Vision-Based Vehicle Speed Measurement Method

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Abstract. This paper introduces a novel method for vehicle speed detection based exclusively on visual information. The proposed system consisting only of a digital camera and a computer is able to identify both the speed of the passing vehicle and its licence plate numbers, which makes it an interesting alternative to existing and expensive photoradar systems. The principle of operation is simple: vehicles are identified by their licence plates and their speed is measured based on the vertical difference of their position in consecutive images. An experimental evaluation shows the high accuracy of vehicle speed measurement, comparable to the one provided by comercially available radar-based systems.

1 Introduction

In the contemporary world we observe a growing need for intelligent traffic management systems that would cope with the constantly increasing traffic. According to the statistics [8], in Poland in 2005 approximately 75% of all people and cargo transportation was the road transportation. Unfortunately the number of vehicles was growing much faster then the infrastructure, which led to the road system overload, higher environment pollution, larger accident number etc. According to various studies, an intelligent traffic system can increase the throughput by 20%, reducing at the same time pollution and acident number.

One of the key issues of traffic monitoring is the automatic vehicle speed measurement. Currently it is done by means of photoradars, which use radar or laser technology for speed measurement and may use image processing techniques for licence plate identification. Although these devices usually perform well, they are expensive and thus cannot be widely used, especially in less economically succesfull regions, where the disproportion between the increasing traffic and the infrastructure is particularly large.

The main contribution of this paper is a novel approach to speed detection that does not require any sophisticated and expensive hardware and uses only visual information both for licence plate recognition and speed measurement. The underlying idea of the proposed method is to use the geometrical information of the camera-road system in order to estimate the velocity of passing vehicles.

L. Bolc et al. (Eds.): ICCVG 2010, Part I, LNCS 6374, pp. 308–315, 2010.

The paper consists of 5 sections. In Section 2 the previous works are reported. In Section 3, the proposed approach is described. Section 4 contains experimental results, and finally, Section 5 concludes the paper.

2 Previous Works

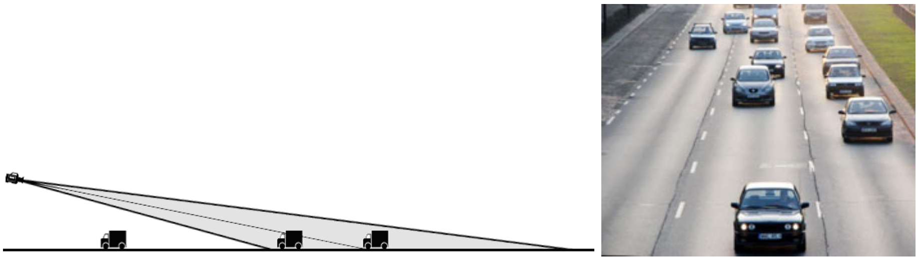
Vehicle speed measurement methods based on video sequences were proposed e.g. in [7,16,4], an interesting method for estimating speed from a single, blurred image, in [5]. More general studies on motion in digital images can be found in [19,18]. The motion and object tracking in traffic scenes was the subject of numerous publications, just to mention [17,11]. In the literature on car license plate recognition (LPR) one can find various approaches. In [14,9] a method based on edge detection on graylevel images combined with adaptive thresholding and template matching is presented. The method described in [13] processed edges on color input image using fuzzy-logic approach to localize license plate while topological features and neural network to recognize characters. Paper [6] describes a method that applies Maximal Stable Extremal Regions to localize the plate and SVM-classifer the the second step of processing. In [2] the proposed algorithm made use of feature-salience theory and applied Hough transform to localize plate and probabilistic classifier in the OCR phase. Statistical approach was also applied in [1]. The morphological approach to license plate localisation can be found in [15,12,3].

3 Proposed Method

The underlying idea of the proposed method is to use the geometrical information of the camera-road system in order to extract the distance covered by the observed vehicles between consecutive videoframes and hence calculate the passing vehicles velocity. This concept, followed by considerations about the image acquisition is described in Section 3.1. Next, the licence plate detection and recognition algorithm is used. For better and faster results, image masking, contour analysis and grammatical analysis is applied as shown in Sections 3.2 and 3.3. Finally, Section 3.4 describes the speed measurement method in detail.

3.1 Camera Setup and Image Acquisition

Usually photoradars are mounted on the side of the road and cover a relatively small sector so as to photograph vehicles in their direct vicinity. The camera is triggered by the radar detecting an incoming vehicle and a photo is taken from a short distance. In our case, however, such a configuration is not possible as we have no other triggering device but a single camera. The only way of detecting moving vehicles is continuous image registration and analysis. In order to measure the velocity we need at least two images of an approaching car. If am inclined camera is mounted centrally over the road like shown in Fig. 1(a) it will register images like the one shown in Fig. 1(b).



