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Monitoring of dynamic objects by observation systems of visible range of waves

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Abstract. The article deals with the problem of correct detection of moving objects when they are monitored by the monitoring system that operates in the visible range of the electromagnetic radiation spectrum. Based on the analysis of existing methods, for detection of moving objects there is proposed an algorithm that is adaptive to destabilizing factors. This algorithm makes it possible to increase the accuracy of moving objects detection. The algorithm takes into account the presence of noise and its heterogeneity, both in space and time, and also removes the influence of moving shadows. The correctness of the algorithms described in this article is confirmed by their software implementation and modelling. In the process of modelling, the accuracy of object detection, proposed by the algorithm under different observation conditions, and the motion parameters of the objects were estimated.
Keywords: video monitoring, detection of moving objects, detection of moving shadows, background subtraction, interframe difference
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1. Introduction

Development of intelligent data recognition systems is becoming increasingly important, with the rapid increase in the amount of information that is collected and exchanged between different monitoring systems by cameras of video surveillance systems to satellites, which carry out surveying of the Earth's surface. The analysis of this information and subsequent decisions to a large extent belong to a human operator: due to natural limitations, the operator cannot quickly process large amounts of data and, therefore, remains a "bottleneck" in the process of collecting, processing and control of visual information, for example, that comes from surveillance cameras, as the human resource is not enough to handle large amounts of data.

The output of modern digital cameras is a sequence of bitmap images, which are called frames. An analysis of the scene, reflected in the frame, is a complex process. The first step in analysing the video of the observed scene is movement revealing which is shown in change of scene image in the process of observation [1]. These changes are conditioned by the following factors: a) the intrinsic noise of the digital video cameras b) dynamic imaging system settings; c) changing of scenes lighting; d) the movement of trees crowns e) moving shadows; and f) moving objects (MO).

Causes a) and b) are false fixation of scene changes; c) and d) occur under real conditions but they are generally uninteresting changes. Only the cases e) and f) are of interest and require extensive studies.

Based on the above mentioned, it is possible to define two basic requirements that must be fulfilled by the detector of MO: 1) resistance to change of scene conditioned by the factors a)-d), 2) computational efficiency, namely the ability to handle a large number of frames per unit of time.

At present, the literature offers a wide range of approaches to the problem solution of MO identification, each of which represents a compromise to some extent between the requirements 1) and 2). However, the most effective methods provide that each frame is compared with the background, so-called reference frame. This approach requires the background model to be generated, even at intensive objects movement, and being continually updated [1-7].

Obviously, the quality of moving objects detection will essentially depend on whether or not background model is correctly formed. Most of the known methods for the moving objects detection suggest that during the formation of the background model a video camera monitors a static scene, but in most cases this assumption is wrong. This paper proposes a solution to the problem of the correct formation of the background model and a number of other problems which appear with the detection of moving objects.

2. Formation of a background model

Typically, the background model is generated by averaging the first N frames of the input video sequence in order to take into account the presence of noise component in a video signal [3, 4]. However, for intensive movement in the camera's field of view, at the formation of the background, a simple averaging of frames will give incorrect results, because the background model will include the components made by moving objects [6]. In order to form a correct background model, it is proposed to carry out the formation of the background during the first *N* frames only in those areas of frame where the movement at this time is not available. To determine the presence of movement in one or another area of the scene method of inter-frame difference is used:

$$M_t = \begin{cases} 1, & I_t(m,n) - I_{t-1}(m,n) \geq \tau \\ 0, & I_t(m,n) - I_{t-1}(m,n) < \tau \end{cases} \tag{1}$$

where $M_t(m, n)$ — binary mask of movement;
t — frame number;
$I_t(m, n)$ — matrix of image elements of the current frame;
$I_{t-1}(m, n)$ — matrix of image elements of the previous frame;
τ — binarization threshold.

Since this method allows to select only the boundaries of moving objects, it is proposed to carry out the blurring of the formed mask M_t to completely fill the entire area of a moving object. This procedure is implemented using morphological operations [10].

