Teaching Ranging and Localization using Bluetooth on Android Devices

Kevin Mack and Mahesh K. Banavar
Department of Electrical and Computer Engineering
Clarkson University, Potsdam, USA
{mackkv, mbanavar}@clarkson.edu

***Abstract*— This paper describes the use of Bluetooth hardware for localization and signal processing education on Android smart-phones and tablets. The localization algorithm uses the Received Signal Strength Indcation (RSSI) value of transmitting devices in order to triangulate their position. The concepts that are featured in the use of this technology have classroom relevant content such as multilateration (a matrix problem in linear algebra), wave properties and interactions (physics), statistics relating to laboratory data, and engineering application concepts (such as software development and coding). These concepts can be taught through classroom demonstrations and interaction. Preliminary data from in-class activities demonstrate the effectiveness of the app for teaching concepts in localization and ranging. Further in-class activities and workshops are planned.**

Index Terms*— *RSSI, Android, localization, Bluetooth, ranging, multilateration, target, anchor

I. Introduction

This paper discusses the use of an Android application to demonstrate concepts associated with Bluetooth localization and ranging (Figure 1). These concepts include a wide range of topics from EM wave propagation to matrix algebra. Localization problems are especially interesting because of the multitude of applications and the depth of the field. Many of these concepts are applied by systems that are in everyday use, such as GPS, RADAR, and SONAR. Introducing these widely known methods as localization problems will give students a better understanding of the Bluetooth localization algorithm and how this problem is related to other similar technologies. Simple interactive demonstrations can be used to help students participate in each stage of the localization process and to examine how this specific algorithm works. As well as learning the core concepts of the problem, students will be able to identify various areas of application upon completing the exercises. Since Bluetooth operates at a frequency of 2.4 GHz (a commonly used radio frequency), this protocol can even be compared to other similar mechanisms such as Wi-Fi and Wi-Fi direct. Though these protocols work in different ways, many of the same concepts, such multipath and interference must be understood in order to analyze these technologies and use them in application areas. As part of the learning exercises, the similarities and differences between similar technologies such as these can be introduced and discussed. This comparison will help students to understand some of the different methods that are available for wireless communication and how they can be employed in localization schemes.

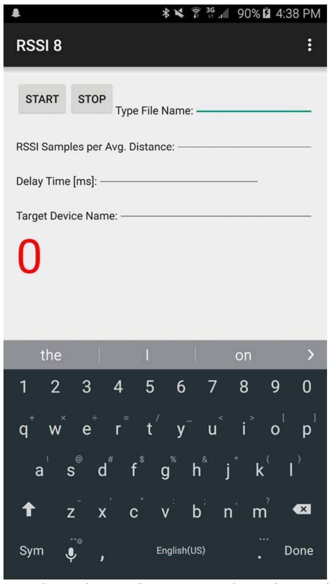

Figure 1: Android application developed for RSSI data logging

In attempting to introduce these ideas into a classroom, it is important to discuss the introduction of mobile devices into the learning environment. Mobile devices can and are beginning to play a larger role in the classroom than ever before. There are several existing applications and platforms that have been developed and used for classroom learning. With online and mobile education becoming widely used, it can be beneficial to use these avenues to help students learn with hands-on activities. One set of applications that has been developed in the signal processing area is Java-DSP (JDSP) [1, 2]. These include the web-based visual programming platform J-DSP [1], the Android-based AJDSP [9], and the iOS-based iJDSP [10]. These apps perform various operations related to digital signal processing. The apps are useful in the classroom because they can take seemingly complex operations and give a visual representation of block diagrams that allow the students to easily break down and understand the process of solving or modeling a specific problem. These apps are able to perform many complex calculations due to the fact that the mobile devices of today have sufficient processing power and memory, and in some cases, connectivity to the internet and other mobile devices. Each device also has a multitude of sensors available, enabling the possibility for including sensor signal processing tasks, the development of mobile health applications, as well as to be used in health-related education modules [6-8]. Even when certain devices do not contain the required hardware, there are add-ons that allow the user to connect to external devices over Bluetooth or Wi-Fi connectivity. In these scenarios, the mobile device acts as the data processor and can display useful information to the user.

In this paper, we describe our work in bringing concepts in localization, ranging, RSSI-based measurements, and algorithm devices into engineering undergraduate classrooms. An app has been developed for collecting received signal strength indicators (RSSI) from Bluetooth transmitters. This data can be used for estimating distances between devices, and subsequently, localization. The app has been used for hands-on activities in class to demonstrate with a simple equivalent, the working of real systems such as GPS. Preliminary results obtained from in-class activities are promising. Further tests, as well as expansions of the app, are planned.

