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Self-Localization Method Used Multiple Omnidirectional Vision System

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Abstract: In this research, we proposed a multiple omnidirectional vision system with three omnidirectional cameras and its calculation method for the measurement of the object position and the self-localization in an autonomous mobile robot. Furethermore, on the identification of the self-position, we tried to improve the accuracy of the measurement by correcting the absolute position based on the measurement error of landmarks in the origin of the absolute coordinate. To confirm the efficiency of our proposed system, we actually performed the measurement experiment.

Keywords: Multiple Omnidirectional Vision, Self-Localization, Autonomous Mobile Robot

1. Introduction

In the research on multiple autonomous mobile robots such as RoboCup, some researches which used the omnidirectional camera were proposed $^{1)}$ $^{2)}$. However, only one omnidirectional camera is almost used in these researches. Therefore, the object image in the mirror is compressed according to the distance. If the height of the object is uncertain, the accurate distance measurement is generally impossible.

On the other hand, there are some researches which use two or more omnidirectional cameras. The research for the vision system which two omnidirectional cameras are perpendicularly fixed is proposed by Koyasu $^{3)}$ and J.Gluckman $^{4)}$. The other research which two omnidirectional cameras are horizontally fixed is proposed by Miki $^{5)}$.

In this paper, we propose a Multiple Omnidirectional VIsion System (called MOVIS) which three omnidirectional cameras are arranged on the robot like as a horizontal and equilateral triangle. As a result, the stereo vision system by the principle of the triangulation is made by each two cameras. The purpose of this research is to realize the object recognition and the position measurement of the robot accurately in real time. Furthermore, we propose the real-time object position measurement and the self-localization method for the autonomous mobile robot used MOVIS. We actually produced MOVIS on the robot. We also report this experimental results.

2. Proposal of MOVIS

Three omnidirectional cameras of M_1, M_2, and M_3 with same performances respectively are used in MOVIS. In this system, the omnidirectional cameras are horizontally arranged in the equilateral triangle on a mobile robot as shown in Fig.1. The center of gravity of the robot and the equilateral triangle vertically exist in the same point.

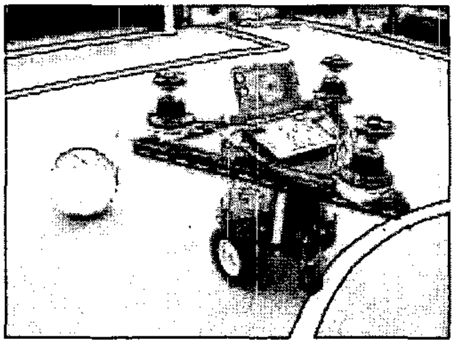

Fig.1: Overview of MOVIS

By the line extended from the center of gravity of the equilateral triangle to the each vertex point, the range of the acquisition of images are divided into three areas which each two cameras perform as the stereo vision with in 120 degrees (For example in Fig.2, M_1 and M_2, M_2 and M_3, M_3 and M_1). The processing procedure of MOVIS is shown in Fig.3.

3. Measurement of Object Position and Self-Localization

The measurement of the object position and the self-localization method used in MOVIS are described in this section.

3.1 Object Position Measurement in Robot Coordinates

In the position measurement, an object position $A(x_a, y_a)$ is obtained by using omnidirectional camera M_1 and M_2 in the robot coordinates. In the view point of $\overline{M_1M_2}$, a slant angle of $\overline{AM_1}$ is $(\theta_1 - \frac{\pi}{6})$, that of $\overline{AM_2}$ is $(\theta_2 - \frac{5\pi}{6})$. The distance between the center of gravity of the robot and the center of camera is assumed as L.

