A Novel Method for Reverberation Cancellation in Single UltrasonicTransducer based Measurement Systems

Subodh P. S[1], Nimmy Mathew[2], Murali R[3], Byju C[4]
Strategic Electronics Group, CDAC(T), Thiruvananthapuram
Email: subodh@cdac.in[1]

Abstract

Ultrasonic transducers find a wide range of applications which include nondestructive evaluation of materials, medical (ultrasound scanners) applications, agricultural applications (pest detection) etc. Typical ultrasonic transducersare piezo electric crystals which converts electrical energy to mechanical energy and vice versa. The basic principle of operation of all ultrasonicdevices involve insonification of region of interest, acquire the echo and extract the parameters of interest from the echo. To successfully characterize the material of interest, information such as start time, signal strength/attenuation etc. has to be derived from the echo. Two major artifacts in the acquired signal which hinder the precise estimation of the parameters are noise and blanking zone. Effective noise removal techniques are in place which eliminates all the noise related artifacts. The blanking zone caused by the reverberation of transducer, even after the excitation signal ceases, is a menace in single transducer based measurements.The presence of echo cannot be detected if it is received in the blanking zone. This has the implication that targets closer to the sensor cannot be subjected to ultrasonic measurements using single ultrasonic transducer. Digital signal processing techniques need to be employed for the removal of reverberation, without affecting the echo present in the blanking zone. This study encompasses a novel method which uses signal processing methods for removal of reverberation. A comparative study on removal efficiency on varying conditions which will enable the choice of optimum parameters based on the specification to be achieved in information extraction of the echo is also discussed in the paper.
Keywords: blanking zone, reverberation, ringing, signal processing, ultrasonic transducer etc

1. INTRODUCTION

Blanking zone refers to distance between the surface of the transducer to the target specimen where measurements cannot be made due to the ringing of the transducers, since echoes, if present in the blanking zone cannot be properly detected. Ringing is the continued vibration of the piezoelectric transducer element beyond the electrical excitation pulse. All piezo electric transducers show this phenomenon irrespective of their design.

Mechanical methods, like altering the construction of the transducer is currently being used to reduce the ringing and hence the blanking zone. This method has a deficiency that the signal level also will become lower, decreasing the sensitivity of the system. Electrically providing an anti-phase signal after the transmission duration also reduces the blanking zone to a certain extent. Both the methods are successful only in reducing the blanking zone, but cannot eliminate it fully.

Digital signal processing techniques are suitably employed and a novel method is found out, which ensures that the echo signal can be detected even if the signal falls inside this blanking zone. This technique ensures that the ringing signal is attenuated to a large extend, without affecting the echo strength, thus enabling detection of the echo.

2. THEORY

The received signal always contains a high amplitude ringing signal in single probe measurement, resulting in the formation of blanking zone. The blanking zone starts immediately after the transmission burst and lasts a few microseconds, duration of which is depended on the medium, transducer design etc. If echo signal gets embedded in this ringing region it cannot be properly detected. This means that the transducer always has to be placed at a certain distance away from the target to avoid the presence of echo in the blanking zone resulting in a reduction of measurement range of the system. The method employed here ensures that the echo signal can be found out even if the signal falls inside the blanking zone.

The ringing frequency is same as the excitation and echo frequency, thereby eliminating the possibility of using filtering for reduction of the blanking zone. The ringing signal follows an exponential decay pattern and it has been observed that the phase of the ringing signal is not consistent between successive transmissions. These factors are taken into consideration while creating an effective mechanism for removal of the ringing signal without affecting the echo.

A signature ringing pattern of the transducer is created prior to actual measurement which is then processed to create a library of ringing signature signals at different phases, each with a high phase resolution. A high accuracy phase matchingis performed with the ringing portion of the received signal using the signature signal and once phase matching is achieved the ringing portion of the received signal can be effectively removed by using the phase matched signature signal. The two main steps involved, viz, signature generation and reverberation signal cancellation is explained below.

