천정 부착 칼라 패치 배열을 이용한 이동로봇의 자기위치 인식

Localization for Mobile Robot Navigation using Color Patches Installed on the Ceiling

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Abstract : A localization system to estimate the position as well as movement direction of mobile robots is proposed in this paper. This system implements a camera fixed on a robot and color patches evenly distributed and mounted on the planar ceiling. Different permutations of patch colors code information about robot localization. Thus, extraction of color information from patch images leads to estimation of robot position. Additionally, simple geometric indicators are combined with patch colors to estimate robot's movement direction. Since only the distribution of patch colors has to be known, the analysis of patch images to is relatively fast and simple. The proposed robot localization system has been successfully tested for navigation of sample mobile robot. Obtained test results indicate the robustness and reliability of proposed technique for robot navigation.

Keywords : mobile robot navigation, localization system, color image analysis

I. Introduction

Localizing capability of mobile robots is extremely important for free ranging path tracking as well as reactive navigation in home robot and human interaction. Therefore, the mobile robot's localization systems have recently attracted attention of many researchers. Previously, dead reckoning method has been widely used for most wheeled mobile robots to calculate their current locations with respect to an inertial frame of reference [1]. This method is simple because no external sensors are required. However, this approach based on the encoded or odometric information from the wheels is subject to major accumulation errors caused by wheel slippage, or by mechanical tolerances and surface roughness. In consequence, the robot may fail to keep track of its true location over long distances. To compensate inaccuracy of dead reckoning, an application of a low-cost rategyro was investigated [2] to fuse dead reckoning estimates for overcoming the wheel slippage problem by means of the Kalman filtering. In [3] a highly cost effective location system was devised based on encoded magnetic compass to compensate abnormal orientation drift influenced by wheel slippage, thereby resulting in robot position recovery. However, magnetic compass does not function well at a place where the magnetic fields vary from position to position. Unfortunately, the low-cost rategyro usually suffers from high drift rate. And these two techniques cannot eliminate cumulative errors caused by surface roughness.

Then another way of using ultrasonic sensors to correct the errors was investigated. If given any known or partially recognized structured environment, the robot measures time-of-flight (TOF) temporal data from its surroundings by using several ultrasonic sensors located on it. Then this temporal information is processed to obtain its spatial location by means of barrier test [4], extended Kalman filtering with environment models [5-8], fuzzy fusion logic [9], or neural networks [10]. Although this approach has been proven to be very reliable, the cost of robot sensing system and rules for sensor settings remain the main problems. This method depends on various conditions, like the robot task definition, amount of a priori knowledge about the environment, and the types of sensors used. Thus, this approach is not easy for implementation and practical use.

Also, vision systems to acquire environmental information for robot navigation have been investigated [11]. However, little research has been done on the space representation for indoor mobile robot with a generic map based on colors. In the method proposed in this paper, patches containing different colors are attached on the ceiling to create a map further used for robot localization. The patch images are acquired by a facing the ceiling camera fixed on the robot. Based on image analysis, the robot can estimate its position with enough level of accuracy.

II. Definition of the COLOR MAP

1. Map construction

Fig. 1 shows the fragment of ceiling divided into 25 squares, where square number represents different patch. Since a camera facing the ceiling is used, the number of captured patches depends on the distance between ceiling and the camera. In this project,

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

그림 1. 천장에 부착한 칼라 패치의 코드 배열.
Fig. 1. Combination of codes on the ceiling.

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this distance is equal to 2.5 meters. The distance between every two adjacent patches is equal to 2 meters to make sure that at least one patch will be acquired for any robot location. Considering these assumptions, the map with 25 different patches covers the space of 10×10 square meters. Then the mobile robot can identify its position inside of this area, which is usually quite enough for indoor using.