(a) (b)

Fig. 1. The camera mounted over the road and looking at the incoming traffic (a), the view from the camera (b)

Now, in order to establish the distance to the observed vehicles one could utilize the fact that the licence plate is a rectangular object of a well known size. Finding its localization and orientation in space [10] would require however a very precise pinpointing of the plate's corners, which is not possible at far distances due to small resolution of the image. Another method could be based on the licence plate area measurement, but the results would be only slightly better for the same reason.

In our method we use a much more precise mechanism (see Section 3.4 for details). It is based on the observation that with the inclined camera, vehicles that are far away appear at the top of the image and they move down in the image as they approach. Establishing this nonlinear relation between the image location and camera-vehicle distance allows for speed measurement with sufficient precision.

Fig. 2. Example of licence plate thresholding. The images show a car captured in shadow and sunshine. By side presented are the extracted plates (top) and effects of constant thresholding (middle - notice the right plate is unreadable) and adaptive thresholding (bottom - both plates are readable).

Since the proposed system is based exclusively on image analysis the resolution and overall quality of the acquired images is crucial. In our tests we used 5 and 6 megapixel images taken with a bright lens camera. This allowed for shorter exposure time while maintaining good image brightness, contrast and sharpness at low ISO rates. Images were taken at approximately 2 fps, which was sufficient for capturing at least 2 images of the same car even at high speeds and left 500 ms for image processing. That would be enough for a fast PC, but probably not for an embedded solution. The pictures were taken during the day in different weather conditions (from sunny to complete overcast).

3.2 Licence Plate Detection

Majority of LPR methods methods work best in situations when the expected size of a licence plate in an image is known a priori. This is the case of static or roadside photoradar LPR systems where the camera-car distance is almost constant and so is the size of the number plate. In our case, however, the linear dimensions of the licence plate doubles or even triples as cars are approaching the camera, which makes the plate detection algorithms more complicated.

Initially in our experiments we used an edge detection and vertical projection method on images with enhanced contrast. Without the enhancement many dirty and thus low-contrast plates were not found. Unfortunately, apart from succesfully detecting the licence plates, this method also returned many false positives such as car body parts with vertical details, gratings, fences, other letterings etc. This was caused by the character of the acquired images that contained many objects of different scale. In the end, all the found regions had to be filtered in order to exclude the non-plate regions. This was done by character analysis as described in section 3.3.

It turned out later during the experiments, that the initial detection step is completely useless. A horizontal series of neighboring characters defines a licence plate not worse than vertical edges used beforehand, but at the same time it returns the extracted characters that can immediately undergo recognition. The overall processing time was also shorter, which was the most important advantage of this approach.

Finally, the plate detection algorithm based on character detection consisted of the following steps:

1. Adaptive thresholding of the entire image - we used different thresholding parameters for different sections of acquired images experimentally tuned to the expected size of the observed number plates. The adaptive thresholding algorithm was particularly succesful in correct segmentation of licence plates in different lighting conditions as opposed to a constant thresholding method (see Fig. 2).
2. Contour extraction from the binary image obtained in step 1 and analysis - rejection of all the contours that do not fall within experimentally defined bounds for size and height to width ratio.
3. Contour groupping - all the contours from step 2 are groupped with their horizontal neighbors. If a contour has too few or too many neighbors of similar size the entire group is rejected.

As the result we obtain not only areas containing licence plates but also extracted characters ordered from left to right belonging to separate plates.

3.3 Character Recognition

The next step of processing is the character classification. All the characters from a single plate are converted into grayscale and scaled down to 7x7 matrix each and normalized as shown in Fig. 3. This particular size was chosen after a number of experiments as it provided the best recognition results. Smaller number of divisions yields too generalized representation and bigger number results in too detailed representation of a particular character.

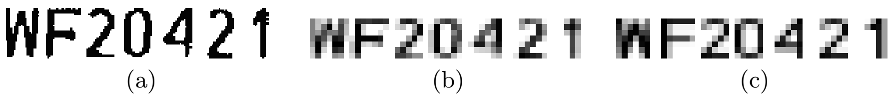


Fig. 3. Extracted characters in original resolution (a) and downsampled to 7x7 pixels (b). The reference characters are shown for comparison (c).

The same scaling and normalization procedure was performed on the reference characters. Only one reference character for each symbol on number plates was used, except for *D*, *8* and *B*, which were the most difficult to differentiate and were represented by two references. For classification template matching with Euclidean metrics was implemented that was further extended by syntax analysis of Polish licence plates. Naturally with such a simple approach and small learning set it was not possible to achive a near 100% recognition rate, but this was not the aim of the research. The identified number plates were used as unique vehicle identifiers to show the feasibility of our speed measurement method described in Section 3.4.

