Finding Moving Targets on the Projection Image from the Laser Emitter of the Multimedia Trainer

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Abstract

The problems of creating a multimedia simulator with a laser emitter for teaching the correct use of various weapons in order to acquire the skills of targeted high-speed shooting are investigated. A hit on the target is determined by the coincidence of the central pixel of the laser response (spot) on the projection image with one of the target pixels. The hardware and algorithmic errors of shooting have been investigated and methods have been developed to reduce them. The analysis of the spots from the laser emitter on the projection image and to find the centroid of the spot is carried out. An algorithm for determining the centroid of a spot through two-stage binarization of the image has been developed and tested, the thresholds of binarization that are optimal for solving the problem have been determined. The test results showed that the obtained accuracy is within the hardware component of the error, and the speed in decision-making is performed in real time.

Keywords 1

image processing, multimedia simulator, laser emitter, video stream, clustering, centroids

1. Introduction

The development of computer graphics methods, real-time image processing and the development of technical means for the effective visualization of dynamic processes have created conditions for the creation of new systems for teaching various skills using virtual environments that simulate one or another subject area of such training. This study proposes mathematical methods and their algorithmic software implementation for creating a multimedia simulator for teaching the correct use of various weapons for acquiring high-speed aimed shooting skills. Note that the laser emitter is attached to a real weapon and when the trigger is pressed, a spot appears on the screen as a result of a shot, which gives the user a complete feeling of the naturalness of the learning process. Along with the use of real weapons, appropriate virtual environments are created by means of computer graphics and various situations are simulated in it, as close as possible to real conditions (Fig. 1) [1]. Such multimedia laser shooting training systems can be used for effective training and rapid mastering of new types of weapons. At the same time, it is necessary to develop more complex modeling systems that support the entire combat training process [2]-[4].

The principle of operation of a multimedia weapon simulator with a laser emitter (see Fig. 1) is as follows. The projector reproduces on the screen a model of a training video with a moving target (for example, a tank). Hitting the target is determined by the coincidence of the central pixel of the laser response (spot) on the projection image with one of the target pixels. The receiving camera-sensor transmits the video stream to the computer, where the corresponding program processes each frame of the video stream in real time [5].

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Figure 1: Multimedia weapon simulator with a laser emitter.

Depending on the results of processing, the video clip may change - for example, an explosion is played (Fig. 2), which is accompanied by the corresponding sounds from the computer speaker.

Figure 2: Imitation of an explosion from hitting a tank

An important problem, the solution of which is proposed in this paper, is the recognition of the position of the central point (pixel) of the laser beam response spot on the screen with a high frame processing speed and sufficient accuracy ($\Delta < 1$ mm). The problem is aggravated by the fact that recognition is carried out on projection images with complex background textures (terrain relief, different seasons) and color effects such as an explosion.

At the same time, the frame processing time should be less than the time interval between frames. Typically, video recording is carried out at a frequency of 25 frames per second, i.e. frames change every 40 ms. During this time, it is necessary to process the image in the frame and, based on the results of processing, make a decision, possibly, to change the video. In the future, the direct processing of the frame will be carried out in 30ms. Note that the requirements for accuracy and speed of image processing algorithms are contradictory, since high accuracy requires more detailed image processing, which is usually achieved at the expense of speed.

Therefore, it is necessary to develop optimal algorithms for solving the problem posed in terms of these requirements and restrictions on frame processing and decision making in real time that is the purpose of this work.

2. Hardware and algorithmic components of the shooting errors

The response of the laser emitter is displayed on the screen as a spot about 8-10 mm in size. The accuracy of shooting from a weapon with a laser emitter depends on the error in determining and the size of the central pixel of this spot [6], [7].

Consider two components of the shooting error:

hardware - depends on the parameters of the laser emitter, the dimensions and characteristics of the projection screen, the resolution and characteristics of the receiving camera-sensor;

algorithmic - depends on the selected algorithm and frame processing methods.

The hardware and algorithmic components of the error are interconnected. Algorithmic processing of the spot pixels determines the coordinates of the center in real numbers, then these numbers are rounded up to discrete values of the coordinates of the central pixel of the spot. The accuracy of choosing the central pixel of the spot depends on the accuracy of the algorithm. On the other hand, the accuracy of determining the algorithmic component to a certain extent depends on the number of pixels that characterize the spot, i.e. on the image resolution [8].

Figure 3 shows images of the same spot at different resolutions of the image displayed on the receiving camera-sensor.

