Mathematical Model, Development of Algorithms and Measurement of Parameters of Objects in Monitoring Systems for Protection of Cultural Heritage

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Abstract. This article is devoted to the creation of a mathematical model processing the output signal of video surveillance systems, based on information about the characteristics of the signals of the objects of observation, in order to protect cultural heritage.
The subject of the study is the relationship between the structure and parameters of the output signal, certain changes in the situation in the area of observation and detection of a signal from foreign objects against the background of noise. Typical physical conditions for the functioning of video surveillance systems are defined and general recommendations for maintaining the operating point are offered. Algorithms have been developed that realize the functionality of the optimal detector device by numerical methods.

Keywords: Preservation of Cultural Heritage, Video Surveillance System, Algorithms, Mathematical Modeling.

1 Introduction

Over the years, Bulgarian culture has been the object of attention and interest of both the cultural community and the state. The existence of the modern state in Bulgaria is developing in all aspects of European-style cultural life. Digital technologies are a tool to stimulate and support research and innovation and determine the face of the future electronic infrastructure for cultural heritage protection (Genova, I., 2012). At the same time, technological progress would not be possible without research and development. The digitization of movable and immovable cultural heritage achieves many goals in different areas. It breathes new life into cultural heritage and stimulates the growth of creative sectors.

The purpose of the tools for control and monitoring of each process is the need to monitor the level of productivity and safety. The tools that are the process of implementation can be video surveillance, webcams to track attention and more. Surveillance cameras can process large amounts of information and be remotely controlled. A system can be set up to monitor and process information on the time spent by citizens in front of exhibits and books in museums, libraries and galleries, as well as to guard the relevant sites. With the help of data processing programs, surveillance cameras will also transmit information about possible actions of people. Profiles can also be prepared to assess interest in each exhibit (Kagami, S., 2016).

2 The Structure of a Digital Video Surveillance System and Characteristics of the Presentation of Video Signals in Digital Form

The Images of objects in the field of view of the video camera, formed on the surface of the photosensitive element are a flat discrete light field. Thus, the state of the visual environment at any time can be characterized by a finite set of illuminance values for array cells (Janesick, J.; Klaasen, K.; Elliott, T., 2015). When using monochrome camcorders, the image is presented as a function of the brightness component.

$$Y=Y(x,y) \quad (1)$$

When using color video cameras, it is necessary to characterize the values of the three main color components - red, green and blue:

$$R=R(x,y)$$

$$G=G(x,y)$$

$$B=B(x,y) \quad (2)$$

Due to the fact that the measurement of these quantities is performed using an analog-to-digital converter, the values of the above functions, as well as their arguments, will be discrete. Usually the values are integers in the range 0-2n ~ 1, where n is the order of the ADC. The bit depth of the ADC used is determined by the general accuracy requirements of the system, in particular the likely dynamic range of illumination (Koford, J.; Groner, G., 2014).

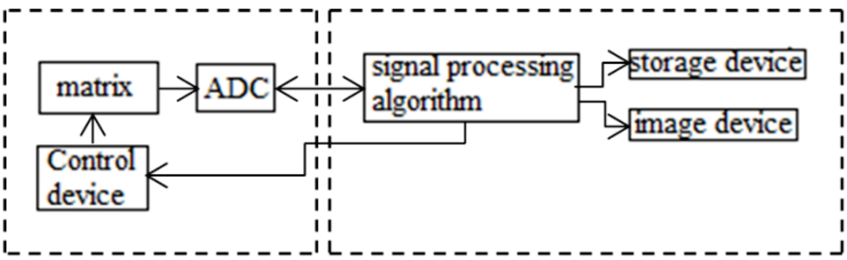

Fig. 1. Digital video surveillance system.

