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Identification and distance detection for ultrasonic sensor by correlation method

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Abstract: This paper presents a method for identification and distance detection for ultrasonic sensors of indoor mobile robot by using correlation scheme. The transmitted signal is identified by correlation between known model patterns and the patterned signal from transmitters and this scheme is useful when multiple sensors are involved. Distance detection by correlation is shown to be more accurate than conventional threshold method.

1. INTRODUCTION

Recognizing environment around self-powered robot is imperative job for moving robots. In particular, for freely navigating mobile robot, it is essential function to detect the distance and direction of obstacles around a robot. Many methods have been studied to detect the obstacles, for example, by using ultrasonic sensor, infrared sensor, laser sensor, RSSI method in zigbee and so on. Among those methods, using ultrasonic sensor costs so low but is highly efficient that it is expected to be the most practical method.

There have been many attempts to estimate distance and angular position of obstacles around a robot by using ultrasonic sensor. One of the popular schemes in arranging sensors is sonar ring type, which will be mentioned in detail later this paper. In sonar ring type, each transmitter is paired with a receiver, and is installed along the circumference of robot body. Another method is using beacons transmitting their positions. Receiver on the circumference of a circular robot (Kleeman, 1992) gets information from beacons. Since the position of the beacons must be known in advance, measurement cannot be accomplished when environment changes.

Thresholding of received signal is quite simple way to distinguish desired signal from noise, and is widely used to measure time of flight for ultrasonic sensor. But, the noise in the signal disturbs measurement severely.

Studies about measuring the direction of obstacles by ultrasonic sensor have been reported also. There are methods of detecting the obstacles by arranging ultrasonic sensor with narrow-width beam and using overlapped data by arranging ultrasonic sensor with wide-width beam (Yata et al., 1999). The method using overlapped data can detect obstacles by using 2~3 transmitters and receivers (Peremans et al., 1993, Kleeman, 1999). It is important issue to group signals from multiple sensors.

This paper suggested the method of the detection of the distance and the method of the identification of the received signal by using signal correlation. The Detection of the distance by correlation is shown to have better performance than conventional threshold method. The identification of the signal is also done by correlation, and is necessary to find out the signal source from which ultrasonic wave transmits, and it would be important information especially when multiple transmitters emit signals simultaneously.

2. IDENTIFICATION AND DISTANCE MEASURING

2.1 Ultrasonic Sensor

The ultrasonic sensor used in this paper is Hagisonic's ultrasonic sensor module with anisotropic beam directivity AI type (Fig. 1). In this paper, because the distance and angular position of obstacles are detected by the overlapped information from the neighboring sensors, ultrasonic sensor with outstanding wide directivity is selected.

Fig. 1 Hagisonic's ultrasonic sensor module with anisotropic beam directivity AI type.

Since the AI type sensor has detection range as 150 degrees horizontally and 60~70 degrees vertically, it is suitable for the purpose of this paper. The directivity data of the AI sensor is shown in Fig. 2.

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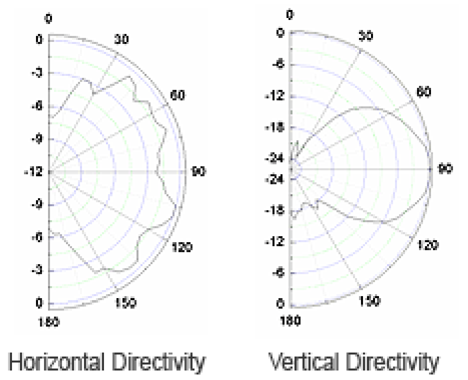


Fig. 2 Directivity of the ultrasonic sensor module with anisotropic beam directivity AI type

A sensor board was developed by RIST using above sensor module and has amplifier and band pass filter.

2.2 Sonar Ring Frame

The frame of the robot is a ring type that can detect obstacles around it (Fig. 3). Sonar ring frame is the structure that can detect obstacles in omni-direction by arranging ultrasonic sensors around the frame.

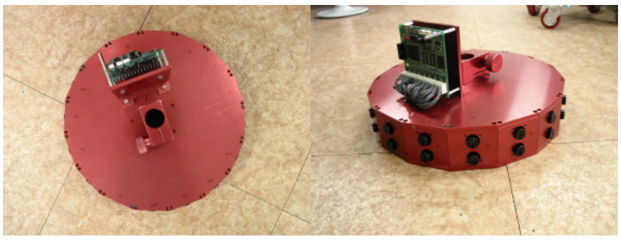


Fig. 3 Sonar ring frame

The ring frame is not a perfect circle. It has the shape of 16 -polygon to attach and detach ultrasonic sensor board on it. Its diameter ranges from 34.3 to 35cm. The 16 ultrasonic sensor boards are mounted on each side of the ring frame by 22.5° degrees. Main controller is also installed on the top of the frame to control 16 ultrasonic sensor boards all at once.

