Adaptive control methods

UDC 004.7:681.5 doi: https://doi.org/10.20998/2522-9052.2025.3.06

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CAMERA CONTROL ALGORITHM AND IMAGE QUALITY ASSESSMENT METHOD TO OBTAIN A QUALITY IMAGE

Abstract. Since small-sized objects are expressed in the image with very few pixels and are located at a fairly large distance from the camera, their recognition by computer vision-supported systems becomes difficult. At this time, the issue of obtaining high-quality images of them becomes relevant. **The object study** is the camera and the images obtained from it. Existing methods have been studied and a new approach that can work faster to obtain high-quality images has been proposed. **The subject of the research is** a method for assessing the quality of the image and controlling the focus of the camera using existing tools in order to obtain a high-quality image. **The purpose of the research** is to create an algorithm for evaluating the image and controlling the camera device in order to obtain a high-quality image for a detection system supported by computer vision for small-sized objects. Improving the quality of the image with the proposed methods creates important conditions for the effective operation of recognition systems operating in real-time. **As a result of the research**, the method for assessing the image in terms of quality and the camera control algorithm for a high-quality image of the object is proposed. The rationale for the proposed main methods of research is given, the results of experimental studies of the proposed methods are presented, and the validity of the adopted theoretical conclusions is confirmed.

Keywords: pixel; Sobel filter; focusing; background; noise; frame; segmentation; object tracking.

Introduction

Obtaining a high-quality image is one of the main conditions for detection with computer vision of small objects located at a sufficiently large distance from the camera device. Because no matter how effectively the detection algorithms work, if the image given to its input is of poor quality, it is impossible to achieve the goal [1, 2].

In object detection systems, the quality of the image of a small object is characterized by the fact that the image appears blurry due to defocusing and the object is located far away, or more precisely, expressed with fewer pixels in the frame. Therefore, before entering the image into the input of the detection system, it is important to enlarge its image, assess its quality in terms of blurriness, and obtain a high-quality image by controlling the focus of the camera device [3].

We can use the camera's zoom capabilities to enlarge objects that appear very small in the image. The zoom used to enlarge the image is implemented in two forms: Optical and digital zoom. During digital zoom, the quality of the image of the object is significantly reduced. Therefore, it is considered advisable to use optical zoom. Optical zoom consists of a lens group consisting of two collecting lenses and 1 diverging lens. To enlarge or reduce the image of the object, it is necessary to move the lenses relative to each other (Fig. 1).

The light beam from the lens group enters the next lens group for focusing.

Since it is not possible to move the lenses in the above-mentioned way in modern smartphones, several cameras with different focal lengths are used. This is because there is a requirement for smartphones to be very small (thin) in size [4].

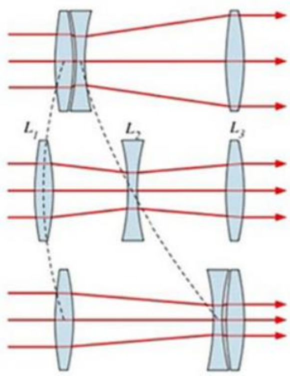

Fig 1. Optical lens group for zoom

Optical systems (photographic lenses) focus the energy (photons) coming from the object to create an image on the sensor. An optical lens is a single optically transparent device that is shaped to transmit and refract light [5] (Fig. 2).

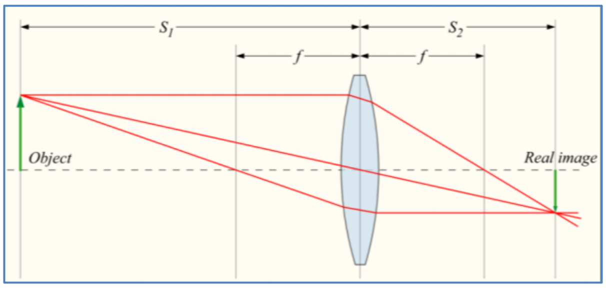

Fig 2. Image capture of an object by a converging lens

In Fig. 2 the following are indicated: f – focal length; S_1 – distance from the object to the camera (optical lens); S_2 – distance from the optical lens to the image,

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$$\frac{1}{f}=\frac{1}{S_1}+\frac{1}{S_2}. \quad (1)$$

As can be seen from Fig. 2, the *f*-focus length depends on the physical structure of the lens and is a constant quantity for a given lens. The variable parameters in formula (1) are S_1 and S_2. That is, the object can be located at different distances (S_1) from the camera device. This diversity leads to the fact that the object's image is taken at different distances (S_2) from the focal point. It is for this reason that when the sensor is located at a distance of S_2 from the lens, it is possible to obtain a quality image in terms of focusing.

