Sensors & Transducers, Vol. 181, Issue 10, October 2014, pp. 23-29

Sensors & Transducers
© 2014 by IFSA Publishing, S. L.
http://www.sensorsportal.com

Study on Determination of Preceding Vehicle Motion State at the Traffic Lights Intersection

[1] Cailin Wu, [2] Huicheng Yang

[1] China College of Electrical Engineering, Maanshan Technical College, Maanshan 241000, China

[2] Anhui Provincial Key Laboratory of Electric and Control, Anhui Polytechnic University, Wuhu 241000, China

E-mail: mzywcl@163.com, hcyang@ahpu.edu.cn

Received: 9 July 2014 /Accepted: 30 September 2014 /Published: 31 October 2014

Abstract: In order to enhance the security of automotive safety systems and reduce traffic accidents in traffic lights intersection, In view of this, it is proposed to apply the distance measurement technology of binocular vision ranging in determination of preceding vehicle motion state at the traffic lights intersection, We study the determination of preceding vehicle motion state at the traffic lights intersection based on binocular vision. The system, which is divided into four steps, adopts the theory combining the binocular stereo vision principle and the triangulation principle. First of all, from different angles, image information with preceding vehicles and traffic lights, collected by two CCD cameras, is processed and positioned. Next, two pairs of corresponding feature matching points is obtained by using the stereo matching method. Furthermore, the distance between the cameras and the preceding vehicle, and the distance between the cameras and the traffic lights are determined, according to the camera calibration technique, the parallax disparity principle and the triangulation principle. Finally, the determination about the motion state of traffic lights intersection is determined according to the distance difference principle. Experimental results show that the design, with high measurement accuracy and application value, realize the determination of preceding vehicle's motion state at traffic lights intersection. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Traffic lights intersection, Binocular stereo vision, Camera calibration, Three-dimensional distance, Determination of preceding vehicle motion state.

1. Introduction

The safety of traffic lights intersection is essential, so we use binocular stereo visual technology to detect preceding vehicle motion state at traffic lights intersection. Binocular stereo distance measure is still a heavy and difficult task in the field of the security of automotive driving. The topic based on parallax principle, is an important part of the machine vision. Its research is focused on the position information of the object. It directly simulates the way of human visual processes image information. Generally, the two images of the measured object are obtained by dual cameras in different positions at the same time. Or, the images are obtained by a single camera panning in different positions at different times. Then, the message is handled, adjusted, located and matched. According to the theory of binocular parallax, the three-dimensional of the object is restored, and the three dimensional outline of the object and the real position is rebuilded. In this way, the actual distance information of the measured target object [2] is acquired by determining the depth information of the object and reconstructing and recognizing the object. In recent years, experts and scholars at home and abroad have been doing massive research in binocular stereo vision and gaining certain achievement.

Existing measuring methods mainly include active ranging and passive ranging. The former one includes laser ranging, ultrasonic ranging and infrared distance and so on. The latter one include based on binocular vision ranging, based on image processing ranging and based on different angles ranging, etc. The active ranging is a way of emission of laser, ultrasonic and infrared to the target object. The reflected laser beam is received by the photoreceptor and the reflected wave is received by the ultrasonic receiver. And then the distance is calculated by the time difference between the measured laser, ultrasonic and infrared and the received reflected laser, ultrasonic and infrared. The passive ranging uses reflected light, to collect images through image capturing device. According to certain geometric features and related principles to process and analysis images, and then it realize the measurement of the target distance [3]. Compared with passive ranging, active ranging has the advantages of without emitting any signals, simple structure, easy to operate, good concealment, repeatable measurements, rapid measurement and so on. So, binocular stereo ranging technology is widely used [6]. This article propose the method using parallel binocular stereo vision ranging technology to obtain the distance from cameras to the front vehicle and the distance from cameras to the traffic light, so as to realize the determination of front vehicles movement state of traffic lights intersection according to distance difference principle. The experimental results indicate that the system design with high-precision measuring, simple and high speed is effectively able to realize the determination of front vehicles movement state of traffic lights intersection.

2. Principle of Binocular Stereo Vision System

The binocular stereo vision system that is based on parallax principle simulates directly the way of human using both eyes to get three-dimensional information. The system is generally composed by a single camera or double cameras. That is, two images of the measured object are obtained through panning a camera from different locations at different times. Or the images are obtained by two cameras from different locations at the same time. Because of imaging differences result of the same pixel of the same target object on the different projected image, namely, the same pixel if projection on the left image then position on the left and if projection on the right image then position on the right, the different locations on the same pixel of the target object appear, which is binocular parallax. The binocular parallax directly reflects the depth information from the camera to the target object. It can restore three-dimensional geometric information of the object, reestablish the three-dimensional shape and the actual position, make sure the depth information of the object, acquire the information of the actual distance from the camera to the measured object according to studying binocular disparity.

