ECE 445 Design Document
Hawkeye Keyfinders

Kexuan Zou, Mengze Sha, Zeran Zhu

TA: Nicholas Ratajczyk

ECE 445 Senior Design

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1 Introduction

1.1 Objective

When people are looking for small objects, like keys in a limited space, they get crazy. The size of the keys are usually small, it can fit into places like under sofa or bed which make it nearly impossible to find. In this project, we will implement an indoor positioning system using RF (Radio Frequency) and triangulation for localizing hard-to-track objects.

1.2 Background

Several existing commercial products, such as Tile [1], aims to solve this problem. Tile utilizes GPS (the global positioning system) technology and low energy Bluetooth to track a small module attached to the key or whatever item to be located. However, Tile has some flaws: It can only track stationary objects; it utilizes GPS which in some cases is not available or inaccurate. We plan to improve this product by providing the user the key’s exact location, mapped onto a confined space. We will design fixed TX stations which send out RF signal, which will be picked up by RX module as received-signal-strength, and the data will be sent over Bluetooth to a mobile device which is accessible to a human. The mobile device calculates the coordinates of the receiver and visualize the position. The system will be designed to be easily scaled up or down by manipulating the radio power and power source, the solution can be further applied to other fields such as providing accurate indoor positioning for autonomous vehicles when the traditional GPS-based localization is not accurate. For small objects tracking, we will integrate a small solar panel to the circuit so it can last a long time with out changing the batteries. The system can eventually be deployed to various conditions to satisfy different needs, from in-door localization to in-door navigation.

1.3 High Level Requirements

• Power consumption. For this project to be successful, especially for the receiver device, a battery life of at least 6 hours under extreme condition (when no recharging from the solar cell is available due to loss of sun light) should be met.

• Accuracy. Depending on the scale of application of our system, our system must match desired localization accuracy. If used in a 20m*20m room space, the localized position must not be away from the actual position of the object by more than 1m.

• Physical size. Depending on the purpose of application, the receiver unit must have a reasonable size. For example, when used for in-door tracking of small objects, the receiver size should not be too much bigger than a normal key ring. Roughly 7cm * 7cm * 2cm should be the upper limit.
2 Design

2.1 Block Diagram

![Block Diagram Image]

A really good communication system candidate is Bluetooth because it consumes very low power (compared to Wi-Fi). The communication device is responsible for transmitting the RSS data to the compute server or the computed location data to a visualization server. Bluetooth module and embedded micro-controller chip satisfy the requirements of size and power.

2.2 Physical Design

Overall Environmental Setup  Rectangle represents the room, and the circle represents Bluetooth range.
**Transmitter Physical Design** A self-made waterproof case will envelope the transmitter. The case encloses PCB board, battery and the base for antenna. The case will have a hold for the antenna extension, which is about 30 cm long. Overall, the transmitter will be the size of 10cm by 10cm by 4cm. The height may be 30cm if the antenna is positioned vertically.

**Receiver Physical Design** The Receiver, as specified in the previous section, should be roughly 5cm by 5cm by 2cm. This requires sophisticated PCB routing. The receiver antenna will be 3cm in length and placed horizontally.

**Receiver Physical Design** *TO DO: 1. DRAW THE PHYSICAL LOCATIONS OF TXS AND RX. 2. THE SIZE OF THE TX COMPARING TO A QUARTER COIN*

**2.3 Block Design**

**2.3.1 Communication**

**Functional Overview**
The communication block will be broadcasting RSSI data. It receives RSS data from the RX module and sends commands to Bluetooth module to have the calculated position sent to visualization server. We chose Bluetooth because it is very energy efficient, and supports sleep mode. We chose a micro-controller because it will highly reduce our PCB size.

The communication block will be composed of an ATmega328 28-pin controller and a RN-42 class 2 Bluetooth chip which will be good for 10 m. The connection between the two chips will be serial data port, like
the RX/TX serial ports on an Arduino board.

