Localization and Obstacles Detection Using Omni-directional Vertical Stereo Vision

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Abstract. This paper describes an omni-directional vertical stereo vision system for an autonomous mobile robot. The system is composed of two omni-directional cameras and enables both the localization with wide range of view and the obstacles detection by 3D measurement of arbitrary direction. The system architecture and an experimental result are shown.

1 Introduction

Mobile robot needs functions of localization and obstacle detection for completion of a task. Works done on the localization problem bring two approaches. The first approach is based on dead reckoning. The second one consists in determining the robot's position and direction without using the initial configuration of the robot. The robot's configuration is calculated from exteroceptive sensor data[1][2][3]. To assure the precision of localization in this approach, many landmarks need to be observed at the same time. Therefore, omni-directional vision system is proposed[4].

The recognition of high landmarks make localization easily because they are usually visible even in the presence of the obstacles. For avoidance of the obstacles, not only direction of the obstacle but also distance between the robot and the obstacle is necessary. The distance cannot be obtained from single camera. The measurement systems are proposed using both the camera and another sensor, for example, ultrasonic sensor[5], laser range finder[1], etc.. In case that plural robots are moving simultaneously, ultrasonic waves sent by one robot interfere in the function of reception of another robot. Laser range finder is weak in recognition of moving obstacles and cannot sense obstacles in 360 degrees of area in real-time.

In this paper, we propose an omni-directional vertical stereo vision system. This system enables both the localization and the obstacles detection. This system consists of two omni-directional cameras. The system recognizes the object

A. Birk, S. Coradeschi, and S. Tadokoro (Eds.): RoboCup 2001, LNAI 2377, pp. 429–434, 2002.

which is located high. In addition to this, the 3D information of the plural obstacles at the side of the robot is calculated with triangulation in real-time.

2 Omni-directional Vertical Stereo

An omni-directional camera(Fig.1) consists of a hyperboloidal mirror which faces downward along the vertical axis and a CCD camera which faces upward along the vertical axis. These two components are mounted onto the top and the bottom of the acrylic resin cylinder respectively. The mirror is equipped with a needle to suppress diffused reflection.

In the ordinary method of stereo vision, the two cameras are configured horizontally and the baseline of triangulation is in the horizontal plane(Fig.2). This configuration brings following problems.

1. An epipolar line becomes curved line. Therefore the computational cost increases.
2. Accuracy of the 3D measurement depends on the direction of a landmark. In Fig.2, Accuracy of position estimation of point 'b' is worse than the one of point 'a'. The position of point 'c' cannot be calculated because point 'c' is not perceptible by the camera1.

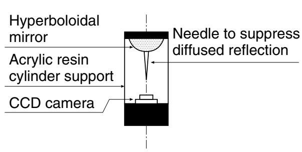

Fig. 1. Omni-Directional Camera

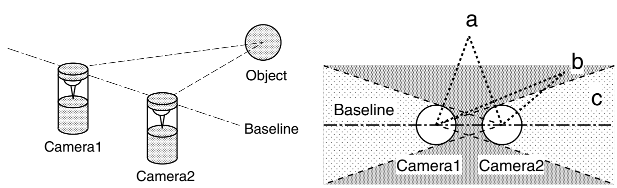

Fig. 2. Horizontal Stereo

To cope with these problems, we developed the omni-directional vertical stereo vision system. Fig.3 shows our system. The system is composed of two vertically arranged omni-directional cameras. The axis of one camera is in line with the axis of the other. The area named 'a' is the area where the object is recognized by both cameras. 3D position of the object in the area 'a' can be calculated by stereo matching. In our omni-directional vertical stereo system, an epipolar line becomes radial straight line. Therefore the computational cost is reduced. Besides, despite of the direction of the landmark, accuracy of the 3D measurement is constant in one horizontal plane.

Fig.4 shows our omni-directional vertical stereo vision. Let OM_i be the hyperboloidal focal point. Let the coordinate value be $(0, 0, bz_i)$. Define $P(X, Y, Z)$ to be an arbitrary point in the 3D space. Let the corresponding points on the image planes of P be $p_i(x_i, y_i)$ Unit vectors $e_i(ex_i, ey_i, ez_i)$ from OM_i to P can be calculated uniquely. Then the following equation is obtained:

$$X = \frac{ex_1 ex_2 (bz_2 - bz_1)}{ex_2 ez_1 - ez_2 ex_1}, Y = \frac{ey_1 ex_2 (bz_2 - bz_1)}{ex_2 ez_1 - ez_2 ex_1}, Z = \frac{ez_1 ex_2 bz_2 - ez_2 ex_1 bz_1}{ex_2 ez_1 - ez_2 ex_1} \quad (1)$$

