Implementation Of Acoustics Based Time Reversal Mirrors For Source Localization

May Phyo Maung, Hla Myo Tun

Abstract: The paper presents the time reversal signal processing for source localization based on finite difference time domain (FDTD) method with the help of MATLAB GUI. There are two simulation approaches to analyze for source location in a perfectly matched layer boundary. We have shown the energy spectrum for propagation of acoustics wave in a room to focus by using array of transducers and source. In these plots we first transmit the signals from the array of transducers to the source and then the signals can be retransmitted back from the source to the array of transducers by using time reverse algorithm. The reverse signals can be focused the location of source based on the proposed method and the localization pointer. The simulation results are evaluated to localize the source by using FDTD method in this work. The application areas of this work are mentioned in this work.

Index Terms: Acoustic Wave, Time Reversal Mirrors, Time Reversal Signal Processing, Source Localization, FDTD, MATLAB GUI.

1 INTRODUCTION

IN this research work, we propose to address this cost limitation by utilizing a network of low cost surface mounted accelerometers. When mounted on solid surfaces, these sensors have the benefit of adapting an ordinary surface into a touch surface. Consequently, the aim of this signal processing module is to localize a finger tap based on signals received from these sensors. Existing algorithms such as that proposed in [1] necessitate training of the system prior to usage; the signals at each target location will be recognized through a matching process during usage. This presents an enormous disadvantage since a significant number of touch locations have to be trained for each location prior to usage. On a technical level, a large number of touch locations will frequently translate to a significant amount of memory and processing requirements. Source localization involves a number of sensors that are spatially separated. The localization accuracy is reliant not only on the quality of the measurements, the number of sensors and the inspection period, but also on how the sensors are being arranged. This is the geometric consequence that is often termed as geometric dilution of precision [2] in geo-location literature. It is therefore important to explore the sensor arrangement that can accomplish the best localization accuracy. The objective of source localization is to recognize the location of an emitting source based on the signal measurements from a number of sensors. In active localization, the source signal waveform and possibly its starting time are identified to the sensors, so that the time of arrival (TOA) of the signal to the sensors can be extracted for source localization. Possibly the more challenging scenario is passive localization, where the source signal and its time-stamp are not identified to the receivers. Moreover, the signal-to-noise ratio (SNR) in the sensor measurements could be very low and a long observation time is needed to attain the source location. Passive localization frequently utilizes time difference of arrival (TDOA) or angle of arrival (AOA) of the source signal to different sensors. Source localization has established numerous applications nowadays in radar, sonar, wireless communications, and sensor networks [3]–[5]. Time reversal is a technique in which a signal is pre-filtered such that it focuses both in time and space. Time Reversal Mirror (TRM) technique, in the virtue of its high resolution in the heterogeneous media, has been widely applied in the area of acoustics and electromagnetics. In this system, FDTD algorithm is employed to simulate the acoustic wave propagation in the UWB environment. A number of tests with numerical data to validate the 2-D acoustic TRM imaging in the context of UWB were investigated and discussed. There are two kinds of stimulation of physical objects: passive and active modes. In the passive mode any change in the acoustic properties of an object, due to its vibration as a consequence of interaction (knocking, tapping etc.), is detected and then used to estimate the location of the interaction. In the active mode, the absorption of acoustic energy at the contact point of an object surface must be ascertained. This investigation focused on signal processing algorithm development, acoustic wave propagation analysis and simulation.

2 BACKGROUND

Approaches for human-machine interface rely on the need for keyboard and the mouse. As new software applications continue to evolve, one of the main drawbacks of such input devices is that they impede ease of operating software or manipulating data which require complex user input operations. As a result, these devices limit the scope and functionality of the PC. This project aims to develop a new paradigm by transforming everyday objects such as tabletops and glass panels into a human-machine interface using a network of low-cost surface mounted sensors. Signal processing algorithms will be developed to localize and track movement of or tapping of fingers on different materials. These locations can be used to control software applications.

