Realization Models of Optoelectronic Matrix Correlator

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ABSTRACT

The article presents a generalized structure of a correlation system, which includes a two-dimensional correlator memory, a preprocessor, a reference memory, and a control unit. Two variants of hardware realization of two-dimensional correlator memory as part of an optoelectronic correlation system are proposed. The functional capabilities of an alternative method of correlation processing of the current optical image are considered, which allows to determine the location of the reference center on the field of the current image. The regular structure of the two-dimensional memory of the correlator ensures its compact placement on a promising element base - on an FPGA chip or on a matrix of smart pixels.

Keywords: correlation, optoelectronic system, correlation matrix, smart pixel matrix

1. INTRODUCTION

In solving a wide range of practical problems, high-speed processing of large data sets determines a special place for optoelectronic devices[1-2]. This is primarily due to the peculiarities of optoelectronic data processing methods due to the combination of digital electronic processing with its versatility and optical processing with its performance[3-5].

In this regard, specific examples of the use of optoelectronic means in artificial intelligence systems for signal and image analysis and object recognition can be given[1,6-7]. Optoelectronic methods and tools are most effectively used for medical diagnostics[8-10].

2. RELEVANCE OF THE TOPIC

Optical and optoelectronic means play a special role in technical vision systems as part of systems for detecting and tracking moving and dynamic objects[11-13]. This applies primarily to mobile robots and their systems for recognizing objects and situations in the environment[14-16]. The use of such systems allows the development of intelligent control systems as part of mobile robots[17-18].

At the same time, one of the most common classical identification methods for detecting and tracking objects is correlation methods based on convolution of the current and reference images[12,15]. At the same time, classical convolution methods are being improved, and one such example is the method of matrix correlation processing of binary images presented in[19]. The novel approach allows not only to determine the location of the center of the reference image on the field of the current image, but also to limit the number of correlation processing cycles to the number of pixels of the reference image[19].

3. RESEARCH GOAL AND PROBLEM STATEMENT

The aim of this work is to analyze the possibilities of optoelectronic implementation of a matrix correlator as part of object recognition systems.

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Given that the main purpose of correlation processing is to search for and coordinate reference of objects, it is worth using the well-known criterion of appearance convergence[12, 15]:

$$K = \sum_{i,j} d(i+k, j+l) \cdot t(i,j), \quad (1)$$

where *t(i, j)* is the value of the reference element with coordinates *(i, j); d(i+k, j+l)* is the value of the image element; *k, l* are the coordinates of the beginning of the image fragment.

It should be noted that estimate (1) is a sufficient statistical estimate in the presence of Gaussian noise. In addition, this estimate is a variant of the discrete convolution of the current image *D* with an arbitrary filter *T*. Thus, such a correlator is a filter in a correlation image processing system.

Estimation (1) also corresponds to the accepted order of correlation processing, i.e., the process of sliding over a part of the current image with a convolution of the reference with successive fragments shifted by a certain amount (rows or columns)[12,15,24].

In this paper, we consider the hardware implementation of correlation image processing, with the two-dimensional memory of the correlator as the basic object of consideration. The functions of such memory are extended, since it is used not only to memorize the generated correlation relief, but also to form the correlation coefficients themselves.

4. STRUCTURE AND FUNCTIONING PRINCIPLE OF THE MATRIX CORRELATOR

Fig. 1 shows a generalized structure of the correlation system, which includes a two-dimensional correlator memory, a preprocessor, a reference memory, and a control unit. The preprocessor is introduced to convert the optical image into a digital binary image and its construction is not considered in this paper.

Thus, the two-dimensional memory of the correlator is a correlation matrix in which the matrix method of correlation processing of the current binary image F with the binary reference image G is performed. In each processing cycle, the corresponding element $g_{i,j}$ is read from the reference memory, which is logically multiplied with all elements $f_{i+k,j+l}$ of the current image F, which are shifted in the opposite direction with the scan of the reference elements G[19].

