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Front Obstacle Detection Based On Fusion of Ultrasonic and Machine Vision

Jie Yu, Binbin Sun, Song Gao, Zhangu Wang

***Abstract*— The environment sensing system of mobile robot is comprehensive and complex, and it is the core technology to realize the intelligent robot. This paper proposed a method, which is based on the combination of ultrasonic fusion and machine vision to detect obstacles in front of the robot. Before the system working, the joint calibration of ultrasonic sensor and camera is carried out, and the information of the front obstacle is realized through the information fusion. The ultrasonic sensor obtains the distance information of the obstacles in front through echo signal and carries out pre-processing of image through edge enhancement and adaptive threshold value to improve image quality. Finally, height and width information of the obstacles is obtained based on utilization of edge detection and Hough Transform. The experiment indicates that the method has considered high efficiency of ultrasonic real-time detection and good recognition accuracy of image morphology. The processing speed of single frame data is 17.7ms.Average relative error of all detection parameters of obstacle is 6.8% so that requirements of mobile robot on instantaneity and accuracy of environmental perception can be satisfied.**

Index Terms—

***Index Terms*— ultrasonic; machine vision; mobile robot; Information fusion**

I. INTRODUCTION

Intelligent mobile robot technology is a cross subject which has developed rapidly in the last ten years. It needs the technical support of many disciplines, such as mechanical design, electronic technology, computer and intelligent control[1]. Environmental perception, which has been paid much attention by scientists in the field of robotics, occupies an important position in that. Various types of sensors have been applied to mobile robots by researchers in that sensor technology development and cost reduction. According to the principle of pinhole imaging and geometric coordinate transformation, a method of robot target localization and ranging based on monocular vision is proposed in document [2]. A method of grid based ORB feature extraction is proposed in document [3], which is based on SLAM technology, combined with computer vision principle and robot probability theory, improves the stability and real-time performance of SLAM system. A binocular CCD front obstacle measurement system is proposed in document[4], which can improve the accuracy and accuracy of obstacle measurement.

In this paper, the advantages of ultrasonic sensor and machine vision are fully considered. The information fusion algorithm is used to perceive obstacles ahead. A joint calibration of machine vision and ultrasonic is conducted before the system starts operation for the sake of obtaining the coordinate transformation of two sensors. The distance information of obstacle in front is obtained by ultrasonic. In order to obtain the contour features and height information of obstacles, the technology of image enhancement, edge extraction and Hof transform is used. Finally, complete the overall perception of the obstacles ahead. The technical process is shown in Figure 1.

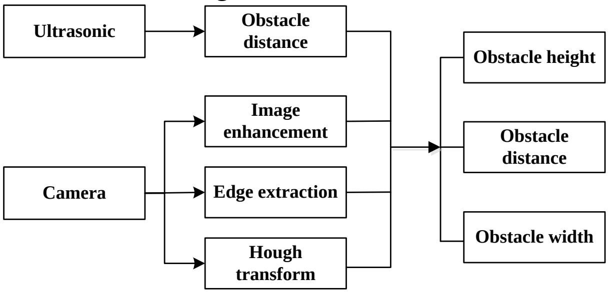


Fig.1.Technology Roadmap

II. FUSION OF ULTRASONIC AND MACHINE VISION

We use ultrasonic sensor and camera to collect information to sense obstacles ahead. Risym HC-SR04 ultrasonic module and MV-VDF300SC monocular camera are adopted in this paper. When the sensors are arranged, the symmetrical axis is kept on the same vertical surface, as shown in figure 2.

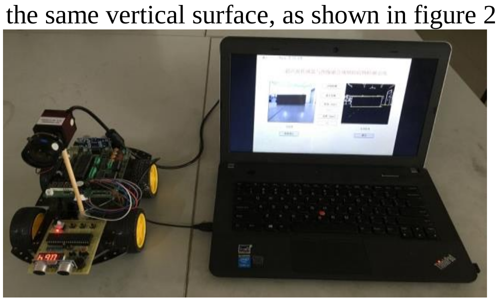


Fig.2. Sensor placement and installation

The camera captures the position relation of three-dimensional objects and presents it by use of two-dimensional space image. The relationship between the two sensors is determined through the geometry of the camera. Camera calibration is completed with the MATLAB toolbox which based on Zhang Dingyou principle. The calibration results are shown in figure 3.