The system utilizes the most classic parallel binocular stereo vision system, which is consisted of two placed parallel identical CCD cameras. The geometric relationship is shown in Fig. 1. Supposing M is a point of the target object. Where f and S represent the effective focal length and the depth distance from the cameras to the target object respectively.

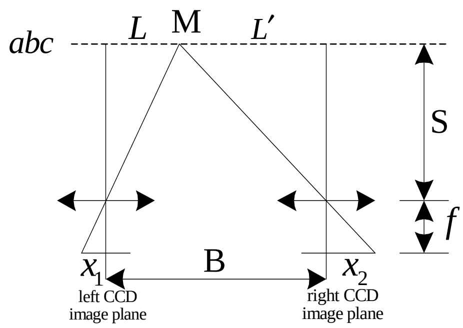


Fig. 1. Principle of parallel binocular CCD parallax ranging.

The two parallel disposed baselines represent two images obtained by camera shooting the same object point (M) at the same time. Where x_1 and x_2 represent the positions of M imaging in the two images respectively [6]. By the triangle similarity theory, the relationship is followed as given in equation (1.1).

$$\begin{cases} \dfrac{L}{x_1} = \dfrac{S}{f} \\ \dfrac{L'}{x_2} = \dfrac{S}{f} \\ B = L + L' \end{cases}, \tag{1.1}$$

Supposing, $x = x_1 + x_2$, after collating, the formula (1.1) is mathematically represented as equation (1.2).

$$S = Bf / x , \tag{1.2}$$

The formula (1.2) shows that knowing S (the distance from camera to object point), B (arm length) and f (effective focal length), we can see that S is inversely proportional to x. In other words, if the value of x is known then the value of S is calculated.

3. Camera Calibration of Binocular Visual

The camera calibration of binocular stereo vision, the calibration parameters of which include internal and external parameters, is the main components of the stereo vision system. In order to solve the internal and external camera parameters, the following four steps must be done by using the camera model. First of all, the acquired image information is processed. Secondly, the geometric information of the object is recovered. Thirdly, the relationship between the camera position and the target is established. Finally, the image coordinate and the world coordinate are got.

3.1. Camera Model

The camera model is the approach of camera calibration. It is to obtain a two-dimensional projection image using imaging transform. Scilicet, exploiting imaging lens to get two-dimensional projection image, we project the three-dimensional information of space images to the two-dimensional image plane of camera. The system adopts classic pinhole imaging camera model as shown in Fig. 2. Supposing E is any point in space. e is its projection position in the image plane and it is also the point of intersection of OE connection and image plane.

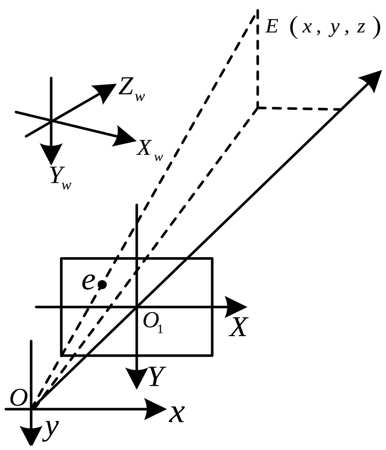


Fig. 2. The principle of pinhole imaging camera model.

The world coordinate of E, which is at any point space, is $X_w = (X_w, Y_w, Z_w, 1)^T$. Supposing the coordinate of camera coordinate system is $x = (x, y, z, 1)^T$ and t is three-dimensional translation vector. R is an orthogonal matrix of $3*3$ and E is an orthogonal matrix of $4*4$ and $0 = (0 \quad 0 \quad 0)^T$. The existed of the geometric relationships is followed as given in equation (2.1).