A. Signature Generation

The functional block diagram for signature generation is given in Fig. 1.

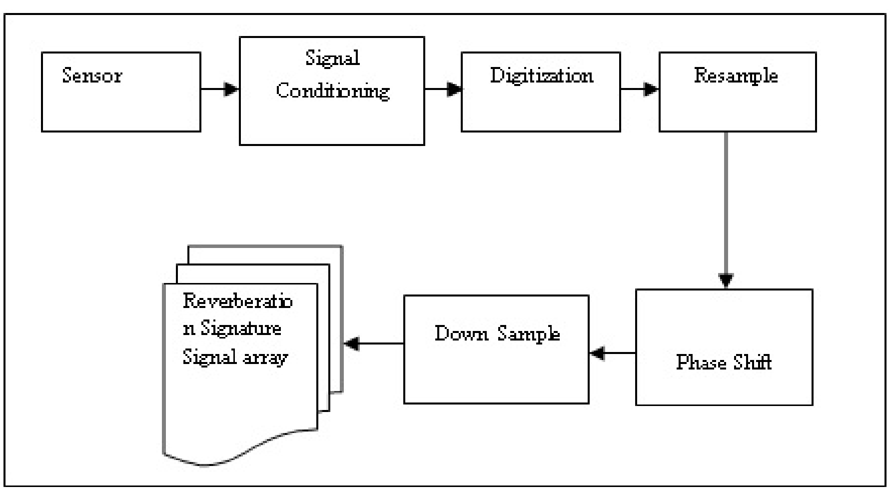

Fig. 1. Signature Generation

The initial step for ringing removal is generation of the reverberation signature. For generating the signature signal, the sensor is focused on to a reflecting surface in such a manner that the echo signal received is out of the region of interest. The signal thus obtained is conditioned and digitized. The digitized signal is re sampled in order to have high phase accuracy. Higher the re sampling higher will be the phase matching accuracy. The re sampled signal is then phase shifted, down sampled and stored as reverberation signature signal each with a phase shift corresponding to one sample of the digitized signal. The reverberation signature library is created by down sampling the signal array.

B. Reverberation Signal Cancellation

The functional block diagram for reverberation signal generation is given in Fig. 2.

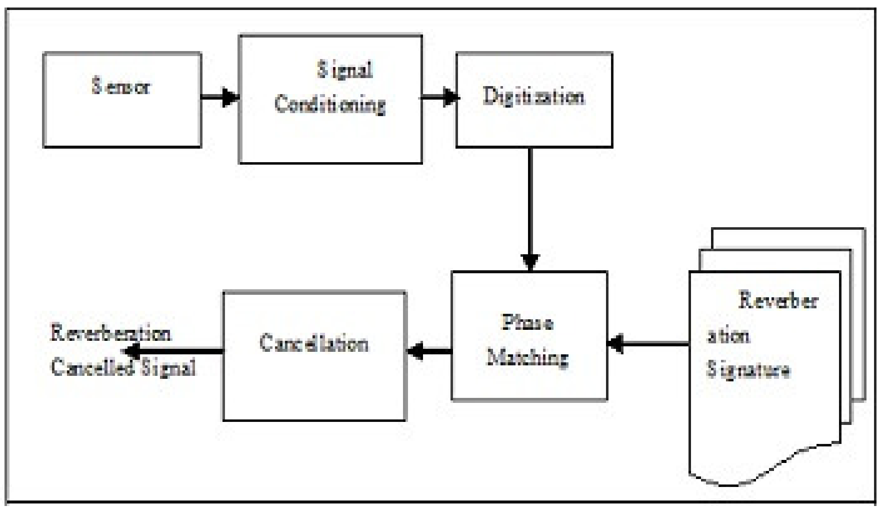

Fig. 2. Reverberation Signal Cancellation.

To cancel the reverberation in the echo, the best fit reverberation signature has to be chosen from the reverberation signature library. The best fit reverberation signature is obtained by phase matching the reverberation signatures with the echo signature. The best phase matched signal is used for removal of the reverberation from the echo.

