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OBSTACLE DETECTION USING RING BEAM SYSTEM

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Abstract: In this paper, we propose a novel obstacle detection system using Ring Beam System (RBS) for mobile robots. This system consists of RBS with a cone mirror, a spherical mirror and a CCD camera. The principle of this system is same as triangulation. The advantages are having no moving parts and detecting all obstacles around the robot simultaneously. Firstly, we calculate a relationship between the position of bright point on picture from CCD camera and the distance to obstacles. Next, we show developed experimental device and results of obstacle detection.
Keywords: Obstacle detection, Triangulation, Mobile robots

1 INTRODUCTION

There are many researches about omni-directional mobile robots, especially for indoor use. So, it is necessary for autonomous mobile robots to detect obstacles around it. The obstacle detection systems are various, for example, image processing using CCD camera [1], ultrasonic wave system, and so on. A triangulation using laser slit and CCD camera is used for obstacle detection because three-dimensional shapes of objects can be measured easily [2]. In this research, using Ring Beam System (RBS) [3] that can project laser slit to all direction, we develop the novel obstacle detection system that has no moving parts.

2 CALCULATING DISTANCE USING GEOMETRIC MODEL

Figure 1 shows the geometric model of our experimental device. The center of spherical mirror whose radius is r is regarded as an origin and coordinates are decided as the figure. Moreover, it is assumed that the CCD camera and the RBS are distance l and d away from the origin, respectively. Here, a distance x to the obstacles is calculated by following equations:

$$f = \sin^{-1}\left[\left(\frac{l}{r}\sin q\right)\cos q - \sin q\sqrt{1-\left(\frac{l}{r}\sin q\right)^2}\right] \quad (1)$$

$$a = \cos^{-1}\left[2\cos(q+f)\cos f - \cos q\right] \quad (2)$$

$$x = r\sin f + (d - r\cos f)\tan a \quad (3)$$

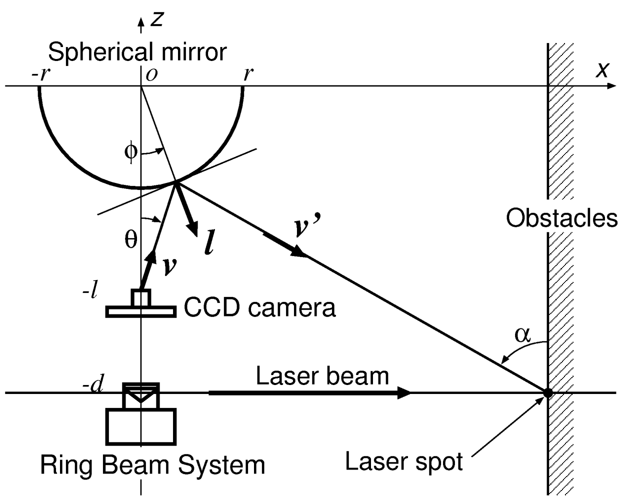

Figure 1. Geometric model of obstacle detection system.