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} = M \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}, \tag{2.1}$$

(X, Y) is the image coordinates of e. (x, y, z) is the camera coordinate of spatial point E. $(u, v, 1)$ is the projection homogeneous coordinates of E in the image coordinate system. f represents the distance between XY and the image plane. The physical size of each pixel in the X-axis and Y-axis direction are dX and dY. From proportional relationship, we can get following equations.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dX} & 0 & u_0 \\ 0 & \frac{1}{dY} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix}, \tag{2.2}$$

$$\begin{cases} X = \dfrac{fx}{z} \\ Y = \dfrac{fy}{z} \end{cases}, \tag{2.3}$$

$$\xi \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = P \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}, \tag{2.4}$$

where ξ is the scale factor. P is the projection matrix. Substituting (2.1) and (2.2) into (2.4), the relationship between E and e is followed as equation (2.5).

$$\xi \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha_x & 0 & u_0 & 0 \\ 0 & \alpha_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} = \tag{2.5}$$

$$= K_1 K_2 X_w = K X_w,$$

Among them, R is a rotation matrix, t is a translation vector, $\alpha_x = f / dX$ is the scale factor in the u-axis or $\alpha_y = f / dY$ is the scale factor in the v-axis and K is a projection matrix of $3*3$. $\alpha_x, \alpha_y, u_0, v_0$ determine K_1 and constitute the internal parameters of the camera at the same time. The position of the world coordinate system determine K_2, which is called external parameter of camera. Determining the value of the matrix K_1, K_2 mean that the internal and external parameters of the camera are determined. And it also realizes the camera calibration [7].

3.2. Camera Calibration

The traditional camera calibration method applies to any camera model, but needing high-precision calibration equipment which is expensive and the calculation and calibration process are complex. This article uses the camera calibration method based on a 2D plane proposed by Zhang Zhengyou etc. and pinhole imaging model. The method is easy to implement and high calibration accuracy without knowing any mobile motion parameters of 2D planar target. In this paper, we make improvements on the basis of Zhang Zhengyou's etc. and realize the standard of internal and external camera parameters. The selected calibration template is the plane chessboard target of $7*9$ as shown in Fig. 3. Fig. 4 is a checkerboard calibration chart and Fig. 5 is the result image after corner extraction.

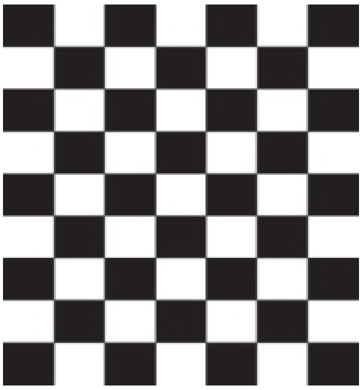


Fig. 3. Checkerboard calibration template.

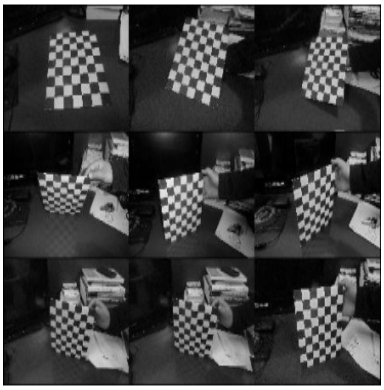


Fig. 4. Checkerboard calibration chart.

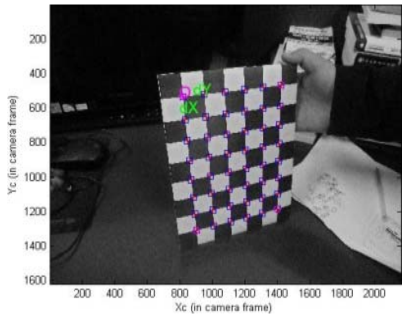


Fig. 5. Result image after corner extraction.

The internal and external parameters of the camera are obtained by the calibration of the cameras as shown in Table 1 and Table 2.

Table 1. The internal parameters.

Parameter names	The internal parameters of camera calibration
Main point (c_c)	$[1109.73361 \quad 790.84093] \pm [7.70256 \quad 1.12948]$
Focal length (f_c)	$[1611.26646 \quad 1615.51706] \pm [2.35420 \quad 5.28701]$
Skew angle ($alpha\_c$)	$[0.00000] \pm [0.00000] \Rightarrow$ angle of pixel axes $= 90.00000 \pm 0.00000$ degrees
Distortion (k_c)	$[-0.02452 \quad -0.07484 \quad -0.00304 \quad 0.00570 \quad 0.00000] \pm [0.04255 \quad 0.23149 \quad 0.00443 \quad 0.00384 \quad 0.00000]$

Table 2. The external parameters.

Parameter names	The external parameters of camera calibration
Rotation matrix (R)	$\begin{bmatrix} -0.07786 & 0.94047 & 0.06596 \\ 0.82298 & 0.00128 & 0.20085 \\ 0.23445 & 0.06107 & -0.88567 \end{bmatrix}$
Translation matrix (t)	$[-59.42696 \quad -62.93115 \quad 417.35110]$

4. Experiment of Determination of Preceding Vehicle Motion State at the Traffic Lights Intersection

In this paper, determination of preceding vehicle motion state at the traffic lights intersection is realized by using binocular stereo vision system and the principle of distance difference. Firstly, the information is collected at traffic lights intersection, and then parallax is got through processing information, locating and using stereo matching methods. Next, the distance from webcam to front vehicle and the distance from webcam to traffic lights are obtained according to camera calibration technique, parallax principle and triangulation principle. Last, determination of preceding vehicle motion state at the traffic lights intersection is achieved according to the principle of distance difference as shown in Fig. 6.