Main controller board was developed by RIST and is shown on Fig. 4. The main CPU of the DSP board is DSP TMS320F2812, and it has $0.5M \times 16$ bit SRAM, $0.5M \times 16$ bit Flash Rom. In addition, The DSP board is capable to operate communication and debugging function by two RS232 transceivers and one USB port. Installed USB 2.0 protocol allows high-speed communication with monitoring program on the PC.

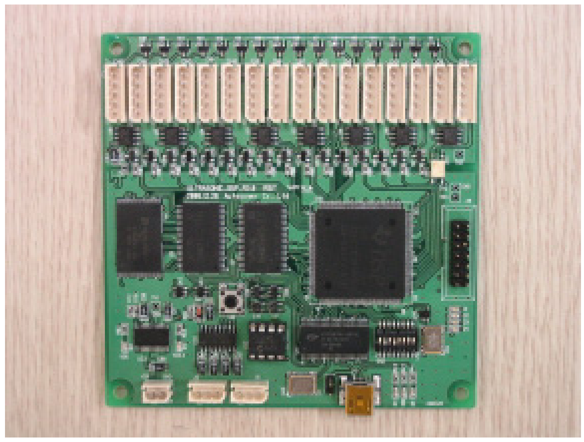
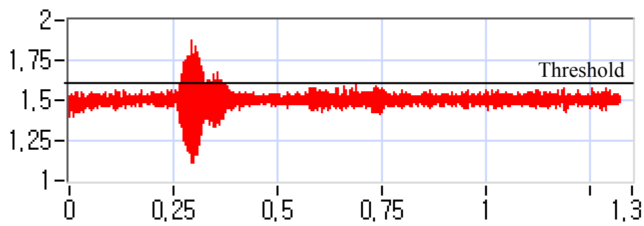


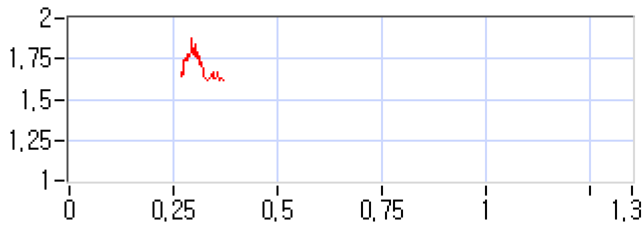
Fig. 4 Main controller board

DSP TMS320F2812 has 16 12-bit ADCs (Analog-to-Digital Converter). It allows us to have the received signals from the 16 ultrasonic sensor boards at once. The DSP board can save 16 set of data from 16 channels.

The number of raw data (Fig. 5a) collected from one ADC channel is about 3200 which is too many for limited amount of memory and causes excessive calculation times when correlation is performed with raw data. Therefore, raw data is converted to envelope data. Envelope data is as shown in Fig. 5b that connects peaks of the raw data above threshold voltage. And this information is saved in the pair of time and voltage only when the voltage is over the threshold voltage. Average number of this pair is only 40.



(a)



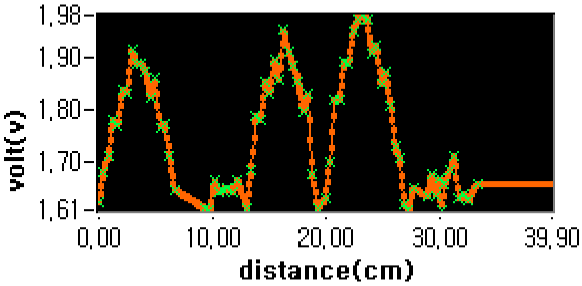
(b)

Fig. 5 Example of data of the ADC channel signal; (a) Raw data; (b) Envelop data

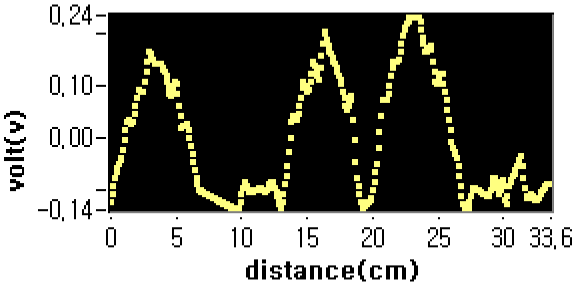
2.3 Identification by Correlation

If the transmitter on the ultrasonic sensor board emits ultrasonic wave with a different pattern from the others, a receiver on the board getting the ultrasonic wave could know which transmitter sent the ultrasonic wave. This fact could be used for grouping signals from multiple sensors, though multiple transmitters emit signals simultaneously.

