Estimation of the Mean Velocity of a Group of Vehicles in Strong Random Noise Conditions

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Abstract. A method of estimating the mean velocity of a group of vehicles moving in one lane was proposed. The vehicle image blurring and the appearance of Gaussian noises at individual stages of image acquisition were considered. The method is based on the signal approximation by application of a parabolic function (formulas (1) and (2)). The algorithm work in strong random noise conditions was verified through appropriate computer simulations.

Keywords: Vehicle velocity estimation, random image distortion, computer simulations.

1 Introduction

In this paper the problem of vehicles velocity estimation based on the image registered by a video camera was considered. In the case of low level noise, the method based on subtracting subsequent image frames is used, which enables identification of moving objects. One such example is an algorithm proposed by Lucas and Kanade [1]. One of the versions of this algorithm includes an application of image derivative. However, signal differentiation procedures in the presence of random noises may yield large errors [3]. In the case of higher noise, the method of subtracting subsequent image sequences becomes useless, since it leads to an increase in the noise level – a summation of noise variance occurs.

In this paper, in which strong random noises are considered, it has been assumed that for individual frames an object position is estimated, and that the velocity is determined on the basis of image sequences (10 or 20). The method will be illustrated using a single moving vehicle, and subsequently, it will be implemented to estimate the mean velocity of a group of vehicles.

2 Estimation of a Single Vehicle Velocity

It is assumed that before the velocity measurement started, a sufficient number of background images had been registered (e.g. 1000), on the basis of which averaging was done, which enabled identification of characteristic background features. It is also assumed that an averaged background image is subtracted from subsequent registered images with a moving vehicle. As a result, it is assumed that the background has a level equal to zero and is disturbed by a Gaussian noise in the same way as was the

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vehicle. In order to simplify these deliberations, vehicles in a simplified grayscale are considered: a figure AS=0.5 is assigned to a light-color vehicle, and a figure AS=-0.5 is assigned to a dark-color one. Assuming that a car velocity equals 90 km/h and that a camera registers 25 frames per second, it can be found that two subsequent frames correspond to the distance of one meter covered by the vehicle. Assuming that the video camera has a resolution of 320 pixels and that the image covers 320 meters of the road, it can be concluded that the distance between two adjacent pixels of the image corresponds to the distance of 1 meter of the road. It is also assumed that the movement of a group of vehicles – each 6-meter long - takes place in one lane, and that the camera is placed on a side of the road.

A model of a vehicle, i.e. a rectangle with a base of 6 pixels, has been blurred using moving average filter, and has taken the shape of trapezium *ys* shown in Fig.1.

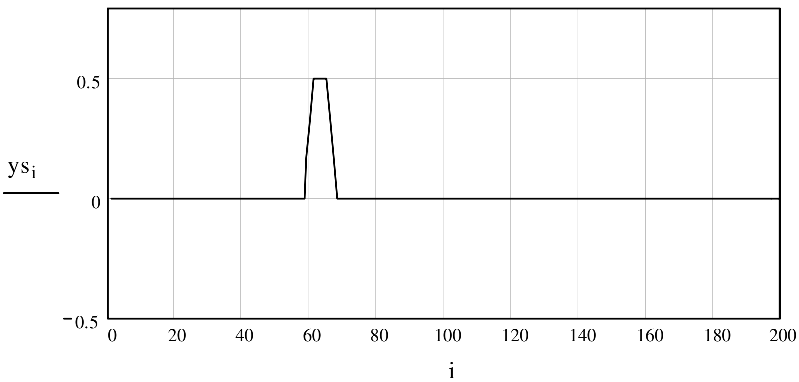

Fig. 1. Model of a single vehicle

The figure presented in Fig. 1 has been disturbed by a Gaussian noise with its standard variation $\sigma = 0{,}3$, which has been shown in Fig. 2.

