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# 영상 추적을 이용한 이동 로봇 제어

## ( Mobile Robot Control with Image Tracking )

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### 요 약

본 논문에서는 이동 로봇 주위의 환경 인식과 자기 위치 인식을 위하여 초음파 센서와 한 개의 카메라를 이용하여 안정적인 이동 경로를 확보할 수 있는 방식을 제시하였다. 개발된 초음파 센서(SRF04)시스템은 주행환경의 지도 작성을 위하여 목표물의 특징 데이터를 작성하고, SDC313(SAMSUNG) 카메라에서 수집된 영상자료와 결합하도록 하여 안정적인 경로탐색이 가능한 이동로봇 제어방식을 실험을 통하여 구현하였다.

### Abstract

This paper represents the stable path recognition by the ultrasonic sensor which gathers navigation environments and the monocular image sensor which generates the self localization information of mobile robot. The proposed ultrasonic sensor and vision camera system recognizes the target and extracts parameters for generating the world map and self localization. Therefore, this paper has developed an indoor mobile robot and has stably demonstrated in a corridor environment.

**Keywords :** Mobile Robot, Ultrasonic Sensor, Vision Sensor, Navigation

### I . Introduction

Recently, various kinds of sensors have been used to get the data for environment recognition, and the interrelationship between robot and its environment is determined based on the acquired sensor information<sup>[1]</sup>. In case that a mobile robot is operated in uncertain environments, multiple sensors have to be used and they reduce the ambiguity and uncertainty in making decisions. Solving the problem of self localization and map-updating make mobile robot control possible in uncertain environment

conditions.

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<sup>[2,3]</sup>.

There are many active researches to apply different kind of sensors for the self localization and obstacle detection. Moreover although the map data are known previously or constructed, the updated map is required for adaptive maneuvering because the environment is not only change but also active owing to continuous mobile robot movement. There are no more versatile and flexible methods than vision methods in obtaining the useful environment information, and so the various methods are developed such as stereovision systems, monocular

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camera system, and Tri-ocular vision system for many robotic applications. In this paper, the sensors such as ultrasonic sensor, infrared sensor and vision camera have been used to detect the obstacles in the navigation environment and provide the capability of map generation and update<sup>[4,5,6]</sup>.

## II. Basic Theory

This chapter surveys the fundamentals of building applications and avoiding an obstacles. The sensor informations that are gathered by the sonar and vision camera are coordinated to produce the environment features from time of flight(TOF) information and to make self localization and obstacle detection. The mobile robot must has an ability to cope with a dynamic environment if it is to be used in the area other than strictly controlled environments. In order to navigate in a dynamic environment, the robot must be intelligent to deal with the issue of uncertainties and incomplete information.<sup>[7,8]</sup>

### 1. Fundamentals of Building Applications

A block diagram of the proposed architecture, shown in Figure 1 illustrates the low-level and mid-level architecture of the system architecture. The architecture uses a hardware abstraction layer, which separates software API capabilities, such as general