4 different model-patterns are considered to identify transmitted signal (pattern 1001, pattern 1011, pattern 1101, and pattern 1111). Each pattern has 4 cycles, where ‘1’ means transmitter sends an ultrasonic wave for a cycle and ‘0’ means transmitter doesn't send an ultrasonic wave but delays for a cycle. When ultrasonic wave is received, it is saved in envelope data format (Fig. 6a) due to the limited memory size. For correlation to be performed, the envelope data is converted into voltage data with 1 mm interval. And then, this voltage data is adjusted down by its average (Fig. 6b) to make its average to be zero.



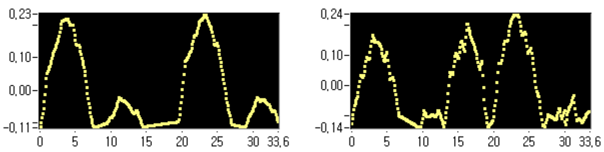
(a)



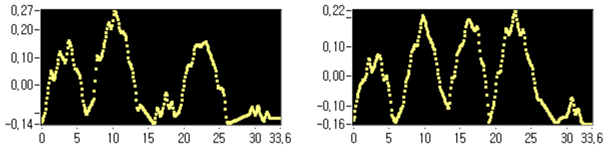
(b)

Fig. 6 Making process for model-pattern 1011; (a) envelop data and converted data generated by interpolation for pattern 1011; (b) pattern 1011 moved below by average.

According to the described process, 4 model patterns are made (Fig. 7). Model pattern is made as a transmitter sends a patterned signal directly to the receiver without any obstacles. And then amplitudes are adjusted to make 4 different patterns have the same peak level (Table 1).



(a) (b)



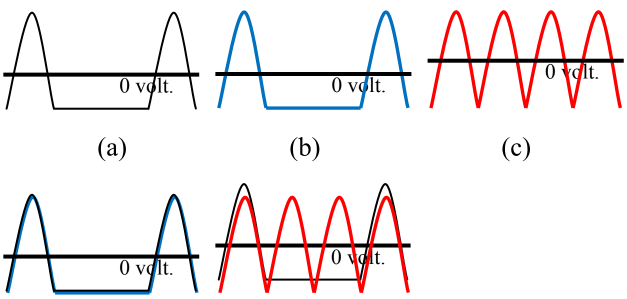
(c) (d)

Fig. 7 Model patterns; (a) pattern 1001; (b) pattern 1011; (c) pattern 1101; (d) pattern 1111

Table 1 Amplitudes of 4 model patterns

	1001	1011	1101	1111
Amplitude	0.0130402	0.0130341	0.0130675	0.0130226

Fig. 8 shows how this algorithm can detect patterns sent by transmitter. Assuming (a) is a received signal, (b) is the model-pattern of 1001, (c) is the model-pattern of 1111, and no noise is regarded for simplicity. The correlation of (a) and (b) produces positive values through all the 4 cycles and gives a result of large positive value (Fig. 8d). If (a) and (c) is correlated, the first and the forth cycle produce a positive values while the second and the third cycle make negative-values, and therefore the correlation result is small-positive value (Fig. 8e). As a result, by comparing the correlation values for 4 different model-patterns, we can choose the pattern of the largest value as the identified pattern.



(a) (b) (c)

(d) (e)

Fig. 8 (a) Received signal; (b) model pattern 1001; (c) model pattern 1111; (d) correlation (a,b); (e) correlation(a,c)

Now, let’s collect envelop data of the reflected signal as it transmits ultrasonic wave with the pattern. The obstacle is a plane wall which is made of steel. Each time, a transmitter transmits ultrasonic wave with a different pattern at a fixed location and then a receiver gets the reflected signal. After that, the monitoring program on the PC converts the envelope data into series of voltage values with 1 mm interval. This voltage data is correlated with 4 model patterns sequentially. After 5 times test, we showed the result as Table 2, where for each test pattern, the largest correlation value is shown to be corresponding to the correct pattern. The results of the test indicate that the proposed method can detect patterns appropriately.