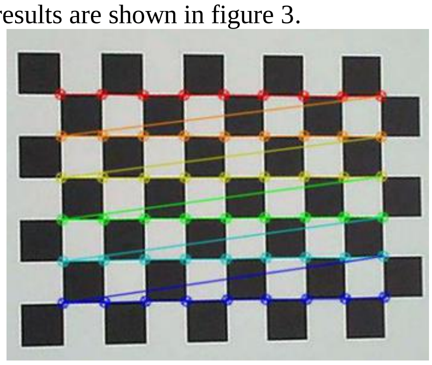


Fig.3. Camera calibration results

The internal parameters are listed as follows:

$$\begin{bmatrix} f_u & 0 & u_0 \\ 0 & f_v & v_0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 2378 & 0 & 1291 \\ 0 & 2374 & 940 \\ 0 & 0 & 1 \end{bmatrix}$$

The distortion coefficient vector is:

$$\begin{bmatrix} -0.1356 & 0.14432 & -0.001021 & 0.006401 \end{bmatrix}$$

fu and fv are the magnification factor of imaging point coordinates on imaging plane to image coordinates after focal length normalization. (u0, v0) is the imaging coordinate of the center point of the optical axis that the coordinate of the main point. The Sensor fusion obstacle detection algorithm based on vision sensor and ultrasonic sensor, which is proposed according to the principle of triangle similarity in imaging process. The basic principles of the algorithm are shown in Figure 4 - Figure 5.

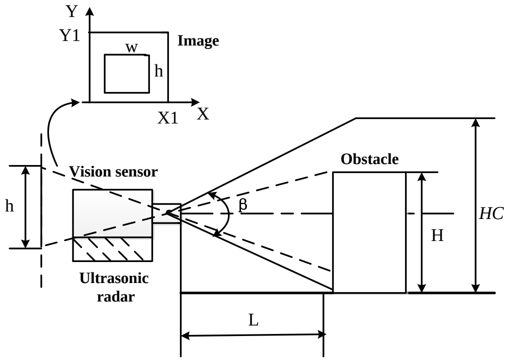


Fig.4. Schematic diagram of height measurement

L is the distance from the obstacle; H is the height of the regular object; β is the vertical viewing angle of vision sensor; X1 is the width of the image to be collected; Y1 is the length of the captured image; w is the width of an obstacle in an image; h is the height of the obstacle in the image. According to the triangle similarity principle in the imaging process, the height measurement formula can be obtained as follows:

$$\left.\begin{aligned} \frac{H}{h} &= \frac{2H_C}{Y_1} \\ H_C &\approx L\tan\frac{\beta}{2} \end{aligned}\right\} \Rightarrow H = \frac{2L\tan\frac{\beta}{2}}{Y_1}h \qquad (1)$$

Similarly, the width measurement formula canJ be obtained according to the measurement process similar to the deduction of the height of obstacles.

$$W = \frac{2L\tan\frac{\alpha}{2}}{X_1}w \qquad (2)$$

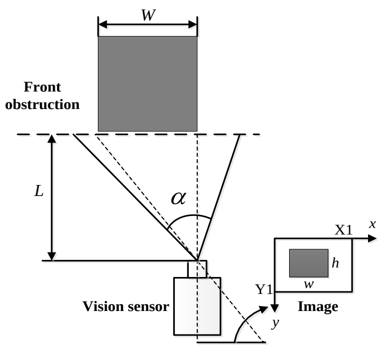


Fig.5.Schematic diagram of width measurement

III. ULTRASONIC SENSOR

The ultrasonic sensor is widely used in the field of environment perception of mobile robots because of their good directionality, penetration ability and simple operation. Hardware configuration is shown in figure 5.

