An Android App for Spatial Acoustic Analysis as a Learning Tool

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***Abstract*—An Android app has been developed to assist in the education of individuals in a science, technology, engineering, and mathematics (STEM) course of study. The Android Reflection Application provides students a means to determine distances to objects while allowing them the ability to manipulate signal envelopes, signal shapes, signal types, and frequency constraints. The convenient and intuitive graphical user interface immerses the user into a richly educational environment allowing for the solidification of fundamental concepts regarding digital signal processing (DSP). In addition to the educational benefits, this application is also being applied to spatial acoustic analysis and assistance in low-visibility. This feature will allow users to determine the best use for a given space whether it is a quiet study room or a room better suited for conference meetings. The effectiveness of this application has not yet been formally tested but suggests a positive result.**

***Index Terms*—Android, DSP, Mobile Echolocation, Autocorrelation, Signal Processing, Spatial Acoustic Analysis.**

I. INTRODUCTION

Mobile technology is the future of education. Many studies have been conducted to determine the current student population's desire to utilize technology in the classroom and its effectiveness [1, 2]. The results suggest that students are not only open to technology in the classroom but prefer it. The effectiveness in one study showed that students taught with technology gained knowledge at the same level as students taught traditionally but with more positive attitudes toward the material [3]. In order to stay relevant in education within the fast-paced technological world, mobile applications (apps) are developed specifically for use in classrooms to customize the learning experiences of a diverse population of students [4, 5]. Some examples are NI LabVIEW Mobile Module for handheld devices [6], iJDSP [7], AJDSP [8], Octave [9], WolframAlpha app [10], and MATLAB Mobile [11].

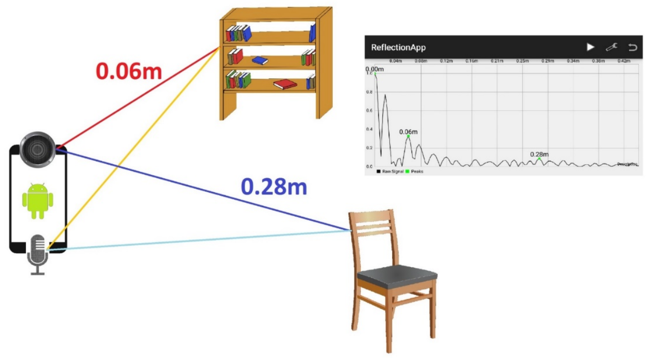

Figure 1. Android app for echolocation.

To convey the educational value of the research presented here, an Android based application has been developed, based on an Android acoustic ranging app [12,13]. This app is audio-based and utilizes echolocation to perform ranging. This app generates a signal that is transmitted through the built-in speaker of the Android device. The signal travels through the environment, strikes objects, and reflects back toward the built-in microphone of the device. The sent and received signals are cross-correlated to calculate the round trip time needed for the signal to be sent and received [14]. The speed of sound propagation is assumed to be constant (342.9464 m/s as used by the app for propagation in air) and with these values a distance estimate can be calculated. A simplified model can be seen in Figure 1.

The rest of this paper is organized in the following manner. Section II develops a basic understanding of the app as a tool for ranging. It also briefly describes a few directions to further the educational benefits accessible by students through this app. Section III discusses the classroom workshops planned for the fall semester of 2016 at Clarkson University. These workshops aim to measure the effectiveness of this app in the classroom as a leaning tool. In Section IV, the future work and work in progress are detailed. Finally, in Section V, the conclusions drawn from the research and its directions are outlined.

II. The Echolocation App

The Android app discussed in this paper uses echolocation for ranging. A user-defined signal is generated from the app, and transmitted using the built-in speaker of the mobile device. As the signal propagates through the environment and encounters objects, the device will receive signals reflected off these objects. Once copies of the signal return, a cross-correlation is performed against the transmitted signal. Peaks in the cross-correlation correspond to the round-trip time taken by the sound signal to reach the object and return to the device. Given the speed of propagation of sound, the distance to the object can be calculated.

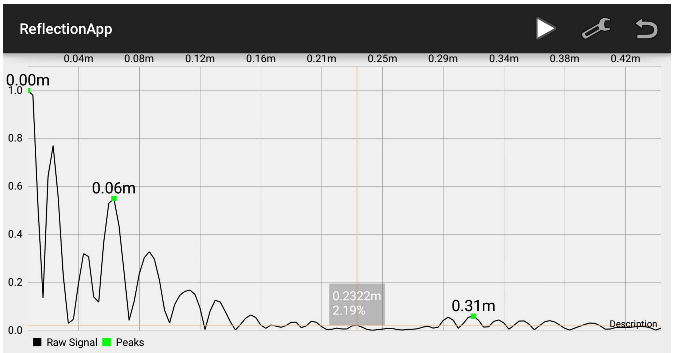

Figure 2. Cross correlation plot with distance estimates at peak values.