Table 2. The result of identification by correlation method for each pattern

Pattern 1001	1001	1011	1101	1111
1st	1.88615	1.28214	1.17522	0.866505
2nd	2.03358	1.38469	1.38872	0.856468
3rd	1.94003	1.36503	1.11024	0.835706
4th	2.12353	1.44344	1.26834	0.787162
5th	1.91022	1.35773	1.07796	0.810271

(a)

Pattern 1011	1001	1011	1101	1111
1st	1.70684	2.21447	1.90176	1.70598
2nd	1.83371	2.28668	1.82054	1.73856
3rd	1.70753	2.1508	1.8343	1.70201
4th	1.77573	2.17711	1.75368	1.61874
5th	1.77358	2.32278	1.86656	1.77297

(b)

Pattern 1101	1001	1011	1101	1111
1st	1.11623	1.90008	2.52455	1.70545
2nd	1.08833	1.83997	2.38922	1.68429
3rd	1.08181	1.87081	2.29767	1.53908
4th	0.931718	1.6715	2.1826	1.51191
5th	1.00121	1.83901	2.35597	1.62941

(c)

Pattern 1111	1001	1011	1101	1111
1st	1.37589	1.81841	2.19171	2.73166
2nd	1.4869	1.86837	2.25646	2.92507
3rd	1.60722	2.12077	2.49904	3.22605
4th	1.70894	2.01946	2.41926	3.13453
5th	1.59905	1.95815	2.41601	3.03135

(d)

2.4 Distance Detection by Correlation

The conventional method of detecting distance for ultrasonic sensor is simply threshold method, where only if a signal above the prefixed threshold is detected, that time is chosen as a time of flight. However the simple threshold method is not only supposed to be influenced by noise, but also has an error between the real beginning position and detected position (Fig. 9).

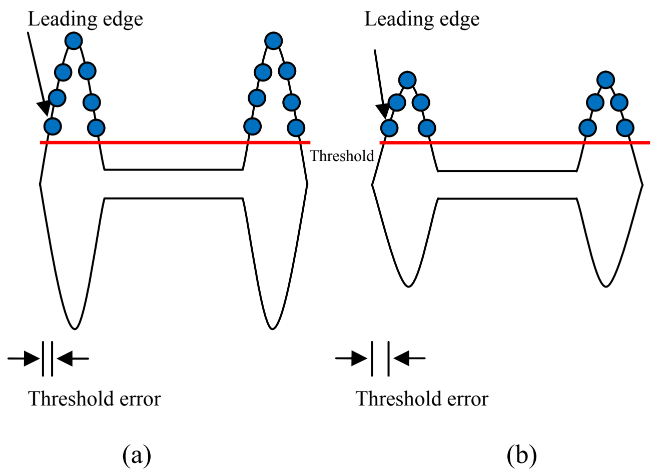


Fig. 9 Distance error (a) with strong signal; (b) with weak signal

On the contrary, correlation method can detect the beginning position of a received signal because correlation considers points which don't appear in simple threshold method (Fig. 10). Disadvantage of using correlation is the increase of calculation.

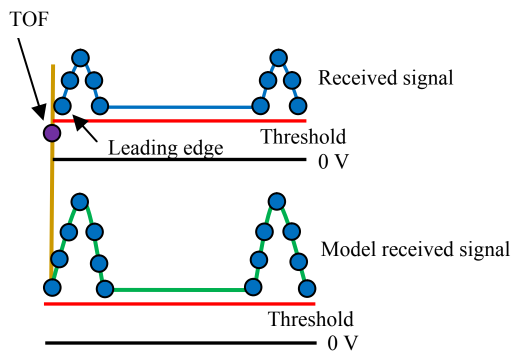
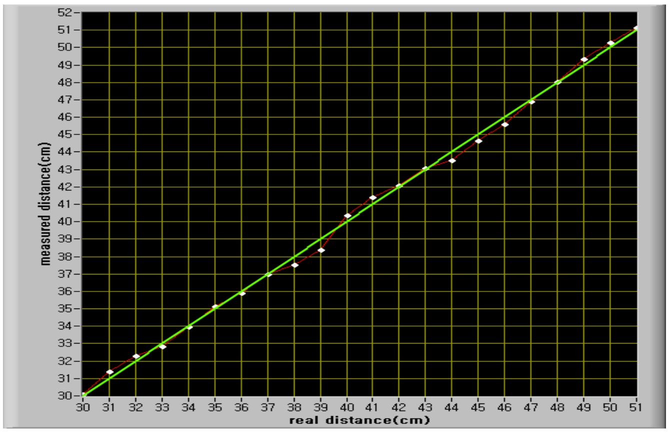


