링 프레임형 초음파 센서의 포물선 피팅에 의한 장애물 식별

Obstacle Identification by Parabolic Curve Fitting using Ultrasonic Sensors Arranged on Ring Frame

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Abstract: This paper proposes a new algorithm for ultrasonic sensors arranged on ring frame to identify obstacles surrounding itself by TOFs (time of flight). The ring frame has multiple channels consisting of a transmitter and a receiver. When the transmitter of a selected channel transmits ultrasonic signal, the TOFs of reflected signals from obstacles are acquired by the receiver of the channel. The process continues for all channels consecutively. Then, by using parabolic curve fitting of TOFs of all channel, the proposed algorithm not only calculates distances from multiple obstacles, but also identifies if the shape of obstacles are point or plane by the coefficients of the curve. By the experiment using 16 ultrasonic transceivers on the ring frame in the environment of two poles and two planes, we show the feasibility of the proposed scheme.

Keywords: ultrasonic sensor, curve fitting, identification of obstacle shape

I. INTRODUCTION

One of the most imperative jobs for an indoor mobile robot is to recognize its surroundings and navigate by itself. For this purpose, mobile robots have to build a global map identifying forbidden areas and obstacles as well as their own positions. Building a global map requires the robot to recognize and memorize the surroundings near by the robot that is so called a local map. Among the many researches that have been conducted on efficient ways of getting a local map, using ultrasonic sensor is the most popular method to get information around the robot because of its low price and simple usage.

Studies using ultrasonic sensors for mobile robot can be categorized by directivity and location. In the matter of directivity of ultrasonic sensor beam, detecting obstacles by several narrow ultrasonic beams is relatively simple but it needs too many sensors and too much time to detect object positions sequentially [1]. On the other hand, using wide ultrasonic beam requires only 2-3 sensors typically, but its algorithm gets very complicated to use overlapped information adjacent to each other [2-5].

From the viewpoint of sensor location, one of the methods is to put the transmitters, beacons, at fixed in-door positions and to get the signal from beacons by receivers attached to mobile robot [6,7]. Although this scheme can exactly detect the position of the robot in a given environment, it is inadequate for unknown or new environments. Another method uses the sonar-ring type arrangement of sensors, where every transmitter is paired with a receiver and is installed along the circumference of the robot body [8-12]. It can estimate relative positions between the robot and obstacles surrounding the robot and can update the changes in the global map quickly even while the environment changes. This scheme, however, needs time to gather local maps because the robot must move all around the in-door spaces to build a global map.

In this paper, we used wide ultrasonic beam sensors to detect the obstacles with a fewer number of sensors and a sonar-ring arrangement for adaptability in the unknown environment. We suggest a new algorithm to build local maps more efficiently in which the obstacle shape is considered to guess the local map at one measurement. The shapes of obstacles are identified by a coefficient of parabolic curve of data from the multiple ultrasonic sensors. Identifying the shape of the obstacle when a local map is built helps building the global map more effectively than the conventional schemes.

II. MOBILE ROBOT

In this paper, the mobile robot uses a non-movable robot frame, not a movable robot since this paper focuses only on environment perception but not on the navigation of the robot. The circle-shaped robot frame is equipped with multiple ultrasonic sensors and a controller board for operating the sensors.

