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Recognition of Object Position by use of Aerial Ultrasonic Sensor

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Abstract

This paper describes a method for recognition of two-dimensional position of an object by use of aerial ultrasonic sensor and signal processing technique, which would become a help for blind person or self-mobile robot. First, we have developed a method for measuring the time difference between the transmitted and the received burst wave by use of one ultrasonic transmitter and three receivers.

Secondly, a new method is developed for measuring the distance to an object by use of M-sequence correlation method. Thirdly, a measurement method to obtain the position of an object is described by use of phase-arrayed ultrasonic sensor, which gives us a wide-range position determination in a short time.

Keyword

pseudo-random M-sequence, cross-correlation procedure, ultrasonic wave array, plural object position recognition

1. Introduction

This research aims at the development of a ultrasonic sensor system which can be used in understanding surrounding environment with high degree of accuracy even in a noisy environment, which would be helpful for getting information on distance for blind person or self-mobile robot. In this paper, we describe three methods for this purpose. One of the ultrasonic sensor systems is the distance measurement system which calculates distance from delay time obtained from the cross-correlation procedure using M-sequence signal. The basic idea of distance measurement is to calculate cross-correlation function between the transmitted signal modulated by M-sequence and the received signal. The second method is to seek the position of object by use of one ultrasonic transmitter and three receivers, which is one of the applications of ultrasonic wave range finder. The third method is the use of ultrasonic wave transmitter of multiple array providing two ultrasonic wave's beams for recognizing object. The generation of two ultrasonic wave's beam is carried out by controlling phase difference between adjoining elements of the sensor array. These methods would be widely applicable for measuring distance and recognizing object in self-mobile robot etc.

2. Measuring the distance by use of M-sequence correlation

2.1 Generation and property of M-sequence

The generation of M-sequence is as follows. The primitive polynomial is shown in Eq.(1) and initial values are (00001).

$$f(x) = x^5 + x^2 + 1 \qquad (1)$$

The property of M-sequence which was used for recognition of object is that the autocorrelation of M-sequence m is as shown in Eq. (2).

$$\phi_{mm}(k) = \begin{Bmatrix} 1 & (k = 0, N, 2N, 3N, \ldots.) \\ \frac{-1}{N} & (k \neq 0, N, 2N, 3N, \ldots.) \end{Bmatrix} \qquad (2)$$

2.2 Principle of measuring the distance

A carrier signal of 40KHz is modulated by M-sequence signal like Figure 1 and burst signal for driving transmitter is generated. The signal is transmitted as pattern of M-sequence from transmitter and received by a receiver. By taking cross-correlation between the transmitted M-sequence u(t) and the received signal y(t) as shown in Eq. (3), we can calculate the delay time between them, from which we can obtain the distance from the transmitter to the receiver.

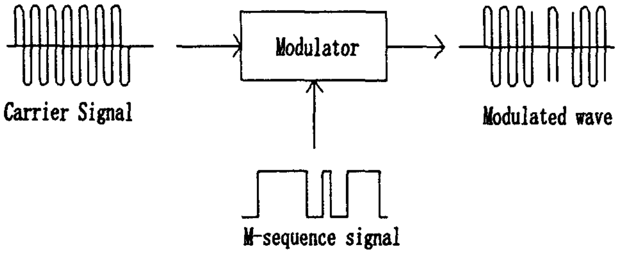

Figure 1 A method of modulation by M-sequence signal

$$\phi_{uy}(m) = \frac{1}{N}\sum_{n=0}^{N-1} u(n)\, y(n+m) \qquad 0 \le m \le n-1 \tag{3}$$

2.3 Experimental result

An experiment is carried out for measuring the distance stated above. The result is shown in Figure 2. It is possible to measure the distance within ± 8cm. When one clock width of M-sequence is 1ms, the resolution becomes 0.1ms because of sampling by 10KHz, so the measuring resolving power of recent experiment is about ± 34.9mm.

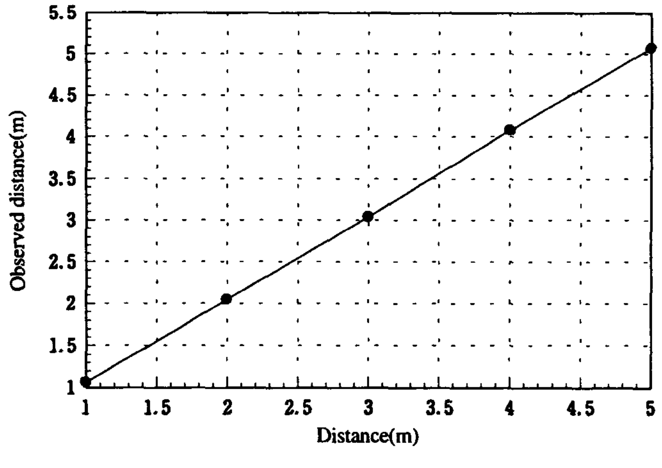

Figure 2 Result of measuring distance using M-sequence correlation

The cross-correlation function between the transmitted M-sequence signal and the received signal is shown in Figure 3. The time delay at which the cross-correlation becomes maximum shows the time delay between them.