2. Patch design

Accordingly to the constructed map, at least 25 different patches will be needed to code 25 numbers. This can be done utilizing patch shape. For example, circle may code digit 1, triangle - digit 2 and so on. However, this method might introduce errors since acquired image can contain also other ceilings elements with size and shape similar to patches used for digit coding. Furthermore, even after focusing on the single patch, its shape can be wrongly decoded due to geometric distortions in acquired image. This is caused by varying camera distance and angle to analyzed patch. Then, some image restoration will be necessary to correct these distortions, increasing computational effort. Application of complex shapes to ensure correct patch analysis independently on the distortions also is not a good solution, because then analysis of every acquired image will become a complex and time consuming task. Thus in the proposed approach the patch is characterized only based on the color information. The permutations of different path colors allow coding of unique number. As usually most ceilings are of constant color (white, tinge or gray with relatively small intensity and texture variations), their color saturation represented in HSV color space is quite low. The background in acquired images (which represents the ceiling) can be then easily removed based on the saturation filter. The HSV is color space where H stands for hue, S for saturation, and V for value. It describes colors as points in a cylinder whose central axis ranges from black at the bottom to white at the top. Angle around the axis corresponds to "hue", distance from the axis corresponds to "saturation", and distance along the axis corresponds to "value" (connected to color intensity). The sample HSV space is shown in Fig. 2.

However, the selection of colors for number coding is not a trivial task, because they may be very similar to each other,

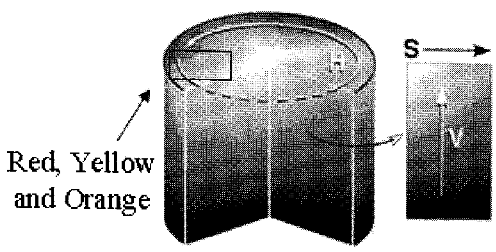


그림 2. HSV 칼라 space.
Fig. 2. HSV color space.

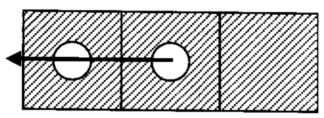


그림 3. 패치상의 두 개의 홀에 의한 방향 표현.
Fig. 3. Expression of the direction with two holes on a patch.

especially in case of dark illumination. For example, pink and red are hard for distinguish even for human eyes when the light is dimmed. In this study, three colors: yellow, orange, and red were selected to form a patch. It has been proven in our project, that these colors are most efficient to be distinguished from each other using common camera. The permutation of three colors gives 33=27 distinct combinations, thus up to 27 different numbers can be coded by patches defined using this color scheme.

To denote patch's direction, two white holes are also added into each patch, as shown in Fig. 3. The middle hole is the initial one. The patch direction is defined from the initial hole to another one, as indicated by arrowhead in Fig. 3.

Because the holes are white, they can be easily extracted from the image by application of saturation filter.

III. Patch Image Analysis

Fig. 4 shows the flow chart of patch image analysis. It implements the following steps:

1. Image pre-processing

1) Transformation of RGB to HSV color space.
2) Application of saturation filter to remove the ceiling background by thresholding.
3) Application of intensity filter to remove a potentially detected lamp that is represented by a very high intensity image region. Again, this is made by image thresholding.
4) Artifact removal by finding patch objects only. This is done using connected component labeling that finds the candidate region that could represent the patch.
5) Since many patches can be detected in a single image, size filtering is used to find the bigger one (based on its area) and to remove the smaller remaining objects.

Fig. 5 shows the original image and its pre-processing results.

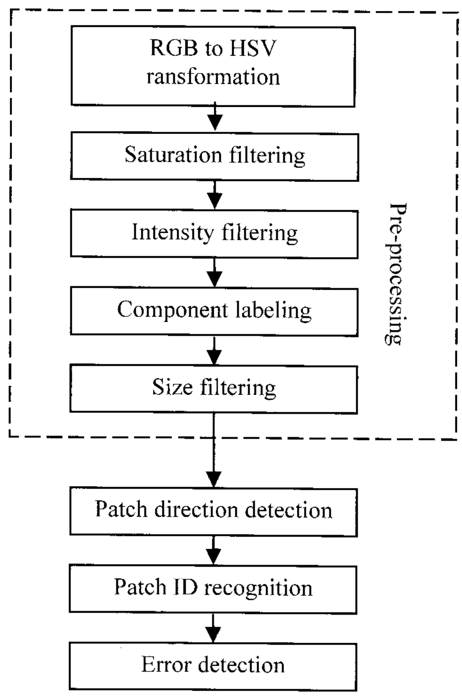
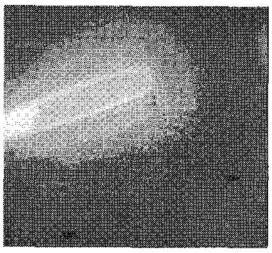
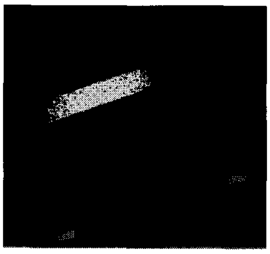


