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GUI환경을 갖는 퍼지기반 이동로봇제어

(Fuzzy Based Mobile Robot Control with GUI Environment)

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요 약

본 논문에서는 이동로봇 주변의 자기위치인식, 광학식 엔코더의 위치 데이터 및 초음파 센서의 환경 지도를 이용하여 퍼지 기반 센서융합 제어방식을 제시하였다. 영상 카메라를 이용하여 자기위치 인식성능을 높이고 초음파 센서에서 감지한 목표물의 형태, 거리와 특징을 퍼지 기반 제어기를 통하여 처리하여 이동로봇 주변의 환경지도를 만들어 자기위치 인식능력의 개선을 실험을 통하여 구현하였다.

Abstract

This paper proposes the control method of fuzzy based sensor fusion by using the self localization of environment, position data by dead reckoning of the encoder and world map from sonic sensors. The proposed fuzzy based sensor fusion system recognizes the object and extracts features such as edge, distance and patterns for generating the world map and self localization. Therefore, this paper has developed fuzzy based control of mobile robot with experimentations in a corridor environment.

Keywords : Mobile Robot, Fuzzy based control, NTSC camera, Self localization

I. Introduction

The developed fuzzy based mobile robot control is capable of generating the world map with sonic sensors and the self localization with monocular image camera. If the mobile robot is operated in uncertain environments and only is provided with the partial information, combining information from multiple sensors has to be used and reduces the ambiguity and uncertainty in making decisions. In this paper, the self localization method using a single camera is developed and the fuzzy based sensor fusion method combines the recognition of sensors[1]. The self localization and map updating are indispensable for mobile robot researches although they are also enable to apply path planning, navigation and tracking control methods[2,3].

There are many active researches to apply different kinds of sensor fusion schemes, for example, occupancy grid method based on the Baysian sensor modeling, Demphaster-shafer method, and Condensation algorithm for self localization and navigation[4]. Also, Thrun and colleagues use the global localization based on Monte Carlo localization method and apply it to mobile robot with sensor fusion such as stereo vision, sonar, range finder and infra-red sensors[5]. There are no more versatile and flexible methods than vision methods in obtaining the useful environment information, and now the fusion sensor methods are efficiently developed such as

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sonic sensor and monocular camera system for most mobile robot applications. This paper uses the fuzzy based sensor fusion of self localization data of environment, position data by dead reckoning of the encoder and world map data from sonic sensors[6].

Ⅱ. Basic Theory

The fuzzy based fusion sensor informations that are gathered by sonic sensors and NTSC camera produce the world map and self localization of the mobile robot environment. In order to prove the efficiency of the proposed fuzzy based control system, the mobile robot controller executes the robust position determination and obstacle detection. And also, the mobile robot must has the functions that are the architecture, image processing, fuzzy based sensing techniques and various sensor models[7].

This paper has also developed a new fuzzy based sensor fusion system both the recognition of environment and the self localization of robot.

1. Fundamentals of Building Applications

The proposed architecture is shown in Fig. 1where the input data consists of image sequences, odometry and sonic information. The sensor system is originally based on the vision and sonar detection.

The processing starts by passing images acquired from the camera and sonic data from the sonar module. Detected features are used to gather information of the object boundaries in the environment of the robot position. By taking odometry information, an initial estimate of position is obtained. This position is then refined by minimizing the discrepancy between the detected features and the projection of world map information[8,9].

