University of Texas Applied Research Laboratory Nov. 2009 Five-Element Acoustic Underwater Dataset

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Introduction

This document introduces the Nov. 2009 Five Element Acoustic Underwater Dataset, consisting of 360 packet transmission samples, each about 0.5 sec. in length. The dataset was collected to support efforts in researching Doppler correction techniques for short-range (<1.25 km range), wideband (62.5 kHz center frequency, 31.25 kHz bandwidth) acoustic transmissions in a shallow underwater channel.

Data was collected on Nov. 6, 2009 at the ARL Lake Travis Test Station. The lake has an estimated maximum depth of 37 m [2]. As seen in Fig. 1, the lake has a nearby dam and hilly former river bed terrain that contribute to high reverberation. Fig. 2 shows the temperature and sound speed profiles—a relatively constant set of temperatures and speeds compared to the thermoclines from the July, 2009 experiment noted in [3].

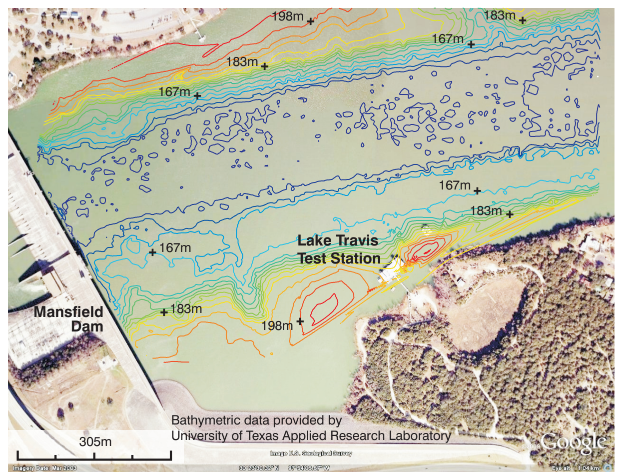


Fig. 1: Aerial view of the Lake Travis test environment with lake bed elevations given above sea level. The water level is 198 m. The five receivers are located at the Lake Travis Test Station. Figure reprinted from [3].

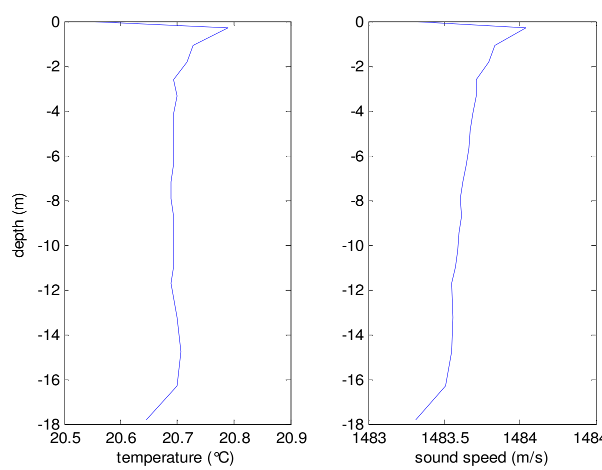


Fig. 2: Temperature and sound speed profile for Nov. 6, 2009.

Methodology

The omnidirectional transceiver was hung to various depths between 1 m and 8 m from a small boat. Transmissions were made at one of 9 positions listed in Table 1 (and shown in Fig. 2), where the boat was either docked to the test station barge (Pos. 1), slowly drifting in the lake (Pos. 2-7), or in motion (Pos. 8-

9). In particular, Pos. 8 involved a vertical, oscillating motion of about 0.5 Hz (from depths of about 5.7 m to 7.2 m) to simulate boat motion from heavy waves, and Pos. 9 involved the towing of the transducer at speeds of ~5 km/h at varying depths no greater than 5 m.

Table 1: Boat and transducer positions.

