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Vehicle Distance Estimation Method Based on Monocular Camera

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***Abstract*— Advanced driver assistance system (ADASs) are important on traffic safety. In ADASs, vehicle distance estimation methods can be classified into sensor based, multiple-camera based, and monocular-vision based methods. However, sensor-based methods mainly apply radar information and are sensitive to the interference of buildings. Multiple-camera based methods require more computation loading. Monocular-vision based methods are more practical, however, their performance need to be improved. In this study, we proposed several techniques to improve the accuracy of the monocular-vision based distance estimation. The proposed algorithm is divided into two stages: feature point extraction, and vehicle distance estimation. In feature point extraction, we find the Harris corners and perform road extraction and find the masks by segmenting the road lane and the tire regions according to their colors and relative locations. Then, polygon approximation is applied to get four corners of the lane. After getting critical feature points, we use the geometric relationship between the camera and the tire bottoms to estimate the distance. However, the tilting angle of the camera may highly affect the accuracy of monocular vehicle distance estimation. In practice, the tilting angle is hard to known explicitly. To solve the problem, we adjust the camera angle according to the standard length of road lanes using yellow and blue feature points. Simulations show that the average error of the proposed algorithm is much lower than that of state-of-the-art methods, which indicates the feasibility of the proposed method.**

***Keywords*— vehicle distance estimation, monocular-vision, Harris corner detection, geometric analysis, ADAS**

I. Introduction

Nowadays, advanced driver assistance systems (ADAS) are popular. Vehicle distance estimation method is an important part of ADAS. In general, distance estimation methods can be divided into two methods: vision-based, and sensor-based. Vision-based systems include stereo vision [1] and monocular vision [2]. Stereo vision method uses the camera with two lenses, it can estimate the long distance accurately. However, computation is complicate for stereo vision methods. Monocular vision distance estimation method uses the camera with a single lens. It can get the optimal result within shorter computation time than stereo-vision method. However, it still cannot achieve high precision in current research. On the other hand, sensor-based method uses the information of radar, laser, the ultrasonic wave, and LIDAR [3] to measure the vehicle distance. However, sensors for the vehicle distance estimation are expensive and can be damaged easily. In this paper, we proposed a vehicle distance estimation method based on monocular vision by getting some critical

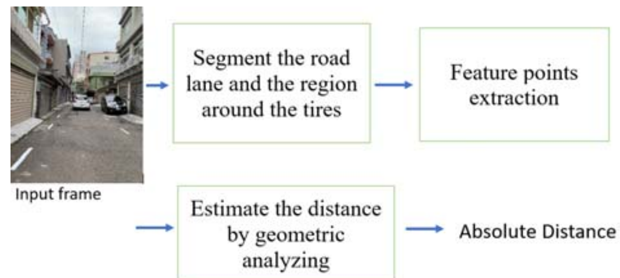

Fig. 1 Flowchart of proposed vehicle distance estimation

feature points. Furthermore, we use those feature points to estimate the distance by geometric relationship between the single lens camera and the feature points.

II. Related Work

Vehicle distance estimation system is used to measure the distance of the car ahead. Many methods are used including, sensor-based method and vision-based method. The related works of these methods are demonstrated in the following sections.

A. Sensor Based Methods

Some of the works use the sensor like radar, LIDAR, or ultrasonic to measure the object distance.

Ultrasonic ranging uses a mechanical wave with a frequency value higher than 20kHz. The ultrasonic ranging devices is combined of a receiver, a transmitter, and a single processing device. It measures the distance by the time the wave passes between the transmitter and the receiver. Ultrasonic wave has a good penetration through snow, fog, and rain. However, the speed of sound wave is relatively slow, so it can't be used in high speed vehicle because of the Doppler effect. Therefore, it is only used in the area of automatic parking systems.

A LIDAR (Laser Imaging, Detection, and Ranging [7]) system emanates UV light and catches the delay time of the reflection to measure the distance between two objects. LIDAR can work without limitations on lighting condition and it has large Doppler shift which can detect the object at low to high speeds. However, Laser is largely impacted by atmospheric and meteorological conditions. LIDAR has been widely used in the remote sensing of the atmosphere, land, oceans and for other aims like estimate the distance of the car ahead to avoid collision.