Requirements and Verifications

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>(8/50) 1. Communication module must be able to read RSS data and send it to other end with in ±5%.</td>
<td>1. Read random voltage levels in microcontroller, send them over Bluetooth, connect the Bluetooth module to a Windows computer, and read the data out of the serial port. 2. Verify that they are the within the tolerance.</td>
</tr>
<tr>
<td>(2/50) 2. Range of the Bluetooth module must be at least 5 meters in a living room setting.</td>
<td>1. Connect the Bluetooth to your phone, and step away from it until the signal is lost. 2. Measure the distance.</td>
</tr>
</tbody>
</table>

Supporting Material

![Image of Arduino and Bluetooth module connection](image-url)

Figure 3: Example connection between Arduino and Bluetooth module [3]

2.3.2 Transmitter

Transmitter Function Overview
The transmitters in our project will serve as the RF beacon to provide the receiver all the signal needed to do positioning. We will design and fabricate five transmitters. The physical size, sub components, transmitted signal strength are all the same except for the transmitting frequency, which is around 433Mhz and 500kHz separated from each other. The receiver can tell which transmitter beacon it is detecting by identifying the incoming signal frequency. The reason we need five Txs is to increase the confidence level and precision of in-door positioning.

Transmitter Components Circuit
The transmitter circuit can be broken down into oscillator, matching network, and antenna. The overall transition chart is attached below.
Oscillator  We use the classical Colpitts Oscillator [7] as the source of transmitter. By changing the capacitance and reactance of the tank circuit, a tunable frequency oscillator can be realized.

![Figure 4: The transmitter signal flow chart](image)

The frequency of the oscillator is given as:

\[
    f_{\text{resonant}} = \frac{1}{2\pi \sqrt{L_1 \times C_{\text{tank}}}}
\]

where,

\[
    C_{\text{tank}} = \frac{C_1C_2}{C_1 + C_2}
\]

By pluggin in the value in the simulation, we set the operating frequency at 433 Mhz.

![Figure 5: The oscillator circuit diagram](image)
The S11 showed in the figure is the one-port S-parameter measuring the reflection of the incident signal. A peak is detected at around 434.5MHz, indicating the oscillation frequency.

**Matching Networks**  The matching network, specifically L-network[8], will maintain the matched impedance through the whole transmitter chain to achieve maximum power transfer. From the simulation, the output impedance of the oscillator is 286 Ω, the input impedance of the amplifier is 50 Ω. We denote this as matching network A. Here we denote the output impedance of the oscillator, 286 Ω, as $R_{\text{Big}}$ and the input impedance of the amplifier, 50 Ω, as $R_{\text{Small}}$. The matching network design method is as following:

$$Q = \sqrt{\frac{R_{\text{Big}}}{R_{\text{Small}}} - 1} \quad (3)$$

$$X_p = \pm \frac{R_{\text{Big}}}{Q} \quad (4)$$

$$X_s = \mp \frac{R_{\text{Small}}}{Q} \quad (5)$$

Where X stands for reactance and subscript p and s stands for parallel and series connection. The inductance and capacitance can be further calculated from reactance X at the given operating frequency $\omega$.

$$L = \frac{X}{\omega}, \quad C = \frac{1}{X\omega} \quad (6)$$

Following the above equations, we implement the impedance matching network(MN) shown below. There are MNs between the amplifier and antenna of the TX (MN A), antenna and the LNA of the RX (MN B), LNA and the coupler(MN C), power splitter and RSSI chip (MN D) at the receiver side. We adopt the same method to figure out the LC value. A detailed table documenting all those MN components value can be found at the end of receiver section.
**Antenna**  We will buy the 10 dBi omni-antenna for the transmitters operating at 433Mhz. The impedance is 50Ω and the gain is 8dB. The antenna will hook up to the bandpass filter.

