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RESEARCH OF THE METHOD OF INCREASING THE OBJECT DETERMINATION ACCURACY ON THE LOW-RESOLUTION VIDEO STREAM

Abstract. Study subject. The article proposes and investigates a method for increasing the accuracy of determination of the distance and the obstacle geometric parameters based on object contours determination using a computer vision system that uses low-resolution sensors. **The goal** is the effectiveness evaluation of the proposed method. **Tasks:** to conduct experimental researches of the quality indicators of the method of increasing the object contours determination accuracy; evaluate the effectiveness of this method. **Used methods:** statistical modeling, laboratory scale tests. **The obtained results**: the analysis of the proposed method efficiency was carried out and the influence of this method on the determination accuracy of the distance and object geometric parameters was evaluated. **Conclusions**: the considered method made it possible to achieve the increasing the determination accuracy of the distance and geometric object parameters by compensating for image blur using the Lucy-Richardson deconvolution algorithm. The obtained data showed a decrease in the maximum error in determining the distance from 8% to 4% and the error in the geometric object parameters from 7.7% to 5.8%. The implementation of this approach was carried out in the Python programming language.

Keywords*:* stereoscopic vision systems; distance determination; geometric parameters determination; monocular vision systems.

Introduction

There are several ways to obtain initial information about the behavior and state of the study objects in modern video monitoring and automated control systems: a multi-sensor approach (stereovision), building an image perspective, the use of fixed cameras and additional object illumination, etc. Each of the presented techniques may well be used in practice, depending on the problem [1, 2].

For the considered problem of the necessary parameters determination, namely the distance to the object and the geometric object parameters, it is necessary to determine the object contours in the image. The accuracy of the object contours determination is directly proportional effect on the determination accuracy of the distance and geometrical object parameters. In turn, the accuracy of contours determining decreases with the distance increasing between the sensor and the object, as the distance increases lost focus sensor and the image becomes blurred, which makes the exact determination circuit [3, 4].

Objective. Effectiveness evaluation of the method for increasing the determination accuracy of the distance and geometric obstacle parameters by using the Lucy-Richardson deconvolution algorithm that can avoid accuracy loss with increasing distance between the sensor and the object.

Image blur level determination

The approach is based on the level determination of the image blur. Since this parameter indicates data loss, namely the loss of accuracy in the object contours determination that causes an error in calculation the distance and geometric obstacle parameters [5-7].

The Laplace kernel is used to determine the level of the image blur, which is represented by the following matrix:

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}.$$

This approach is used to determine the image boundaries and is a discrete analogue of the Laplace filter.

Since the image is in "2D" format, and for this it is necessary to take the derivative in both dimensions and for this the Laplace operator will be used:

$$Laplace(f) = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}.$$

Laplacian extracts image areas that contain fast intensity changes, much like the Sobel and Scharr operators. Like these operators, Laplacian is often used for edge detection. It is assumed that if the image contains a large dispersion, then there is a wide variation of responses as the boundary, and not extreme, representing a normal-focus image. But if there is a very low dispersion, then there will be a small variation of responses, indicating that the image has very small margin. As you know, the more blurry the image, the less margins [8, 9].

To implement this method it is necessary to take the image channel presumably shades of gray and produce convolution using the Laplace kernel presented above, and then obtain the response variance. The obtained dispersion will be used as an estimate of the image blur [10, 11].

In implementing this approach, it was used designed interface, which allowed to carry out measurements on a series of images to determine the level of blur images. In turn, the images were taken at different distances from the object, to obtain the blur level changes depending on the distance to the object changes. Below is a set of measurements from the six images taken at different distances, namely from 0.5 m to 3 m, with a step 0.5 m (Fig. 1).

a b c

Fig. 1 Set of images for determining the blur depending on the distance:
a – is the distance 0.5 and 1m; b – is the distance 1.5 and 2m; c – is the distance 2.5 and 3m

The Table 1 below shows the dispersion values obtained because of measurements. Below is a plot of the dispersion versus distance (Fig. 2).