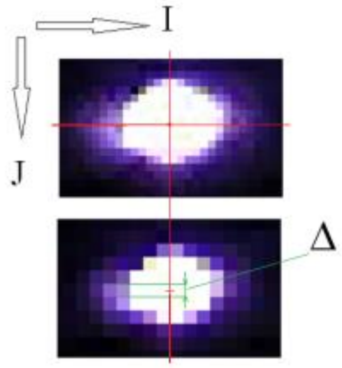


Figure 3: The center of the spot at frame resolutions (in the upper figure, the frame size is 1280 pixels (i) by 720 pixels (j), in the lower figure 640 by 360, respectively).

As follows from the figure, for a frame with a resolution of (1280*720), the coordinates of the central pixel of the spot were determined relatively accurately. After reducing the resolution to 640*360, the problem arose of which of the neighboring pixels to choose as the centroid of the spot - with coordinates (i, j) or with coordinates $(i, j+1)$. In both cases, we obtain an error in determining the center equal to Δ/2, where Δ is the pixel size. Note that Δ/2 is the maximum possible error in determining the centroid, which depends on the resolution of the receiving camera-sensor. With a resolution of 1280*720 and a screen size of 1670mm*940mm, the maximum possible hardware error in mm is 0.5*1670/1280 = 0.7mm (or 0.5*940/720 = 0.7mm). With a resolution of 640*360 and the same screen size (1670mm*940mm), the maximum hardware error doubles (Δ/2=1.4mm).

From this we can conclude that if the hardware error is too low, then it is not necessary to achieve a significant increase in accuracy algorithmically, since after such a determination of the coordinates of the spot center, the pixel closest to this center is ultimately selected, i.e. the error will be determined by the pixel size. Therefore, one of the important requirements for the accuracy of the algorithm is the choice of the nearest pixel to the center of the spot [9],[10].

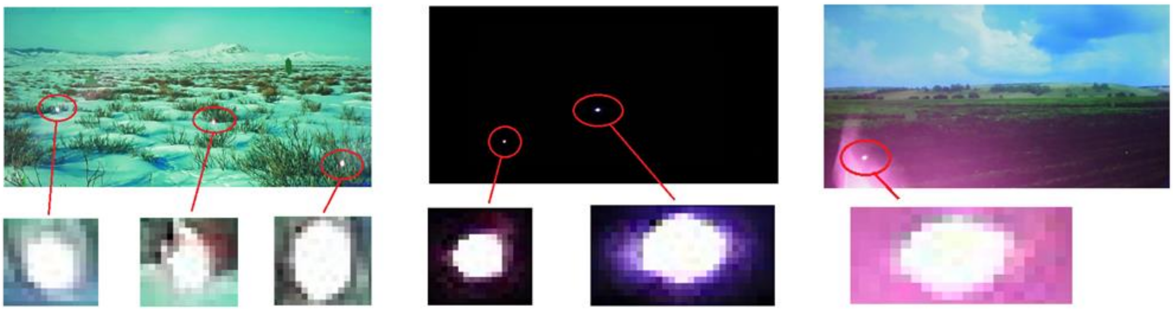
3. Analysis of spots from a laser emitter on a projection image

All frames of video images usually have various kinds of defects and noise. This is due to both the hardware component (aberrations) and the influence of external factors, while the noise components of the images are combined with the useful signal.

Depending on the nature of the origin, aberrations are divided into color (chromatic) and geometric (called distortion). Chromatic aberrations are optical distortions caused by different angles of refraction of light waves of different lengths. The aberrations of optical systems also include noise due to the properties of the sensitive elements of cameras, for example, dark dots on a light background (the so-called black defect) due to non-working pixels that occur during the production of photosensors.

External factors are due to the relationship between the illumination of the video lens (useful signal) and the light flux reflected from local objects (noise), blurring of the image due to the movement of the subject, etc.

Below are frames (Fig. 4) obtained on a projection image with point responses from a laser emitter.



a) b) c)

Figure 4: Projection images with spots from the laser emitter.

The figures show defects that can affect the accuracy of solving the problem:

In Fig. 4a), the shape of the spot, which is in the middle, is distorted under the influence of background points, and on the spot on the right, a dark pixel stands out against a light background (black defect) - the last pixel in the upper left corner.

In Fig. 4b), the spots are on a black background; however, the color of the pixels is still distorted along the edges of the spot due to chromatic aberrations - an excess of violet color is noticeable.

