The use of the spatial-structural model of a video signal from the television scanistor in tasks of monitoring the geometric parameters of small objects

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Abstract. The paper proposes a video signal model for determining the size and coordinates of the light zone on a television scanistor. The key idea is to represent the profile of the light zone in the form of a vector of spatial and structural parameters that can localize the light zone and restore its width and illumination. The use of the spatial-structural model of the video signal allows expanding the scope of scanistor optoelectronic systems for monitoring the geometric parameters of small objects.

1. Introduction

The developments of television, robotics, automatic control and tracking systems, image recognition, and the creation of visual receptors for artificial intelligence systems are directly related to the development of high-sensitivity, high-speed vision systems [1,2]. The TV single-line scanistor is intended for converting the spatial distribution of illumination into electrical signals used for monitoring, processing and transmitting optical information in computer vision systems, in particular, for automatic non-contact control and measurement of coordinates, dimensions and movements of various objects [3,4]. Scanistor optical-electronic systems (SOES) are characterized by high accuracy, speed, reliability, and ease of technical implementation [5,6]. However, some issues affecting the accuracy of linear measurements related to the features of the scanner as a light-to-signal converter [7], remain poorly studied. This work aims to improve the accuracy of the width measurement as applied for the narrow light zone using a single-line scanistor.

2. Spatial-timing transformation of information in the scanistor

In SOES, the registration of light relief (in the form of controlled light zones (LZ) along the photosensitive surface) is carried out continuously by increasing the amplitude of the unfolding sawtooth voltage and corresponding linear movement along the scanistor of the equipotential line of zero potential. To select the video signal (VS) from the scanistor it is advisable to use the survey scheme shown in Fig.1 (where SC – scanistor; SVG – sawtooth voltage generator; OVS – offset voltage source; CVC – current-voltage converter; PC – personal computer).
Figure 1. SOES block diagram for measuring the size and movement of light zones.

It can be shown that a sequential survey of elementary photodiode cells of the SC a video signal is generated which is a convolution of the input function of the SOES (in the form of controlled LZ) and the hardware function of the scanistor and is described by the relation [6]:

\[
V(t) = \frac{4L \cdot b \cdot l}{T} j_x \left[ \frac{1}{\exp \alpha(E_e - E_c) + 1} \right] + \frac{L \cdot b \cdot l}{T} 2 j_{eb} (1 + K_a) \left[ \frac{1}{\exp \alpha(E_e - E_c) + 1} \right] x_2, \tag{1}
\]

where \( L \) – coefficient depending on the method of differentiation; \( b, l \) – scanistor width and length, respectively; \( \alpha = A \frac{KT}{q} \); \( K \) – Boltzmann constant; \( q \) – electron charge; \( A \) – coefficient reflecting the degree of non-ideal transition of the scanned structure; \( T^\circ \) – temperature in Kelvin degrees; \( E_e = E_0 \cdot \frac{x_0}{l} \) – emitter potential at the polling point \( x_0 \); \( \frac{x_0}{l} \) – a coordinate normalized at the polling point; \( E_0 \) – emitter bias constant voltage; \( E_c = E_0 \cdot \frac{t_0}{T} \) – value of the sawtooth voltage at the time of the poll \( t_0 \); \( T \) – sawtooth period; \( \frac{t_0}{T} \) – normalized time at the time of the survey; \( j_x, K_a \) – dark saturation current and asymmetry coefficient of the current-voltage characteristics of the photodiode cell, respectively; \( j_{eb} \) – increment density of the saturation current of the photodiode cell in lighting; \( x_1, x_2 \) – coordinates of the beginning and end on the scanistor of the light zone (in this case the duration of the time interval from the beginning of the sawtooth voltage to the maximum of the video signal is proportional to the distance of the middle of the LZ from the beginning of the scanistor).