2.1 Criterion for the Presence of an Object in a Point

The task of determining the points of the image in which there is a foreign object is of paramount importance, and the quality of its solution largely determines the efficiency of further signal processing. The main principle of the preliminary assessment of the presence of a foreign object in the image is the comparison of the illuminance at a given point of the current image with the illumination of the same point of the reference image (Kountchev, R.; Kountcheva, R., 2019). Changes in the visual environment of the camcorder's field of vision cause changes in the brightness of the image on the photosensitive element, resulting in a change in the type of functions that characterize the resulting image. The appearance of a foreign object (for example, an observer who was not present at the initial moment of observing an object) in the field of view - in this case a change in illumination at points belonging to the object itself is likely. However, it cannot be said that such a change will be registered in the whole area of the image in which the object is actually present. Only items from the site will be found. which have a high contrast, which differ significantly in brightness or color from the background Changing the position of the background element is a situation in which a change in the image can be registered both in the area where the object was originally located and in the area where has moved. Image change may be caused by photosensitive matrix noise and ADC quantization errors (Hsia, C., 2018). In all cases, the conclusion about the change in brightness implies a comparison of the characteristics of the current image with some reference image. Let the reference image be selected according to some criteria and be described by a set of functions $Y_0(x, y)$, $U_0(x, y)$, $V_0(x, y)$. The current image is described by a similar set of functions Y(x, y), U(x, y), V(x, y). We will consider that the criterion for the presence of an object at the selected point (x_0, y_0) is the implementation of at least one of the following conditions:

$$|\mathrm{Y}(\mathrm{x}_0, \mathrm{y}_0) - \mathrm{Y}_0(\mathrm{x}_0, \mathrm{y}_0)| \geq \mathrm{T}_\mathrm{y},$$
$$|\mathrm{U}(\mathrm{x}_0, \mathrm{y}_0) - \mathrm{U}_0(\mathrm{x}_0, \mathrm{y}_0)| \geq \mathrm{T}_\mathrm{u}, \quad (3)$$
$$|\mathrm{V}(\mathrm{x}_0, \mathrm{y}_0) - \mathrm{V}_0(\mathrm{x}_0, \mathrm{y}_0)| \geq \mathrm{T}_\mathrm{v}.$$

We write the expression of the criterion in the following form:

$$R_{n\mu_0}(x_0, y_0) = \begin{cases} 1, R_{y_{n,y_0}} + R_{u_{n,\mu_0}} + R_{v_{n,v_0}} > 0 \\ 1, R_{y_{n,y_0}} + R_{u_{n,\mu_0}} + R_{v_{n,v_0}} = 0 \end{cases} \quad (4)$$

Where

$$R_{y_n y_0}(x_0, y_0) = \begin{cases} 0, |Y_n(x_0, y_0) - Y_0(x_0, y_0)| < T_y \\ 1, |Y_n(x_0, y_0) - Y_0(x_0, y_0)| \geq T_y \end{cases}, \quad (5)$$

$$R_{u_n \mu_0}(x_0, y_0) = \begin{cases} 0, |U_n(x_0, y_0) - U_0(x_0, y_0)| < T_u \\ 1, |U_n(x_0, y_0) - U_0(x_0, y_0)| \geq T_U \end{cases}, \quad (6)$$

$$R_{V_n V_0}(x_0, y_0) = \begin{cases} 0, |V_n(x_0, y_0) - V_0(x_0, y_0)| < T_V \\ 1, |V_n(x_0, y_0) - V_0(x_0, y_0)| \geq T_V \end{cases}, \quad (7)$$

Obviously, this criterion cannot be used directly to decide on the presence of a foreign object, as a positive result is possible in each of the described cases of changes in illumination. However, the use of this criterion with the appropriate choice of thresholds Ty, Tu, Tv, allows to significantly reduce the effect of equipment noise and low fluctuations in illumination, while ensuring acceptable sensitivity to beneficial changes. It should be noted that the optimal threshold values can be functions of both coordinates and time (Petrov, N.; Dimitrova, K.; Baskanbayeva, D., 2021).