1. Ultrasonic Sensor

Recently, most mobile robots have some ultrasonic sensors with narrow-width beam so that they can detect the locations of obstacles on a line of sight at each ultrasonic sensor. However, this scheme uses too many sensors to increase the resolution of measurable angle and it wastes too much time because the robots sequentially detect omni-directional obstacles.
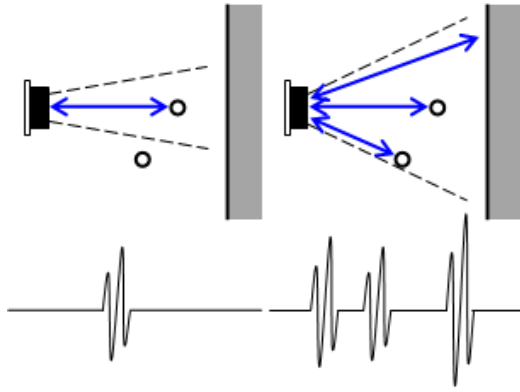
그림 1. 좁은 범위와 넓은 범위에서 초음파 센서의 지향성.
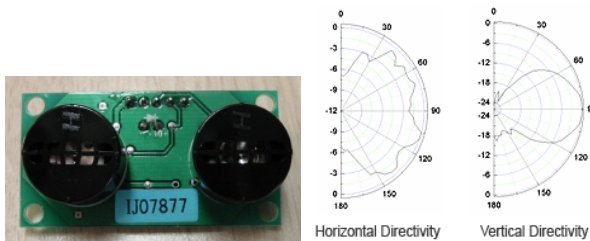Fig.　1. Ultrasonic sensors with narrow and wide range directivity.

그림 2. Hagisonic사의 초음파 센서모듈.
Fig.　2. Hagisonic's ultrasonic sensor.

To resolve these problems, researches have been conducted on the methods of detecting obstacles by using multiple ultrasonic sensors. In these methods, the location information is recognized by using a relatively few sensors because the distance data collected from the multiple ultrasonic sensors is synthesized. Thus, the ultrasonic sensors with a wide-width beam are preferred over the ultrasonic sensors with a narrow-width beam. Fig. 1 shows the difference between wide-width and narrow-width beam. The ultrasonic sensors with wide-width can receive a lot of information at once.

The ultrasonic sensors used in this paper are Hagisonic's ultrasonic sensor modules with an anisotropic beam directivity of AI type. The Hagisonic's sensor and its directivity are shown in Fig. 2. Since the AI type sensor has a detection range of 150 degrees of horizontal directivity and a 60~70 degree vertical directivity, the Hagisonic's sensor is suitable for using the overlapped data.

2. Sonar-ring Frame

The frame of the robot is a ring type that can detect obstacles around it as shown in Fig. 3. The sonar-ring frame is a structure that can detect obstacles in omni-direction by arranging ultrasonic sensors around the frame. The ring frame is not a perfect circle, but it has the shape of 16-polygon on which an ultrasonic sensor board can be attached and detached. Its diameter ranges from 34.3 to 35cm. The 16 ultrasonic sensors boards are mounted on each side of the ring frame with a 22.5° interval.

The main controller is installed on the top of the frame to control the 16 ultrasonic sensor boards all at once. Fig. 4 shows the main controller board installed on the ring frame. The CPU of the main controller board is DSP TMS320F2812, and it has 8M
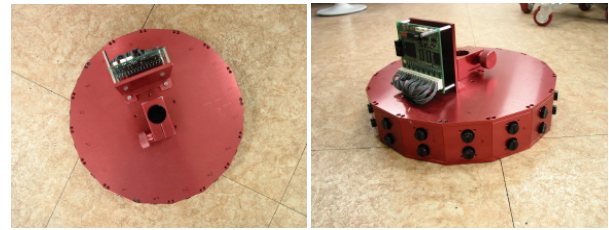

그림 3. 소나링 프레임.
Fig.　3. Sonar-ring frame.

그림 4. 주제어 보드.
Fig.　4. Main controller board.

SRAM and 8M Flash ROM. Equipped with two RS232 transceivers and one USB port, the DSP board is capable of debugging and communicating with the monitoring program on the PC.