그림 4. 패치 인식을 위한 플로우 차트.
Fig. 4. Flow chart for the patch recognition.



(a) Original image



(b) After saturation filtering

(c) After intensity filtering

(d) After connected component labeling and size filtering

그림 5. 전처리 후의 결과.

Fig. 5. Results of image pre-processing.

$$\theta = \arctan\left(\frac{y_1 - y_2}{x_1 - x_2}\right) \quad (1)$$

The blue rectangle on Fig. 5d indicates detected patch.

2. Estimation of patch direction

$$(x_3, y_3) = (2x_2 - x_1, 2y_2 - y_1) \quad (2)$$

Patch direction is estimated based on the white holes detection, located inside of the patch, as described in p. 2.2. The patch background is removed by application of saturation filter, as shown in Fig. 6. Then connected component labeling is used at first to extract the holes from the patch. In order to localize the holes, scan along the boundary of the blue rectangle (that delineates thepatch) is performed, elements found close to the boundary are neglected, and finally size filtering is used to select the biggest two components considered as the holes.

Assume that the centers of two holes are points (x_1, y_1) and (x_2, y_2), whereas the center of the blue rectangle is point (x_c, y_c). Then the two distances from each hole to point (x_c, y_c) are calculated and the smaller one is chosen to indicate the middle hole. Supposing that its center is defined by (x_2, y_2), then the angle between 0x axis and patch direction (see Fig. 7) can be calculated accordingly to eqn. (1):

3. Number recognition based on patch colors

The coordinates of third patch's center point (x_3, y_3) as shown in Fig. 8 can be easily calculated by eqn. (2):

Computing the median hue value in a given neighborhood around points (x_1, y_1), (x_2, y_2) and (x_3, y_3), three patch colors can be evaluated. Then the number coded by this patch can be extracted from the predefined codebook.

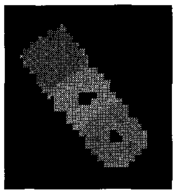


그림 6. 패치 영상.

Fig. 6. A sample of a patch image.

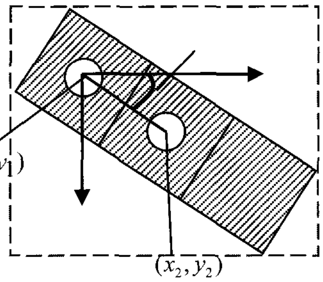


그림 7. 패치의 방향 계산.

Fig. 7. Estimation of patch direction.

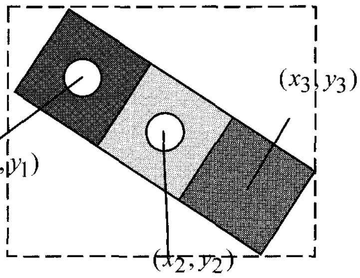


그림 8. 코드 표현을 위한 3개의 칼라.

Fig. 8. Three components of different colors for code expression.

4. Error detection

Due to different possible patch locations in the acquired image, some patch detection errors may occur, even with assumed simple patch structure. In that case, the localization system should be notified and reprocess again until the valid localization result will be obtained. In the discussed system, two rigid rules are used to detect the potential patch detection errors.

