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RESEARCH OF THE METHODS EFFICIENCY FOR DETERMINING THE DISTANCE AND GEOMETRIC OBJECTS PARAMETERS OF TECHNICAL VISION SYSTEMS

Abstract. Study subject. The article discusses methods for determining the distance to objects and their geometric parameters using the vision systems. **The goal** is a comparative analysis of the quality indicators of the most used methods for determining the distance and geometric parameters of the object. The following **task** is to analyze and experimentally study the quality indicators of methods for determining the distance and geometric parameters of the object; to assess the efficiency of monocular and stereoscopic systems in laboratory conditions. Used methods: statistical modeling, laboratory field tests. The obtained **results**: a comparative analysis of the efficiency of the known methods for determining the distance and geometric parameters of the object. The quality indicators estimates of the studied methods for determining the distance and geometric parameters are obtained. **Conclusions**: the algorithms for the implementation of the investigated methods for determining the distance and geometric object parameters, used in stereoscopic and monocular vision systems, have been implemented; experimental results have been obtained that allow a comparative analysis of their effectiveness. The software products modeling the considered methods, operating in real time in the Python environment, are obtained.

Keywords*:* stereoscopic vision systems; determining the distance; determining the geometric parameters, monocular vision systems.

Introduction

Now days the robotics field associated with the autonomous mobile robots development has acquired great relevance. The use of this robots type has found its application in the civil and military fields: for reconnaissance of the territory and premises that have been destroyed; in natural disaster zones where a man cannot enter; in areas with a high level of danger to humans [1-4].

To use such robots, they must have a number of functions that allow them to move autonomously, analyzing the environment. One of these functions is the ability of the robot to recognize an obstacle and get a route around the obstacle. For this, the robot must directly determine the distance to the obstacle and its geometric parameters, which is an urgent scientific and technical task of a mobile robot navigation [5].

The article discusses and analyzes three basic methods aimed for solving this problem. The first investigated method is based on the use of the minimum composition of the technical vision system, consisting of one video camera and the so-called "beacon", which is an object with known geometric parameters.

The second investigated method is a method based on the use of a computer vision system consisting of a video camera and a laser radiation source. The determination of distance and geometric parameters is carried out using the method of laser triangulation.

The third investigated method is the use of stereoscopic technical vision systems, which involves the use of two identical video cameras with a certain base between them.

Objective. To evaluate the effectiveness usage of methods for determining the distance and geometric parameters of an obstacle, to build optimal routes for moving mobile robots, based on a comparative analysis of the basic methods algorithms in laboratory conditions, by comparing the measurement results obtained via an optical channel with the results of measurements of real geometric parameters and distances to the object – the obstacles.

Determination of distance and geometric parameters using the "beacon"

Determination of the distance and geometric parameters of the obstacle in this method is based on the use of only one video camera and a "beacon" with known parameters, located in the area of interest. To determine the parameters of the object, the video camera, located of the interest area. After that, the video stream goes through the numbers of processing [5]:

- identification of a "beacon" in the area of interest (using color detection);
- determining the "beacon" contours;
- determining the "beacon" size in the image;
- determining the object of interest;
- determining the object contours;
- determining the object size in the image;
- calculation of distance and geometric parameters of the object.

After determining the object contours of interest, its dimensions in the image in pixels are determined. Next, the distance to the object and its geometrical parameters are calculated.

For example, the "beacon" dimensions are known, it is a square with a side of 7sm which is installed at a distance 2,3 m. The distance to the object of interest is calculated using the following relationship:

$$d = f \cdot h_r \cdot h_i / \left(h_o \cdot h_s \right), \qquad (1)$$

where d is the design distance, mm; f is the focal length of the video camera obtained as a result of calibration, mm; h_r is the real beacon width, mm; h_i is the image height in pixels; h_o is the beacon width in pixels, h_s is the height of the video camera matrix, mm.

