ALGORITHMIZATION OF IMAGE PROCESSING FOR IDENTIFICATION OF DYNAMIC OBJECTS

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Abstract: Modern monitoring and operational decision-making systems based on image series have become widely used for a wide variety of applications. At the stage of identification of graphic images, the affiliation of the found dynamic object to the class of objects of interest is established on the basis of a comparative analysis of its contours with a given template. The identification process is considered and the algorithm of machine graphics is given, including, firstly, image preprocessing using the Gauss smoothing operator, secondly, the search for object boundaries using the Kenny operator, thirdly, image post-processing for interpolation of the obtained discontinuous contours of the object using mathematical morphology operations and local processing of a set of contours.

Key words: motion vectors, image series, fast processing, analytical solution, machine graphics.

1. INTRODUCTION

At the stage of identification of graphic images, the affiliation of the found dynamic object to the class of objects of interest is established on the basis of a comparative analysis of its contours with a given template. The preceding stages are described in [1].

The machine graphics algorithm for identifying dynamic objects consists of the following stages, some of which are described earlier:

1. Image preprocessing using the Gaussian smoothing and noise reduction

operator.

2. Detection of boundaries using the Kenny operator, consisting of the following processes:

- searching for boundaries using Sobel's gradient approach,
- suppression of non-maxima,
- double threshold filtering and tracing of the ambiguity area.

3. Post-processing of the image for interpolation of the obtained discontinuous contours of the object using mathematical morphology operations and local processing of a set of contours.

4. Comparative analysis of the obtained contours of an object with a template based on invariant moments that are not sensitive to changes in scale and rotation.

5. If the objects are similar in invariant characteristics, then the resulting result is sent to other subsystems for further analysis.

6. Exit from the image identification algorithm.

The block diagram of the machine graphics algorithm for identifying dynamic objects is shown in Figure 1. The description of the basic methods is given in accordance with [2].

2. THE STAGE OF IMAGE PREPROCESSING USING A GAUSSIAN FILTER

There are a large number of basic analytical solutions for image preprocessing that allow for the noise reduction procedure to prepare for analysis, such as linear, Gaussian filter, nonlinear, median, ranking, adapted, combined, hybrid and others.

As a smoothing filter, a Gaussian filter [3] was chosen as an image preprocessing tool, using the law of normal distribution and having simplicity of implementation, simplicity of calculations and naturalness of the image after processing.

The application of Gaussian blur to the image is based on the convolution operation, which is the calculation of a new intensity value of the current pixel, taking into account neighboring pixels. The convolution kernel is a*b matrix, where a is the number of rows and b is the number of columns.

Image processing using the Gauss filter is carried out by superimposing the central element of the convolution kernel on each pixel of the original image and calculating a new value using the formula (1) following from the Gauss equation in the special case for two dimensions [3]:

$$I'(x,y) = \sum_{h=-r_h}^{r_h} \sum_{v=-r_v}^{r_v} I(x-h, y-v) * \frac{1}{\sqrt{2\rho\sigma}} * e^{\frac{\sqrt{h^2+v^2}}{2\sigma^2}} \quad (1)$$

where $I'(x,y)$ is the new pixel value with coordinates (x,y), r_h is the horizontal blur radius taking into account $a=r_h*2+1$, r_v is the vertical blur radius taking into account $b=r_v*2+1$, σ is the standard deviation of the Gaussian distribution, which sets the degree of blur.