III. ESTIMATING THE DISTANCE AND THE ANGLE OF AN OBSTACLE BY PARABOLIC CURVE FITTING

1. Distance detection using ultrasonic sensors

DSP TMS320F2812 has 16 12-bit ADCs. DSP TMS320F2812 allows us to have all the signals received from the 16 ultrasonic sensor boards at once. The DSP board can save 16 sets of data from 16 channels. The controller board obtains raw data by sampling the ultrasonic signals received from ultrasonic sensors. Using the raw data allows the robot to recognize the shape of an ultrasonic wave easily, but there is too much data for the limited amount of memory and takes too much time to process raw data.
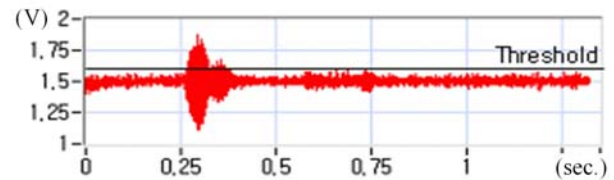
(a) Raw data.
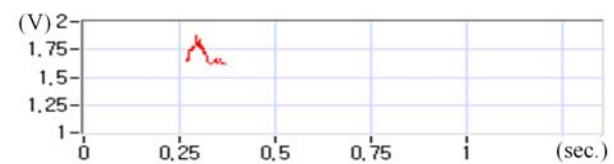
(b) Envelop data.

그림 5. 수신된 초음파 신호 데이터의 예.
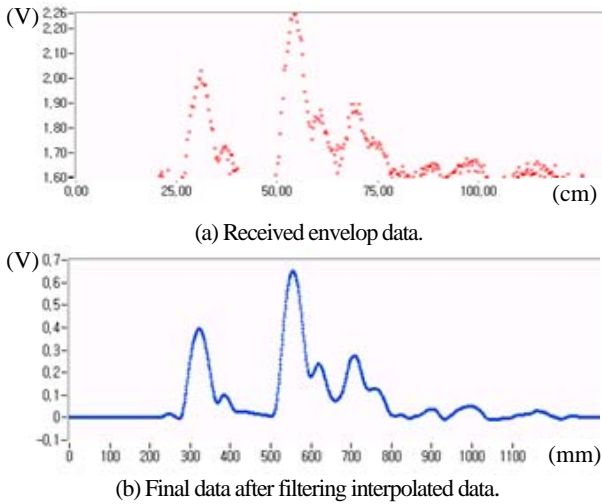Fig.　5. Example of received ultrasonic signal.

(a) Received envelop data.

(b) Final data after filtering interpolated data.

그림 6. 초음파 신호의 수신절차.

Fig.   6. Retrieving procedure of ultrasonic signal.

그림 7. 선두에지 검출.

Fig.   7. Leading-edge detection.

Therefore, raw data is converted to envelop data. Although envelop data has a fewer number of ultrasonic data than raw data, the characteristics of the ultrasonic signals can be recognized quickly by using the envelop data. Fig. 5 shows the ultrasonic signal. The envelop data connects the peaks of the raw data above threshold voltage, and the information is saved in a pair of time and voltage only when the voltage is over the threshold voltage.

Envelop data is not suitable for software filtering and leading edge detection because of irregular storing. Thus the envelop data is converted to data with 1mm interval by linear interpolation. The envelop data in a channel is shown in Fig. 6(a), where the x-axis represents distance (cm) and the y-axis represents voltage (V).

The linear-interpolated data is adjusted down to make its minimum data to be zero, which makes it easy to process the signals. This data is converted to smooth signal by the software filter before detecting the leading edges. At this step, noises included in the envelop data are removed (For example, thermal noise, and cross-talk). However, the delay of the signal must be considered when the leading edges are detected because of the software filter. Fig. 6(b) shows the final ultrasonic signal after the software filter procedure. In this figure, the x-axis represents distance(mm) and the y-axis represents voltage(V).

An ultrasonic sensor can receive the ultrasonic signals reflected from more than two objects as well as from only one object. Therefore, we propose an algorithm that can detect more than two leading edges at each sensor board.