Taking into account the above, it can be concluded that the presence of an autofocus system in the camera is one of the main conditions for obtaining a quality image.

In modern cameras, the autofocus process uses methods that differ from each other in various ways. These methods are as follows [6]:

1. Contrast detection. The principle of operation is based on the analysis of the contrast in the image by the camera. The lenses are adjusted until the contrast reaches a maximum, that is, the object is kept in the center of focus. With this method, it is possible to obtain accurate focusing, however, the processing speed is very low, especially in low light.

2. Phase detection. It uses special phase detection sensors or pixels on the camera sensor to calculate how far the image is out of focus and directly moves the lens to the correct position. Phase detection allows for fast and accurate focusing. In low light conditions, it is less efficient than contrast detection.

3. Depth-from-Defocus (DFD). Analyzes two slightly out of focus images and predicts the direction and amount of focus adjustment required. It is faster than contrast detection in terms of processing speed, but is not as good for moving objects.

4. Dual Pixel Autofocus (DPAF) (Used by Canon). Each pixel on the sensor is divided into two parts, allowing the sensor to directly measure the phase difference. It has very fast and smooth focusing, suitable for tracking moving objects. It can work in very low light conditions.

5. LiDAR Autofocus (Used in High-End Cameras & Phones). Uses a laser to adjust focus by measuring distance. It can focus on objects at close range and works well in low light conditions. It is very expensive economically.

6. AI-Based Autofocus. It uses machine learning to recognize faces, eyes, or specific objects to achieve focus. It is suitable for tracking subjects in complex images. It requires intensive processing and does not work well with objects (non-human).

Image quality can be measured by fully referenced image evaluation by comparing the blurred image with the re-blurred version created by applying a Gaussian filter. This is based on the observation that the blurred image changes less than the original image after the re-blurring process. Bong et al. [7] predicted the no-reference blur value (BIBS) of an image by applying a re-blurring process in which two special states are selected during the re-blurring process: the state where the re-blurred image starts to change its pixel values $\sigma = \sigma_{min}$) and the state where it never changes again ($\sigma = \sigma_{max}$). The image quality is then measured based on the difference in the shape of the local histogram between the image and its re-blurred versions [7].

Having observed that blur affects the moment energy, Li et al [8] presented a blind image blur evaluator (BIBLE) to assess image quality based on the variance normalized moment energy. The flowchart of BIBLE is shown in Fig. 3. The gradient image is divided into equal-sized blocks, and the Tchebichef moments of all blocks are computed. Then the block's energy is calculated by summing up the squared non-DC moments. Finally, image quality is measured by the variance normalized moment energy together with a visual saliency model to adapt to the HVS characteristics.