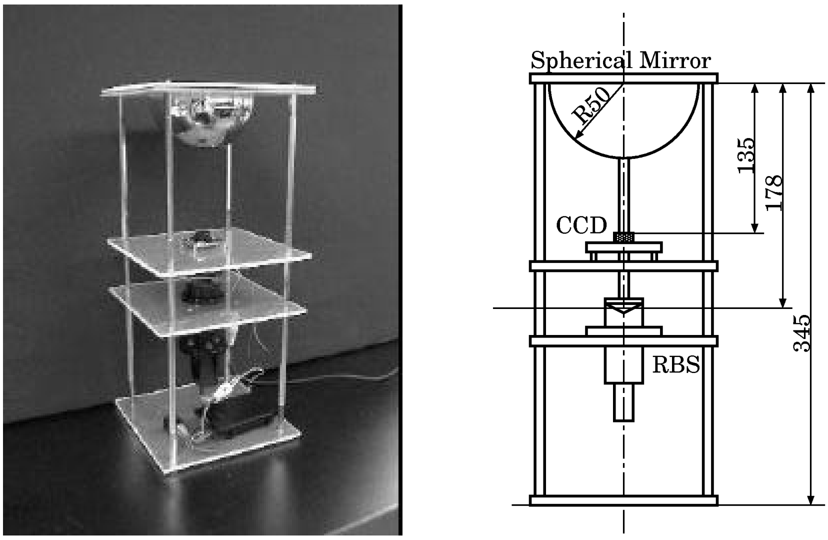

Figure 2. Experimental device.

Figure 3. Example of obtained picture.

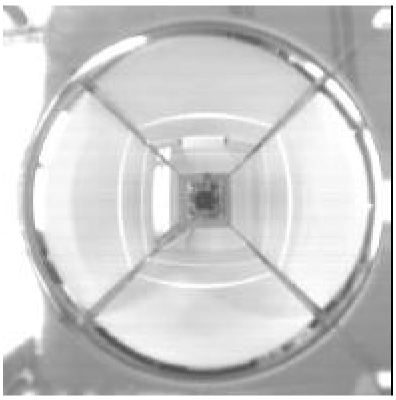

Figure 4. Picture of inside of a box in case of applying laser slit by RBS

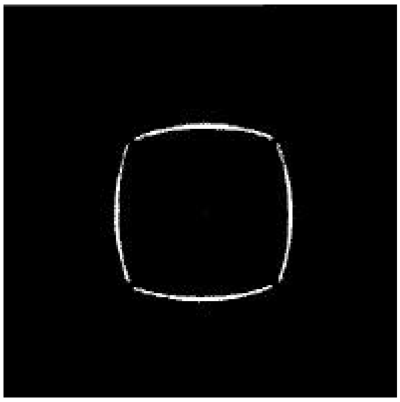

Figure 5. Detecting result of bright line.

3 EXPERIMENT (1)

The experimental device consists of a spherical mirror, a CCD camera and a RBS with a cone mirror. Developed experimental device is shown in figure 2 and an example of obtained picture using this obstacle detection system is shown in figure 3. This picture is obtained while this experimental system is put on a desk in our laboratory.

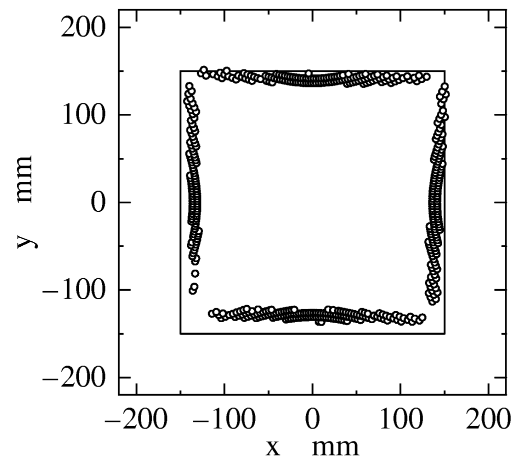

Figure 6. Measuring result of inside of box.

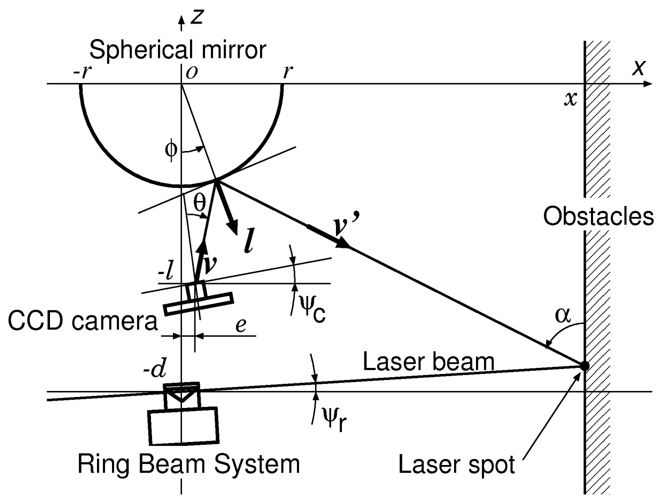

Figure 7. New geometrical model with geometrical errors.