After morphological filtering binary mask of moving objects, M_t is used to form the background (see Fig. 1) by blending the current frame $I_t(m, n)$ with a background in the previous step $B_{t-1}(m, n)$ with the coefficient r:

$$B_t(m,n) = \begin{cases} rI_t(m,n) + (1-r)B_{t-1}(m,n), & M_t(m,n) = 0 \\ B_{t-1}(m,n), & M_t(m,n) = 1 \end{cases} \tag{2}$$

where $B_t(m, n)$ — background model image;
r — mixing ratio, that depends on the speed of objects movement.

Most of the existing methods for the allocation of moving objects take into account the presence of noise in the video signal but do not take into account the change in the noise level in space and time. Therefore, during formation of a background pattern, it is preferable to estimate the noise parameters to account its variable effects both in space and in time [1].

Taking into account the presence of many independent random factors, determining the camcorder output signal fluctuations, it is possible to consider with sufficient precision the camera noise as a random variable which is described by the normal law of distribution and is characterized by the mathematic expectation, mean square deviation and dispersion (Fig. 2) [1].

Fig. 1. The result is formation of the background model

Fig. 2. Dispersion of camera noise

3. Detection of moving objects

After completion of the formation process of the background model and parameters evaluation of camera noise, detection of moving objects is carried out by subtracting the background:

$$M_t^*(m,n)=\begin{cases}1, & I_t(m,n)-B_t(m,n)\geq\tau\\ 0, & I_t(m,n)-B_{t-1}(m,n)<\tau\end{cases} \quad (3)$$

where $M_t^*(m,n)$ — binary mask of the detected moving objects by background subtraction.

The choice of the values τ is affected by various factors (amount of noise, the contrast of the movable object with respect to the background, and others).

Based on the properties of the normal distribution law, which describes the noise of our monitoring camera system, it can be assumed that the criterion 3σ background pixel values, taking into account noise should fall in the range of $\tau_1 = I_t(m,n) - 3\sigma$ to $\tau_2 = I_t(m,n) + 3\sigma$ with probability 0.9973.

Taking into account the property, the expression for the detection of movement (3) can be written as follows (see Figure 3, 4) [1]:

$$M_t^*(m,n) = \begin{cases} 1, & |I_t(m,n) - B_t(m,n)| \geq 3\sigma \\ 0, & |I_t(m,n) - B_t(m,n)| < 3\sigma \end{cases} \quad (4)$$

where σ — mean square deviation determined in the process of formation of a background model for each pixel (see Fig. 2).

Fig. 3. The current frame of the input video signal

Fig. 4. The binary mask of the detected moving objects

In order to remove wrongly marked points in the current binary mask $M_t^*(m,n)$, and for combining properly selected points in the objects, there occurs its filtering using morphological operations [10] (see Fig. 5).

Fig. 5. The binary mask of the detected moving objects after filtration

In order to have the algorithm to be adaptive to change of the background, for example, change of scenes lighting, it is needed to constantly update background models at the time of observation. The update is performed by the „mixing" of the current frame $I_t(m, n)$ with a background model at the previous step $B_{t-1}(m, n)$ with the coefficient α, if the frame pixel belongs to the background and β, if the pixel belongs to the moving object:

$$B_t(m,n) = \begin{cases} \alpha I_t(m,n) + (1-\alpha) B_{t-1}(m,n), & M_t^*(m,n) = 0 \\ \beta I_t(m,n) + (1-\beta) B_{t-1}(m,n), & M_t^*(m,n) = 1 \end{cases} \tag{5}$$

where $0 < \beta < \alpha < 1$ — mixing coefficients.

4. Detection and removal of moving shadows

One of the main reasons of the characteristics deterioration of algorithms for the detection of moving objects is the perception of the moving shadows as the parts of the selected objects, which leads to negative consequences, in particular distortion of the shapes of objects, increase in false detection probability, object classification errors, combining several objects into one. This shortcoming complicates further analysis and processing of the result of the detection of moving objects, so it is advisable to carry out the detection of moving shadows in order to reduce their impact on the accuracy of the detection of moving objects.

