AN ACOUSTIC ARRAY FOR UNDERGRADUATE INSTRUCTION

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ABSTRACT

We describe an acoustic array project and testbed for use in undergraduate instruction and research. The testbed consists of eight high-quality acoustic microphones connected to a programmable data acquisition system controlled by a laptop. The system is portable, allowing for outdoor data collections. The system can be used for collecting data that is processed off-line and can also perform real-time signal processing tasks. The project and hardware provide hands-on signals and systems experience for undergraduate students.

1. INSTRUCTIONAL GOALS

As Electrical Engineering curricula evolve, there is a trend toward emphasizing signals and systems early in the program [1] and increasing design and teamwork experiences for undergraduates [2]. In keeping with this trend, we have developed a set of acoustic array projects centered around a hardware testbed.

The main instructional goals of the microphone array project are:

- to provide a hands-on hardware system for undergraduate students interested in signals and systems,

- to provide team-oriented projects for undergraduate capstone design courses, independent study projects, and honors thesis projects within our department, and

- to provide research experience to undergraduates, linked with existing graduate student research endeavors.

In addition, we sought to provide a demonstration and data collection capability to support graduate research.

A system that meets these goals must be flexible, modular, simple, and low cost. The system must be flexible enough to support a variety of student projects, yet be easy enough to use so that undergraduate students quickly come up to speed and make progress on projects. Finally, the system should be linked to our research program, to facilitate graduate student mentoring of undergraduates and to leverage faculty time.

2. THE MICROPHONE ARRAY TESTBED

To meet these instructional needs and constraints, we have developed an acoustic microphone array system that includes data acquisition and processing capabilities. We developed a testbed that would support speech processing projects as well as outdoor vehicle localization and tracking problems. The outdoor data acquisition capability required that the system be portable.

The hardware consists of eight microphones and preamplifiers, a portable National Instruments data acquisition unit, and a laptop computer whose functions are data storage, data acquisition control, and real-time signal processing.

Eight Emkay BL 1994 microphones are used for acoustic signal acquisition. Each microphone is connected to a differential preamplifier and is fed into a National Instruments data acquisition system. The National Instruments hardware is housed in a SCXI-1000DC chassis powered by a built-in 12-volt battery. The chassis contains an SCXI-1140 8-channel simultaneous sample-and-hold card to which the microphone outputs are connected, followed by an SCXI-1141 8-channel programmable anti-aliasing filter. These cards have combined programmable gains up to 10^5.

The signals are fed into a National Instruments AI-16E-4 16-channel, 12-bit data acquisition card installed in a laptop computer. The data acquisition card can sample data and store it to the laptop hard disk at rates of up to 250 samples per second.

The entire data acquisition system is lightweight and portable. The system weighs under 25 pounds and is housed in a $7 \times 10 \times 8$ inch SCXI chassis cabled to a laptop. A photograph of the system is shown in Figure 1.

Figure 1: Acoustic array hardware. Three microphones are seen at left. The National Instruments SCXI chassis is on the right, and the laptop containing the data acquisition card is in the middle.

Figure 2: Indoor array configuration board.

The microphone array is configured in one of two ways. For indoor applications, we have built an aluminum platform with 23 milled holes for placement of the microphones (see Figure 2). Several array geometries can be tested by moving the microphone mounts to different holes on the platform. For outdoor data collections, we have built a set of aluminum spikes to drive into the ground at desired locations.

Data acquisition is handled by a Labview program, which controls the data acquisition hardware via the NI-DAQ software available from National Instruments. Data processing is performed using either Labview or Matlab.

The project goals of simplicity and cost have motivated our choice of an acoustic testbed over more expensive options, such as a radio frequency testbed. With an acoustic testbed and inexpensive data acquisition equipment, we are able to directly sample the signal without modulating to baseband. The goals of flexibility and short design cycle times motivate the use of Labview for data acquisition and the use of Labview or Matlab for algorithm development and implementation.

3. DESIGN PROJECTS

A number of student design teams have used the microphone array system described above, and other projects are in progress or planned. Below is a summary of these student projects.

3.1. Data Acquisition

An initial goal was to develop a functional and user-friendly data acquisition system. Students determined the hardware settings needed and wrote Labview code to acquire and log data. Labview facilitates building a GUI for setting number of channels, sampling rate, anti-aliasing cutoff filter, and amplifier gains.

In this project, students learn about several practical aspects of data acquisition, including signal conditioning, the need for simultaneous signal samples, dynamic range and quantization issues, and differential versus single-ended signal voltages. In addition, students learn aspects of GUI design and interfacing hardware to software.

System calibration is a related problem that has not yet been addressed, but is planned as a future project.

3.2. Vehicle Tracking and Characterization

In this project we place the microphone array near a road, and record the acoustic signatures of passing vehicles. The system should detect the vehicle, and track its direction of arrival. In addition, the system should generate a beamforming output of the vehicle signal. Finally, characterization of the output signal is of interest to characterize the vehicle; example characteristics to determine are Doppler shift and engine RPM.

Students working on this project learn principles of DOA estimation, tracking, and broadband array beamforming. The signal characterization component introduces students to spectral analysis of signals. The slow variation in signal properties allow students to explore time-frequency processing of signals at an elementary level.

3.3. Teleconferencing Microphone Array

The microphone array is placed on a conference table with a number of people seated around the table. The objective is to form a series of beams, each pointed to one speaker at the table while simultaneously nulling interference from other speakers around the table.

Here students learn about DOA estimation and tracking as well as broadband array beamforming. Students also learn about signal nulling and adaptive nulling.

3.4. Vehicle Hands-off Telephony

An array of microphones is placed in a car near the driver. The goal is to form an array beam to receive the driver's voice while simultaneously minimizing road noise and interference from other acoustic sources.