**Requirements and Verifications**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
</table>
| (6/50) 1. The matching networks should work within the 3-dB bandwidth of the transmitted signal. The mismatching factor (MF) from ports of different components must be larger than 0.8 | 1. A. Simulate and measure the impedance over the bandwidth.  
B. Measure the impedance of each port from multimeter and calculate the MF. |
| (7/50) 2. The signal detected at the receiver should be at least -90 dBm      | 2. Attach the antenna used in the receiver on the spectrum analyzer and record the data 10 meters away from the transmitter |
| (5/50) 3. The bandpass filter must be able to have the stopband attenuation less than -30dB and less then -5dB attenuation for passband. | 3. We will run the simulation first to verify the result then use the network analyzer to monitor the filter performance. |

**2.3.3 Receiver**

**Receiver Function Overview**

We will attach the Rx to the item to be positioned. Since we have five Txs transmitting different frequency signal, the Rx will have five channels, corresponding to those five different frequencies after the filtering, and correlate the received signal strength to voltage information. We will use the AD8310[10] log-Amp to perform this task. The output voltage will be directed to the communication block for the computing.

**Receiver Circuit**

The receiver circuit has antenna, band pass filters, Low Noise Amplifier(LNA), Isolator(directional coupler),RSSI chip, power splitter, and matching networks. An overview of block layout is attached below.
**Antenna**  We will buy the 2 dBi omni-antenna for the receiver operating at 433Mhz. The impedance is 50Ω. The antenna connects to the bandpass filter.

**Directional Coupler**  We will use the directional coupler, chip number CP0402W2700FNTR[20], as an isolator to prevent signal leakage back to receiver antenna and radiate away. The coupler we use will have 0.3dB insertion loss[20], meaning only 7 percent of the power being wasted at the component.

**Power Splitter**  The power splitters we use will divide the incoming signal evenly to two output ports. In our design, we will have 5 RSSI chips. Therefore, the one receiver channel from antenna needs to be split to five channel. We will use 4 power splitter chips, Model PD0922J5050S2HF[21]. Three of chips will divide the incoming channel into 4 channels and one extra chip will further divide one channel to create the ultimate 5 channels. The insertion loss of the chip is low as 0.4dB and the amplitude balance figure and phase balance figure shows very little distortion to the divided signal, hence a good candidate for the power splitter.

**Bandpass-filters**  The RLC band-pass filter will cancel out signal in the unwanted frequency band. By achieving this, the greater SNR will be expected and thus the receiver can detect the signal better. By the aid of [13], we designed 3rd BPF filter centered at 433 Mhz with 10 Mhz passband and -5dB maximum passband ripple.

![Figure 9: The Bandpass Filter circuit diagram](image)

The simulated performance matches the expectation:

![Figure 10: The Bandpass Filter circuit simulation](image)
**Power Amplifier** We use the Class A broadband amplifier[9] to boost the received signal strength. The gain is around 18dB around 433 Mhz. The power evaluation is necessary to calculate the Rx’s battery life since it is the major power sunk in the Rx.

Figure 11: The circuit diagram of the amplifier

By adjusting the resistance, the gain can be tuned.
The S21 showed in the figure is one of the four two port S-parameter denoting the forward transmission gain. The result shows that 18dB power gain is observed at the operating frequency.

**Supporting Material**

The AD8310 chip[10] can identify the input signal strength as low as -87 dBm and interpret it as output voltage.
**MN value documentation**  The documentation of inductance and capacitance we use is listed below. The naming convention follows what we defined earlier at the transmitter and receiver blocks diagram.

