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Recognition Resolution Enhancement of Ultrasonic Sensors via Multiple Steps of Transmitter Voltages

Seung You Na, °Min Sang Park

Dept. of Electronics Eng., Chonnam National University, Puk Ku, Kwangju 500-757, KOREA
Tel: +82-62-520-6394; Fax: +82-62-520-6390; E-mail: syna@orion.chonnam.ac.kr

Abstracts Ultrasonic sensors are widely used in various applications due to advantages of low cost, simplicity in construction, mechanical robustness, and little environmental restriction in usage. But the main purposes of the noncontact sensing are rather narrowly confined within object detection and distance measurement.

For the application of object recognition, ultrasonic sensors exhibit several shortcomings of poor directionality which results in low spatial resolution of objects, and specularity which gives frequent erroneous range readings. To resolve these problems in object recognition, an array of the sensor has been used. To improve the spatial resolution, more number of sensors are used in essence throughout the various devices of the sensor arrays. Under the disguise of a fixed number of the sensors, the array can be shifted mechanically in several steps.

In this paper we propose a practical sensor resolution enhancement method using an electronic circuit accompanying the sensor array. The circuit changes the transmitter output voltage in several steps. Using the known sensor characteristics, a set of different return echo signals provide enhanced spatial resolution. The improvement is obtained with neither the cost of the increased number of the sensors nor extra mechanical devices.

Keywords Resolution Enhancement, Ultrasonic Sensor, Driver Voltage Steps

1. INTRODUCTION

Machine vision system using various noncontact sensing devices are widely employed in the area of mobile robots and factory automation for object detection and collision avoidance. But there are many difficulties and shortcomings in vision system for applications in real situation.

Vision systems are liable to suffer from difficulties in dealing with reflective and transparent objects such as metal and glasses. Also the operation of the vision system highly depends on the environmental light conditions.

Image processing of the vision system usually contains a lot of information as compared with relevant signals, therefore it takes much time to hinder from real time operation. To reduce the burden of the information amount, object detection rather than pattern recognition is applied with ease in real problems. In this case, the resolution of the sensor becomes the foremost important factor to consider.

Ultrasonic sensors are becoming indispensable components in every sensor of automation equipments due to many advantages of low cost, simplicity in condstruction, mechanical robustness, and little environmental restriction in usage. But the main purposes of the noncontact sensing device are rather narrowly confined within object detection and distance measurement.

To widen the realm of the application to object recognition, ultrasonic sensors need to improve the recognition resolution to a certain amount. To resolve the problem of spatial resolution restriction, an increased number of the sensors in the forms of a linear array or 2-dimensional array[1] of the sensor has been used. Also better resolution has been obtained by shifting the array in several steps using mechanically actuators[2].

In this paper we propose a practical sensor resolution enhancement method using an electronic circuit accompanying the sensor array. The circuit changes the transmitter output voltage in several steps. Using the known sensor characteristics, a set of different return echo signals provide enhanced spatial resolution. The improvement is obtained with neither the cost of the increased number of the sensors nor extra mechanical devices.

After reviewing the theory of the acoustic transducer, an electronic subsystem to the sensor array is developed utilizing the physics of ultrasound propagation. The experimental setup is described along with results achieved for several objects.

2. AN ACOUSTIC TRANSDUCER

2.1 TOF(time of flight)

A set of ultrasonic sensors of combined type from Polaroid which transmit pulses and receive return echoes also is used in this paper. The return echo to be received can be represented as in Fig. 1 in general. The distance measurement is obtained by the time of flight at which the return echo reaches the given threshold level(τ) for the first time as follows

$$z_0 = \frac{ct_0}{2} \qquad (1)$$

c : the speed of sound in air(343 m/s at 15℃)
t_0 : traveling time

Since the transducer has a time varying gain amplifier circuit inside the receiver part, echo sound field amplitude variation due to distance changes is compensated accordingly. Also the environmental effects to the sound speed is calibrated within the measurement range.

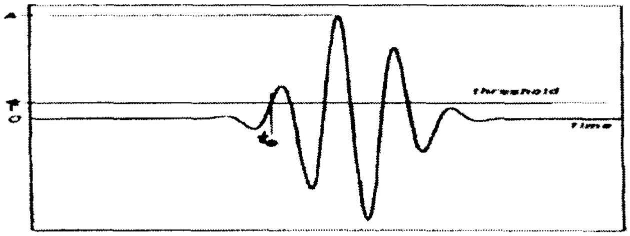

Fig. 1. A typical echo produced by ultrasound ranging system

2.2 Echo Amplitude Variation Due to Object Pattern

A method using several steps of transmitter driver voltage is considered to improve the sensor resolution in this paper. Even for an object at a fixed distance when we applied different voltages to the transmitter, return echoes show different ultrasound amplitude and therefore we get different distance measurements according to the patterns and postures of an object. Ultrasound pressure at a point far from a transducer is given by