2.1 Research Objectives

- To develop the time-reversal focusing for human computer interface applications by using UWB acoustics waves
- To design the Graphical User Interface (GUI) based on time-reversal focusing with the help of MATLAB

2.2 Research Direction

- In this research work, single transmit multiple receive sensors in the acoustics domain with wideband signals will be focused. The acoustics simulation is performed using the FDTD algorithm with PML boundary conditions.
- Theoretical analysis of the time reversal based algorithms
- Simulations that tested the time reversal algorithms in a number of realistic scenarios;

2.3 Contributing Research Areas

While the main contribution of this research report is the development of time-reversal focusing for human computer interface applications by using UWB acoustics waves, a number of the other contributions can be described as follows:

- An investigation into the suitability of source localization for HCI development
- The development of methods to localized of senor arrays for HCI deployment

3 Implementation and Simulation Results

3.1 Software Development

We have implemented to develop the time-reversal focusing was designed for human computer interface applications by exploiting the ultra-wideband (UWB) acoustics waves based on the structure of Figure. 1.

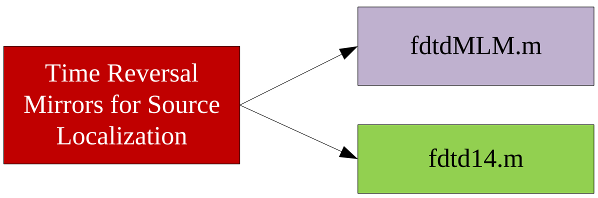

Fig.1. Linking Function of MATLAB GUI Implementation

3.2 Overall System Flowchart

We have to define some variables to set up for time reversal focusing simulation environments.

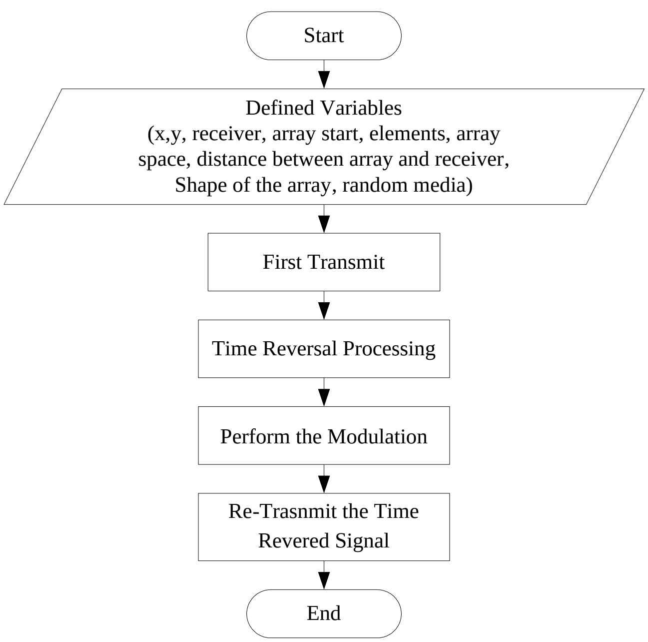

Fig.2. System Flowchart

The x, y, array start, elements, array space, distance between array and receiver, shape of the array and random media for proposed scenario. In a time reversal experiment, the medium covering the targets is illuminated by an array of transmitters. The signal propagates through the medium, interacts with the targets and the return echoes are recorded by an array of receivers called time reversal array or time reversal mirror (in the generalized case the transmitter and receiver arrays can be separated). These recorded signals are reversed in time and sent back to the probing medium where they will experience all the events that scattered signals faced and finally focus on the position of the targets. The overall flowchart is shown in Fig.2.

3.3 Localized Based on Transducer Array

According to the first simulation approach for source localization, the number of transducers in array as fixed (10 transducers) and the only one transmitter are specified by specific purpose.

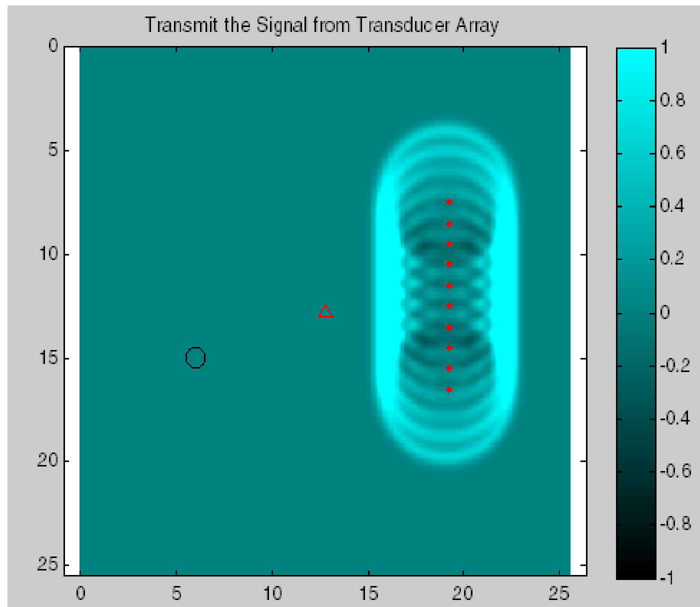

Fig.3. Screenshot Result of Transmit the Signal from Transducer Array (Before Localization)

