# Signal Processing and Machine Learning Concepts using the Reflections Echolocation App


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***Abstract*— This paper describes the use of a space usage determination algorithm for teaching signal processing and machine learning concepts to undergraduate electrical engineering and computer science students. An Android device transmits a high-frequency signal in an unknown space. The device determines the reflective properties of this unknown space by analyzing the received signal. Based on the features extracted from this signal, the app measures distances and determines how the space can be utilized for various application such as libraries, conference rooms, or laboratories. The application and related algorithms use concepts such cross-correlation, feature extraction, learning/training algorithms, and discrimination/decision making.**

**These concepts are typically covered in undergraduate classes such as Digital Signal Processing, Control Systems, and Probability and Statistics; and graduate-level classes such as Pattern Recognition and Detection and Estimation Theory. The app is used to create compelling demonstrations and immersive exercises to teach basic concepts related to signal processing and machine learning. Undergraduate student hands-on workshops and outreach activities are planned to evaluate the effectiveness of this approach. Assessment results will be presented at the conference.**



***Keywords—mobile education apps; STEM; machine learning, signal processing, echolocation***


## I. Introduction

Studies show that students taught with the use of technology gained knowledge and developed a more positive attitude towards the subject's content when compared to students taught by a traditional method [1-3,18,20]. In response to this trend, mobile applications (apps) are being developed to customize the learning experiences of students [4, 5].

Mobile devices such as tablets and smartphones have large memory, high processing power and a large number of sensors such as accelerometers, gyroscopes, GPS receivers [26, 27], microphones, cameras, and speakers [15]. These capabilities enable the development of apps, which can assist in classroom education. In the systems and signal processing areas, these include mobile versions of established desktop programs such as NI LabVIEW Mobile Module for handheld devices, iJDSP, AJDSP, Octave, WolframAlpha app, and MATLAB Mobile [6-11,22,23].

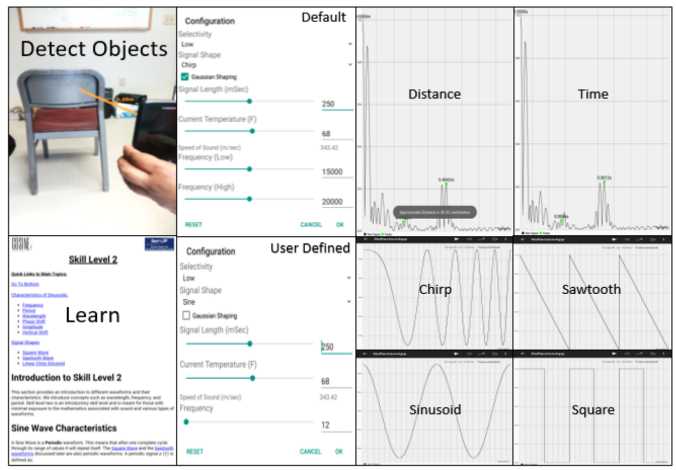



Figure 1. The Reflections app [17].

In this paper, we present our work-in-progress in using the Reflections app (Figure 1) for signal processing and machine learning education in undergraduate electrical engineering classes. The "Reflections" app [17] is audio-based and utilizes echolocation to perform ranging. A signal is generated and transmitted through the speaker of the Android device. The signal travels through the environment, strikes objects, and reflects back towards the device. The sent and received signals are used to calculate the time needed for the signal to be sent and received [12-14], and a distance estimate is calculated. An example of the app being used and the return with the detected object are shown in Figure 2. In addition to ranging capabilities, the app comprises: (a) notes covering concepts in signals, systems, and echolocation; (b) accompanying videos that explain concepts, as well as app demonstrations; and (c) quizzes to help users assess their skill levels.

The rest of this paper is organized as follows. Section II develops a basic understanding of the app as a tool for ranging and demonstrates the basic features of the app. In Section III,

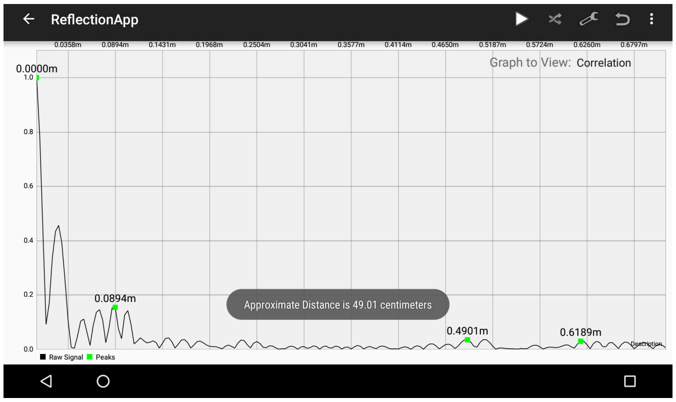



Figure 2. The Reflections app being used to detect an object approximately 49cm away from the mobile device. The graph shows the location of the object and a notification provides a visual readout of the distance to the object.