$$p_i(z, \Theta) = (p_0/z) \cdot e^{-2\Theta^2/\Theta_0^2} \qquad (2)$$

where p_0 : constant, Θ : declination
Θ_0 : bandwidth

Received return echo which is attenuated by $\frac{(e^{2\alpha z})}{z^4}$ has a pressure given by

$$p_r(z, \Theta) = (\frac{kp_0}{z^5}) \cdot e^{-2\Theta^2/\Theta_0^2} e^{-2\alpha z} \qquad (3)$$

where k = proportion coefficient, z = distance
α = reduce coefficient($11.92 \times 10^{-11} \times f^2$)

The receiver voltage which is proportional to the magnitude of the return echo is also given by

$$v_r(z, \Theta) = (\frac{k_1 v_0}{z^5}) \cdot e^{-2\Theta^2/\Theta_0^2} e^{-2\alpha z} \qquad (4)$$

In case when Θ=0, eq.(4) becomes

$$v_r(z, \Theta) = (\frac{k_1 v_0}{z^5}) \cdot e^{-2\alpha z} \qquad (5)$$

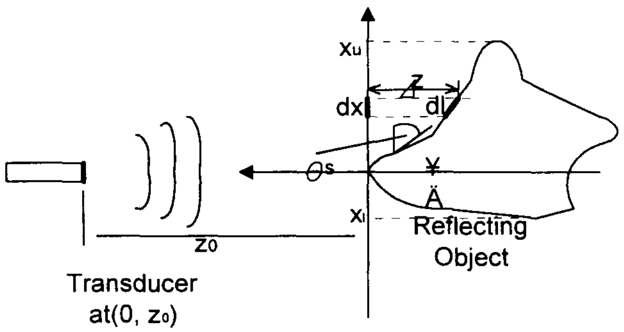

Fig. 2. Reflection of echo at Θ=0

Referring to Fig. 2, the receiver voltage when Θ=0 due to return echoes from rough surface is given by

$$V_r = \frac{v_r(z)}{R_0 L_{cal}} \int_{x=x_l}^{x_u} R(\Theta_s) e^{-jk2\Delta z}\, dx \qquad (6)$$

V_r : receiver voltage , $k = 2\pi f / c$: wave number
R_0 : reflection coefficient, $L_{cal} = x_u - x_l$
v_r : receiver voltage from a point at z
$R(\Theta_s)$: reflection coefficient depending on surface
Δz : surface contour elements

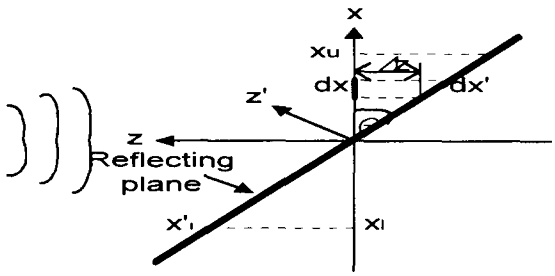

Fig. 3. Reflection of echo when $\Theta \neq 0$

Similarly the receiver voltage when $\Theta \neq 0$ is represented by

$$V_{r_{plane}} = \frac{v_r(z) R(\Theta)}{R_0 L_{cal}} \int_{x=x_l}^{x_u} e^{-jk2\Delta z}\, dx \qquad (7)$$

Since $\Delta x = x' \cos\Theta$, $\Delta z = x' \sin\Theta$,

$$V_{r_{plane}} = \frac{v_r(z) R(\Theta) \cos\Theta}{R_0 L_{cal}} \int_{x=x_l}^{x_u} e^{-jk2\Delta z}\, dx \qquad (8)$$

Eg.(6) and (8) reveal the relationship between the receiver voltages and the object shape and posture. Moreover several steps of transmitter voltage are applied sequentially to find out the variations of receiver echo signals due to object sizes and incident angles. The results are exploited by the following experimental setup to improve the transducer resolution.

3. SYSTEM IMPLEMENTATION

The experimental setup consists of a transducer array, an electronic controller and a DSP as in Fig. 4. An electronic controller is a submodule which provides a series of transmitter voltage to the transducer array. Using 8255(PPI) for parallel array I/O, transducer driver sets a maximum voltage of 430V, and then the voltage is step down sequentially by an accompanying circuit in Fig. 5. The return echo signal is detected and then the TOF is measured using 8253(PIT) to give the distance measurement.