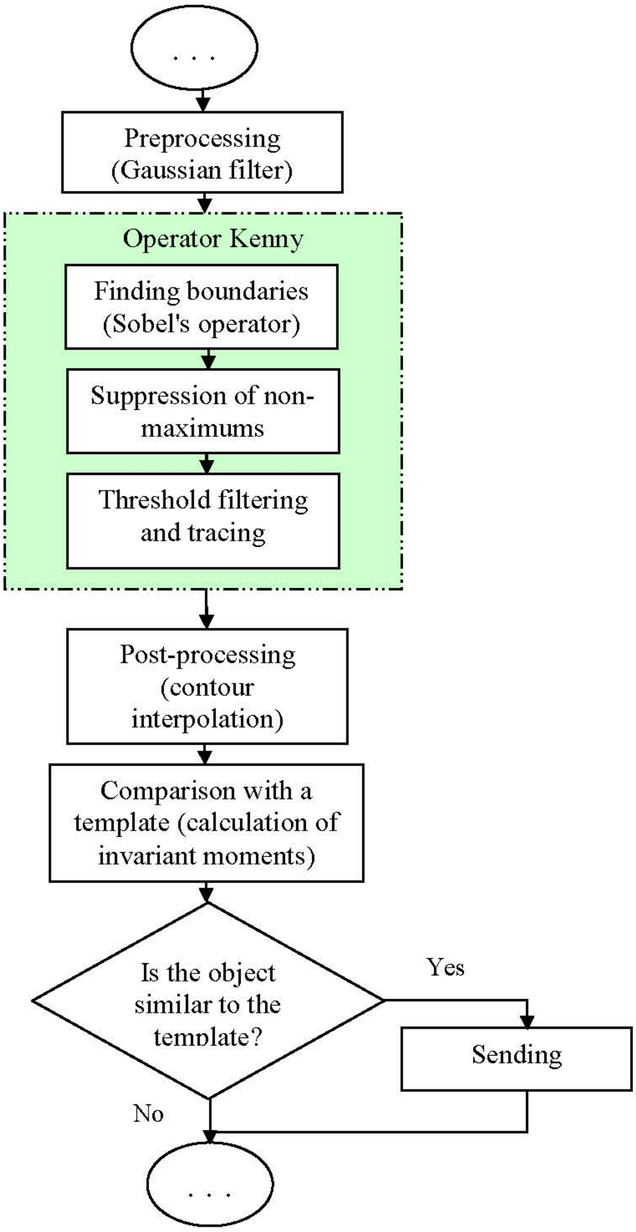

Fig 1. A machine graphics algorithm for identifying dynamic objects

Applying a convolution to each pixel of the image imposes a blur effect, depending on the selected convolution core size and the blur coefficient. Within the framework of the developed algorithm, the values of the Gaussian filter kernel are used, which are close to the first derivative of the Gaussian σ=1.4, a=5, b=5.

Figure 2 shows a graph of the core of the Gaussian filter used to solve the noise reduction problem in preparation for further analysis.

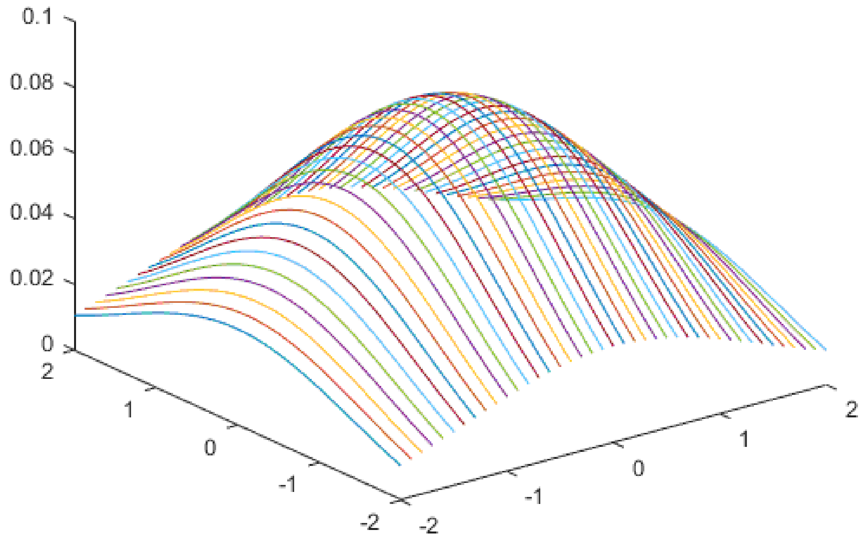

Fig. 2. Graph of the Gaussian filter kernel at σ=1.4, a=5, b=5

3. KENNY'S MACHINE GRAPHICS ALGORITHM FOR DETECTING OBJECT BOUNDARIES

The set of basic analytical solutions for identifying objects in images can be divided into the following groups:

- Methods based on the use of binarization, characterized by simplicity, high processing speed, but having the result of working with an excessive number of errors [4].

- Graph theory methods that differ in the representation of an image in the form of a weighted graph and allow finding complex boundaries of objects, but having too high a level of resource consumption and low processing speed [5].

- Methods of searching for regions that directly combine neighboring points into one area on the same basis, and have a high probability of error with large segment sizes [6].

- Methods using a Markov random field based on the assumption that the characteristic of an image pixel depends on a certain set of neighboring points and characterized by high complexity of implementation [7].