<table>
<thead>
<tr>
<th>MN values</th>
<th></th>
<th></th>
<th>source impedance(Ω)</th>
<th>load impedance(Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN A</td>
<td>48</td>
<td>3.4</td>
<td>286</td>
<td>50</td>
</tr>
<tr>
<td>MN B</td>
<td>6.81</td>
<td>3.26</td>
<td>50</td>
<td>9.87</td>
</tr>
<tr>
<td>MN C</td>
<td>56</td>
<td>2.7</td>
<td>418</td>
<td>50</td>
</tr>
<tr>
<td>MN D</td>
<td>41.37</td>
<td>19.81</td>
<td>50</td>
<td>41.76</td>
</tr>
</tbody>
</table>

**Requirements and Verifications**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>(6/50) 1. The battery life of the Receiver must last longer than 6 hours.</td>
<td>1. We will probe the battery and monitor its voltage level over 6 hours and plot the power assumption graph.</td>
</tr>
<tr>
<td>(6/50) 2. The correct voltage output of the RSSI chip must be picked up correctly and communicate to the server with low latency. A. The output voltage error should be smaller than +0.05V. B. The latency between RSSI chip collecting the input level and the server receiving the data should be less than 10ms.</td>
<td>2. To test A. We will monitor the output voltage at the pin and compare it with the suggesting graph given by the datasheet. If the error is within 0.05V, the result is satisfactory. B. We will compute the latency by logs of the bluetooth module and the server. Since the key is supposed to be stationary in our project, if less than 10ms detected between log entries, the result would be satisfactory.</td>
</tr>
</tbody>
</table>

### 2.3.4 Power

**Transmitter Power management**  Since the role the transmitter plays in our project is merely a single pulse generator, the only components that will consume power is the BJT, or the amplifier. The input voltage feeding into the BJT is 12V. The RF choke, or an inductor, is necessary to block the RF signal to flow back into battery and guarantee better power delivery to the antenna. The choke will be placed between the collector and the power supply. Reader can refer to the transmitter section for detailed schematics. The power supply would be 12V batteries.

**Receiver Power Management**  Some of the components that consume power in the receiver is the pre-amplifier, bluetooth, ATmega 328 chip, and the RSSI chip. Here is a list of different components power voltage information.

<table>
<thead>
<tr>
<th>Power voltage of components of the Rx</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Input voltage (V)</td>
</tr>
<tr>
<td>Pre-Amplifier</td>
<td>12</td>
</tr>
<tr>
<td>Bluetooth [3]</td>
<td>5</td>
</tr>
<tr>
<td>ATmega 328 [4]</td>
<td>5</td>
</tr>
<tr>
<td>RSSI [10]</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Thus two voltage regulators are necessary to transfer 12V supply to 3.3V and 5V. We will use AP 2120N-3.3TRG1 \cite{18} to perform the 3.3V transformation and L78L\cite{19} to do the 5V task.

In our project, to increase the Rx’s lifehour, we will incorporate a solar panel to it. Thus the battery we use for the Rx will be 12V recharged battery. The size solar panel must be comparable respected to the receiver physical size. We will use Sundance Solar 700-10850-23 12.0V 45mA \cite{22} solar panels. Since our solar panel power output is 0.54 watts at most, we do not need a charging controller for it.

2.3.5 Server

Localization algorithm overview In this section we present a robust, accurate localization algorithm that utilizes received signal strength indicator (RSSI) corresponding to each transmitters. Generally, the RSSI distance method depends on the RSS from fixed transmitter anchors and a distance-loss model to evaluate the user’s position through a localization algorithm, which we will discuss later this section. Recall that in our block diagram, 5 transmitters are specified in the RF modules and are deployed at different physical locations. Let \((x^{(i)}, y^{(i)})\) designate the physical location of transmitter \(TX_i\), then the receiver \(RX\) would receive a distinct \(RSSI_i\) for each transmitter anchor. \(RX\) then collects all RSSI and send them to the server via Bluetooth in real-time, where the server carried out the algorithm to determine the distance of \(RX\) to each \(TX_i\) and map the trackable object in a Cartesian coordinate system. The localization algorithm can use a minimum of 3 RSSI values to evaluate the approximate location of the object, but to make the algorithm more robust, our proposed method utilizes all 5 transmitter anchors each time.

