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Remote Whispering Applying Time Reversal

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## Abstract

The purpose of this project was to explore the use of time reversal technologies as a means for communication to a targeted individual or location. The idea is to have the privacy of whispering in one's ear, but to do this remotely from loudspeakers not located near the target. Applications of this work include communicating with hostages and survivors in rescue operations, communicating imaging and operational conditions in deep drilling operations, monitoring storage of spent nuclear fuel in storage casks without wires, or clandestine activities requiring signaling between specific points. This technology provides a solution in any application where wires and radio communications are not possible or not desired. It also may be configured to self calibrate on a regular basis to adjust for changing conditions. These communications allow two people to converse with one another in real time, converse in an inaudible frequency range or medium (i.e. using ultrasonic frequencies and/or sending vibrations through a structure), or send information for a system to interpret (even allowing remote control of a system using sound).

The time reversal process allows one to focus energy to a specific location in space and to send a clean transmission of a selected signal only to that location. In order for the time reversal process to work, a calibration signal must be obtained. This signal may be obtained experimentally using an impulsive sound, a known chirp signal, or other known signals. It may also be determined from a numerical model of a known environment in which the focusing is desired or from passive listening over time to ambient noise.

## Background and Research Objectives

Time Reversal (TR) is a technique that provides spatially localized energy focusing and has been shown to provide secure, optimized underwater acoustic communication between two locations [1-3]. There have been a few studies that have explored the use of airborne TR communications in highly reverberant environments (i.e. racquet ball courts, parking garages) for Morse-code communications [4-5] and for imaging purposes [6-7], but these studies have not utilized typical room environments. This research aimed to develop covert extraction techniques of the calibration signal required for successful TR communications and to determine the range of applicability and limitations of using to TR communicate private, audible speech in various environments.

It was found that private communications are possible in a typical conference room. Speech-like sounds could be heard at all locations in the room but observers of a live demonstration of the focusing could not understand the speech unless they were at the target location. It was also found that several types of signal processing methods could be used to further mask the intelligibility of the speech without destroying the ability to communicate to the desired focal location. Proof of concept of communicating to a target inside a room with the equipment outside the room was also accomplished.

One major focus of this work was to develop covert means of extracting the calibration signal necessary for successful communications in clandestine operations. One of the methods proposed and studied was to record ambient noise present in the room of interest and record that noise at the location of both where the transmitting sources would be placed and at the intended, target location.

## Scientific Approach and Accomplishments

A set of proof of principle demonstrations of private speech communications was conducted using four loudspeakers, a microphone, and a laser vibrometer setup in a conference room (see Figure 1). To start with, successful private communications were demonstrated by placing the loudspeakers inside the room along with using a microphone for the calibration. A demonstration of simultaneously focusing two speech signals to two different locations was also done (see the first video demo at Ref. [8]). Further, we showed that a masking white noise could be added to the TR broadcast to mask the speech at most locations in the room but allow the target location to still understand the speech (see the second video demo at Ref. [8]). Private communications were also be made with the loudspeakers placed outside the room (along a wall with several windows) and by using a microphone for calibration (see the third video demo of focused pulses at Ref. [8], listen for the pronounced pop at the microphone location). Then communications were demonstrated using loudspeakers and a laser vibrometer in the same room (see the fourth video demo at Ref. [8]). In this case the laser was used to remotely obtain the calibration signal to focus sound that one could hear at or near the location where the laser was shining.

To explore the idea of using ambient noise to extract the calibration signal, measurements were conducted in the facilities at Brigham Young University (BYU) by the project's Principle Investigator (PI). Two microphones were setup in a large reverberation chamber to record 40 seconds of white noise that was broadcast from a loudspeaker (see Figure 2). The time-synchronized recordings of the noise were cross correlated. The cross correlation response has two halves which, according to ambient noise signal extraction theory, should be identical if the technique is performing well. These two halves were summed to provide the calibration signal. To determine the quality of the extracted calibration signal from ambient noise, a loudspeaker was placed at one of the microphone locations and the calibration signal between the two microphone positions could be obtained as a direct reference calibration signal. Figure 3 shows the comparison of these two results. One issue with obtaining the direct reference calibration signal is that the loudspeaker and microphone could not be collocated. Thus one might expect a delay in the reference calibration signal, which is indeed seen when comparing peaks in Figure 3 (arrows added to identify delays). The respective delays of each arrival of sound (peaks in the signal) will depend on the path orientation relative to the path distance between the loudspeaker and microphone that should be collocated. Qualitatively the extracted calibration signal from ambient noise looks like it matches the direct reference measurement well, though the true quality of the ambient noise extraction cannot be determined due to the imperfect nature of the direct reference measurement (source and receiver could not be collocated).