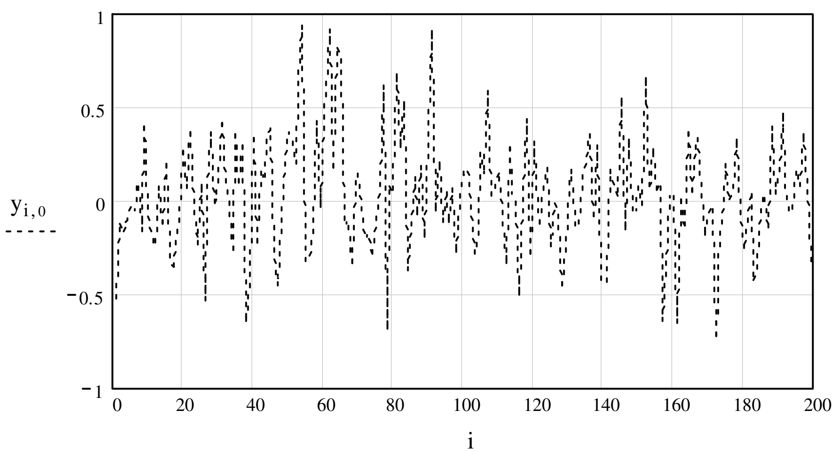

Fig. 2. A sample figure representing a vehicle in the presence of random noises obtained through computer simulations

In order to estimate a vehicle position, a parabolic approximation was adopted in the following form.

$$f(i, j) = a0_i + a1_i \cdot j + a2_i \cdot j^2 \tag{1}$$

where $j = -M, -M+1,.., M$.

Trend parameters were determined using formulas:

$$a1_i = \frac{\sum_{j=1}^{M} j \cdot \left(y_{i+j} - y_{i-j}\right)}{B}$$

$$a2_i = \frac{\sum_{j=1}^{M} \left(y_{i+j} - y_{i-j}\right)\left(j^2 - B\right) - B \cdot y_i}{D} \tag{2}$$

$$a0_i = \frac{\sum_{j=1}^{M} \left(y_{i+j} + y_{i-j}\right) + y_i - C \cdot a2_i}{2M+1}$$

where: $B = \dfrac{M(M+1)}{C}$; $C = B(2M+1)$; $D = \dfrac{C}{15}(2M-1)(2M+3)$

y_i - registered signal

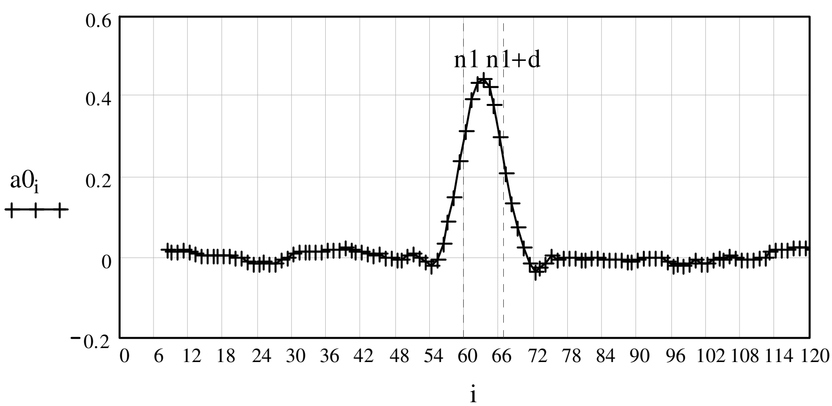

Fig. 3. Averaged values of coefficient $a0_i$. Vertical lines define the interval (n1, n1+d) in which a vehicle is present.

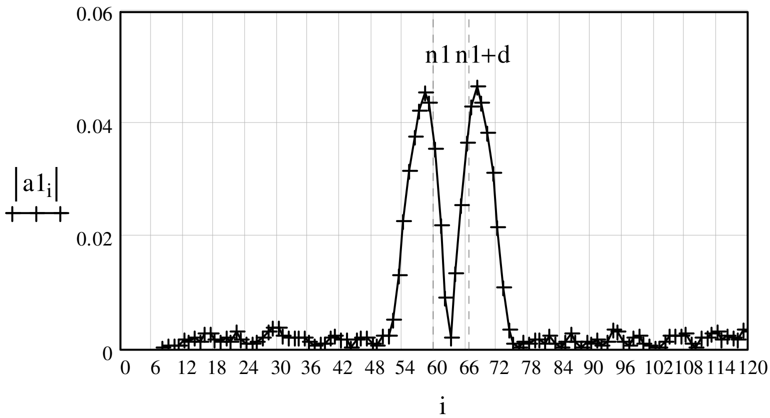

Fig. 4. Averaged absolute values of coefficient $a1_i$ .Vertical lines define the interval (n1, n1+d) in which a vehicle is present.

Fig. 3, Fig.4. and Fig. 5 show the values of trend parameters obtained by averaging the results of a hundred of computer simulations.