Table 1 – **Dispersion level measurement results**

Distance	0.5	1	1.5	2	2.5	3
Dispersion	1064.46	1105.43	1082.98	81686	764.70	794.96

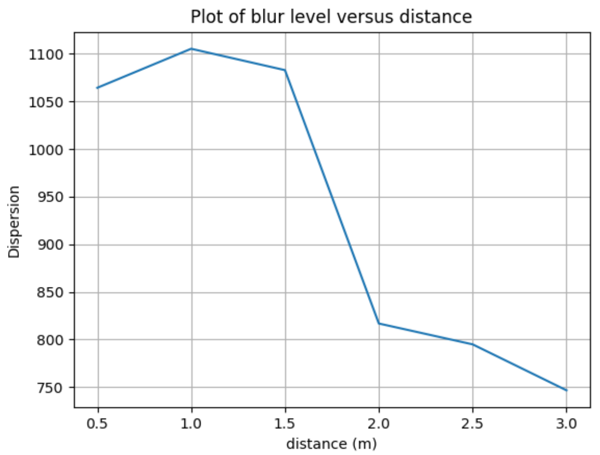


Fig. 2. Graph of dispersion versus distance to the object

As seen from the graph, the least blurry image obtained at a distance of 1m from the sensor. Therefore, this value will be the reference, i.e. all changes from this value will be subject to additional adjustment.

Image Blur Compensation Method

As mentioned above, image blurring changes in proportion to the distance from the sensor to the object. Especially this dependence is manifested on the sensors with low bandwidth. In turn, this affects the subsequent measurements of parameters such as the distance and the geometric object parameters, since the object contour in the image is blurred and becomes not exact.

It is proposed to use the Lucy-Richardson deconvolution algorithm to compensate for image blur.

When an image is created with the optical system and detected, e.g., with photographic film or a charge-coupled device (CCD), it inevitably is blurred, with the ideal point source does not appear as a point, but extends into the so-called point spread function. Extended sources can be decomposed into the sum of many individual point sources, so the observed image can be represented by a transition matrix p, acting on the underlying image:

$$d_i = \sum_j p_{i,j}\, u_j \,,$$

where $p_{i,j}$ is the intensity in a pixel of the underlying image and u_j is the detected intensity in a pixel.

In general, the matrix describes the part of the light from the original pixel j, which is detected in a pixel i. In most good optical systems (or, in general, linear systems that are described as being shear invariant), the transfer function p can be expressed simply by the spatial displacement between the original pixel j and the observation pixel i: $u_j j d_i i p_{i,j}$:

$$p_{i,j} = P(i - j)\,,$$

where $P(\Delta i)$ is called the point spread function.

In this case, the above equation becomes a convolution. It was written for one spatial dimension, but most imaging systems are two-dimensional, with the source, detected image and the point spread function having two indexes.

Thus, the detected two-dimensional image is a convolution of the underlying image with the two-dimensional point spread function $P(\Delta x, \Delta y)$ plus added detection noise.

In order to estimate, given the observable and known P $(\Delta ix, \Delta jy)$, we use the following iterative procedure, in which the estimate which we call for the iteration number t, is updated as follows: $u_j d_i u_j \hat{u}_j^{(t)}$