In Fig. 4c), the brightness of the extreme pixels and the shape of the spot are distorted under the influence of an external factor (glare on the frame).

Analyzing the images as a whole, we note the signs of spots that are important for the problem being solved:

The intensity (brightness) of the pixels of the spots is close to the maximum (255,255,255) and contrasts well with the background;

A sharp drop in intensity is noted at the edges of the spot;

The intensity of the pixels increases towards the center of the spot, especially at the edges.

The intensity gradient of the extreme points essentially depends on the contrast with the points of the surrounding background.

The size of the spots is different - from 6 to 12 mm (10-20 pixels for an image resolution of 1280 * 720), while the size of the characteristic region is approximately 10% larger.

The spots are drop-shaped, close in shape to a circle or ellipse.

Let's analyze these features. The first two features allow us to assume that, with a certain degree of accuracy, the central pixel of the spot can be determined as the center of mass of pronounced light pixels. The third sign shows that the center of the spot can be determined through the dependence of the change in the intensity of points towards the center. The fourth feature indicates that when determining the center of the spot through a change in the intensity of the points, it should be taken into account that the intensity of the points along the outer contour of the spot differs significantly. In this case, the last two signs indicate that it is necessary to determine the size and shape of the characteristic region for processing the pixels of each spot.

4. Algorithm for determining the spot centroid from a laser emitter

The term "centroid" is used mainly as a substitute for the physical terms - "center of gravity" and "center of mass", when it is necessary to emphasize the geometric aspects of this concept, including in images. In this case, the centroid of a fragment of a discrete halftone image is determined by analogy with the center of gravity of physical objects, where instead of the weight of each point, (x, y) its intensity is taken $I(x, y)$ [11], [12]. The centroid coordinates were C_x, C_y determined in terms of moments of a M_{ij} discrete image with pixel intensity $I(x, y)$:

$$\{C_x, C_y\} = \{\frac{M_{10}}{M_{00}}, \frac{M_{01}}{M_{00}}\},$$
$$M_{00} = \sum_x \sum_y I(x, y),$$
$$M_{ij} = \sum_x \sum_y x^i y^j I(x, y), \quad (1)$$

Important properties of sub-images derived from moments include:

- area (for binary images) or sum of color levels (for halftone images);
- centroid with coordinates C_x, C_y.

To determine the centroid of a spot from a laser spot, it is necessary to solve two problems:

- Find spot points.
- Determine the centroid from the points of the spot.

Determining the centroid of the spot is solved in two stages (Fig. 5):

- The position of several points of the spot is approximately determined through image binarization by the maximum possible lower threshold, which cuts off noise effects;
- The size of the spot is refined through binarization of the image fragment with a lower threshold selected around the detected points of the spot, and the coordinates of the centroid are already determined from this fragment.

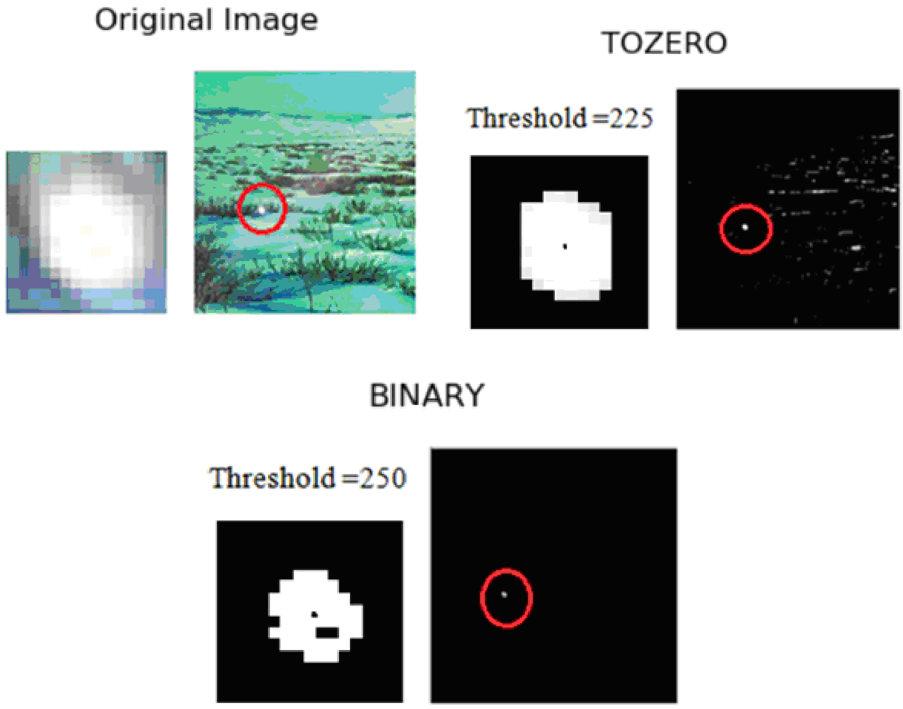


Figure 5: Stages of spot centroid determination.

