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Procedia Engineering 29 (2012) 1938 – 1943

Procedia Engineering

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2012 International Workshop on Information and Electronics Engineering (IWIEE)

A Novel Traffic Stream Detection Method Based on Inverse Perspective Mapping

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Abstract

Traffic stream detection in intersection is an important part of Intelligent Transportation System (ITS). The traditional image-based detection methods are vulnerable to background noise and the perspective effect of stationary camera, thus we propose a novel traffic stream detection method based on inverse perspective mapping (IPM). The method firstly eliminates the geometric distortion of sequence image using IPM transform, and extracts the marking lines in lane area by introducing in geometric constraints of structural road. On this basis, we extract the contours of vehicles queue using background difference method, and give two kinds of metrics to measure traffic stream, that is vehicles contour area based method and vehicles queue length based method. Experiment results show that the proposed algorithm is effective and robust.

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Keywords: inverse perspective mapping (IPM); marking lines detection; traffic stream detection; background difference method

1. Introduction

It is significant to get accurate real-time road traffic information (such as traffic direction, traffic density, vehicle queue length, etc.) to help traffic management department for scientific and effective use of existing transport resources, vehicles scheduling and traffic control decision makings. The commonly used traffic detection methods include electromagnetic induction device method, ultrasonic detection method and video-based traffic detection method. The first two methods tend to bring about measurement error due to the fact that the speed and type of vehicles vary dramatically and their reflected signals are

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doi:10.1016/j.proeng.2012.01.240

always unstable in practice, while video-based traffic stream detection method benefits much from its low-destructive, economic efficiency, and high degree of automation characteristics and is widely used currently.

Traditional video-based traffic stream detection methods often first extract the absolute difference between the traffic queue and the background image, then segment the differential image with a proper threshold, and reconstruct the outline of foreground vehicles through filtering and morphological processing. In practical applications, however, such method is vulnerable to illumination changes, shadows and other extraneous events. In addition, as images obtained from the camera have a strong perspective effect, the contours of vehicles queue tend to produce geometric visual distortion, which will definitely reduce the measure accuracy to some extent.

To ensure efficient detection of traffic stream under different environmental conditions and improve its measurement accuracy, this paper fully utilizes the feature of structural road and proposes a novel processing method to detect the traffic stream of flat road. The proposed method firstly eliminates the perspective effect of original image by using an improved inverse perspective transform (IPM) algorithm[1]; on this basis, ameliorate the performance of Hough transformation by introducing in parallel nature and distance constraints between marking lines to detection lanes area in the image; Then, adopt the background difference method to extract contours of vehicles in all lanes and give two ways of traffic flow measurement according to the control points in area of interest.

2. Description of inverse perspective transform

In the Euclidean space, define two kinds of description of traffic scene, i.e. the world coordinate system W and the image coordinate system I. The coordinate transformation relationship from I to W can be shown in Fig. 1.

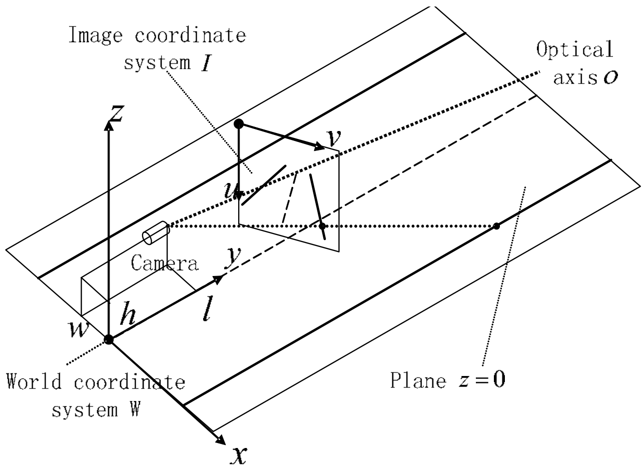

Fig. 1. Schematic diagram of IPM.