$$\hat{u}_j^{(t+1)} = \hat{u}_j^{(t)} \sum_i \frac{d_i}{c_i} p_{ij} ,$$

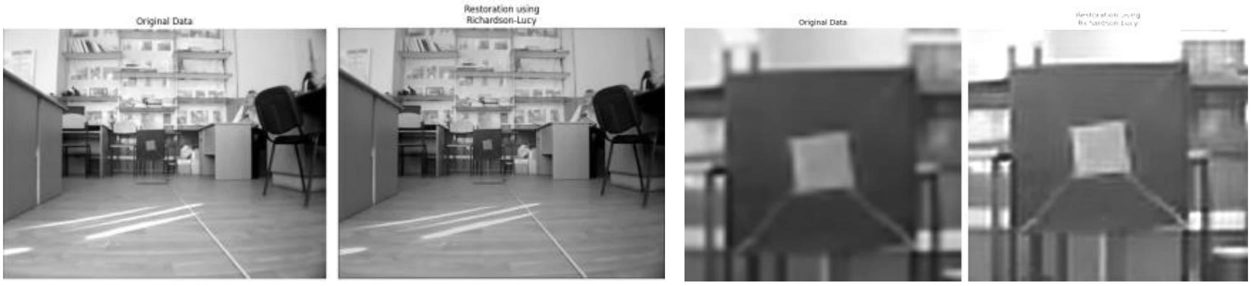
where $c_i = \sum_j p_{i,j}\, \hat{u}_j^{(t)}$.

Empirically, it has been shown that if this iteration converges, it converges to a maximum likelihood solution for u_j. Let us write this more generally for two (or more) dimensions in terms of convolution with the point spread function P:

$$\hat{u}_j^{(t+1)} = \hat{u}_j^{(t)} \left(\frac{d}{\hat{u}_j^{(t)} \otimes P} \otimes P*\right) .$$

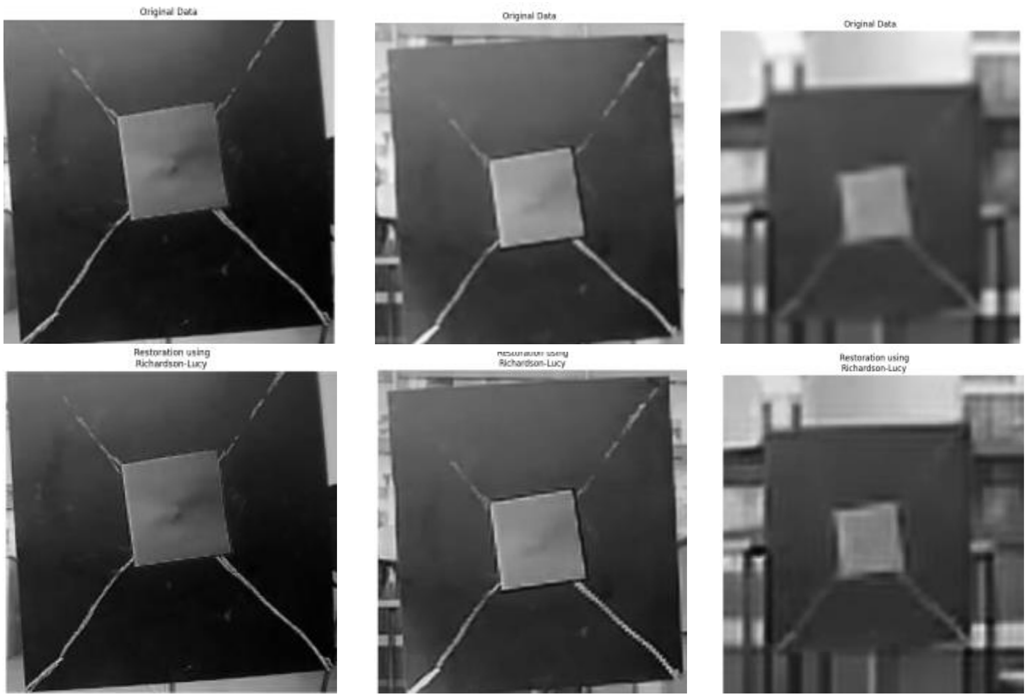
Based on this method, a number of measurements were carried out with measurements of the dispersion level before and after applying the method [12]. Below in Fig. 3 shows the results of using this algorithm for the studied image.

