Traversing a door for mobile robot using PCA in complex environment

Min-Wook Seo, Young-Joong Kim, and Myo-Taeg Lim

1, 5-ka, Sungbuk-gu, Anam-dong, Seoul 136-701, Korea
(Tel : +82-2-3290-3698; E-mail: s1hanul; kyjoong; mlim@elec.korea.ac.kr)

Abstract: This paper presents a method that a mobile robot finds location of doors in complex environments and safely traverses the door. A robot must be able to find the door in order that it achieves the behavior that is scheduled after traversing a door. PCA(Principal Component Analysis) algorithm using the vision sensor is used for a robot to find the location of door. Fuzzy controller using sonar data is used for a robot to avoid an obstacle and traverse the doors.

Keywords: Mobile robot, PCA, Door recognition, avoid obstacle

1. INTRODUCTION

In recent years, various types of robots have been used in human assistance, welfare, amusement, and the others. An intelligent robot should make decision behavior according to the facing environment, and also should require its perceptual system and action system. There are various kinds of actions that a mobile robot must achieve basically in order to achieve a big task in indoor environment. Since a mobile robot must record its position in order to find goal, it must be able to recognize strangers in order to achieve security tasks. And also it must be able to find and traverse a door for map building and navigation.

Usually, a door's shape is a rectangle with a knob. Based on this fact, people can find a door easily by experience and direct observation in interior of building when people visit first time. So, some methods were researched by this information. The doors are extracted from using dilation and afterwards with a very simple algorithm that enhances the columns merging those columns separated by very thin spaces [1]. There are some problems when not only the image of door is not columns separated by very thin spaces but also many column elements of image happen in off-door image. The color of the door panels is used to identify closed doors and this information is used for self-localization. The doors are extracted from the rest of the environment using their characteristic color [2]. [3] presents the problem of using a "simple" polyhedral model of doors for detection and servoing through doors. The robust method to autonomously find doors in a corridor that is composed of cluttered environments with a Ranger is presented [4]. There are many algorithms for pattern recognition.

PCA is a useful statistical technique that has found application in fields such as face recognition and image compression, and is a common technique for finding patterns in data of high dimension. Eigen Space Method is attempted by [16][17]. It is verified good for the recognition strategy [17].

Fuzzy logic has been utilized in navigation systems for mobile robots over a decade. Early in 1991, Yen and Pfluger [5] proposed a method of path planning and execution using fuzzy logic for mobile robot control. From then on, the efficiency of using fuzzy logic in mobile robot navigation systems has been demonstrated [6]-[9]. A comprehensive study of fuzzy logic-based autonomous mobile robot navigation systems is given in [10]. Recently, several new solutions to the mobile robot navigation problem based on fuzzy logic in unknown environments have been proposed [11]-[13]. There also exist methods combining fuzzy logic with other algorithms, such as genetic algorithms [14], potential fields and neural networks [15].

To increase performance that a mobile robot finds a door, this paper proposes a method that a mobile robot finds location of doors in complex environments and safely traverses the door. PCA (Principal Component Analysis) algorithm using the vision sensor is used for a robot to find the location of door and fuzzy controller using sonar data is used for a robot to avoid an obstacle and traverse the door.

The organization of this paper is as follows: In Section 2, we present a pre-processing of vision data, introduction of PCA and door recognition by PCA. In section 3, we present a fuzzy rule-base for a mobile robot using sonar. In section 4, we present a result of experiment with Pioneer-2 mobile robot. Finally, we draw conclusions..

2. DOOR RECOGNITION

2.1 Pre-processing for Eigenspace Mapping

The quantity of an image data (640×480 pixel) per a frame that was entered through a CCD camera is very large. So, it is necessary to diminish the image data. If we should use this image (640×480 pixel), the mobile robot that has limited hardware resource could not operate in real-time. So 160×120 pixel image data is used in this paper. To simplify the reduced image, we used sobel filter. Through this process, we extracted some door images (Positive Image); we extract a door image with changing the camera position, and off-door images (Negative Image) that are consisted of office surrounding environment image. Fig. 1 is a part of Positive Images and Fig. 2 is a part of Negative Images that is used in experiment.