The simplest way to detect leading edges is a simple threshold scheme. This scheme sets a threshold on the amplitude of signals, and the data above that threshold is regarded as meaningful data. Signal blocks are received from an ultrasonic sensor when the ultrasonic wave is reflected from objects. The first positions of these blocks are the leading edges of corresponding objects. Although the simple threshold scheme is simple and speedy, a signal block can be separated by one or more data errors in the block. In addition, this method has an error between the real beginning position and the detected position.

Another way to detect leading edges is to use the cross-correlation scheme [10]. A reference signal block is saved in advance for this scheme. The largest values by the correlation of
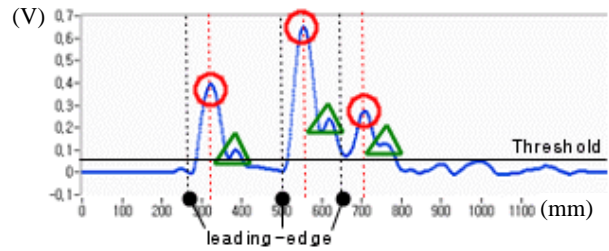
signals received from ultrasonic sensor board and a reference signal block are regarded as leading edges. The cross-correlation scheme can detect the beginning position of a received signal because the cross-correlation considers points which do not appear in a simple threshold scheme. However, this scheme causes an increase in calculation of cross-correlation.

This paper proposes a new algorithm that can be applied to the ultrasonic sensors. The reflected wave of a Hagisonic's ultrasonic sensor has two sequential peaks as if they were reflected from two objects. Also, it has one peak when the strength of the wave is weak. Therefore, the positions detected by a peak or by two sequential peaks are chosen as the leading edges.

We found that the first peak is stronger than the second peak in the two sequential peaks, and the single peak is strong enough to recognize an object. Fig. 7 shows this procedure. First, the proposed algorithm detects all the peaks above the threshold voltage and then it decides whether a peak among them is two sequential peaks or one peak. Of the two sequential peaks, the first peak is chosen as a meaningful peak and the second peak is ignored. In this figure, the red circles are meaningful peaks and the green triangles are the peaks that are ignored. The former positions of the meaningful peaks are determined as leading edges. All leading edges are detected by following this procedure.

2. Estimation of the distance and angle of obstacles

The distance of an obstacle is obtained by using TOF. As is well known, the distance of an obstacle is easily obtained as

$$d = \frac{1}{2}ct, \qquad (1)$$

where c is the sound speed, which is about 340 m/s in the air, and t is the time of flight.

Equation (1) is reasonable when the transmitter and the receiver

(a) Same transducer.   (b) Different transducer.
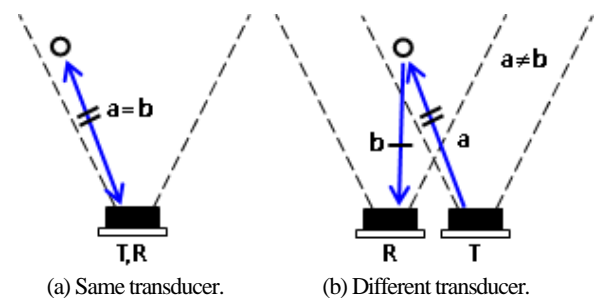
그림 8. 송신기와 수신기에 의한 초음파 경로.

Fig.   8. Ultrasonic wave path by transmitter and receiver.
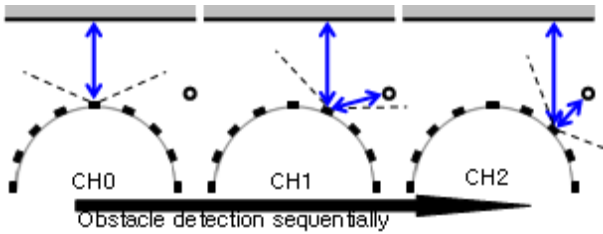
그림 9. 여러 개의 초음파 센서에 의한 거리검출.
Fig. 9. Distance detection by multiple ultrasonic sensors.