Pos.	Range	Motion	TX Gain
1	15 m	Docked to barge	-13 dB
2	103 – 187 m	Free floating	-10 dB
3	297 – 390 m	Free floating	-7 dB
4	426 – 496 m	Free floating	-7 dB
5	719 – 765 m	Free floating	-1 dB
6	839 – 873 m	Free floating	-3 dB
7	1221 – 1269 m	Free floating	-3 dB
8	160 – 239 m	Simulated vertical "wave" motion	-7 dB
9	267 – 73 m	Towing at ~3 kts	-10 dB

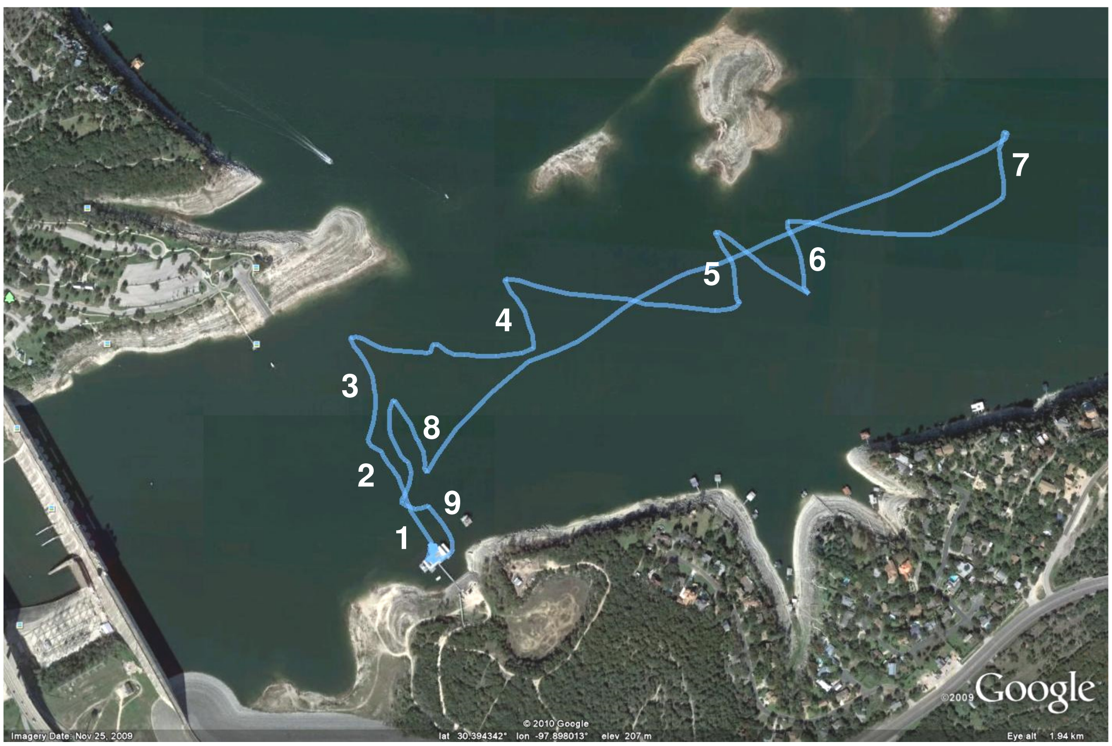


Fig. 2: GPS map of transmitter path during experiment. Position numbers from Table 1 are marked.

The transducer on the boat was connected to an amplified DAC operating at a 500 kHz sample rate. This DAC was the IOTech Personal Daq/3000 [1]. At unity gain, the transducer placed about 1 W of acoustic power into the water, although the gain was manually configured at each position in order to ensure adequate signal level at the receiver (e.g. reasonable signal to electronic noise ratio and no clipping). The transmitting transducer sensitivity is shown in Fig. 3.

The receiver, mounted at the test station, consisted of a planar array of 5 directional hydrophones. Their arrangement is shown in Fig. 4, with horizontal and vertical half-power beamwidths of approx. 45º and 10º, respectively. The theoretical beam pattern of each receiver is shown in Fig. 5. The array was submerged to a depth of 4.6 m and rotated (when needed) to generally face the transmitter. The received signals were preamplified and sampled at 200 kHz by another 1 MHz multiplexed DAC [1]. Although the DAC sampled each channel sequentially in each 5 μs window, the sequences were upsampled and shifted to allow the samples to be treated as simultaneously coincident across all five channels.