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B. Vision Based Methods

Vision based method can also be divided into two types one is stereo vision and the other is monocular vision.

Stereo vision method [10] uses the camera with at least 2 lenses. It is a model which is based on two eyes of the human. The difference between the two locations of the same object which taken by two different cameras is defined as “stereo disparity” [9]. “stereo matching” is the process to determine the locations corresponding to the same points in the two images.

Therefore, some of the works use stereo vision to measure the distance of the car ahead. However, the disadvantage of stereo matching process is that it needs high mathematical capacity.

Monocular vision method uses the camera with a single length to measure the distance of the vehicle ahead by some geometric analysis. Huang *et al.* [2] performed a method to measure the longitudinal distance of the vehicle ahead based on the vanishing point of the road lane by detecting the positions of the vehicle and the vanishing point. However, they did not consider the deflection of the vehicle during driving, so the method only can measure the front vehicle. The current monocular vision method still cannot estimate the absolute distance of the vehicle ahead accurately.

III. The Proposed Method

Fig. 1 presents the flowchart of our proposed vehicle distance estimation based on monocular camera.

A. Geometric Relationships for Vehicle Distance Estimation

We proposed a method based on geometric relationship to calculate the absolute distance of the car ahead using the single lens camera. As in Fig. 2, the height of the camera h_c is known. We can calculate the absolute distance D by (1) if we know the angle θ.

The angle of view of the camera θ_{cam} is fixed. We can get it from the specification of the camera. With the value of θ_{cam} and $y1$, and $y2$ points on the image as shown in Fig. 3. We can get the angle θ by (2) where M is the rows of the image.

$$\mathrm{D} = \frac{h_c}{\tan\theta} \tag{1}$$

$$\theta = \frac{\frac{y1+y2}{2} - \frac{M-1}{2}}{M-1} \times \theta_{cam} \tag{2}$$

However, most of the time the angle of the camera might tilt (not horizontal). If we just estimate the absolute distance by the critical feature points and (1), we might get high absolute error comparing with the ground truth.

B. Reference Road Marking

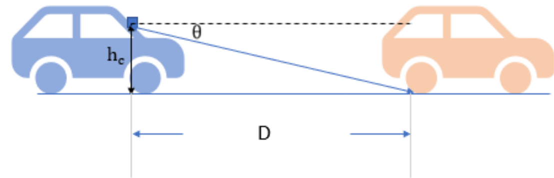

Fig. 2 Geometric relationship between the camera and the vehicle ahead.

Fig. 3 ($x1$, $y1$) and ($x2$, $y2$) are two crossing points of the tire and the road

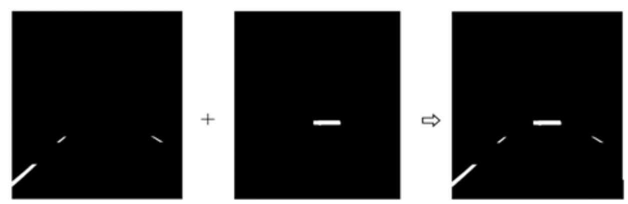

Fig. 4 Road marking (left), the shadow region around the tires (middle), and the final mask (right)

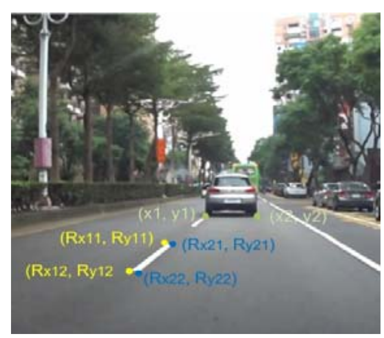

Fig. 5 Corner points of the lane and crossing points of the road and tires.