The more the number of reference signatures in the library, the more the accuracy will be for the phase matching process, but with a trade off on process intensiveness of the computation. The processing speed can be increased by using parallel processing architecture and/or by the usage of intelligent algorithms which make predictions on the best phase match, based on the phase match results of previous acquisitions, since the phase match results are found to vary within a stipulated boundary values for successive transmissions.

3. TEST SETUP

The experimental test setup for reverberationcapturing is given in Fig. 4.

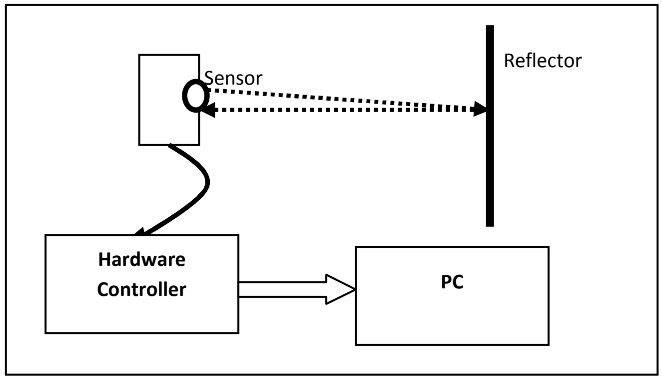

Fig 4. Test Setup for Reverberation Capturing

The hardware controller consists of a sensor which is focused on to a reflecting surface, Signal Conditionerand Digitizer block. The Sensor converts electrical energy to acoustic energy and vice versa. The same sensor is used for both transmission and reception. Transmission section of Signal Conditioner generates the transmission signal with the required transmission frequency, width, level and pulse repetition interval. It is designed around a Digital Data Synthesizer which generates the low level transmission signal. The low level signal is amplified using an output amplifier to the required level. Receiver section of Signal Conditioner amplifies and conditions the weak noisy signal received from the transducer to a level which can be digitized by the ADC. The Digitizer is a DSP based system. The main function of the hardware controller is to control the synthesizer and acquire the received signal at the required sampling rate. The acquired reverberation or the ringing signal of the transducer is captured and then send to the PC through the Ethernet cable and stored in the library for further use.

The Reverberation or the ringing signal of the transducer in the captured echo signal is removed by phase matching and subtracting signal with the signature stored in the library.

4. EXPERIMENTAL RESULTS

Fig. 5 shows the original received signal with reverberation and echo

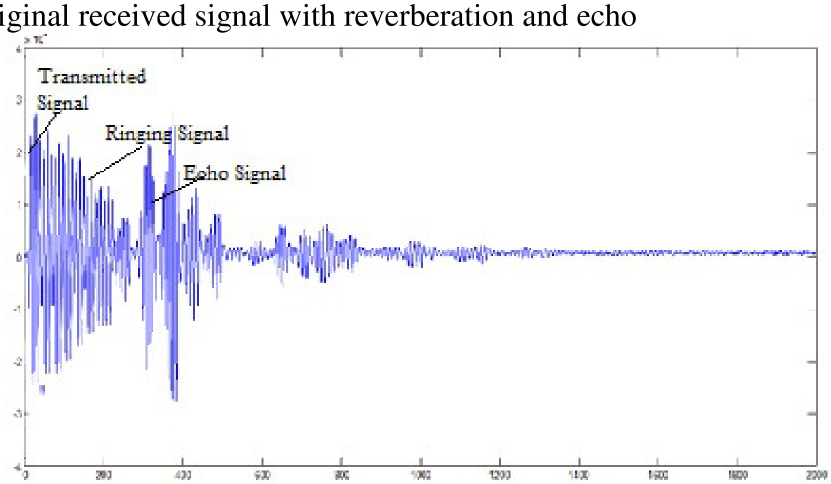

Fig. 5. Received signal having reverberation and echo signals

The processed signal after reverberation cancellation is given in Fig. 6.