The geometric object parameters are calculated using the following expression:

$$w_r = d \cdot w_o \cdot h_s / (w_t \cdot f), \qquad (2)$$

where w_r is the estimated real width of the desired object; d is the calculated distance, mm; f is the focal length of the video camera obtained as a result of calibration, mm; h_i is the image height in pixels; w_o is the width of the searched object in pixels; h_s is the height of the video camera matrix, mm [4, 12].

Using these dependences, an algorithm for calculating the distance and geometric parameters using a monocular vision system was proposed and implemented. The algorithm is implemented using the Python tools [7-9] and related libraries OpenCV [10, 11] and shown in Fig. 1. Fig. 2 shows the main window of the program for the algorithm implementation of the determining the distance and geometric parameters using a monocular vision system. The results obtained by the searching of this method for determining the distance and geometric object parameters are presented in the Table 1.

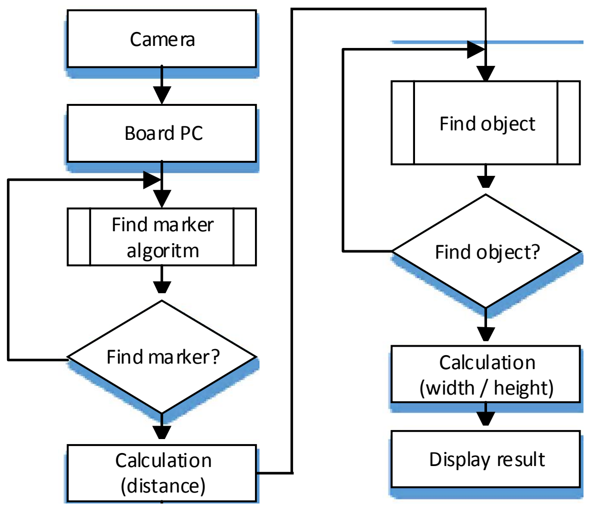


Fig. 1. Algorithm for determining the distance and geometric parameters using a monocular vision system

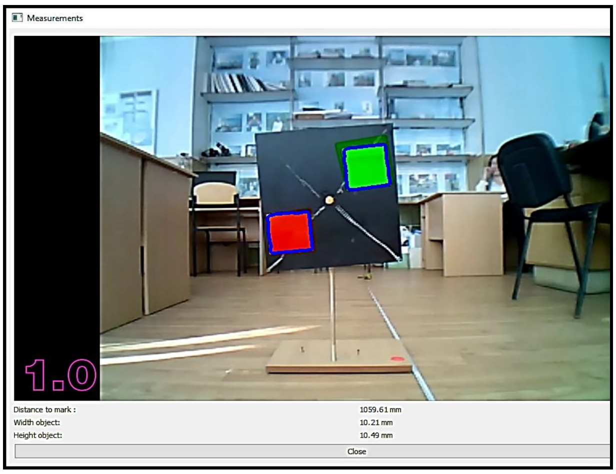


Fig. 2. The main window of the program for the implementation of the method using a monocular vision system

Table 1 – **Measurements results using a monocular vision system**

Real distance, mm	Received distance, mm	Actual dimensions (h / w), cm	Received dimensions (h / w), cm
500	509.12	10/10	10.29 \ 10.05
1000	1059.61	10/10	10.21 \ 10.49
1500	1615.29	10/10	11.28 \ 10.85
2000	2192.67	10/10	11.55 \ 11.39
2500	2783.85	10/10	12.43 \ 12.65
3000	3379.74	10/10	13.87 \ 13.85

The results obtained during the experiment showed that the accuracy of the determination depends on the distance. The average error was 8.51% for determining the distance and 16.05% for determining the geometric parameters. The dependence of the error on the distance can be seen in the graph below (Fig. 3).