Fig. 10 Distance detection by correlation method

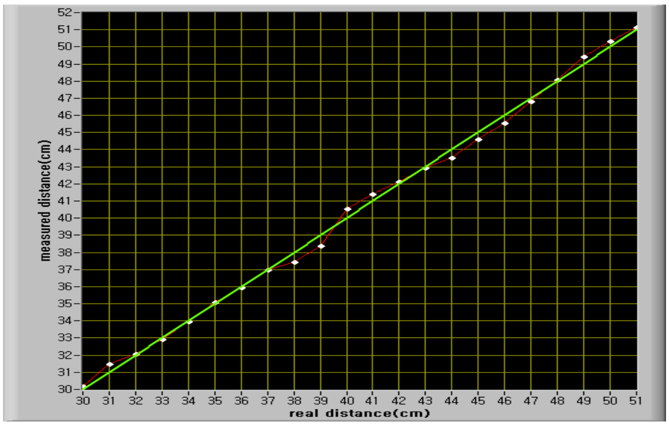
Followings are experiments on distance detection by using correlation method. The obstacle is a steel plane wall. Distance to be detected is from 30cm to 51cm by 1cm interval. After repeating a test for 5 times at each point, the average of measured value is recorded. The minimal measurable distance is 30cm because we put a blind range to avoid the direct reception from the neighboring wide-angle sensors. The result of the test is shown in Fig. 11, which shows that proposed method can detect the distance with reasonable precision. The errors identically shown in all the graphs are likely to be caused by inaccurate ruler, hand-held positioning, the imprecise angle of reflection, and so on. The RMS error for each pattern is shown in Table 3 and it is calculated as

$$RMS\ error = \sqrt{\frac{1}{N}\sum^{N}(d_{r,i} - d_{m,i})^2}$$

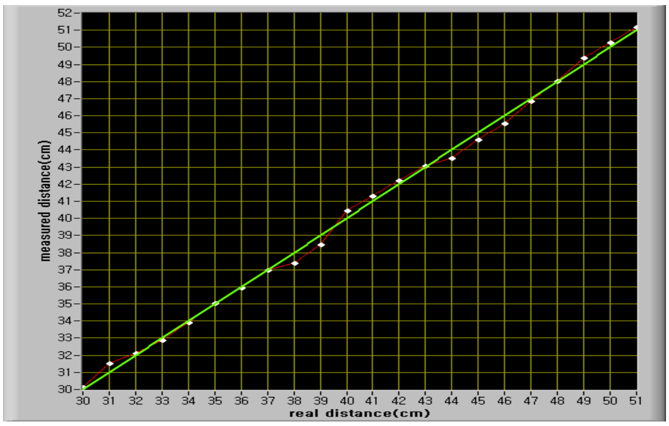
, where $d_{r,i}$ is the real distance at location i, $d_{m,i}$ is the measured distance at location i, and N is the number of measurements. This error can be smaller when measurements are taken repeatedly and their averages are used.



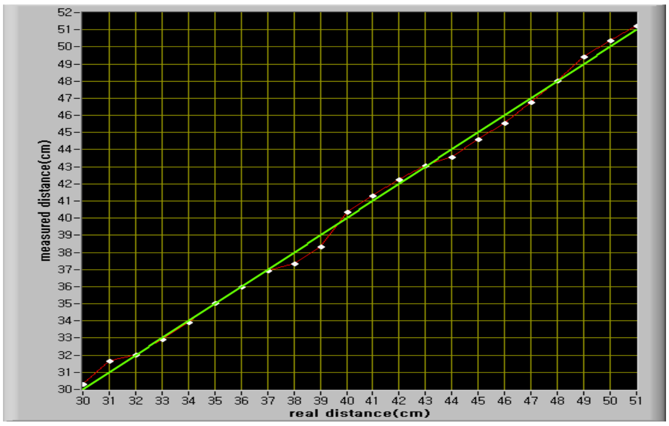
(a)



(b)



(c)



(d)

Fig. 11 Result of distance measurement experiment; (a) pattern 1001; (b) pattern 1011; (c) pattern 1101; (d) pattern 1111

Table 3. RMS error for each pattern

	1001	1011	1101	1111
Error(cm)	0.254746	0.283985	0.271332	0.30021

3. CONCLUSION

This paper shows a method of identification of received ultrasonic wave by giving patterns in each transmitted signal and shows how we can detect the distance, where these two are accomplished by correlation.

Identification of the signal provides useful information for figuring obstacle especially when multiple transmitters are used simultaneously. And the detection of the distance using correlation method can measure distance more exactly than the conventional threshold method because it can find a position which doesn't appear in simple threshold method.

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