Let us consider a scene point and may it has the colour (*R*, *G*, *B*), then, after a drop of shadow to this point, it will has the colour *k*(*R*, *G*, *B*), where the *k* coefficient determines how luminance is changed at this point. It turns out that to this fact it is enough to create a detection algorithm and remove shadows with sufficient accuracy for most applications.

Let be $\left(B_R, B_G, B_B\right)$ — the colour of the pixel P_B in the image background and $\left(I_R, I_G, I_B\right)$ — the colour of a given pixel in the image of the current frame P_I. First, let us move to HSV colour space $\left(B_R, B_G, B_B\right) \rightarrow \left(B_H, B_S, B_V\right)$ and $\left(I_R, I_G, I_B\right) \rightarrow \left(I_H, I_S, I_V\right)$.HSV (HSB) — colour model based on three characteristics of colour: colour hue, saturation and value of colour, which is also called luminance (brightness). Thus, if the movable shade in the scene, which is responsible for the pixel value I_V is significantly reduced, compared to B_V, and the value I_H, I_S — virtually unchanged, compared to B_H, B_S. Thus, the pixel p_I is considered as a part of the shade if the following three conditions are realized [8, 9]

$$\tau_{V1} \le \left(I_V(m,n)/B_V(m,n)\right) \le \tau_{V2} \tag{6}$$

$$\left|I_S(m,n) - B_S(m,n)\right| \le \tau_S \tag{7}$$

$$\left|I_H(m,n) - B_H(m,n)\right| \le \tau_H \tag{8}$$

where $I_H(m,n), I_S(m,n), I_V(m,n)$ — hue, saturation and brightness of a pixel of the current frame P_I;
$B_H(m,n), B_S(m,n), B_V(m,n)$ — hue, saturation and brightness of the pixel background P_B;
$\tau_{V1}, \tau_{V2}, \tau_S, \tau_H$ — thresholds which are optimized empirically.

Figure 6 shows a binary mask of the detected moving shadows.

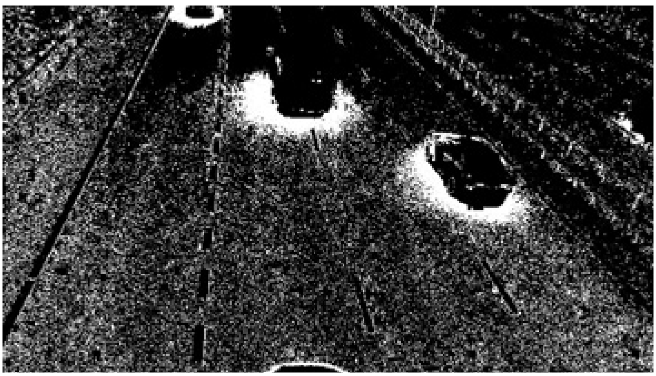

Fig. 6. The binary mask of the detected moving shadows

Fig. 7. Binary mask of the detected moving shadows after filtration

Next, there is filtration of this mask by a median filter (Fig. 8).
Figure 8 shows the detected movable shadows in the current frame.

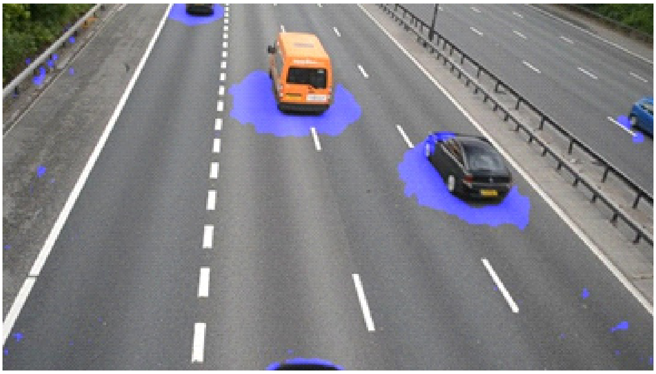

Fig. 8. Detected moving shadows in the current frame

The binary mask of the detected moving objects without shadows influence elimination is the same as shown in Fig. 5.