Assuming that the coordinates of mounting position of the camera in the world coordinate system is (w, l, h), the calibrated parameters of camera are as follows; γ represents the angle between the projection line of optical axis at z=0 plane and y-axis (Fig. 2-a); θ represents the deviation angle of optical axis to z=0 plane (Fig. 2-b); 2α represents field of view of the camera in horizontal and vertical direction (Fig. 2-a,b); R_x and R_y represent the horizontal and vertical resolution of traffic image.

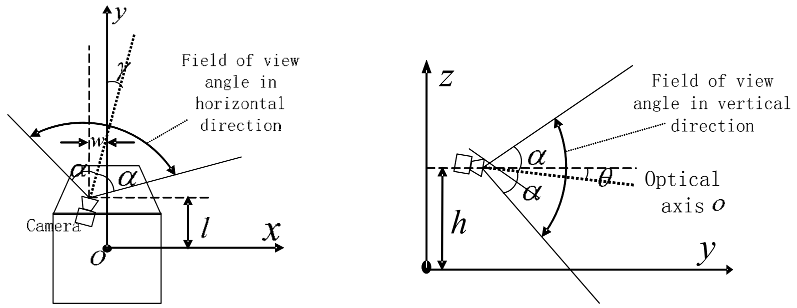

Fig. 2. Cutaway view of the world coordinate system. (a) Plane of xoy. (b) Plane of yoz.

Through coordinate transformation, the inverse perspective transform model from I to W is shown in equation (1).

$$
\begin{aligned}
x &= h\times ctg\left(\frac{2\alpha}{R_y-1}u-\alpha+\theta\right)\times\sin\left(\frac{2\alpha}{R_x-1}v-\alpha+\gamma\right)+d,\\
y &= h\times ctg\left(\frac{2\alpha}{R_y-1}u-\alpha+\theta\right)\times\cos\left(\frac{2\alpha}{R_x-1}v-\alpha+\gamma\right)+l.
\end{aligned}
\tag{1}
$$

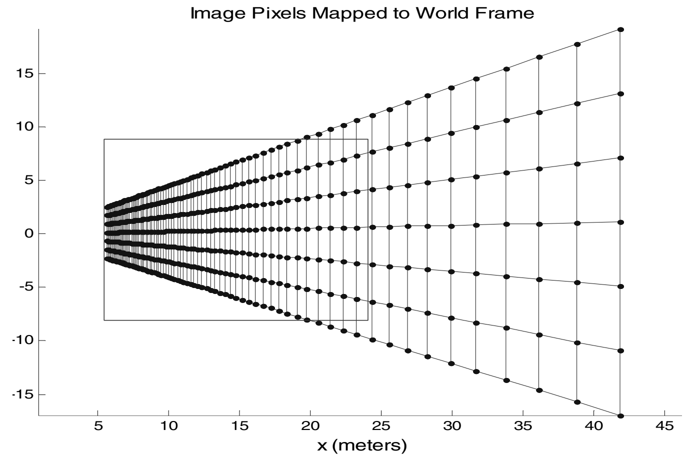

Fig. 3. Pixel correspondence relations before and after IPM transform.

However, in practical systems, the direct utilization of (1) will bring about blank pixels in the resultant image [2], as shown in Fig. 4-b, because this equation is nonlinear and such transformation is not bidirectional one-to-one mapping, but unidirectional to one mapping. Therefore, we adopt a reverse IPM transform model, just as shown in equation (2), which stuffs the resultant image by calculating its mapping source in original image. In such way, we can ensure that each pixel in resultant image will find its correspondence in original image and accordingly remove blank points effectively (Fig. 4-c).

$$
\mathrm{u}=\frac{(R_y-1)\left(\arctan\dfrac{h}{\sqrt{(x-d)^2+(y-l)^2}}+\alpha-\theta\right)}{2\alpha},\quad v=\frac{(R_x-1)\left(\arctan\dfrac{x-d}{y-l}+\alpha-\gamma\right)}{2\alpha}
\tag{2}
$$

The comparison of IPM processing result using (1) and (2) respectively is shown in Fig. 4.