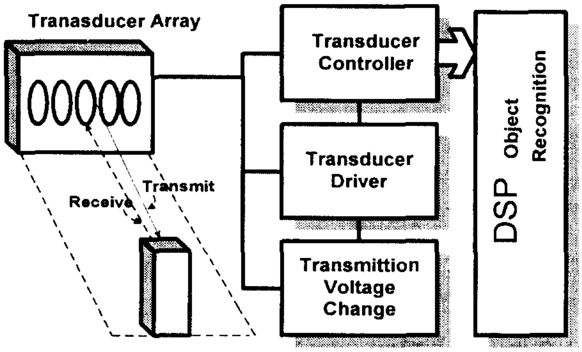

Fig. 4. System block diagram

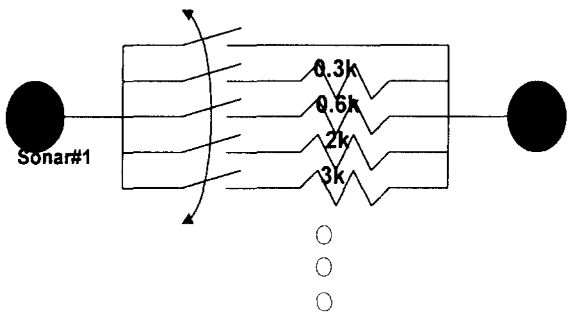

Fig. 5. Multiple steps of the transmitter voltage

4. EXPERIMENT AND RESULTS

4.1 Experimental Procedure

One pulse echo mode which detects the first return echo is used among the various distance measurement methods for ultrasonic sensors. To avoid erroneous readings due to wave interference between adjacent transducers, each transducer is activated sequentially. Received signals from outside of an interested range are discarded to reduce error originating from multiple reflections or from noninterested objects.

Ultrasonic sensors of 3.58Cm width are positioned in a line with gaps of 5Cm each other. Distance measurement data are recorded with the variations of 1) five steps of transmitter voltage 2) object distance 3) incident angles to an object to find out the transducer characteristics. Positions are labeled as a, b, c, d and e, as shown in Fig. 6 with angles of 0, 3° and 6° .

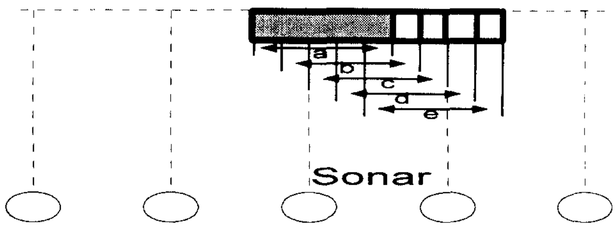

Fig. 6. Positions and angles of an object

The distance gap for each position which is used to characterize object positions in order to enhance the recognition resolution is nearly the same regardless of the object distances of 40Cm, 50Cm or 60Cm as shown in Fig.7, Fig.8 and Fig.9. Marks of "l" denote the selected voltage sets which show significant changes of distance as the transmitter voltage is changed. Five sets of distance readings and corresponding voltages as shown by the marks of "l" in Fig.7~Fig.11 are selected to significantly discriminate the positions and angles of an object. Transmitter voltages of 400, 410 and 430V are used for the discrimination of flat objects and transmitter voltage of 400, 424, 427 and 430V are used for round objects in experiments.

Table 1. Type of objects

Type	Size of Object
1	W:6cm, H:18cm, Plane
2	W:8cm, H:18cm, Plane
3	W:10cm, H:18cm, Plane
4	W:14cm, H:18cm, Plane
5	W:10cm, H:18cm, Sphericity
6	W:15cm, H:18cm, Sphericity