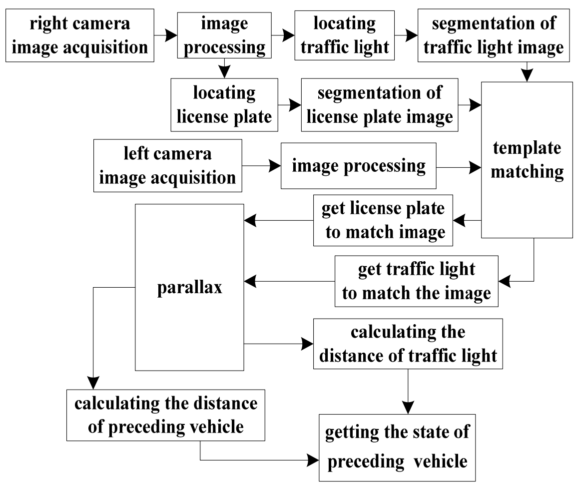


Fig. 6. The flow chart of the system of determining the movement state offront vehicles at traffic lights intersection.

4.1. Simulation of Determination of Preceding Vehicle Motion State at the Traffic Lights Intersection

In the first place, information about the two images of the front traffic lights intersection is collected from different angles by loading placed in parallel around two CCD cameras as shown in Fig. 7.

(a) The right original image of the traffic light intersection.

(b) The left original image of the traffic light intersection.

Fig. 7. The left and the right original images of the front traffic lights.

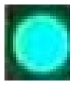
Following this, the plate and the traffic lights are located in line with fixed aspect ratio of plate and the traffic lights lit. The plate image and the traffic lights image after located are obtained by segmentation and are marked out with rectangular box as shown in Fig. 8.

Afterwards, to match with images after image processing according to the methods of stereo matching and the maximum cross-correlation, the matching images of the plate and traffic lights, which are marked out with rectangular box, are obtained as shown in Fig. 9.

Lastly, the located plate image marked out with rectangular box in the right is extracted. The left corner of the rectangular box in the positioned traffic lights image is considered as feature points.

(a) The right located plate image and traffic lights image after segmenting

(b) The right located plate image after segmenting



(c) The right located traffic lights image

Fig. 8. Location and segmentation of the license plate and traffic lights location on the right.

Fig. 9. Matching image of the right license plate and right traffic lights images on the left.

The plate matching points and the traffic lights matching points are picked up by using the global matching method. The pixel coordinates of two matching points in positioning image and matching image are obtained. The two parallaxes are computed. The distance between the webcam and the front vehicle and the distance between the webcam and the traffic lights are calculated according to the internal and external parameters of the camera and the triangulation principle with imaging differences of a same target in different projected image. The value of difference between the distances from the webcam to traffic lights to the distance from the webcam to front vehicle is calculated according to the principle of distance difference. The value subtracts the length of the car body, and the distance between the preceding vehicle and traffic lights is obtained. If the change of the distance is relatively large means the front car is in motion. In contrast, it means the car is in static. So, determination of preceding vehicle motion state at the traffic lights intersection is achieved.

4.2. Results and Discussion

The experiment employs the two CCD cameras placed in parallel to collect two images from different angles and to obtain the result of the front vehicle's state at traffic lights intersection as shown in Fig. 3 and Fig. 4.

Table 3. The result of the front vehicle's stationary state at traffic lights intersection.

Distance to the front vehicle /m	**Distance to traffic lights /m**	**Distance between the front vehicle and traffic lights /m**	**Deviation /m**	**Relative error**
10.41	70.16	55.75	2.95	5.59 %
7.73	62.29	50.56	-2.24	4.25 %
6.27	65.25	54.98	2.18	4.13 %
4.16	62.69	54.53	1.73	3.27 %
2.89	58.27	51.38	-1.42	2.68 %
1.93	56.97	51.04	-1.76	3.34 %

Among them, the front vehicle stop at the traffic lights junction and the distance to the traffic lights is 52.8 m. The deviation and the relative error are described to the distance between the front vehicle and the traffic lights. The results can be drawn from Table 1, the deviations are within 3 meters and the relative errors are within 6 %. Therefore, the state of the front vehicle is stationary. The requirements of the preceding vehicle at traffic lights intersection fully meet.