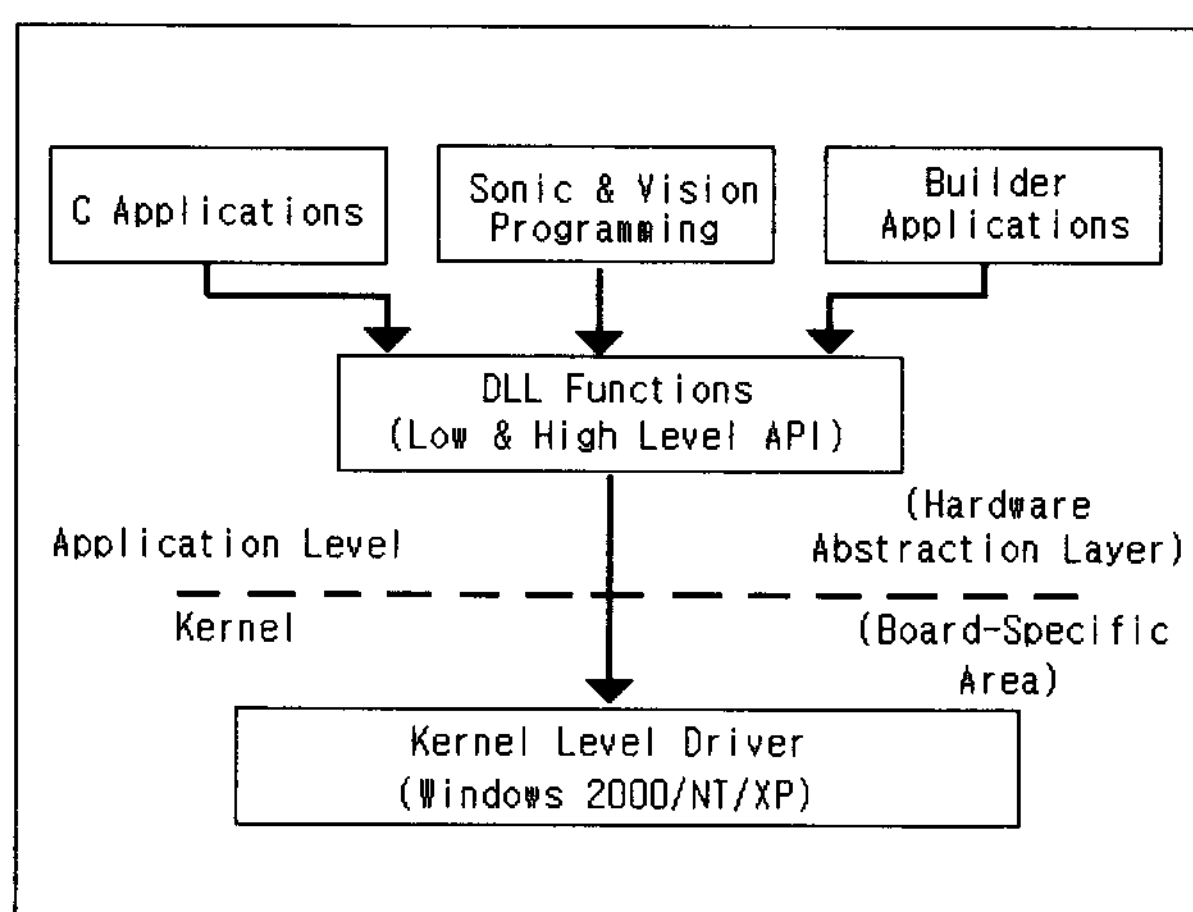


그림 1. 시스템 구조

Fig. 1. System Architecture.

acquisition and control functions, from hardware specific information. This layer provides the new specific hardware without having to recompile user's applications. Import libraries contain information about their DLL-exported functions, indicating the presence and location of the DLL routines.

Depending on the development tools, DLL routines information is given through import libraries or through function declarations<sup>[9]</sup>.

### 2. Ultrasonic and Vision sensors

Sonar (SOund Navigation and Range finder) is a device that can transmit and receive the sound wave in one package based on the piezoelectric effect. The time of flight(TOF) method is adopted for the purpose of collision avoidance. The measured pulses typically come from an ultrasonic energy source. Therefore, the relevant parameters involved in range calculation are the speed of sound in air( roughly 0.3m/ms). In this paper, the SRF04 ultra-sonic rangars are used. The SRF04 only need to supply a short 10uS pulse to trigger input to start the ranging. The SRF04 would send out an 8 cycle burst of ultrasound at 40khz and raise its echo line high. It then listens for an echo, and as soon as it detects one it lowers the echo line again. The echo line is therefore a pulse whose width is proportional to the distance to the object. By timing the pulse it is possible to calculate the range in centimeters or anything else. If nothing is detected then the SRF04 will lower its echo line anyway about 36mS. In fact, it is possible in some cases for the transmitting and receiving transducers to be the same device<sup>[10,11]</sup>.

There are no more versatile and flexible sensor than vision sensors in obtaining the useful environment information, and so the various methods are developed for many robotic applications. When a mobile robot executes the job, its motion is executed based on the self localization and the obstacle detection. 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<sup>[12,13]</sup>.

The self localization algorithm is based on the assumptions that the floor is flat and there exists a parallel straight 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<sup>[14,15]</sup>.

### 3. Image Processing Techniques

The image processing techniques are used to enhance, improve, or otherwise alter an image and to prepare it for image analysis. Usually, during image processing information is not extracted from the image. The intention is to remove faults, trivial information, or information that may be important, but not useful, and to improve the image. There are many subprocesses in the image processing fields. But in this paper, we use the histogram analysis, thresholding, and edge detection technique.

A histogram is a representation of a total number of pixels of an image at each gray level. And histogram information can help in determining a cutoff point when an image is to be transformed into binary values. Then a histogram can be used to determine what the noisy gray level is in order to attempt to remove or neutralize the noise. Thresholding is the process of dividing an image into different portions by picking a certain grayness level as a threshold, comparing each pixel value with the threshold, and then assigning the pixel to the different portions or levels, depending on whether the pixel's grayness level is below the threshold or above the threshold.

Edge detection is a general name for a class of routines and techniques that operate on an image and result in a line drawing of the image. The lines represent changes in values such as cross sections of

planes, intersections of planes, textures, colors and lines<sup>[2]</sup>.

### 4. The model of Mobile Robot

Figure 2 illustrates the mobile robot based on this paper.