Firstly, the transducer array emitted the acoustic wave to localize the source where the other side of the transducer array. The localization pointer moved to the source from the transducer array based on the localization algorithm which was mentioned in the previous chapter. Fig.3 shows the screenshot result of transmit the signal from transducer array (before localization). After that the localization pointer reached near the source and the absorbed acoustic waves by time reversal algorithm to the transducer array are uniformly retransmitted from the source. Fig.4 illustrates the screenshot result of re-transmit the signal from transmitter (before localization). At that time, the localization pointer was moved to the transducer array from the detected source because of the re-transmitted acoustic wave distribution. This stage is no operation stage. Fig.5 mentions the screenshot result of no operation between the re-transmitted stages (before localization). Secondly, the next acoustic waves were emitted from the transducer array for localization of source because the localization pointer cannot detect the exact location of source. Fig.6 demonstrates the screenshot result of transmit the signal from transducer array (localization stage).

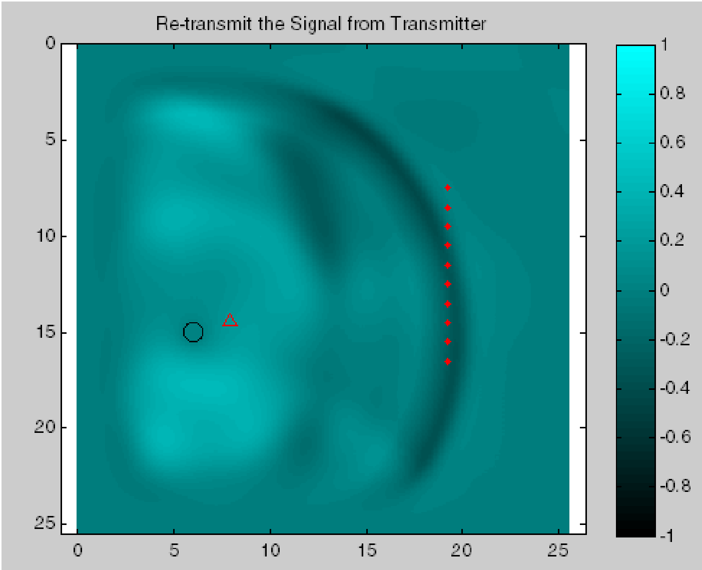

Fig.4. Screenshot Result of Re-transmit the Signal from Transmitter (Before Localization)

After reaching the localization pointer near the source and the absorbed acoustic waves by time reversal algorithm to the transducer array are uniformly retransmitted from the source. Fig.7 mentions the screenshot result of re-transmit the signal from transmitter (localization stage). Just then, the localization pointer was moved to the transducer array from the detected source because of the re-transmitted acoustic wave distribution. This stage is no operation stage. Fig.8 develops the screenshot result of no operation between the re-transmitted stage (localization stage).

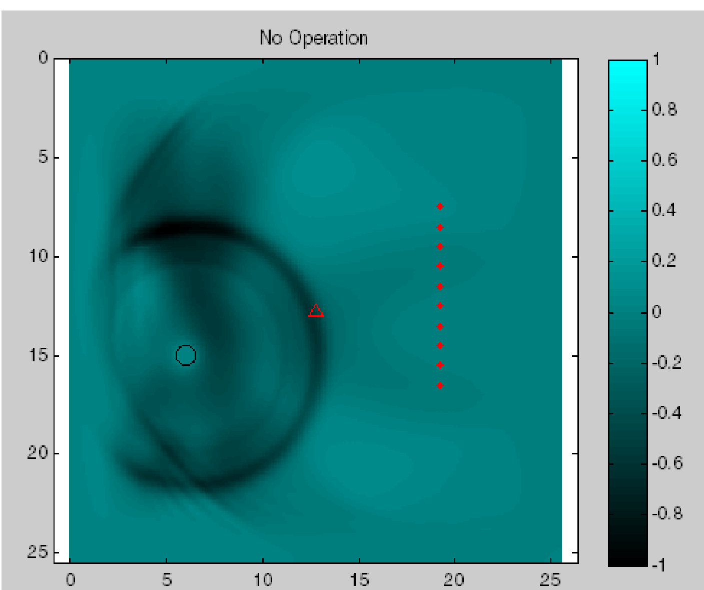

Fig.5. Screenshot Result of No Operation between the Re-transmitted Stage (Before Localization)

