ENLARGING THE SHORT RANGE DETECTION LIMIT USING INPUT SHAPING TECHNIQUE IN LOW DAMPING ULTRA-SONIC TRANSDUCERS

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Recently, detecting short range are required increasingly in surround imaging for smart cars. It is required to detect the close obstacles or image around the smart car within a couple of wavelength of driving frequency. In paper, the input shaping technique (IST) in low damping ultrasonic transducer is proposed for enlarging the short range detection limit when the pulse-echo ultrasonic imaging is applied. For high efficient and high sensitive sensing the ultrasonic signal, the transducer should have low damping characteristics. However, with low damping characteristics, it is difficult to detect the short range because slow decaying signal. IST is to generate a command to make zero residual vibration of transducer, so that pulse signal is generated with only one cycle of natural frequency of transduce. The transducer can receive the echo signal after one cycle of pulse to enlarge the range of detection limit.

In this experiment, the 25 kHz ultrasonic transducer is used for smart car application. When the 10V pulse input is applied to the transducer, the acoustic signal lasts more than 20 cycles. It is required to wait more than 800 micro second for the transducer to change into receive mode. Especially, when the obstacle is soft, it is required to wait more time because of weak echo signal. With conventional method, it is not easy to detect less than 150 mm due to the coupling effect of pulse signal. Through IST method, the pulse signal is controlled to have several cycle. After giving 3cycles of input for 120 micro second, the transducer is changed into received mode and detects the echo signal of the obstacle positioned at 100mm. The echo signal is converted to digital with 2.5Msps, so that the potential resolution would be about 0.5 mm. These results are quite enough for smart car application to have precise surround image

Keywords: ultrasonic transducers, pulse echo, short range detection

1. Introduction

Recently, detecting short range are required increasingly in surround imaging for smart cars. It is required to detect the close obstacles or image around the smart car within a couple of wavelength of driving frequency. With conventional imaging, echo waveforms are acquired during backscattered pulse-echo detection. Acoustic imaging technique have successfully been used to detect voids, flaw, and cracks in media. Virtually all acoustic imaging technique use pule-echo technique, especially in biomedical applications [1-3]. In pulse-echo technique the SNR is the important element to get precise image. Multi-level pulse-shaping techniques have been used for better SNR, resolution and harmonic suppression in PZT ultrasound systems. Besides these benefits, the use of multi-level technique to improve the combined power efficiency of the CMUT transducer and transmitter has been studied

[4]. In this paper, we introduce a driving circuit to realize the damping function to reduce the mechanical vibration while considering the ultrasonic output and input impedance so that the distance can be precisely measured at a close distance by using one ultrasonic transducer. In addition, attenuation correction was performed by applying signal gain to signals obtained by considering the spreading effect of ultrasonic waves in the air. Through this, an experimental apparatus and a result that confirm whether the ultrasonic transducer has a precise accuracy at a close distance using the ultrasonic transducer will be described.

2. Pulse echo with single transducers

2.1 Modelling of ultrasonic transducers

The transducer is modelled as electric circuit as in Fig. 1. It converts the electrical signal to mechanical energy in the first stage. And mechanical energy is changed to acoustic pressure in the medium. Where, V is input voltage, Cm, M, R is spring constant, mass, damping in mechanical system. Mr and Rr are acoustic parameters in media [5].

When the input signal is applied, a lot of vibration occurs due to a small damping value in the mechanical structure. Ultrasonic waves generated by the ultrasonic transducer also has the residual vibration to continue. As shown in Fig. 1-b, the addition of a damping element mainly reduces the mechanical vibration. Also, when the ultrasonic wave generated from the ultrasonic transducer returns and is converted into the electric signal through the mechanical system, the signal can be reduced through the damping element.

In order to simultaneously implement the transmitting (TX) and Receiving (RX) functions using a single transducer, it is necessary to increase the electrical impedance after applying the ultrasonic wave to obtain a sufficient voltage gain when measuring the RX signal. Therefore, the FET switch element at the amplifier stage must be configured in the circuit (red).