II. Mobile app for Ranging and Localization

In order to record RSSI values in real-time from a transmitting device, an application called "RSSI Data Logger" was developed. The app, shown in Figure 1, was designed so that the user could record as many RSSI samples as desired into a text file on their mobile device. The user has control over certain parameters such as file name, the number of RSSI samples, delay time between Bluetooth scans, and the Service Set Identifier (SSID) of the targeted device. Once the user has defined these parameters, the Bluetooth scan can be initiated and the device will continuously scan for Bluetooth devices within range. Since the RSSI value is available when the Android device is made "discoverable", no pairing of devices is necessary; in fact, this RSSI value becomes hidden when devices are paired.

Because the transmitting device need only be discoverable, this expands the usage to include non-Android devices as well. Table 1 represents all of the devices that have been used in various ranging and RSSI sampling experiments. All of the devices listed with Android Operating Systems can be used as a transmitter or a receiver, while all other devices can only be used as transmitters.

This application is simple to operate and requires minimal user interaction. Once the user has entered the scan parameters, (File name, the number of samples to be taken, delay time between scans, the name of target device), the app will continuously scan for Bluetooth devices within range.

In order to ensure the accuracy of ranging results, a calibration step has been added to the algorithm. What this calibration step allows for is the adaptation of our model to different environments. In some environments, the reflections and attenuation of the signal may cause the curve fitting constants, used to convert power to distance, to change. For example, in some environments, the attenuation constant G has been found experimentally to be much higher than the accepted value in free space. This means that environmental factors such as room size, furniture present, radio interference, and many other factors can influence how quickly the signal attenuates. Once the calibration step has been completed and the curve fitting constants are established, the algorithm then collects the signal strength data from the target device and implements ranging. After each anchor has a range estimate, the least-squares algorithm to triangulate the target can be applied. The algorithm in Figure 4 depicts the current computational method which has the data exported to MATLAB for processing. As discussed in the Future Work section of this paper, an application is currently being developed to perform all calculations in real-time on Android hardware.

A. Classroom Exercises

The app was used in class activities in the spring semester of 2016 in the Digital Signal Processing (EE401) class at Clarkson University. Participants were junior and senior undergraduate students majoring in Electrical Engineering and Computer Engineering. A pre-quiz was administered to the students before the activities began. After a short demonstration and the hands-on activities, a post-quiz and survey were administered. The questions in the pre- and post-quizzes are summarized in table 1. In this section, we describe the exercises performed by the students during this session.

Table 1: Summary of questions given in pre/ post-quizzes

Main Concept	Question Summary
Terminology	A terminology question that asks the participant to correctly assign definitions to the terms "anchor" and "target".
# of Anchors	This question gives the setup for several localization experiments and asks which is likely to be more accurate. The participants were given one choice that had the most anchors and the least number of targets, which is the best case.
Triangulation	Participants are asked where the localization estimate will be when given three ranging circles with one intersection point.
Accuracy I	Participants are given several localization experiment outputs, with ranging circles included, and are asked to choose which one is most likely to be more accurate. The perceived accuracy is based on how closely all of the ranging circles intersect at one point.
Accuracy II	This question asks whether or not ranging estimates need to be perfect in order to get accurate localization estimates. The question is designed to reinforce that noisy range estimates can still be useful when used in the localization algorithm.

Additionally, a similar app that could record Bluetooth Low Energy (BLE) data was used in the Stimulating Opportunities After Retirement (SOAR) program in the Spring semester of 2017 at SUNY Potsdam. SOAR is a member-directed learning group, which is sponsored locally by the college's Center for Lifelong Education and Recreation (CLEAR). SOAR is one of several hundred groups affiliated with the Road Scholar Institute Network [11]. In this program, two ninety minute

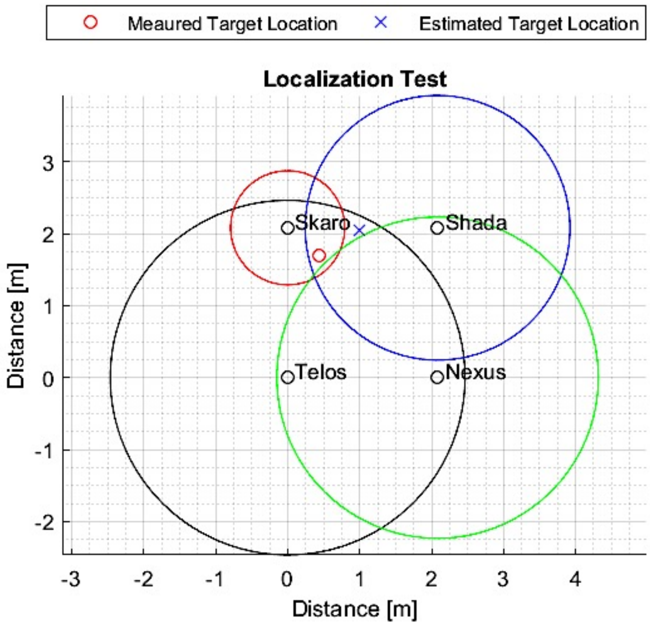

Figure 2: Output from a localization test after data has been collected. The MATLAB script plots and labels the positions of the anchors and the estimated position, as well as the measured position, of the target device.

sessions were used to teach the participants about localization principles like GPS, and a pre-lecture quiz was administered to gauge their prior knowledge of the topic. The participants were then given a presentation on Bluetooth localization and completed a localization exercise before being administered a post-quiz.