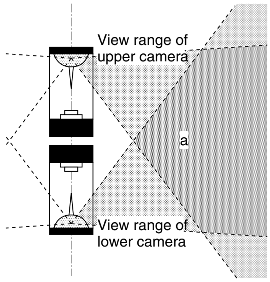

Fig. 3. Omni-Directional Vertical Stereo

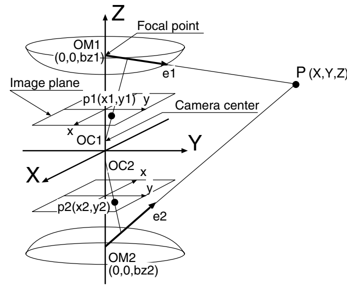

Fig. 4. Camera Coordinate

3 Construction of Omni-directional Vertical Stereo Vision System

We developed the omni-directional vertical stereo vision system and mount it on our autonomous mobile robot. Fig.5 shows our system and the images obtained by the system. Occlusion occurs by the support pillar in the image of lower camera. Refinement of the shape of the pillar would decrease the occlusion.

The vision system is composed of two omni-directional cameras, CPU board (K6–2 300MHz, 64KB memory) and two image capture/processing boards (HITACHI IP5005, 256x240 pixel). The image of each camera is captured by the corresponding image/processing board. Then the boards process the captured images respectively.

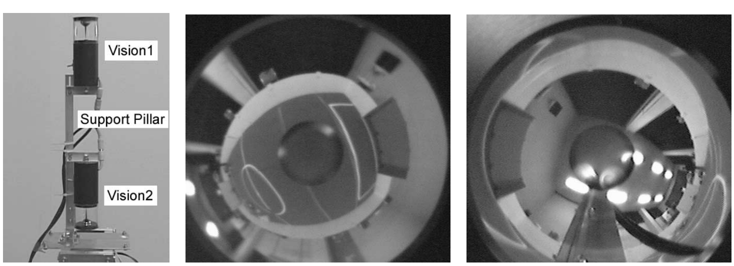

Fig. 5. Omni-Directional Vertical Stereo Vision and Images Taken by the System

3.1 Localization

Our robot moves around in the soccer field shown in Fig.6. Let Σ_B be an internal base frame. Let a, b, c and d be the positions of all posts as landmarks. Let r be the position of the robot. Let r' be the candidate for position of the robot. Localization is made based on the directions of the landmarks. We make two circumscribed circles(Fig.7) where the angle "$a-r'-b''$ and the angle "$c-r'-d''$ are constant respectively, i.e.,

$$(x-a_1)^2+y^2=r1^2,\ a_1=-2010+\frac{1000}{tan\theta_1},\ r_1=\frac{1000}{sin\theta_1}$$
$$(x-a_3)^2+y^2=r3^2,\ a_3=2010-\frac{1000}{tan\theta_3},\quad r_3=\frac{1000}{sin\theta_3}$$

One of the intersection of two circles is the position of the robot, i.e.,

$$\begin{cases} X=\frac{1}{2}\{(a_3+a_1)-\frac{r_3^2-r_1^2}{a_3-a_1}\} \\ Y=\pm\sqrt{-\frac{1}{4}(a_3-a_1)^2+\frac{1}{2}(r_3^2+r_1^2)-\frac{1}{4}\frac{(r_3^2-r_1^2)^2}{(a_3-a_1)^2}} \\ \quad if\ \ \theta_4\geq\theta_2\ \ then\ \ Y\geq 0\quad else\quad Y<0 \end{cases} \tag{2}$$

A set of singular points exists where the robot cannot localize this point(Fig.8). If the robot is on this circumference, a_1 and a_3 equals to 0 and equation(2) cannot be solved. In this case, other localization method is necessary for example, dead reckoning.

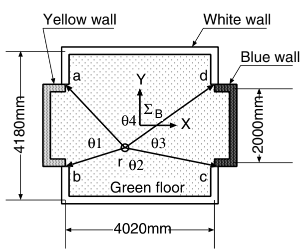

Fig. 6. Soccer Field

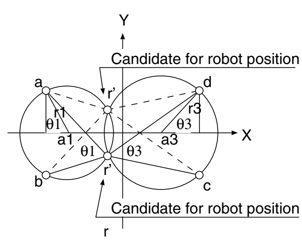

Fig. 7. Localization

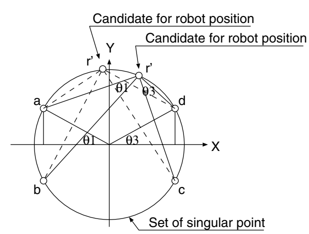

Fig. 8. Singular Points

3.2 Obstacle Detection

We have evaluated the obstacle detection error. Vertical plane which includes the Z axis of our system is divided into regular grids with intervals of $200mm$ along the horizontal axis and $100mm$ along the Z axis. At each point we have measured the obstacle detection error. The obstacle detection error on point $(L,Z)=(200(n+1),100n)n=0,1,2...$ is shown in Table1.

We used a ball of $75mm$ radius as an obstacle. Each cell contains the average of errors along horizontal axis and the average of errors along Z axis. The blank cell means that the obstacle is not recognized by both cameras. In the cells neighboring the blank cells, The error is larger.