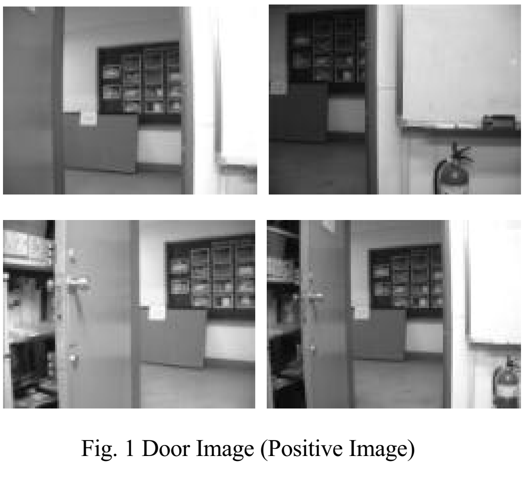

Fig. 1 Door Image (Positive Image)

Fig. 2 Off-door image (Negative Image)

2.2 Eigenspace Mapping

Training images can be viewed as a vector. If the image's width and height are w and h pixels respectively, the number of components of this vector will be $w \cdot h$. Each pixel is coded by one vector component. The construction of this vector from image is performed by a simple concatenation of rows or columns. The main idea of the PCA is to find the vectors that best account for the distribution of training images within the entire image space.

Let the training set of images be $\Gamma_1, \Gamma_2, \Gamma_3, \ldots, \Gamma_M, (\Gamma \in R^N)$. The average of the set is defined by:

$$\Psi = \frac{1}{M}\sum_{n=1}^{M}\Gamma_n \tag{1}$$

M means the number of images in the training set. Each training image differs from the average image by the vector

$$\Phi_i = \Gamma_i - \Psi \tag{2}$$

This set of large vector Φ is then subject to the Karhunen-Loeve expansion, to produce the M orthonormal vectors u_n, and their associated eigenvalues λ_n that optimally describe the distribution of the data in error sense of an RMS(root mean square). The vector u_k and scalars λ_k are the eigenvectors and eigenvalues with respect to the C (covariance matrix) where the matrix $A=[\Phi_1, \Phi_2, \Phi_3, \ldots, \Phi_M]$. Covariance matrix of Φ is calculated by equation (3).

$$C = \frac{1}{M}\sum_{n=1}^{M}\Phi_n\Phi_n^T = \frac{1}{M}AA^T \tag{3}$$

The matrix C, however, is N by N. And determining the N eigenvectors and eigenvalues is an intractable task for typical image sizes. We need a computationally feasible method to find these eigenvectors [17].

If the number of data points in the image space is less than the dimension of the space, ($M < N$), then, dimension of eigenvector will be only M rather than N. The remaining eigenvectors will have associated eigenvalues of zero. Fortunately we can solve the N by N dimensional eigenvectors in this case in terms of the eigenvectors of an M by M. Consider the eigenvectors v_i of A^TA such that:

$$A^T A v_i = u_i v \tag{4}$$

Multiplying both side by A, we have:

$$AA^T A v_i = u_i A v_i \tag{5}$$

From which we see that $A \cdot v_i$ are the eigenvectors of $C^{'}=A^TA$. A new image region is transformed into eigenspace representation by equation (6).

$$u_l = \sum_{k=1}^{M} v_{lk}\Phi_k \tag{6}$$

So, we calculate the eigenvalues and eigenvectors not from C but from C'. The result images from equation (6) are shown in Fig. 3. There are top 4 eigenspace images. Training images are consisted of 20 Positive Image and 40 Negative Image.