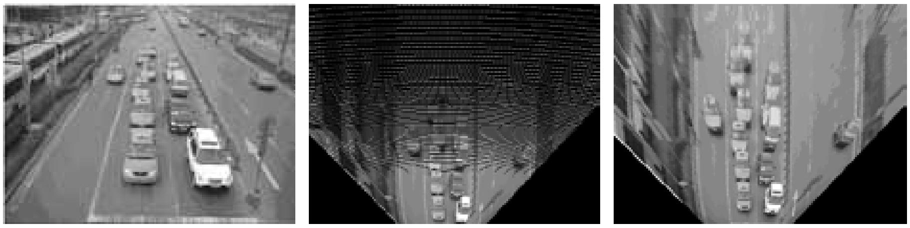

Fig. 4. The results of IPM algorithm. (a)The original image. (b) IPM transformation using (1). (c) IPM transformation using (2).

3. Traffic stream Detection based on IPM algorithm

3.1. Marking lines extraction based on geometric constraints of structural road

To detect vehicles queue in image sequence, we first need to locate lane area in traffic scene that we are interested in, usually named Region of Interest (ROI) [3]. Hough transform [4] is a generally used method, which in essence is a kind of clustering to find a set of pixels satisfying specific analytical form of expression. However, it is difficult to effectively extract lane markings by only simply using this kind of algorithm for it is sensitive to the impact of background changes, just as the case shown in Fig. 5.

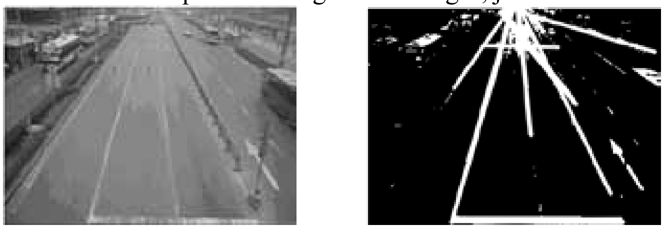

Fig. 5. Lane markings detection result of Hough transformation. (a) The original image. (b) Result image after traditional Hough detection processing.

For images processed by IPM transform operation, roads demonstrate its inherent geometry characteristic, thus it is significant to add the following constraints to locate lanes area on the basis of Hough transformation.

- The angle between marking line and the horizontal direction of image coordinate system is not too small.
- Marking lines should be relatively parallel to each other.
- The distance between adjacent marking lines should be appropriate, and the width of adjacent lanes should be roughly identical.

Based on the above constraints, we use the following search algorithm to locate marking lines in image sequences..

Step 1: Detect all the straight lines in the image using Hough transformation algorithm and get a collection of A. Each line is indicated with its intersection point and angle with horizontal direction, i.e. Line(theta, X_label).

Step 2: Traverse the collection of A, find out all the lines with angle of theta larger than ANGLE_TH and form a subset named B, in which elements are candidate of real marking lines. ANGLE_TH is defined as the lower bound.

Step 3: if two lines in set of B are subject to the inequality $|theta_m\text{-}theta_n| \leqslant$ TORRANCE_TH, Then we judge whether these two candidate lines meet the parallel constraints of practical marking lines. Test all lines in set B with the assertion and get a new candidate set called C.

Step 4: Calculate the distance of every two lines in set C and obtain the real marking lines set D, in which the distance of all the lines is larger than a proper parameter DIS_TH.

Assign proper values for parameters ANGLE_TH, TORRANCE_TH and DIS_TH according to the specific applications, and we can easily find all marking lines in the image. The processing result is shown in Fig. 6.

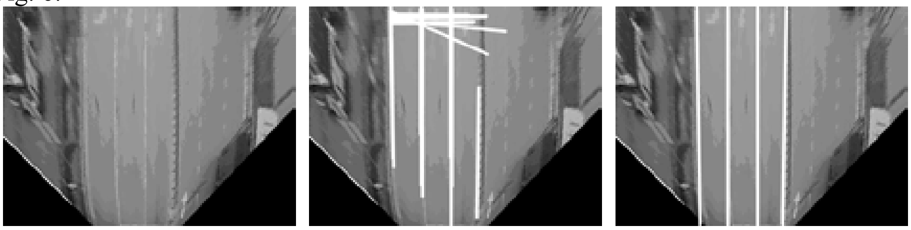

Fig. 6. Marking lines detection in lane area. (a)The original traffic image after IPM. (b) Result image of traditional Hough detection. (c) Result image using the algorithm proposed in this paper.