2.2 Characteristics of Video Surveillance Facilities

1. Area of the image of the object S', taking into account the discreteness of the image, the concept is introduced as the number of points at which the presence of the object is detected (R = 1):

$$S'=\sum_{y=0}^{n_v-1}\sum_{x=0}^{n_{y-1}} R(x,y), \quad (8)$$

where n_v and n_y are the amount of horizontal and vertical elements of the image. Such a formulation implies accepting the value of the area of the matrix element as a unit of measurement. Thus, the image of an object with a unit area characterizes an object with a surface area:

$$S=(\frac{ax_0}{F})^2, \quad (9)$$

where a is the length of the side of the matrix, x0 is the distance from the object to the observation point, and Fe is the focal length of the lens.

2. Conditional center is a point that allows to characterize the movement of complex object. The coordinates of the points are defined as the arithmetic mean of the corresponding coordinates of the points of the whole object:

$$x_n = \frac{1}{S'}\sum_i(x_i - x_n)^2 \quad (10)$$

$$y_n = \frac{1}{S'}\sum_i(y_i - y_n)^2, \quad (11)$$

3. The variance of the coordinates of the object is a statistical characteristic that characterizes the distribution of the object in space. It is defined as a mathematical expectation of the square deviation of the coordinates of the object from the coordinates of the conditional center:

$$D_x = \frac{1}{S'}\sum_i(x_i - x_n)^2 \quad (12)$$

$$D_y = \frac{1}{S'}\sum_i(y_i - y_n)^2, \quad (13)$$

Determining this value is especially important when solving the problem of isolating a signal from a foreign object located in a limited area of the image, against the background of interference. The time the object is present at the point is the value of the time interval between two consecutive moments of change in when the criterion of the action of the object changes to opposite values (Nikolov, B.; Kostov, N.; Yordanova, S., 2018).

3 Determining the Time of Stay of an Object in the Field of View of the Video Surveillance System

The criterion for the presence of an object at a given point characterizes the change in a certain area of the video image, which may show one or more objects in the field of view.

A reference image must be selected, which is necessary to calculate the presence criterion. There are a number of algorithms for determining the presence of an object, which differ mainly in the method of selecting a reference image (Nikolov, B.; Kostov, N., 2014). One of the most famous of these is motion detection. In this algorithm, the image immediately preceding the analyzed image is selected as the reference. In this case, the criterion for the presence of an object at a given point is calculated as follows:

$$T(x, y)=T_{n,n-1}(x, y) \tag{14}$$

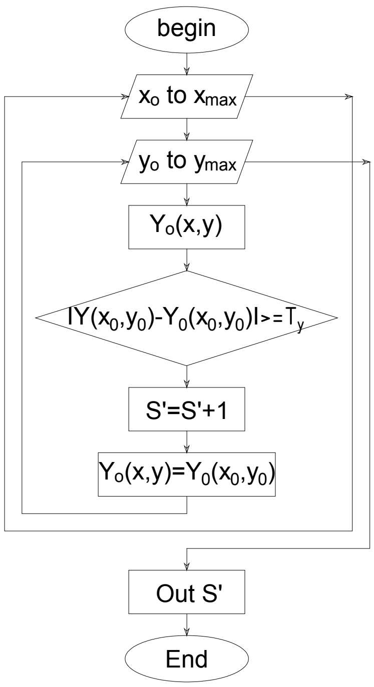

Fig. 2. Flowchart of motion detection algorithm.

A flow chart of the algorithm that performs these calculations is shown in fig 2. The result of this algorithm is the value S'of the image area of the object. In figure 3, the dots show areas of the image where the presence of an object will be detected.

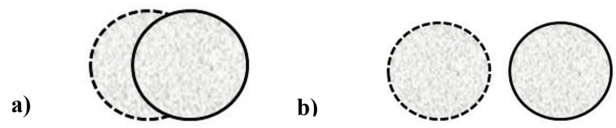

Fig.3. Errors in determining the area of the monitored object.

Obviously in such a situation the area of the object will be determined incorrectly and the measurement error will depend on the frequency of change of the image, its size and speed of movement. In case a), for example, the error will be insignificant, while in case b) the area will double.

This method is especially difficult to use when analyzing a video image containing multiple moving objects that are not usually of interest for surveillance purposes.