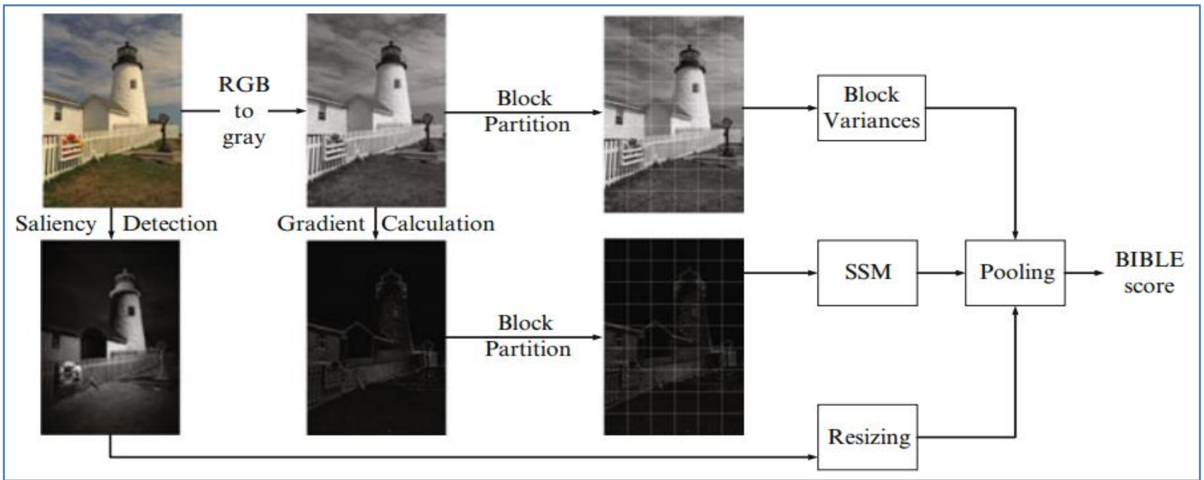


Fig. 3. The Flowchart of BIBE

It is assumed that natural scenes contain certain statistical properties that could be altered by the existence of distortions. Therefore, by modeling the statistical distributions of image coefficients, image quality can be estimated by deviations of these statistics. Wang et al. [9] proposed a blur-specific NR-IQA method BIBE based on the NSS of gradient distribution, where the flowchart of BIBE is shown in Fig. 4.

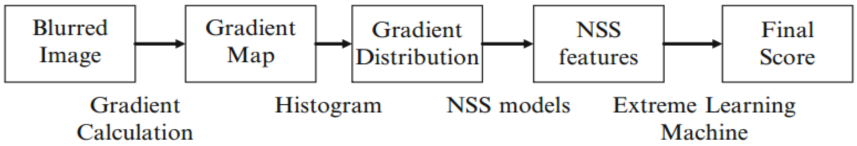


Fig. 4. The flowchart of BIBE

First, the blurred image is passed through the horizontal and vertical Prewitt filters to get the gradient map. Then, the gradient-related distributions represented by histograms are modeled using the generalized Gaussian distribution (GGD) or asymmetric GGD. Finally, the NSS features (parameters of the models) are fed into the extreme learning machine [10, 11] to predict image quality. Having observed that over-complete dictionaries learned from natural images can capture edge patterns, Li et al. [10] proposed a blur-specific NR-IQA method SPARISH based on the sparse representation.

Fig. 5 shows the flowchart of SPARISH. An over-complete dictionary is learnt to construct a sparse coding model for the image gradient blocks, then the variance-normalized block energy over high-variance image blocks is used as the quality score, where the block energy is obtained from the sparse coefficients.

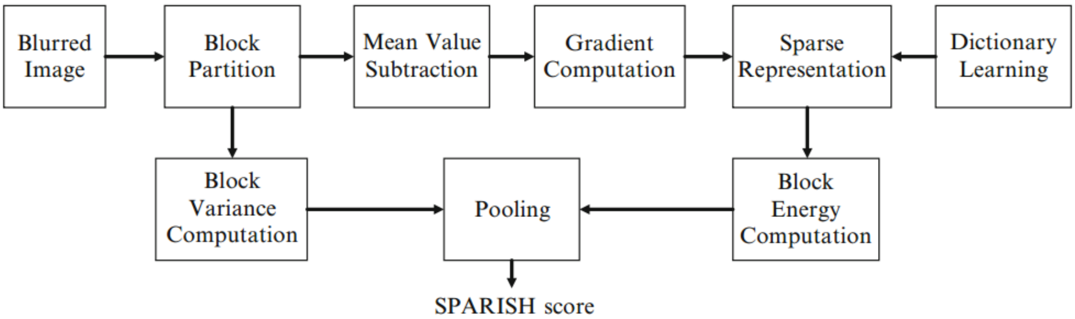


Fig. 5. The flowchart of SPANISH

To determine the effectiveness of the above methods, images taken from the TID2013 and BID datasets were used, and the results are as shown in Table 1 [6].

Table 1 – **Result of method**

Metod	TID2013	BID
	Vaxt (seconds)	Vaxt (seconds)
BİBS	0.184	3.333
BİBLE	0.916	10.982
BİBE	0.481	7.138
SPARİSH	1.485	25.217

General statement of the research problem

When detecting an object, the quality of its image in the image is one of the main conditions. Because the performance indicators of CNN depend on the quality of the image given to its input [12]. However, since the distance from the object to the camera, weather conditions, illumination level and size of the object vary, it is necessary to improve the quality of the image of that object in real time. Considering this, it is necessary to first magnify the object when detecting it and determine whether the resulting images are of good quality or not, and if not, take steps to improve the quality. On the other hand, one of the main criteria set for object detection systems operating in real time is its speed.