The first rule: as the center of the patch overlaps the initial hole, the same is also true for the center of the blue rectangle that delineates the patch. Assume point (x_c, y_c) is the center of that rectangle, and this rule can be expressed as follows:

$$\sqrt{(x_2 - x_c)^2 + (y_2 - y_c)^2} \le 0.5 \times \frac{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}}{2} \quad (3)$$

The second rule: the results of estimation point (x_3, y_3) coordinates should be the same for two different approaches. As shown in Fig. 9, assume θ is the angle between 0x axis and the patch direction, d is the distance between points (x_1, y_1) and (x_2, y_2), x_l and x_r represent x coordinate of the rectangle's left and right border, y_t and y_b represent y coordinate of the rectangle's top and bottom border. Because each of the patch

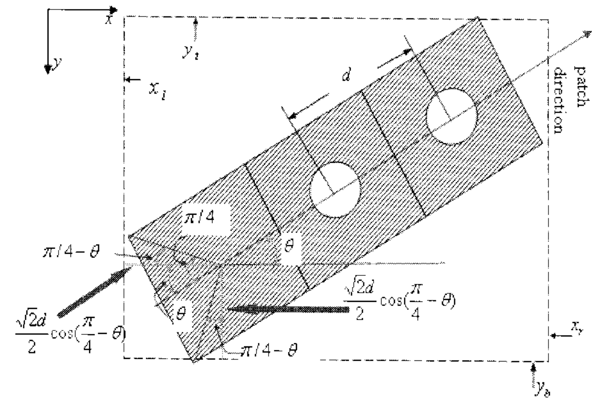


그림 9. 에러 검출 규칙.

Fig. 9. Illustration for error detection rules.

components is a square, the following equation (4) can be applied to compute coordinates (x_3, y_3). Here (x_3, y_3) is replaced by (x_3', y_3').

$$(x_3', y_3') = \left(x_l + \frac{\sqrt{2}d}{2}\left|\cos(\frac{\pi}{4}-\theta)\right|, y_b - \frac{\sqrt{2}d}{2}\left|\cos(\frac{\pi}{4}-\theta)\right| \right) \quad (4)$$

This formula will depend on which quadrant θ belongs to. The (4) represents the case when θ is in the first quadrant.

Result obtained using eqn. (4) can be compared with this estimated by formula (2). The evaluated center point coordinates (x_3', y_3') should be similar to the values (x_3, y_3). To check this, the eqn. (5) can be used:

$$\sqrt{(x_3'-x_3)^2+(y_3'-y_3')^2} \le 0.5\times \frac{\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}}{2} \quad (5)$$

If formulas (3) and (5) are true, then both two rules are satisfied. This means a correct detection of the analyzed patch.

IV. Experiment and Accurary

1. Estimation of robot precise position

Obtaining the number coded by given patch, the robot location can be known approximately. For example, if the number 3 was detected, then the robot is in the third square. However, every square covers an area with 2*2 square meters, and to estimate more precise robot location, patch's position in the analyzed image should be also considered. Fig. 10 presents one of possible patch location.

The center point of each patch in real coordinate system is (xpr, ypr), the center point of camera in real coordinate system is (xr, yr). Thus the real distance from center of camera (which denote accurate robot position projected onto the ceiling) to the center of to the patch center is d. Then, eqn. (6) can be used for estimation of accurate robot location:

$$(x_r, y_r) = \left(x_{pr} - d\times\cos(\theta_2-\theta_1-\frac{\pi}{2}), y_{pr} + d\times\sin(\theta_2-\theta_1-\frac{\pi}{2}) \right) \quad (6)$$

The robot movement direction is then defined by the angle$\pi/2-\theta_1$.