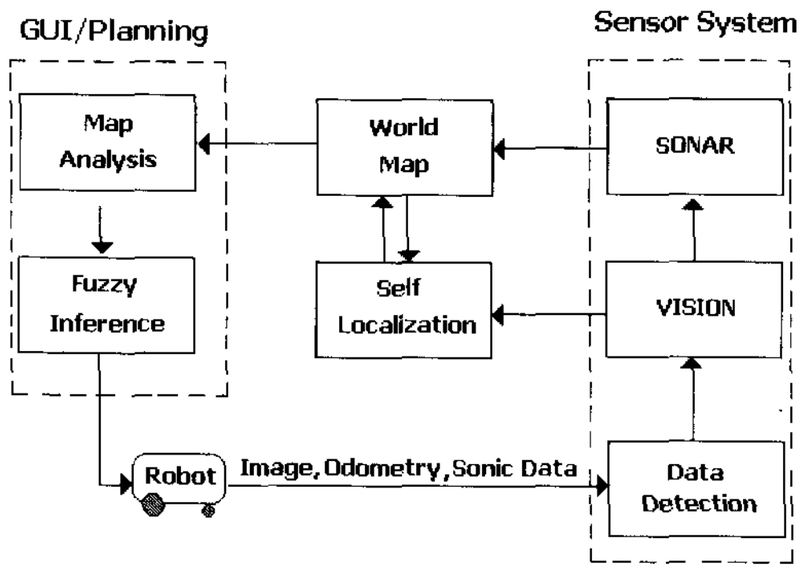


그림 1. 맵 빌딩 구조
Fig. 1. Map Building Framework.

2. Image Processing for Mobile Robot

The feature point extraction is vital to successful self localization, since the captured image is easily contaminated by the noises from the illuminations and geometrical characteristics in a corridor environment. And the robust image processing algorithms are required so that the information from that image can be used as key features for the self localization. The feature point extraction in the image captured by NTSC camera consists of the following stages: edge detection, histogram, thresholding, and the probabilistic calculation of the image pixels along the corridor lines. The corridor scene obtained during the navigation of the mobile robot has a number of feature information.

The edge detection can identify and locate discontinuities in the pixel intensities of an image, and provide information about the location of the boundaries of objects and the presence of discontinuities. The histogram is a fundamental image analysis tool that describes the distribution of the pixel intensities in an image and the thresholding consists of segmenting an image into two parts : a particle region and a background region. This process works by setting pixel values ranging from 0 to 255.

With pattern matching algorithms, this technique finds template matches regardless of poor lighting, blur and noise environment. Use pattern match to quickly locate known reference patterns or feature in an image, and create a model or template that represents the object for which are searching.

Finally the current robot pose from the self localization and the detected obstacle information are sent to the supervising mobile robot fuzzy controller[10,11].

One example of the corridor scene which is captured during the robot navigation is shown in Fig.

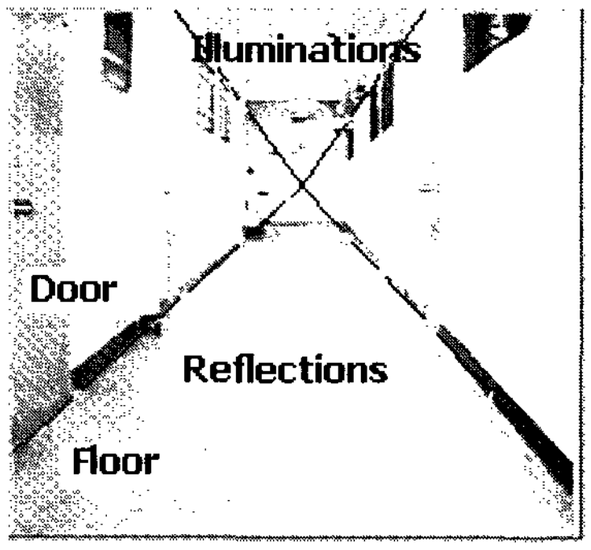


그림 2. 복도 전경
Fig. 2. Scene of Corridor.

2. The illumination and reflection by the environment are distributed widely along the corridor.

Although various kinds of research have been continued and even though there are many reports about the sensors, it is known that the vision based method have merits of the suitability and the simplicity under the ceiling lights and many doors of the corridor[12,13].

The self localization algorithm is based on the assumptions that the floor is flat and there exists a parallel straights lines along the corridor and vertical lines at sidewalls, and that the geometrical 2D invariant data along the corridor are also constructed in offline mode. The intersection points between the vertical lines and the floor are used as the feature points to calculate the invariant. The corresponding points between the image and prepared geometrical invariant database in offline mode play important roles in image based self localization and obstacle detection[14,15].

3. Fuzzy Based Sensing Techniques

In this paper, the proposed fuzzy based sensor fusion scheme is shown in Fig. 3. A vision processing block used the edge detection, histogram and thresholding methods, where the optical center of the camera is aligned to the corridor center in order to prevent the failure of feature data extraction originated from the capturing image.

