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Distance Measurement with an Image Processing Approach

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Abstract: Robots have been studied over a couple of decades. Nowadays, a lot of robots have been developed for improving the productivity at factories or helping with the daily chores in offices. Most of the robots, however, are still at the stage of being controlled remotely or performing a set of predefined tasks. In order to do things autonomously, a robot must be capable of recognizing and interacting with its environment. This research starts from adding to a mobile robot the capability of measuring the distance away from the obstacles and eventually aims at developing an autonomous mobile robot that could avoid collisions with obstacles in a dynamically changing environment. Stereo images are used for the distance measurement. The robot carries two cameras with their optical axes in parallel and at the same altitude. In order to measure the distance, the robot needs to find the corresponding pixels in the two images captured by the two cameras at the same physical location. This correspondence identification process needs to be in a fast speed. This paper discusses the details about the methodology and algorithms.

Keywords: robot, image processing, parallax, correlation, parallel computation, Quad core.

I. INTRODUCTION

This research aims at developing a robot that moves autonomously in a dynamically changing environment. In order to do so, it is considered a basic capability for the robot to identify obstacles and measure the distance away from the obstacles.

Stereo image processing approach is considered a right way to solve the problems. Two cameras are mounted on the mobile robot with their optical axes in parallel and at the same altitude. Finding the corresponding points/pixels in the two images captured by the two cameras at the same physical location is the key for the distance measurement. Information such as color, lightness, and shape is used for the identification of the corresponding points. As soon as the corresponding points are located, the distance could be calculated. Based on the distance and the speed at which the robot is moving towards the obstacles, a control command will be generated and sent to the robot so that any potential collision will be avoided. The process from image processing to the control command generation needs to be fast and close to be real-time. The accuracy of finding corresponding points is evidently critical as well.

II. System Organization

Fig.1 shows the robot that is developed in this research. A pair of cameras, a laser sensor, and a laptop PC are mounted on the mobile robot. The two cameras are at the same altitude with their optical axes in parallel.

At the current stage, this mobile robot is still moving in a static indoor environment. But the ultimate goal of this research is to put the robot in a dynamic environment with moving obstacles.

Fig.1. The robot

OPTOTRAK shown in Fig. 2 is used to evaluate the performance of the stereo image processing algorithm in terms of the accuracy of the distance measurement. OPTOTRAK is a system that can accurately measure the 3D coordinates of infrared markers attached to obstacles.

Fig.2. OPTOTRAK

III. Locating Corresponding Points

1. Stereo Matching

For any given point inside the right image, image processing algorithms are used to find the corresponding point in the left image. Fig. 3 shows the coordinate systems for both the right and left images. For a point with ordinate of y and abscissa of x in the right image, the corresponding point in the left image will still have ordinate of y because of the way that the two cameras are mounted. Due to the same reason, the abscissa of the corresponding point in the left image is larger than x. With this information, searching for the corresponding point in the left image will be limited to a narrow zone to the right of the point of (x, y) in the left image.

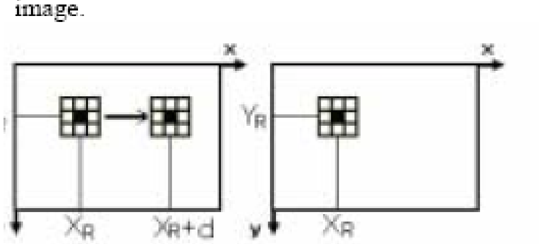
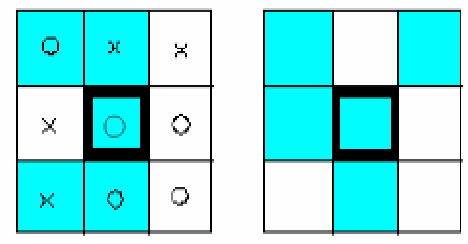


Fig.3. Stereo matching

2. Identification of Correspond Points

As shown in Fig. 4, a mark of "○" is placed on the pixel that has similar attributes such as color information as the pixel in the right image. A mark of "×" is placed, on the other hand, if the attribute such as color is over a predefined threshold.



(a) Left image (b) Right image

Fig.4. 3*3 Region

Experimental results indicate that kernel size of 3x3 is good enough for the identification of corresponding points.