(a) Envelop data for the channels (CH0~CH5).
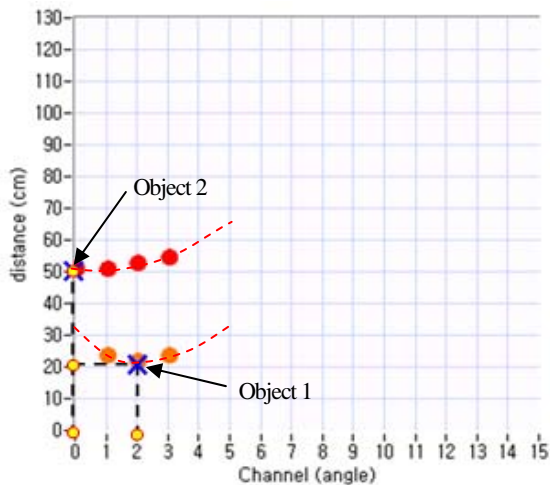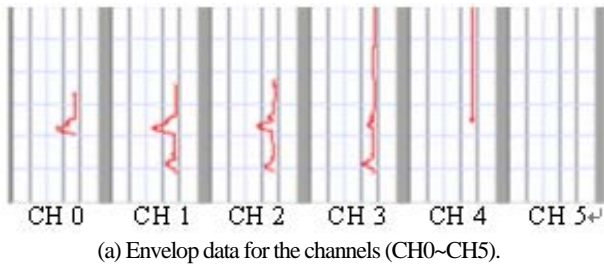
(b) Detecting the distance and the angle by parabolic curve fitting.

그림 10. 거리 및 각도 검출방법.
Fig. 10. Method of detecting distance and angle.

are the same transducer as shown in Fig. 8(a). Both a and b are the distance between the transducer and the object. However, a and b are different if the transmitter and the receiver are different transducers as shown in Fig. 8(b). In this case, equation (1) is not applicable.

To resolve this problem, the controller board sequentially operates only one sensor board at a time. The distance and the angle of obstacles are adjusted again after all the sensor boards finish detecting them. Fig. 9 shows this process. There are a planar obstacle in front of a sensor board on channel 0 and a circular obstacle in front of the sensor board on channel 2. The mobile robot receives the ultrasonic wave from channels 0 through 15 continually.

Fig. 10(a) shows the envelop data when all the sensor boards complete the detection. The leading edges, distance of the obstacles, are detected by the two-peak detection method at each firing as mentioned above. Fig. 10(b) shows the leading edges detected from all channels. All leading edges are grouped by Yata's scheme [4]. The accurate distance and angle of an obstacle

is calculated by the minimum value of the fitted parabolic curve and its corresponding angle of channel. For the example, we can see that an object is located at about 50 cm ahead of CH0 and the other is at 20cm ahead of CH2.

IV. IDENTIFICATION OF OBSTACLE SHAPE

1. Parabolic shape according to obstacle shape

As shown in Fig. 11, all the obstacles have different parabolic shapes. The parabolic shape of the fitting data from a point object is sharper than that from a planar obstacle, since the transmitted signal arrives at the receivers reflected by only one point of the object, while the signals from a planar object have multiple reflection points. With this idea, we can determine whether the shape of the object is planar or point-shaped.

To set up the classification standards, we obtained the coefficients of a quadratic equation as

$$y = a_2 x^2 + a_1 x + a_0. \tag{2}$$

They can be found by the least square method as

$$\begin{pmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \end{pmatrix} = \begin{pmatrix} \sum x_i^2 & \sum x_i & N \\ \sum x_i^3 & \sum x_i^2 & \sum x_i \\ \sum x_i^4 & \sum x_i^3 & \sum x_i^2 \end{pmatrix} \begin{pmatrix} a_2 \\ a_1 \\ a_0 \end{pmatrix}, \tag{3}$$

where $i = 0,1, \cdots, N$ and N is the number of leading edges. Also, x_i and y_i are the angles and the distances of leading edges, respectively, and the angle and the distance of an object can be estimated by

$$angle = \frac{-a_1}{2a_2}, distance = \frac{-a_1^2}{4a_2} + a_0. \tag{4}$$

The coefficient of x^2, a_2, determines the eccentricity of the parabolic curve. Therefore, we can classify the shape of an obstacle by using a_2.