Presence detection - this method is a development of the previous one and includes it as an auxiliary. The selection of the reference frame is made periodically after a time interval of the order of a few tens of seconds. The update time should be delayed if a foreign object is found in the frame. Since the discovered foreign object is not present in the reference image (for example, the observers initially standing in front of the exhibit), its characteristics will be determined quite accurately. In this way, the residence time of only certain people who are standing in the visual space of the surveillance camera at a certain moment will be taken into account (Fig. 4).

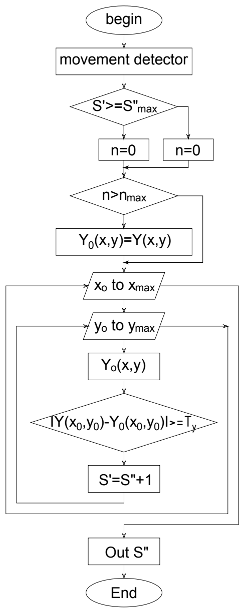

Fig. 4. Flowchart of motion detection algorithm.

The main disadvantage of this method is the difficulty in using it against the background of distributed interference, which can lead to false delays in updating the reference framework. It can be removed by modifying the criterion for the presence of an object at a point using white noise filtering. Consecutive video images, in addition to useful information, contain noise, which manifests itself in the change in the amount of light over time at the points of the image, even if there are no visible changes in the field of view. Such noise can cause false alarms in the system when automatic image analysis is used. White noise suppression may be based on the difference between its statistical characteristics and the characteristics of the changes caused by the movement of objects in the observation area. This is the sum for n period of change of the measured value of the change in the illuminance of the individual elements of the current image Yn with respect to the reference image K_0:

$$S_m(x, y)=\sum_{k=0}^{n}(Y_0\,(x, y)\text{-}Y_{m-k}(x, y), \quad (15)$$

for white noise it will aim for the value S = 0, while for stable changes in the image, this value will increase almost monotonically with decreasing brightness of the current image. In this way, the sites will be registered only if their condition remains virtually unchanged for a certain period of time.

4 Algorithm for Spatial Selection of Multiple Objects and Limiting the Area for Image Analysis

In case two or more spatially separated objects are found in the image, the calculation of their parameters using algorithms defined for single objects will be uninformative. For example, for objects located in different parts of the image, the calculated area of the "equivalent" object will be equal to the sum of their areas. The "conditional center" will be located in a straight line connecting the centers of these sites, at a point which in the general case may not belong to any of the sites. The characteristics calculated in this way practically do not give an idea of the individual parameters of each of the objects.

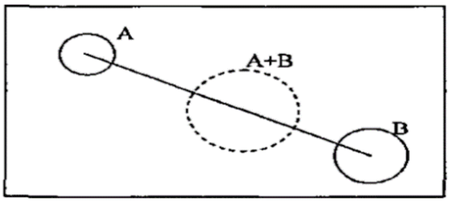

Fig. 5. Measurement errors in the case of multiple objects.

$$B_0(x_0\text{-}1, y_0),\ C_0(x_0+1, y_0),\ D_0(x_0, y_0\text{-}1),\ E_0(x_0, y_0+1),$$

for these points or

$$K(x,y)=\begin{cases}0, P(x,y)=0\\1, P(x,y)=1\end{cases}, \quad (16)$$

In this context, the problem of selection, given the knowledge of all points, when the presence of foreign objects is considered detected, comes down to termining the affiliation of each point to a particular object. If we choose an arbitrary point A0, then for it $K(x_0, y_0) = 1$. Let's check the value of the function P(x.v) at the points that are not adjacent to A_0, namely at the points: $B_0(x_0-1, y_0)$, $C_0(x_{0+}1, y_0)$, $D_0(x_0, y_0-1)$, $E_0(x_0, y_0+1)$, for these points:

$$K(x,y)=\begin{cases}0, P(x,y) = 0\\ 1, P(x,y) = 1\end{cases}, \quad (17)$$

Then point A_0 is moved to each of the four adjacent points for which P = 1 and the described algorithm is repeated. In this way, with a certain number of iterations, all points belonging to a given object will be marked. We will define similarly the points belonging to the other objects. The block diagram is described in fig.6.