From these figures, three methods of vehicle center estimation are obtained:

- coefficient $a0_i$ maximum method
- $|a1_i|$ minimum method, having earlier determined the position of maximum values
- coefficient $a2_i$ minimum method.

As a result of a numerical experiment, the strongest resistance to random noise proved the method based on coefficient $a0_i$ maximum. In this paper this method was applied (marked as variant I) along with its modification which consisted in the search for the maximum value of the product L of subsequent coefficients $a0_i$ (variant II).

The algorithm of vehicle velocity estimation is the following. For consecutive (e.g. 10) images we determine the values of pixels for which the maximum of coefficient $a0_i$ occurred, as well as their median. The values of pixels whose distance from the median exceeds 20 are replaced with the mean value of their neighbors. In the case of outermost pixels (the first or the last), the linear extrapolation of the values of two closest pixels is performed. For the obtained set a linear trend is determined. Its slope of a straight line determines the vehicle velocity. In the case of variant I, root mean square error $rmse_{10} = 0{,}129$ was obtained for the sequence of 10 images and $rmse_{20} = 0{,}040$ for 20 images – calculations were made for a window 2M +1 = 15 (formula (2)). Variant II yielded the following error values: $rmse_{10} = 0{,}109$, $rmse_{20} = 0{,}033$ - for M = 7 and L = 4 respectively.

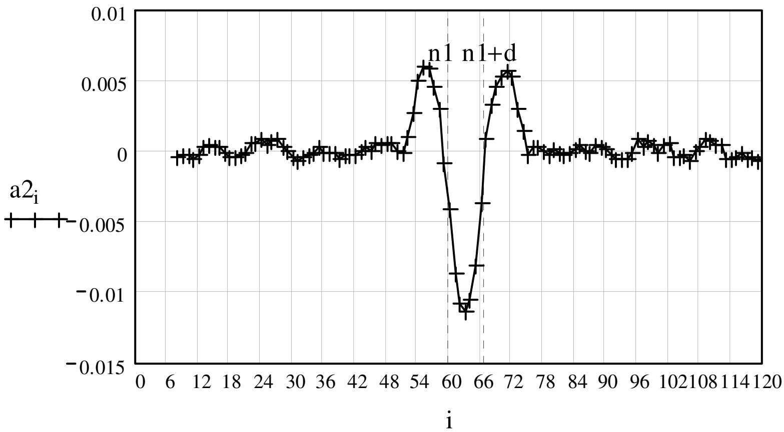

Fig. 5. Averaged values of coefficient $a2_i$. Vertical lines define the interval (n1, n1+d) in which a vehicle is present.

The limitation of this method is the number of wild pixels with the values diverging strongly from the median. In the case of noise of the level $\sigma = 0{,}3$ it constituted up to 30%, which guaranteed the right median value. For $\sigma = 0{,}4$ erroneous observations constituted up to 50%, which rendered correction impossible.

3 Estimation of Vehicle Group Velocity

Fig. 6 shows the model of a group of three vehicles – each 6 pixels long (6m) – with the distance between the centers of the vehicles equal 15 pixels (15m), which means that the real distance between the vehicles was 9 pixels (9m).