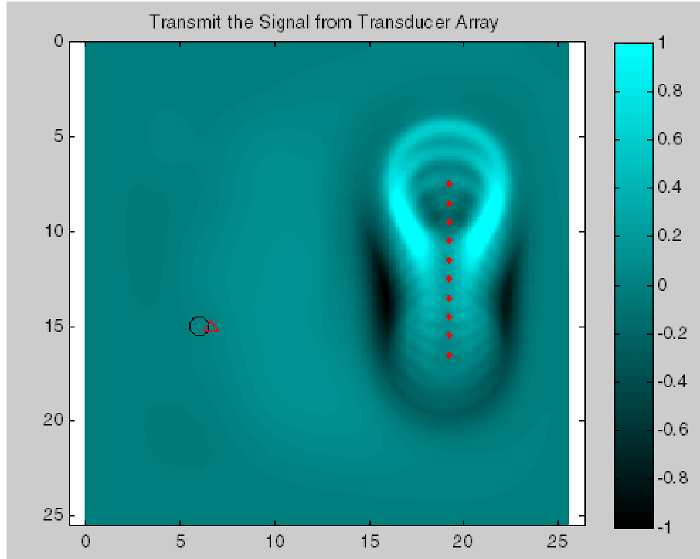

Fig.6. Screenshot Result of Transmit the Signal from Transducer Array (Localization Stage)

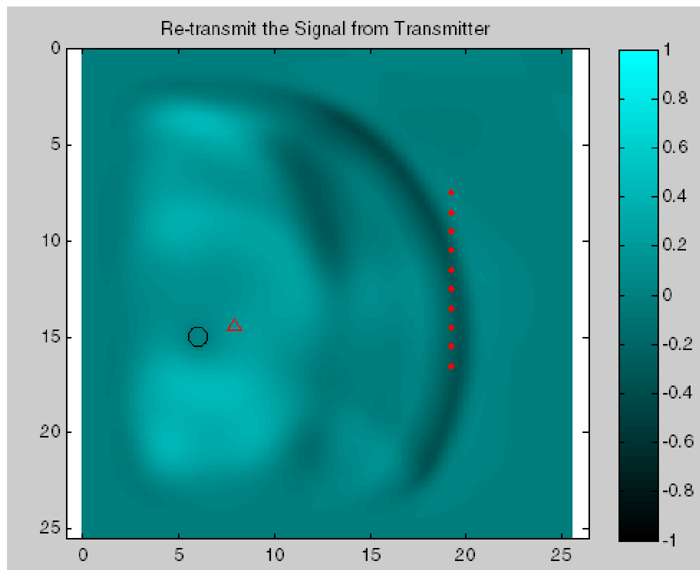

Fig.7. Screenshot Result of Re-transmit the Signal from Transmitter (Localization Stage)

3.3 Room Impulse Responses Model Development

Real room acoustic impulse responses (AIRs) modelled by infinite impulse response (IIR) filters require high model orders. Many problems involving the estimation of AIRs reduce to high dimensional optimisation problems. The transfer function due to the acoustics of a room generally does not change considerably with time, but do vary with the spatial locations of the sound source and observer. Assuming both are spatially stationary, a linear time-invariant (LTI) model is appropriate. The all-pole model can parsimoniously approximate rational transfer functions, and typical all-pole model orders required for approximating room transfer functions (RTFs) are in the range $50 \leq P \leq 500$ - around a factor of 40 lower than all-zero model orders. A room acoustic impulse response (AIR), rir(t), may be modelled by a LTI all-pole filter of order P, as given by:

$$rir(t) = -\sum_{p \in P} a(p) rir(t-p) + \delta(t), \; t \in Z \quad (1)$$

where $a=\{a(p), p \in P \triangleq \{1,\ldots,P\}\}$ are the model parameters, P is the number of poles, and δ (t) is the Kronecker delta. In many applications, such as single channel blind dereverberation, an estimate of the AIR is required and, in general, this reduces to a high-dimensional optimisation problem. This is difficult to solve because attempts to model the entire acoustic spectrum by a single W filter leads to a large computational load, as well as numerical problems resulting from the size of the parameter space [11].