In this system, the erroneous feature extraction from the captured image means self-localization failure and in turn leads the mobile robot to be gone astray. And so image capture including both side

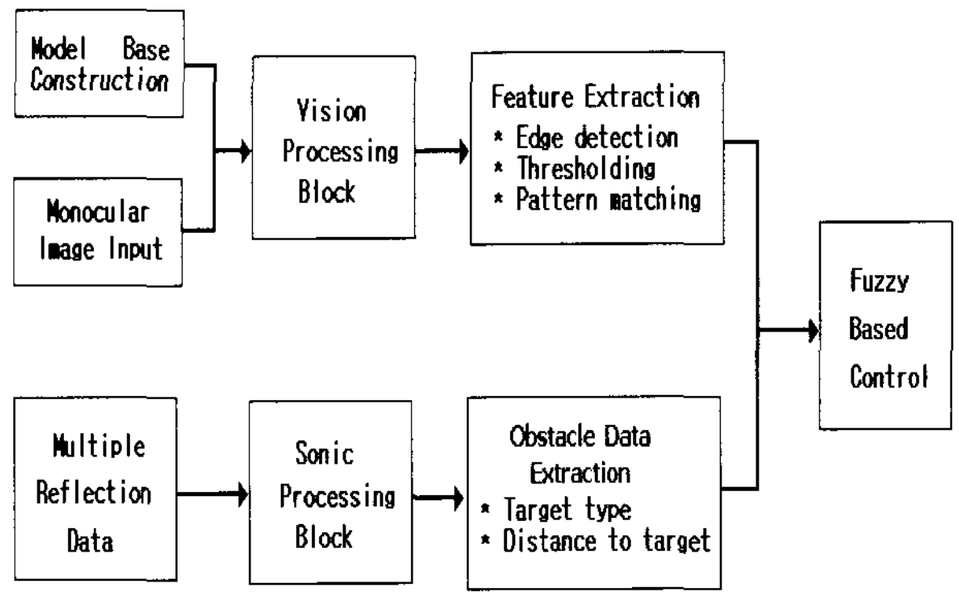


그림 3. 퍼지 제어기 구조
Fig. 3. Fuzzy Controller Diagram.

walls along the corridor is very important to make the self-localization success. Multiple reflection block is world map generation and complements the probable erroneous data extraction of above block. The fuzzy based control block represents the master controller of mobile robot and supervises the all control action such as motion control, path planning, tracking, and sensor fusion. The MAMDANI fuzzy model is adopted as basic construct of fuzzy control system[16,17,18].

The correctness of the image based self localization data has to be verified so that the self localization data from image processing be used as periodical correction basis of mobile robot position.

The error sources of image based self localization are as follows. Such as the extracted edge information is susceptible to illumination of indoor. When confronted with protruded objects to interfere the vanishing line extraction, the false vanishing points are detected to incur erroneous feature extractions, and finally results in self-localization failure.

4. Sensor models of Mobile Robot

Most mobile robots are mounted with encoders to count the turns of wheels while the robot is navigating. Typical configuration is such that two wheels of robot are equipped with encoders. At each sampling period τ, an estimate of angular displacement $\Delta\theta_R$ and $\Delta\theta_L$ is provided during the period. The corresponding translation ΔS and

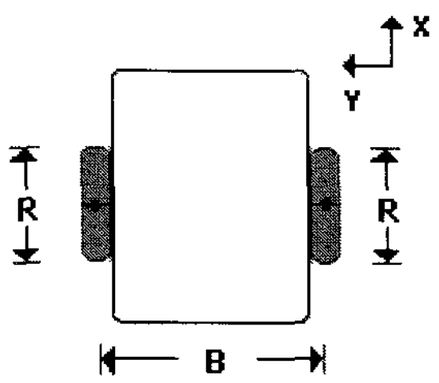


그림 4. 이동 로봇 바퀴

Fig. 4. Mobile Robot Wheels.

rotation $\Delta\theta$, measured respect to the mid-point of the wheel's axis, are given by :

$$\Delta S \simeq R(\Delta\theta_R + \Delta\theta_L)/2 \quad (1)$$

$$\Delta\theta \simeq R(\Delta\theta_R - \Delta\theta_L)/B \quad (2)$$

Where R is the wheel radius and B is the wheel baseline.