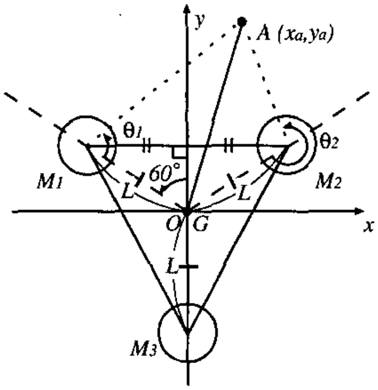

Fig.2: Object Position Measurement in Robot Coordinates

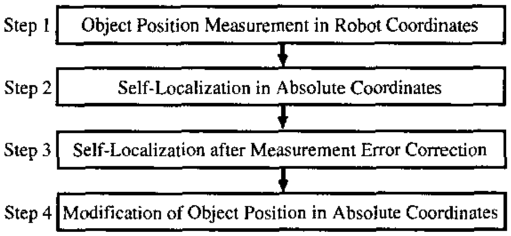

Fig.3: Processing Procedure of MOVIS

As a result, a position (x_a, y_a) of the object A in the robot coordinates is shown in the equation (1) and (2).

$$x_a = \frac{\sqrt{3}}{2}L \cdot \frac{\tan(\theta_2 - \frac{5\pi}{6}) + \tan(\theta_1 - \frac{\pi}{6})}{\tan(\theta_2 - \frac{5\pi}{6}) - \tan(\theta_1 - \frac{\pi}{6})} \quad (1)$$

$$y_a = \frac{1}{2}L + \sqrt{3}L \cdot \frac{\tan(\theta_2 - \frac{5\pi}{6}) \cdot \tan(\theta_1 - \frac{\pi}{6})}{\tan(\theta_2 - \frac{5\pi}{6}) - \tan(\theta_1 - \frac{\pi}{6})} \quad (2)$$

3.2 Self-Localization in Absolute Coordinates

In this research, the field of the RoboCup medium robot league was used in the experiment of measurement, and corner poles were used as a landmark for the self-localization. The coordinate axis in the absolute coordinates is shown in Fig.4. Positions of the corner pole p and q are assumed a width Fw and a depth Fd respectively from the origin of the field. Moreover, the position of the center of gravity of the robot is assumed as (X_r, Y_r) and the slant angle of x *axis* of the robot coordinates in the absolute coordinates β. In the robot coordinates, assuming that positions of corner pole p and q obtained from the position measurement are $p(x_p, y_p)$ and $q(x_q, y_q)$ respectively, the equation (3) and (4) show the relation between corner pole position in the robot coordinates and the absolute robot position.

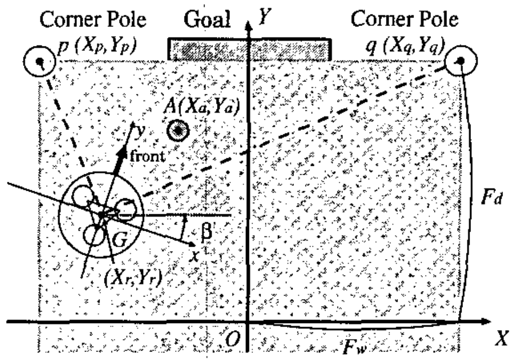

Fig.4: Self-Localization in Absolute Coordinates

$$\begin{pmatrix} -Fw \\ Fd \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} x_p + X_r \\ y_p + Y_r \end{pmatrix} \quad (3)$$

$$\begin{pmatrix} Fw \\ Fd \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} x_q + X_r \\ y_q + Y_r \end{pmatrix} \quad (4)$$

The slant angle β is shown in the equation (5). In addition, a center of the gravity position (X_r, Y_r) of the robot in the absolute coordinates is obtained by equation (6) and (7). By the landmark position $p(x_p, y_p)$ in the robot coordinates and β obtained by the equation (5), the self-localization position (X_r, Y_r) in the absolute coordinates is obtained.

$$\beta = \tan^{-1}\frac{y_q - y_p}{x_p - x_q} \quad (5)$$

$$X_r = -x_p + (\cos\beta)Fw + (\sin\beta)Fd \quad (6)$$

$$Y_r = -y_p - (\sin\beta)Fw + (\cos\beta)Fd \quad (7)$$

3.3 Self-Localization after Measurement Error Correction

At first, the robot is fixed at the origin point. In this case, the robot coordinates and the absolute coordinates are equal. After the measurement of the self-localization, we assume that positions of right and left corner pole are $(\tilde{x}_p, \tilde{y}_p)$ and $(\tilde{x}_q, \tilde{y}_q)$ respectively including the measurement error. In this case, we replace x_p, y_p, x_q and y_q in equations (5) to (7) to x'_p, y'_p, x'_q and y'_q in the equation (8).

$$x'_p = x_p\frac{-Fw}{\tilde{x}_p}, \qquad y'_p = y_p\frac{Fd}{\tilde{y}_p}$$

$$x'_q = x_q\frac{Fw}{\tilde{x}_q} \qquad y'_q = y_q\frac{Fd}{\tilde{y}_q} \quad (8)$$

The self-localization position with the measurement error in the origin point in equation (5) to (7) was modified by using x'_p, y'_p, x'_q and y'_q instead of x_p, y_p, x_q and y_q.