In this experiment, we measure inside of a box with sides 300mm long as an obstacle. Firstly, we obtain two pictures by the CCD camera and a picture board in PC: one is a picture in case of applying laser slit by RBS (figure 4) and another is in case of no laser beam. Secondly, we calculate differences of these two pictures to detect the bright line on obstacles. Figure 5 shows the detecting result of bright line. Finally, we calculate angles q for each bright point in figure 5 and calculate the distance x to obstacles using equations (1)–(3). Figure 6 shows measuring result of inside of the box. In this figure, solid lines give the position of the real obstacles and small circles give the position of detected obstacles. This result shows the possibility of detecting obstacles using our system.

4 CONSIDERATION OF GEOMETRICAL ERRORS

In the experiment, a maximum measuring error is 15.4 mm. We think that factors of this error are errors of center axis of each device and parametric errors, for example, the length between the CCD camera and the spherical mirror. Therefore, we build a new geometrical model with geometrical errors in figure 7. Same as figure.2, the center of spherical mirror whose radius is r is regarded as an origin and coordinates are decided as the figure. Moreover, it is assumed that the CCD camera and the RBS are distance l and d away from the origin, respectively. As geometrical errors, we introduce a position error of CCD camera e, an orientation error of CCD camera y_c and an orientation error of RBS y_r. The position errors and the orientation errors are 3 degrees of freedom. However, it seems that the position errors along z-axis are included position l and d. Position errors *x* and *y* of RBS can be ignored because the slit ray from RBS extends horizontally. Here, we discuss about influence that error factors give to results of measurement, so we use easier 2 DOF model. A relationship between a distance x to the obstacles and q is calculated by following equations:

$$f = \sin^{-1}\left[\frac{l\sin(q - y_c) + e\cos(q - y_c)}{r}\cos - \sin(q - y_c)\sqrt{1 - \left\{\frac{l\sin(q - y_c) + e\cos(q - y_c)}{r}\right\}^2}\right] \quad (4)$$

$$a = \cos^{-1}[2\cos(q - y_c + f)\cos f - \cos(q - y_c)] \quad (5)$$

$$x = \frac{r\sin f + (d - r\cos f)\tan a}{1 + \sin y_r \tan a} \quad (6)$$

5 ANALYSIS OF ERRORS

We discuss about the influence that each geometrical parameter gives to the results of measurement. Using equations (4) - (6), differentials between distance x and geometrical parameters are as follows:

$$\frac{\partial x}{\partial l} = 2.23, \quad \frac{\partial x}{\partial d} = 1.46, \quad \frac{\partial x}{\partial e} = 14.8, \quad \frac{\partial x}{\partial r} = -8.87, \quad \text{when } x = 150. \quad (7)$$

Here, each value of differential represents an error of detecting distance for a small variation of the geometrical parameter. We can find out that an influence of position error of CCD camera e is biggest.

About orientation errors, following equations shows differentials.

$$\frac{\partial x}{\partial y_c} = -2270, \quad \frac{\partial x}{\partial y_r} = -219, \quad \text{when } x = 150. \quad (8)$$

These differentials cannot be compared with above position errors shown by equation (7), because a unit of equation (7) is different from a unit of equation (8). However, we can realize that an influence of orientation error of CCD camera y_c is bigger than an influence of orientation error of RBS y_r.

6 PARAMETER IDENTIFICATION AND EXPERIMENT (2)

We identify the parameter e that is the position error of CCD camera. In fact, it is necessary to consider an error in x-axis e_x and in y-axis e_y for position errors of CCD camera. However, the measurement result of inside of box in figure 5 is almost symmetry with respect to y-axis. Therefore, we identified only the parameter e_y. Figure 8 shows a result of measuring experiment after the identification of the parameter.