2. Experiments

The classification standards are shown on Fig. 12. The obstacles are simply classified as point-shaped or planar object. They are identified by using "point" and "plane", but there is a
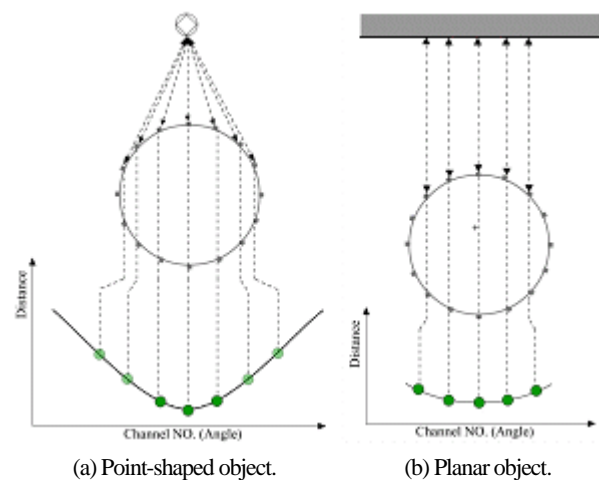

(a) Point-shaped object.   (b) Planar object.

그림 11. 물체에 따른 포물선의 모양.
Fig. 11. Parabolic shape by the obstacle.

그림 12. 물체의 분류기준.
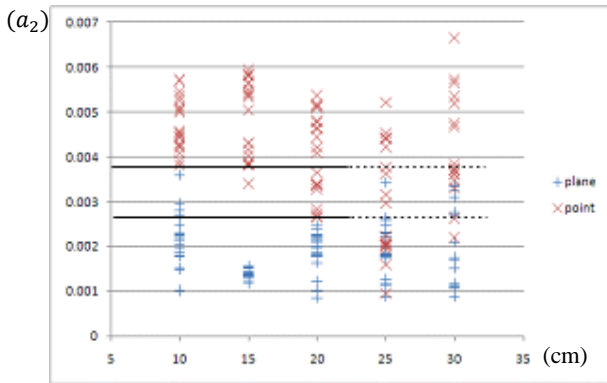Fig. 12. The classifying standards for obstacles.

그림 13. 거리에 대한 x^2의 계수.
Fig. 13. The coefficients of x^2 according as distance.

range which is difficult to determine whether the obstacle is planar or point-shaped when a_2 is between "point" and "plane". "upper" and "lower" are the upper limit and lower limit of a_2, respectively. a_2 is regarded as an abnormal value when it is bigger than "upper" or smaller than "lower". When a_2 is between "upper" and "point", the obstacle is a point-shaped object; and when a_2 is between "plane" and "lower", it is a planar object.

The following experiments were conducted on identification of two objects in order to determine the classification standards. A planar obstacle is a steel plane, and a point-shaped obstacle is a steel pole whose diameter is about 3cm. Distance to be detected is from 10cm to 30cm with intervals of 5cm. After repeating a test for 20 times at each point, the estimated coefficients of x^2 are recorded. The maximum distance is 30cm because we cannot detect a point-shaped obstacle when the measured distance is more than 30cm. The coefficients of x^2 according to distance are shown on Fig. 13. As a result, we can set up the classification standards when the distances of obstacles are less than 20cm. However, it is difficult to set up the standards when the distances are more than 25cm.