The algorithm results are shown in Fig. 10 and Fig. 11.

Fig. 9. Detected moving objects on the elimination of shadows influence

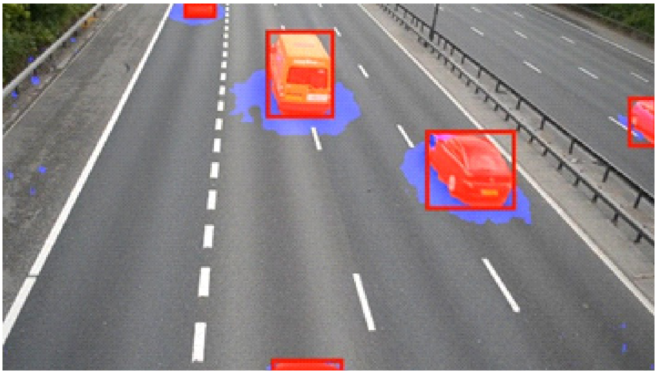

Fig. 10. Presentation of the results of the algorithm

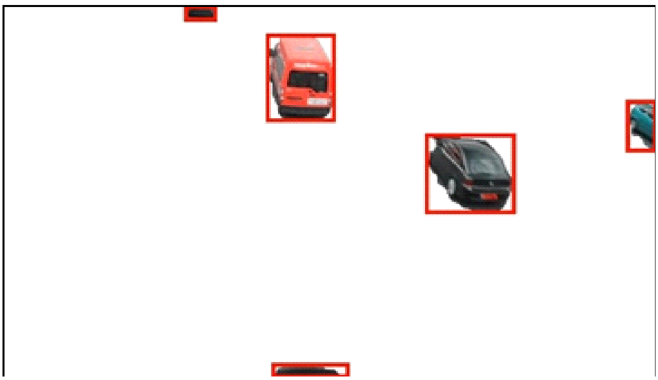

Fig. 11. The detected moving objects in natural colours with no background

5. The accuracy of moving objects detection

To determine the accuracy of moving objects detection by the proposed algorithm, its modelling is performed under various conditions of monitoring. Under the detection accuracy (detection and recognition) it is meant as the ratio of the number of moving objects' pixels detected by the algorithm to the total number of moving objects' pixels.

Test video is generated for modelling with the size of 1280 × 720 pixels, digital camera viewing angle of 60 degrees, and typical meaning of the camera own noise — 36 dB.

Figure 12 shows the dependence of the accuracy and precision of moving objects detection from the peak signal/noise ratio when the object of 45 km/h speed and at a distance from the observation point 100 meters.