Figure 14: Overview of localization algorithm and server setup

Log distance path loss model For this problem we use the mainstream log distance path loss model. It can be used to predict the propagation loss for radio waves in a certain medium (i.e. air) so that we can
calculate the approximated distance from TX to RX. When TX is moved from its original position \(d_0\) to \(d\), the path loss (measures in dB) at \(d > d_0\) is given by [5]

\[
\text{RSSI}_{d_0 \rightarrow d}(d) = \text{RSSI}(d_0) - 20 \log \left(\frac{d}{d_0}\right) + \mathcal{O}(\chi_{\sigma}).
\]

where \(\chi_{\sigma}\) is a Gaussian distributed random variable with standard deviation \(\sigma\) [5]. To simplify calculation, we let \(d_0 = 1\) m [6] and so we have the following

\[
\text{RSSI}_d = -20 \log(d) + \overline{\text{RSSI}}_{d_0},
\]

where \(\overline{\text{RSSI}}_{d_0}\) is the mean RSSI received by RX at \(d = 1\) m.

**Localization algorithm** For simplicity of illustration, assume there are 3 TX anchors in range of RX, the location of RX and TX are \((x_r, y_r)\), \((x_i, y_i)\), respectively, in a Cartesian coordinate system, and \(d_i'\) designates the estimated distance between TX\(i\) and RX we obtained from equation 8, then the squared error \(\delta^2\) between \(d_i\) and \(d_i'\) is

\[
\delta_i^2 = (d_i - d_i')^2 = (x_r - x_i)^2 + (y_r - y_i)^2 - d_i'^2 \\
= 2x_r x_i + 2y_r y_i - (x_r^2 + y_r^2)
\]

We have the following linear equation [6]

\[
w^T x = y,
\]

where

\[
x = \begin{bmatrix} 2(x_1 - x_3) \\ 2(y_1 - y_3) \end{bmatrix}, w = \begin{bmatrix} x_r \\ y_r \end{bmatrix}, y = \begin{bmatrix} x_r^2 + y_r^2 - x_i^2 - y_i^2 - d_i'^2 + d_i^2 \\ x_i^2 + y_i^2 - x_r^2 - y_r^2 - d_r'^2 + d_r^2 \end{bmatrix}
\]

To find optimal \(w\), we have the ordinary least square form as an analytical solution

\[
\hat{w} = (x^T x)^{-1} X^T y
\]

And \(w = [x_r, y_r]^T\) is the estimated location of RX.

**Bootstrap aggregation** Since the above procedure only utilize 3 TX anchors, in our scenario we can evaluate \(w\) for the combination of every 3 TX anchors and uses majority voting to determine the most likely position of RX. This intuition is supported by statistical groundings and is a widely accepted technique in machine learning. Formally, we define a weaker learner to be a regressor or classifier that is only slightly related to the true regressor or classifier, with a probability \(\epsilon < 0.5\) for misclassification. In bootstrap aggregating, we fit \(m\) weak learners \(\hat{h}_i(x) \rightarrow \hat{y}_i\) for \(i \in [m]\), each has misclassification rate of \(\epsilon < 0.5\). The \(m\) models are combined by majority voting to create the final, more accurate classifier.

To see why bootstrap aggregation reduces error rate for our localization algorithm discussed above, let us suppose that each individual weak learner we obtained from equation 11 has error rate \(\epsilon = 0.4\). We have 5 TX anchors in total, and so we have 5C3 = 10 weak learners. Assume each weak learner is built independently, then we have a binomial distribution \(B(n = 10, p_0 = 0.6)\), where number of trials \(n = 10\) and success probability in each trial \(p_0 = 0.6\). Majority voting requires at least half of the weak learners to success in their predictions, and so by using bootstrap aggregation we can achieve a success rate of \(P(X \geq 5) = 0.83\), as illustrated by figure 12.
Figure 15: Binomial distribution \( B(n = 10, p_0 = 0.6) \). The red region represents the probability where at least half of the weak learners succeed.