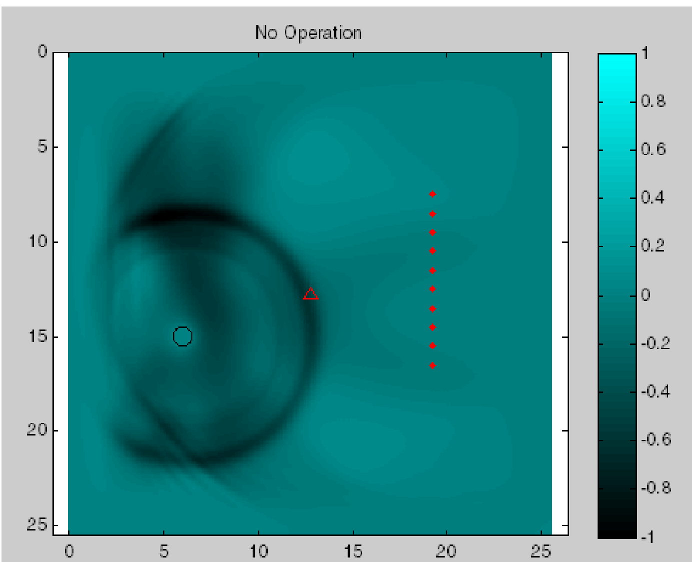

Fig.8. Screenshot Result of No Operation between the Re-transmitted Stage (Localization Stage)

RIR is a program that calculates our room impulse response h(t). This program differs from the model in two ways. First it uses discrete time instead of continues time.

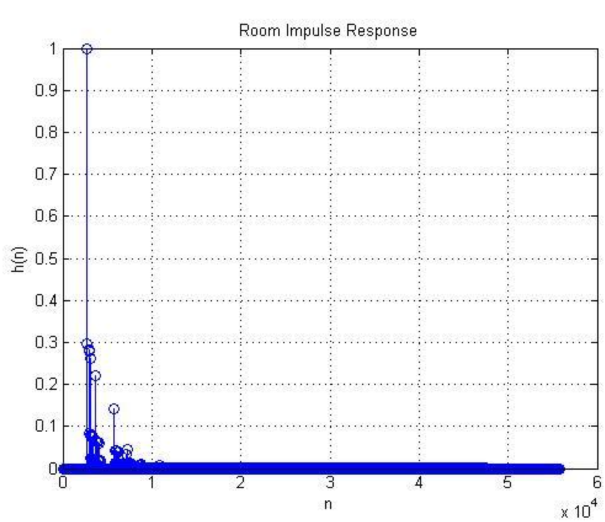

Fig.8. Room Impulse Response for Proposed Model

Second, it finds $a_{i,j,k}$ and $e_{i,j,k}$ only when $a_{i,j,k}=1$. This is done to conserve memory. Fig.8 shows the room impulse response for proposed model. The room impulse response shows the satisfactory of the successful condition for proposed room in simulation study.

4 Conclusion

Time reversal focusing to exploit spatial/multipath diversity existing in rich scattering environments to improve the capability of target localization algorithms was introduced. Time reversal focusing was provided a built-in feature to adapt the transmitted waveform to the multipath environment and enhances the performance of the localization algorithms. The effectiveness of acoustics wave time-reversal focusing was observed in the presence of a perfectly matched layer. The surface layer changes the propagation velocity and direction of the acoustics waves and can manoeuvre them away from the location of a source. The surface layer further complicated the wave field since waves could propagate under as well as through the surface layer. Regardless of these effects, time-reversal focusing was effective and performed significantly superior than time-delay focusing. We can extend to track the moving targets for time reversal focusing techniques by using UWB acoustics waves. Time-reversal techniques may also be extended to types of waves other than sound waves. Some researchers in the radar community are exploring their possible application to pulsed radar, using electromagnetic waves in the microwave range. Another type of wave occurs in quantum mechanics: the quantum wave functions that describe all matter.

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