3.4 Modification of Object Position in Absolute Coordinates

The absolute position of an object A is (X_a, Y_a). The position (x_a, y_a) of an object A in the robot coordinates is obtained from equations (1) and (2). After the measurement correction, by the modified β' modified self-localization position (X'_r, Y'_r), we can obtain the modified object position X_a and Y_a from equations (9) and (10).

$$X_a = \cos\beta'(x_a + X'_r) - \sin\beta'(y_a + Y'_r) \quad (9)$$

$$Y_a = \sin\beta'(x_a + X'_r) + \cos\beta'(y_a + Y'_r) \quad (10)$$

4. Experiments

Half field of the RoboCup middle-size league (500cm width and 400cm depth) is used for the measurement environment. Corner poles (−250,400) and (250,400) are used for the landmark, and an orange ball is used for the measurement object. The robot is arranged so that the robot coordinates and absolute coordinates always become parallel, and the range of the measurement is within 120 degrees sensed by two forward cameras.

A mobile robot equipped with MOVIS is arranged on the lattice points (13 points of A to M) at 1m intervals (see in Fig.5). Positional error $D(=\sqrt{dx^2 + dy^2})$ of each measurement point was obtained from the positional error (dx, dy) between the measurement position and the real position. Experimental results is shown in Table 1 to 4 and Fig.6 to 9.

In the experiment of the object position measurement, we confirmed good accuracy in case of short distance between the robot and the object. However, large error existed in case of large distance.

The reason of this results is because there is a large distortion generated from the angle error by the measurement except near and in front of the object.

The measurement error was found overall within the range of about 20 to 40cm, and an especially large error was found at the point A and C in the self-localization experiment. We consider that this results caused because the measurement error is large except near and in front of the landmark.

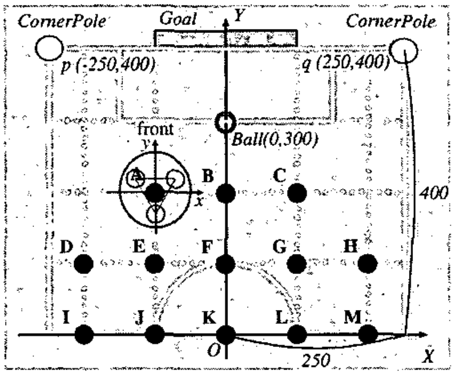

Fig.5: Measurement point

In the self-localization experiment after the measurement error correction, the accuracy of the measurement became higher about 50% as compared with the results before the error correction. However, we also found some points with lower accuracy.

5. Conclusions

In this research, we proposed a multiple omnidirectional vision system (MOVIS) with three omnidirectional cameras and its calculation method for the measurement of the object position and the self-localization in an autonomous mobile robot.

Furthermore, on the self-localization, we tried to improve the accuracy of the measurement by correcting the absolute position based on the measurement error of landmarks in the origin of the absolute coordinates.

To confirm the efficiency of our proposed system, we actually performed the measurement experiment. As a result, it was possible to measure the object position correctly up to a certain distance and we found that the self-localization of the robot is available. In addition, we confirmed that the accuracy of the self-localization is improved by the correction of the absolute position.