The basic strategy for autonomous navigation of mobile robot is to follow the given path estimating the robot position. When the robot knows its initial position, the robot can calculate its position through accumulating wheel rotations. This method is called dead reckoning. For dead reckoning method, the major errors are generated due to followings :

(i) Slipping motions of wheels
(ii) Resolution of encoder
(iii) Mechanical parameter error
(iv) Radius variation of wheel due to load change
(v) Road condition

Researchers have attempted to minimize the problems caused by encoders. Dead reckoning method can be combined with self localization method which is based on the absolute estimate of the position using visible external landmarks. In this case the error is bounded. But detection of external reference or landmarks may not always be possible. So combine the two approaches can provide accurate position system.

An ultrasonic sensor is probably the most popular sensor for mobile robots, because it is simple and gives distance information directly. The disadvantage of an ultrasonic sensor is that it is difficult to measure the accurate directions. A single sensor gives the range to an object located on an arc of the wave. Typical disadvantages of ultrasonic sensors are following :

(i) Variation in the speed of propagation
(ii) Uncertainties to determine the time of arrival of the reflected pulse
(iii) Inaccuracies in the timing circuitry
(iv) Interaction of the incident wave with the target surface
(v) Wide beam-width which yields uncertain measurements with the main lobe.

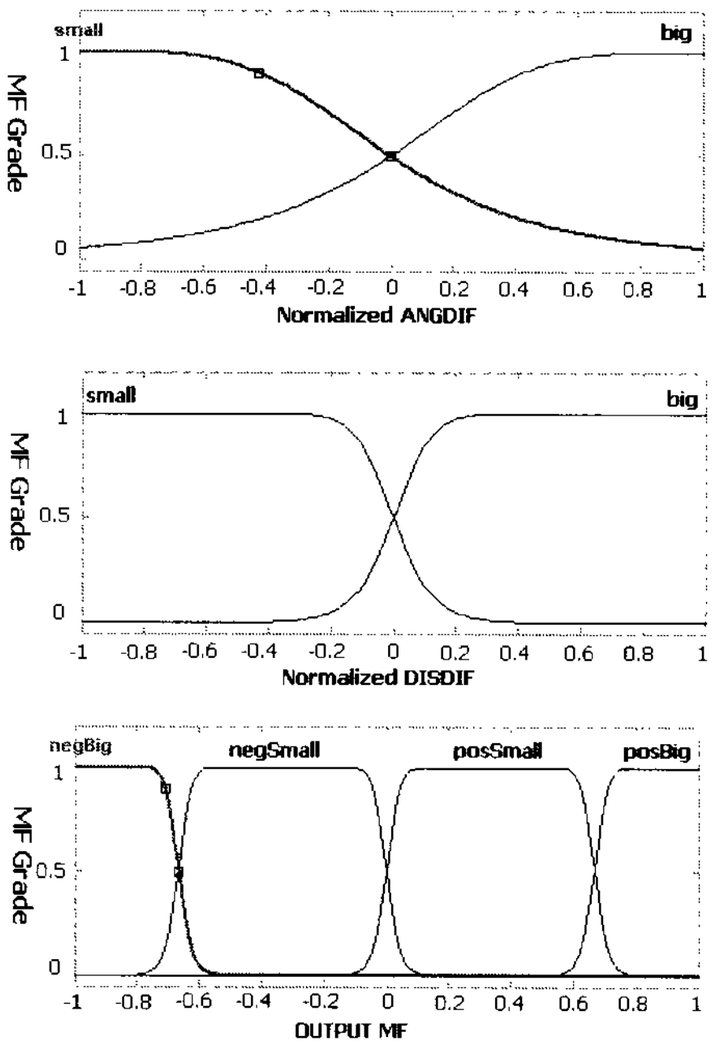
To overcome these disadvantages, multiple sonic sensors are used and advanced algorithm is derived to fuse multiple sonar readings such as multi-level sensor fusion for mapping. Typical methods are Bayesian approach for map building and neural network fusion[19,20].