When the number of pixels with mark of "○"inside the kernel is over a predefined threshold, the pixel at the center of the kernel is considered the corresponding point. When there are more marks of "×", on the other hand, the pixel at the center of the kernel will be ignored. For the current kernel size, the threshold is set to be 5.

3. Correlation Method

Correlation method is used for estimating the probability that the pixel identified in the left image is actually corresponding to the point selected in the right image. Formula (1) shows the way of calculating the correlation coefficient.

$$C = \frac{Cov}{Dev_{right} \times Dev_{left}} \quad (1)$$

C: coefficient of correlation
Dev: standard deviation
Cov: Covariance

$$Dev_{right} = \sqrt{\frac{1}{m \times n}\sum_{i=1}^{m}\sum_{j=1}^{n}(right[i][j] - \mu_{right})} \quad (2)$$

$$Dev_{left} = \sqrt{\frac{1}{m \times n}\sum_{i=1}^{m}\sum_{j=1}^{n}(left[i+d][j] - \mu_{left})} \quad (3)$$

$$Cov = \frac{1}{m \times n}\sum_{i=1}^{m}\sum_{j=1}^{n}(right[i][j] - \mu_{right})(left[i+d][j] - \mu_{left}) \quad (4)$$

right: pixel value in the right image
left: pixel value in the left image
μ : mean
m: height of region(m is 3 in the case of 3*3 region)
n: wide of region(n is 3 in the case of 3*3 region)
d: parallax

The threshold for C is set to 0.7.

4. Evaluation

First of all, pixels belonging to the region which has corresponding region in the right image are selected. Then, the correlation between the two images is calculated where pixels with the coefficient over the predefined threshold are identified. In the case that more than one pixels are identified as the correspondence to the pixel selected from the right image, the kernel size will be expanded to 5x5 and the correlation will be re-calculated. Finally, the points with the highest coefficients of correlation are identified as the corresponding points.

The above mentioned image processing algorithms have been implemented. The accuracy of finding corresponding points has also been evaluated.

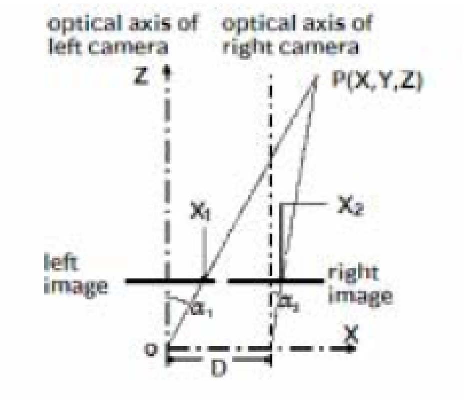
Experiments proved that the corresponding points can be identified in a characteristic region with acceptable accuracy. However, the corresponding points in non-characteristic region is hard to identify. This is because the variance is small in the non-characteristic area. With a small variance, the coefficient of correlation drops below the threshold. Therefore, without identifying the corresponding points in the area of low variance, the image processing could save plenty of time. Basically, edge detection is helpful in terms of locating the region of interests..

In the case that obstacles have the similar shape and color on the image, it is hard to identify the corresponding points on the obstacle. In this case, finding the corresponding points in the background but close to the obstacle proves to be a valid solution.

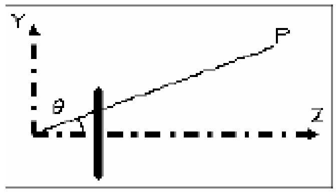
5. Calculation of Distance

A. Equation of distance

As soon as the corresponding points are identified, parallax could be measured. With the parallax, the distance away from the obstacle could be calculated. Fig. 5 illustrates the way of parallax in the stereo imaging mechanism. Formulae (5) to (7) shows the the way of calculating the distance.



(a) Top view



(b)Elevation

Fig.5. Calculation distance

$$X = \frac{fD\tan\alpha_1}{x_1 - x_2} \quad (5)$$

$$Y = \frac{fD\tan\theta}{x_1 - x_2} \quad (6)$$

$$Z = \frac{fD}{x_1 - x_2} \quad (7)$$

B. Experiment

The distance measured through the image processing appoarch is compared with the distance measured with OPTOTRAK device.