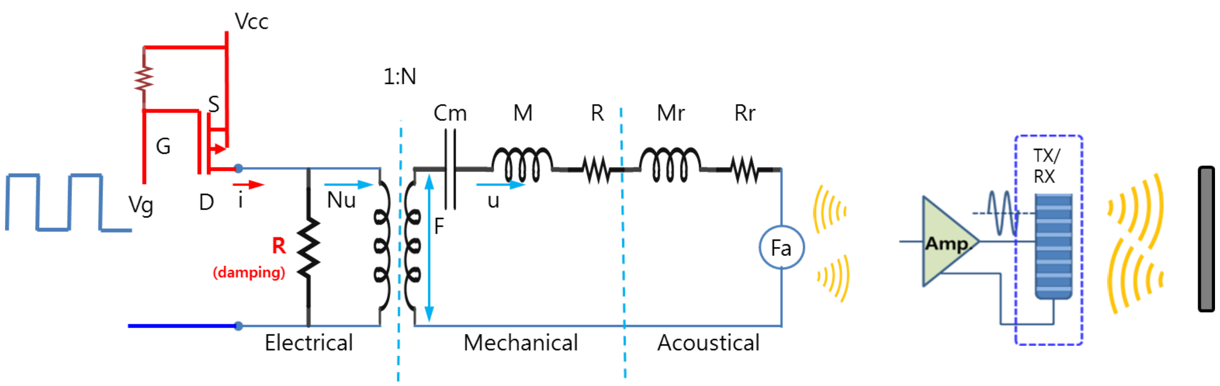

Figure 1: Modelling of ultrasonic transducer and Impedance increase in reflection circuit

2.2 Attenuation correction gain according to the detection distance

Let v(x,y,t) be the value received after the ultrasonic wave is generated. The time is proportional to the distance, Z = ct / 2, where t = 2Z / c, so the value attenuated by the spreading effect of the sound wave must be compensated. The appropriate compensation value is called time / depth-dependent gain. In order to compensate for the reduction caused by the spreading effect, suppose that the ultrasonic element to be a point source and apply the reciprocal relation to it. If the compensated value is represented by R(x,y,z), the following relation is obtained.

$$\mathrm{R(x,y,z)} = \frac{ct}{2} e^{ct\,a} |v(x,y,t|_{t=2z/c} \quad (1)$$

where $\frac{ct}{2} e^{ct\,a}$ is the gain term for attenuation correction, and c is the speed of wave in air.

In order to confirm the compensation effect, the ultrasonic device generates the sound wave and measures the return signal. The signal before compensation and the signal after compensation are shown in Fig. 2. As you can see in the picture, if you compensate, small signal at long distance will increase, so you can measure the distance with high sensitivity by sensing the return signal.