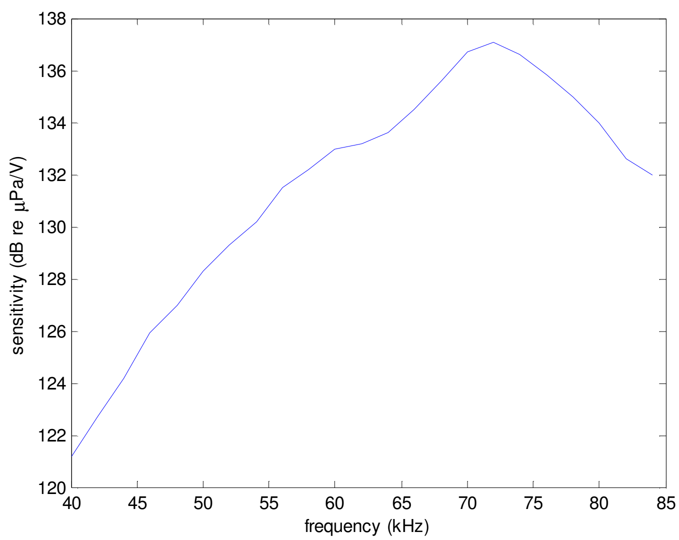


Fig. 3: Transmitting transducer sensitivity at 1 m.

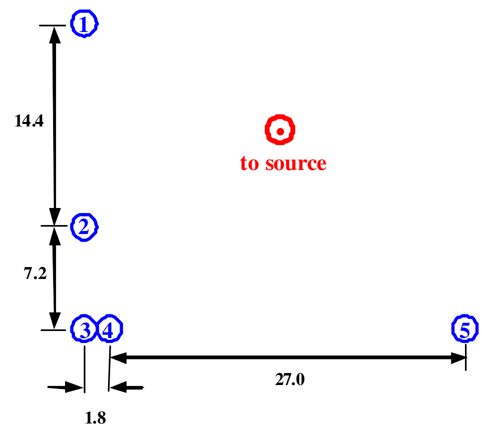


Fig. 4: 5-element receive array dimensions (in inches)