Below there are the results of using the algorithm for images at different distances, namely 0.5m to 3m in 0.5m steps. Fig. 4 shows the images numbers at different distances. After processing by the algorithm, the interest areas in the image were highlighted for clarity. As you can see from the object image the blur significantly decreased. Comparison of the algorithm results is presented in the Table. 2.



a b

Fig. 3. The result of the Lucy-Richardson algorithm for blur compensation:
a – is the original image, b – is the increased area of interest for clarity



a b c

Fig. 4. Images numbers of the algorithm application

Table 2 – **Comparison of indications dispersion (blur level) before and after the application of the Lucy-Richardson deconvolution algorithm**

Distance	Dispersion level without applying the algorithm	Dispersion level with applying the algorithm
0.5 m	1064.46	3671.48
1.0 m	1105.43	3221.33
1.5 m	1082.98	3600.89
2.0 m	816.86	2853.67
2.5 m	764.70	3254.07
3.0 m	794.96	2859.61

As can be seen from the results obtained and the plot shown in Fig. 5, the dispersion value of the processed images has increased several times. This means that the image clarity is significantly increased which positively affect the further determination of the object contours, of distance calculations and object geometrical parameters.

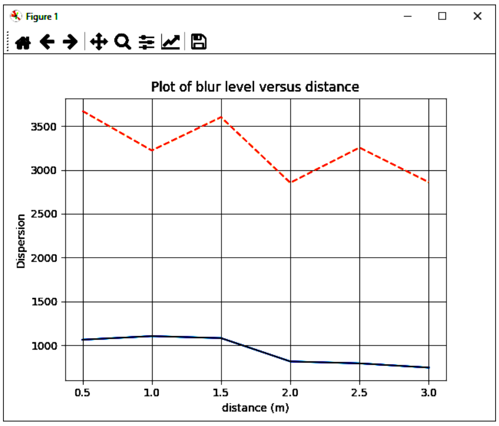


Fig. 5. A plot of the dependence of the blur level on the distance: the solid line represents data of the original image; stroke line represents the processed image

Study of the accuracy determining the distance to the object

To study the effect of this method on the accuracy determining the distance to the object, a number of measurements were carried out.

The first step of this study was to measure the distance without blur compensation in the image. As before, the study is carried out in the laboratory using a black square screen, on which is placed a red square label in size 10 cm [13, 14].

Below is a table and graph of experimental measurements and comparisons with the actual distances (tabl. 3). From the obtained results, it is evident that the peak error in determining the distance was more than 8% at a distance of 2.5 m.

The next stage of the study was to determine the distance of the images with blur compensation. Below in Fig. 7 shows the results of measurements carried out on the image with blur compensation. A complete list of measurements is shown in Table 4.

Using this approach achieved to increase the accuracy of measuring the distance to the object. Comparison of the results is shown in Table 5 and Fig. 8.