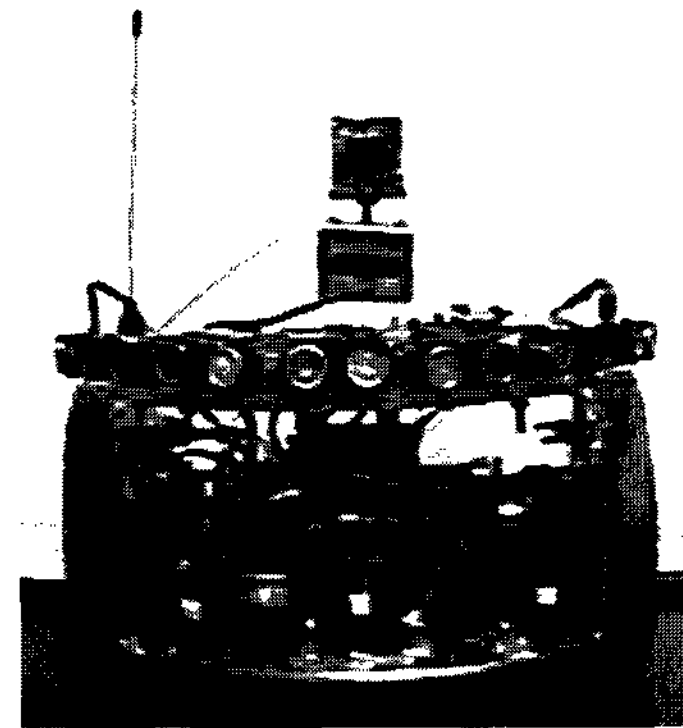


그림 2. 이동 로봇의 구조

Fig. 2. Structure of Mobile robot.

The nomenclature of mobile robot is listed in Table 1.

표 1. 이동 로봇의 기계적인 차원

Table 1. Mechanical dimensions of mobile robot.

Descriptions	Symbol	Dim
Distance between the center of each wheels	D	0.235m
Distance between the rotational center and the contact point of caster with surfaces	d	0.001m
Distance between center and caster in X axis	XA	0.12m
Radius of main wheel	rw	0.07m
Radius of caster wheel	rA	0.012m
Mass of mobile robot	Mm	22.3Kg
Mass of main wheel	Mw	1.2Kg
Mass of caster wheel	mc	0.75Kg

The relationship between global coordinate(X-Y coordinate) and local coordinate(x-y coordinate) is derived in Eq(1).

$$\begin{aligned} X &= x \cos \theta_c - y \sin \theta_c + X_c \\ Y &= x \sin \theta_c + y \cos \theta_c + Y_c \end{aligned} \quad (1)$$

or, in matrix form as Eq(2).

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \cos \theta_c & \sin \theta_c \\ -\sin \theta_c & \cos \theta_c \end{bmatrix} \begin{bmatrix} X - X_c \\ Y - Y_c \end{bmatrix} \quad (2)$$

Denoting the pose and velocity of the robot as  $P_c$  and  $\dot{P}_c$ , we can derive following Eq(3) and Eq(4).

$$P_c = \begin{bmatrix} X_c \\ Y_c \\ \theta_c \end{bmatrix} \quad (3)$$

$$\dot{P}_c = \begin{bmatrix} \dot{X}_c \\ \dot{Y}_c \\ \dot{\theta}_c \end{bmatrix} = \begin{bmatrix} v_c \cos \theta_c \\ v_c \sin \theta_c \\ \omega_c \end{bmatrix} = \begin{bmatrix} \cos \theta_c & 0 \\ \sin \theta_c & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_c \\ \omega_c \end{bmatrix} = J_q \quad (4)$$

Where Jacobian matrix converts velocity and angular acceleration of robot into velocity and acceleration in absolute coordinates<sup>[16,17]</sup>.

Motor parameters are calculated by following equations.

$$\tau_m = \frac{R_a J_M}{(R_a B + n K_t K_b)} = 2.4 [\text{sec}]$$

$$K_M = K K_t = 2.4 \times 0.78 = 1.88$$

Moment of inertia for mobile robot is calculated.

$$\hat{A} = 12.95 (kgm^2), \hat{B} = 0.10473 (kgm^2)$$

So the plant model of the mobile robot is written as Eq (5)<sup>[18,19]</sup>.

$$W_c(s) = \frac{1}{2(\hat{A}\hat{B})S} \left\{ \frac{2\hat{B}K_M}{\tau_M S + 1} \right\} \left\{ \frac{K_D S^2 + K_P S + 1}{S} \right\} W_E$$

$$= \left\{ \frac{0.145}{S(2.4S + 1)} \right\} \left\{ \frac{K_D S^2 + K_P S + K_I}{S} \right\} W_E \quad (5)$$

### III. Image and Sonar Processing for Mobile Robot

The image processing algorithms are explained based on the 2D invariant and relative positioning relationships upon which the self localization data is

extracted. The capability of monocular image sensor so as to correct the position uncertainty in the dead reckoning based robot position is discussed.