The two different groups give a comparison of how these concepts can be taught to college students in the technical fields of Electrical and Computer Engineering (as in the DSP classroom), versus adults who don't necessarily come from technical backgrounds (as in the SOAR coarse).

B. *Ranging Exercise*

In order to demonstrate the first step in localization, ranging, to classroom participants, the application was deployed and several instructions were given to students. In the first step, students, working in pairs, experimented with the devices and measured fluctuating received signal strength values as they moved around the room relative to a transmitting device. This exercise was done to have the class actively participate in the data collection process and to help them understand how distance is related to the RSSI values. Students were also shown that ranging solely from RSSI values can produce errors that need to be dealt with either in preprocessing or in the localization algorithm itself. Further, students were introduced to several concepts that must be considered when performing real-time calculations on hardware. Concepts such as computational power and time vs. accuracy, the number of samples required to produce the desired result, efficiency of calculation vs. speed, etc., were used to show how algorithms can be designed and what the trade-offs may be. These concepts are addressed to give an idea of all the facets involved in developing and implementing algorithms on hardware.

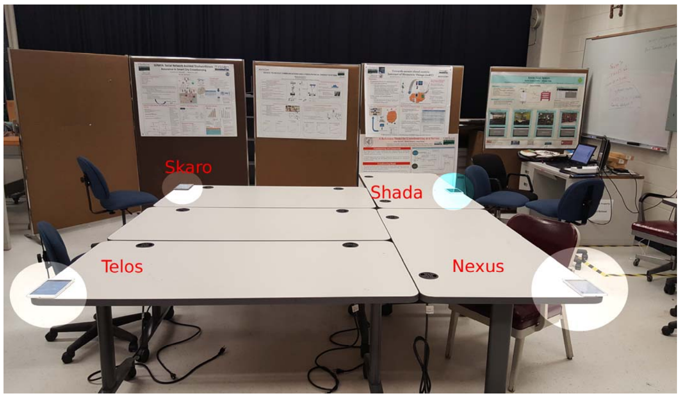

Figure 3: Example of a localization anchor setup

Localization Exercise:

1. Ensure device's Bluetooth is on and open the RSSI Logger app
2. Enter the target device information, number of desired RSSI samples, and any other input parameters in the RSSI Logger app
3. Place the device at predetermined anchor position (masking tape was used to mark pre-measured anchor locations prior to the exercises)
4. If the target is in position, begin scanning by pressing the "Scan" button in the app
5. When enough samples have been taken, the app will stop scanning and the running average value will be on-screen
6. Use the average value RSSI to convert to distance: power [dBm] → power [Watts] → distance [meters]
7. Report ranging estimate to proctor or collect enough ranging estimates to achieve localization

Figure 4: Describing a localization exercise procedure

C. *Localization Exercise*

In this exercise, several groups of students were asked to put their Android devices in specified anchor locations throughout the classroom. Once in position, they were given the SSID of the target device. Once all the parameters were entered into the app, the students would record several RSSI samples from the transmitter. Then using the instructions given to them, would convert the power from dBm to Watts, and then from Watts to distance (in meters). As each subsequent group reported their distance, the localization algorithm in MATLAB solved the problem in real-time in front of the students. Figure 2 is an example of the output of the localization algorithm. Each circle around the anchors represents the distance found and reported by the students. Anchors are denoted by their device names, Skaro, Shada, Nexus, and Telos. This demonstration is especially useful because it allows several groups to contribute to the steps of solving a multilateration problem. Further, the students could see that even though ranging results produced some error, the overall output from the algorithm was able to minimize these errors and produce an acceptably accurate result. The experimental setup is given in figure 3, with the procedure is described in figure 4.

III. Assessment Results

In order to assess the learning of the material, pre- and post-quizzes were given to the students. The quizzes consisted of the same questions and had varying topics that are related to localization. The area where students showed most improvement was related to the number of anchors present to the accuracy of the localization result. The results from the DSP classroom exercises are given in figure 5, while the results from the SOAR program are given in figure 6.