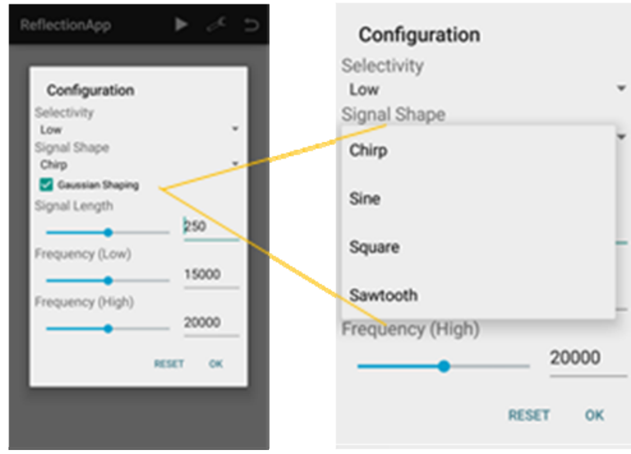



Figure 3. The configuration window in the Reflections app. Users can select the signal type, shape, length, and frequencies where appropriate (from [29]).

the educational value of the app and its use in classes is discussed. Finally, in Section IV, concluding remarks and future work are presented.

## II. Echolocation Application and Features of the App

### A. *Echolocation*

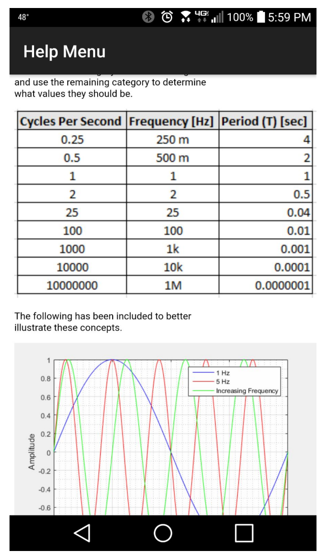
In this section, the Android-based echolocation demonstration is described. Using a configuration interface as shown in Figure 3, a user-defined signal is generated. The configuration screen allows users to select different signal types, single lengths, start and end frequencies (where applicable), and options for shaping the transmitted signals. This configurable signal is then transmitted from the speaker of the Android device. Reflections from objects in the area are then received by the device microphone. The return signal and the original signal are correlated using the fast Fourier transform (FFT) for fast computation [12, 14, 19]. Peaks in the cross-correlation and the speed of propagation of sound are used to compute round-trip time from the device to objects and back to the device.

The results of the distance estimation are presented to the user via a graph as shown in Figure 2. Peaks in the correlation graph are marked using a peak-detection algorithm. The locations of the objects at the detected peaks can be marked using either the distance to the object or the time of flight to the object. The app enables users to select a text display showing the distance to the first detected object. As options for users, a text-to-speech option provides an audio message that calls out the distance to the nearest object; and the vibrate option provides tactile feedback, with long vibrate signals signaling a closer target and short signals indicating a distant object.

If a distance of interest is not identified by the peak detection algorithm, a cursor has been implemented to find the distances to any points of interest on the cross-correlation signal. Zoom and pan features are also implemented that also allow users to view data outside the main view, as well as to distinguish closely spaced points.

### B. *Educational Features of the App*

The Reflection app has several educational tools embedded into it to better promote student learning. Here, we describe the companion education tools embedded in the app.




| Cycles Per Second | Frequency [Hz] | Period (T) [sec] |
|---|---|---|
| 0.25 | 250 m | 4 |
| 0.5 | 500 m | 2 |
| 1 | 1 | 1 |
| 2 | 2 | 0.5 |
| 25 | 25 | 0.04 |
| 100 | 100 | 0.01 |
| 1000 | 1k | 0.001 |
| 10000 | 10k | 0.0001 |
| 10000000 | 1M | 0.0000001 |

Figure 4. Notes embedded in the app. The figure shows the relationship between frequency and time period for a sinusoidal signal.

Supporting material: Supporting material embedded in the app include notes, exercises, and quizzes The notes can be accessed from within the app, as well as the companion website [16]. These embedded notes include detailed background material at multiple skill levels, including material suitable for students at middle school, high school, undergraduate, graduate, and professional levels. An example of the notes embedded in the app is shown in Figure 4, where the relationship between frequency and period of a sinusoid is described.