The app presents the results to the user by plotting these distance estimates on the cross correlation graph. An example of the resulting plot with distance estimates is shown in Figure 2. If a distance of interest is not identified by the peak detection algorithm, a user-defined cursor has been implemented to allow for just that. The zoom and panning feature also allows the user to view data further away as well as get a closer look at tightly spaced peaks. To allow the app to compute the cross correlation in a timely manner, the fast Fourier transform (FFT) is utilized [12, 14].

III. Educational Value

The ranging algorithm can determine distance estimates with fairly good accuracy when using the default Gaussian enveloped sinusoidal chirp. However, to better convey the concepts involved in cross correlation, many types of signals have been added to the configuration window's signal shape drop-down menu, as shown in Figure 3. The addition of these signals allows students to visualize the effects of signal shape and enveloping on cross correlation.

The cross correlation of a single frequency sinusoid produces a cross correlation similar to the one depicted in Figure 4. To describe this result, cross correlation can be related to another concept of signal processing, convolution. When the received signal is compared against the sent signal, a peak in the cross correlation is generated. With a single frequency sinusoid this will happen at each period for the entire duration of the signal length. Further explanation can be provided as to how we get around these issues by introducing the concept of a chirp. A chirp has a range of frequencies that

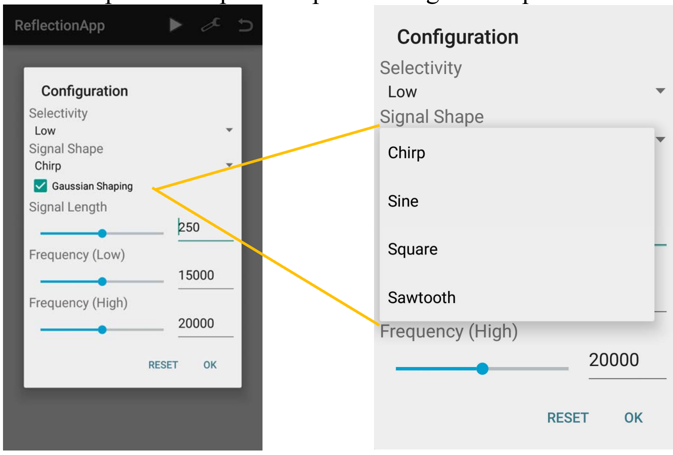

Figure 3. Configuration window (left) showing the adjustable parameters; signal shape options (right).

reduces the repeated peaks of cross-correlation. To further minimize erroneous peaks, envelope shaping can change the amplitude of the signal from uniform to varying amplitude. Figure 5 presents a sawtooth chirp, with uniform amplitude, that was developed for this app. Figure 6 is the same signal with a cubic envelope applied. Figure 7 shows the correlation of this shaped signal. However, this simulated cross correlation does not include noise.

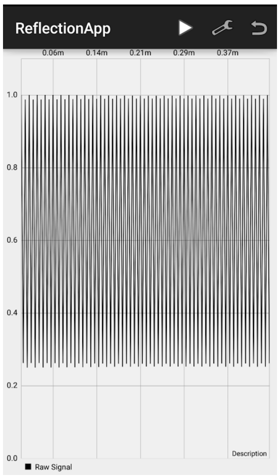

Figure 4. Correlation output of a single frequency sinusoid.

As shown in Figure 7, the correlation of a shaped chirp with itself (autocorrelation) produces a sharp peak. This result is a preferred output, because the generated peak is close to the ideal case and provides precise distance estimation. If the peak was to be wider, the estimation would include more error, because the actual location of the object could exist anywhere within the peak's width.

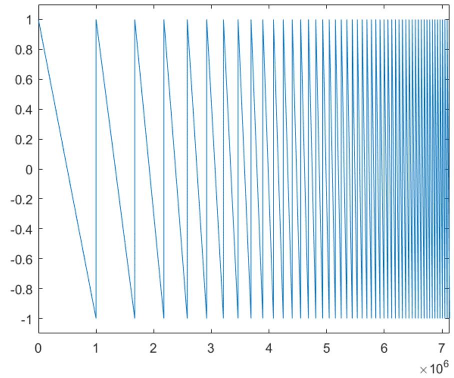

Figure 5. Sawtooth chirp with uniform amplitude.