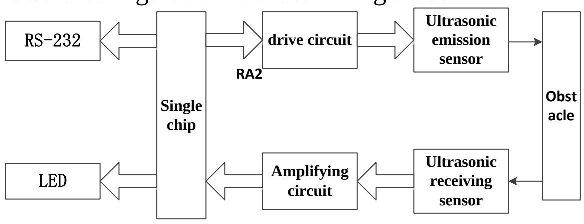


Fig.5.Hardware component of ultrasonic system

The principle of ultrasonic ranging is echo detection. As long as the time of ultrasonic return is measured, the distance can be obtained, as shown in Figure6.

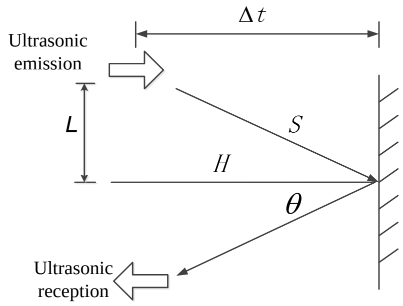


Fig.6. Ultrasonic distance measurement principle

$$H = S\cos\theta \qquad (3)$$

$$\theta = arctg(\frac{L}{H}) \qquad (4)$$

L—Half of the center distance between two probes; The propagation distance of ultrasonic wave is:

$$2S = vt \qquad (5)$$

V—ultrasonic propagation velocity in medium; T—The time required for an ultrasonic wave from launch to reception.

To substitute (4), (5) in (3), the equation is as follows:

$$H = \frac{1}{2}vt\cos[arctg\frac{L}{H}] \qquad (6)$$

Among them, the propagation velocity of ultrasonic wave v is a constant at a certain temperature (for example, at temperature T=30 degrees, V=349m/s); If the measured distance H is much larger than L, then (6) becomes:

$$H = \frac{1}{2}vt \qquad (7)$$

Therefore, as long as the time of ultrasonic propagation t is measured, the distance H can be measured.

IV. FEATURE EXTRACTION OF OBSTACLES BASED ON MACHINE VISION

A. Image preprocessing

In order to extract the edge feature of the obstacle clearly from the original image, and eliminate the useless information and noise contained in the original image, the image needs to be preprocessed.

Firstly, the edge enhancement of the image is carried out by Sobel operator. The Sobel operator can suppress the influence of noise and reduce the degree of edge blur by weighting the pixel position. The operator template used is shown in figure 7.

$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \qquad \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

(a)Horizontal (b) Vertical

Fig.7. The sobel templates of horizontal and vertical

In order to better extract the contour features of obstacles and satisfy the requirements of the images under different illumination intensities, the image is processed with binaryzation by the method of progressive threshold segmentation.

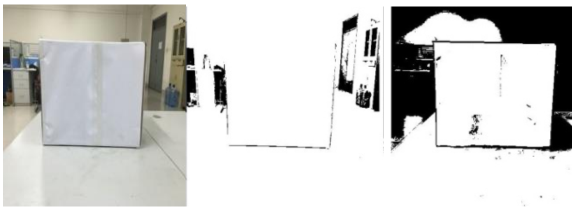
After experiments and experiences many times, it can be considered that the average value of the gray scale distribution of obstacles is 70 - 210, and the confidence interval is $1-\alpha$ =99.5% that the obstacle distribution interval is shown below.

$$[\mathrm{Int}^{-}(\overline{X}-u_{\frac{\alpha}{2}}\sqrt{\frac{s^2}{n}}),\mathrm{Int}^{+}(\overline{X}+u_{\frac{\alpha}{2}}\sqrt{\frac{s^2}{n}})] \quad (8)$$

Where $\overline{X}=\frac{1}{n}\sum_{i=0}^{n}x_i$ represents the grey population mean, as an estimate value of the mean value u, x_i is the sample, and n is the sample number. $s^2=\frac{1}{n-1}\sum_{i=0}^{n}(x_i-\overline{X})^2$ represents the estimate value of variance σ^2.