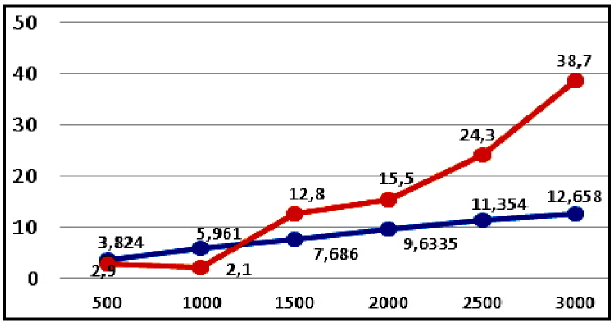


Fig. 3. Error change graph

Determination of distance and geometric parameters using a lidar-type system

The method is based on a computer vision system that works in the manner of a laser rangefinder. This system includes a direct source of laser radiation and a video camera that records this scene. The received data is processed by the calculator. Distance determination is based on the use of laser triangulation. In this method, the laser point is a pointer to the object to which the distance is measured [2].

The reflection is recorded by a webcam, which is installed at some distance from the laser, thereby forming a triangle between the object, the camera and the laser. The reflection of the laser point entering the camera forms an angle between the direction of the laser and the reflection of the point on the camera, which allows you to determine the distance to the object (Fig. 4).

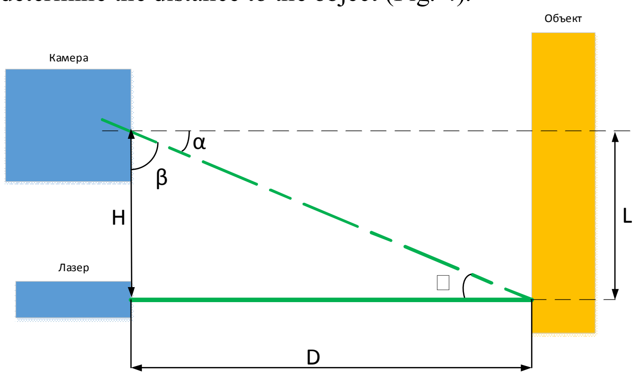


Fig. 4. Laser triangulation

The distance to the object is determined as follows:

$$D = H/\tan\theta\,, \tag{3}$$

where D is the distance to the object, H is the distance between the webcam and the laser, $\tan\theta$ is the angle between the laser beam and the laser point.

The angle between the laser beam and the returned laser point can be found using the expression:

$$\theta = P + R + R_o\,, \tag{4}$$

where P is the number of pixels from the center of the focal plane; R is radians per pixel pitch; Ro is the radius offset.

This method allows you to measure the distance to moving objects in real time. The implementation results are presented in Table 2.

Table 2 – **Results of measurements using laser triangulation**

Real distance, mm	Received distance, mm	Error, %
500	490	2
1000	998	0.2
1500	1500	0
2000	1970	1.5
2500	2450	2
3000	2920	2.6

The obtained results analysis of determining the distance showed that the maximum error is 2.6%.

To determine the geometric object parameters we use the scheme shown in Fig. 5.

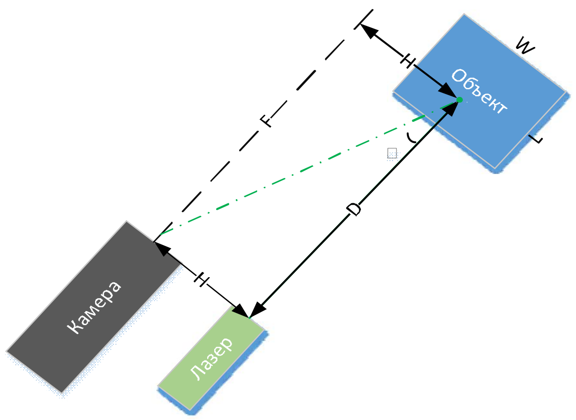


Fig. 5. Installation diagram for determining the object size

The essence of the method is to consider a rectangle formed by a laser beam and the focal plane line, as shown in Fig. 5, where: *D* is the laser beam, *F* is the frame center line.