4 Localization and Obstacle Detection/Avoidance Experiment

We show an experimental result of localization and obstacle detection/avoidance with our omni-directional vertical stereo vision. We located the obstacle on the

700	–	–	–	–	–	–	42.9	113.6	40.5
	–	–	–	–	–	–	-54.4	-13.9	-37.7
600	–	–	–	–	57.3	136.5	143.3	104.2	25.9
	–	–	–	–	-88.6	1.6	15.0	-2.1	-31.0
500	–	–	–	123.2	170.5	148.4	111.4	69.5	36.4
	–	–	–	-25.6	34.1	28.9	19.3	5.7	-6.4
400	–	–	–	187.7	124.1	125.6	73.2	73.6	43.4
	–	–	–	30.0	11.9	33.5	13.3	8.5	-0.4
300	–	–	146.5	129.4	93.3	114.8	85.3	92.5	53.7
	–	–	31.3	9.1	10.2	35.1	32.2	17.4	4.5
200	–	115.6	101.5	98.2	70.2	87.0	56.5	63.4	32.6
	–	26.8	22.1	15.3	13.3	36.5	22.6	23.1	16.0
100	–	73.6	73.0	82.8	62.0	94.9	50.7	42.1	46.1
	–	16.4	23.2	24.6	26.9	48.6	41.5	36.7	20.5
Z=0	77.0	59.2	48.7	74.8	53.6	63.8	61.9	65.4	49.2
	22.6	17.2	15.1	29.8	20.0	39.1	45.1	37.7	35.1
	L=200	400	600	800	1000	1200	1400	1600	1800

Table 1. Obstacle Detection Error

point $(0,0)$. The robot moves from the point $(-1500,0)$ to the point $(1500,0)$. Calculation cycle of our vision system is $100msec$.

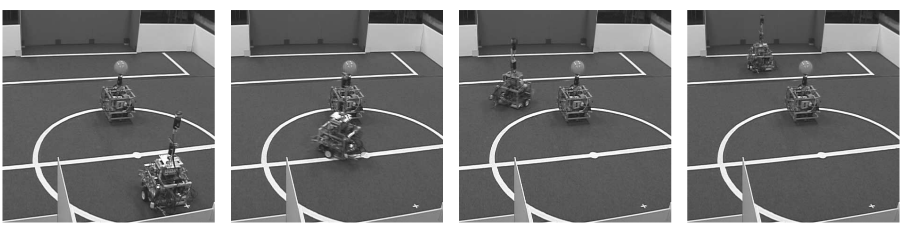

Fig. 9. Robot Movement

Fig.9 shows the snapshot of the robot movement. Fig.10 shows the loci of the robot. The continuous line indicates the estimated position of the robot based on dead reckoning. The broken line indicates the estimated position of the robot based on our vision system. To avoid the obstacle, the robot turned to the left. Then, to reach the goal, the robot turned to the right and went straight. In the neighborhood of the goal, the robot successfully stopped. In this case, robot's movement time is short(7 seconds) and the floor is flat with sufficient coefficient of friction. Therefore, the localization by dead reckoning is more accurate than the one by our system. In the actual usage of the robot, the movement time becomes long and the field is not ideal. Our system can estimate the position and direction of the robot within constant range of error independent of movement time or characteristics of the floor.

Fig.11 shows the distance between the robot and the obstacle obtained by 3D calculation. Fig.12 shows the direction of the obstacle in the coordinate frame attached to the robot. The robot determined the 3D position of the obstacle of any direction with sufficient accuracy.

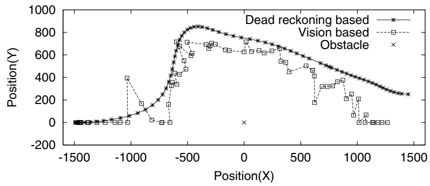

Fig. 10. Loci of the Robot

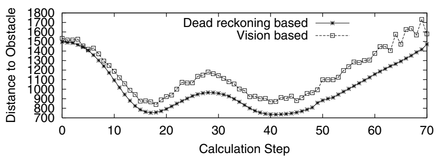

Fig. 11. Distance between the Robot and the Obstacle

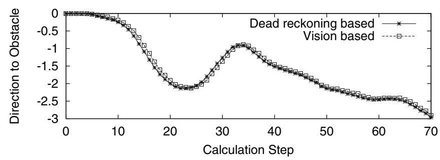

Fig. 12. Direction of the Obstacle in the Coordinate Frame Attached to the Robot

5 Conclusion

Omni-directional vertical stereo vision system has been proposed. Wide range of view enables the usage of many landmarks in one calculation of the localization and increase the robustness of localization. The ability of 3D measurement of arbitrary direction enables efficient motion planning of the robot. This characteristics is useful for cooperation of multi-robots. Each robot recognizes the object and others and plans the optimal motion of the robot.

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