The inability to collocate the source and receiver does not only pose a problem with determining the quality of the proposed ambient noise signal extraction, but also for the practical implementation of the extracted signal in application. Further work needs to determine how the source and receiver may be collocated or whether a reversible source/receiver transducer may be used. Once this issue is resolved, one can explore the quality of the ambient noise signal extraction versus the length of recording time, the number of noise sources used, and/or the environmental conditions of the room (i.e. room size, and acoustical properties). While the ambient noise calibration signal extraction technique showed promise, it was not conclusive and further work needs to be done.

In FY13, the PI received LDRD Reserve Funding to study time reversal vibrational communications. The work completed provided proof of concept but it was not carried through to the point where a journal aricle could be published. The experiment utilized an 8.10 m long pipe system with 12 junctions and a 3 m portion encased in concrete. A single shaker source was mounted to one end of the pipe system with a triaxial accelerometer on the other end. The PI took the opportunity to conduct better measurements than were previously done and as a result presented on them at an Acoustical Society of America conference and submitted a journal article on this work for peer review in the Journal of the Acoustical Society. Figure 4 shows how individual communication signals may be independently transmitted to any of the 3 channels of the accelerometer, allowing at least three channels of independent, simultaneous communications between a single source and a single receiver.

## Impact on National Missions

Secure acoustic communications are important to global security (GS) needs and this work has been generated discussions with GS program managers, as Dept. of Defense customers are looking for technologies to allow them to communicate with acoustic or vibration signals in situations where wires and radio communications are not feasible or not desired.

This work provides a significant research advance for energy resource extraction technologies. Our experiments on vibrational transmissions using time reversal have shown communication rates of at least 20 kbit/s and perhaps even 1 Mbit/s. Additionally, this research provides a means to communicate monitoring information through sealed nuclear reactor vessels and storage casks for safe operations and reliable storage of spent fuel.

**References**

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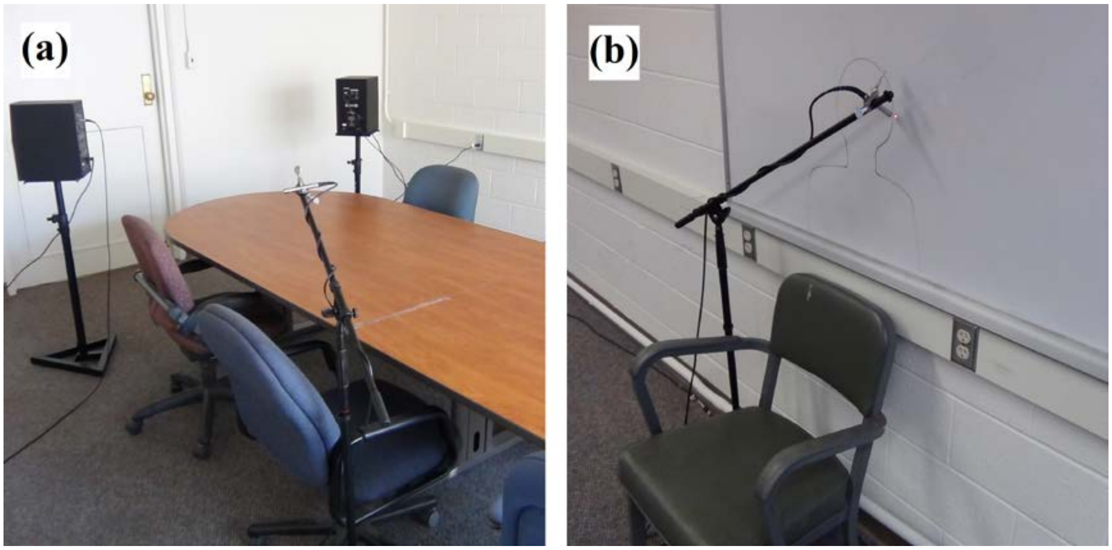

Figure 1. Photographs of the conference room setup used for demonstrations of audible private communications. (a) Photo of two of the loudspeakers used and the microphone placed at a seat location. (b) Photo of a small laser spot shining on a white board above a chair with an outline of a hostage drawn on the board (note that the microphone was placed at the same location in order to record what one would hear at that location.