Given that we know the distance between the camera and the laser and is 10.4 cm, for example, then the distance from the frame center to the laser mark is the same, it remains to find the distance from the frame center to the mark in pixels, and calculate the pixel size in the formed plane using expression:

$$K = 10{,}4/D_{center}\,, \tag{5}$$

where: D_{center} is the distance from the frame center to the mark in pixels.

Further, taking into account the equation result (5), we find the object width.

$$W = K \cdot W_{px}\,, \tag{6}$$

where W_{px} is the object width in pixels.

The object height is the same as the width.

$$L = K \cdot L_{px}\,, \tag{7}$$

where L_{px} is the object height in pixels

The general procedure algorithm implementing the proposed method is shown in Fig. 6.

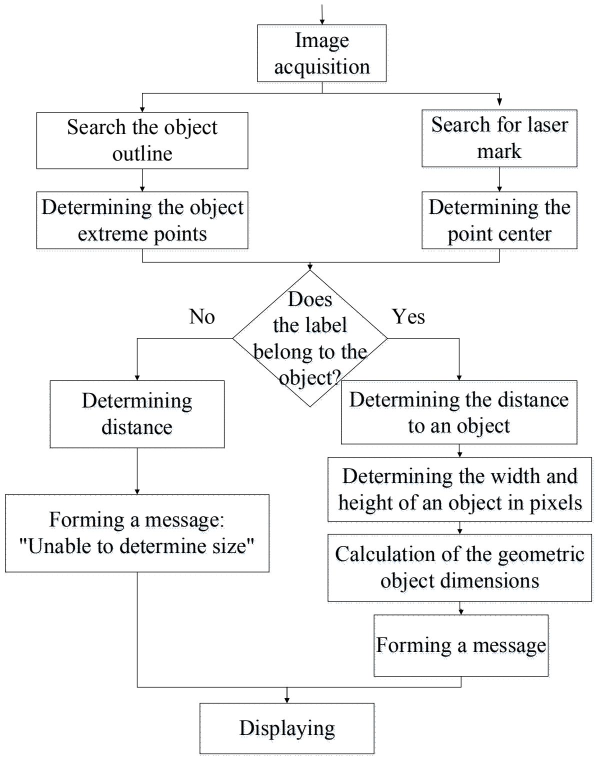


Fig. 6. Determination of distance and geometric parameters using a lidar-type system

Using the algorithm shown in Fig. 6, the geometric object dimensions are determined only if the label points to it. Otherwise, the distance is simply determined, since it can merge with the environment. The developed interface that implements the algorithm of this method clearly shows the method results. The main interface window is shown in Fig. 7. The results of determining the geometric object dimensions are presented in Table 3.

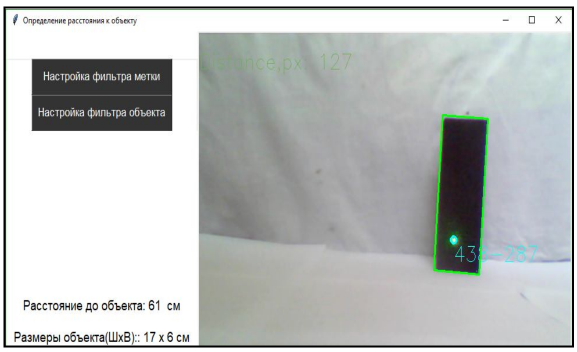


Fig. 7. Main interface window of determination the distance and geometric parameters using the "lidar" type system

Table 3 – **The results of determining the geometric dimensions**

Real dimensions (h / w), mm	Received dimensions (h / w), mm	Error, %
180/63	170/60	5.5
108/74	100/70	7.4
163/82	150/80	7.9
165/223	150/210	9.09

As can see in Table 3, the error in determining the object size can be up to 9.09%, the result is rather ambiguous, however, the sizing accuracy depends on many factors, such as the input image quality, as well as the accuracy of object determination in the image. The resulting error does not relate to the object size calculation, but directly to the object definition.