#### 1. Image Analysis

The feature point extraction in the image captured by one camera is gathered by the following steps: line finding, vanishing point detection, vertical line extraction, basis feature extraction of the door frames, and the probabilistic calculation of the brightness mean and standard deviation of the image pixels. The corridor indoor scene obtained during the navigation of mobile robot has a number of vertical and horizontal lines.

One example of the corridor scene which is captured during the robot navigation in the door environment is shown in Fig 3.

In this paper, image analysis function adopts the histogram which provides the general description of the appearance of an image and helps identify various components such as the background, objects, and noise. The histogram is a fundamental image analysis tool that describes the distribution of the pixel intensities in an image, and determine whether an image contains distinct regions of certain grayscale values.

The histogram is the function H defined on the grayscale range [0, ..., k, ..., 255] such that the number of pixels equal to the gray-level value k is

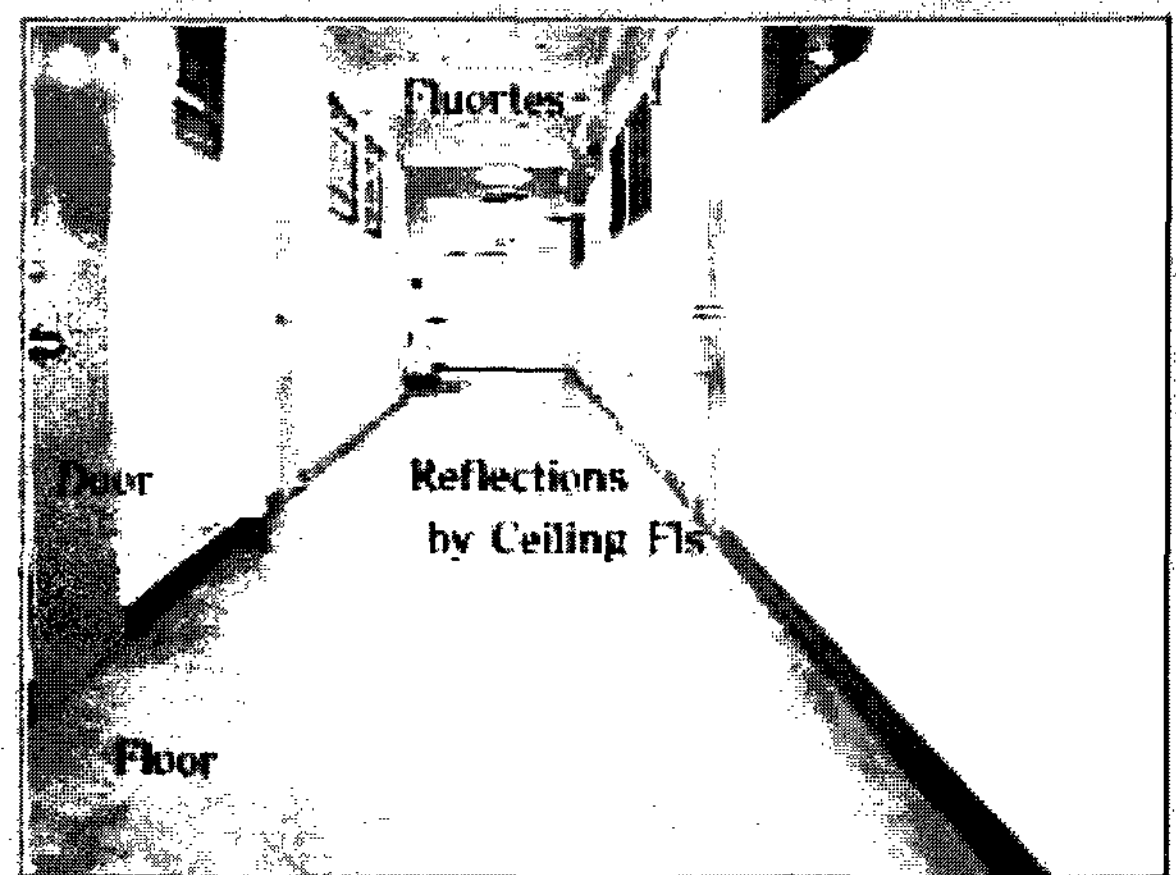


그림 3. 복도 전경

Fig. 3. Scene of Corridor.

$$H(k) = n_k \quad (6)$$

where  $k$  is the gray-level value

$n_k$  is the number of pixels in an image

The probability function is

$$P_{Linear}(k) = n_k/n \quad (7)$$

where  $P_{Linear}(k)$  is the probability that a pixel is equal to  $k$ . The histogram obtained by projecting the corridor environment is shown in Fig 4. with the edge strength of 40.