The transition to binary images allows not only to identify informative pixels in the current F and reference G images, but also to simplify the process of classical correlation processing of the form (1) by applying logical multiplication, and instead of summing, use the operation of increment (increase by one)[19].

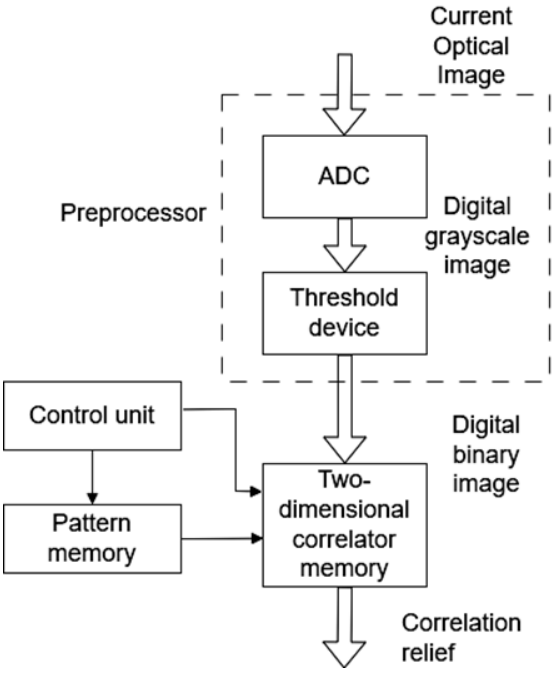


Figure 1. Generalized structure of the correlation system

The dimension of the information field of a two-dimensional correlation matrix (Fig. 1) is determined by the dimensions of the current ($N \times M$) and reference ($n \times m$) images and is equal to $(N+n-1) \times (M+m-1)$ [19]. This is due to the fact that it is not the shift of the reference on the field of the current image that is assumed, but the shift of the entire current image depending on the scan of the reference elements. As a result, the duration of the correlation process primarily depends on the dimension ($n \times m$) of the reference, and in the case of cross-correlation $N >> n$, $M >> m$.

If the scan of the reference G starts from its central (zero) pixel when the dimensionality of both images F and G is odd, then the maximum pixel values of the correlation relief will determine the location of the reference centers on the field of the current image[19].

Structurally, a two-dimensional correlation matrix has a regular arrangement of computing cells and links between them horizontally and vertically (along rows and columns). Figure 2 shows the functional diagram of a computing cell, which consists of two functional parts:

a) the transit part, which contains the MX multiplexer and the D-trigger and stores information (pixel $f_{i,j}$) and shifts it in a certain direction to the corresponding address;

b) a computing part containing an RS-trigger and a logic element I, which generates a signal $\delta_{i,j}$ of the form:

$$\delta_{i,j} = g_{i,j} \cdot \bar{f}_{i,j}, \tag{2}$$

when $\delta_{i,j} = 1$, that resets the RS-trigger to zero and thus forms the zero pixel $c_{i,j}$ of the correlation relief[19].

The presence of a computing part indicates the functional power of the two-dimensional correlator memory.

Expression (2) corresponds to the process of normalized correlation processing, which results in the presence of a unit signal in those pixels that correspond to the location of the defined reference center in the field of the current image[19].