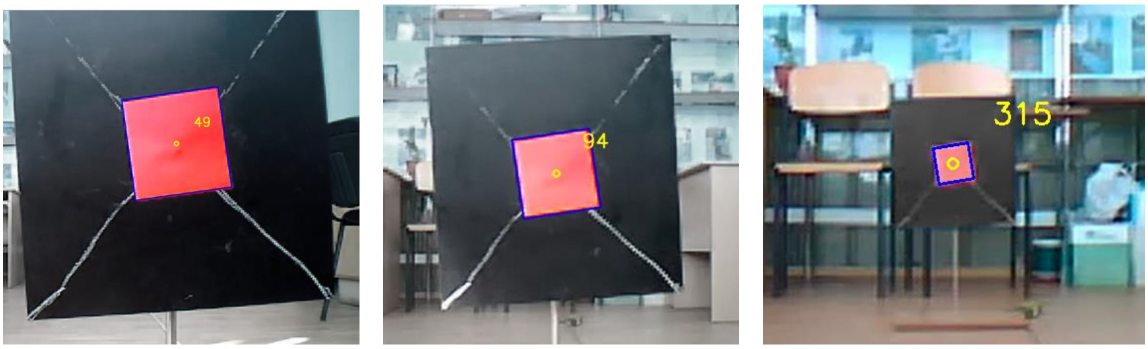


Fig. 6. Experimental measurements without blur compensation

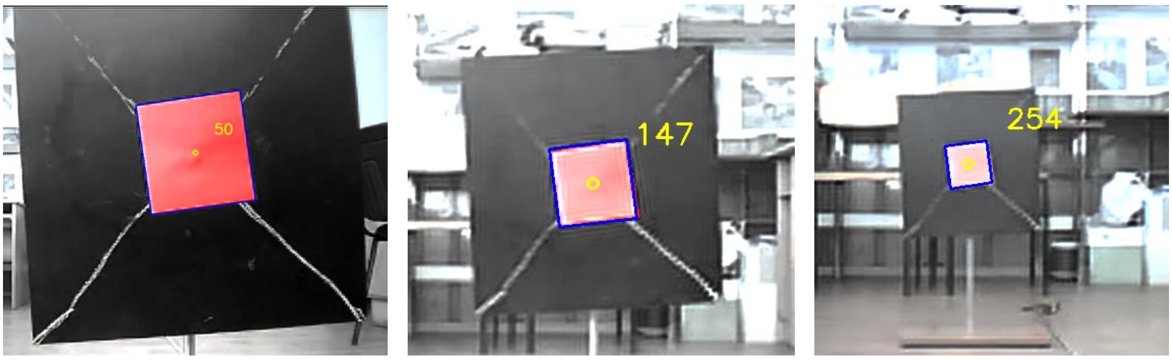


Fig. 7. The measurement results of compensated blurring images

Table 3 – **Distance measurement results without blur compensation**

Actual distance	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm
Measured distance	49 cm	94 cm	142 cm	210 cm	271 cm	315 cm
Error	2%	6%	5.4%	5%	8%	5%

Table 4 – **Measurement results of the distance to compensate blurring**

Actual distance	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm
Measured distance	50 cm	96 cm	147 cm	201 cm	254 cm	305 cm
Error	0%	4%	2%	0.5%	1.6%	1.6%

Table 5 – **Comparison of the results of measuring the distance to the object**

Actual distance	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm
Measured distance (without compensation)	49 cm	94 cm	142 cm	210 cm	271 cm	315 cm
Measured distance (with compensation)	50 cm	96 cm	147 cm	201 cm	254 cm	305 cm

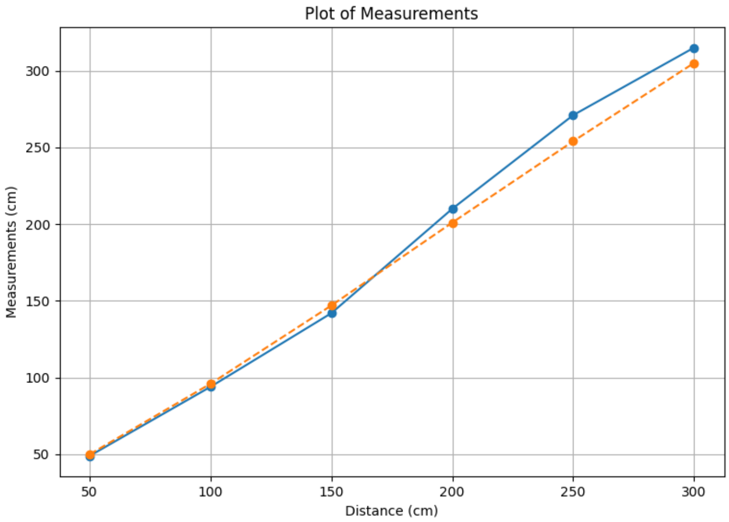


Fig. 8. Graph of comparing the measurement results (the solid line represents a graph of measurements without blur compensation, and a dash line – with blur compensation)

As seen from the obtained results, the increase in accuracy made it possible to reduce the measurement error from a maximum error of 8% before blur compensation, to a maximum error of 4% after compensation.