Thresholding consists of segmenting an image into two regions: a particle region and a background region. This process works by setting to 1 all pixels that belong to a gray-level interval and setting all other pixels in the image to 0. Thresholding converts the image from a grayscale image, with pixel values ranging from 0 to 255, to a binary image, with pixel values of 0 or 1. And therefore thresholding enables to select ranges of pixel values in grayscale and color images that separates the objects under

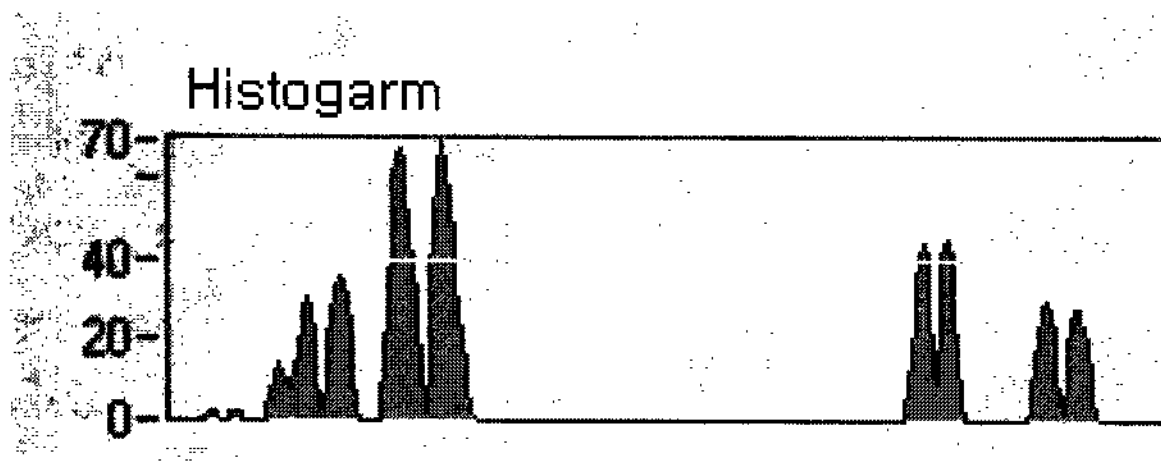


그림 4. 히스토그램

Fig. 4. Histogram.



그림 5. 복도 스레시홀딩

Fig. 5. Thresholding of corridor.

consideration from the background. Figure 5 shows the corridor image with 100 grayness levels.

## 2. Sonic multiple reflection system(SMRS)

In this chapter, the proposed sonic multiple reflection system(SMRS) obtained the recognition of environment as shown in Fig 6.

Since the mono reflection plate need to be rotated  $270^\circ$  to get the indoor information around the mobile robot, therefore it takes too much time to get the reflection data at every sampling step( $0.9^\circ/\text{step}$ ). In this paper, SRF04 ultra-sonic rangefinders are used. The SRF04 only need to supply a short 10uS pulse to trigger input to start the ranging. The SRF04 would send out an 8 cycle burst of ultrasound at 40khz and raise its echo line high. It then listens for an echo, and as soon as it detects one it lowers the echo line again. The echo line is therefore a pulse

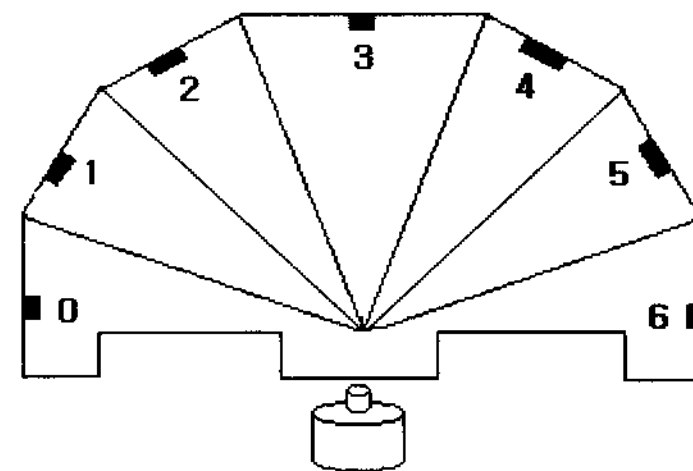


그림 6. 다중 반사형 초음파 센서 배치

Fig. 6. Sonic multiple reflection sensor.

