Timing synchronization of independent transmitting and receiving acoustic devices.

Tom Fedenczuk, Eva-Marie Nosal
Rhonda Suka, and Willie O. Diguc
CIMES/ORE, University of Hawaii
Honolulu, Hawaii, USA
tmf@hawaii.edu

Joseph R. Olson
Cetacean Research Technology
Seattle, Washington, USA

***Abstract*—When designing underwater surveillance acoustic arrays with multiple receiving hydrophones and transmitting transducers, researchers may have the luxury to develop custom data acquisitions systems with the appropriate number of receiving and transmitting channels located in one unit. This unit then digitizes and records the hydrophone signals using a single clock and processing circuitry. This ensures correct timing and a homogeneous signal path that reduces unknown variables affecting the signals. Fedenczuk is currently developing such a system as part of the CIMES (Center for Island, Maritime, and Extreme Environment Security) passive acoustics harbor and shallow water surveillance system. In the mean time we face a problem that researchers often encounter: working with multiple transmitting and receiving sources that operate independent of each other and on different timing clocks. In response to this problem we have designed a configuration technique that employs short-duration analog synchronization signals that match the timing of various transmission and acquisition systems with negligible signal loss and complete signal exclusion to and from the transducers and hydrophones. We successfully tested and employed this technique and present its results and schematics.**

Keywords- underwater acoustics; timing; synchronization; harbor surveillance

I. INTRODUCTION

The CIMES (Center for Island, Maritime, and Extreme Environment Security) Passive Acoustics Project is aimed at advancing capabilities in underwater maritime surveillance. A network of widely spaced hydrophones has been designed and built and is being prepared for deployment near Honolulu Harbor, Hawaii. The network is designed to record autonomously or be connected to an underwater observatory with real time monitoring capabilities of surface and underwater targets [1].

Ideally, data acquisition systems for use in underwater acoustic surveillance should be customized so that all transmitting and receiving channels are processed using a single clock and processing circuitry. For applications such as target tracking that require precise measurement of arrival times, all channels should be sampled simultaneously using individual A/D converters rather than one over-sampled A/D converter that iteratively processes a group of channels. This ensures correct timing and a homogeneous signal path that reduces unknown variables affecting the signals.

With limited time or resources, researchers may find themselves using more than one acquisition or transmission system that do not natively communicate or synchronize with each other. The CIMES passive acoustics project encountered this problem during our initial experiments using existing equipment while the custom array was being built; two provisional acquisition systems and one transmitter needed some method of common timing or synchronization. Our method uses a synchronization signal that is transmitted simultaneously to each acquisition system via cables, switches and connectors.

II. SYNCHRONIZATION METHOD

Our method relies on injecting a high frequency signal into each autonomous acquisition system simultaneously (Fig. 1). In an active acoustic system, if a transmitter is also used to generate a signal that is relayed to a transducer, it is best to use a dual channel transmitter and transmit the synchronization signal on one channel and the transducer signal on the other. In a passive system, a single channel transmitting device may be used. There should be enough of a pause between the end of the synchronization signal and the beginning of the transducer signal so that there is no overlap between the two. Researchers should ensure that the synchronization signal or any cross channel noise does not exceed the maximum input voltage of the acquisition system.

At the transmitter output, the synchronization signal is separated using physical splitters into the same number of channels as there are acquisition systems. Each system requires only one synchronization signal regardless of how many receiving channels it supports. The synchronization signal is transmitted via cable to each acquisition system. At the input of the acquisition system, there are two options when accepting a synchronization signal. The first is to add a splitter to one of the input channels; this allows both the synchronization cable and a separate hydrophone cable to be connected to the same channel. The second option is to dedicate one of the system's input channels to exclusively receive the synchronization signal. The first option does not sacrifice one of the acquisition channels. However it can introduce signal loss or contamination due to the splitter. It also creates a closed circuit

that connects all of the acquisition systems to each other and mixes the split hydrophone signals together. This circuit needs to be opened before signals from the hydrophones can be properly received and processed. Opening the circuit can be done with a switch or by manually removing the synchronization cable from each acquisition system. In an active system, the timing between the synchronization signal and the transducer signal should be increased to allow sufficient time to break the circuit. The second option removes the closed circuit issues but sacrifices one hydrophone channel per acquisition system. In order to minimize signal disturbance, the transmitter and data acquisition systems should be close to each other and cable lengths should be kept to a minimum.