Using modified geometrical model, we carried out an experiment of detecting obstacles. We selected passageway in front of our laboratory for the measuring environment, because proposed sensing system was loaded on mobile robot for indoor use. The measuring environment is shown by figure 9. In this figure, the laser slit from RBS can be seen on a wall and a door.

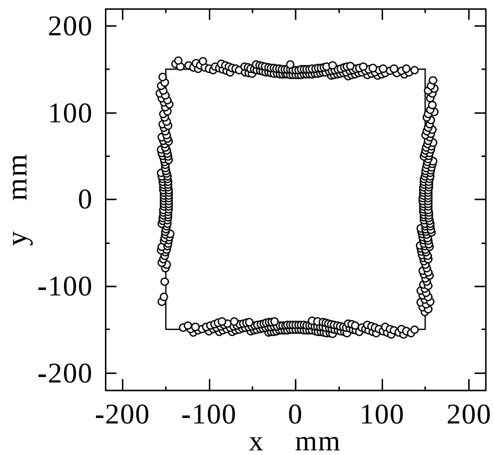

Figure 8. Measuring result of inside of box after parameter identification.

Figure 9. Measured Environment

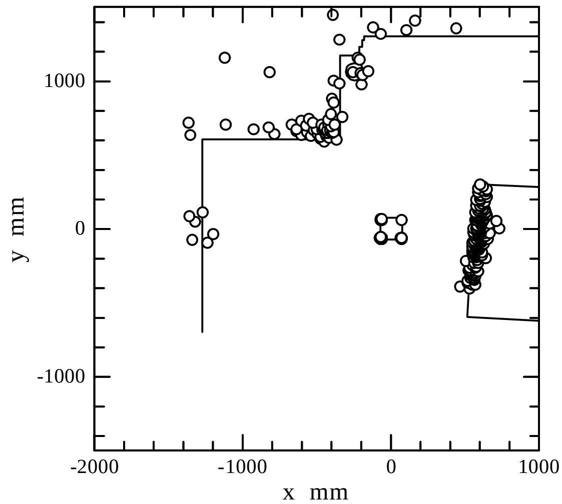

Figure 10. Result of detecting obstacles

Figure 10 shows a result of an experiment of detecting obstacles. The developed measuring system is put at a position (0,0). The four detected points around it are results of detecting the four poles included in the measuring system. The points on the right side of the origin are results of detecting a box that is fixed in order to put a computer. This result of experiment shows the possibility of detecting obstacles under the real environment using our developed system.

7 CONCLUSIONS

We proposed a novel obstacle detection system using RBS (Ring Beam System), a spherical mirror and CCD camera for indoor use mobile robots. We showed the calculating method of distance to obstacles and carried out the experiment of detecting obstacles. The result of experiment shows the possibility of detecting obstacles using our system, however, there are some errors from parametric errors or geometrical errors. Therefore, we build another geometrical model include geometrical errors and identified parameters based on the result of experiment. After the identification of unknown parameters, we carried out the other experiment of detecting obstacles and the result of experiment shows the possibility of detecting obstacles around this system simultaneously under the real environment.

REFERENCES

[1] Y. Yagi, Real-time Omnidirectional Image Sensors, *Journal of the Robotics Society of Japan* **13** (3) (1995) 347-350 (Japanese).
[2] S. Kato and S. Tsugawa, Obstacle Region Detection Sensor by Extended Slit-Ray Projection: Detection Technique and Architecture for a High-Speed Processing Realization, *Proceedings of the 5th Symposium on Robot Sensors* (1996) 109 (Japanese).
[3] Y. Kawaguchi, J. Mizuno and K. Ito, Principle of Ring Beam System (R.B.S.) and Its Applications, *O plus E* **210** (1997) 96-99 (Japanese).

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