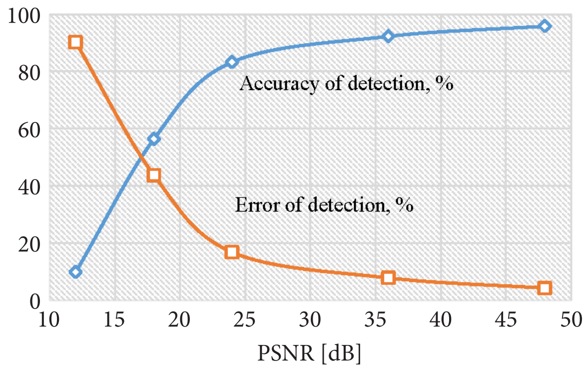

Fig. 12. The accuracy of detection depending on the peak ratio of signal/noise

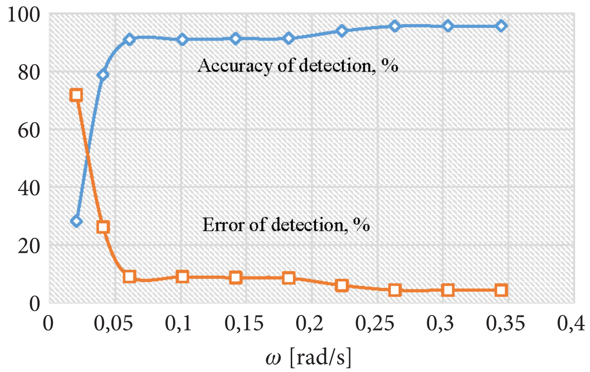

Fig. 13. The detection accuracy depending on the angular velocity of the object
(wartości na osi poziomej powinny być pisane z kropkami)

Figure 13 shows the dependence of the accuracy and error detection of moving objects on the angular velocity of the object at the peak signal/noise ratio of 36 dB and at a 100-meters distance from the observation point.

Figure 14 shows the dependence of the accuracy and precision of moving objects detection from a distance to the object on the observation point at the peak signal/noise ratio of 36 dB and an object speed of 45 km/h.

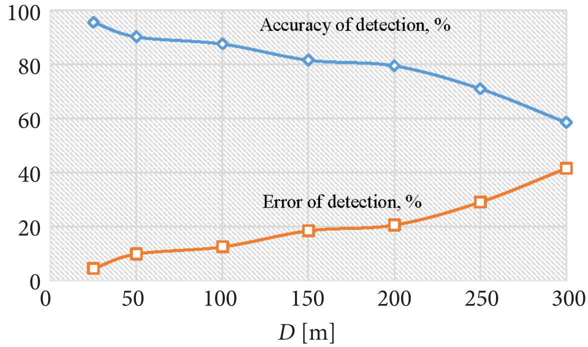

Fig. 14. The accuracy of detection, depending on the distance to the object

6. Conclusions

The proposed algorithm for the moving objects detection can effectively detect moving objects at the presence of destabilizing factors in particular:

- allows to perform the correct formation of the background model even at the existence of intensive movement in the camera's field of view;
- is adapted, both in space and in time, to a level change of a digital video camera noise, and change of the background;
- statistical evaluation of binarization threshold which is carried out during the operation of the algorithm, allows to use the algorithm with virtually any digital camera, regardless of its intrinsic noise level, without empirical tuning of the algorithm parameters;
- removal of the moving shadows allows to eliminate their impact on the quality of moving objects detection;
- detection results visualization by highlighting the area of moving objects in their natural colours without uninformative background allows dramatically decrease the amount of data that comes from the video camera.

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I. PRUDYUS, V. TKACHENKO, L. LAZKO, P. KONDRATOV, S. FABIROVSKYY, A. HRYVACHEVSKYI

Monitoring obiektów dynamicznych przy pomocy systemów obserwacyjnych z widzialnego zakresu fal

Streszczenie. Artykuł porusza problem prawidłowego wykrywania poruszających się obiektów, gdy są one monitorowane przez system monitorujący działający w widzialnym zakresie spektrum promieniowania elektromagnetycznego. Na podstawie analizy istniejących metod zaproponowano adaptacyjny algorytm uwzględniający czynniki destabilizujące. Algorytm ten umożliwia zwiększenie dokładności wykrywania poruszających się obiektów. Uwzględnia on obecność szumu i jego niejednorodność, zarówno w przestrzeni, jak i w czasie, a także eliminuje wpływ ruchomych cieni. Poprawność algorytmów, opisanych w tym artykule, potwierdzono w czasie ich realizacji i modelowania. W trakcie symulacji przeprowadzono oszacowanie dokładności detekcji obiektów według zaproponowanego algorytmu w różnych warunkach obserwacji i dla różnych parametrów ruchu obiektu.

Słowa kluczowe: monitoring wideo, wykrywanie poruszających się obiektów, wykrywanie poruszających się cieni, odejmowanie tła, różnica między ramkami

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