For convenience, each acquisition system recording is started at approximately the same time. The synchronization signal is transmitted at the start of the recording before any important signals from the hydrophones are received. If researchers have concerns about clock drift, another synchronization signal at the end of the recording can be transmitted. For long duration recordings additional synchronization signals can be inserted.

The received signal on each synchronization channel is cross-correlated with the transmitted synchronization signal. The time difference between the cross-correlation peaks for each synchronization channel gives the timing offset between the systems. Precision in timing offset is determined by the sampling rate of the system and the sharpness of the autocorrelation peak of the synchronization signal. Synchronization signals with sharp synchronization (autocorrelation) peaks useful for this application include m-sequences and sine sweep signals (chirps). Signal choice depends on specifics of the system (e.g. sampling rate, linearity of response, system noise). Hydrophone/transducer receiving/transmitting frequency responses need not be considered because the synchronization signal bypasses both and is linked directly from the signal generator to the acquisition system.

III. Application and Results

We used two identical data acquisition systems (Fig. 2). Each system digitized two channels simultaneously at 24 bit, 192 kHz sampling per channel to a 5 GB solid state memory card. A two channel transmitter was used to transmit the synchronization signal in the right channel and a transducer test signal in the left channel after a 3 second pause. The data acquisition system had standard XLR inputs and the transmitter had RCA outputs. Adapters were used to convert and split both connector types to BNC connectors that were native to both the synchronization, hydrophone, and transducer cables. We split the left channel to accept both the synchronization and hydrophone signals. After each synchronization signal had been received, we manually opened the synchronization circuit to prevent hydrophone signal mixing. We used four preamplified hydrophones with a linear frequency response range of 0.02 – 40kHz (±3dB) and 0.02 – 70kHz (±5dB). Because the distance between the transducer and hydrophones was small (<30 m), we did not need to amplify the transducer signal, eliminating the chance of accidentally overloading the synchronization line.

At the data acquisition system, cross-talk between channels was undetectable at a signal peak amplitude of -2dB or less. A signal amplitude of -1dB leaked into the other channel with a signal separation of 27dB between the two channels. The arrival times of both the original and the leaked signal were identical. The leaked signal did not exhibit any additional late arrivals indicating that no additional leaked signals had arrived from the transducer itself or were picked up by the hydrophones. On both of the recorders, the channel that was used to receive both the synchronization and the hydrophone signals exhibited a signal loss from the hydrophones of approximately 3dB. We attribute this loss to the synchronization splitters. In order to rule out differences in channel or hydrophone sensitivity, we swapped synchronization channels as well as hydrophones. The results were consistent across all four channels and hydrophones. The splitters did not introduce any delay in signal arrival from the hydrophones themselves.

We used a 30kHz bandwidth linear chirp with 30kHz center frequency as our synchronization signal. The large bandwidth and a high signal-to-noise ratio on the synchronization channels result in a very sharp synchronization peak; the Cramer Rao lower bound for the delay estimator [2] corresponds to a standard deviation of less than 1μs. Actual timing precision was limited by the 192 kHz sampling rate of the system, which gives a theoretical timing precision about 5μs. To shift this limit back down to the 1μs limit imposed by the CRB, the synchronization signals are upsampled before cross-correlation with the original signal.

To test the timing precision empirically, measurements of timing offset were repeated 5000 times. Figure 3 shows a histogram of the resulting measurements shifted to zero mean. The measured delays are nearly normally distributed with a standard deviation of 1.4μs. This agrees well with our theoretical limit of 1μs.