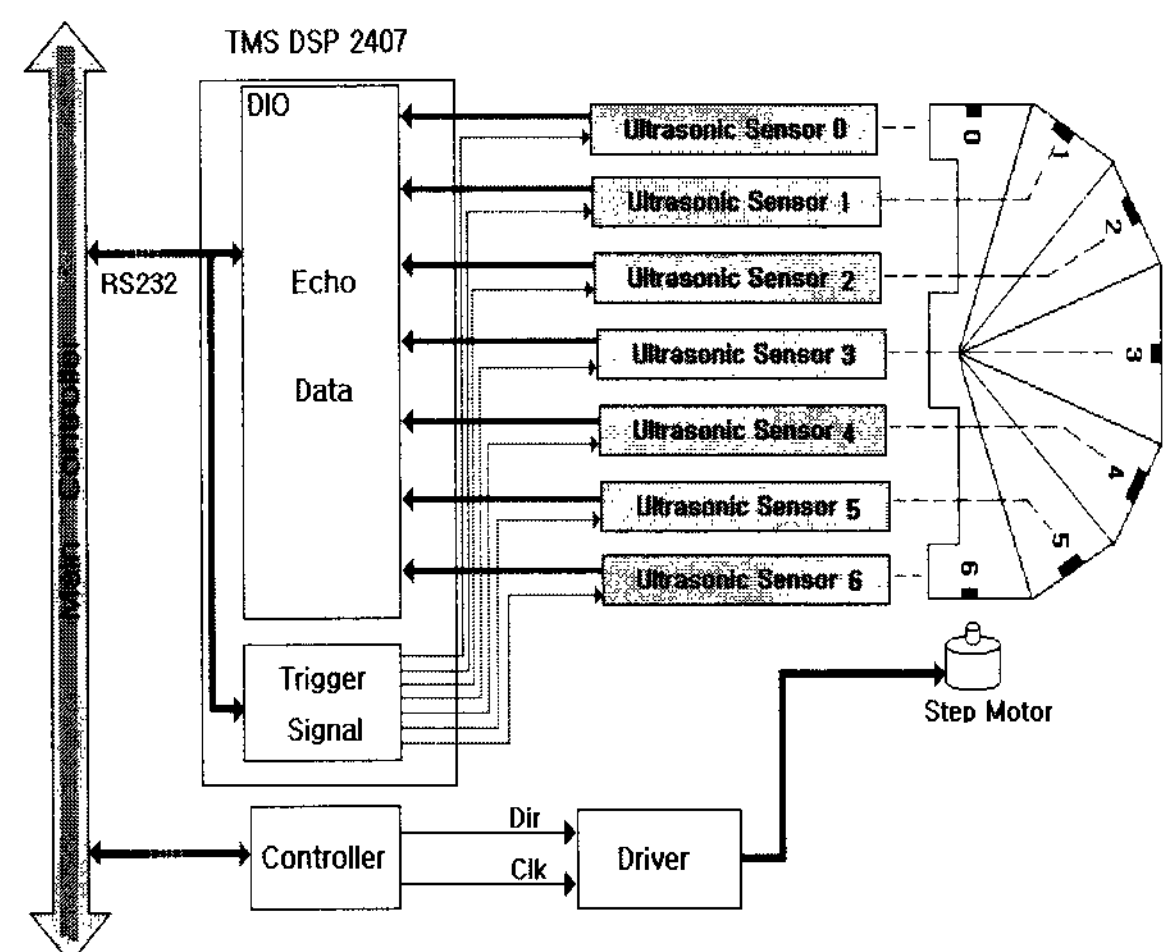


그림 7. 다중 반사형 초음파 구조

Fig. 7. Configuration of SMRS.



whose width is proportional to the distance to the object. By timing the pulse it is possible to calculate the range in centimeters or anything else. If nothing is detected then the SRF04 will lower its echo line anyway about 36mS. The absolute range to an observed point is directly available as output with no complicated analysis required, and the technique is not based on any assumptions concerning the planar properties or orientation of the target surface. The data acquisition system of sonic multiple reflection is configured so as to transmit the sonar in sequence and get the waveform including the target features in forms of reflection as shown in Fig 7.

As shown in above Fig 7, the Sonic multiple reflection system(SMRS) is connected to the TMS 320DSP2407 and the data acquisition hardware is installed in PCI bus of IBM PC. Also the SMRS is designed to batch process with Visual C++6.0 based on Win XP GUI environment from the multiple reflection data acquisition<sup>[20]</sup>.

#### IV. Experiments of Mobile Robot

##### 1. Hardware configuration of control system

The control system for mobile robot is shown in Fig 8. as following<sup>[21,22]</sup>.

The main controller consists of IBM-PC(Pentium 4, Win-XP), and motion controller is installed to control main wheel DC motors and to process the data from sensor combination units which are sonar sensor,

infrared sensor and optical encoder. Independently operating, the sonar and infrared sensors are devised to generate the local information around mobile robot in real time through wireless RF232C port<sup>[23,24]</sup>.

##### 2. Characteristics of Motion controller

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. Motion control schemes basically control mobile robot by differential steering based on the position and velocity data by the optical encoders and wireless communication through RF232C port.

