Analysis of discriminatory characteristics of a video sensor with an exponential correlation function

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Abstract. This article presents an analysis of the characteristics of the video sensors functioning both in the visible and “thermal” regions of the spectrum. The influence of errors caused by the non-linearity of the discriminatory characteristic (DC) in the idealized model is studied. The article is devoted to the refinement of the model, taking into account the constant exponent parameter and introducing its value into the algorithm implemented by the onboard video sensor.

1. Introduction

In autumn 2015, presidents and heads of government of nearly one and a half hundred states gathered in Paris at an environmental conference to discuss climate change caused by human activities. One of the manifestations of this influence on nature turned out to be fires that destroy not only forests, but also settlements on almost all continents. The leaders considered the strategic issues and tactical decisions are made by engineers - in this area can offer the use of robotic systems - unmanned aerial vehicles (remotely piloted air system (RPAS) ) and fire-fighting equipment (RPAS FFE) for searching, automatic detection, tracking and liquidation of fires. RPAS and RPAS FFE will be able to perform the indicated functions with the help of on-board video sensors functioning both in the visible and “thermal” spectral regions [1].

On-board video sensors that automatically accompany the tracking objects - vizors are video sensors that calculate the mismatch by measuring the correlation functions (CF) of the reference and current images of the foci of ignition [2]. Such video sensors are characterized by high noise immunity, and discriminators that implement the differential method for calculating the mismatch between the reference and current directions of the line of sight (LP) are the least demanding on computer resources [3].It is known that the CF of the image of the underlying surface formed by the onboard video system of the RPAS and RPAS FFE, for example, television [4], is exponential (Figure 1).

\[ K(X) = e^{-\alpha |X|} \]

(1)

where \( \alpha \) – is the exponent constant, depending on the conditions of use of the onboard video sensor, for example, Figure 1 illustrates the CF of various types of the underlying surface, characterized by parameters \( \alpha_1, \alpha_2, \alpha_3 \).
Figure 1. The exponential nature of the CF television system PRAS.

This feature should be taken into account when developing on-board video sensors and, in particular, for PRAS and PRAS FFE, since in automatic systems the requirements for accuracy of calculations for the meter are incomparably higher than in automated systems, where the operator can correct errors of measurement of mismatches [5].

The resources available on-board control computers - controllers, place great demands on the algorithms they implement: in terms of memory footprint, speed, etc. [6]. These requirements are met by the differential method of calculating the mismatch between the reference and the required positions of the line of sight.

Taking into account (1), the reference exponential CF $K(X - \Delta)$, $K(X + \Delta)$ and the discriminating characteristic (DX) $D(X)$ they form when implementing the differential method are analytically and graphically described as follows (Figure 2):

$$K(X - \Delta) = e^{-\alpha |X - \Delta|},$$
$$K(X + \Delta) = e^{-\alpha |X + \Delta|},$$
$$D(X) = K(X - \Delta) - K(X + \Delta) = e^{-\alpha |X - \Delta|} - e^{-\alpha |X + \Delta|},$$

Figure 2. Exponential CF - $K(X + \Delta)$, $K(X - \Delta)$, nonlinear and linear discriminatory characteristics DC ($X$) of the PRAS video sensor.
which, after normalizing the argument, up to a factor of $\frac{2}{\epsilon^\alpha}$ is described by a hyperbolic sine:

$$D\left(\frac{X}{\Delta}\right) = \frac{2 \text{Sh} \left(\frac{X}{\Delta}\right)}{e^\alpha}$$

(3)

Usually, when constructing DCs, they are linearized and the mismatch in such video sensors is calculated under the hypothesis of its linearity. From (4) it is easy to obtain an analytical expression for the error in determining the mismatch by a discriminator tuned to a linear DX and caused by neglecting the exponential nature of the correlation function of the onboard controller:

When determining the characteristics of the discriminatory characteristics of a one-dimensional differential video sensor with an exponential correlation function, we analyzed the discriminatory characteristic $D(\alpha, X, \Delta)$ [4] with the parameters:
- exponent constant $\alpha = 1$ (in the future, the results obtained can be compared with the solutions obtained for $\alpha < 1$ or $\alpha > 1$);
- mismatch (argument) $Z \in \{-3 \ldots 3\}$, since $D(1, X \geq 3, 0) \leq 0.05$, which with a 5% error can be considered a zero value and the behavior of the exponential function beyond the specified limits for the problem being studied is not of interest;
- samples $i \in \{0 \ldots L\}$, where $L$ is the maximum number of the sample;
- a fixed shift $\Delta = 1.5 \alpha^{-1}$ (in this case, the aperture of the discriminatory characteristic on the segment $[-\Delta \ldots +\Delta]$ is equal to $2\Delta = 3\alpha^{-1}$).

2. Results and Discussion

The algorithm for constructing the discriminatory characteristics of a one-dimensional differential correlator with an exponential correlation function in the MS Excel spreadsheet processor is as follows:
- mathematical description of the correlation function,
- setting the values of the parameters $\alpha, \Delta$ and the number of samples $n$,
- calculation of the $i$-values of the argument $X$,
- calculation of the values of the correlation function shifted by $+\Delta$,
- calculation of the values of the correlation function shifted by $-\Delta$,
- the calculation of the values of the discriminatory characteristics $D_i(X_i, \Delta)$,
- calculation of the linearized discriminatory characteristics $D_{lin}(X_i, \Delta)$,
- rationing of correlation functions and discriminatory characteristics.

An analysis of the results and a comparison of the discriminatory characteristics formed by the difference of the correlation functions shifted by $\pm \Delta$ with the linearized DC (see Figure 2) leads to the conclusion that the working section of the real discriminatory characteristic is non-linear at $X \in [-1.5 \ldots 1.5]$.

Therefore, to construct a correlator that is tolerant to changes in the conditions of use, expressed in a change in the parameter $\alpha$, the following problems are of interest:
- formalization of the work site of discriminatory characteristics;
- clarification of the influence of the parameters $\alpha$ and $\Delta$ on the accuracy of determining the mismatch of the correlator;
- minimization of the error in calculating the mismatch by optimizing the ratio of the parameters $\alpha$ and $\Delta$.

A computer analysis of the error in calculating the mismatch under various conditions (5) made it possible to propose an adaptive algorithm for determining the mismatch by the differential correlator in the PRAS and PRAS FFE video sensor:

1. Depending on the conditions of use of the onboard video sensor of the PRAS and PRAS FFE, the coefficient $\alpha$ is calculated.
2. The value of $\delta$ is determined.
3. The maximum value of the discriminatory characteristic in the given conditions of combat use is calculated by $-D_{\text{max}}\left(\frac{Z}{\Delta}\right)$, if $\frac{Z}{\Delta} = 1$.

4. To build a discriminatory characteristic, normalization is performed

$$d\left(\frac{X}{\Delta}\right) = \frac{D\left(\frac{X}{\Delta}\right)}{D_{\text{max}}\left(\frac{X}{\Delta}\right)}$$

5. After constructing the discriminatory characteristics, the value of the mismatch is calculated as follows:

$$x = \Delta d^{-1}\left(\frac{X}{\Delta}\right)$$

(4)

where $d^{-1}$ – inverse function $d\left(\frac{X}{\Delta}\right)$.

To verify the mathematical model of the video sensor and analyze the influence of the parameters of the real discriminatory characteristics on the error of calculation of the mismatch, it is proposed to develop and create a collimator - a simulator of visual environment (IVO), which allows you to create images of different foci of ignition taken into account by parameter $\alpha$, the structural diagram of which when combined with the on-board video sensor is shown in Figure 3.
Figure 3. The block diagram of the pairing of the video sensor and the collimator - a simulator of visual environment

3. Conclusion
Therefore, the study of the influence of errors caused by neglecting the nonlinearity of the HX in an idealized model is an urgent task. The quality of the video sensor tracking of the source of fire will improve if we compensate for the error in the calculation of the mismatch during its processing during the calculation of the mismatch. Achieving this goal is possible by refining the model, taking into account the parameter a and introducing its value into the algorithm implemented by the onboard video sensor.

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