3.4 Speed Measurement

The proposed system is able to measure the speed of incoming vehicles in real-time (on a fast PC). It uses recognized licence plates to identify approaching vehicles and estimate their velocity. The algorithm is able to cope with more than one licence plate at a time. The principle of speed measurement is the following: if we can measure the distance covered by a vehicle between two consecutive frames, we can calculate its speed. The algorithm localizes all license plates (or the coordinates of their centers of gravity in the binarized image) within both frames and finds ono-to-one correspondence between them. Assuming correct plate recognition on both images, we have – for each observed car – two *image positions*: initial on the first frame and final on the second one. As shown Fig. 4, an *image position* y can be converted to the *road distance* d from the reference point A. The difference of the final and the initial *road distance* is the sought lenght of vehicle travel between the two images.

The non-linear relation $d=f(y)$ that is used to calculate the *road distance* d based on the *image position* y of an object at the road level was found experimentally by measuring the image position and the road-level position of the

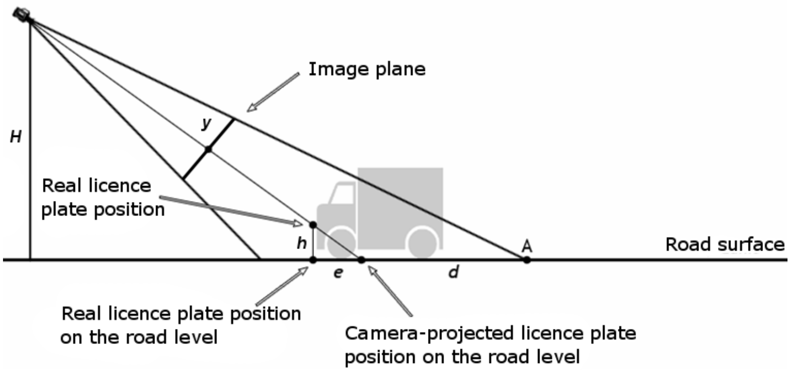


Fig. 4. The principle of vehicle position measurement with a single camera. The distance d of a vehicle from the reference point A in the camera field of view is proportional to the position of the vehicle in the image plane y.

road stripes on one of the pictures in the sequence shown in Fig. 5. Due to the fact that we use the position of the licence plate center as a reference point, an error e in distance measurement is introduced. This error could be eliminated if the precise elevation over the road-level of a given licence plate h was known. Unfortunately the elevation of licence plates varies. The average height of a licence plate was around 40 cm, while approximately 90% of them were mounted between 30 and 50 cm over the street level (as measured for 100 licence plates on one of the main streets in Warsaw). Simple calculations based on the theorem of Thales yield the following formula for the relative error of the distance covered by a car between two consecutive frames: $\delta = \frac{h}{H-h}$.

Fig. 5. A typical sequence of images acquired by our system. Car A is being overtaken by cars B and C. It is clear that car A is the slowest and car B is the fastest among the three. Moreover, car A is maintaining a constant velocity of 45±1 km/h as measured by an onboard GPS device. Velocities of cars B and C are unknown. The average measured speed in km/h returned by our system is: 46,0 (A), 83,7 (B), 62,9 (C).

Assuming that the camera is mounted 7.5 meters over the street level (which was the case in our experiments), the relative error of speed measurement for 90% of the vehicles would be between +4.2% and +6.9%. However, if we consider the average elevation of licence plates of 40 cm and assume that for 90% of vehicles the diversion from the average is ±10 cm, the relative error decreases to an acceptable level of ±1.4%. The above holds only if the licence plate is perfectly localized in the image and the *d=f(y)* relation is precisely found. In real-life situations, the imprecision of the these two measurements may contribute to an additional error as shown in Section 4.

4 Experimental Evalution and Results

We evaluated our algorithm[1] on a number of traffic video sequences of type shown in Fig. 5. We used a car with a licence plate elevated exactly 40 cm above the ground and a GPS device for speed measurement. We assume that the driver was able to maintain constant speed with accuracy of ±1 kmh. The collected data for three different velocities are depicted in Table 1 below.

Table 1. Actual car velocities (in km/h) as indicated by GPS versus values measured with the proposed method. The licence plate elevation was precisely known.

Actual velocity	Measured velocities
43 ± 1	43.3; 44.0; 42.9; 44.1; 42.6; 44.0
55 ± 1	54.9; 56.0; 55.9; 56.2; 56.9
71 ± 1	70.7; 71.1; 71.0; 69.1

The measured velocities' errors are practically within the precision range of the GPS. The final error for the proposed method with 90% confidence level at velocities around 100 km/h should not exceed 4% and is less for lower velocities, which is comparable with commerically available speed radars. Unfortunately for rare cases of extremely high mounted licence plates, the error will by much higher and at the moment there is no compensation mechanism implemented although it can be done based on the size of the observed vehicle.