The upper part of the barrier segmentation is chosen as the threshold of the segmentation region. Then the threshold T can be calculated as:

$$T=\mathrm{Int}^{+}(\overline{X}+u_{\frac{\alpha}{2}}\sqrt{\frac{s^2}{n}})+1 \quad (9)$$



(a) original (b) fixed threshold (c) adaptive threshold

Fig.8. Different threshold segmentation results

B. Edge extraction of obstacles

The noise and data quantity of the image are greatly reduced after preprocessing. In order to obtain the edge feature of the obstacle, Canny operator is used to detect the edge of the image, which has the advantages of low bit error rate, high location accuracy and false edge suppression. With the edge detection, the threshold is calculated automatically, which has a good effect on images containing noise. The test results are shown in Figure 9.

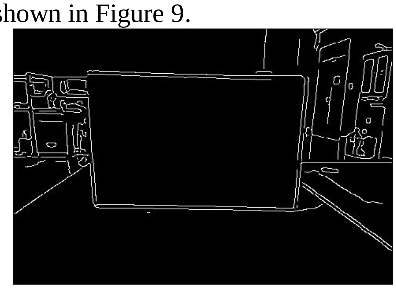


Fig.9. Canny operator edge detection

C. Hough transformation line extraction

On the premise of obtaining the edge features of obstacles, the upper and lower boundary lines of the horizontal straight lines of obstacles are extracted by Hough transformation. The effective method of Hough transformation is used to detect line for binary image, it essentially used for coordinate transformation of images. In order to facilitate the detection and recognition of the transformed results, the points in the image space are mapped into the parameter space. After the Hough transformation, the results of transverse line detection are shown in Figure 10.

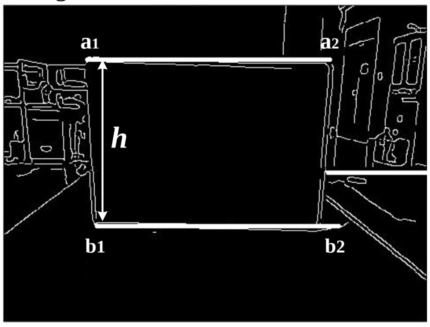


Fig.10. Hough transformation straight line extraction

Take the maximum of Ymax that the vertical coordinate value in horizontal line to be detected is the upper boundary, and take the minimum ordinate value of Ymin is the lower boundary. The height of the obstruction is h=Ymax-Ymin, according to the formula (1), the actual height of the obstacle is obtained.

According to the transverse line obtained by Hough transformation, the pixel coordinates of the four endpoints of the upper and lower boundaries are obtained respectively. As shown in figure 10, the upper boundary width is $w_1=a_2-a_1$; similarly, the width of the border is $w_2=b_2-b_1$. According to the symmetry characteristics of obstacles, the formula of the obstacle width is given as follows: $w=(w_1+w_2)/2$. Finally, according to the formula (2), the actual average width of obstacles in front is calculated.

V. EXPERIMENTAL RESULTS

In order to verify the effect of the front obstacle detection method based on ultrasonic sensor and machine vision fusion, the system verification interface was designed by using Matlab's GUI and Simulink toolbox. The image resolution is set to 500x375.The obstacle detection distance is less than 5m. The experimental results are shown in Figure 11 - figure 12:

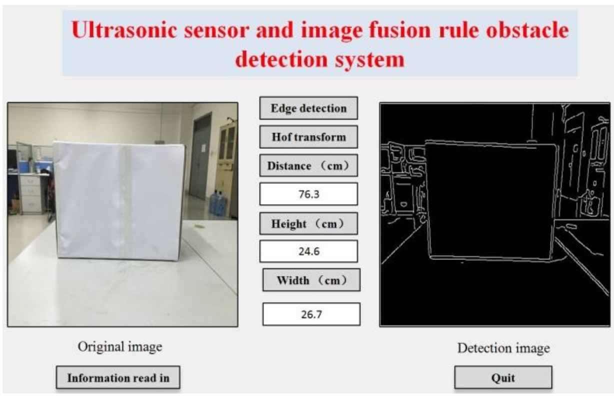


Fig.11.Image enhancement and edge detection

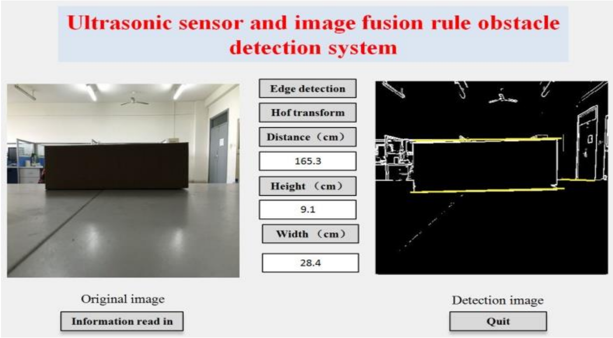


Fig.12.System boundary extraction and measurement

In order to obtain the error of measurement value, the measured data of 50 sets of obstacles were collected by random manner are compared with the actual width, height and distance of obstacles. The following experimental statistics are obtained, as shown in Table 1.

Table1 Experimental statistical data

Unit/cm		Width	Height	Distance
Relative error of mean height		8.25%	6.41%	5.74%
standard deviation	actual value	21.32	16.57	126.32
	measured value	19.56	15.51	119.12

The comparative analysis between the measured parameters and the actual data of each obstacle is shown in figure 13:

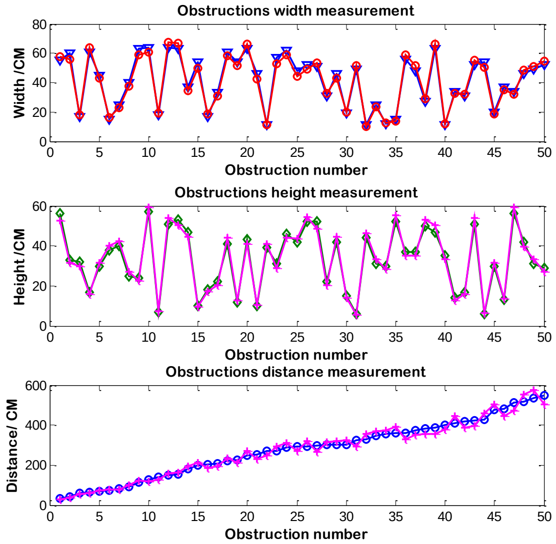


Fig.13. Comparison of measurement parameters and real parameters

The biggest advantage of the obstacle detection based on the combination of ultrasonic and machine vision is that it has faster processing speed and more concise model under the premise of ensuring the precision and accuracy rate of measurement. The performance comparison results of each detection method are shown in Table 2.

Table2 Performance comparison of various detection methods

Performance parameter	Monocular vision	Binocular vision	Paper method
Single frame average processing speed /ms	32.3	58.6	17.7
Average error of Measurement /%	7.1	5.3	6.8
Model average size /KB	23	40	14

VI. CONCLUSION

A method is proposed to detect the front rule obstacles based on the combination of ultrasonic sensor and machine vision in this paper. It makes full play of the advantages of good real-time and high accuracy of ultrasonic sensor for short distance measurement. At the same time, it also takes into account the machine vision morphological, which has the comprehensive advantages of measurement. The experimental results show that this method has higher measurement accuracy for front regular obstacles. The average relative error of each measurement parameter is 6.8%, and the processing speed of single frame data is 17.7ms that the real-time detection has obvious advantages. Moreover, the dependence of the system on hardware performance is reduced, and the requirement of mobile robot for environment perception is also satisfied through the more concise model.

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AUTHOR PROFILE


Jie Yu

She was born on 13th May, 1991 in Shandong province, China. She is a graduate student at the Shandong University of Technology, and major in transportation engineering. Hers research direction is the intelligent automobile. Hers research content is front obstacle detection.


Binbin Sun

He was born on October, 1987 in Shandong province, China. He is a lecturer at the Shandong University of Technology. His main research direction is matching theory and control technology of electric vehicle energy power system, intelligent vehicle and intelligent transportation system.


Song Gao

He was born on October, 1965 in Shandong province, China. He is a professor at the Shandong University of Technology. His main research direction is matching theory and control technology of electric vehicle energy power system, intelligent vehicle and intelligent transportation system.


Zhangu Wang

He was born on September, 1989 in Shandong province, China. He is a graduate student at the Shandong University of Technology. His research direction is the intelligent automobile. His research content is front obstacle detection.