3. The results of experiments

The mobile robot is set as shown in Fig. 14, where there are two point-shaped obstacles and two adjacent planar obstacles. The mobile robot transmits and receives ultrasonic wave from channel 0 to channel 1 in sequence, and the envelop data of reflected signals are recorded at each firing.
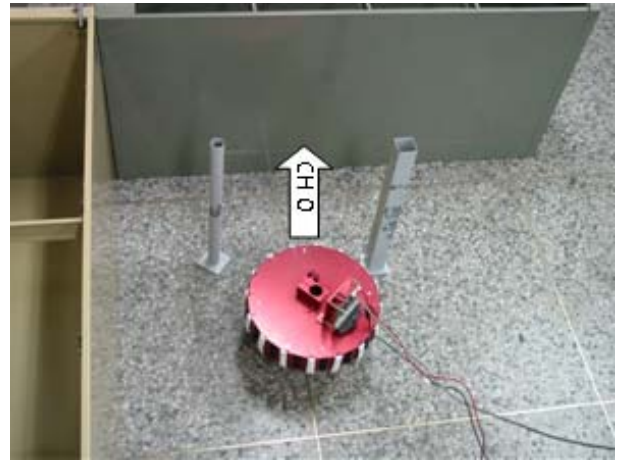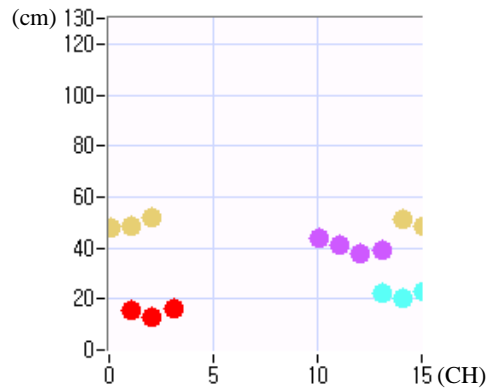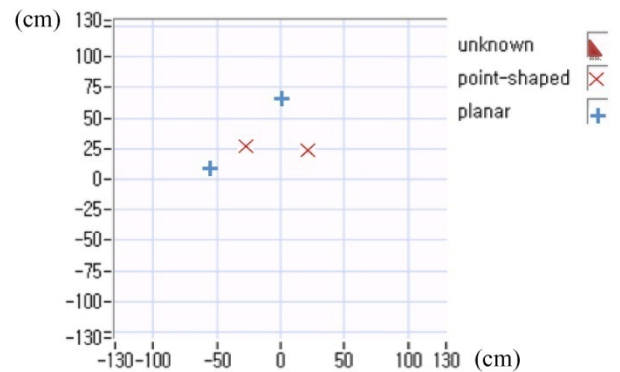

그림 14. 실험환경.
Fig. 14. Experimental environment.

(a) Leading-edge detection.

(b) Local map.

그림 15. 검출된 선두 에지와 로컬 맵.
Fig. 15. Detected leading-edges and local map.

Fig. 15(a) shows the detection of all leading edges by the two-peak detection scheme. The leading edges are grouped, and each group has its own color. There are 4 colors for 4 obstacle groups on Fig. 15(a). Fig. 15(b) shows a local map built by the method suggested in this paper. The mobile robot is located at (0, 0) in this figure. The distance and the angle of the obstacles are detected by parabolic curve fitting, and the obstacle shapes are identified by the classification standards. The blue points are point-shaped obstacles, and the green points are planar obstacles.

V. CONCLUSIONS

In this paper we proposed a new algorithm to design a ring-frame with multiple ultrasonic sensors, presenting a method of identifying the environment that surrounds the robot by using TOF data received from the sensors. The obstacle shapes are identified and recognized by using a2, the coefficient of x^2, in the equation (2), when the distances of the obstacles are less than 20cm. The obstacle shapes cannot be identified when the obstacles are far from the mobile robot, but they are recognized when the obstacles are close to the mobile robot.

The navigation of mobile robots is accomplished by building a global map. The global map is completed by the local maps using the obstacle information collected from the mobile robot. Identification of the obstacles that is made possible by the proposed algorithm will provide useful information for building the global map.

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