The ultrasonic ranging system is developed by making usage of the time of flight of sonar on purpose with SRF04 units. Also it extracts the features such as distance and target types based on the obtained raw data and finally recognize an environment. The infrared sensor(GP2Y0A02YK) is adopted to discern the characteristics of short distance things. It distinguishes the features of target type between 20cm and 150cm. And it is less influence on the colors of reflected objects and their reflectivity, due to optical triangle measuring method. Sequentially operating, these units are communicated to main controller through RF232C channels and the latest obtained information of an environments is sent to the main controller. The main controller obviously operates the robot by the sensor combination, the obstacle avoidance and the path planning.

#### V. Conclusions

Figure 9 shows the acquired data with sonar sensor combinations where the sampling data according to the distance changes.

It is known that this SMRS system and its recognition experiments are excellent in

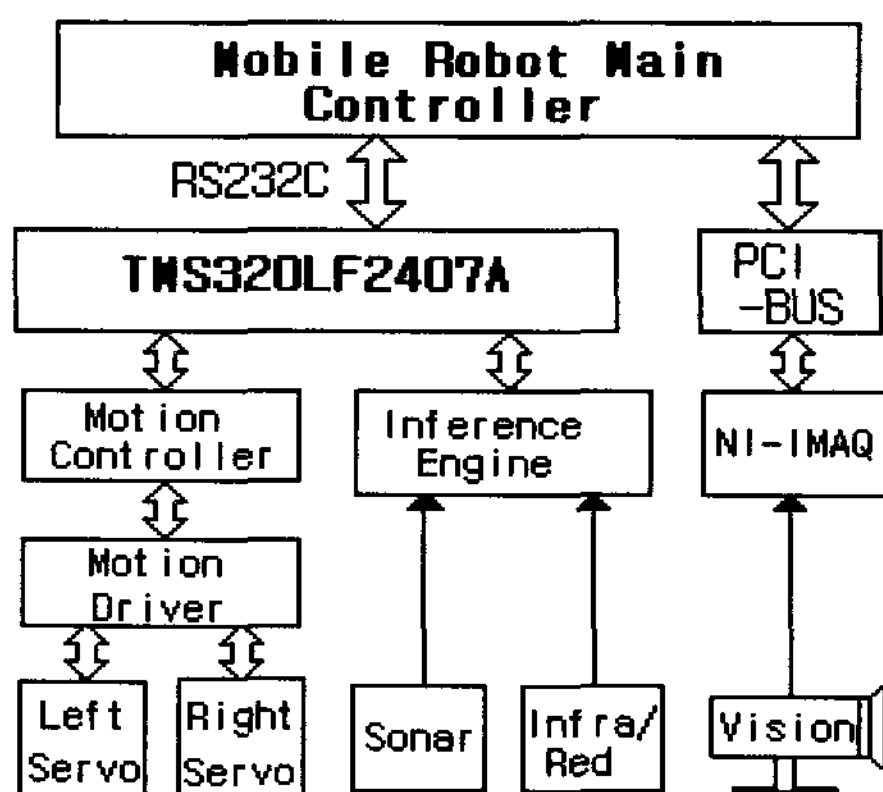


그림 8. 제어 시스템의 블록도  
Fig. 8. Block of Control system.

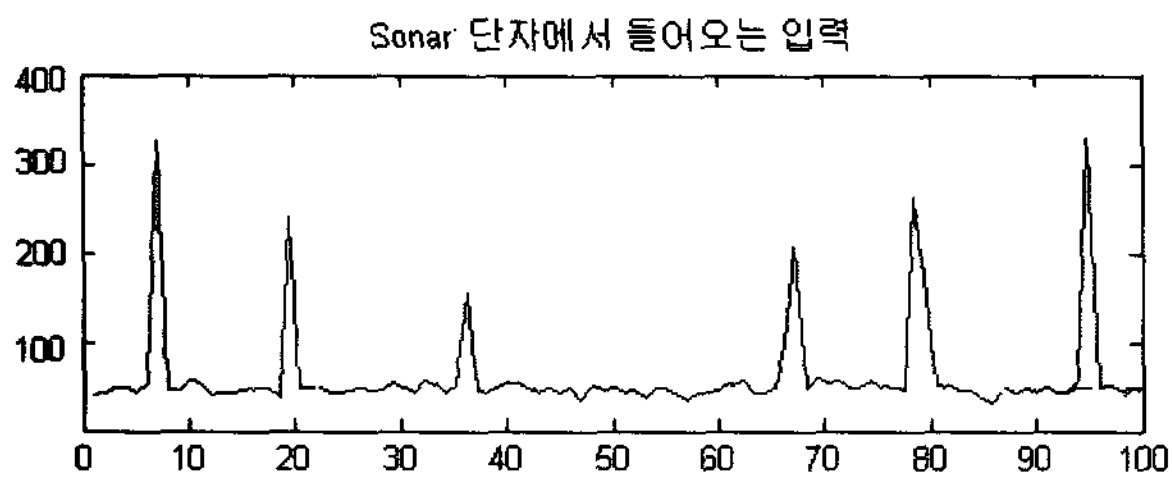


그림 9. 복도의 다중 반사 파형

Fig. 9. Multiple reflection waveforms of Corridor.