**Visualization**  After we have \( RX \)'s location \((x_r, y_r)\), and predefined \( TXs \)'s locations \((x_i, y_i)\), \(\forall i \in [n]\), these points are rendered in a custom map so users can track the object in real time. For the purpose of demonstration, we will use Windows as our platform because it supports Bluetooth communication of raw data packets, and run a python script that draws illustrations on an interactive canvas. Since the localization algorithm is somewhat computationally-heavy, and the program is expected to update coordinates in real-time, we will limit the visualization program to minimal visual effects so as to save some computational cost. The Cartesian coordinate system makes integration to GPS coordinates simple, but we won’t go into details for now.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>((7/50)) 1. Distance predicted by the final estimator ( h^* ) should be within a 1-meter radius of its true location.</td>
<td>1. For each instance of validation, the distance ((\hat{x}, \hat{y})) estimated using the localization algorithm is compared with its physical location ((x, y)).</td>
</tr>
<tr>
<td>((3/50)) 2. The visualization tool should run at a rate of 10 frames per second to achieve real-time location update.</td>
<td>1. measure the time difference of each iteration of the algorithm and make sure each one of them takes at most 10 − (\xi), (\xi \geq 0) (ms) to finish.</td>
</tr>
</tbody>
</table>

### 3 Tolerance Analysis

**Impedance Mismatching**  To ensure the receiver can successfully pick up the signal from the Tx through air attenuation and path loss, the available power delivered to the transmitter antenna must be optimized. This can be done by conjugated impedance matching through the whole network. Reflection between different sub-components of the transmitter is minimized.

The reflection coefficient when load is matched with 50Ω reference impedance is given by:
\[
\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{50 - 50}{50 + 50} = 0
\] (12)

where \(Z_0\) is 50.

The mismatched power loss is given by:

\[
ML_{dB} = -10 \log_{10}(1 - \rho^2)
\] (13)

\[
\rho = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|}
\] (14)

From the [16], the capacitance variation is 5 percent.
The inductance variation is 10 percent. [17]

By changing all those values by the maximum variation, we simulate the worst case:

\[\text{Figure 16: Tx simulation without matching networks}\]

m2 marks the result without matching network and m1 is the one with the MN. The remarkable difference between two signal strength illustrates the importance of adopting the MN.
The difference is simply:

\[
difference = 20 \log_{10} \left( 10^{\frac{-21.209}{20}} - 10^{\frac{-31.619}{20}} \right) = -24.18 dB
\] (15)

The theoretical relative difference is 0.2 between the MF of matched and maximum allowed MF 0.8. After converting to dB scale, the theoretical value is about -7dB. The simulation result lies much smaller comparing to -7dB. Therefore, The tolerance analysis is passed.

The components variation will also shift the resonant frequency. The BPF has the passband of 10Mhz and the separation between different transmitted signal is 10Mhz. The half of the separation is 5Mhz. Frequency derivation within this range will stay in the filter passband and not interfere other transmitted band. The maximum frequency shift in the worst case is 4.2Mhz, within the 5Mhz range.

**Signal Strength Detection**  With the maximum mismatching factor we calculated above and the possible path loss at 10 meters away given by:

\[
FSPL = 20 \log_{10}(d) + 20 \log_{10}(f) + 20 \log_{10}\left(\frac{4 \pi}{c}\right) - G_t - G_r = 29.17 dB
\] (16)

where the \(d\) denotes the distance, \(f\) the frequency, \(c\) the speed of light, \(G_t\) the transmitter gain, and \(G_r\) the receiver gain. All above units are in SI.

