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Localization of Mobile Robots with Omnidirectional Cameras

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Abstract—Localization of mobile robots are important tasks for developing autonomous mobile robots. This paper proposes a method to estimate positions of a mobile robot using a omnidirectional camera on the robot. Landmarks for points of references are set up on a field where the robot works. The omnidirectional camera which can obtain 360 [deg] around images takes photographs of these landmarks. The positions of the robots are estimated from directions of these landmarks that are extracted from the images by image processing. This method can obtain the robot positions without accumulative position errors. Accuracy of the estimated robot positions by the proposed method are evaluated through some experiments. The results show that it can obtain the positions with small standard deviations. Therefore the method has possibilities of more accurate localization by tuning of appropriate offset parameters.

Keywords—Mobile robots, Localization, Omnidirectional camera.

I. Introduction

AUTONOMOUS mobile robots such as robotic vacuum cleaners, guiding robots and rescue robots have been active in our living fields. Since most of these mobile robots are controlled on some coordinates, localization of mobile robots are important tasks for developing autonomous mobile robots. Although famous methods have been used widely, such as odometryies that calculate traveled distance from rotation of wheels and inertial navigation systems consist of gyro sensors and acceleration sensors, these methods need a system to reset accumulative errors. Otherwise, GPS can obtain positions without accumulative errors, but their accuracy is about several meters order. When it is used in buildings, the accuracy is to be worse due to weak receive sensitivity. Therefore, a localization method which has high position accuracy and no accumulative errors is expected.

Leonard and Durrand-whyte [1] proposed a localization method for using landmarks that were object shapes extracted from image datas. Elfes [2] developed a sonar-based mapping and navigation system for an autonomous mobile robot operating in unknown and unstructured environments. Godha et al. [3] developed a DGPS/MEMS INS integrated system, which is able to provide a navigation solution with accuracy levels appropriate for land vehicle navigation. Betke and Gurvits [4] proposed a method to localize mobile robots by using some landmarks. Nuchter [5] implemented 3D outdoor slam. Seki [6] proposed obstacle avoidance method for nonholonomic mobile robots. Hornung [7] developped 3D navigation system for cluttered environment.

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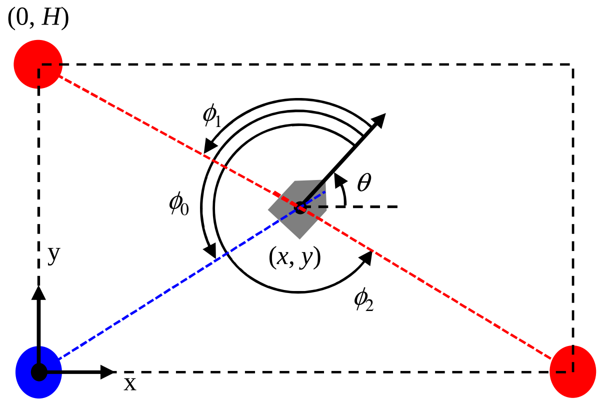


Fig. 1 Landmark positions and difinition of directions

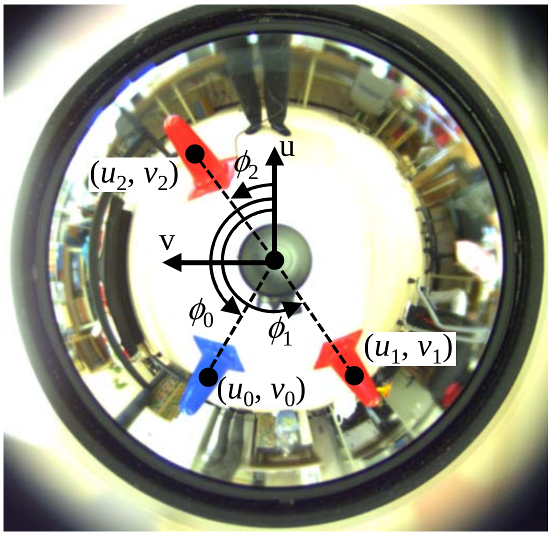


Fig. 2 Omnidirectional picture and landmark directions

This paper proposes a method to estimate robot positions without accumulative errors by using omnidirectional cameras. Since an omnidirectional camera consist of an image sensor and a hemispherical mirror, 360 [deg] around pictures are obtained by capturing the mirror with the image sensor. This omnidirectional camera is equipped with a mobile robot and captures its surrounding. Three landmarks for points of