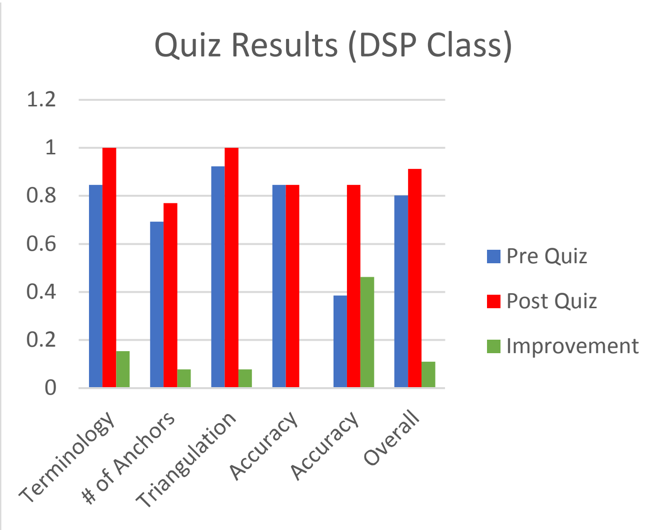

Figure 5: Results from the in-class quizzes (DSP Class)

The questions were designed to reinforce the concepts covered in the lecture and to provide a metric to measure the effectiveness of the lectures and activities on learning.

Further evaluation activities are planned in the fall semester of 2017. Results from these activities and all combined results will be presented at the conference.

IV. Future work

There are several ways to expand these classroom demonstrations in order to cover more concepts that are associated with different topics. In order to include ideas related to EM wave propagation and shielding, a simple Faraday cage could be constructed around one of the Bluetooth devices. The function of this cage will be to shield the device from receiving wireless signals. The exercise would demonstrate that Bluetooth signals are unable to penetrate such an enclosure. Students will be able to see how EM waves can propagate through some materials, such as how Wi-Fi and Bluetooth do with walls but are unable to penetrate through others. Once again these same concepts can apply to many different types of wireless signals.

Further, demonstrations in different environments could be done in order to show students how these differences can affect the propagation of a radio signal. The experiment would have participants collect several RSSI samples at a known distance, and then again at the same distance apart but with a barrier in between. Reflection and interference from obstacles can cause attenuation of the signal and it is an important issue to understand when dealing with wireless communication and Bluetooth localization. In this case, it can be shown that one of the challenges faced with ranging is that the strength of the Bluetooth signal does not necessarily depend solely on distance.

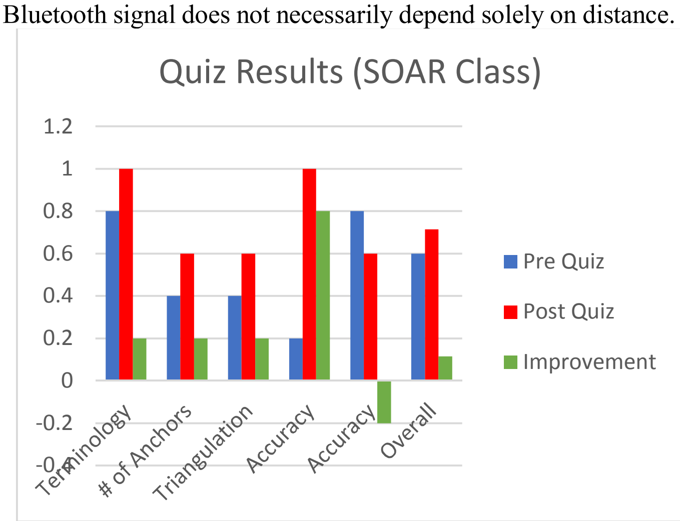

Figure 6: Results from the in-class quizzes (SOAR Class)

Finally, a new Localization app is currently in development which would allow users to perform localization in real-time on their mobile devices. Instead of exporting the data from each subsequent anchor device into MATLAB, the app will allow a master controller device to gather all of the necessary data and to perform all computations. This app allows more complete localization experiments to be performed in front of the classroom and allows for a broader scope of experiments to be performed. More experiments to be performed include testing the number of anchors vs. accuracy of results; whether localizing multiple targets simultaneously will cause interference; how to best use the limited computational power of mobile devices; and localization in different spatial environments.

V. Conclusions

In this paper, we described our efforts to design and use an Android app for Bluetooth ranging and localization for education. The app was used in a session in the Digital Signal Processing class at Clarkson University in the spring semester in 2016. Concepts covered included localization, ranging, and effects of different parameters in the process.

From the data collected in the classroom, it can be seen that the applications developed in this research can be used to teach students about the concepts that are encompassed by localization problems. Since this localization scheme uses Bluetooth hardware and Android devices, topics related to both areas can also be included and discussed alongside the topics specific to localization. Students will also be able to observe the process behind implementing an algorithm on Android hardware and the challenges associated with it. Extensions to the app and further in-class activities are planned to better understand the effectiveness of this tool.

Acknowledgements

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