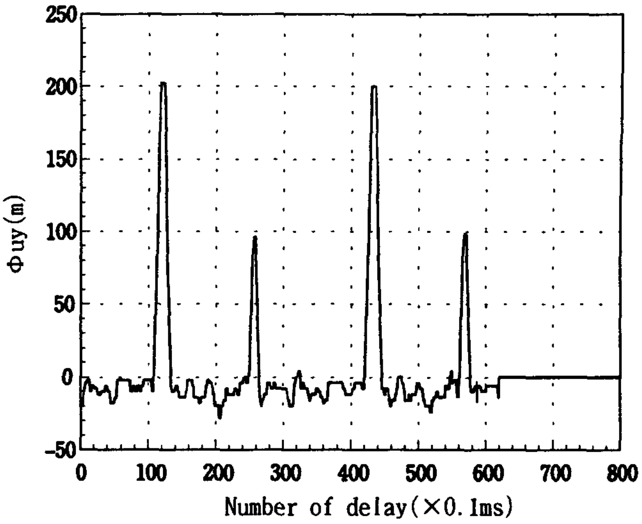

Figure3 Cross-correlation function between the transmitted M-sequence and the received M-sequence

3. The object recognition using one transmitter and three receivers of ultrasonic sensors

3.1 The principle of measuring distance by a way of pulse reflex

This principle is the same as that of commercially available ultrasonic wave range finder. The method is to measure the time delay between the transmitted and the received pulse.

3.2 The principle of measuring the value of coordinate for object

Since the principle of measuring distance by a way of above-mentioned pulse reflex is applicable, we can obtain the coordinates of the object, by combining three receiver circuits and one transmission circuit. As is shown in Figure 4, we put transmitter and receiver 1 piece each at the origin of x-y coordinates and put two receivers on right and left side of the origin. L1, L2 and L3 are twice the distance between the origin and the object and M (Lx, Ly) is the coordinates of object. Each distance L1, L2, L3 are measured from the time delay between that transmitter and receiver. From geometric consideration we have,

$$S = (l_2 + l_3 - l_1 + 2Ls)/2 \tag{4}$$

$$A = \sqrt{s(s - l_2 + l_1/2)(s - l_3 + l_1/2)(s - 2Ls)}$$

$$Ly = A / Ls \qquad Lx = \sqrt{\left(l_1/2\right)^2 - \left(Ly\right)^2}$$

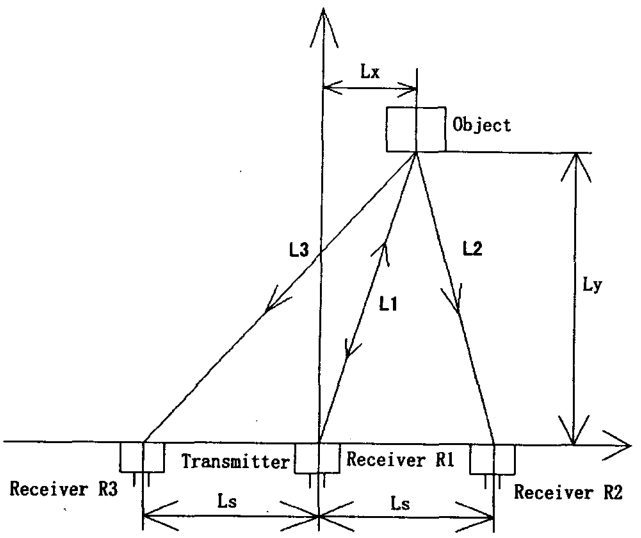

Figure 4 The configuration for recognition of object by use of one transmitter and three receivers

3.3 Experimental result

Using cylinder of diameter 15cm made of corrugated cardboard as object, we obtained coordinates of the object from the above mentioned method. The result is shown in Figure 5. The maximum distance error is 13.2cm. The accuracy of distance measurement is considered to be mainly due to the configuration of the experiment and to be improved.