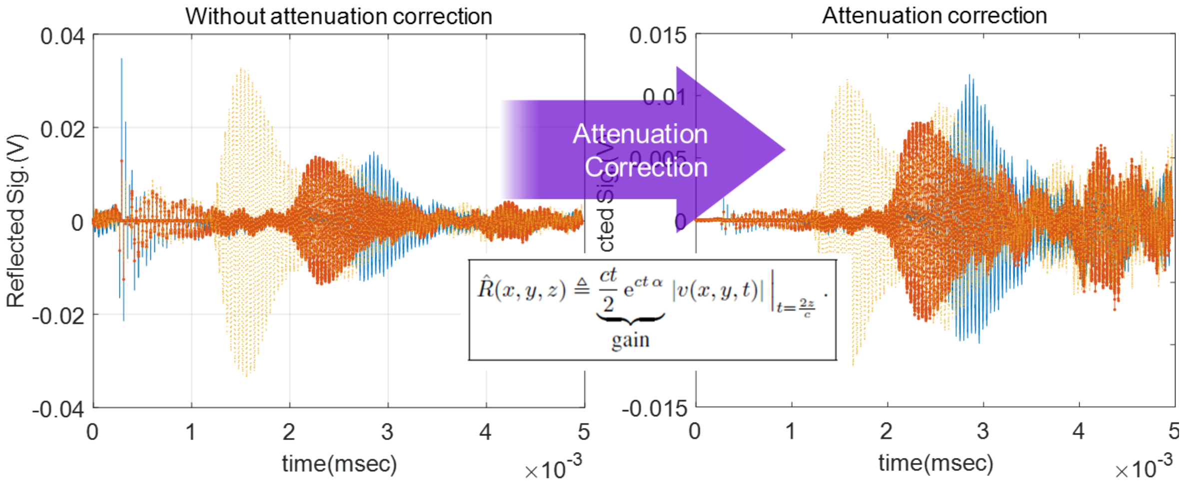

Figure 2: Attenuation correction based on wave spreading effect

3. Short range distance detection

3.1 Experimental setup

An ultrasonic device was used to confirm the distance measurement performance at a short distance. The ultrasonic device was 250 ST180 having a resonance frequency of 25 kHz by Prowave Co.. The ultrasonic device was installed in the anechoic chamber, the ultrasonic wave reached and reflected surface was installed, and the reflection surface was mounted on the motor driven stage. The stage driven by the motor is controlled by the distance of 0.01mm resolution and is a product of Suruga seiki Co. In order to compare the distance measurement experiment using a single ultrasonic element and the conventional distance measurement experiment using two ultrasonic elements, a hole through which an ultrasonic element can be installed at a distance of 30 mm is installed in a portion where the ultrasonic element is mounted. The overall configuration of experimental setup is shown in Fig. 3.

The circuit generating the signal was constructed as shown in Fig. 1, and the generated signal and the return signal were measured through an oscilloscope.

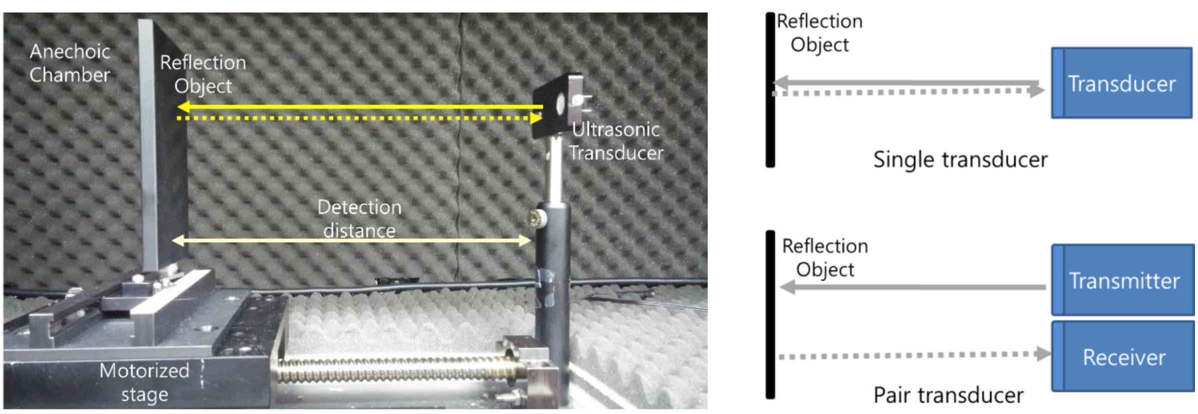

Figure 3: Experimental setup for distance detection, and configuration of transducers

3.2 Distance measurement with single ultrasonic transducer

We tested the accuracy of distance measurement at a short distance range using single ultrasonic transducer. The distance was measured by placing the reflection surface at 100, 200 and 300 mm respectively and generating ultrasonic waves. The waveform of the ultrasonic wave is a square shape with three cycles. Since one cycle is 40 microseconds, four cycles take 160 microseconds. After the sound waves are generated, they go back to the reflection plane. If the reflecting surface is at a position of 100 mm, the distance will be doubled due to the reciprocation, and it will be about 583 microseconds when the sound velocity at 20 degrees in air is 343 m/s. The two times and three times of this time distance are 200mm and 300mm, respectively, and the results shown in Fig. 4 are obtained. As shown in the experiment results, it can be seen that ultrasonic signal is generated by using one ultrasonic element and the return signal can be detected with a large gain, and the short distance is accurately measured through this signal.