III. Fuzzy Based Sensor Fusion

The membership functions of input and output are shown in Fig.5. The fuzzy inference has the correctness of the image based self localization, in which the difference between the vanishing angle of image, which is denoted as ANGDIF, and the difference between image based self localization data and the incremental position from dead reckoning, which is denoted as DISDIF, are taken as fuzzy inputs.

Fig. 5(a) shows the membership function grades for inputs and output, and Fig. 5(b) shows the input-output surface graph simulated in MATLAB following the definitions until now[21,22].

The threshold to confirm the correctness of the image based self-localization is selected to the values higher than -0.4 and less than 0.4 along the Z axis in Fig.5.(b). The mobile robot information is corrected



(a) MF grades for input and output

(b) Overall input-output spaces

그림 5. 입-출력 소속 함수
Fig. 5. Input-Output Membership Functions.

by the image based self localization if the defuzzified output is lower than the threshold 0.4 and higher than -0.4 as discussed in Fig.5 or by the position information from the detected features by sonar sensors. The overall configurations such as self localization from image processing, dead reckoning from incremental encoder operation which generates the digital pulses and world map generation from sonar operation which generates the target type, distance and azimuth of environment as shown in Fig.6.

The rule evaluation table in Fig.7 used the two input parameters of fuzzy inputs such as ANGDIF and DISDIF.

The defuzzified output of the fuzzy inference is ranged from -1 to 1, which is a measure to represent

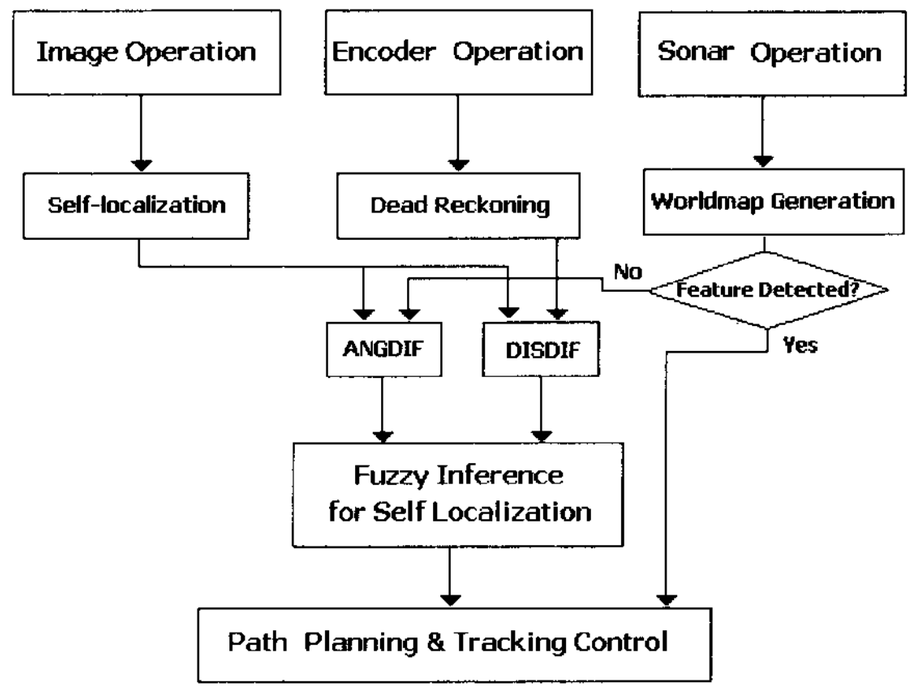


그림 6. 이동 경로 검출
Fig. 6. Finding Path along a corridor.

Normalized ANGDIF

Normalized DISDIF	HIGH(2)	MED(1)	LOW(0)	
HIGH(2)	HIGH(2)	HIGH(2)	MED(1)	1
MED(1)	HIGH(2)	MED(1)	LOW(0)	0
LOW(0)	MED(1)	LOW(0)	LOW(0)	-1
	1	0	-1	

그림 7. 퍼지 룰 평가표
Fig. 7. Fuzzy rule evaluation table.

the certainty of the image based self localization data, that is, the more the output value approaches to 1 or -1, the more erroneous the image based self localization is. If the image based self localization is confirmed according to the defuzzified output, the robot position can be corrected and updated by the image based self localization data.