Taking a zoomed image of an object

An object detected as a result of a change between frames and expressed in fewer pixels in the image can be enlarged using the camera's zoom function. The upper limit of magnification is determined by the predefined pixel dimensions. For example, if an object with a size of 50×50 is detected in the image, a new image of that object with a size of 500×500 is obtained by zooming the camera 10 times. If the object is 200×200, and 500×500 image can be obtained using the camera's 2.5 times zoom. Here, the size of 500×500 is considered the size requirement set by the image quality assessment system for the input image. It should also be noted that one of the main conditions is the type of lens group used in the camera from which the image is obtained. Thus, focusing disorders can occur when the camera zooms in or out on the object. Cameras with this feature are considered devices with a varifocal lens group. In cameras with parfocal lens groups, zooming in/out operations do not affect the focus of the object.

Image quality assessment

The need to assess the quality of images obtained during small object detection by a camera is actually related to the blurring of the object. The following reasons are usually responsible for blurring: out-of-focus, relative motion of the object relative to the camera (object movement and camera shake), non-ideal camera systems (e.g., lens aberration), atmospheric turbulence, and post-processing steps of the image (such as compression and denoising) [13, 14]. Apart from the Bokeh effect used to enhance the expressiveness of the image, any unintentional blurring is known to degrade the image quality. Image quality assessment methods can be divided into three categories: Full Reference, Reduced Reference, and No-reference (Fig. 6). Full-reference image quality assessment methods determine which of two images is of higher quality for this purpose. Partial-reference quality assessment methods, on the other hand, require some information about the image to be referenced. If there is no quality information about the image whose quality is being assessed, no-reference image quality assessment (İQA) methods are used.

This feature further complicates the process of no-reference image quality assessment.

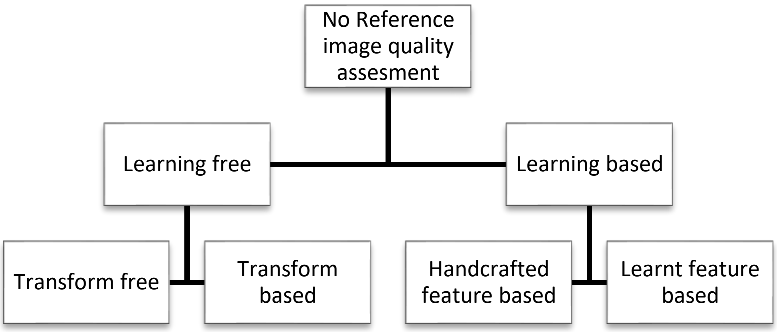


Fig. 6. Classification of blur-specific No-Reference Image Quality Assessment methods

As in many practical applications, the use of no-reference image quality assessment methods is necessary in the detection of drones and other small objects with video cameras due to the lack of a reference image to assess the quality of the image. In general, blur-based İQA methods can be classified according to the technology they use as follows [15] (Fig. 6).

Learning free IQA methods use classical methods that are distinguished by their simplicity and speed. It should be borne in mind that the blurred appearance of an object in an image is due to the fact that the edges of its elements appear not as sharp lines, but as “spread out”. In this regard, edge detection can be used to determine whether the object in the image is of good quality in terms of blurring.

Two types of filters can be used to detect edges: Gaussian-based and Gradient-based filters. Gradient-based filters include operators that calculate the first-order derivative of the image (Sobel, Previt, Robert). Gaussian-based filters include operators that calculate the second-order derivative of the image (Canny, Laplace transform of the Gaussian detector).

Edge detection by applying a filter

The main feature of the Sobel operator is its simplicity, its ability to provide approximate values for the gradient magnitude, and its ability to detect edges and directions. In digital image processing, a convolution matrix or mask is a small matrix used to detect edge obtained by convolution between a kernel and an image [16–19].

The Sobel filter is a gradient-based method that searches for strong changes in the first-order derivative values of an image. In this case, the detector uses 3x3 convolution matrices (Fig. 7). One of them calculates the gradient along the *x*-axis and the other along the *y*-axis in a two-dimensional coordinate system.

As mentioned above, the Sobel operator measures the spatial gradient in an image and reveals regions of higher spatial frequency that resemble edge states. The filter is often used to find an approximate absolute amount of gradation at all points in an input grayscale image [20–24].