The value of the upper threshold at both stages of processing is 255, since the intensity of the central pixels of the spot is close to the maximum.

The spot centroid determination algorithm consists of the following steps:

One signal is extracted from the original color image - usually the RGB (Red, Green, Blue) image is converted to grayscale. There may be other options, see below for details.

Image smoothing is not required, since at this stage it is only necessary to find a few bright dots of the spot, and when smoothing, their intensity decreases.

Image binarization with BINARY threshold type [13] (Fig. 6). The threshold is chosen from approximately 246 to 254, see test cases below. Note that a threshold that is too high leaves few spot points, and a threshold that is too low leaves background pixels in the image.

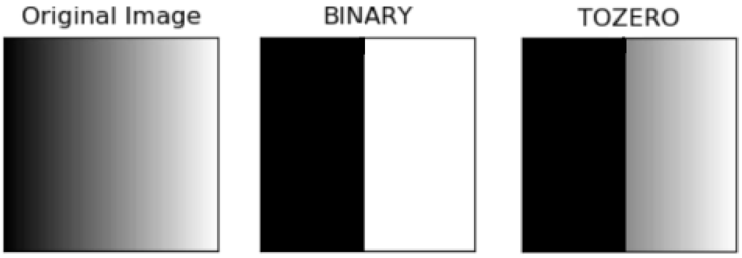


Figure 6: Types of binarization thresholds for the 1st (BINARY) and 2nd (TOZERO) stages of the algorithm.

All closely located points within a radius of 20 mm (35 pixels) are grouped into spots, random spots with up to 3 pixels are discarded.

The "centers of mass" of the found spots are determined through the moments (1).

A fragment of the image around the center of the spot is determined by the center of mass - a square, the size of which exceeds the size of the spot detected at the 1st stage by approximately two times.

We return to the processing of the halftone image. The fragment of the image selected in the previous step is smoothed. Smoothing is implemented with a discrete Gaussian kernel approximation $\sigma = 1$. It is not advisable to use a larger value σ due to the loss of information about the real intensity of the spot points, which is important for solving the problem. Anti-aliasing with large-radius filters suppresses noise, but blurs the image.

Binarization of a halftone image fragment (2nd stage of processing) with TOZERO threshold type (see Fig. 6). This type of threshold allows you to zero out the outer pixels of the spot and leave the intensity of the pixels inside and at the edges of the spot in grayscale. The value of the lower threshold is chosen so that only points characterizing the spot remain within the image fragment, the remaining points become black (intensity is 0). As a result, the image is divided into dots, which are displayed in shades of gray with a gradation ranging from 180 to 255 (see test results below), and black dots outside the spot, which are cut off by a threshold up to 180.

The position of the center of gravity of the image fragment is determined through the moments (1). After binarization, those pixels that have become black are not taken into account when calculating the center of gravity of an image fragment, since their intensity is 0. Therefore, the center of gravity is determined only by the points characterizing the spot.

The original image can be represented by one of the color models (RGB, HSV (Hue, Saturation, Value), etc.)[13], [14].

When using the RGB image model, it is difficult to give preference to any of the signals. Usually, the image is converted to grayscale by the formula

$$Y' = 0.299R + 0.578G + 0.114B \qquad (2)$$

The disadvantage of such a conversion is that signals of different colors can get the same intensity after conversion to a grayscale image, and after conversion, some of the information necessary for determining the boundaries by gradient methods may be lost.

When determining the centroid using the HSV model, the H (brightness) signal can be preferred, since the points of the laser spot are characterized by high brightness. However, the brightness of the dots of the spot significantly depends on the external illumination. Therefore, the gradation range of the signal on the histogram may decrease if the lighting is too bright - the image contrast deteriorates. In this case, it will be more difficult to calculate the gradient points. We also note that image contrast correction can be performed using linear histogram stretching [14],[15].