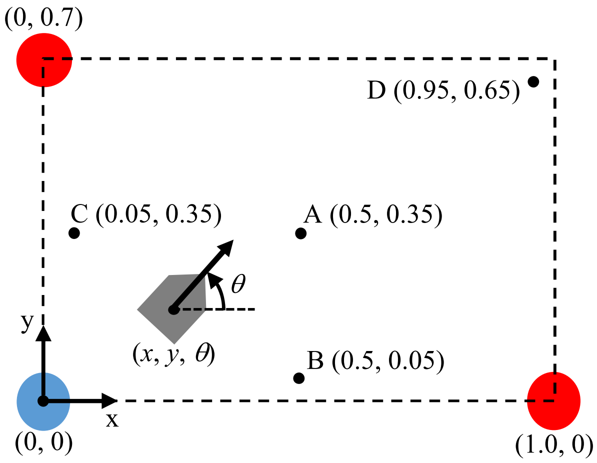


Fig. 3 Experimental settings

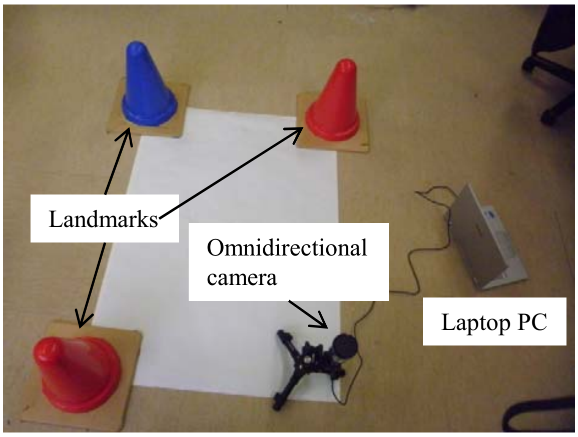


Fig. 4 Experimental environment

references are set up on a field where the robot works and are captured with the omnidirectional camera. The positions of the robots are estimated from directions of these landmarks that are extracted from the captured images by image processing. Since the positions are estimated from the captured image, there are no adding up calculations and no accumulative errors. When the directions of the landmarks are measured precisely, the accuracy of estimated position will be higher than GPS. The accuracy of proposed method are evaluated through some experiments.

II. Problem Settings

A robot is equipped with a omnidirectional camera on the top of the robot. The camera can take its 360 [deg] surrounding. Landmarks are set up on the field at known positions as shown in Fig. 1. To distinguish these landmarks, the blue one is on the origin, and the others are red on the points of (0, H) and (W, 0) of the world coordinate. The robot can work only in the area $W \times H$. These landmarks are observed by the omnidirectional camera, and their directions (ϕ_0, ϕ_1, ϕ_2) are extracted where the front of the robot is 0 [deg]. The direction ϕ_0 is for the landmark on the origin. The directions ϕ_1 and ϕ_2 are for the landmarks on the points (0, H) and (W, 0), respectively. The robot position is represented by its position on the world coordinate and its direction, (x, y, θ), as shown in Fig. 1. The robot position (x, y, θ) is estimated from the measured landmark directions (ϕ_0, ϕ_1, ϕ_2).

III. Observation of Landmark Directions by Image Processing

Fig. 2 shows an picture captured by the omnidirectional camera. As shown in this figure, the u-axis is assigned vertically and v-axis is assigned horizontally. Landmark areas are extracted by colors and classified by labeling process, then the landmark directions are calculated with the center of gravity of each area. At the first, the captured images are converted from RGB color code to HSV color code. Then, the converted images are binarized with each threshold on the hue, saturation, and value layers, respectively. After that, these layers are integrated by logical sum to one image which has only landmark areas. Since if some lack appear in the landmark areas, it will be a cause of errors for calculating the center of gravities, the areas are treated by opening and closing processging. Then, the landmark's center of gravities are calculated, where the point of (u_0, v_0) is for the center of gravity of the extracted blue area and the points of (u_1, v_1) and (u_2, v_2) are for the extracted red areas. The landmark directions (ϕ_0, ϕ_1, ϕ_2) are calculated by equations that are based on these center of gravities as follows.