There are 2 inputs and one output in the rule evaluation table defined as shown in Fig.7. Based upon that, the rule evaluation for the defuzzification is performed. The output membership function grades for defuzzification are defined as Table 1.

The output membership function grades are defined by 3 kinds of grades as shown in Fig. 7 from which

표 1. 출력 소속 함수 등급
Table 1. Output membership function grades.

Output	Error Possibility of self localization
HIGH(2)	High possibility of error(Less believable)
MED(1)	Low possibility of error(Believable)
LOW(0)	High possibility of error(Less believable)

the center of gravity(COG) is calculated to get the crisp output. This COG is the output of FUZZY inference, indicating the error possibility of image based self localization data. And so the error possibility of image processing is defined as a result of fuzzy inference by following definitions.

FUZOUT0 = HIGH grade to the Error possibility
FUZOUT1 = LOW grade to the Error possibility
FUZOUT2 = HIGH grade to the Error possibility

Finally the COG for defuzzification is calculated by following equation which is taking advantage of singleton.

NUM0 = OUTMF0 × FUZOUT0
NUM1 = OUTMF1 × FUZOUT1
NUM2 = OUTMF2 × FUZOUT2
DEN0 = FUZOUT0 + FUZOUT1 + FUZOUT2

$$DFUZOUT = \frac{(NM0 + NM1 + NM2)}{DEN0} \quad (3)$$

Ⅳ. Experiments of Mobile Robot

The main controller consists of TMS320LF2407 and processes the data from sensor combination units which are NTSC camera, sonar sensors, and optic encoders which are attached to the wheels. Independently operating, the combination sensors are devised to generate the local area information around mobile robot in real time through wireless RF232C port[23,24].

Human beings memorize a place using both metrical information and pattern classification. It should be more flexible for a mobile robot to navigate if these two cues are used. While the mobile robot shown in Fig.8 rotates, the sequence of bearing and images are taken simultaneously.

To determine a boundary vertical edge by fusing the observations of sonar and image data. If there is a boundary vertical edge, it can be detected from omni-directional image. Since D_I is measured from a 2D camera image, and D_S is measured from the metrical information of a sonar, they are independent. Thus we measure a boundary vertical line by computing the simultaneously probability D_e.

$$D_e = D_I \times D_S \quad (4)$$

D_e is calculated for every angle position. if the D_e

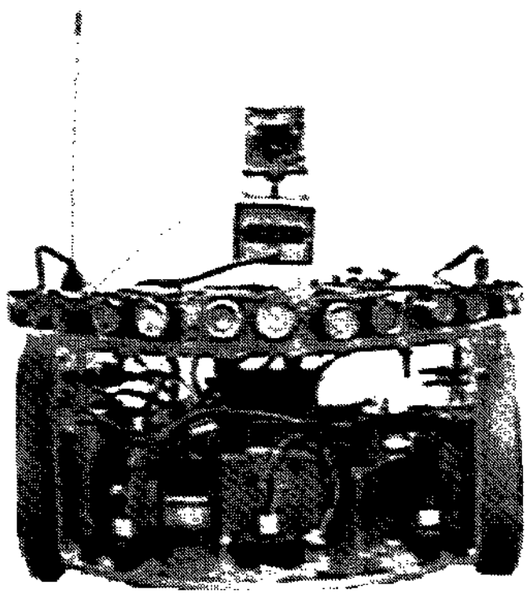
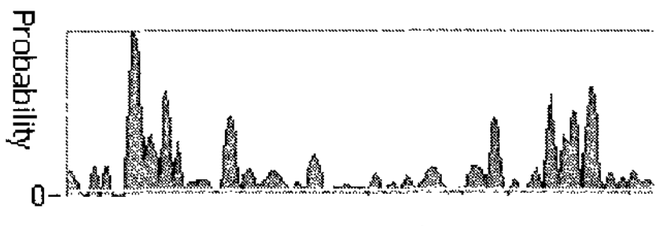
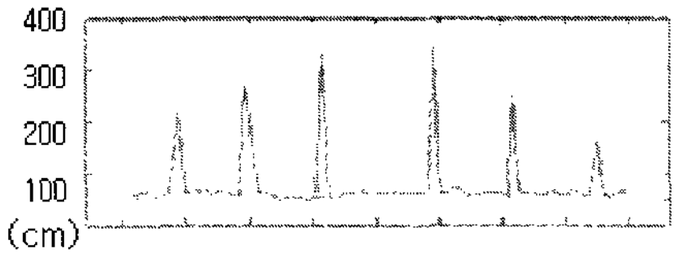


그림 8. 이동 로봇 구조
Fig. 8. Fuzzy Controller Diagram.