5. Algorithm testing and results analysis

The algorithm described above provides for the assignment of image binarization thresholds at 2 stages:

- When determining the position of the spot.
- When all points of the spot are selected and the position of the centroid is determined from them.

In order to determine the optimal lower thresholds for image binarization at the first and second stages of image processing, as well as to evaluate the resulting accuracy of determining the centroid coordinates, an experimental testing of the algorithm is carried out. To test the algorithm, an image of the maximum possible complexity is selected - laser spots against the background of snow cover (see Fig. 4a). Before binarization by BINARY type (see Fig. 6), a color image (RGB model) is converted to grayscale (GRAY) according to formula (2).

At the first stage (see Fig. 5), complete cutting off of noise (points that do not belong to laser spots) starts from a binarization threshold of 248 (Fig. 7).

a

b

c

Figure 7: Determination of the binarization threshold (1st stage of processing), after which only the points of the laser spot remain on the image

At the second stage (see Fig. 5), cutting off noise (dots that do not belong to laser spots) may also be necessary. This problem is solved, as in the first stage, by choosing the lower binarization threshold.

At the same time, the threshold value at the second stage can be significantly lower compared to the binarization threshold at the first stage, since the area of the selected image fragment is much smaller and therefore the probability of the appearance of noise points within the image fragment around the spot is negligible.

On Fig. 8 shows the results of tests with a fragment of the image of the left spot (see Fig. 7a), enlarged in scale. They allow us to estimate how the position of the center of mass changes for different values of the lower binarization threshold (1st stage of processing).

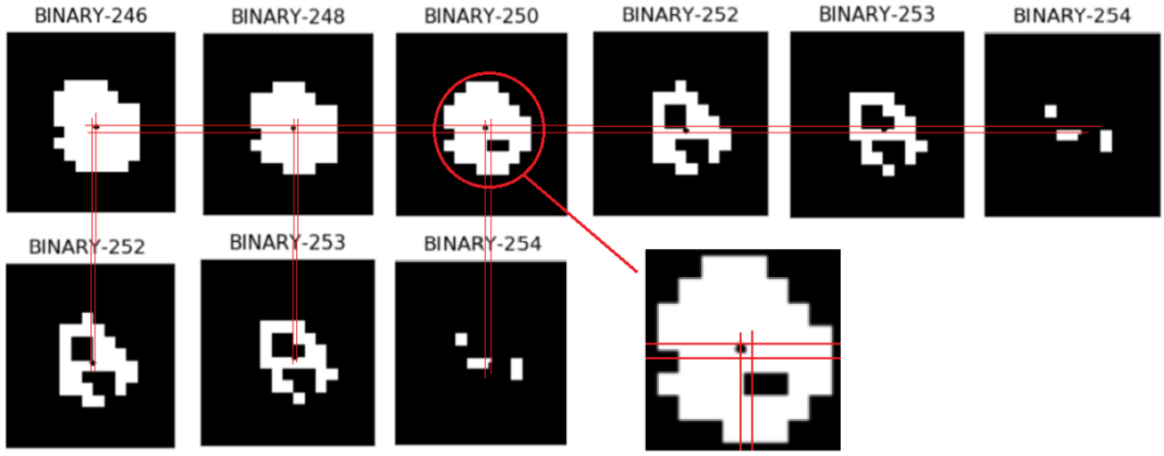


Figure 8: Influence of the value of the lower binarization threshold (1st stage of processing) on the size, shape and position of the center of mass of the image fragment

On Fig. 9 shows how the value of the lower binarization threshold (2nd stage of processing) affects the position of the centroid.

The top row (see Fig. 9) shows the results of tests to determine the centroid for an image fragment with shades of gray and low lower intensity thresholds (130-180). Here, the accuracy of determining the coordinates of the centroid goes beyond one pixel. The spread of coordinates is explained by the fact that the intense points of the image fragment include, together with the points of the spot, the points of the background.

In the middle row in Fig. 9 shows the results of tests with intensity thresholds from 180 to 220. As can be seen from the figure, the position of the centroid practically does not change at different thresholds. Here, the thresholds are optimal – all spot points are captured and, basically, background points are cut off. The background points still remain on the image fragment, but their influence on the position of the centroid is small due to the lower intensity compared to the central points of the spot.