$$\phi_i = \tan^{-1}\left(\frac{v_i}{u_i}\right) \qquad (i = 0, 1, 2) \tag{1}$$

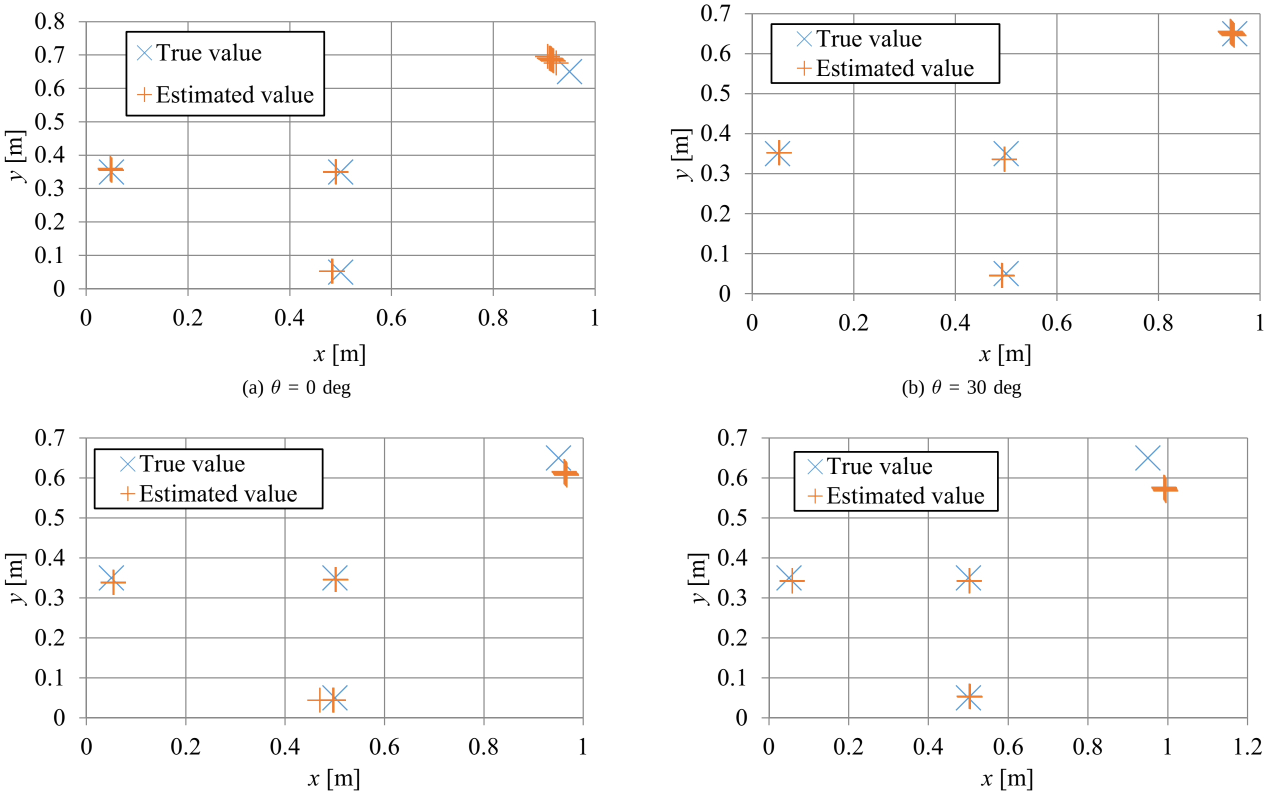
IV. Localization from Landmark Directions

Robot position (x, y, θ) are estimated from the landmark directions (ϕ_0, ϕ_1, ϕ_2) that are measured by image processing. On the world coordinate, the three lines below passing through each landmark should be cross on a point of the robot position.

$$\begin{aligned} y &= \tan(\theta + \phi_0)\, x \\ y &= \tan(\theta + \phi_1)\, x + H \\ y &= \tan(\theta + \phi_2)\,(x + W) \end{aligned} \tag{2}$$

Therefore, the robot position are calculated by solving the simultaneous equations of these three line equations as follows.

$$\begin{aligned} x &= \frac{H}{\tan(\theta+\phi_0) - \tan(\theta+\phi_1)} \\ y &= \frac{H\tan(\theta+\phi_0)}{\tan(\theta+\phi_0) - \tan(\theta+\phi_1)} \\ \theta &= \tan^{-1}\left(\frac{HM_2 + WM_1\tan\phi_2}{-WM_1 + HM_2\tan\phi_1}\right) \\ M_1 &= \tan\phi_0 - \tan\phi_1 \\ M_2 &= \tan\phi_0 - \tan\phi_2 \end{aligned} \tag{3}$$



(a) θ = 0 deg (b) θ = 30 deg (c) θ = 60 deg (d) θ = 90 deg

Fig. 5 Results of localizetion experiments

V. Experiments

Some experiments were implemented to evaluate the accuracy of proposed localization method. As shown in Fig. 3, one blue and two red road cones are set up on a graph paper with 1.0 [m] $\times$ 0.7 [m] size. The points of A to D in Fig. 3 are observation points. The robot positions were observed for 10 times on these points with its direction is 0, 30, 60, and 90 [deg], respectively. The accuracy of estimated positions were evaluated by averages, standerd deviations, and relative errors. Fig. 4 shows an experimental environment picture. The bases of road cones were masked not to change the center of gravity due to its angles.