- Methods of searching for boundaries that have low sensitivity to changes in characteristics and allow achieving high accuracy using additional tools for pre-processing and post-processing of object contours to eliminate gaps [3].

To detect a dynamic object inside the found area of interest, an analytical solution proposed by John Kenny was used, which allows you to represent an object as a set of contour points for effective comparison with a template object that allows you to determine whether the resulting object belongs to the class of objects of interest. Also, the advantages of the chosen approach are the effective results of image processing in shades of gray, the flexibility of setting the detection accuracy due to the presence of stages for selecting convolution operations to search for values and directions of the intensity gradient, as well as additional filtering of the obtained points.

Kenny's boundary detection detector is a multi-stage algorithm for detecting a wide range of object boundaries in images, the main stages of which are described in [3].

Stages of Kenny's machine graphics algorithm applied to a preprocessed image:

1. Search for boundaries based on calculating the value and direction of the gradient of pixel intensities. The boundaries of objects are marked where the gradient gets the maximum value.

The Kenny boundary detector assumes obtaining an approximating value of the pixel intensity gradient using mechanisms based on the convolution operation to calculate the result for the horizontal and vertical directions in the image.

A numerical experiment conducted in the work on the comparative analysis of gradient methods of boundary allocation based on the convolution operation [8] showed that the Sobel operator is most suitable for solving the problem of detecting the boundaries of a dynamic object.

Convolution kernels for obtaining an approximating value horizontally and vertically are represented by formulas (2) and (3), respectively:

$$H_x = \begin{matrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{matrix} \qquad (2)$$

$$H_y = \begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{matrix} \qquad (3)$$

The components of the gradient using a mask are calculated using formulas (4)-(5):

$$G_x = \sum_{i=-1}^{1} \sum_{j=-1}^{1} I_{x+i,y+j} * H_{x_{i+1,j+1}} \qquad (4)$$

$$G_y = \sum_{i=-1}^{1} \sum_{j=-1}^{1} I_{x+i,y+j} * H_{y_{i+1,j+1}} \qquad (5)$$

The resulting value for each pixel is determined by the formula

$$G = \sqrt{G_x^{\,2} + G_y^{\,2}} \qquad (6)$$

The direction of the gradient can be defined as an angle θ in radians, in the range $\pi \le \theta \le \pi$:

$$\theta = \text{arctg}\left(\frac{G_y}{G_x}\right) \quad (7)$$

The resulting angle θ is rounded to degrees with the values: 0, 45, 90, 135 based on the calculation that 1 Rad is equal to 180/ρ degrees and conditions: if $\theta < 0$, then $\theta = \theta + 180$.

Rounding degrees is carried out according to the following rules:

- $\theta = 0°$, if $|\theta > 0| \in [0;\ 22,5]$ or $(157,5;\ 180]$,
- $\theta = 45°$, if $|\theta| \in (22,5; 67,5]$,
- $\theta = 90°$, if $|\theta| \in (67,5; 112,5]$,
- $\theta = 135°$, if $|\theta| \in (112,5; 157,5]$.

Operations for obtaining approximating values in the horizontal and vertical directions are independent and applicable for parallel and distributed data processing software systems.

2. Suppression of non-maxima to clarify the boundaries in the image, based on the principle: the direction of the gradient is the direction of the maximum increase of the function.

Rules for the border refinement procedure:

- For each pixel, a segment of several pixels long is considered, oriented in the direction of the gradient and centred in the analysed pixel.

- The border of the object is represented by pixels in which the local maximum of the gradient is reached.

The principle of suppression of maxima is not shown in Figure 3, in which the values of gradients are indicated by numbers, but by arrows of their direction.

2 ⇧	4 ⇧	1 ⇨	3 ⇨	11 ⇨
1 ⇧	3 ⇧	5 ⇨	4 ⇨	10 ⇨
1 ⇧	11 ⇧	4 ⇩	22 ⇩	11 ⇩
4 ⇧	3 ⇧	4 ⇩	6 ⇩	8 ⇩
1 ⇧	6 ⇧	7 ⇩	11 ⇩	5 ⇩

Fig. 3. The principle of suppression of non-maxima

3. Double threshold filtering and ambiguity area tracing

At this stage, two intensity thresholds are used: upper and lower.

Suppression of pixels that do not belong to the border of the object is carried out according to the following rule:

- Pixels having intensity values less than the lower threshold are suppressed;

- Pixels with intensity values above the upper threshold belong to the reliable boundary of the object;

- Pixels having intensity values in the interval of the upper and lower thresholds are an area of ambiguity that is processed by the tracing mechanism.