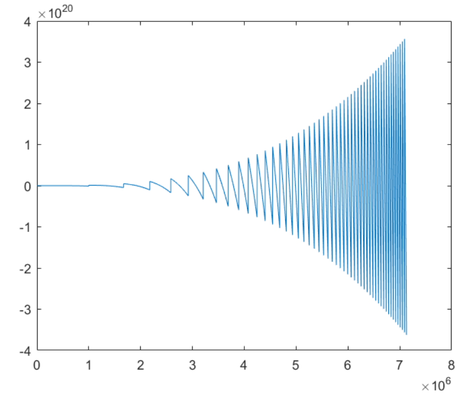

Figure 6. Shaped envelope of a sawtooth chirp.

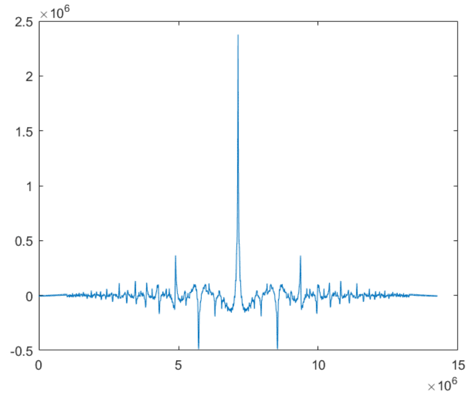

Figure 7. Cross correlation of envelope shaped sawtooth chirp.

Beyond ranging, the correlation data can be analyzed to give the user an idea about the reflective properties of a given space. Data collection has been conducted to this aim by taking ten to fifteen readings in a variety of different room types. A statistical approach can be taken to categorize each room by its reflective properties. Methods, including *k*-means clustering can be introduced to students with this app. Other concepts that can be introduced using this type of data and the app are feature selection and dimensionality reduction. In future editions of the app, these functions will be incorporated to add both in terms of functionality and education demonstrations.

IV. Proposed Classroom Workshops

In this section, a few sample classroom workshops for undergraduate students are described. These workshops are currently planned for the fall semester of 2016 at Clarkson University's junior-level EE 321 Systems and Signal Processing class.

To begin, a pre quiz would be conducted to establish baseline knowledge. Questions would cover concepts such as the relationship between correlation and convolution, the FFT compared to the DTFT, and the effects of signal type, envelope shaping, and the effects of frequency on correlation. After completing the pre quiz, exercises as described below would be performed. After the hands-on exercises, students will be provided with a post-quiz and survey to assess what they have learned, as well as to obtain subjective information about the app.

The first exercise and discussion would be designed to initially introduce the app to the students. They would perform ranging on various items in the classroom to see that the resulting distance estimation is fairly accurate. They would learn how to navigate from the home screen to the configuration window. A brief discussion detailing echolocation and how it is performed by the app would take place. Links to concepts in convolution, which are covered in the class curriculum, would be made. This would provide students with a tangible application for a previously theoretical concept.

The second exercise would consist of varying various operational parameters. To begin, the default settings would be used: a chirp signal with Gaussian shaping and a frequency range of 15k Hz to 20k Hz. This would show the students an appropriate cross correlation plot. A brief discussion would describe what characteristics of the signal make this correlation result a good one. The concepts of peaks and their widths as they relate to object location would be described.

Next, envelope shaping would be removed and all other parameters would remain unchanged. The students would repeat the previous exercise trying to maintain the same distance from the same object. The resulting correlation would be very similar to the first with slightly wider peaks. A discussion about why this happened would take place explaining again the importance of signal shaping as it applies to correlation.

Finally, the signal type would be changed to a square without envelope shaping, and maintaining the default frequency of 15k Hz. The resulting correlation would look very similar to that of Figure 4. A discussion of what causes this result would take place and the students would be asked to predict whether or not the sine signal would produce a result like the chirp signal or like the square signal. This would solidify the concept of correlation and explain why we avoid single frequency signals for correlation.

Following the exercises, a post quiz and survey would be administered. The post quiz would cover identical concepts covered in the pre quiz. In addition to the quiz, the survey will provide us with feedback concerning the performance of the app and possible ways for improving its functionality or appearance to better suit the needs of the students. Questions regarding the apparent helpfulness of the app would also be included.

With results from the pre- and post-quizzes, the improvement on individual concepts would be analyzed. This result would provide an indicator as to the effectiveness of the app in an educational setting. The students' feedback would then be considered and implemented if feasible, and additional workshops will be conducted.