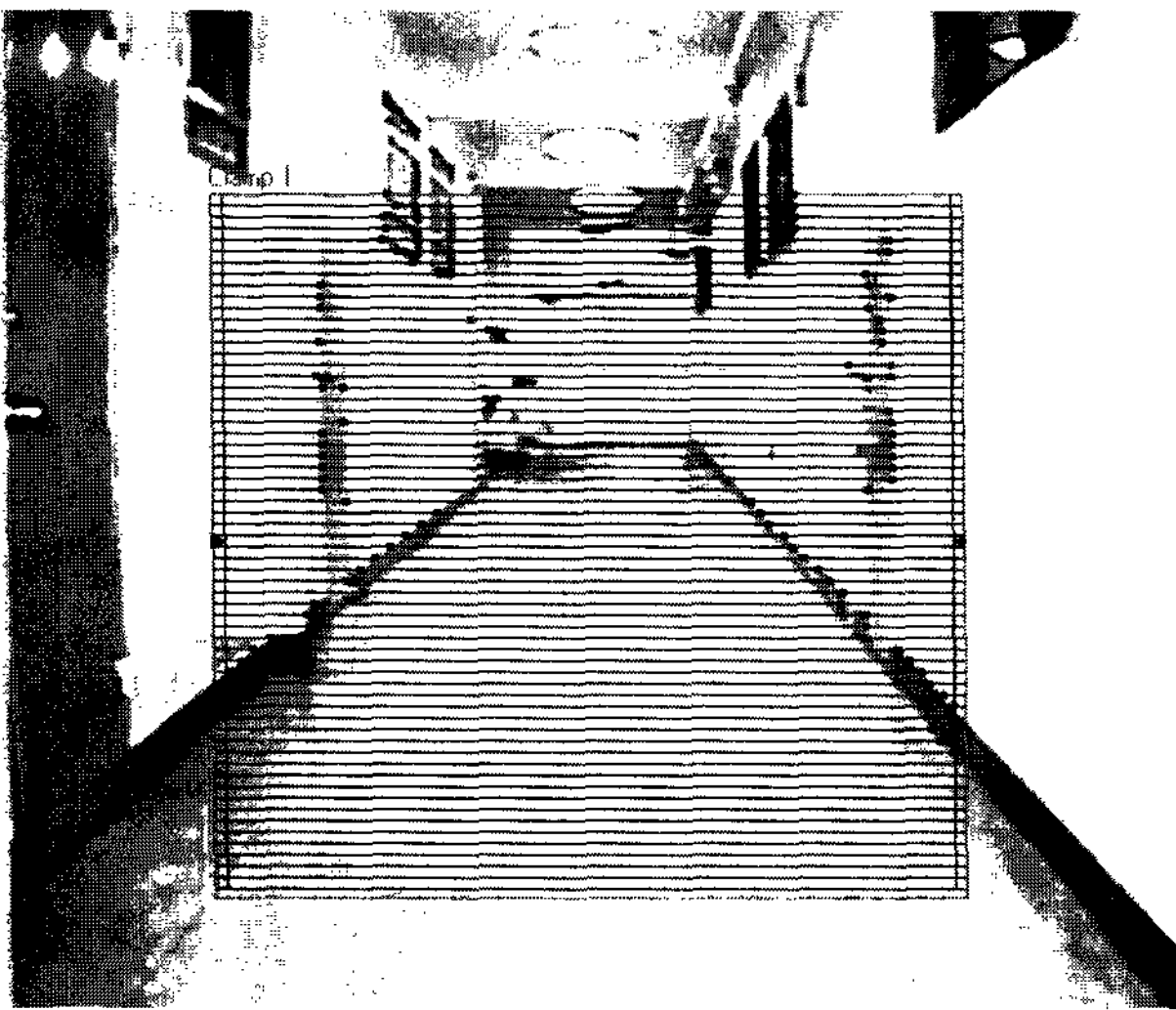


그림 10. 이동 로봇 경로의 엣지 검출

Fig. 10. Edge detection of Mobile robot path.

discrimination of the plane, the corner, and the cylinder in the mobile robot navigation environment. Edge detection finds edges along a line of pixels in corridor. Use 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 IMAQ Vision system is used to experiment the edge detection and therefore specify the search region in the corridor. Figure 10 shows the result of edge detection experiment on the corridor that is used for path of mobile robot.

The ultrasonic sensor developed for recognizing the indoor environment is based on the IBM PC using Windows XP OS and TMS320LF2407 Visual C++. It is not appropriate to be operated in a standalone mode. And so it is necessary to develop SMRS as an embedded controller for full stand alone mode, and to execute the navigation along the corridor referencing

the image based self-localization and feature data from world map by ultrasonic sensor interchangeably.

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