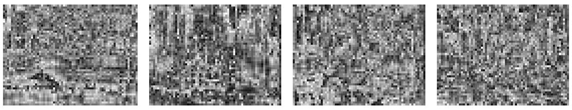

Fig. 3 Eigenspace ($\lambda_1 \sim \lambda_4$)

2.3 Door Recognition using Eigenspace

Training image can be reunited using eigenspace image that is obtained through section 2.2. In other words, training images that are used in an experiment are represented by linear combination of eigenspace.

$$EW = A \tag{7}$$

E is eigenspace matrix and W is coefficient matrix. Because each column of E is orthonormal, we can find W_P and W_N from equation (8).

$$\begin{aligned} W_P &= E^T \cdot \textit{Positive image} \\ W_N &= E^T \cdot \textit{Negative image} \end{aligned} \tag{8}$$

Each weight group, W_P and W_N, is described as $W_P=[w_1, w_2, w_3, \ldots, w_m]$, $w \in R^N$ and $W_N=[w_1, w_2, w_3, \ldots, w_l]$, $w \in R^N$. When new image will be entered through CCD camera, we can find weight vector (w_k) of new image from equation (9).

$$w_k = E^T(\Gamma - \Psi) \tag{9}$$

According to Euclidian distance, we can know that new image belongs to Positive Image group or belongs to Negative Image group.

$$\varepsilon = \|w_i - w_k\|^2, (i = 1,2,\ldots,m+l) \tag{10}$$

If the smallest w_i of ε belongs to W_P, a new image is a door and if the smallest w_i of ε belongs to W_N, we can judge that the new image is not a door. Flow chart of vision system is

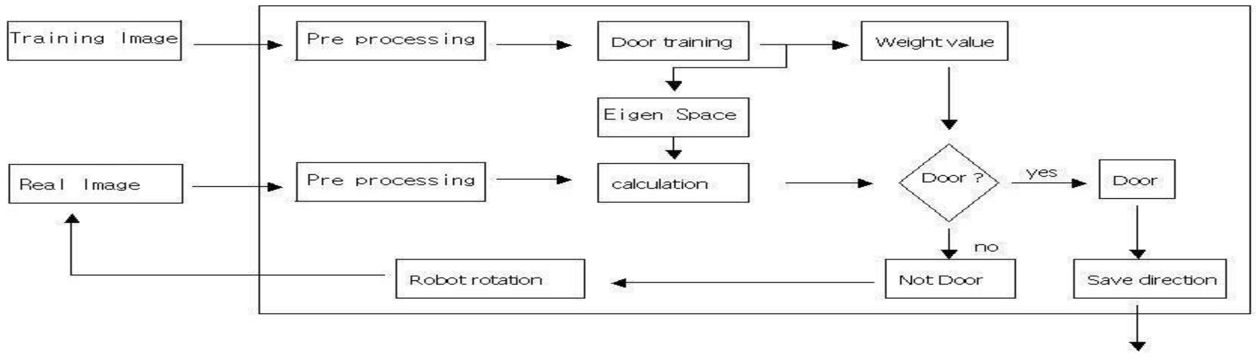

Fig. 4 Flow chat of vision system

presented in Fig. 4.

3. MOBILE ROBOT CONTROLLER

3.1 Fuzzy Controller

Sonar sensors measure the time elapsed between the transmission of a signal and the receiving of an echo of the transmitted signal to determine the distance to an obstacle. The sonar sensors on mobile robots can be used to detect objects around the mobile robot and to avoid collision with unexpected obstacles.

The goal of navigation in this paper is to make the mobile robot avoid an obstacle and traverse a door. The motion of the mobile robot will be realized by the control of its linear velocity and heading angle. Therefore, the input fuzzy variables of the fuzzy controller are the forward distance of robot between mobile robot and obstacle, and the side distance that is difference between left distance and right distance. The output fuzzy variables are chosen as the heading angle (θ) and linear velocity (v).

Mobile robot and location of sonar sensor are presented in figure 5.