The input data of the algorithm is an array of values of P (x, y), containing vmax by ymax elements. The output data are: array K (x, y) with the same dimension as P(x, y), containing the number of objects to which the corresponding points belong, integer variable N, containing the total number of objects in the image, one-dimensional array L(N) containing the dimensions (in pixels) of the individual objects. For the stable operation of the algorithm it is necessary to fulfill the condition P(x, y) = 0, for x = 0, $x = x_{max}-1$, y = 0, $y = y_{max}-1$. In some cases, when powerful sources of interference come into view of the camcorder, the effect of which cannot be attenuated by other means, a possible solution may be to limit the area of the image in which foreign objects are expected to appear.

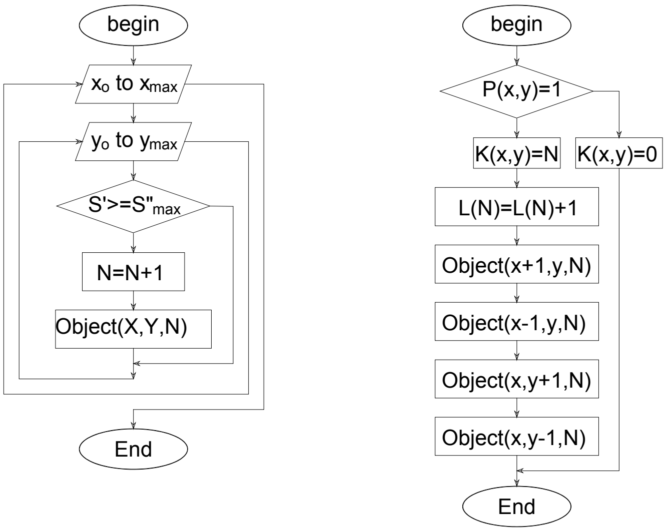

Fig. 6. Flowchart of algorithm for spatial selection of objects.

It is possible to choose objects that change their position in space quite slowly against the background of rapidly changing noise. Let us have a reference image described by the function $Y_0(x, y)$. Let us also obtain subsequent images $Y_n(x, y)$ at time intervals Δt_n. The life of an object at a given point, given by the coordinates (x_0, y_0) at the time of arrival of the nth image, will be determined by the following formula:

$$\tau_n(x_0, y_0) = P(x_0, y_0)\tau_{n-1}(x_0, y_0) + \Delta t_n \quad (18)$$

If the object is not found in the next image P ((x_0, y_0)= 0), its presence time is reset and a new countdown begins. If when obtaining an image (n = m), the value of τm will exceed the value of some predefined thresholds τ_{max}:

$$\tau_n(x_0, y_0) > \tau_{max} \quad (19)$$

The site is considered to meet the selection condition. In this case, the object is assigned to the element of the reference image and its lifetime is also reset. In this way, the sites will be registered only if their condition remains virtually unchanged for a certain period of time. This period can be taken into account and based on this, for example, the time spent by citizens in front of an exhibit, painting or other can be determined and a rating arrangement can be created according to the interest of observers.

5 Conclusions

In the present work, studies have been conducted on the main tasks that arise when using technical means of monitoring. The proposed solutions are applicable to surveillance systems with different structures and purposes. The main focus of the work is on creating a noise-resistant model of video surveillance system, which includes algorithms for image analysis to detect the presence and measure the parameters of foreign objects.

Methods and algorithms for measuring the spatial coordinates of objects are proposed, which allows the use of a video camera system to measure the three coordinates of an object, as well as spatial selection of multiple objects according to the coordinate, spatial selection algorithm that allows to determine the set of points belonging to each of the objects, in case of the presence of several foreign objects on the image; perform individual measurements of the characteristics of each of the objects, as well as additional selection of noise objects, the dimensions of which are usually much smaller than the dimensions of important objects.

This article outlines opportunities to explore and exploit the potential of the digital space, to protect and improve access to knowledge, cultural values and heritage. Digital Presentation and Preservation of Cultural and Scientific Heritage to present the paper.

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