IV. Discussion

The synchronization method worked well for our intended purposes. It allowed us to use our existing high-quality acquisition systems without being constrained by their limited number of channels. The two systems are also very portable and flexible, hence will continue to be used with the synchronization method even after our custom acquisition system is complete. The minimal crosstalk at high signal amplitudes is not a concern as the neighboring channels are not being used for data collection during the synchronization procedure. The loss in signal amplitude attributed to the splitters might be resolved if a switch is used instead of the splitter. We recommend that researchers implement a procedural verification method that ensures that the circuit is opened after each synchronization signal is received. Failure to do so is often unnoticed in the field and does not become apparent until detailed analysis of arrival times is performed during postprocessing. Even then, the channel mixing from the closed circuit is often hard to identify.

This synchronization method should also work with data acquisition systems that are dissimilar from one another, although connector adapters might need to be altered.

However, different sampling rates and acquisition system circuitry might affect arrival times.

ACKNOWLEDGMENT

This material is based upon work supported by the U.S. Department of Homeland Security under Grant Award Number 2008-ST-061-ML0002. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

REFERENCES

[1] E.M. Nosal, CIMES (Center for Island, Maritime, and Extreme Environment Security) Passive Acoustics Project http://www.cimes.hawaii.edu/acoustics2

[2] W. Burdic (1991). Underwater acoustic system analysis, 2nd ed. Prentice-Hall, Inc

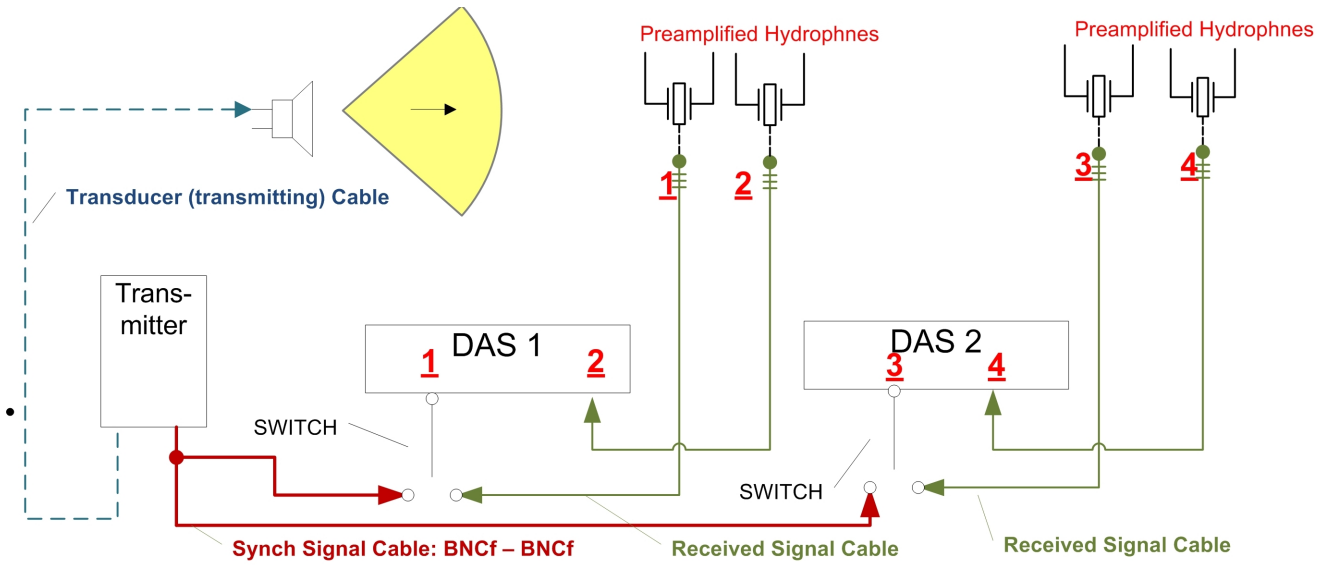


Figure 1. Schematic of signal synchronization method.