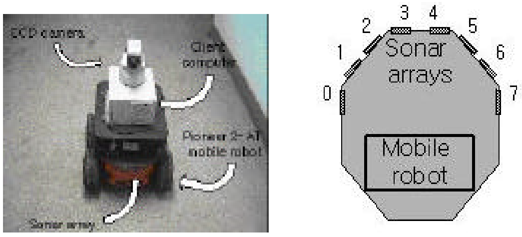

Fig. 5 Mobile robot system

Input fuzzy variables are presented in equation (11).

$$\begin{aligned} D(k) &= \min(sonar(3), sonar(4)) \\ L(k) &= \min(sonar(1), sonar(2)) \\ R(k) &= \min(sonar(5), sonar(6)) \\ SD(k) &= L(k) - R(k) \\ SA(k) &= sonar(0) + sonar(7) \end{aligned} \qquad (11)$$

D(k) is forward distance of the robot between the mobile robot and an obstacle, *L(k)* is left distance of the robot, *R(k)* is right distance of the robot, *SD(k)* express difference between left distance and right distance of mobile robot, and *SA(k)* is used in pass a door.

The linguistic terms have the following meanings:

Table 1 Input linguistic variables

Fuzzy Label	Meaning
Near	Near
Far	Far
N	Negative
Z	Zero
P	Positive

Table 2 Output linguistic variables

Fuzzy label	Meaning
S	Slow speed
M	Middle speed
F	Fast speed
SL	Rotate to small left
SR	Rotate to small right
Z	Fix angle
LL	Rotate to large left
LR	Rotate to large right

Linear velocity of the robot is consisted of the following rule;

.If *D(k)* is Near and *SD(k)* is Positive, then v is Small and θ is Small Left.

.If *D(k)* is Near and *SD(k)* is Zero, then v is Middle and θ is Zero.

⋮ ⋮

.If *D(k)* is Far and *SD(k)* is Negative, then v is Middle and θ is Large Right.

Linear velocity of fuzzy controller is presented in table 3.

Table 3 Linear velocity rule

SD(k) D(k)	N	Z	P
Near	S	M	S
Far	M	F	M

If an obstacle or a wall is near to a mobile robot, θ will be

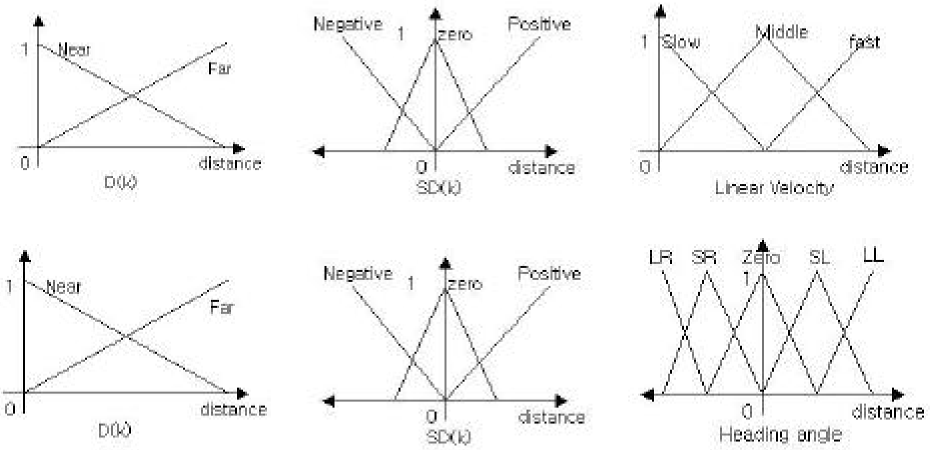

Fig. 6 Membership functions of linear velocity and heading angle

increased and if that is away then, θ will be decreased. With this truth, heading angle rule table is composed. Heading angle rule of fuzzy controller is presented in table 4.

Table 4 Heading angle rule

SD(k) D(k)	N	Z	P
Near	SR	Z	SL
Far	LR	Z	LL

The fuzzy control actions of v and θ are inferred using the Mamdani's compositional rule of inference. The defuzzification method is used center of gravity method.