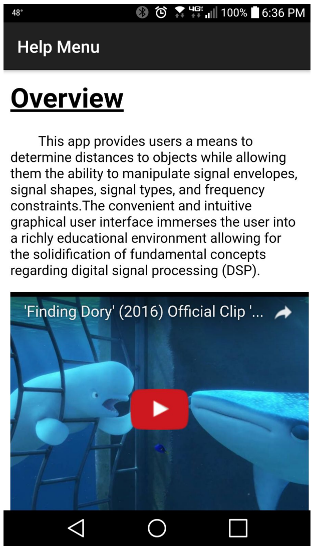



Figure 5. An example of a video embedded into the Reflections app. Videos are of two types: some like those above help students relate to concepts being covered; others provide demonstrations of the app.

In addition to descriptions and equations, practice problems are provided to help users better understand the material. Additionally, users can test their knowledge in the areas covered in the app using quizzes provided at each skill level. The quiz interface provides complete feedback including solutions and references back to the notes for further study.

Videos: Two types of videos are included in the app (see Figure 5). One set of videos describes concepts. These include snippets of instructional videos specifically recorded to accompany the app. The second type of videos is app demonstrations. These show features of the app, as well as simple examples that showcase useful features of the app and how the app can be used for achieving specific learning objectives. In addition to being embedded into the app, these videos are available on the companion website [16] and on YouTube.

## III. In-Class Activities

### A. *Signal Processing Concepts*

In order to evaluate the effectiveness of the app in demonstrating concepts in signal processing, a workshop was conducted in the fall semester of 2016 at Clarkson University's junior-level EE 321 Systems and Signal Processing class.

A pre-quiz was administered to measure the skill level of the students before the app was used. Questions covered 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, a short presentation describing the use of the app was made to the students. Following this, students were asked to perform a series of exercises. The first exercise introduced the app to the students. Students then performed ranging to various objects in the classroom to see that the distance estimation is fairly accurate. In the process, the students learned how to use the app to navigate from the home screen to various windows in the app. The echolocation demonstrations of the app connected to concepts covered in class and related abstract concepts to applications that can be visualized. Additional exercises had students vary signal and app parameters so that the effects of the different signals, signal types, and signal shapes on the correlation output can be seen.

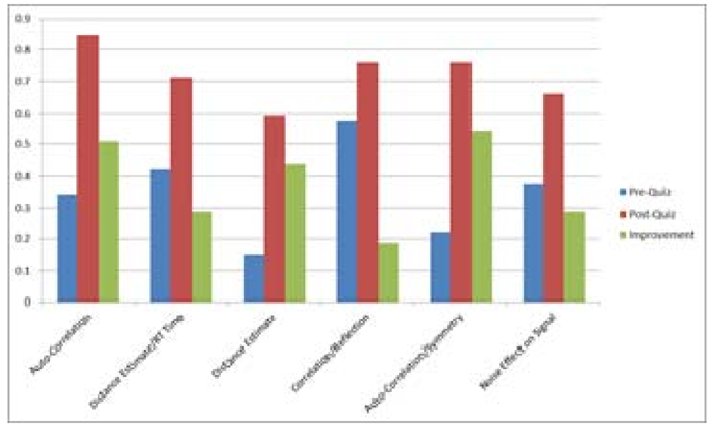



Figure 6. Student responses in the pre-quiz, post-quiz, and improvement in learning due to using the app.

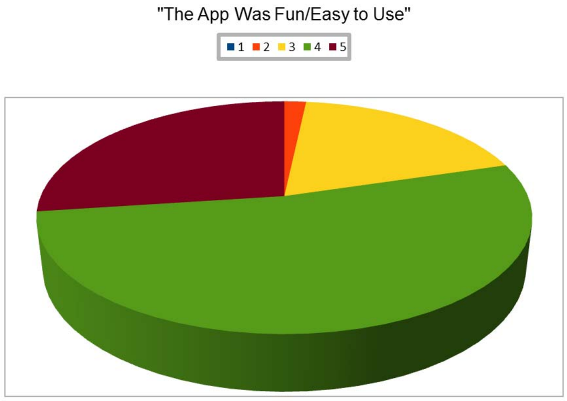
After the hands-on exercises, students were provided with a post-quiz to assess what they have learned, and a survey to obtain subjective information about the app and the user experience. Based on these activities, students were able to learn concepts such as characteristics of signals resulted in "good" correlation; the relationship between the locations of correlation peaks and object location; and the relationship between correlation peak width and resolution.

The results from the workshop are shown in Figure 6 and Figure 7. As can be seen in Figure 6, students showed improvement in multiple areas of interest, including autocorrelation, distance estimation, and noise effects. Students were also asked about the app itself and how they perceived the usefulness of the workshop to teach them concepts in signals and systems. As shown in Figure 7, most students agreed that "The app was fun to use"; "The exercises were helpful"; and "The workshop was helpful".