However, there is a disadvantage of this method, which consists in the fact that for the application of this method it is necessary to use an image reduced to grayscale. To do this, the original image, which has three dimensions, need to be converted to grayscale, which in turn is one-dimensional.

However, the inverse transform to produce is not possible, because we do not know which of the channels belong to values for color restoring.

Thus, there is a problem with color detection, used to determine the object in the frame.

To solve this problem, we used various methods of overlay images, namely, the original image has been superimposed on the processed image in the «Color Dodge» mode.

In Color Dodge overlay mode the lower layer is divided into an inverted upper layer. This lightens the lower layer depending on the value of the upper layer: the brighter the upper layer, the stronger it affects the color of the lower layer. Mixing of any color with white gives white color, mixing with the black does not change the image. The operation is irreversible due to possible reflections clipping (clipping occurs in the same range as for Linear Dodge.). When the upper layer comprises a uniform color, this effect is equivalent to change the white point on the inverted color. The perceived contrast increases when there is no cut-off.

Thus, it was possible to return the color to the image and not lose sharpness after processing by the method deconvolution Lucy-Richardson. However, the original color of the image has been lost, so the functions to change the brightness and contrast were also used.

Study of the accuracy of determining the geometric object parameters

The next step in analyzing the effectiveness of this approach is to measure the geometric object parameters. The study was carried out by analogy with measuring the distance to the object.

First, the measurements were made of the object sizes at no handles images, i.e. without blur compensation. The obtained measurement parameters are presented below in Table 6 and in Fig. 9.

As seen from the obtained results, the peak error in determining the geometric parameters is 7.7%.

In the next step the measurements of geometric object parameters on images with blur compensation. The results are shown below in Fig. 10 and Table 7.

Fig. 9. Measuring of the geometric object parameters on the image without blur compensation

Table 6 – **The results of measuring the geometric object parameters in the image without blur compensation**

Distance	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm
Measured distance	10.0 × 10.43	10.6 × 10.94	10.17 × 10.73	9.5 × 9.94	9.2 × 10.46	9.51 × 9.82
Error	2.15%	7.7%	4.5%	0.5%	1.6%	3.35%

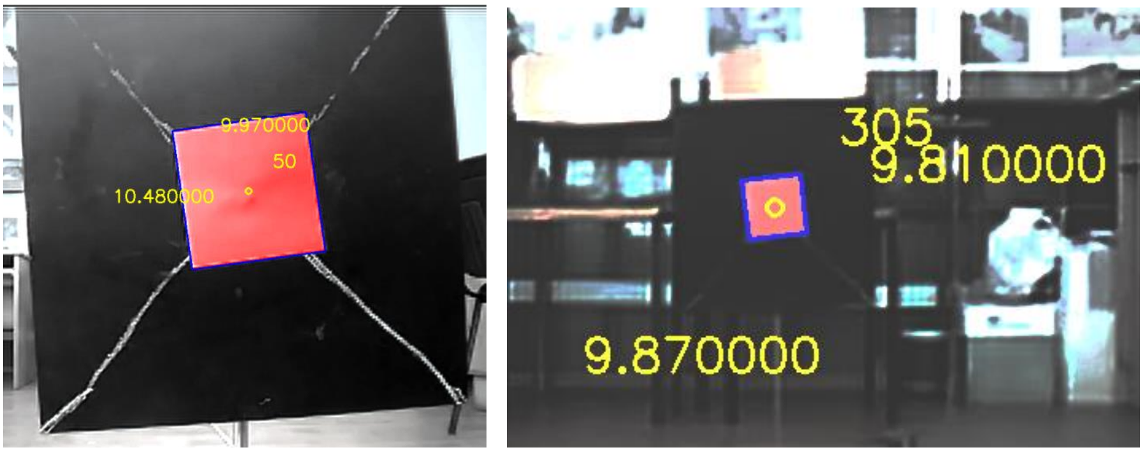


Fig. 10. Measuring the geometric object parameters on the image with blur compensation