(a) Corridor Threshold



(b) Edge Strength



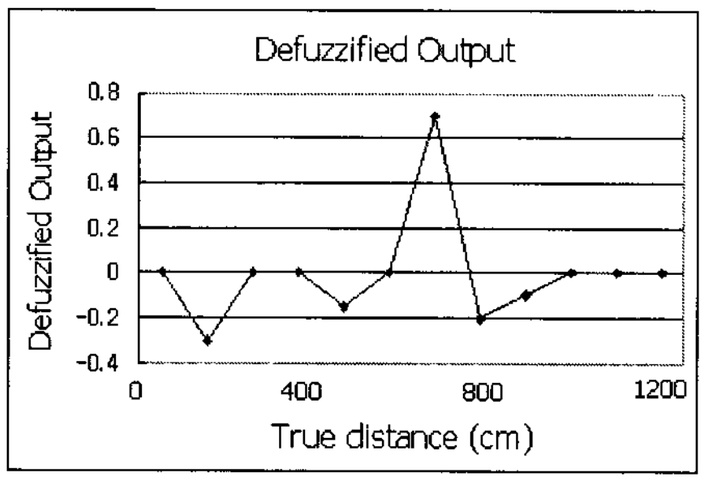
(C) Sonic Distance

그림 9. 이동 경로 특성 검출
Fig. 9. Finding features along a corridor.

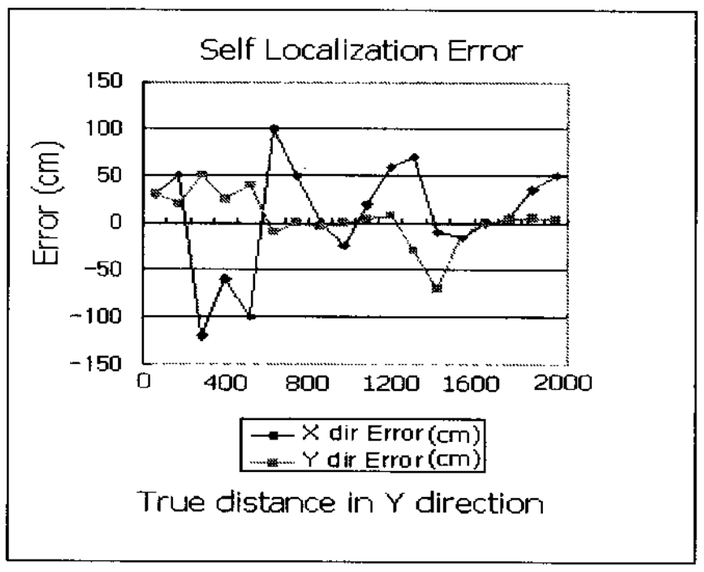
is bigger than a threshold, a boundary vertical line segment is determined which appears in the omni-directional image and has the distance of the corresponding NTSC camera.

The debugging and emulating tests are executed on the controller based on IBM PC in stand alone mode. Motion controller, which is possible to do coordinate motion based on the TMS320LF2407A (30MIPS, C2000 Code Composer), controls the robot motion to execute maneuvering such as obstacle avoidance, and autonomous navigation by sensor combination in door environments.

Fig. 9 shows the edge detection finds edges along a line of pixels in corridor and uses the edge detection tools to identify and locate discontinuities in the pixel intensities of an image. The discontinuities are typically associated with abrupt changes in pixel intensity values that characterizes the boundaries of objects in a scene. In this paper NTSC camera is used to experiment the edge detection and threshold to specify the objects. Fig. 9 shows the result of edge strength experiment on the corridor that is used for path of mobile robot.