As mentioned in Section 3.3, the character classification algorithm was rather simple and the correct licence plate identification rate was only around 83%.

Image processing time on a laptop (PentiumM 1.8 GHz) computer was around 1 second for each frame (2816 x 2112), so the algorithm can perform in real time on a fast computer without modifications.

5 Conclusions

This paper introduces a novel concept for vehicle speed measurement based exclusively on image analysis. The experimental evaluation shows that the achieved results are very promising and they are on par with comercially available radar based systems. The main advantage of our approach is low cost and high accuracy of the system.

[1] Authors would like thank student Mr. Marcin Lewkowicz for his help in pursuing this research.

References

1. Fan, X., Fan, G.: Graphical Models for Joint Segmentation and Recognition of License Plate Characters. IEEE Signal Processing Letters 16(1), 10–14 (2009)
2. Chen, Z.X., Liu, C.-Y., Chang, F.-L., Wang, G.Y.: Automatic License-Plate Location and Recognition Based on Feature Salience. IEEE Trans. on Vehicular Technology 58(7), 3781–3786 (2009)
3. Iwanowski, M.: Metody morfologiczne w przetwarzaniu obrazow cyfrowych, AOW EXIT (2009)
4. Maduro, C., Batista, K., Batista, J.: Estimating Vehicle Velocity Using Image Profiles on Rectified Images. In: Araujo, H., Mendonça, A.M., Pinho, A.J., Torres, M.I. (eds.) IbPRIA 2009. LNCS, vol. 5524, pp. 64–71. Springer, Heidelberg (2009)
5. Lin, H.Y., Li, K.J., Chang, C.-H.: Vehicle speed detection from a single motion blurred image. Image and Vision Computing 26, 1327–1337 (2006)
6. Donoser, M., Arth, C., Bischof, H.: Detecting, Tracking and Recognizing License Plates. In: Yagi, Y., Kang, S.B., Kweon, I.S., Zha, H. (eds.) ACCV 2007, Part II. LNCS, vol. 4844, pp. 447–456. Springer, Heidelberg (2007)
7. Cho, Y., Rice, J.: Estimating Velocity Fields on a Freeway From Low-Resolution Videos. IEEE Trans. on Intelligent Transportation Systems 7(4), 463–470 (2006)
8. Glowny Urzad Statystyczny, Transport - Wyniki dzialalnosci w 2005 r., Departament Statystyki Uslug GUS, Warszawa (2006) (in Polish)
9. Shapiro, V., Gluchev, G., Dimov, D.: Towards a multinational car license plate recognition system. Machine Vision and Applications 17, 173–183 (2006)
10. Staniak, M., Czajewski, W.: Lokalizacja i identyfikacja obiektow dla celu manipulacji Postepy Robotyki: Systemy i wspoldzialanie robotow. In: Wydawnictwa Komunikacji i Lacznosci, Warszawa, vol. II, pp. 85–94 (2006) (in Polish)
11. Wu, Y., Shen, J., Dai, M.: Traffic object detections and its action analysis. Pattern Recognition Letters 26, 1963–1984 (2005)
12. Iwanowski, M.: Automatic car number plates detection using morphological image processing. Przeglad Elektrotechniczny 81, 58–61 (2005)
13. Chang, S.L., Chen, L.S., Chung, Y.C., Chen, S.-W.: Automatic License Plate Recognition. IEEE Trans.on Intelligent Transportation Systems 5(1), 42–53 (2004)
14. Shapiro, V., Dimov, D., Bonchev, S., Velichkov, V., Gluhchev, G.: Adaptive License Plate Image Extraction. In: Proc. of CompSysTech. 2003 (2003)
15. Hsieh, J.W., Yu, S.-H., Chen, Y.-S.: Morphology-based License Plate Detection from Complex Scenes. In: Proc. of ICPR 2002 Conf. (2002)
16. Dailey, D.J., Cathey, F.W., Pumrin, S.: An algorithm to estimate mean traffic speed using uncalibrated cameras. IEEE Trans. on Intelligent Transportation Systems 1(2), 98–107 (2000)
17. Siyal, M.Y., Fathy, M.: Image Processing Techniques For Real-Time Qualitative Road Traffic Data Analysis. Real-Time Imaging 5, 271–278 (1999)
18. Duric, Z., Rivlin, E., Rosenfeld, A.: Understanding object motion. Image and Vision Computing 16, 185–797 (1998)
19. Broida, T.J., Chellappa, R.: Estimation of Object Motion Parameters from Noisy Images. IEEE Trans. on Pattern Analysis and Machine Intelligence PAMI-8(1), 90–100 (1986)