressed, more explicitly, by displaying the image on screen, thus conforming to the previous phenomenological attempt, thus:

$$\text{MRTD} = MRT_1(C_1, B_1, R_1) = MRT_0(T_0, \Delta T_0, R_0) \cdot MRT_A(SNR, SCR, \sigma) \tag{5}$$

As in paper [2], for weak thermal transparency conditions (for example σ>0,5), it is important to know the ratio between thermal signal downgrade by the atmosphere and the correct value (non downgrade) of the thermal transfer function MRT and the observation probability, that can be described by the relations:

$$MRT = MRT_{th} \exp\left(N \cdot R \cdot L\right) / \sqrt{(\varepsilon / 7)} \tag{6}$$

$$MRT_1 = \frac{\Delta T \cdot e^{-\sigma L}}{SNR} \tag{7}$$

$$P(SNR) = \frac{SNR^E}{1 + SNR^E} \tag{8}$$

And E is given by the relationship

$$E = 2{,}7 + 0{,}7 \cdot SNR \tag{9}$$

where the difference ΔT (with significance of contrast) between the object's temperature and the temperature of its background, ε is the aspect factor of the object under observation, *N* is Johnson's coefficient of statistical certainty, MRT_{th} represents the threshold value of MRT (value which can be detected when the spatial angular frequency of the object tends to zero), and *R* is the sensor's resolution.

One can notice here the scene parameters (the scene resolution corresponds to the form factor ε related to the distance *L*, the display resolution corresponds to the value *R*, and the observation probability corresponds to the coefficient N).

An intuitive diagram is given in Figure 8.

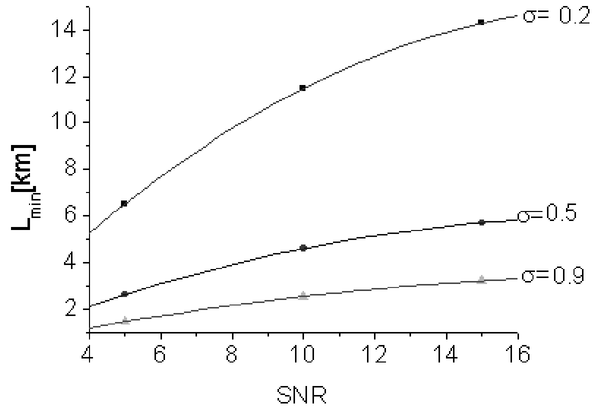


Fig. 8. The influence of SNR on the minimum detection distance for different perturbation levels (quantified by the coefficient of optical attenuation sigma); the MRT was chosen 2^0C. For example, at the visibility limit, SNR=2.25, MRT=2^0C, $\Delta T=5^0$C, σ =0.8, it follows that L=100m.

Starting from the results presented in [3-6], one can describe the variation of the detection, recognition and identification probabilities (Figure 9), with the observation certitude quantified here by the parameter N, previously described.

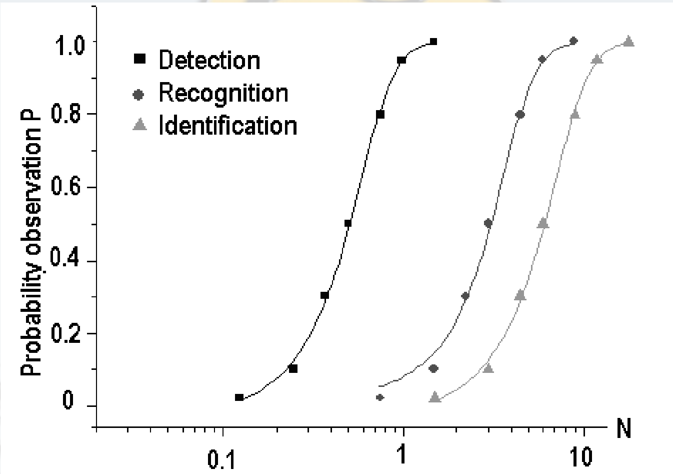


Fig. 9. Increase in the observation probability with the number of pairs of lines/object dimensions

By extrapolation of the data comprised in the diagram above, taking into account the expression [7]:

$$P = 0.5 - 0.5\sqrt{1 - e^{-4.2\left(\frac{C_x}{C_{x0}} - 1\right)^2}} \tag{10}$$

one can propose the relationship:

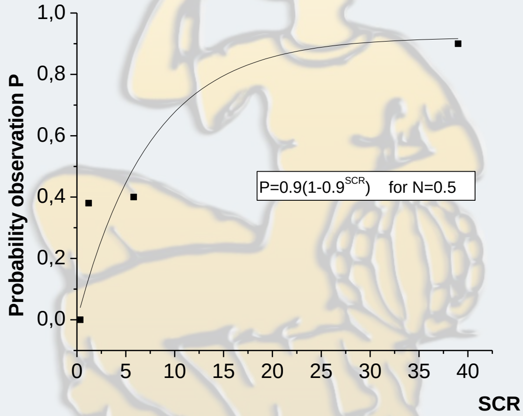
$$P_0 = 0.5 - 0.5\sqrt{1 - e^{-4.2(\frac{\Delta T}{MRT} - 1)^2}} \quad (11)$$

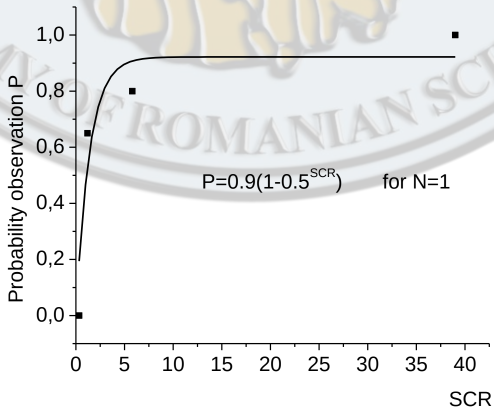
If one considers the light intensity of the object of interest, then the ratio SCR is given by the relationship (11) and, in the case of a negative contrast (when the background signal is stronger than the object of interest), SCR is described by equation (12):

$$SCR = \frac{|g_{0\max} - g_{mediu}|}{clutter} \quad (12)$$

$$SCR = \frac{|g_{0\min} - g_{mediu}|}{clutter} \quad (13)$$

Based on the SCR formulas from the results presented in [6], one can describe the graphs from the figures, with the corresponding relationships:





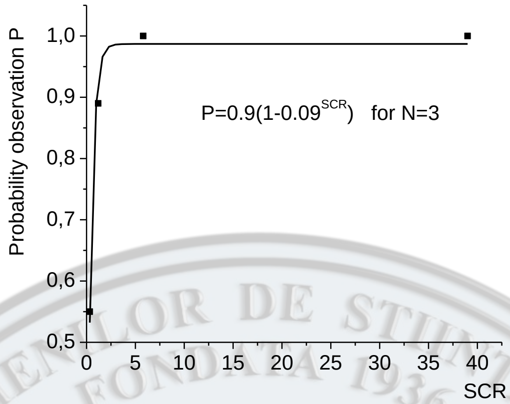


Fig. 10. Variation of P as a function of SCR for three different values of N: 0.5 ,1, 3

$$P_A = \left[1 - \left(\frac{0.4}{N} \right)^{SCR} \right] \cdot \frac{SNR}{e^{\sigma}} \tag{14}$$

which leads to the relationship:

$$P_1 = \left(0.5 - 0.5\sqrt{1 - e^{-4.2(\frac{\Delta T}{MRT} - 1)^2}} \right) \cdot \left[1 - \left(\frac{0.4}{N} \right)^{SCR} \right] \cdot \frac{SNR}{e^{\sigma}} \tag{15}$$

Conclusions

The authors highlight that in the domain of reduced thermal visibility, the thermal transfer function has to be defined by 3 coordinates, due to the image noise.

Essential problems that appear at the use of sensors for the air acquisition are linked to the variations of atmospheric absorption, which appear through air currents that transport aerosols of different concentrations or air quantities of different temperatures; all these variations lead to the dramatic reduction of image qualities, and in the situation where reduced ambient visibility already existed, the image sensors are practically swamped by noise.

A fundamental weight in the perception of air thermal image is given by the clutter noise, especially within the detection limits. The recognition and identification are less influenced at values SCR>5.

The authors proposed a pragmatic and suggestive relationship to set off the variation of the perception related to the clutter.

R E F E R E N C E S

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