-1	0	+1
-1	0	+1
-1	0	+1

G_x

+1	+1	+1
0	0	0
+1	+1	+1

G_y

Fig. 7. 3 × 3 convolution matrix of the Sobel detector

The mechanism for calculating G_x and G_y can be summarized as the process of sliding a filter over the input image, where the value is calculated for one pixel and then shifted to the right by one pixel step. When the filter reaches the end of a line, it moves to the beginning of the next line. The following example shows the calculation of the G_x value (Fig. 8):

a_{11}	a_{12}	a_{13}	...
a_{21}	a_{22}	a_{23}	...
a_{31}	a_{32}	a_{33}	...
...	...	...	...

Input

1	0	-1
2	0	-2
1	0	-1

Filter

b_{11}	b_{12}	b_{13}	...
b_{21}	b_{22}	b_{23}	...
b_{31}	b_{32}	b_{33}	...
...	...	...	...

Output G_x

Fig. 8. Calculation of the G_x value

The filter consists of positive and negative coefficients [25]. Thus, the resulting image will contain both positive and negative values. Thus:

1. The regression of zero goes to the half-gray level. Thus, a negative gradient appears dark, and a positive gradient appears bright.

2. The absolute value of the gradient must be chosen (for values between 0 and 255).

3. High positive and negative gradients appear bright, and the filter is sensitive to horizontal and vertical transitions.

From the calculation of G_x and G_y, it is easy to identify outliers.

The G_x and G_y gradient estimates are combined for each pixel in the image, and when combined, the gradient measure is obtained using:

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

Here G_x and G_y are the matrices obtained by filtering the x and y axes, respectively (2).

For more complete edge removal, filtering can also be performed on the diagonals.

In this case, left and right diagonal filters are used (Fig. 9).

a_{11}	a_{12}	a_{13}	...
a_{21}	a_{22}	a_{23}	...
a_{31}	a_{32}	a_{33}	...
...	...	...	...

Input

0	1	2
-1	0	1
-2	-1	0

Left diagonal

b_{11}	b_{12}	b_{13}	...
b_{21}	b_{22}	b_{23}	...
b_{31}	b_{32}	b_{33}	...
...	...	...	...

Output G_{ld}

a_{11}	a_{12}	a_{13}	...
a_{21}	a_{22}	a_{23}	...
a_{31}	a_{32}	a_{33}	...
...	...	...	...

Input

2	1	0
1	0	-1
0	-1	-2

Right diagonal

b_{11}	b_{12}	b_{13}	...
b_{21}	b_{22}	b_{23}	...
b_{31}	b_{32}	b_{33}	...
...	...	...	...

Output G_{rd}

Fig. 9. Filtering the image along the right and left diagonals

In this case, we use the results obtained based on 4 types of filtering to calculate the gradient size:

$$G = \sqrt{G_x^2 + G_y^2 + G_{ld}^2 + G_{rd}^2} . \qquad (3)$$

Expression of quality in quantities

Considering that the resulting image is grayscale, pixels with higher intensity (white) in the image indicate sharper edges. Therefore, the greater the total number of pixels with an intensity above a certain value, the sharper the edges, i.e., the better the image quality. Considering that the intensity of pixels varies between 0 and 255, it is appropriate to take that value as the average intensity, i.e. 125.

Using the method discussed in the article, the quality assessment in terms of blur is carried out in the following stages:

1. The input image is accepted and converted to grayscale.
2. Various variants of Sobel operators are applied.
3. The gradient is calculated.
4. The total number of pixels with an intensity greater than 125 (Q_n) is found.

After assessing the quality of the image, the focus of the camera device must be controlled to obtain a quality image. By increasing or decreasing the distance S_2 between the lens and the sensor in the camera setup (Fig. 2), the .current quality indicator (Q_n) is compared with the previous indicator (Q_{n-1}), and the largest value of Q_n is considered the optimal distance for S_2.