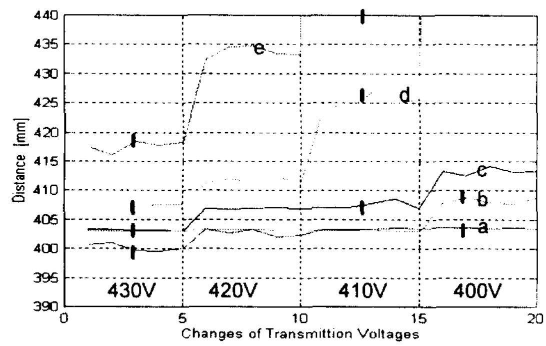

Fig. 7. Distance 40Cm from Sonar

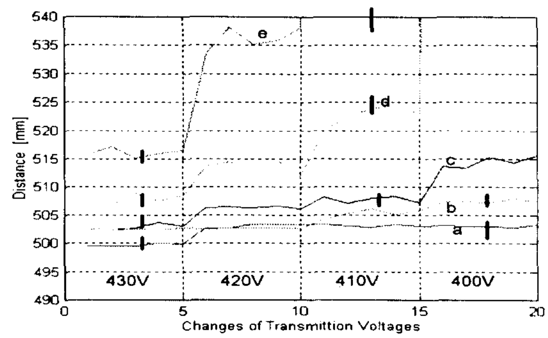

Fig. 8. Distance 50Cm from Sonar

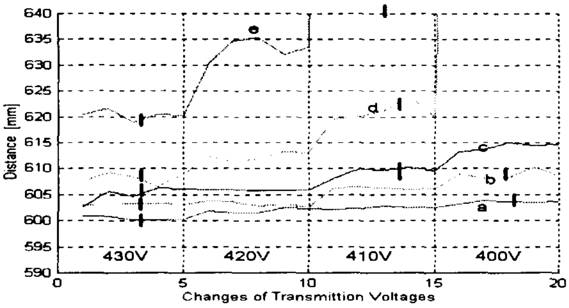

Fig. 9. Distance 60Cm from Sonar

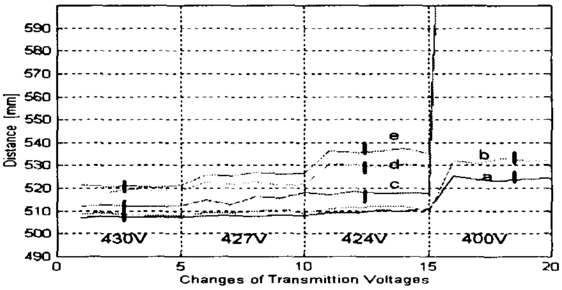

Fig. 10. Distance 50Cm with angle of 3°

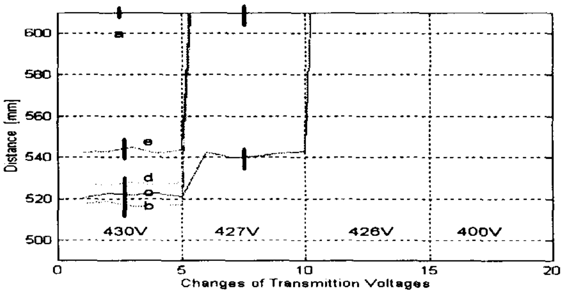

Fig. 11. Distance 50Cm with angle of 6°

4.2 Results

By exploiting the informations of positions and angles of an object which are derived by the changes of transmitter voltages, the results of transducer measurements are significantly improved as shown in Fig. 12~Fig. 17. Each Sensor produces a set of five distance data through the processing of raw distance readings and the corresponding transmitter voltages.

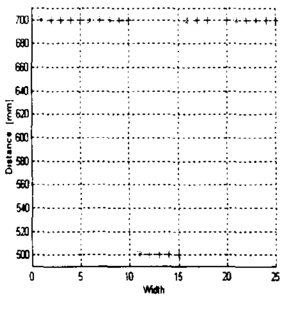

Fig. 12. Results of type 1

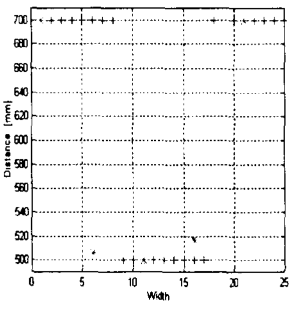

Fig. 13. Results of type 2

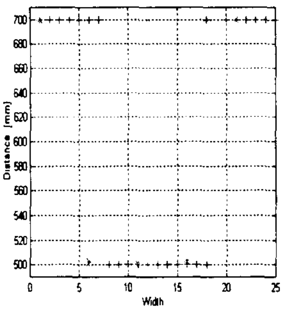

Fig. 14. Results of type 3

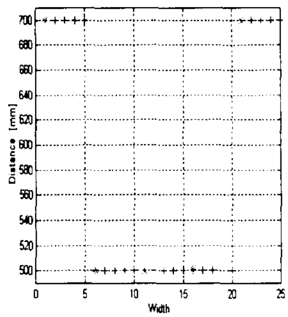

Fig. 15. Results of type 4

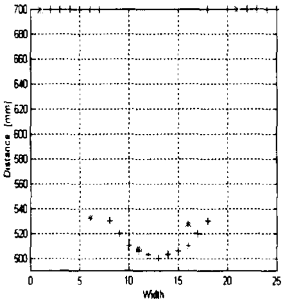

Fig. 16. Results of type 5

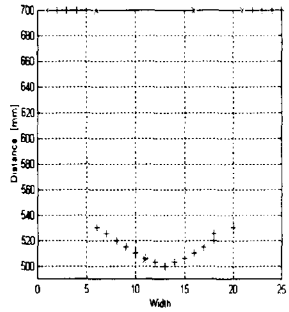

Fig. 17. Results of type 6

5. CONCLUSIONS

A practical sensor resolution enhancement method is proposed using an electronic circuit accompanying the sensor array. Using the known sensor characteristics, a set of different return echo signals corresponding to a set of transmitter voltages provide enhanced spatial resolution. The improvement is obtained without the burden of increased number of the sensor or without extra mecchanical actuators.

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