Determination of distance and geometric parameters using a system of the "stereo pair" type

One of the effective ways to measure the distance to an object and its geometric parameters is the use of stereoscopic vision systems. The method involves the use of two identical cameras with a certain distance between them, which is called the base. In the case of two identical cameras with parallel optical axes, the distance to the point is defined as

$$r_t = f \cdot d / \left(x_1 - x_2 \right), \quad (8)$$

where f is the focal length; d is the distance between cameras; $x1$ and $x2$ are projections coordinates on the left and right images [3].

For a more convenient practical application of (1), we represent it in the form

$$r_H = dH / \left(tg(\alpha) \cdot (x_1 - x_2) \right), \quad (9)$$

where d is the base (distance between cameras); H is the horizontal image resolution; α is the video camera's angle of view; x_1 and x_2 are coordinates of the point to which the distance is determined, in the coordinate system of the first and second video cameras, respectively.

For the possibility of using formula (9), it is assumed that the images received from the cameras are rectified. That means that the video cameras are located so that in their coordinate systems the coordinates of the point to which it is required to determine the distance, $y1$ and $y2$ are equal. This means that the horizontal lines in the images are in the same plane. The difficulties in using this method is the difficulty of correctly installing the two cameras: the cameras axes must be parallel to each other, and perpendicular to the line connecting the cameras centers. Due to improper cameras installation, a significant measurement in accuracy can result (the difference of one degree can lead to an error of more than two times). To use this method, an algorithm was developed (Fig. 8).

In fig. 9 shows the screen of the developed software for vision systems with the implemented algorithm for determining the distance and dimensions of the object described above.

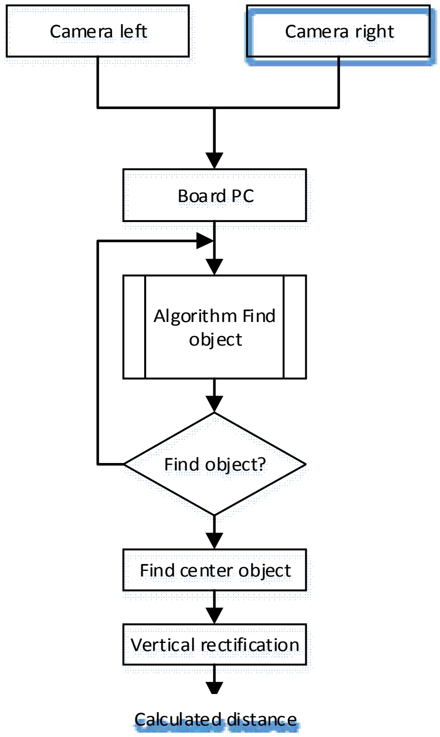


Fig. 8. Algorithm for determining the distance and geometric parameters using a stereo pair

Experiments using this method were carried out on a laboratory bench. This bench is a setup where two identical video cameras are fixed strictly parallel. With the ability to adjust the distance between cameras, the so-called base. During the experiment, measurements were carried out at distances from 0.5 m to 3 m, with a step of 50 cm. The results obtained during the experiment are presented in Table 4.