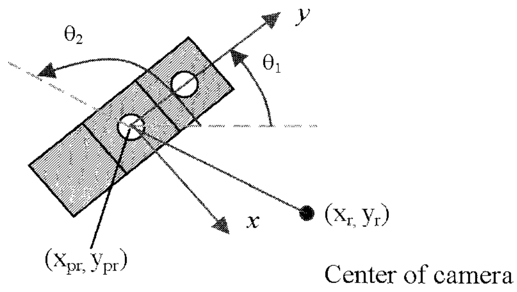
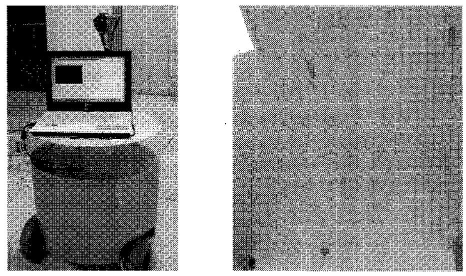


그림 10. 영상에서의 패치의 위치의 예.

Fig. 10. Sample patch location in the image.



(a) (b)

그림 11. (a) 실험에 사용한 로봇 (b) 천장에 부착된 패치.

Fig. 11. (a) mobile robot used in the experiments (b) colored patches on the ceiling.

2. The accuracy of proposed robot navigation system

To verify robustness of the proposed approach, we have repeatedly tested the proposed robot localization system in a real indoor environment using wheel mobile robot (Fig. 11).

In all experiments, first we project "color map" from ceiling to the floor and set several moving traces for the robot that have many points indicate the real position. Then the robot follows the trace and takes visual images in the enviroment. When arrives the set points, it is convenient to compare the real position on the floor with the one caculated by the robot. Every trace is about ten meters long, and the robot is taken off to another when one trace is finished. All localization experiments were performed in simulation using 100 random real positions.

표 1. 다른 환경 하에서의 위치 정확도.

Table 1. Localization accuracy in different environment.

Different enviroment	High-accuracy localization (error<=5cm)	Low-accuracy localization (error<=20cm)
Strong light source	92	96
Dim place	89	91
Ceiling height changed	95	98

표 2. 다른 환경하에서의 방향 정확도.

Table 2. Direction accuracy in different environment.

Different environment	Direction accuracy (error<=3°)
Strong light source	89
Dim place	86
Ceiling height changed	91

The software was run in several tests, with different environment and accuracy level. The number in both tables means the correct position as well as the direction in the total 100 selected samples.

It is obvious that the result is worst in dimmed light condition, because the camera could not acquire good quality image. Moreover, when the light source is too strong to making uneven ceiling light distribution, localization errors also occur (as shown in Fig. 11b, we can see a light source in the top left corner). Since the algorithm proposed in this paper is based on patch colors, lighting conditions strongly influence the obtained measurement accuracy. However, this problem can be solved using a light projector fixed on the robot towards the ceiling to obtain smooth and even ceiling light distribution.

The distance between every two patches is 2 meters in this project, but the distance from camera to ceiling is not fixed, and it depends on the room structure. For example, if the ceiling is higher, then the camera is farther away from patches. The length d in Fig. 10 will be larger even for the image acquired for the same robot position. To correct this possible location error a special patch with default length was attached to the ceiling as a reference. When the ceiling height changes, based on estimated length of this reference patch, the real distance between camera and ceiling can be calculated.

V. Conclusion

In this paper, a new system for mobile robot navigation was introduced. It represents an indoor environment by color map, which is used for the projection of robot location into a planar ceiling. The patches used for map construction indicate robot movement direction and its position. Experimental results demonstrated that proposed system provides fast and accurate estimation of robot position. The evaluated localization error is in range of 5 centimeters while the direction error is less than 3 degrees. This makes the proposed system reliable for practical applications.

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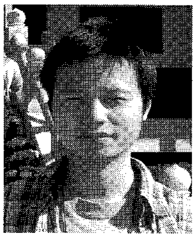

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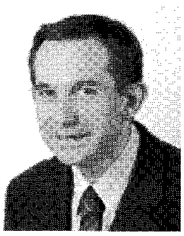

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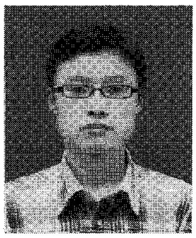

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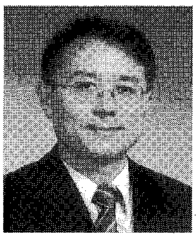

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