The tracing mechanism is the assignment of pixels to the boundary of an object, if they are connected to one of the established boundaries.

Based on the results of using the Kenny boundary detector described in [3], after image processing, the boundaries of objects are fuzzy, in the form of discontinuous contours. A digital image interpolation stage is required to find the intermediate values of the contours of the object.

4. POST-PROCESSING OF IMAGES BY METHODS OF MATHEMATICAL MORPHOLOGY AND LINEAR INTERPOLATION OF A SET OF POINTS

To the binary image obtained after applying the Kenny boundary operator, that is, having intensity values of 0 or 1, the closure operation is applied, which is one of the tools of mathematical morphology. A detailed description of the definition of mathematical morphology and the methodology of morphological analysis on graphic objects is presented in [9].

The closure is an erosion operation performed after the build-up operation and the result of which is demonstrated in Figure 4. The selected basic analytical solution makes it possible to eliminate breaks in the contours of the object and provide post-processing of the image for a more accurate analysis of belonging to the class of the object of interest.

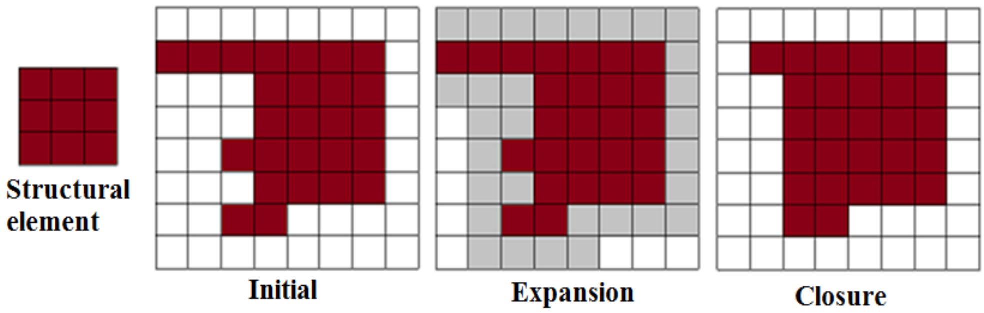

Fig. 4. Scheme of application of closure as an operation of morphological analysis

The concepts of erosion and build-up operations are closely related to the definition of a structural element, which is an element of arbitrary fixed size and structure. Within the framework of the developed algorithm, a structural element in the form of a 3x3 pixel matrix is used, as shown in Figure 4. If we imagine the contours of the object obtained after using the detector in the form of black pixels with intensity values equal to 0, then the structural element is filled with the same values. Rules for applying the build-up operation to the original binary image, shown in Figure 4:

Image processing using the build-up operation is carried out by superimposing the central pixel of the structural element on each pixel of the original image and transferring the matrix of the structural element to the corresponding pixels of the original image, if at least one of their intensity values matches.

The rule for applying the erosion operation to the resulting binary image after the build-up operation, shown in Figure 4:

Image processing using the erosion operation is carried out by superimposing the central pixel of the structural element on each pixel obtained after the image enlargement operation. If at least one of the single pixels of the matrix of the structural element does not match the intensity value with the corresponding pixel of the image, then the intensity values for the analyzed area of the image other than the structural element are transferred.

Thus, as a result of the erosion operation, the boundaries of objects that are thinner than the structural element are erased.

After image processing by means of mathematical morphology, linear interpolation of the obtained points of the contour of the object is carried out, described in [10].

The need to apply this approach is due to the need to ensure the completeness of the contour of the object and cut off excess points of the resulting set. This basic analytical solution does not require complex resource-intensive calculations and ensures even greater identification accuracy.

For each of the obtained contour points of the object, a set of obtained contour points within a radius of n pixels is considered.

Belonging to the same contour of the object of two points I(x, y) and $I(x_0, y_0)$, located no more than within a radius of n pixels from each other, is due to the formulas (8)-(9):

$$|G(x,y) - G(x_0,y_0)| \leq E \quad (8)$$

where G is the gradient value, E is a non-negative threshold value;

$$|\theta(x,y) - \theta(x_0,y_0)| \leq T \quad (9)$$

where θ is the value of the gradient direction in radians, T is a non-negative angular threshold value.