Table 7 – **Measuring of the geometric object parameters on images with blur compensation**

Distance	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm
Measured distance	9.97 × 10.48	10.34 × 10.82	10.19 × 10.83	9.93 × 10.3	9.84 × 10.37	9.81 × 9.87
Error	2.55%	5.8%	5.1%	0.5%	2.65%	1.6%

As can be seen from the obtained results, it shows that the peak error has been reduced to 5.8%. However, in some cases, the error increased, what could affect intermediate image is converted to grayscale and restore images that distort the brightness and contrast, and affect the accuracy of determining the geometric object parameters.

Conclusion

Studies using the deconvolution Lucy-Richardson algorithm to compensate for image blur, provided data that allow a comparative analysis of the parameters for measuring the distance to the object and the geometric object parameters.

The use of the Lucy-Richardson deconvolution algorithm made it possible to halve the peak error in determining the distance from 8% to 4%, and the average error rate was 1.6%. The conducted experiment of measuring the geometric objects parameters to reduce the peak bit error from 7.7% to 5.8%, and the average error was 3.03%.

To record the experimental data through a camera with a resolution of 640x420 pixel for the demonstration this approach most clearly.

In addition, this approach can be used on cameras with higher resolution, such as aerial photographs, which will increase the accuracy of determining the objects size and the height calculation.

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Дослідження методу підвищення точності визначення об'єкта на відеопотоці низької роздільної здатності

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

Анотація. Предмет вивчення. У статті пропонується і досліджується метод підвищення точності визначення відстані і геометричних параметрів перешкоди на основі визначення контурів об'єкта за допомогою системи технічного зору з використанням датчиків низькою роздільною здатністю. Метою є оцінка ефективності запропонованого методу. **Завдання:** провести експериментальні дослідження, показників якості методу підвищення точності визначення контурів об'єкта; оцінити ефективність роботи даного методу. **Використовувані методи:** статистичне моделювання, лабораторні натурні випробування. **Отримані результати:** проведено аналіз ефективності роботи запропонованого методу і оцінено вплив даного методу на точність визначення відстані і геометричних параметрів об'єкта. **Висновки:** Розглянутий метод дозволив отримати підвищення точності визначення відстані і геометричних параметрів об'єкта шляхом компенсації розмиття зображення, за допомогою алгоритму деконвуляції Люсі-Річардсона. Отримані дані показали зниження максимальної помилки визначення відстані з 8 до 4% і помилки геометричних параметрів об'єкта з 7,7 до 5,8%. Реалізація даного підходу виконувалася на мові програмування Python.

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

Исследование метода повышения точности определения объекта на видеопотоке низкого разрешения

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

Аннотация. Предмет изучения. В статье предлагается и исследуется метод повышения точности определения расстояния и геометрических параметров препятствия на основе определения контуров объекта с помощью системы технического зрения использующей датчики низкого разрешения. **Целью** является оценка эффективности предлагаемого метода. **Задачи**: провести экспериментальные исследования, показателей качества метода повышения точности определения контуров объекта; оценить эффективность работы данного метода. **Используемые методы**: статистическое моделирование, лабораторные натурные испытания. **Полученные результаты**: проведен анализ эффективности работы предлагаемого метода и оценено влияние данного метода на точность определения расстояния и геометрических параметров объекта. **Выводы**. Рассмотренный метод позволил добиться повышения точности определения расстояния и геометрических параметров объекта путем компенсации размытия изображения, с помощью алгоритма деконвуляции Люси-Ричардсона. Полученные данные показали снижение максимальной ошибки определения расстояния с 8 до 4% и ошибки геометрических параметров объекта с 7,7 до 5,8%. Реализация данного подхода выполнялась на языке программирования Python.

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