Being used in SOES it becomes relevant to ensure a high linearity of the spatial-timing transformation of information, i.e., consisting of two stages of photoelectric conversion of the measured coordinate (or size) into a time interval. At the first stage, the coordinate of the controlled light zone is converted to the coordinate-setting voltage on the resistive divider of the scanistor. The second conversion of this voltage during the survey is performed by the sweep sawtooth voltage. The total conversion error of coordinate \( x \) (or size) LZ into the time interval \( t \) is determined by the linearity of the relation of the coordinates of the scanning border of scanistor (equipotential line of zero potential) and the value of deployer voltage:

\[
x = t \cdot \frac{l}{T}. \tag{2}
\]
Figure 2 shows the dependencies of the light component of the video signal $V(\hat{x})$ (Fig. 2b), its first (Fig. 2c), and second (Fig. 2d) derivatives and their corresponding videopulses for LZ (Fig. 2a) of different widths and the same illumination.

![Figure 2](image)

**Figure 2.** Shapes of video signal curves, its first and second derivatives, and corresponding videopulses for light zones of different widths.

The light flux $\Phi$ forms light zones on the photosensitive surface of the scanistor, the profiles of which correspond to the graph in Fig. 2a. The output video signal of the scanistor (Fig. 2b) corresponds to the expression (1) and, in fact, is a blurred profile of the light zone. Thus, the task of analyzing the video signal of the scanistor is to determine the parameters of the light zone (coordinates, width, and illumination) from the blurred video signal of the scanistor.

In addition, due to the strong blurring of the video pulse of the narrow light zone, the amplitude of the scanner video signal ceases to be proportional to the magnitude of the LZ illumination, which does not allow measuring the illumination of the narrow LZ using the scanistor.

Figure 2 shows the stages of traditional processing of the video signal of the scanistor. In this case, to determine the boundaries of light zones video signal of the scanistor is twice differentiated (Fig. 2c – the first derivative, and Fig. 2d – the second derivative), and the moments of change of sign of the second derivative signal of the video signal correspond to the boundaries of light zones, but only for broad light areas. For narrow LZ (when their width $\hat{x}_2 - \hat{x}_1$ does not exceed doubled value of the switching zone of scanistor structure $2\Delta x_S = \frac{8l}{E_{0}\alpha}$), the moments of change of sign of the second derivative of the videopulse of scanistor not correspond to the boundaries of the LZ, which is clearly seen on the chart of the second pulse in Fig. 2d. This is due to the fact that the scanistor structure is not able to capture short videopulses of light zones, blurring them. In addition, due to the strong blurring of the videopulse of a narrow light zone, the amplitude of the video signal of scanistor ceases to be proportional to the illumination value of LZ, which does not allow to measure illumination of narrow LZ by scanistor.
It should be noted that determining the coordinates and dimensions of objects in the production conditions is an urgent and complex task [4-6]. The relevance of the problem is increased in the case of measuring the geometric parameters of small-sized objects in the conditions of image blurring [7-11] (e.g., when contactless control of fiber diameters during their manufacture in fiber optics, wire diameters in the cable industry, etc. [9-10]). At the same time, it is advisable to use the block diagram shown in Fig. 1 to select and process the video signal from the scanistor.

SOES is a linear system with constant parameters, and it can be represented as a block diagram in Fig. 3. In this case, the operation of the SOES is described by a pulse function \( h(\hat{x}) \), the effect \( f(\hat{x}) \) is the profile of the light zone (dashed line in Fig. 2b), and the reaction \( v(\hat{x}) \) is the video signal of the SOES (solid line in Fig. 2b).

The pulse function of the scanistor is a video signal from a single illuminated photodiode cell (for an infinitely narrow light zone) [8]:

\[
h(\hat{x}) = k_A \exp \left( \frac{E_0}{U_0} \right) \left[ \exp \left( \frac{E_0}{U_0} \right) + 1 \right]^2,
\]

where \( k_A \) – constant coefficient of the aperture SOES; \( U_0 = \frac{1}{l} ; \hat{x} = \frac{\hat{x}_0}{l} \).