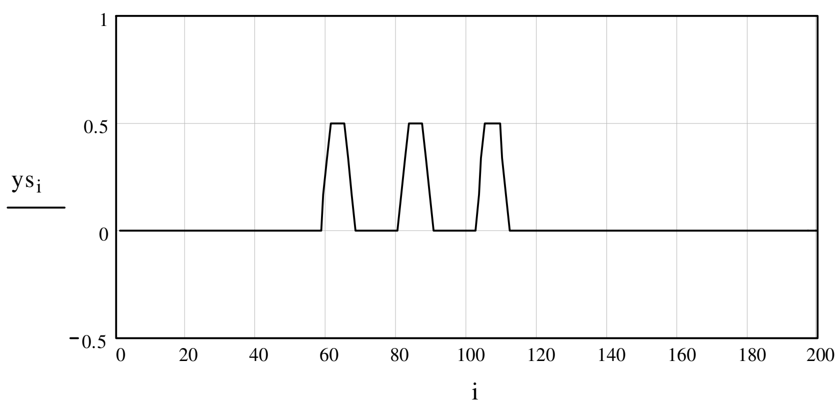

Fig. 6. Model of a group of vehicles

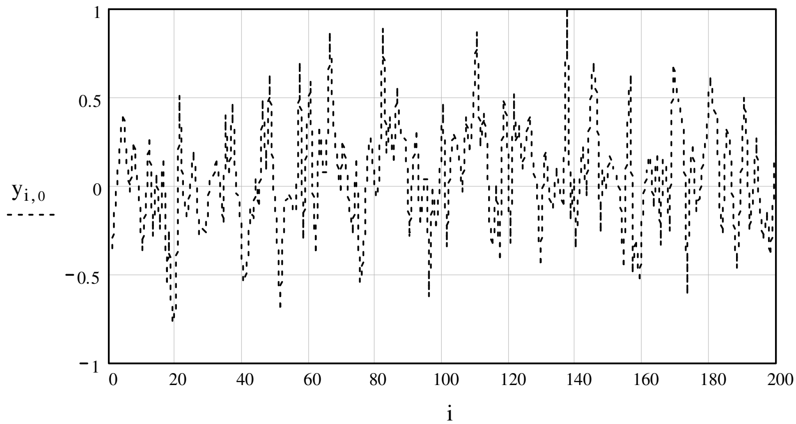

Fig. 7. Fig. 6 disturbed by Gaussian noise with standard deviation $\sigma = 0{,}3$

Fig. 7 shows an example of computer simulations in which random noise ($\sigma = 0{,}3$) was added to the image shown in Fig. 6.

The algorithm of velocity estimation for a group of vehicles is similar to the algorithm described in section 2. For a given image, pixel i_1 coordinates of coefficient $a0_i$ maximum are determined, and subsequently, this action is repeated excluding points $i_1 - 5, i_1 - 4, ..., i_1 + 5$, obtaining the value of pixel i_2. Another exclusion of points $i_2 - 5, i_2 - 4, ..., i_2 + 5$ allows to determine coordinate i_3 corresponding to the third extremum. The determined coordinates i_1, i_2, i_3 are then put in order of increasing value. The described actions are repeated for every image. Subsequently, three groups are determined: the first including the coordinates of pixels which, as a result of arranging, were placed in the first position; the second including pixels in midposition; the third including pixels in the last position. For each group, which represents the location of an individual vehicle, its velocity is determined – following the algorithm described in section 2.

Table 1 includes the results of computer simulations performed for the sequence of 10 images. In both variants (I and II) the window size (formula (2)) was 2M + 1 = 15,

Table 1. Results of vehicle group velocity estimation

Variant	Vehicle	Velocity	bias	rmse	mae
I	I	0,976	-0,024	0,130	0,106
	II	0,943	-0,057	0,130	0,108
	III	0,918	-0,083	0,133	0,115
	group	0,945	-0,055	0,086	0,074
II	I	1,017	0,17	0,074	0,055
	II	0,994	-0,006	0,037	0,029
	III	0,979	-0,021	0,087	0,067
	group	0,997	-0,003	0,040	0,031

however in the case of variant II, product L = 6 of consecutive values of coefficient $a0_i$ was considered.

The last column of the table includes the values of mean absolute error.

The most important error criterion is *rmse*, since it is a square root of mean square error (*mse*), where *mse* is the sum of variance and the square of *bias* [2].

The velocity of a group of vehicles was derived as a mean of results for individual vehicles obtained for subsequent computer simulations. Looking at the table, it can be concluded that the velocity of a group of vehicles in Variant II has smaller bias than velocity biases for individual vehicles. However, the value of error *rmse* became smaller for both Variants I and II.

4 Conclusions

In this paper we proposed a method of estimating average velocity of a group of vehicles based on the image registered by a video camera including high level noise. The algorithm is based on the approximation of a signal using a parabolic function (formulas (1) and (2)). Two variants of the method were considered: a direct search for the position of the maximum of coefficient $a0_i$ (variant I) as well as determining the position of the product maximum of L consecutive values of this coefficient (variant II). Having analyzed the data presented in Table 1, it can be concluded that Variant II yields half as large errors (rmse, mae) as Variant I, and that the average velocity of a group of vehicles is burdened with a smaller error than the errors of velocity values for individual vehicles.

In calculations also the cases of AS = - 0.5 (a dark vehicle) were considered. Their results were similar to those presented in Table 1.

Taking into consideration the fact that the calculations are made for the sequence of 10 images, which corresponds to the time of registration t = 0.4s, it can be concluded that the method concerns the instantaneous value of velocity.

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