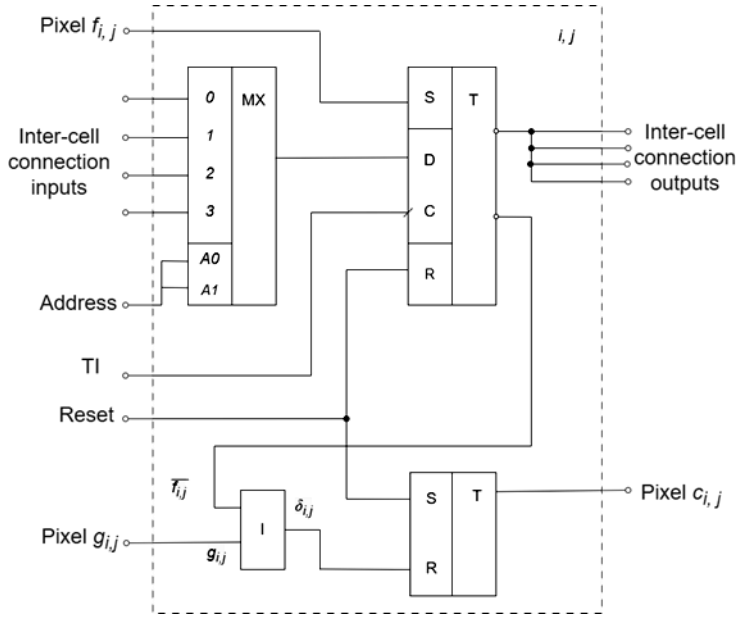


Figure 2. Functional diagram of a computing cell

5. IMPLEMENTATION OPTIONS FOR THE OPTOELECTRONIC MATRIX CORRELATOR

If it is necessary to solve the problem of accelerated determination of the center of the reference on the field of the current image, the correlation process is greatly simplified if the reference image looks like Fig. 3 with a dimension of 3×3 pixels. In addition, in this case, the reference memory (Fig. 1) can be implemented as a shift register and placed in the control unit.

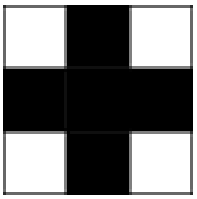


Figure 3. Binary reference image

The optoelectronic approach to correlation image processing involves not only representing the input image in the optical range, but also forming the output correlation relief for the convenience of video surveillance also in optical form. In view of this, two variants of the optoelectronic matrix correlator are possible, the basic unit of which is its two-dimensional memory (Fig. 1).

The first option is that the regular structure of the two-dimensional memory with adjacent interconnections of simple computing cells (Fig. 2) determines its effective placement in one FPGA chip, for example, in the FLEX10K chip by Altera[20-21]. But in this case, it becomes necessary to connect a matrix of LEDs for optical visualization of the correlation relief.

The second option involves the implementation of a two-dimensional correlator memory on a smart pixel's matrix[22-23]. In this matrix, an individual smart pixel represents a fragment of an integrated circuit, combining optical information input/output devices with an electronic circuit for data processing[22-25]. The complexity of the electronic circuit can vary significantly, from devices that provide signal generation and amplification to those that perform complex information processing[7-8]. Therefore, a matrix containing computing cells (Fig. 2) can be easily integrated into a smart pixel array chip. In this case, due to the possibilities of forming the optical two-dimensional signal output, there is no need for additional transformations of the digital image into the corresponding optical image of correlation relief. This is due to the capabilities of smart pixel arrays, which largely align with the functional purpose of the proposed two-dimensional correlator memory.

6. RESULTS

The use of binary current and reference images allows to simplify the schematic solution for constructing computing cells and their interconnections in the structure of the two-dimensional memory of the correlator. And this, in turn, makes it possible to implement it as part of an optoelectronic correlation system in two versions with the output of the correlation relief in the optical range.

At the same time, the two-dimensional memory of the correlator can be compactly located in a matrix form on a promising element base, namely, in a FPGA chip or on a smart pixel's matrix.

7. CONCLUSIONS

1. Due to its dual nature, namely, the ability to receive and output information in optical form and process it electronically, optoelectronic methods and means find their effective application in a wide range of practical tasks. This is especially true for the processes of analyzing and recognizing objects in images.

2. Converting an input optical image into a binary image, firstly, speeds up the process of correlation processing by applying high-speed logical multiplication and increment operations. Secondly, this approach allows to normalize the correlation results, for example, when determining the location of the reference center on the field of the current image.

3. The use of the matrix method of correlation processing affects the structure of both computing cells and the corresponding interconnections in the correlator's two-dimensional memory. In turn, the regularity of the structure of the two-dimensional memory of the correlator allows its compact implementation both on the FPGA chip and the smart pixel's matrix.

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