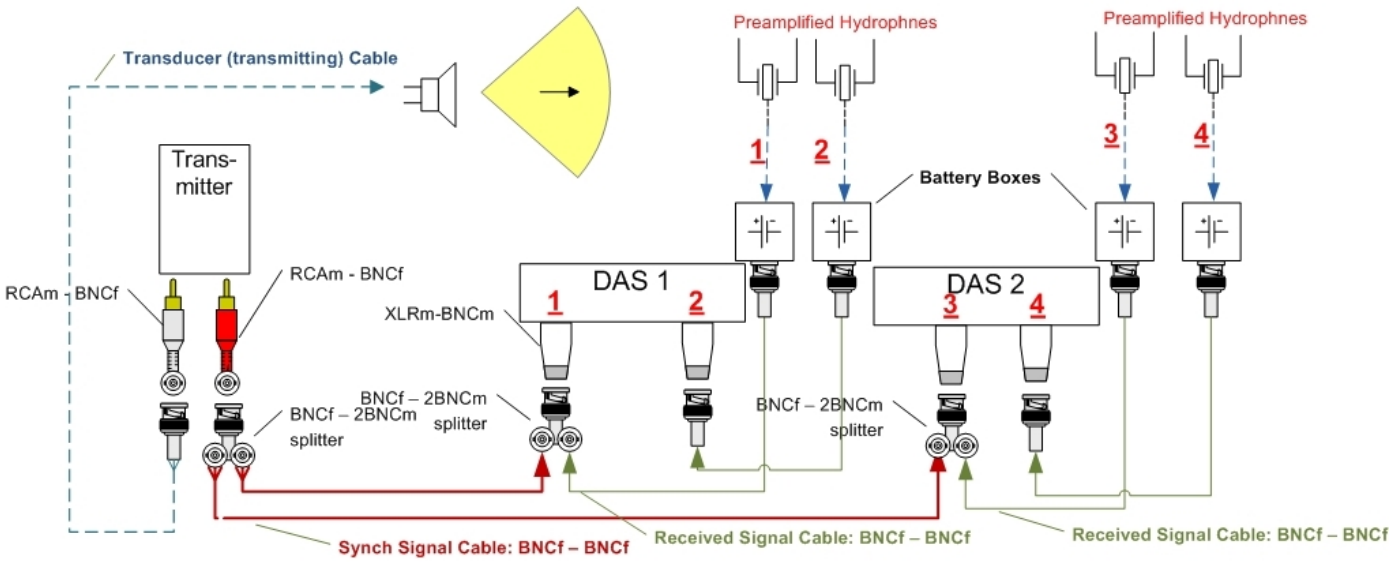


Figure 2. Schematic of synchronization hardware used during testing.

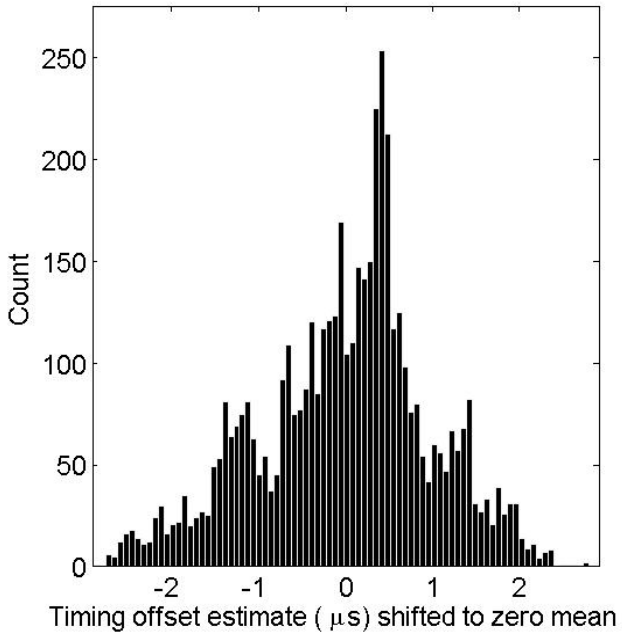


Figure 3. Histogram of measured timing offsets. Standard deviation is 1.4μs and corresponding to the precision limit of our synchronization system.