Therefore, we adjust the angle by using the reference road marking with fixed length 1 m. After extracting the road marking lines and the shadow region around tires according to brightness, as in Fig. 4, we can estimate the length of the road marking lines ($length_{lane}$) using (1) and (2) to measure the difference between distance of the points Ry11, Ry21 and Ry12, Ry22 as shown in Fig. 5.

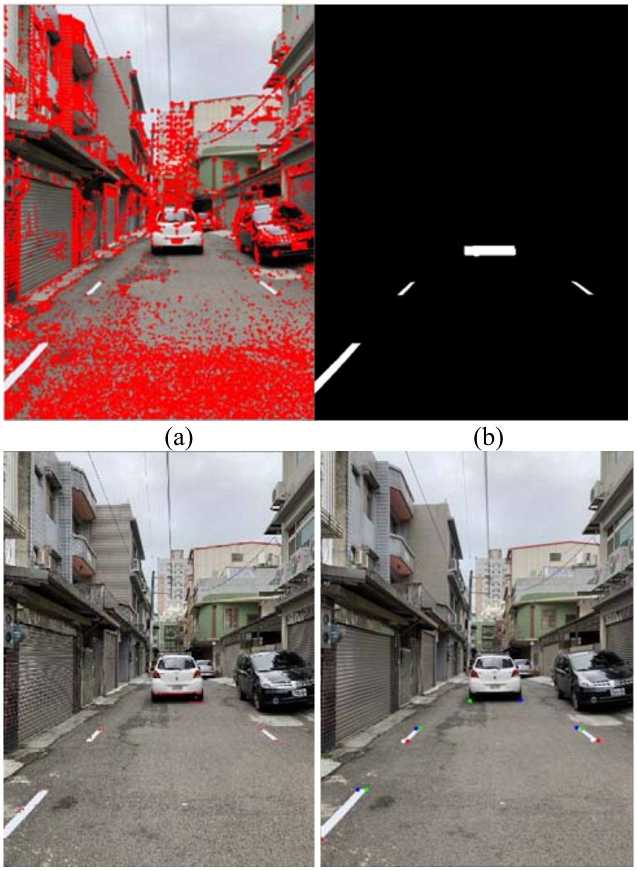

Fig. **6** (a) Feature points of Harris corner detection. (b) Mask of road lanes and the region around tires. (c) Feature points after filtering by mask in (b). (d) Final feature points.

Finally, we can calculate the θ after considering the angle tilt by (3). With the θ, we can estimate vehicle distance by (1).

After adjusting the angle of the camera by (3), we can reduce the error rate from 7.662% to 1.0546%.

$$\begin{aligned} &initial\ tilt = 0 && \rightarrow Length_{lane1} \\ &2^{nd}\ tilt && \rightarrow Length_{lane2} \\ &final\ tilt = 2^{nd}\ tilt \times \frac{1 - Length_{lane1}}{Length_{lane2} - Length_{lane1}} \\ &\theta = \theta + final\ tilt \end{aligned} \tag{3}$$

C. Feature Points Based Vehicle Distance Estimation

To get the feature points of the four corners of the lane and the crossing points of the tire and the road, we use Harris corner detection to detect those points. However, there are too many unwanted points as shown in Fig. 6(a). Therefore, we desire to design a mask to filter out those unwanted feature points. The mask is combined with the intersection of white pixel and the road segmentation and the region including the tires. The final mask is shown as Fig. 6(b).

TABLE I. COMPARISON BETWEEN THE EXPERIMENTAL DISTANCE AND THE GROUND TRUTH. (I) THE PROPOSED METHOD W/O LANE ADJUSTMENT. (II) PROPOSED METHOD WITH LANE ADJUSTMENT (III) BOUNDING BOX W/O LANE ADJUSTMENT. (IV) BOUNDING BOX WITH LANE ADJUSTMENT