To assist in administering the quizzes, these questions, along with companion notes are embedded into the app. An example of this is shown in Figure 8.

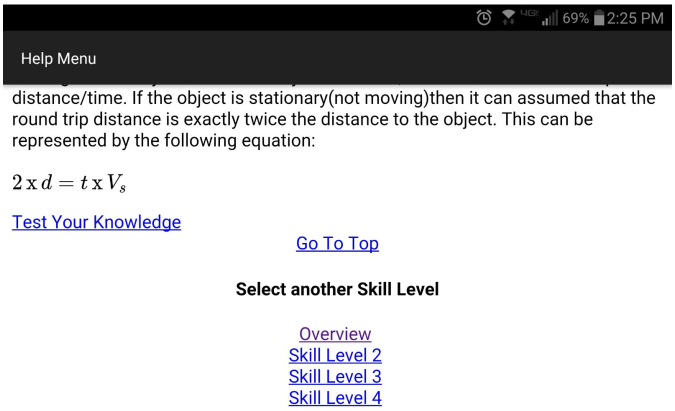

Figure 8. Notes and quiz module built into the reflection app.

V. Future Work

Aside from those already described, signals such as a square wave signal that varies through a range of pulse width modulation (PWM) as well as pseudorandom noise-like signals will be implemented on the app. Pre-recorded signals such as bat-chirps will also be stored and used. In addition, options of different types of envelopes are being considered. The implementation of these new selectable features will deepen the educational value of the app and broaden the concepts covered.

Finally, a new direction of interest to be considered is the determination of ranged objects' characteristics. By further analyzing the reflected signal strength, it is hoped that identification as to whether an object is hard or soft can be established. Consider the data collected by the app in Figure 9 and Figure 10 of a soft blanket and a hard metal box, respectively. The initial peak amplitude reflected by the blanket is substantially lower than that of the metal box. These applications can see educational benefits in areas as varied as mathematics and statistics, power engineering, and materials science.

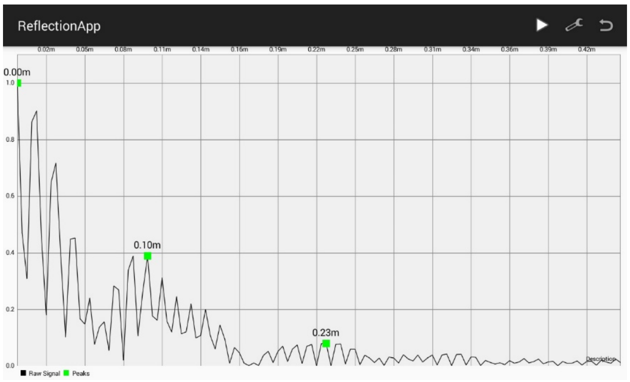

Figure 9. Cross correlation plot generated by ranging a soft blanket.

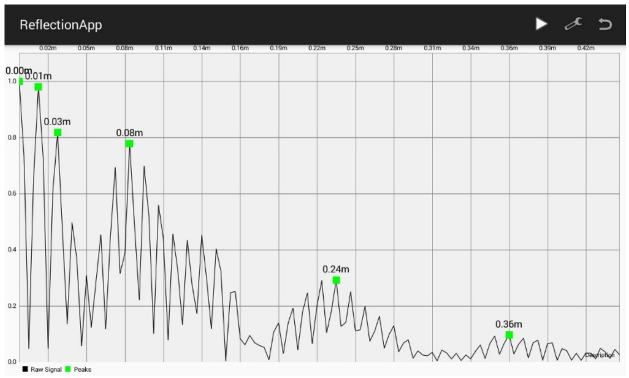

Figure 10. Cross correlation plot generated by ranging a hard metal box.

VI. Conclusions

The app presented in this paper has a large educational potential in the classroom. Although the effectiveness has not yet been tested the value seems apparent. The applications to undergraduate signal processing education include topics such as correlation, convolution, FFT for fast computation, and a close look at the effects of many different parameters on the cross correlation of many different signal types. The app also shows promise in lending itself to mathematics and statistics education, presenting applied statistical methods in a clear and relatable way.

In addition to the solid educational foundation, the practical applications of this app are relevant to many fields of study. The spatial acoustic analysis provides an efficient and cost effective way for individuals to test room treatments such as carpeting or acoustic tiling. The limited visibility application provides a way for visually impaired or blind individuals to traverse a room with comfort knowing whether the objects in front of them will cause physical damage or not.

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