If θ is big at the moment that a mobile robot passes a door, then the mobile robot will be bumped to a door. We limited value of defuzzyfication of θ to solve this situation. From *SA(k)*, we can know the moment a mobile robot passes a door. A threshold, 40cm, is space that remains between a robot and a door when a robot passes door.

$$\begin{cases} Heading\ \ angle(-\frac{\pi}{36}\sim\frac{\pi}{36})(rad/step) \\ \qquad\qquad ,if\ \ SA(k)\le 40cm \\ Heading\ \ angle(-\frac{2\pi}{9}\sim\frac{2\pi}{9})(rad/step), \\ \qquad\qquad ,if\ \ SA(k)>40cm \end{cases} \tag{12}$$

3.2 Mobile Robot System

Behavior flow chart of a mobile robot is presented in Fig. 7.

Door recognition behavior; When it is required a mobile robot must pass a door, a mobile robot acts this behavior using proposed algorithm to find a door.

Save direction of a door; A mobile robot stores door's direction from present position of robot.

Avoid obstacle & Approximation to a door behavior: A mobile robot goes to direction of a door with avoiding an obstacle.

Approximation to direction of a door: A mobile robot compares direction of a door with own direction.

Traversing a door behavior: A mobile robot using limited Heading angle traverses a door.

Fig. 7 Flow chart of robot system

4. EXPERIMENTAL RESULT

One part of experiment image was introduced in Fig. 1 and Fig. 2. 40 Negative Images and 20 Positive Images that were captured with a CCD camera on the top of the robot are used in order to train images. Maximum distance range of sonar sensor is limited to 3m, according to an experiment space. The mobile robot's width used in an experiment is 50cm and a door's width is 80cm.

When the mobile robot rotates 360° at position of a, b, and c, Table 4 describes a result of an experiment about whether the mobile robot could find a door.

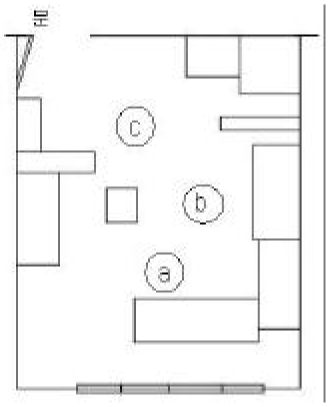

Fig. 8 Initial position of a mobile robot

Table 4 Accuracy for door recognition

Position of a robot	door / off-door	off-door / door
A	0% (0/30)	0% (0/30)
B	0% (0/30)	0% (0/30)
C	0% (0/30)	0% (0/30)

Position of a robot	door / door	off-door / off-door
A	100% (30/30)	100% (30/30)
B	100% (30/30)	100% (30/30)
C	100% (30/30)	100% (30/30)

Door / off-door; decide on a door, in the case of off-door.
Off-door / Door; decide on off-door, in the case of a door.
Door / off-door; decide on a door, in the case of off-door.
Off-door / off-door; decide on off-door, in the case of off-door.

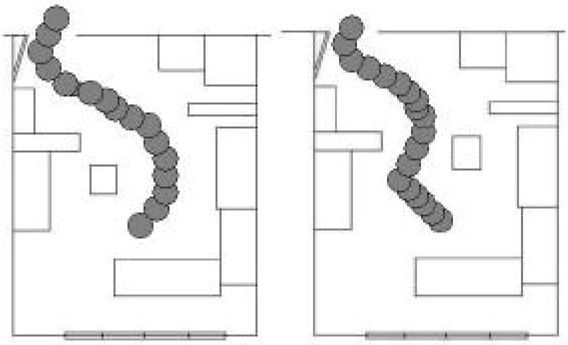

Fig. 9 A route of the mobile robot

80% success rate is shown in an experiment that a mobile robot is traversing a door.

5. CONCLUSION

This paper presents a method that a mobile robot finds location of doors in complex environments and safely traverses the door. The PCA algorithm has been tested on our mobile robot Pioneer-2 in real office environments. According to result of using PCA, we could confirm superior performance in recognition of a door. The proposed method can be used for an intelligent mobile robot to increase performance of a mobile robot.

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