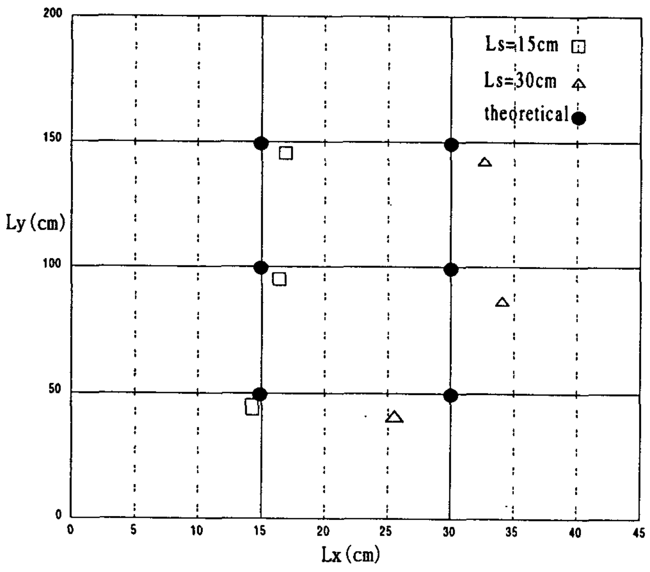

Figure 5 The result of recognition

4. Object localization by ultrasonic transmitters in an array

If ultrasonic transmitters are configured in an array and their spacing d is aproximately equal to each transmitter's wavelength λ, this array transducer can form two ultrasonic beams simultaneously. The method of recognizing objects by using the beams is explained as follows.

4.1 Ultrasonic beam sweeping by arrayed transmitter

In Figure 6, if ultrasonic wave has wavelength λ, and a beam is transmitted in θ s, from the arrayed sensor which consists of multiple elemental devices arranged equal interval d, phase difference of ultrasonic wave between adjoining elemental devices is described as equation (5).

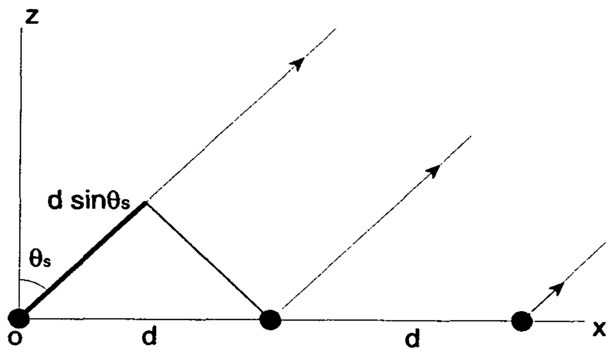

Figure 6 Phase difference of the ultrasonic wave's elemental devices which are arranged in X axis

$$\phi = (2\pi d/\lambda)\sin\theta_s \qquad (5)$$

Therefore to change the traveling direction of ultrasonic beam, phase difference between adjoining elemental devices shoud be controlled. More precisely, considering directionality a(θ) of each transmitter, the magnitude of amplitude formed by arrayed transmitter of 9 element at point P(x, y) on 2 dimensional plane is described as equation (6).

$$P(\vec{r}) = \left| \sum_{i=-4}^{4} \frac{a\left(\angle\left(\vec{r}-\vec{r}_i\right)\right)\exp\left(-j\left(\vec{k}\left(\vec{r}-\vec{r}_i\right)+\phi_i\right)\right)}{\left|\vec{r}-\vec{r}_i\right|} \right| \qquad (6)$$

In case of d= λ, and θ s=30°, it is expected that two beams will become right and left symmetry as shown in Figure 7.

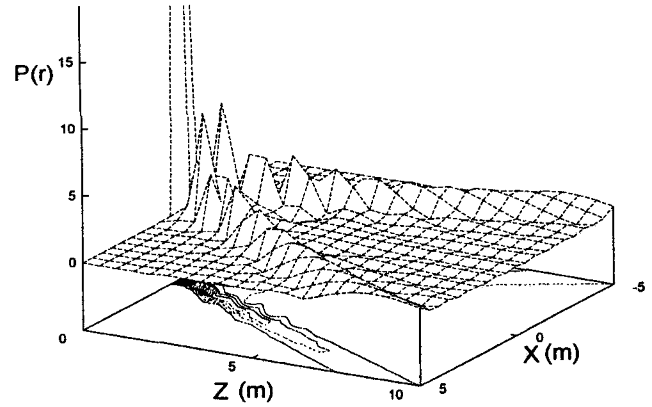

Figure 7 Sound pressure amplitude strength distribution of θ s =30°

4.2 Object localization

In order to simplify the case of Figure 8, we explain the method of locating an object in case where there is one object on an ultrasonic beam of right hand.