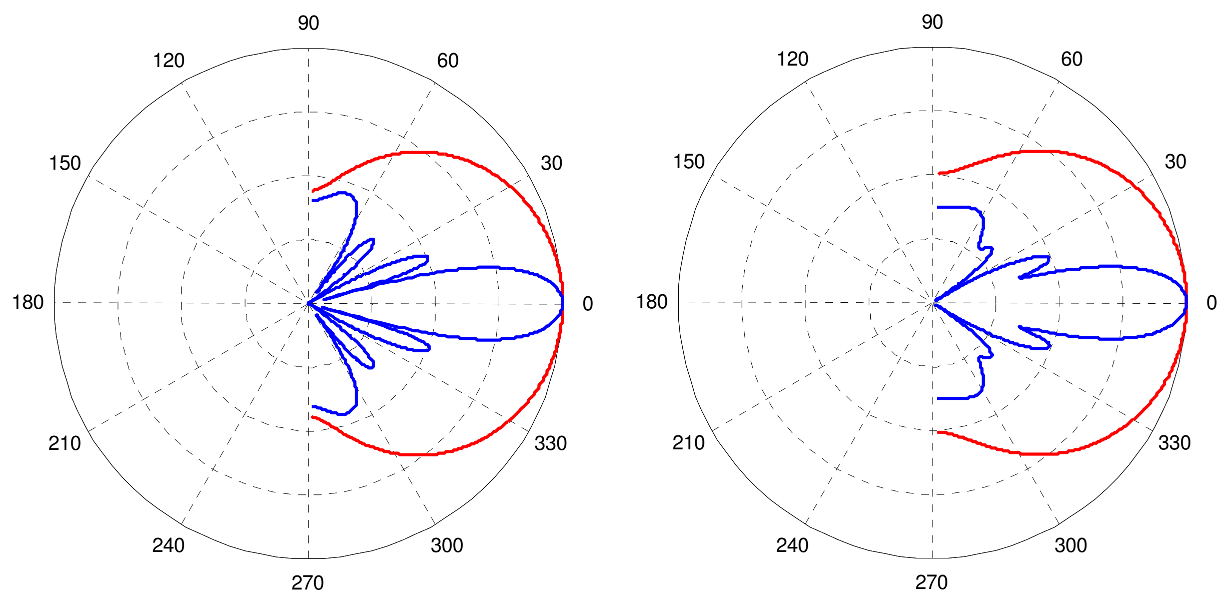


Fig. 5: Theoretical broadband receive element beampattern over low data rate band (left) and high data rate band (right). Vertical plane shown in blue, horizontal in red. Graphs depict 10dB/div.

We note that the recorded data samples contain sporadic noise spikes. It is suspected that these artifacts were introduced by the preamplifier equipment that was used with the receiver elements. These spikes can be sufficiently mitigated with filtering.

Packet Structure

A total of 18 different types of signals were repeatedly transmitted and recorded at each lake position. We denote each signal as a *block*. Specifications for all blocks are listed in Table 2.

Table 2: Block descriptions.

Blk #	Descriptor	LFM BW (kHz)	LFM dur. (ms)	LFM to data (ms)	Modl.	Symbol rate (ksym/s)	Symbols transmitted	Pulse shape
1	LFM downsweep	31.25	25	-	-	-	-	-
2	Square fast BPSK	15.625	25	125.032	BPSK	15.625	4096	Square
3	Square fast QPSK	15.625	25	125.032	QPSK	15.625	4096	Square
4	Square slow BPSK	3.90625	25	125.128	BPSK	3.90625	1024	Square
5	Square slow QPSK	3.90625	25	125.128	QPSK	3.90625	1024	Square
6	LFM downsweep w/ pilots	31.25	25	-	-	-	-	-
7	SRRC fast BPSK w/ pilots	15.625	25	125.032	BPSK	15.625	4096	SRRC
8	SRRC fast QPSK w/ pilots	15.625	25	125.032	QPSK	15.625	4096	SRRC
9	SRRC slow BPSK w/ pilots	3.90625	25	125.128	BPSK	3.90625	1024	SRRC
10	SRRC slow QPSK w/ pilots	3.90625	25	125.128	QPSK	3.90625	1024	SRRC
11	LFM downsweep	31.25	25	-	-	-	-	-
12	SRRC fast QPSK	15.625	25	125.032	QPSK	15.625	4096	SRRC
13	SRRC fast 16QAM	15.625	25	125.032	16QAM	15.625	4096	SRRC
14	SRRC fast 64QAM	15.625	25	125.032	64QAM	15.625	4096	SRRC
15	SRRC fast 256QAM	15.625	25	125.032	256QAM	15.625	4096	SRRC
16	SRRC 3 fast QPSK bursts	15.625	25	125.032	QPSK	15.625	64	SRRC
				144.432	QPSK	15.625	64	SRRC
				163.832	QPSK	15.625	64	SRRC
17	SRRC 3 fast QPSK bursts	15.625	25	125.032	QPSK	15.625	64	SRRC
				144.432	QPSK	15.625	64	SRRC
				163.832	QPSK	15.625	64	SRRC
18	5 Periodic LFM upsweeps	15.625	25	-	-	-	-	-

All data packets use a center frequency of 62.5 kHz. All packets that use square root raised cosine pulse shape have a rolloff factor of 1. Each block that contains an entry for "LFM to data" in Table 2 consists of an LFM upsweep over the "LFM BW" bandwidth, followed by a gap (specified by "LFM to data"), and then data. In other words, a typical packet structure is as shown in Fig. 6, as used in analysis in [4].