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Table 1: Positional Error of Object Position Measurement in Robot Coordinates

	Object Position		Positional Error		
	X	Y	dX	dY	D
A	104	100	4	0	4
B	1	107	1	7	7
C	-112	116	-12	16	20
D	195	198	-5	-2	5
E	103	206	3	6	6
F	7	218	7	18	19
G	-102	215	-2	15	15
H	-234	241	-34	41	53
I	213	309	13	9	15
J	114	321	14	21	25
K	-25	330	-25	30	39
L	-90	326	10	26	27
M	-212	344	-12	44	45

Table 2: Positional Error of Self-Localization in Absolute Coordinates

	Self-Localization Position		Positional Error		
	X	Y	dX	dY	D
A	-2	198	98	-2	98
B	-34	179	-34	-21	39
C	181	200	81	0	81
D	-220	64	-20	-36	41
E	-79	87	21	-13	24
F	-7	80	-7	-20	21
G	91	82	-9	-18	20
H	217	60	17	-40	43
I	-175	-37	25	-37	44
J	-113	-50	-13	-50	51
K	-27	-34	-27	-34	43
L	69	-12	-31	-12	33
M	215	-67	15	-67	68

Table 3: Positional Error of Self-Localization after Measurement Error Correction

	Self-Localization Position		Positional Error		
	X	Y	dX	dY	D
A	-10	206	90	6	90
B	-35	195	-35	-5	35
C	194	203	94	3	94
D	-232	87	-32	-13	34
E	-78	106	22	6	22
F	0	98	0	-2	2
G	111	100	11	0	11
H	248	76	48	-24	53
I	-183	-10	17	-10	19
J	-110	-21	-10	-21	23
K	0	0	0	0	0
L	100	11	0	11	11
M	253	-45	53	-45	69

Table 4: Positional Error of Absolute Object Position after Measurement Error Correction

	Modified Object Position		Positional Error		
	X	Y	dX	dY	D
A	39	317	39	17	42
B	-47	300	-47	0	47
C	20	328	20	28	34
D	-66	279	-66	-21	69
E	-18	303	-18	3	18
F	-28	314	-28	14	31
G	-20	294	-20	-6	20
H	-34	314	-34	14	36
I	-29	315	-29	15	32
J	-45	299	-45	-1	45
K	-25	330	-25	30	39
L	-25	336	-25	36	43
M	-21	301	-21	1	21

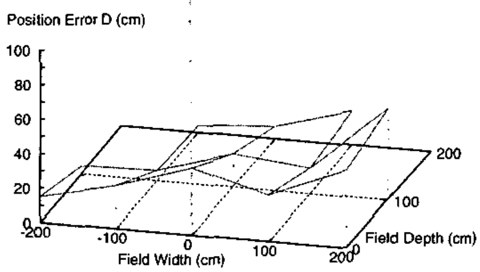

Fig.6: Positional Error of Object Position Measurement in Robot Coordinates

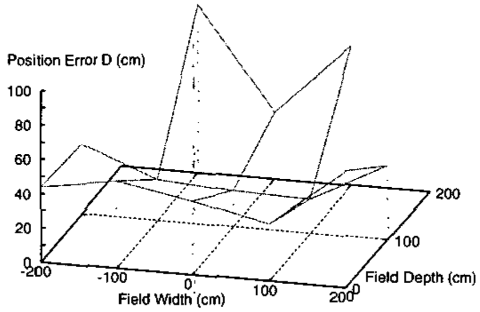

Fig.7: Positional Error of Self-Localization in Absolute Coordinates

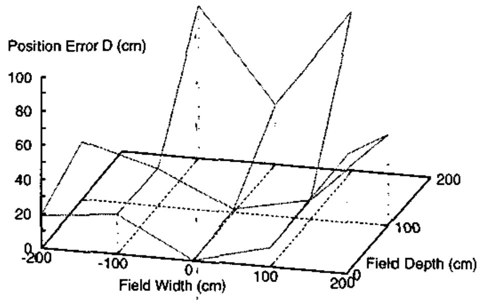

Fig.8: Positional Error of Self-Localization after Measurement Error Correction

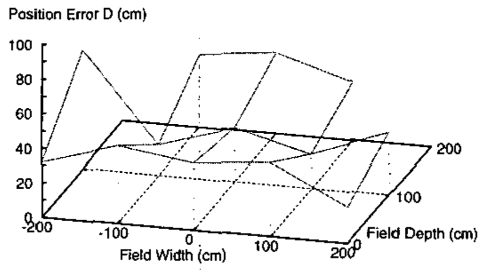

Fig.9: Positional Error of Absolute Object Position after Measurement Error Correction