A NOVEL APPROACH TO CAMERA CALIBRATION METHOD FOR SMART PHONES UNDER ROAD ENVIRONMENT

Bijun Le, Jian Zhou, Maosheng Ye, Yuan Guo

State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, China, (Lee, zj2007, guoyuan)@whu.edu.cn

School of Geodesy and Geomatics, Wuhan University, China, heryms@163.com

Commission V, WG V/1

KEY WORD: Road Lane Markers, Machine Learning, Camera Calibration, Smart Phone

ABSTRACT:

Monocular vision-based lane departure warning system has been increasingly used in advanced driver assistance systems (ADAS). By the use of the lane mark detection and identification, we proposed an automatic and efficient camera calibration method for smart phones. At first, we can detect the lane marker feature in a perspective space and calculate edges of lane markers in image sequences. Second, because of the width of lane marker and road lane is fixed under the standard structural road environment, we can automatically build a transformation matrix between perspective space and 3D space and get a local map in vehicle coordinate system. In order to verify the validity of this method, we installed a smart phone in the ‘TuZhi’ self-driving car of Wuhan University and recorded more than 100km image data on the road in Wuhan. According to the result, we can calculate the positions of lane markers which are accurate enough for the self-driving car to run smoothly on the road.

1. INTRODUCTION

Camera calibration is the crucial step in photogrammetry, which is the determination of parameters necessary to establish the projection equations between the world coordinate system and image geometry\[1\]-\[2\]. In self-driving car, obtaining the camera parameters called Pos information is the necessary part for the 3D reconstruction which is a great implement in the advanced driver assistance systems\[3\]-\[4\].

There are many approaches for camera calibration. The commonest way is to make full use of the control points in the world coordinate system and their corresponding image points in the image plane to solve the parameters by the collinearity equation or direct linear transformation, namely spatial resection or DLT\[5\]-\[6\]. Another typical one based on monocular vision, is to use the geometrical relationship of the three vanishing points to calculate the parameters called camera self-calibration\[7\]-\[9\]. However, both methods mentioned above are not practical and applicable in self-driving car due to their complexity in computation and the requirement in control points. The first method needs considerable time to match the corresponding points. The second is ineffective when there are no three vanishing points. Therefore, in this paper, we propose a new camera calibration method that uses single monocular image by estimating the single vanishing point and width of the lane marker. It is not only greatly simplifies the computation, but also performs well in precision. This method was applied in the TuZhi car and the stable results suggest its promising future in the application of real time self-driving.

2. Methodology

2.1 Lane Detection

At first, we can detect the lane marker feature points in a
perspective space and calculate edges of lane markers in image sequences. In order to determine which points belong to lane marker, the Hough transform is used to fitting the possible line segments of lane markers as the initial information of the lane markers. Then, we output the lines segments of the lane markers by iterating the initial information until it converges.

![Diagram of lane detection process]

Fig 1. The process of lane detection

A scanning line is set to detect the row which contains lane markings in the image. The lane markings displayed in the image as a white line having a constant width. As the figure 2 shows, the black line means the gray value of pixels along the scanning line. In order to accurate locate edges of a lane marking, we propose a novel slider window with the length of 2*N+1 to process the image data. Because of the regularity of the gradient of the lane marker, the edge points of the lane marker will be appearing on the paired max and the min position with fixed width w.

![Sliding window diagram]

Fig 2. The sliding window

$g(x) = \sum_{i=0}^{N} h(k) \ast f(i)$ (1)

Transform maps the image plane into the parameter space and count the line parameters. After the Hough Transformation, the lines are shown clearly in the image plane.

![Hough Transform diagram]

Fig 3. Hough Transform

Then we apply Hough Transform on the image. The Hough We make an information collector to store the information of lane marker to help our algorithm define which are true lane markers and how to choose them from possible line segments. By iterating, we can finally output the lane markers which have a high confidence level of 95%.

![Edge points of lane markings](a)

![Line segment of lane markings](b)

Fig 4. (a) edge points of lane markings. (b) line segment of lane markings
2.2 Extraction of Vanishing Points

A set of parallel lines in the real scenes which do not parallel to the image plane when projected to the image plane. And the vanishing points which contain the direction information of the lines are defined by the intersection points of the lines. Finding the vanishing point greatly helps determine the estimation of attitude parameters of the camera since the relation between vanishing points and attitude parameters. In addition, in the road system, this process of analyzing will be greatly simplified by the lane marker detection.

\[ V_i = m_i \times m_j \]  \hspace{1cm} (2)

And because of the high effectiveness of lane detection algorithm, the inaccuracy of the vanishing point is less than 2 pixels.

2.3 Attitude Parameters Measuring

In order to achieve a better result of attitude parameters, building a model revealing the relationship between the world coordinate and the image coordinate system is an essential part. What’s more, the complexity of the model will greatly influence the process of the coordinate transform. Thus we create the model based on the position and pose of the camera. The figure 7 shows the model. The \( \theta \) and \( \gamma \) stand for the pitch angle and the course angle, \( z \) is the camera height.