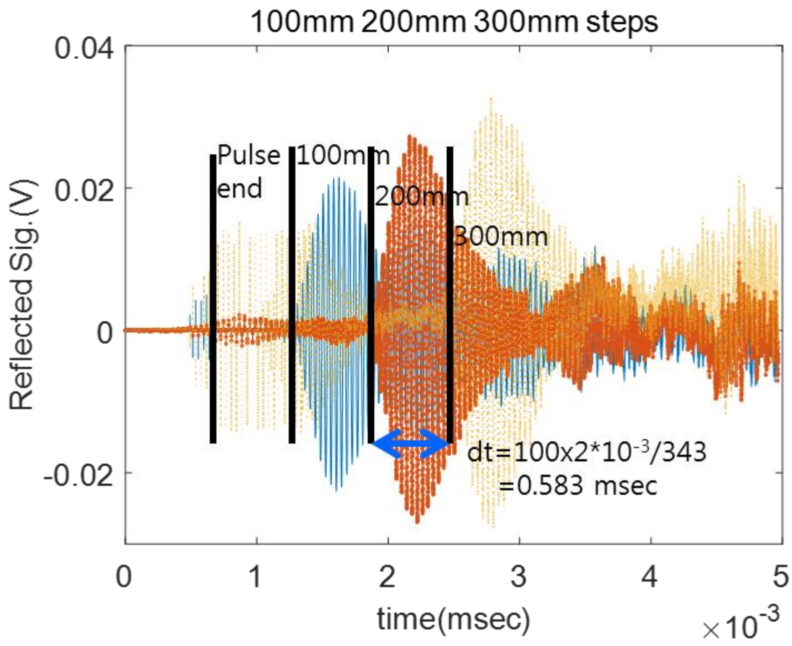

Figure 4: Short range distance measurement with single ultrasonic transducer

3.3 Single transducer and Pair transducers

The use of single transducer and the use of a pairs are important in terms of cost. A conventional method is to use the two as a pair, which can be developed by separating the driver circuit and the sensing signal processing circuit, which is advantageous in terms of signal gain. In addition, it can be measured at the same time as generating a pulse from a TX ultrasonic device, so there is no dead time and it is very advantageous to measure an object at a close distance. On the other hand, when a transducer is used, generation of ultrasonic waves and measurement are not possible at the same time, so there is a dead time in measurement, which makes it difficult to measure an object at a close distance. Also, when one transducer is used, it is advantageous to have a low impedance circuit which can easily drive the current by reducing the internal resistance from the viewpoint of the driver circuit. However, since the impedance is too low from the viewpoint of the returning signal, it is difficult to secure the signal gain. As shown in Figure 1, it is important to utilize FETs to satisfy both the driver impedance and the impedance for signal gain.

In Fig. 5, the signal obtained by using one ultrasonic element and the signal obtained by using a pairs are shown together. As shown in the figure, when two transducers are used, there is no signal reduction due to coupling at the beginning, and there is a merit that the gain is higher. In addition, it secures the sensitivity that can measure not only primary reflection but also secondary reflection. However, because of the use of two, there is a disadvantages of confusion due to the reflected signal from the side wall in the front part, even if it is out of scope. In conclusion, even with a single transducer, it can be said to have the same accuracy and signal sensitivity as two transducer based measurements.