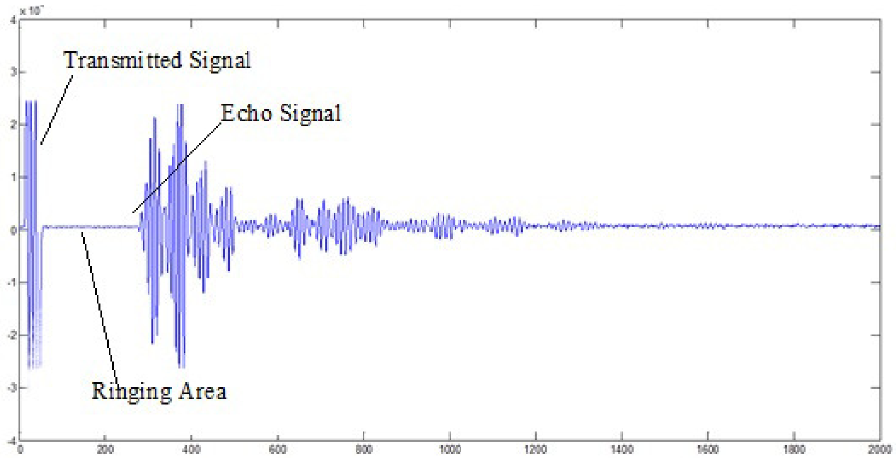

Fig. 6. Received signal after reverberation cancellation

The received signal after subtracting with reverberation signal without phase matching is shown in Fig.7.

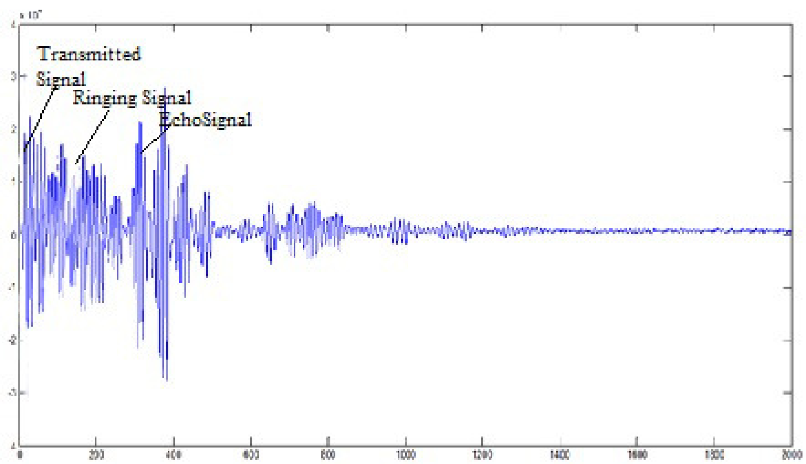

Fig. 7. Received after subtracting with a reverberation signature without phase matching

The Figure 6 clearly shows that the reverberation can be effectively removed only by the algorithm specified. Simple subtraction will result in unpredictable results as shown in Fig.7 since the reverberation signature used is not phase matched with the reverberation of the acquired signal.

A quantitative classification of the amount of reduction obtained in reverberation with respect to the re-sampling scale is tabulated in Table 1.

Table 1. Effect of Resampling on Reverberation cancellation

Re-sampling Factor	**Amplitude Reduction (dB)**
5	26
10	39
20	50

The results show that the reverberation cancellation is more effective when the re-sampling factor is increased.

5. CONCLUSION

The method employed has successfully detected the presence of echo in the blanking zone by effectively removing the reverberation without affecting the echo. The maximum reduction achieved is of the order of 50dB. The parameter which controls the reduction efficiency is the re-sampling factor. A tradeoff has to be made between efficiency of reverberation removal and the process intensiveness depending on the accuracy of the echo detection needed. This method, if employed effectively can result in building nondestructive test systems where the distance between transducer and target is not constrained by the presence of blanking zone.

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