In the bottom row in Fig. 9 shows the results of tests with intensity thresholds from 220 to 253. Here, the accuracy of determining the centroid coordinates is within one pixel. The spread of coordinates is explained by the fact that the intensities of the extreme points of the spot are not taken into account. In addition, the shape of the spot at high thresholds is distorted due to the random spread of intensities over the center of the spot.

Thus, the tests performed allow us to evaluate the accuracy that is achieved at the 1st and 2nd stages of image processing.

At the 1st stage, the position of the center of mass changes within one pixel (see Fig. 8) - when the lower intensity threshold is selected from 246 to 254. An error of one pixel corresponds to an error of 1.4mm at a resolution of 1280 * 720 and a screen size of 1670 * 940 .

At the second stage, the position of the center of gravity remains stable at the intensity threshold from 180 to 220. Therefore, the algorithmic component of the error does not affect the shooting accuracy, since the spread of the actual values of the centroid coordinates is much less than the pixel size. Ultimately, the task is not to find the values of the centroid coordinates in real numbers (x, y), but to find the corresponding indices of the (i, j) central pixel of the spot, which are determined through the operation of mathematical rounding: $i = Round(x / w), j = Round(y / w)$, where w is the pixel size.

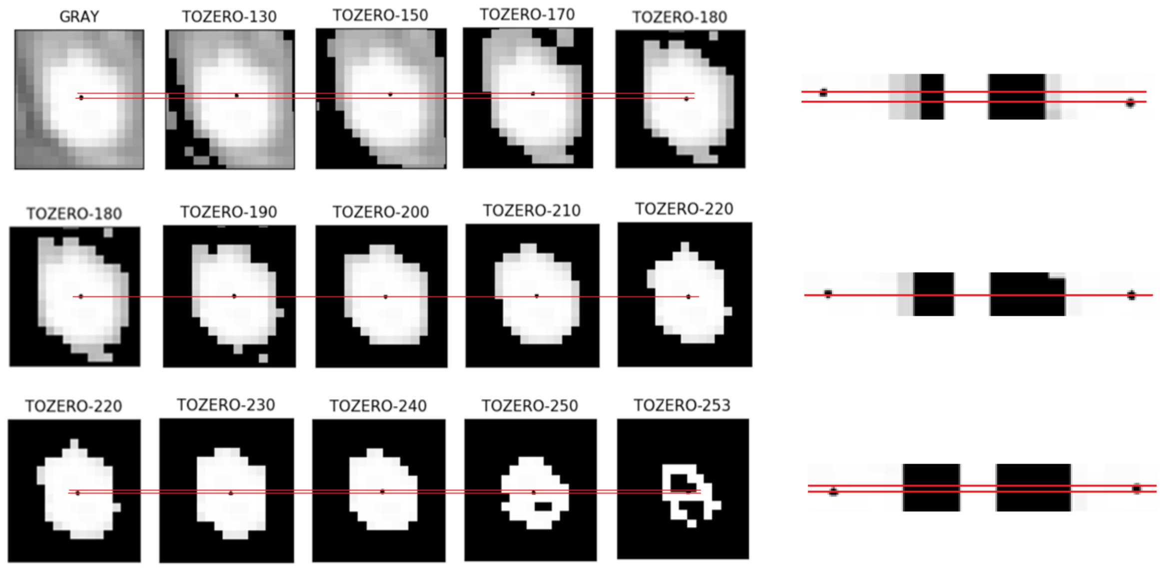


Figure 9: Influence of the value of the lower binarization threshold (2nd stage of processing) on the size, shape and position of the center of gravity of the image fragment

Therefore, taking into account the possibility of choosing a wide range of thresholds for both the first and second stages of image processing, as well as the fact that the tests were carried out for an image with a complex background texture, we can conclude that the accuracy of centroid determination by the proposed algorithm is quite high and does not depend significantly way from external factors (background textures, lighting, etc.) [16-20].

6. Discussion and conclusions

The evaluation of the hardware and algorithmic components of the error in recognition of the centroid of the spot from the laser emitter of the small arms simulator is carried out.

Research has been carried out on image processing methods related to the problem of spot recognition and determination of their characteristics.

An algorithm for determining the spot centroid through two-stage image binarization has been developed and tested, and optimal binarization thresholds for solving the problem have been determined.

The accuracy of the algorithm is sufficient - within the limits of the hardware component of the error. The speed of the algorithm is high due to its simplicity.

In further work, it is planned to refine the algorithm, providing the possibility of an adaptive choice of thresholds for binarization, as well as determining the contours of the spot using gradient methods.

7. References

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