Table 4. The result of the front vehicle's motive state at traffic lights intersection

Distance to the front vehicle /m	**Distance to traffic lights /m**	**Distance between the front vehicle and traffic lights /m**	**Deviation /m**	**Relative error**
10.36	71.55	57.19	2.39	4.37%
8.19	62.21	50.02	-3.78	7.16%
6.25	65.79	55.54	1.74	3.23%
4.13	57.40	49.27	-3.53	6.69%
2.91	58.35	51.44	-1.36	2.58%
1.87	56.98	51.11	-1.69	3.21%

Among them, the front vehicle stopped at the traffic lights junction and the distance to the traffic lights is 54.8 m at first. Afterward, the front vehicle moved forward one meter and stopped. Ultimate, the front vehicle moved forward one meter and stopped again. The deviation and the relative error are used to describe the distance between the front vehicle and traffic lights. The results can be drawn from Table 2, the deviations are within 3 meters and the relative errors are within 5 %. Therefore, the state of the front vehicle is stationary. The deviations are outside 3 meters and the relative errors are outside 6 %. The requirements of the preceding vehicle motion state at the traffic lights intersection meet fully.

5. Conclusions

In this essay, it is proposed to apply the distance measurement technology of binocular vision ranging in determination of preceding vehicle motion state at the traffic lights intersection through analyzing and doing experiment according to binocular stereo vision system and triangulation principle. The scope of using binocular stereo vision system is expanded. Its focus on the study of binocular stereo vision system using in safe driving at traffic lights intersection. Determination of preceding vehicle motion state at the traffic lights intersection is completed by using binocular stereo vision system, triangulation principle and distance difference principle. The results show that the method meets the requirements for determination of preceding vehicle motion state at the traffic lights intersection. The design of this system has higher measurement accuracy, simple structure, high-speed and feature that is easy to complement.

Acknowledgements

The authors would like to thank of the Foundation of quality engineering teaching and research project of Anhui Province (No. KJ2014ZD004).

References

[1]. Zhang Guangjun, Machine vision, *Science Press*, Beijing, 2005, pp. 24-125.
[2]. Shen Lin, High precision ranging based on binocular CCD, Ph.D. Thesis, *Changchun University of Science and Technology*, Changchun, 2011, pp. 2-5.
[3]. Liu Guoliang, Manufacture and research on parallax ranging system based on CMOS, Ph.D. Thesis, *Nanjing University of Posts and Telecommunications*, Nanjing, 2013, pp. 14-19.
[4]. Gao Weisong, Qian Hui, Chen Peng, Simulation of human motion based on binocular stereo vision, *Computer Engineering*, Vol. 36, Issue 24, 2010, pp. 158-160.
[5]. Liu Pan, Wang Jinhai, Distance measurement system based on parallel binocular stereo vision, *Journal of*

Computer Applications, Vol. 32, Issue S2, 2012, pp. 162-164.
[6]. Steve Vallerand, Masayuki Anbara, Naokazu Yokoya, Binocular vision-based augmented reality system with an increased registration depth using dynamic correction of feature positions, *Proceedings of the IEEE Virtual Reality*, Vol. 10, Issue 7, 2003, pp. 82-27.
[7]. Cai Jianrong, Zhao Wenjie, Stereo vision system calibration based on dual-camera, *Journal of Jiangsu University*, Vol. 27, Issue 1, 2006, pp. 6-9.
[8]. Bo Fanyan, Research on the techniques of digital image matching, Ph.D. Thesis, *Hefei University of Technology*, Hefei, 2010, pp. 34-41.
[9]. Z. Y. Zhang, Flexible camera calibration by viewing a plane from unknown orientations, in *Proceedings of the Seventh IEEE International Conference on Computer Vision*, Kerkyra, 1999, pp. 666-673.
[10]. Zhang Fengjing, Wang Hongyang, Zhang Xuan, Research on the early-warning-of-collision system based on stereo vision, *Ship Electronic Engineering*, Vol. 2, Issue 8, 2012, pp. 134-136.
[11]. Li Xuejuan, Digital rangefinders based on binocular parallax, Ph.D. Thesis, *Tianjin University*, Tianjin, 2007, pp. 7-14.
[12]. Xu Jie, Chen Yimin, Shi Zhilong, Distance measurement using binocular-camera with adaptive focusing, *Journal of Shanghai University*, Vol. 15, Issue 2, 2009, pp. 169-174.

2014 Copyright ©, International Frequency Sensor Association (IFSA) Publishing, S. L. All rights reserved.
(http://www.sensorsportal.com)