As can be seen in Fig. 6, by taking advantage of the distortion correction feature of IPM transform and introducing in structural constraints of marking lines, we can effectively detect lane area in traffic image.

3.2. Contours of vehicle queue extraction based on background difference method

Set the rectangular area surrounded by the border markings lines as region of interest, and adopt background differencing method to extract foreground vehicles in traffic images [5], as shown in Fig. 7-b.

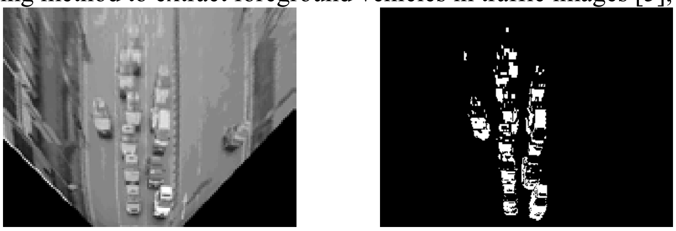

Fig. 7. Contours of Vehicle queue detection in lane area. (a) Traffic image after IPM. (b) Result of vehicle queue extraction.

3.3. Traffic stream detection

We make use of the distortion correction characteristic of IPM transform and develop two ways of measurement to count traffic stream respectively, which are vehicles contour area based method and vehicles queue length based method.

The former method firstly extracts all the rectangular contours of vehicles in lane area; then finds out the control points of the minimum outsourcing convex set of all the rectangles and regards the area surrounded by the convex sets as a measurement of traffic stream.

The later method extracts the rectangular contours of vehicles in lane area at first too; however, it set the four vertices of a rectangular as control points; then finds out the minimum bounding rectangular which contains all the control points, calculate length of the bounding rectangular and adds the length of all the lane together to measure the traffic flow of the intersection at this moment.

Under these two measurement criteria, the traffic stream detection result is shown as follows.

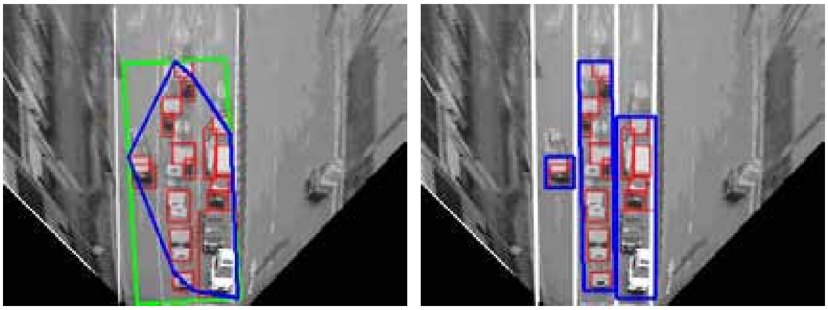

Fig. 8. Traffic stream detection result. (a) Result of vehicles contour area based method. (b) Result of vehicles queue length based method.

As seen in the Fig. 8, under the assumption that average gap between vehicles and average geometry length of each vehicle in traffic queue is similar, both of the proposed methods can be used as an effective measurement of traffic streams in intersections. Besides, since IPM transform is characteristic for visual bias elimination, method proposed in this paper is more practical and obviously superior to traditional methods.

4. Conclusions

The IPM-based traffic stream detection method proposed in this paper has the following characteristics.

- Effectively eliminate the pixel blanks of basic IPM algorithm by adopting a kind of reverse transformation, and improve the image quality after IPM operation.
- Utilize the inherent geometry constraint of structural road as a search constraint to improve the marking lines detection accuracy of Hough transformation.
- Make use of IPM transform to eliminate the geometric distortion of traffic image and develop two kinds of methods to measure traffic stream, whose results are more intuitive and accurate than the traditional methods.

However, the search constraints proposed in this paper do not satisfy with undulating roads or roads with corners. Therefore, it is our future study work to generalize some more reasonable and universal constraints suitable for all type of roads and all traffic conditions.

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