GT (m)	7	10	13	15	20
(i) (m)	7.09	9.877	11.33	14.91	18.9
$\Delta(\boldsymbol{m})$	0.09	0.123	1.67	0.09	1.1
(ii) (m)	7.03	10.03	12.88	15.03	20.68
$\Delta(\boldsymbol{m})$	0.03	0.03	0.12	0.03	0.68
(iii)(m)	7.99	9.56	10.82	14.47	17.96
$\Delta(\boldsymbol{m})$	0.99	0.44	2.18	0.53	2.04
(iv) (m)	7.21	10.08	12.7	15.13	21.33
$\Delta(\boldsymbol{m})$	0.21	0.08	0.3	0.13	1.33

TABLE II COMPARISON OF AVERAGE ERROR AND AVERAGE ERROR RATE OF THE PROPOSED METHOD AND OTHER STATE-OF-ART MONOCULAR VISION-BASED METHODS.

	$\bar{\Delta}\ (m)$	$\bar{\delta}(\%)$
Proposed w/o lane adjustment	0.9372	7.662
Proposed with lane adjustment	**0.1786**	**1.0546**
Bounding box w/o adjustment	1.2362	9.81
Bounding box with adjustment	0.4096	2.719
Method [4]	0.1923	1.086
Method [5]	N/A	4.702
Method [6]	N/A	1.333

After filtering by the mask in Fig. 6(b), it still remains some unwanted points as shown in Fig. 6(c). We use some methods to extract the critical feature points exactly. For the corner points of the road lane, we apply polygon approximation method to get the four corners of the road lane. For the crossing points of the road and tires, we pick the left down and right down feature points in the region around the tires. We can get the final desired feature points as shown in Fig. 6(d)

With the feature points as Fig. 6(d), we can calculate the vehicle absolute distance using the geometric relationships which discuss in Section III.A.

IV. EXPERIMENT RESULT

We use four evaluation metrics as in (4) to compare our proposed method with some state-of-art methods.

$$Absolute\ Error \Delta(m) = \left| L_{ground\ truth} - L_{experiment} \right|$$
$$Average\ Error\ \bar{\Delta}\ (m) = \frac{1}{n}\sum_{i=1}^{n} \Delta_i$$

TABLE III AVERAGE ERRORS OF DISTANCE ESTIMATION BY DIFFERENT METHODS.

Distance range	0-10m	10-20m
Method [11]	0.74	1.77
Method [12]	0.81	1.81
Method [4]	0.38	0.85
Proposed method with lane adjustment	**0.032**	**0.277**

$$Average\ Error\ rate\ \bar{\delta}(\%) = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{\Delta_i}{L_{ground\ truth\ i}}\right| \quad (4)$$

In Table I, we compare the absolute error between four classes, our proposed distance estimation method with and without lane adjustment, and bounding box method with and without lane adjustment.

We can find that our proposed method using crossing points of the road and tires with lane adjustment has the smallest absolute error in five testing distance than other methods. We get the critical feature points which are the crossing points of the road and tires. Furthermore, we adjust the initial angle of the camera by applying lane adjustment. Therefore, we can estimate the distance of vehicle ahead much more accurate, while the bonding box method using the middle point of the down edge of the bonding box might have some deviation.

We also compare the average error and the average error rate of the distance estimation result with other state-of-art monocular vision-based methods proposed in [6], [7], and [8]. The results are shown in Table II. Our proposed method with lane adjustment is better than the other best method by reducing the error rate about 0.0314%

We compare the average error of the distance estimation result with methods [11], [12], and [4]. The results are shown in Table . The result shows that the average error of our method is the best for distance estimation within different distance ranges. The average error of the estimation result using our proposed method is reduced by 0.348 m comparing to the better one of other state-of-art methods in distance range of 0-10 m. Moreover, in the range of 10-20 m, our methods reduce the distance average error by 0.96 m comparing to method [4].

V. CONCLUSION

We extract some representative feature points of the frame filtering by the mask we designed. After extracting the feature points, we apply the geometric relationship between the camera and the feature points to estimate the distance. The average error is 0.1786m outperform other state-of-art methods shown in Table II. Furthermore, Table III shows that our proposed method outperforms other methods not only in short distance (0-10 m) but also in long distance (10-20 m). The over performance in our proposed distance estimation system is more robust and stable.

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