An obstacle is put at the distance ranging from 50cm to 200cm. Starting from 50cm, for each measurement the obstacle is moved 25cm farther. Fig. 6 shows the error changes at the different distances.

As shown in Fig. 6, the maximum error distance is about 20cm. In general, the farther the obstacle is moved away, the larger the error becomes. This is because the size of a pixel covers a larger area of the obstacle which introduces more error in the distance measurement. In this case, a control command should be generated to move the robot forward.

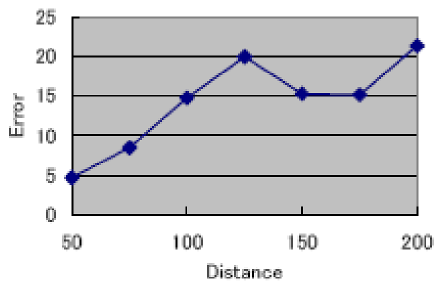


Fig.6. Error graph

IV. Parallel computation

Parallel computation technology is used to improve the image processing speed.. In fact, a multi-core processor is used to accomplish the parallel computation. An image is divided into four fields and each pixel data are passed to four CPU (Quad core) and the same image processing algorithm is executed in each of the CPUs. It is going to be leveraged so that real-time processing could be expected.

V. Sensor

1. The Relation between Image processing and Sensor observation

Other than the parallel computation approach for the improvement of processing speed, identifying region of interest so that the image processing algorithms will only be applied to the ROIs is another way to speed up the entire process. For this reason, distance information measured through a laser sensor is incorporated. The laser sensor is mounted underneath the robot. It is assumed that all the obstacles are touching the ground. In the case that obstacles hanging from ceiling or If obstacles hang from ceiling or protruding from a wall, it will be difficult for the laser sensor to detect. Since the laser sensor cannot detect obstacles below it, obstacles below the sensor position will be ignored or considered not hindering the movement of the robot. That is also the reason that the laser sensor is mounted underneath the robot. It it also assumed that there is no hole and no slope on the ground.

The laser sensor will constantly scan the space in the direction that the robot is moving towards. The distance data collected by the laser sensor helps the robot to decide whether it can pass through between obstacles or not. In the case that the distance between obstacles is larger than the width of the robot, it is considered that the robot can pass through. However, there is a situation that a obstacle such a a table is right in front of the robot. The part that block the robot is actually located at the position higher than the height of the sensor. Although the distance data collected from the laser sensor may reach a conclusion that the robot can still pass through, the robot will actually collide at the top part of the table. In this case, image processing based approach will be used.

Fig.7 illustrates the case that the robot is moving towards a table . When the laser sensor find the table legs, the robot calculates the space between the table legs. Since the space between the legs is larger than the width of the robot, the robot will consider it possible to pass through. Of course, if the table top is way higher than the height of the robot, the robot could pass under the table. But if the table top is right in front of the robot, collision will happen. In this particular case, the image processing based approach will be more reliable.

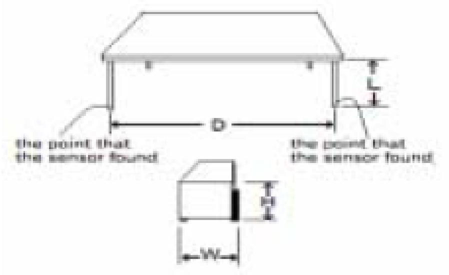


Fig.7. A table is used as an obstacle.

2. Application

The data collected through the laser sensor helps to limit the region of interest for the image processing algorithms to be applied. Fig. 8 shows an example.

Fig.8. Limited image region

VI. CONCLUSION

An image processing based approach for the measurement of distance from a mobile robot to obstacles is presented. Incorporating the data collected through laser sensor helps with the identification of region of interests for applying image processing algorithm. This proves to be an effective way of improving the image processing speed.

Experimental results proved the effectiveness of this approach. But at the same time, it is found that identifying the corresponding points when there are similar obstacles in terms of color, lightness, or shape is not very accurate. This is one of the problems that need to be solved in order to achieve the ultimate goal of developing an autonomous mobile robot in a dynamic environment.

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