Once the model is built, a 2D point can be projected into a 3D point by using the attitude parameters and the equalities. In other words, with the connection between the two coordinate system created, the 3D reconstruction of the road will be easily to complete.

According to the parameters mentioned above, the formula revealing the relationship between the two coordinate systems can be derived.
Fig 7. the camera and road model

\[ x(u,v) = h \times \cot \left( \theta - \alpha + u \times \frac{2\alpha}{m-1} \right) \times \cos \left( \gamma - \beta + v \times \frac{2\beta}{n-1} \right) + x_0 \]  
\[ y(u,v) = h \times \cot \left( \theta - \alpha + u \times \frac{2\alpha}{m-1} \right) \times \sin \left( \gamma - \beta + v \times \frac{2\beta}{n-1} \right) + y_0 \]

(4)
(5)

where \( u, v \)=image coordinate; \( x, y, z \)=space coordinate; \( \theta \)=pitch angle; \( \gamma \)=course angle; \( \alpha \)=transverse angle of view; Longitudinal angle of view; \( h \)=camera height \( m, n \)=size of the image; \( x0, y0, z0 \)=camera’s space coordinate.

From the formula above, another formula which transform the world coordinate into image coordinate can be derived

\[ u(x,y,z_0) = \tan^{-1} \left( \frac{h \times \sin \left[ \tan^{-1} \left( \frac{y - y_0}{x - x_0} \right) \right]}{2\alpha/m - 1} \right) - \left( \theta - \alpha \right) \]  
\[ v(x,y,z_0) = \tan^{-1} \left( \frac{y - y_0}{x - x_0} \right) - \left( \gamma - \beta \right) \]

(6)
(7)

Thus we are creating the relationship between the two coordinate systems. According to the definition of vanishing point, we can easily get the expression of it. In this part, we let \( x \) tend to infinity. The result is:

\[ \text{Vanish}_x = \lim_{x \to \infty} u(x,y,z_0) \]  
\[ \text{Vanish}_y = \lim_{x \to \infty} v(x,y,z_0) \]  
\[ \text{Vanish}_z = \frac{m-1}{2} - \frac{m-1}{2\alpha} \theta \]  
\[ \text{Vanish}_\gamma = \frac{n-1}{2} - \frac{n-1}{2\beta} \gamma \]

(8)
(9)
(10)
(11)

So far, it is easily to find that the attitude parameters are highly related linear with the vanishing points. Therefore, it is very convenient to look up for the location of the vanishing point to compute the attitude parameters.

### 2.4 Spatial Constraint to Solve Camera Height

Once we get the attitude parameters, we can use the formula above or create the Rotation matrix to recover the connection between the real space and images. We get a point in the image and then transform it into the point in the real world or the scene.

For the camera height \( h \), we put forward a new and highly effective approach to calculate it. Because of the width of lane marker and road lane is fixed under the standard structural road environment, we can automatically build a transformation matrix between perspective space and 3D space and solve the \( h \)
parameter.

For the edge points on the lane markers, we find the corresponding points by the regulations of parallel. By the least square fitting, not only can the parameter $h$ be solved, but also the accuracy of attitude parameters can be greatly improved. Strictly speaking, because of the existence of other vanishing points, the distance in the real world of the selected points are not equal to the lane width. But we can prove that this error is less than 2 pixels which is a very small error that can be negligible under the condition of $\gamma < 5^\circ$.

3. **Experiment**

We test our algorithm in the self-driving car 'TuZhi' (figure 8) with smart phone. The focal length is 1090 mm, each frame's size is 1280×720. With the result of lane detection, the vanishing point with high accuracy can be calculated. According to the formula above, the attitude parameter and camera height $h$ can be estimated. Thus, we apply inverse perspective transformation on the image to reconstruct the road. With a set of continuous images, the road can be stitched. In addition, the width of the road or the distance between cars can be estimated accurately. From figure 9, the results of the 3D reconstruction are clearly shown. All the roads and lane markers become a set of parallels again.

![Fig 8. 'TuZhi' self-driving car.](image)

![Fig 8. Experiment result, figure a is the original image, figure b is the result of 3D reconstruction](image)

4. **Conclusion**

We have proposed a simple and real-time approach for the camera calibration, based on the vanishing points and the geometrical constraint of the lane marker width. By using the images from smart phone installed on the 'TuZhi' car, the result is accurate enough for many applications. As its simplification in computation, it can be widely used in self-driving car.
However, this method's precision is closely related to the
improvement in the work.

**Acknowledge**

I would like personally thank the following people and institutes
which support me a lot with my gratitude.

At first, without the help of my tutor BiJun Lee, I would not
complete my experiment successfully. It is the kind
encouragement and massive instructions that benefit me a lot.

Then, I wish to express my gratitude to the funding of the
program, Chinese National Natural Science Foundation. With
their great support, I can devote myself to the experiment and
research.

Finally, I want to thank all the people in the laboratory who
supplied me a lot of data of great value.

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