4. IMPLEMENTATION

The array is used in two educational venues: in a formal Electrical Engineering Capstone Design course and in individual studies projects.

4.1. Capstone Design Course

In Winter Quarter 2000 we offered a ten-week capstone design course on Microphone Array Processing. All students entering the course have taken a course on linear systems that uses a text such as Kamen and Heck [3] or Haykin and Van Veen [4]. Some students have also completed a senior-level digital signal processing course using Porat [5] as a text. Students were divided into three teams of four students each, and given a specific subproblem to address. The three subgroups were:

- **DOA Estimation and Beamforming**
  The goal was to develop and implement an algorithm for DOA estimation and for designing array weights to form a broadband beam in a specified desired angle of arrival.

- **Signal Characterization**
  The goal was to use the beamformer output signal from a moving vehicle to determine spectral peaks and estimate the engine RPM and vehicle velocity from Doppler shift.

- **Differential GPS System**
  The goal was to develop a differential GPS system for tracking a moving vehicle with respect to the array center. The GPS data is used as ground truth to validate array-based DOA estimation algorithms.

In addition, the subgroups had to work collaboratively to set up and carry out data acquisition experiments.

Students prepared weekly written progress reports and met weekly with a faculty instructor as subgroups to discuss progress and ask questions. In addition, each group prepared a Preliminary Design Review at the end of the fourth week, and a Final Design Review at the end of the quarter. Both reviews included a written report and an oral presentation. The report and presentation addressed both the technical design and the team management plan.

Figure 3: Photographs from an outdoor data collection using the acoustic array. A three-element triangular array of microphones was used to collect signals from vehicles driving by and of overhead aircraft.

The class planned and successfully completed an outdoor data collection experiment. In the experiment, several vehicles were driven past a three-element microphone array (see Figure 3). Data from airplanes and helicopters flying overhead were also collected. An example spectrogram from helicopter data is shown in Figure 4.

The DOA Estimation and Signal Characterization subgroups were successful with their designs, and a data collection was successfully carried out. The GPS subgroup did not implement their design due to hardware ordering and delivery delays.

4.2. Independent Study Projects

Eight undergraduate students ranging from sophomore to senior level are involved with ongoing independent projects on the microphone array. These students work singly or in pairs to accomplish subtasks in the evolution of the program. Some of the current student projects include:

- Least-squares 2-D (frequency–angle) filter design for broadband arrays

- Array geometry design

- Real-time beam steering

- Matlab GUI for data presentation and analysis

- Microphone preamplifier power supply design

- Differential GPS system for tracking ground truth

Students and faculty meet weekly as a group to discuss progress, overall design goals, and any problems.
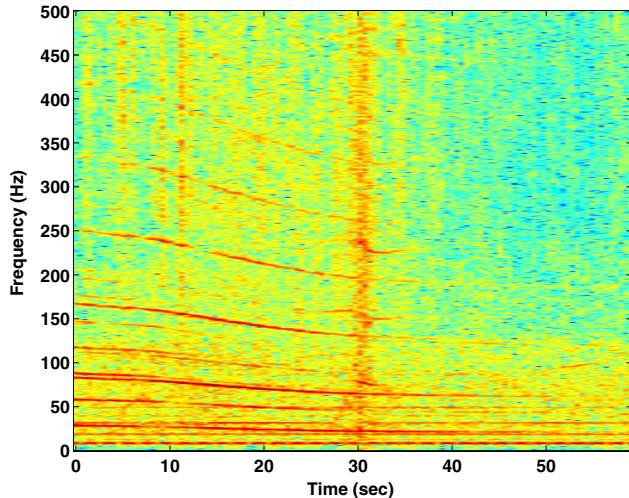
Figure 4: An example spectrogram from a helicoptor signal obtained during an outdoor data collection.

Some undergraduate projects are linked to graduate student research problems; these include 2-D filter design for broadband beamforming, array geometry design, and DOA estimation and accuracy analysis. The graduate students attend group meetings and work with undergraduates on these problems.

5. EXPERIENCES AND LESSONS LEARNED

Our experience in the project has highlighted some important lessons. These include:

- **Emphasize good design principles**
  Students rarely come into the project knowing good design principles, and these must be taught by structuring the course and by example from others. We encourage students to:

  – test subcomponents
  – break down a larger problem into clearly-defined smaller problems
  – define clear intermediate goals

- **Ensure that goals for students are both reachable and clearly understood.**
  At the same time, accept the fact that students may sometimes fail to achieve the goals. Students often meet learning objectives even if the engineering design goals are not met.

- **Be willing to invest in design tools.**
  It is easy to underestimate the cost of engineering time; good design tools and hardware, while

sometimes initially expensive, save cost and headaches over the long term. Labview for data acquisition and real-time signal processing has proven to be a wise investment.

- **A complex engineering system is not needed to meet the learning objectives of the project.**
  Even simple design problems effectively illustrate the main educational objectives we seek.

- **Be prepared to generate good-quality tutorials that introduce new topics.**
  We find that most undergraduate students are not able to learn topics beyond material in prerequisite courses on their own. Focused tutorials presented early improve the engineering productivity and enjoyment of the students.

- **Don't underestimate ordering delays.**
  Hardware selection, ordering, and setup times often took much longer than we originally expected.

6. CONCLUSIONS

Although it is in the early stages of development, the acoustic array project appears to be successfully meeting the intended educational objectives. The undergraduate students obtain hands-on experience with signals and systems while learning principles of good design. The group format encourages students to learn and improve oral and written technical communication skills, good experiment design and documentation, and teamwork. Students learn about basics of data acquisition, and learn to apply basic and advanced concepts in signal processing to an engineering design problem.

ACKNOWLEDGEMENT

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