(a) Defuzzified Output



(b) Self localization Error

그림 10. 퍼지 제어기 출력과 오차
Fig. 10. Fuzzy controller output & Error.

Fig. 10(a) shows the defuzzified output of the fuzzy control system. The defuzzified output values 0.72 are larger than 0.4 at distance 680 cm and can be used for correcting data of robot position. Fig. 10(b) shows the error values of y direction along with corridor.

Overall the correcting information of the robot position is acquired during navigation except at specific distance.

V. Conclusion

In this paper, the fusion sensors such as the vision, sonar and optic encoder based on the fuzzy based control are used and enhanced the self localization accuracy in mobile robot navigation. To overcome the self localization failure sometimes happened by uncertain characteristics of sensor ambiguities, the fuzzy based fusion controller improves the self localization accuracies. The sonic sensor generates the world map and obstacle detection in navigation by the extracted feature information. Finally it's possible to execute the navigation along the corridor referencing the image based self localization and the feature data from the world map by the sonic data. Futhermore, it is necessary to develop the intelligent sensor fusion technique and embedded controller so that the sensor can be efficiently used in compact size and full stand alone mode.

References

[1] Moravec, H. P., "Sensor fusion in certainty grids for mobile robots", AI Magazine, pp61-74, 1998.
[2] JOHN J. CRAIG, Introduction to ROBOTICS, Addison-Wesley Pub co. 1989.
[3] Saeed B. Niku, Introduction to Robotics, Prentice Hall, 2001.
[4] Murphy, R.,"Demper-Shafer theory for sensor fusion in autonomous mobile robots", IEEE Trans. on Robotics and Automation Vol.14,

NO.2, 1998.
[5] S.Thrun, W.Burgard, and D.Fox, "A Probabilistic approach to concurrent mapping and localization for mobile robots", Autonomous Robots, Vol.5, no 3, pp.253-271,1998.
[6] Nicholas Ayache, "Artificial Vision for Mobile Robot", MIIT Press, 1991.
[7] R.C. Luo and M.G. Kay,"MultiSensor Integration Fusion in Intelligent Systems",IEEE Trans. Systems, man, and Cybernetics, Vol.19, no.5,, pp901-931, 1988.
[8] F. Kobayashi, D. Masumoto and F. Kojima, "Sensor Selection based on Fuzzy Inference for Sensor Fusion", IEEE Trans, on Robotics and Automation, 25-29, July, 2004.
[9] S. Sheckar, O. Khatib and M. Shimojo, " Object Localization with multiple Sensors", Int. J. of Robotics Research, vol7, no.6, pp.34-44, 1988.
[10] M. Piasek, "Mobile robot Localization of fuzzy logic fusion of multisensor data", Robotics, Autonomous Syst, vol.12, pp.155-162, 1994.
[11] James Maas, Industrial Electronics, Prentice-Hall, 1995.
[12] Frank L. Lewis, Optimal Estimation, John Wiley & Sons, 1986.
[13] Abraham Kandel, "Fuzzy techniques in pattern recognition", Florida state university, Tallahassee, 1982.
[14] Li-Xin Wang, "A Course in Fuzzy Systems and Control", Prentice-Hall, 1997.
[15] Simon Haykin, "Neural Networks", 2nd Edition, Prentice-Hall, 1999.
[16] Jun Yan, Michael Ryan, J. Power, "Using fuzzy logic", Prentice-Hall, 1994.
[17] Peter Vas, "Vector Control of Electric machine", Clarendon Press, 1990.
[18] Philippe Coiffe, "An Introduction to ROBOT TECHNOLOGY", 1982.
[19] 홍선학, "센서결합을 이용한 이동로봇제어", 대한전자공학회, 제42권 2호, 2005.
[20] 홍선학, 제어계측공학, 성안당, 2001.
[21] J. S. R. Jang, "Neuro-Fuzzy and Soft Computing", 1997.
[22] Robert S. Strum, "Contemporary Linear Systems, Using MATLAB", 1994.
[23] TMS320LF2407 DSK Technical Reference, Digital Spectrum, 2000.
[24] Measurement and Automation, National Instrument. 2003.

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