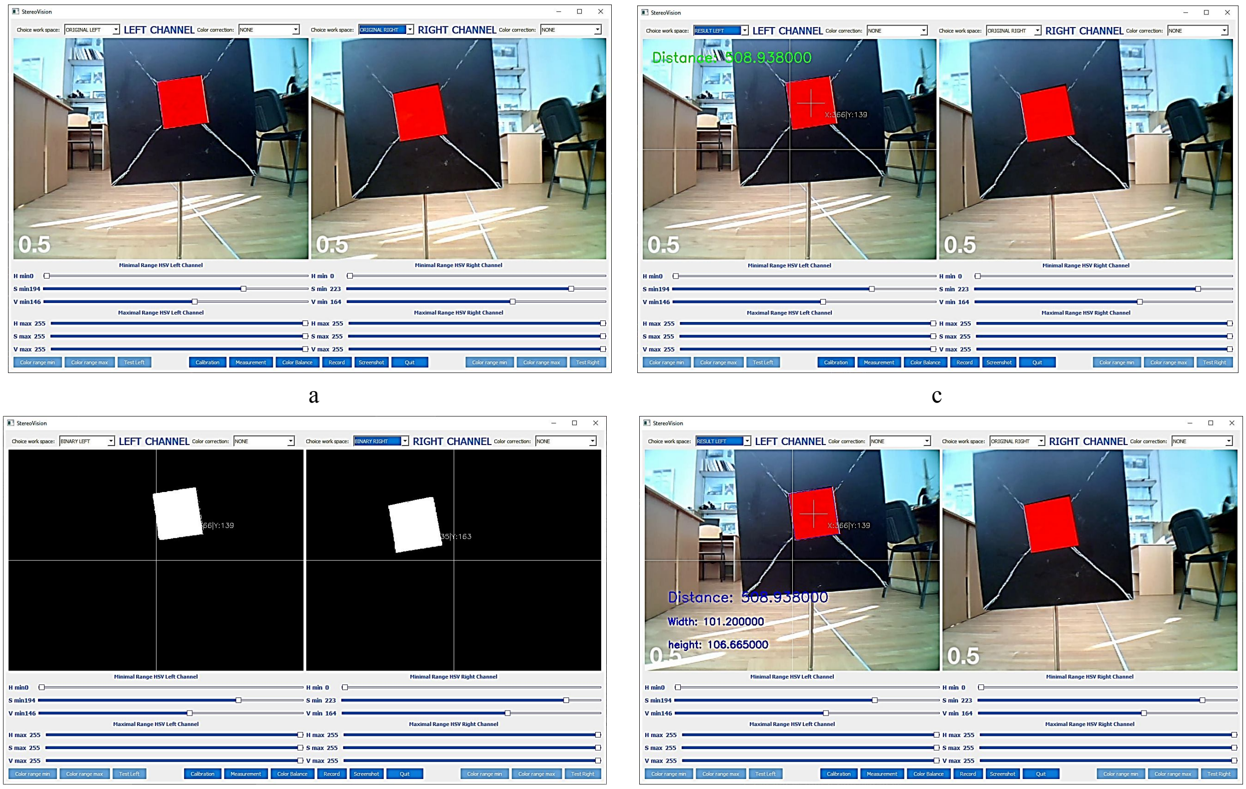
Table 4 – **Obtained experimental results for determining the distance and geometric parameters using the "stereo pair" system**

Real distance, mm	Received distance, mm	Actual size W / H, mm	Received size W / H, mm
500	508	10/10	10.12 / 10.66
1000	1041	10/10	9.34 / 9.57
1500	1563	10/10	9.14 / 9.21
2000	2171	10/10	8.87 / 8.98
2500	2723	10/10	8.31 / 8.12
3000	3298	10/10	8.04 / 7.83

As shown by the experiment results, provided in the Table 4. This system allows you to determine the distance and geometric parameters of the object with a maximum error of 9.93% to determine the distance. In addition, the average error for determining the geometric object parameters was 11.08%.

Conclusions

The performed research of methods for determining the distance and geometric object parameters, and the results analysis obtained made it possible to evaluate the effectiveness of these methods and identify their disadvantages and advantages.



a c

b d

Fig. 9. Software screen for vision systems:
a is the program main window; b is the binary image of the selected object; c is the window for determining the distance to the object; d is the window for determining the distance and geometric parameters of the object

Obtaining data when implementing the method using the "Beacon" was with the largest error at the maximum distance. One of the reasons for this is not the accuracy of determining the object in the video image, but since in this method it is necessary to determine the contours of two objects, the accuracy of the determination doubly affects the final result. Also, the most significant drawback is the fact that calculations can be carried out only for objects located in the same plane.