Results and Discussion

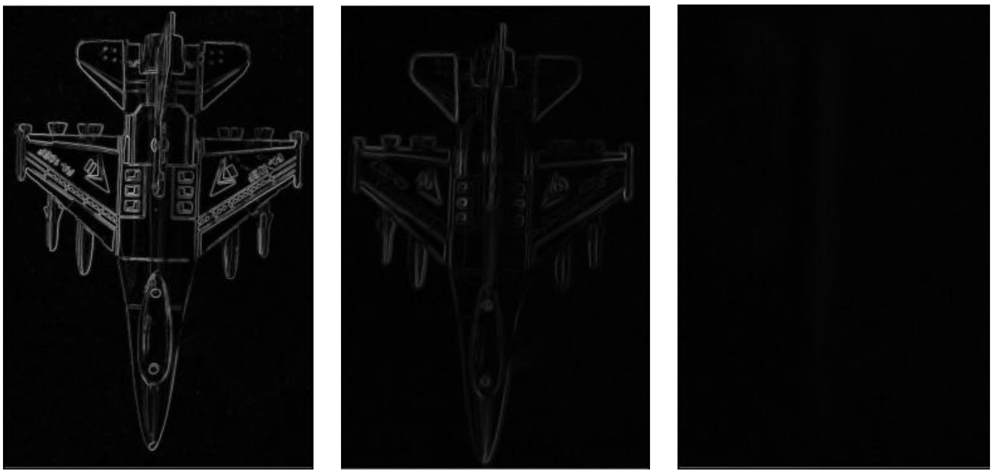
The article considers the issue of obtaining a high-quality image for the input of a small-sized object detection system using a camera. For this purpose, methods for controlling both the zoom and focus functions of the camera are proposed. Initially, a newly entered object is detected by checking the difference between frames and using the camera's zoom, the image of that object is brought to a certain pixel size. Using the camera's zoom function, the object is enlarged several times depending on the size of the image.

In the next stage, the process of focusing on the object in the image is considered. As an example, one high-quality and two relatively blurred images of the same object were taken. The main purpose of choosing a white background for the object in the image is to complicate the issue a little, considering that the object in the image also consists mostly of white.

The 3 sample images shown in Fig. 10 were processed using 4 filters, the gradient was calculated, and the edges were detected. Considering that edges appear sharper in a quality image in terms of blur, the number of pixels with an intensity greater than 125 was found to quantify their quality. The processing process was performed using PYTHON (Fig. 11).

a b c

Fig. 10. Unblurred (a) and blurred (b) and (c) images of an object placed on a white background.



a b c

Fig 11. Gradient calculation results of images (a), (b) and (c)

The total number of pixels with intensity greater than 125 is 21434, 2996 and 3081 for images (a), (b) and (c) respectively.

The results obtained for all three images (different quality images of the same image) show that indeed the edges of the quality image are more clearly visible and the number of pixels with intensity greater than 125 is more than the others.

By increasing or decreasing the focus of the camera, it is possible to find the focus where this number is the largest. Using this result, it is possible to find the optimal value of the camera focus to obtain a quality image with the proposed method.

The proposed method was applied to images from the TID2013 and BID datasets and an average time of 0.56 and 2.73 seconds was required for image processing, respectively, which can be considered a fairly good result.

Conclusions

Since small objects are represented by very few pixels in the image, their detection by recognition systems becomes difficult. For this reason, providing a high-quality image to the input of the recognition system is one of the main conditions. The article considers the issue of obtaining a high-quality image by controlling both the zoom and focus of the camera. For this purpose, image quality assessment methods are investigated and a new method is proposed that can work quickly in real time using existing tools.

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Received (Надійшла) 12.02.2025
Accepted for publication (Прийнята до друку) 28.05.2025

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Алгоритм керування камерою та спосіб оцінки якості зображення для отримання якісного зображення

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Анотація. Оскільки невеликі за розміром об'єкти виражені на зображенні дуже малою кількістю пікселів і розташовані на досить великій відстані від камери, їх розпізнавання системами комп'ютерного зору ускладнюється. У цей час актуальним стає питання отримання якісних зображень з них. **Об'єктом дослідження** є фотоапарат і отримані з нього зображення. Було вивчено існуючі методи та запропоновано новий підхід, який може працювати швидше для отримання високоякісних зображень. **Предметом дослідження** є метод оцінки якості зображення та управління фокусом камери за допомогою існуючих засобів з метою отримання якісного зображення. **Метою дослідження** є створення алгоритму оцінки зображення та керування пристроєм камери для отримання якісного зображення для системи виявлення з підтримкою комп'ютерного зору малогабаритних об'єктів. Підвищення якості зображення запропонованими методами створює важливі умови для ефективної роботи систем розпізнавання, що працюють в режимі реального часу. **В результаті дослідження** запропоновано методику оцінки якості зображення та алгоритм керування камерою для отримання якісного зображення об'єкта. Наведено обґрунтування запропонованих основних методів дослідження, наведено результати експериментальних досліджень запропонованих методів і підтверджено обґрунтованість прийнятих теоретичних висновків.

Ключові слова: піксель; фільтр Sobel; фокусування; фон; шум; рамка; сегментація; відстеження об'єктів.