5. ALGORITHM OF COMPARATIVE ANALYSIS OF GRAPHIC OBJECTS BASED ON THE METHOD OF INVARIANT MOMENTS

In the comparative analysis of graphic objects, comparisons of their features, characteristic features, representing special points and lines, structures and areas, etc., play an important role. There are two main analytical solutions to this problem based on point and contour features.

Taking into account the main drawback of the point features approach, due to instability to foreshortening distortions and lighting changes of dynamic objects, an approach based on such a stable characteristic as the shape of the object, which is a set of many contour points, was chosen.

To carry out the procedure of comparing the obtained contour of the object O_1 with the template O_2 and determining whether O_1 belongs to the class of the object of interest, invariant moments are used that are insensitive to image rotations and changes in its scale. The mathematical justification of the method is based on the theory of algebraic invariants.

Image moment – weighted average (moment) pixel intensities of the image, as well as a function of moments that are selected in such a way as to have some necessary property or interpretation.

Image features constructed on the basis of power moments and describing the silhouette of an object are invariants of moments.

Let the contour of the object consist of N points, where x_i, y_i are the coordinates of the i-th point. Then the machine graphics algorithm for comparing two objects contains the following steps described in [110]:

1. Determination of the central moments of the order not higher than the third according to the formula (10) for the compared objects O_1, O_2:

$$M_{pq} = \frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^p (y_i - \bar{y})^q, \; p+q \le 3 \tag{10}$$

where $\bar{x}$ and $\bar{y}$ are the average values calculated by formulas (11), (12):

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{11}$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{12}$$

2. Calculation of moments invariant to rotation, transfer and mirroring operations for compared objects O_1, O_2 by formulas (13)-(19):

$$M_1 = m_{20} + m_{02} \tag{13}$$

$$M_2 = (m_{20} - m_{02})^2 + 4m^2{}_{21} \tag{14}$$

$$M_3 = (m_{30} - 3m_{12})^2 + (3m_{21} - m_{03})^2 \tag{15}$$

$$M_4 = (m_{30} + m_{12})^2 + (m_{21} + m_{03})^2 \tag{16}$$

$$\begin{gathered} M_5 = (m_{30} - 3m_{12})^2 (m_{30} + m_{12})^2 [(m_{30} + m_{12})^2 - 3(m_{21} + m_{03})^2] + \\ (3m_{21} - m_{03})(m_{21} + m_{03})[3(m_{30} + m_{12})^2 - (m_{21} + m_{03})^2] \end{gathered} \tag{17}$$

$$\begin{gathered} M_6 = (m_{20} - m_{02}) + [(m_{30} + m_{12})^2 - (m_{21} + m_{03})^2] \\ +4m_{21}(m_{30} + m_{22})(m_{21} + m_{03}) \end{gathered} \tag{18}$$

$$\begin{gathered} M_7 = (3m_{21} - m_{03})(m_{30} + m_{12})[(m_{30} + m_{12})^2 - 3(m_{21} - m_{03})^2] - \\ (m_{30} - 3m_{12})(m_{21} + m_{03})^2 [3(m_{30} + m_{12})^2 + (m_{21} - m_{03})^2] \end{gathered} \tag{19}$$

3. The distance between objects is calculated by the formula (20):

$$R(O_1, O_2) = \sum_{i=1}^{7} | m_i(O_1) - m_i(O_2) | \qquad (20)$$

Thus, if the distance $R(O_1, O_2)$ between the template of the object of interest O_2 and the resulting contours of the object O_1 does not exceed the acceptable threshold, then the objects are considered equal.

6. CONCLUSION

1. The identification process is considered and the algorithm of machine graphics is given, including, firstly, image preprocessing using the Gauss smoothing operator, secondly, searching for object boundaries using the Kenny operator, thirdly, image post-processing for interpolation of the obtained discontinuous contours of the object using mathematical morphology operations and local processing of a set of contours.

2. For the operation of searching for the boundaries of an object included in the Kenny machine graphics algorithm, the convolution kernels of the Sobel operator were used to obtain an approximating value horizontally and vertically, since numerical experiment showed its effectiveness in detecting.

3. As a mathematical morphology tool for post-processing the obtained contours of the object and eliminating gaps, a closure was used, which is an erosion operation performed after the build-up operation. After applying this image processing method, local contour processing was carried out, which made it possible to determine whether the resulting set of points belonged to the contour.

4. The algorithm for processing the obtained image contours to obtain comparative characteristics is based on the central and invariant to the operations of rotation, transfer and mirroring of image moments.

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