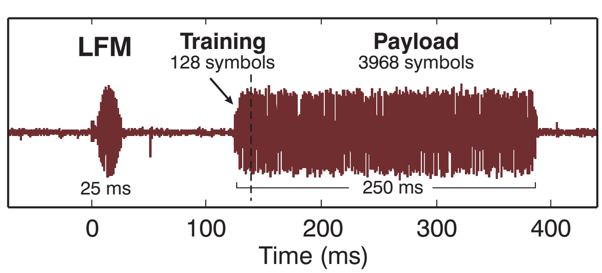


Fig. 6: Packet structure of Block #8. Figure reproduced from [4].

The symbols in Blocks #2-5, 7-10, and 12-15 begin with four repetitions of a Barker sequence. The same four repetitions of the Barker sequence (but reversed) also appear as the symbols at the end of each of these blocks. In blocks with modulations of higher order than BPSK, the symbols used in the Barker sequence are mapped to opposing sides of the respective constellation. (See the `dStructs.content.keySyms` and `dStructs.content.sym2BitMap` arrays that accompany the data, explained further below for the specific mappings). Each Barker sequence in Blocks #2, 3, 7, 8, and 12-15 is 13 elements in length. In the "slow" Blocks #4, 5, 9, and 10, each Barker sequence is 5 elements in length. Contrary to the structure of the other blocks, in Blocks #16 and 17 each "burst" begins with a pair of 11-element Barker sequences. These do not end with any reversed Barker sequences.

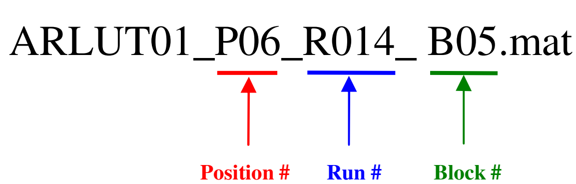
Note that one of Fig. 6's purposes is to show the portion of payload symbols used for equalizer training in the [4] analysis. Apart from the presence of Barker sequences as described, no other intentional symbol sequences are found within the payload; instead, symbols are pseudo-random. (Note, then, that the use of 128 training symbols in Fig. 6 is arbitrary, as any number of symbols may be used for training).

Blocks were transmitted and recorded in three groups. Group 1 consisted of Blocks #1-5, Group 2 consisted of Blocks #6-11, and Group 3 included Blocks #12-18. The receiver recorded for 20 seconds while all blocks of one group were repeatedly transmitted sequentially; therefore, there usually exist about 5 or 6 repetitions of each block in the dataset.

In Group 2 (Blocks #6-10), there exists a pair of pure pilot tones. One is positioned at 45 kHz and the other is positioned at 87 kHz. The pilot tone is continuous through the duration of the blocks, but fades in from silence over 100 ms at the start of Block #6 and then fades out over 100 ms at the end of Block #10. This fading was put in place to avoid any disjoint signals from entering the water when Group 2 repeated. (We were unsure of the real-time behavior of our playback hardware and software when used in the field, and found it safest to transmit silence at the moment of the repeat).

Data Files

Samples from each recording have been separated into individual blocks. All five channels are stored in each file. The files were written in the .MAT file format using MATLAB R2008a. Corresponding file naming is: `ARLUT01_P##_R###_B##.mat`. See Fig. 7.



File parameter	Description
Position #	Position index (see Table 1)
Run #	Increments for every new packet within a given condition (i.e. multiple samples of a particular environment)
Block #	Data block number (see Table 2)

Fig. 7: File naming scheme.

There also exists a series of "ground truth" samples; these are the data that were transmitted.

Annotations

Embedded in each data file is a structure called `dStructs` that contains the following fields:

OVERALL IDENTIFICATION: For all blocks in a sequence.

- `block` is the block number within the sequence.
- `runIndex` identifies the run index within a series of repeated runs of a sequence.
- `condition` is an index associated with a particular set of conditions; here, it corresponds with position number.
- `tLength` is the tether length of the transducer at the time of measurement (in meters); 0 may be used to signify ambiguity or no applicable value.
- `range` provides an approximate value of range from the transmitter to the receiver, in meters.
- `power` is the power level relative to unity gain that the transmission was emitted in dB.