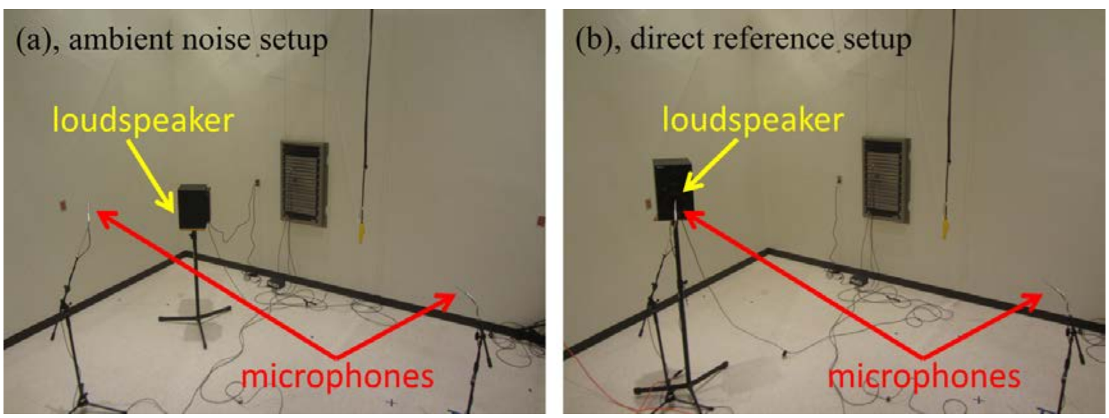

Figure 2. Photographs of the reverberation chamber used for ambient noise extraction of the calibration signal. (a) Setup used to extract the calibration signal from ambient noise. (b) Setup used to extract the calibrations signal directly between the microphones.

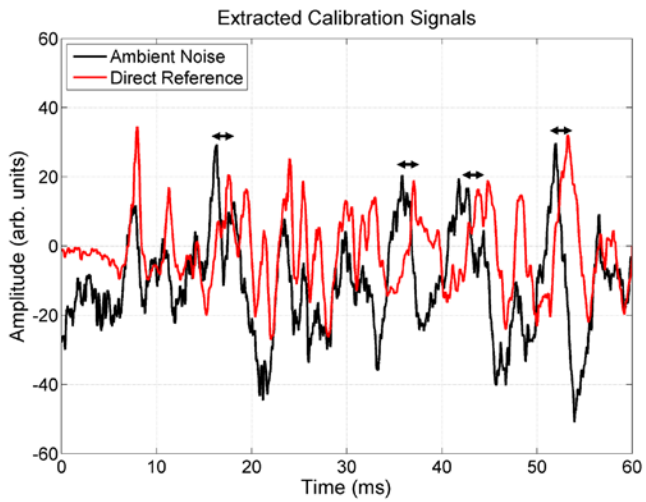


Figure 3. Sample calibration signals extracted from ambient noise and using a direct measurement setup. The ambient noise signal was extracted using the setup pictured in Figure 2(a), while the direct reference signal was extracted using the setup pictured in Figure 2(b).

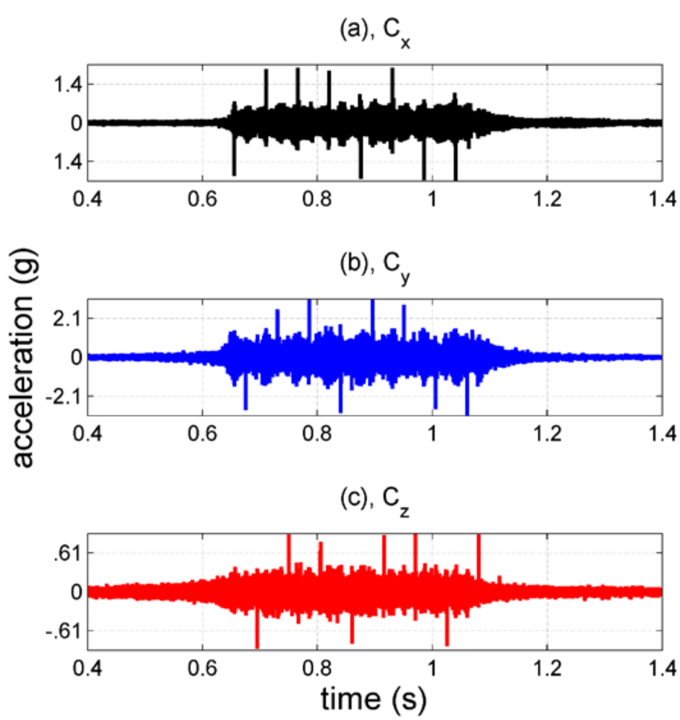


Figure 4. Sample signal transmissions from one source to one 3-axis receiver. Each subplot represents the signal transmitted to each axis of the 3-axis receiver. The transmitted signals are the ASCII representations of the letters “t”, “l”, and “m”.