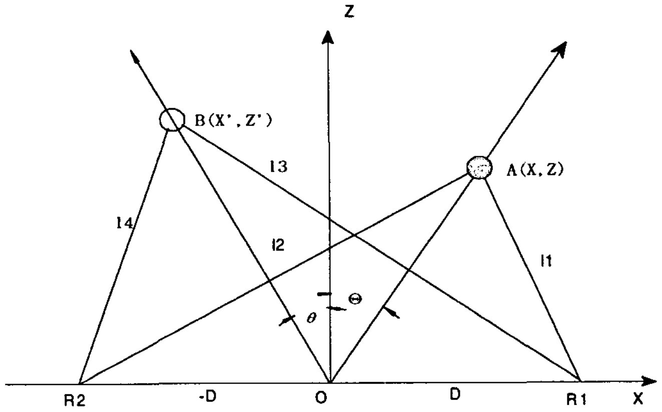

Figure 8 Configuration of object localization by ultrasonic sensor

Center of arrayed transmitter is put on the origin of coordinates as shown in Figure 8 and propagation distances from the transmitter to receiver R1 and R2 via the objects represented as l1 and l2 , respectively. The angle between an ultrasonic beam of right hand and Z-axis is Θ and distance to the receiver is D. Measured values of right and left receivers for the object are lm1 and lm2, and measurement error for l1 and l2 is described as e1 and e2. Here, an estimate to seek for x, z value which minimizes this error e1, e2, is shown in equation (7). By a numerical technique calculation based on Newton-Raphson method coordinate's estimate (X, Z) can be computed from equation (7).

$$e1 = lm1 - l1 \qquad e2 = lm2 - l2 \qquad (7)$$

$$e1 + e2 + \alpha\frac{x}{z} \rightarrow \min \qquad \alpha : \text{undecided constant}$$

To determine which beam the object is located on, we can test equation (8). By using similar method, we can determine the correct combination as their total error is smaller than the other combination.

$$lm1 \geq lm2 \rightarrow X \geq 0 \qquad (8)$$

$$lm1 < lm2 \rightarrow X < 0$$

4.3 A result of experiment

In case where two objects were placed at (-45cm, 100cm) and (45cm, 100cm) like Figure 8, a result of objects localization using two ultrasonic beam is shown in Figure 9. Though some fluctuation is seen in Figure 9, estimation of the position of objects is successfully carried out and it is seen that this system can reconstruct some shape of the objects.

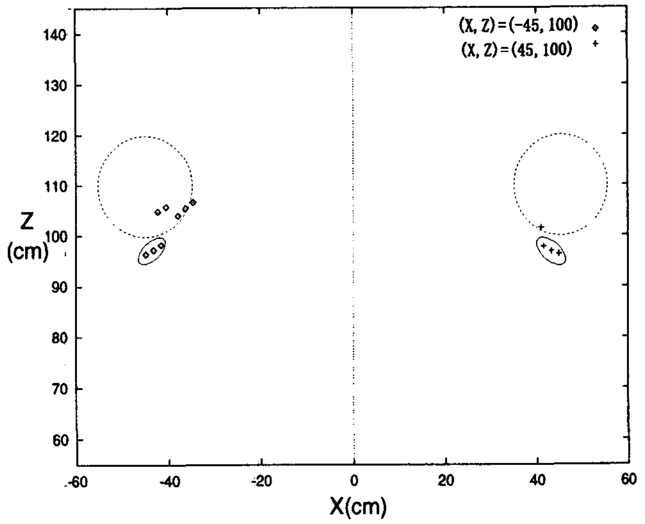

Figure 9 Object localization using two ultrasonic beams

5. Conclusions

It is shown that the distance measurement by use of M-sequence correlation method which enables time delay calculation from cross-correlation between the transmitted M-sequence and the received signal is widely applicable for an ultrasonic sensor system which can recognize surrounding environment with high accuracy even in a noisy environment.

To localize objects by ultrasonic sensor, it is also shown that pulse ecoh using a principle of ultrasonic wave range finder can be used, which is realized by combining three receivers and one transmitter. In addition, an ultrasonic sensor, which is set up in an array and making two ultrasonic beams is shown to be able to localize separated objects simultaneously by using two ultrasonic beams. It can be said that recognition of object using ultrasonic sensor is possible by 3 kinds of keys about distance measuerment method: M-sequence correlation , pulse echo and phased array. The applicability of our method for future robot and an ancillary visual sensor is to be investigated.

6. References

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