The results of localization experiments are shown in Fig. 5. Fig. 5 (a) to Fig. 5 (d) shows the result of θ = 0 [deg] to θ = 90 [deg], respectively. Averages, standard deviations, and relative errors are summarized in Table I to Table IV. The average values show that the accurate localization was realized by the proposed method with less than 0.01 [m] position errors exept D point. At the D point, since the errors of measuring landmark directions affect greatly more than other observation points, because the robot is on the farthest point from three landmarks, the position estimation errors are largest in the observation points. Otherwise, since the standard deviation values are almost all very small, more accurate estimation will be expected by tuning appropriate offset. At the B and C point, althou the relative errors of y and x are large values, the cause of this errors are the small true values. The errors of average values of these points are less than 0.01 [m]. The bias errors are attributed that deformation of the camera lens or the mirrors.

VI. Conclusion

This paper proposed a method to estimate robot positions by omnidirectional camera. Three landmarks for points of references were set up on a field where robots work, and the landmark directions were measured from captured omnidirectional images through image processing. The robot positions were estimated from the landmark directions and their known points. The proposed method were evaluated thrugh some experiments. The results showed the standard deviations were very small, and if the appropriate offset values were finded, more accurate estimation about less than 1 % relative errors will be expected. For future, we have to identify the causes of position errors and improve the accuracy of localization. The psoposed method will be evaluated in more large outdoor firlds. Image processings will be enhanced in functionality. Development of landmarks for actual environment are necessary.

TABLE I: Evaluation of position estimation accuracy when θ = 0 [deg]

	Average			Standard deviation			Relative error		
	x [m]	y [m]	θ [deg]	x [m]	y [m]	θ [deg]	x [%]	y [%]	θ [%]
A	0.490	0.350	0.11	3.15×10^{-4}	2.54×10^{-4}	4.69×10^{-3}	1.88	0.0450	–
B	0.483	0.052	-1.01	5.21×10^{-4}	1.71×10^{-4}	2.48×10^{-2}	3.37	4.51	–
C	0.049	0.357	0.15	9.77×10^{-4}	1.99×10^{-3}	8.47×10^{-2}	2.03	1.87	–
D	0.914	0.687	2.48	4.41×10^{-3}	4.88×10^{-3}	3.11×10^{-1}	3.78	5.71	–

TABLE II: Evaluation of position estimation accuracy when θ = 30 [deg]

	Average			Standard deviation			Relative error		
	x [m]	y [m]	θ [deg]	x [m]	y [m]	θ [deg]	x [%]	y [%]	θ [%]
A	0.497	0.336	30.25	1.51×10^{-4}	1.31×10^{-4}	1.55×10^{-2}	0.61	4.02	0.84
B	0.492	0.045	29.59	3.61×10^{-4}	1.65×10^{-4}	1.59×10^{-2}	1.59	10.13	1.36
C	0.053	0.352	30.33	8.45×10^{-5}	1.65×10^{-4}	1.00×10^{-2}	6.50	0.55	1.09
D	0.945	0.651	30.12	2.29×10^{-3}	3.07×10^{-3}	1.79×10^{-1}	0.58	0.16	0.41

TABLE III: Evaluation of position estimation accuracy when θ = 60 [deg]

	Average			Standard deviation			Relative error		
	x [m]	y [m]	θ [deg]	x [m]	y [m]	θ [deg]	x [%]	y [%]	θ [%]
A	0.502	0.346	59.81	9.04×10^{-5}	9.31×10^{-5}	6.49×10^{-3}	0.34	1.29	0.32
B	0.494	0.044	59.52	8.20×10^{-3}	4.92×10^{-5}	1.70×10^{-2}	1.16	11.51	0.79
C	0.054	0.338	59.30	1.07×10^{-4}	2.92×10^{-4}	1.14×10^{-2}	8.30	3.31	1.17
D	0.964	0.612	59.46	1.79×10^{-3}	2.78×10^{-3}	1.58×10^{-1}	1.47	5.92	0.90

TABLE IV: Evaluation of position estimation accuracy when θ = 90 [deg]

	Average			Standard deviation			Relative error		
	x [m]	y [m]	θ [deg]	x [m]	y [m]	θ [deg]	x [%]	y [%]	θ [%]
A	0.502	0.342	89.78	1.38×10^{-4}	6.70×10^{-5}	4.64×10^{-3}	0.47	2.17	0.24
B	0.503	0.053	90.83	7.64×10^{-4}	3.62×10^{-4}	2.75×10^{-2}	0.67	6.61	0.92
C	0.058	0.342	89.73	6.96×10^{-5}	2.18×10^{-4}	4.47×10^{-3}	16.62	2.21	0.30
D	0.993	0.573	86.61	1.46×10^{-3}	2.70×10^{-3}	1.47×10^{-1}	4.48	11.79	3.77

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