A lidar-type technical vision system showed a good result, the error in determining the distance was 2.6%. This method is the most accurate among the methods considered. In turn, the error in determining the geometric parameters did not exceed 9.09% at the peak distance. The main disadvantage of this method is the presence of a laser radiation source, which in turn can greatly distort the data when used on reflective surfaces. In addition, the parameters are calculated directly on the laser mark, i.e. in order to determine the distance and parameters of an object, it is necessary that the mark is located on this object. The method for determining the distance and geometric parameters using a stereo pair made it possible to determine the distances to the object with an error not exceeding 9.93% and to determine the geometric object parameters with an average error of 11.08%. This approach has the greatest potential among those considered. Its disadvantage is the design complexity, namely, the cameras installation so that their axes are parallel. Even a deviation of 0.1° may distort the final result.

In this work, the effectiveness of using these methods was experimentally analyzed using the developed software product in Python using the resources of the OpenCV library. The proposed algorithms make it possible to implement the work of the considered methods in real time.

The measurement accuracy is significantly influenced by such factors: the quality of the video stream, illumination and transparency of the environment (nebula or smoke, etc.).

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Дослідження ефективності методів визначення відстані і геометричних параметрів об'єкта систем технічного зору

В. І. Барсов, О. Ю. Костерна, О. В. Плахотний

Анотація. Предмет вивчення. У статті розглядаються методи визначення відстані до об'єктів та їх геометричних параметрів з використанням систем технічного зору. Метою є порівняльний аналіз показників якості найбільш використовуваних методів визначення відстані та геометричних параметрів об'єкта. **Задачі**: провести аналіз і експериментальні дослідження показників якості методів визначення відстані та геометричних параметрів об'єкта; оцінити ефективність роботи монокулярних і стереоскопічних систем в лабораторних умовах. Використовувані **методи**: статистичне моделювання, лабораторні натурні випробування. Отримані **результати**: проведено порівняльний аналіз ефективності роботи відомих методів визначення відстані і геометричних параметрів об'єкта. Отримано оцінки показників якості досліджуваних методів визначення відстані та геометричних параметрів. **Висновки**. Реалізовано алгоритми виконання досліджуваних методів визначення відстані та геометричних параметрів об'єкта, які використовуються в стереоскопічних і монокулярних системах технічного зору, отримані експериментальні результати, що дозволяють провести порівняльний аналіз їх ефективності. Отримано моделюючі розглянуті методи програмні продукти, що працюють в реальному часі в середовищі Python.

Ключові слова: стереоскопічні системи технічного зору; визначення відстані; визначення геометричних параметрів; бінокулярні системи технічного зору.

Исследование эффективности методов определения расстояния и геометрических параметров объекта систем технического зрения

В. И. Барсов, Е. Ю. Костерная, А. В. Плахотный

Аннотация. Предмет изучения. В статье рассматриваются методы определения расстояния до объектов и их геометрических параметров с использованием систем технического зрения. **Целью** является сравнительный анализ показателей качества наиболее используемых методов определения расстояния и геометрических параметров объекта. **Задачи**: провести анализ и экспериментальные исследования показателей качества методов определения расстояния и геометрических параметров объекта; оценить эффективность работы монокулярных и стереоскопических систем в лабораторных условиях. Используемые **методы**: статистическое моделирование, лабораторные натурные испытания. Полученные **результаты**: проведен сравнительный анализ эффективности работы известных методов определения расстояния и геометрических параметров объекта. Получены оценки показателей качества исследуемых методов определения расстояния и геометрических параметров. **Выводы**. Реализованы алгоритмы выполнения исследуемых методов определения расстояния и геометрических параметров объекта, используемых в стереоскопических и монокулярных системах технического зрения, получены экспериментальные результаты, позволяющие провести сравнительный анализ их эффективности. Получены моделирующие рассматриваемые методы программные продукты, работающие в реальном времени в среде Python.

Ключевые слова*:* стереоскопические системы технического зрения; определения расстояния; определение геометрических параметров; монокулярные системы технического зрения.