As for any linear system with constant parameters, the convolution ratio \( v(\tau) = \int f(\tau)h(\hat{x} - \tau)d\tau \) is valid for SOES. Convolution of the light zone profile signal with the pulse function explains the blurring of the SOES video pulse fronts. The amount of blurring is completely determined by the pulse function of the SOES and does not depend on the width of the light zone. Thus, the impact signals from narrow light zones are blurred so significantly relative to their width that the traditional method of determining the width of the light zone by the first or second derivatives of the video signal of the SOES ceases to work (as illustrated in Fig. 3c and 3d).

3. Results and discussion

In this paper, to solve the problem of determining the size and coordinates of the light zone from the blurred video signal of the scanistor (Fig. 2b), it is proposed to use spatial and structural parameters (SSPs). In [12-16], it is shown that SSPs make it possible to estimate the width of a rectangular impact signal, localize it in space, and determine its amplitude from the blurred response of the signal transmission path.

In [13], five SSPs of the video signal are defined: mass \( M \), centroid \( C \), dissipation \( D \), extent \( E \), and brightness \( Y \). SSPs are calculated using one-dimensional moments \( W_0, W_1, W_2 \), using the following expressions:

\[
M = W_0;
C = W_1 / M;
D = (W_2 / M) - C^2;
E = 2\sqrt{3D};
Y = M / E.
\]

The physical meaning of the SSP when applied to the SOES video signal is as follows [11]:

—«mass» describes the total (integral) mass of the video signal;
—«centroid» is the coordinate of its center of gravity;
—«dissipation» describes the degree of localization of the mass of a video signal in the vicinity of its center of gravity;
—«extent» is numerically equal to the width of the video pulse of LZ with a rectangular shape;
The spatiotemporal model of the SOES assumes describing the video signal of the SOES as a vector of the SSP $S_v = (M_v, C_v, D_v, E_v, Y_v)$, and the pulse function of the SOES as a vector $S_d = (M_d, C_d, D_d, E_d, Y_d)$. In this case, the SSP vector $S_v$ is calculated from the SOES video signal, and the vector $S_d$ is calculated from the SOES pulse function (3). In this case, using the properties of SSP [13, 16], it is possible to estimate the width and illumination of the light zone as follows:

1) «dissipation» of the light zone profile [16]

$$D_i = D_v - D_d;$$ (9)

2) «extent» of the light zone profile

$$E_i = 2 \sqrt{3 D_i};$$

3) «brightness» of the light zone profile

$$Y_i = \frac{M_v}{E_i}.$$ 

The «extent» $E_i$ and «brightness» $Y_i$ of the light zone correspond to the width and amplitude of the rectangular signal of the light zone profile.

The proposed method for restoring the parameters of the light zone (width and illumination) is based on the property of dissipation [14], which consists in the ability to take into account the «value» of the blur when performing calculations using the expression (9).

To check the adequacy of the proposed spatial-structural model of the SOES video signal, an experiment has been conducted in which the width of the LZ was calculated in the traditional way by changing the sign of the second derivative of the SOES video signal (solid line in Fig. 5) and with the use of SSP (dashed line in Fig. 5). The width of the LZ varied from 0 to half the length of the scanner.

The analysis of graphs in Fig. 5 shows that when the LZ width is more than 1.5% of the length of scanner the traditional method of measuring the LZ width gives a result close to linear, however, the results of measurements of narrow light zones with a width of less than 1.5% of the length of scanner give higher values, which agrees well with the graphs in Fig. 2d. The measurement of the width of the LZ using a SSP shows a linear dependence of the measured size relative to their true values for all values of LZ width, including narrow LZ.

4. Conclusions

1. This paper proposes a spatial-structural model for describing a video signal from a television scanner, which allows us to estimate the width and illumination of the light zone from a blurred video signal, taking into account the influence of the pulse function of the SOES.

2. The spatial-structural model of the video signal allows you to expand the scope of the scanner in the case of narrow light zones, when the traditional methods of analyzing the boundaries of light zones using derivatives stop working.

5. References

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