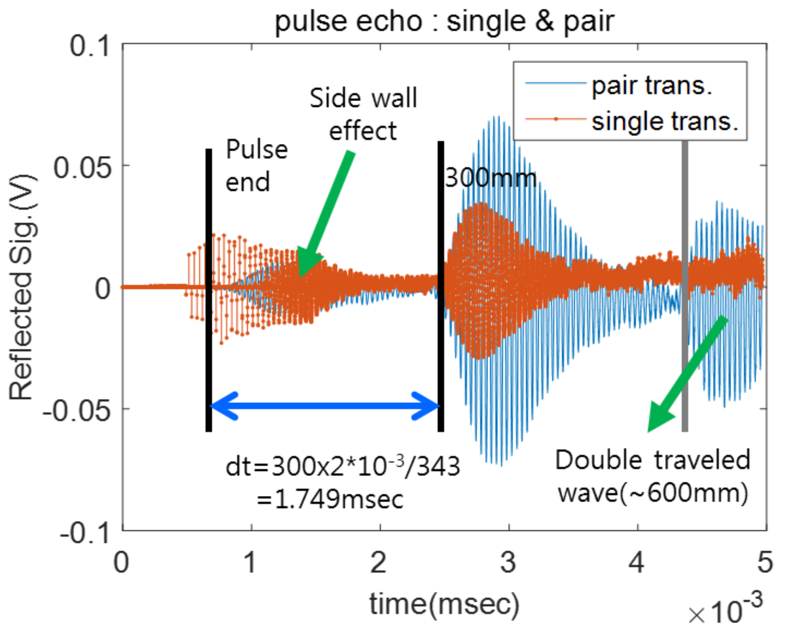

Figure 5: Comparison measurement using Single transducer and Pair transducers

3.4 Measurement resolution at close distance (100mm obstacle)

The distance of the motor driven stage was set at 99.5, 100.0, and 100.5mm, respectively, in order to see whether the distance measurement was possible at a close distance.

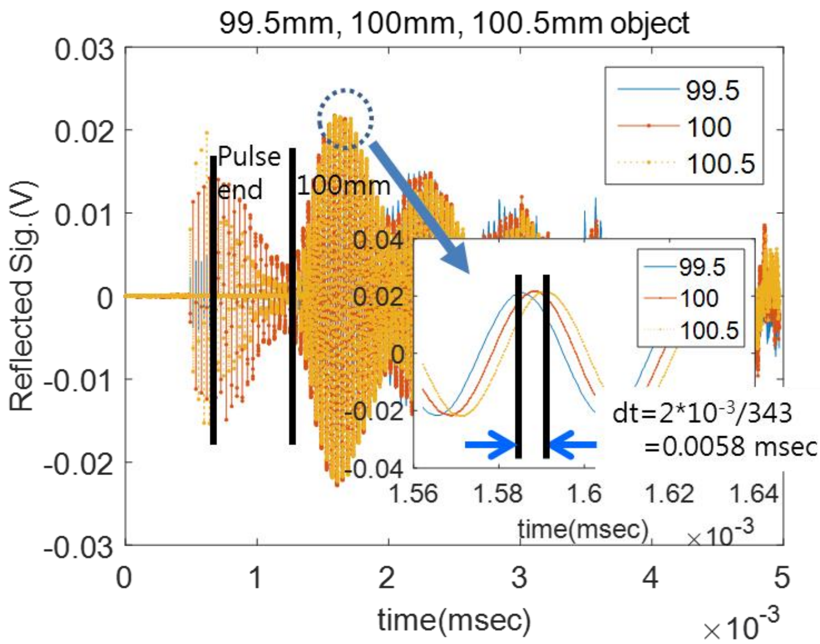

Figure 6: Comparison measurement using Single transducer and Pair transducers

Figure 6 shows the result of measuring the return signal after generating the ultrasonic wave. Even though it is not easy to distinguish any distance difference between 99.5 and 100.5㎜, it is possible to obtain with a time difference of 0.5mm difference. The difference in distance of 1 mm is about 5.8 microseconds when the round trip distance is taken into consideration, which is consistent with the experimental results. Since the signal returned from this experiment is sampled at 3.2 MHz, the potential resolvable distance is about 0.1 mm. Of course, if distance goes away, there is the loss of resolution due to the noise effect. However, as shown in the experimental results, it can be seen that the intensity of the signal is small and the noise is small at close range.

4. Discussions

In this paper, single transducer based pulse echo distance measuring is performed. Single transducer has an advantage over pair transducer in cost and double travelled wave distortion reduction. Since the transducer has under damping characteristics, damping shaping technique is applied to reduce the residual vibration after pulse train is finished. After applying attenuation correction in time distance relationship, the robust signal is obtained to improve the distance resolution.

The echo signal is converted to digital with 3.2Msps, so that the potential resolution would be about 0.1 mm. Experimental results show that the distinction of distance within 0.1mm within 0.5mm displacement becomes clear. Utilizing a single transducer and reducing residual vibration through damping can be very helpful in obtaining the distance image.

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