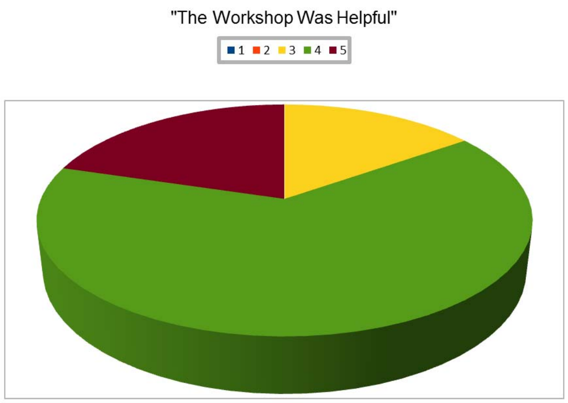
### B. *Machine Learning Concepts*

The Reflections app can be used for space usage determination [24,25]. Since each space has a different configuration, based on the cross-correlation signal in each space, the best use for the space can be determined. In order for the application to make a right decision, the application will be trained with the features of several pre-identified spaces (library, classroom, office, etc.) (see Figure 8).

Using this application, specific examples of concepts that can be demonstrated in classrooms include: (1) how machine learning can be used in signal processing; (2) how peak finding




(a) Student response to “The app was fun/easy to use”.




(b) Student response to “The workshop was helpful”.

Figure 7. Student responses to various questions evaluating the ease of use of the app and the perceived helpfulness of the workshop activities. All responses are on a 1-5 rating with 1 being the lowest and 5 the highest.

algorithms can be used for feature identification and extraction; and (3) how training and learning algorithms provide the basis for decision making and artificial intelligence.

Two workshops are planned: one at Clarkson University and one at Arizona State University, in the senior-level DSP classes, in the fall semester of 2017. The workshops will follow a similar format to the workshop described in Section III-A and in [28]. The results from the workshop will help us analyze the improvement on individual concepts, and will be an indicator of the effectiveness of the app and this approach to machine learning education in an educational setting. Student feedback will be collected and implemented where feasible. Additional workshops will also be conducted in signal processing and applications courses that are designed for non-EE majors [21]. Results from the workshops will be presented at the conference.

## IV. Conclusions and Future work

In this work-in-progress, we presented an echolocation app, Reflections, and its possible applications to signal processing and machine learning education. The app has embedded

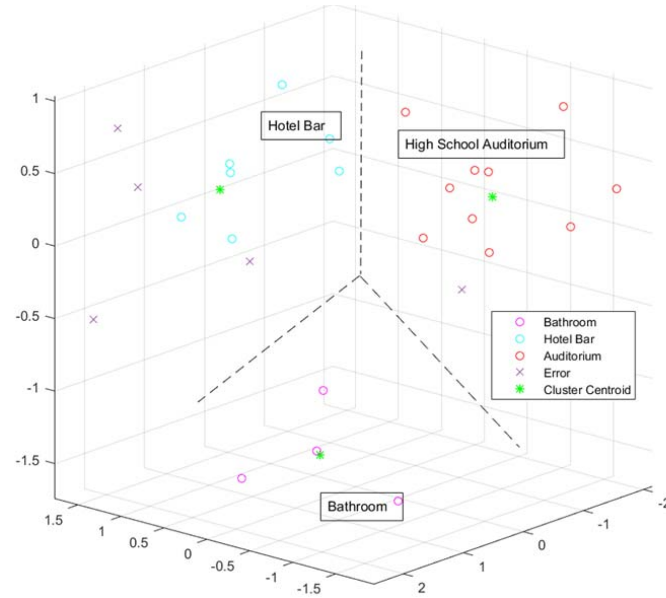



Figure 8. The Reflections app can be used for space assessment. This, in turn, can be used to teach concepts in machine learning. In the example above, a clustering algorithm is used to distinguish data collected between three types of rooms.

features such as notes, companion videos, and quizzes, which can be used for students at various education levels such as middle schools, high schools, undergraduate, and graduate studies. Furthermore, these features are embedded in the app, allowing the app to be self-contained and ideal for use in less formal learning environments. 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 machine learning education, presenting applied probability and statistics methods in a clear and relatable way. Results from assessment workshops confirm the effectiveness of the app in teaching signal processing concepts; workshops to evaluate its effectiveness in teaching machine learning concepts are planned.

In terms of future work to the app, in addition to the signals already available in the app (Figure 3, right panel), other signals such as a square wave, a pulse width modulated (PWM) signal, as well as pseudorandom noise-like signals will be implemented. Pre-recorded signals such as bat-chirps will also be stored and used. Finally, future work is planned in the areas of developing new course material, notes, videos, and quizzes. Other future extensions include applications in object and sensor localization [27] where the authors will use results from research to develop an app for use in signals and systems classes.

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