BLOCK-LEVEL: These are specified for each block.

- `filename` is a string stating the filename.
- `time` is the time stamp (in MATLAB time format) that is associated with the data collection process.
- `gpsLat` is the GPS coordinate of the position that coincides with the block.
- `gpsLng` corresponds with `gpsLat`.
- `gpsRcvrLat` is the latitude of the receiver.
- `gpsRcvrLng` is the longitude of the receiver.
- `note` is a string field that can be used to specify additional information about this block.
- `motion` is a string reference to the type of motion that is recorded in this block.
- `speed` is the approx. speed of the transmitter, derived from GPS data.
- `leader` is the offset (in samples) to the start of the LFM in the waveform. This is used to automatically reconstruct successive segments.
- `trailer` is like leader but for the other end. To reconstruct two successive blocks as they were originally transmitted and recorded, omit either the trailer of the first block or the leader of the second block and append the two blocks' remaining samples.
- `sampLength` is the number of samples that were recorded—the array length.

CONTENT DESCRIPTOR: These are in a `contents` struct in each `dStruct`, or found in the `annotate.mat` contents struct array addressed by the `contentID` index.

- `fSamp` is the sampling rate of the original waveform in Hz.
- `fCarrier` is the center frequency in the original waveform (assuming single-carrier) in Hz.
- `lfmBW` is the full bandwidth of the channel (Hz), as used by an LFM sweep.
- `lfmDur` is the duration of the LFM sweep in samples.
- `modl` is a string identifier for the modulation of the waveform.
- `fSym` is the symbol rate in Hz.
- `sym2BitMap` is the mapping from symbol to bit map for this content.
- `keySyms` is the key symbols (e.g. ground truth) associated with this content.
- `lfm2DataDelay` is the duration in seconds from the LFM upsweep to the beginning of the data. For Blocks #16 and 17, this is an array of three times that correspond with each "burst".
- `txPulseShape` is a string identifier stating what the transmit pulse shape is.

`lfm2lfmDur` is the duration from the start of one LFM upsweep to the next one.
`note` is a string annotation

All of the `dStructs` structures are also stored in a struct array found in the file `annotations.mat`. This file contains another struct array called `contents`. The index within `dStructs.contentID` corresponds with the respective `contents` structure, containing the fields as defined above in "Content Descriptor".

Reference Note

The paper "Doppler Estimation and Correction for Shallow Underwater Acoustic Communications" [4] uses a subset of 29 packets from this dataset. The 5 boat positions used in that paper are numerically indexed according to the mappings listed in Table 3. Block #8 is used in the paper for analysis. Note that the positions reported in the paper's Table 1 are subsets of the positions listed in this document's Table 1 because not all blocks are used in the analysis.

Table 3: Mappings for position indices listed in [4].

Index in [4]	Dataset index
1	1
2	3
3	7
4	8
5	9

Dataset Usage

Use of this data for academic or nonprofit research purposes is encouraged. The use of the data must be acknowledged in corresponding reports or papers. This dataset is introduced and referenced from [4].

Acknowledgment

This research was supported by Independent Research and Development funds from the Applied Research Laboratories at The University of Texas at Austin in Austin, Texas.

References

[1] Measurement Computing Corporation, "IOTech Personal Daq/3000 Series User's Manual," accessed June 2010, http://www.mccdaq.com/manuals.aspx

[2] Lower Colorado River Authority. "Historical Lake Levels: Highland Lakes." http://www.lcra.org/water/conditions/historical.html.

[3] K. Nieman, K. Perrine, K. Lent, T. Henderson, T. Brudner, and B. Evans, "Multi-stage and sparse equalizer design for communication systems in reverberant underwater channels," submitted to 2010 IEEE Workshop on Signal Processing Systems.

[4] K. Perrine, K. Nieman, K. Lent, T. Henderson, T. Brudner, and B. Evans, "Doppler estimation and correction for shallow underwater acoustic communications," submitted to 2010 IEEE Asilomar Conf. on Signals, Systems and Computers.