In the receiver section we mentioned the minimum signal strength the RSSI chip can pick up is -87 dBm. The directional coupler will have insertion loss -2dB. With the maximum tolerance included, we can calculate the minimum signal detected by the RSSI chip:

\[
RXRSS = (TXRSS) - 31.7 dBm - (PathLoss)29.17 dBm - (Couplerloss)3dB - (MNloss * 3)30dB - (BPFpassbandloss)3dB + (TX, RXcross - polarized)0dB + (PreampGain)18dB = -78 dBm <= -87 dBm
\]

Therefore, including the worst scenario, the RX can still differentiate the incoming signal. This means our design passes the tolerance check.

4 Cost and Schedule

4.1 Cost Analysis

**Labor**

\[3 \times $40/h \times 10h/week \times 16weeks = $19.2k\]

**Parts**
### Cost analysis

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost (Prototype)</th>
<th>Cost (Bulk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD8310ARMZ-REEL7TR-ND (Log Amp) *5</td>
<td>$54.95</td>
<td>$21.5</td>
</tr>
<tr>
<td>ATmega328PU</td>
<td>$4.33</td>
<td>$1.63</td>
</tr>
<tr>
<td>RN-42</td>
<td>$24.95</td>
<td>$24.95</td>
</tr>
<tr>
<td>PCB *6</td>
<td>$198</td>
<td>$22.6</td>
</tr>
<tr>
<td>Transmitter Antenna *5</td>
<td>$17.15</td>
<td>$17.15</td>
</tr>
<tr>
<td>Receiver Antenna</td>
<td>$2</td>
<td>$2</td>
</tr>
<tr>
<td>Resistor SMT *60</td>
<td>$6</td>
<td>$0.08</td>
</tr>
<tr>
<td>Inductor SMT *50</td>
<td>$12</td>
<td>$0.2</td>
</tr>
<tr>
<td>Capacitor SMT *80</td>
<td>$8</td>
<td>$0.18</td>
</tr>
<tr>
<td>Power divider *4[19]</td>
<td>$2.96</td>
<td>$1.56</td>
</tr>
<tr>
<td>Directional coupler[20]</td>
<td>$0.55</td>
<td>$0.33</td>
</tr>
<tr>
<td>Voltage regulators[21]</td>
<td>$0.73</td>
<td>$0.35</td>
</tr>
<tr>
<td>Solar panel[22]</td>
<td>$10.49</td>
<td>$10.49</td>
</tr>
</tbody>
</table>

### 4.2 Schedule
<table>
<thead>
<tr>
<th>Week</th>
<th>Kexuan Zou</th>
<th>Mengze Sha</th>
<th>Zeran Zhu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct.01</td>
<td>Finish localization algorithm research and adaptation to our design.</td>
<td>Finish the transmitter circuit design and simulation. Buy antennas, RSSI Chips for Rx and Tx</td>
<td>Finish Bluetooth module research and parts selection.</td>
</tr>
<tr>
<td>Oct.08</td>
<td>Fine-tune and verify bootstrap aggregation scheme based on the theoretical RX readings.</td>
<td>Finish the Rx circuit design and simulation</td>
<td>Finish Bluetooth serial port communication hook up and testing. Finish Serial port communication and Bluetooth module control code which runs on Arduino.</td>
</tr>
<tr>
<td>Oct.15</td>
<td>Help with PCB layout design/hardware integration.</td>
<td>Finish the Rx and Tx PCB layout design and get ready for the first round PCB order</td>
<td>Design Bluetooth module interconnection with PCB.</td>
</tr>
<tr>
<td>Oct.22</td>
<td>Start working on server integration, localization algorithm implementation and optimization.</td>
<td>Solder one transmitter and receiver module and test the performance, verify the RSSI chip works</td>
<td>Design and verify the lower and upper interface. Lower interface talks to the receiver module, and upper interface uploads data to server.</td>
</tr>
<tr>
<td>Oct.29</td>
<td>Measure RSSI readings based on the finished RX prototype. Fine-tune leaning models if necessary.</td>
<td>Modify the circuit diagram and get ready for the second round PCB order</td>
<td>Integrate Bluetooth module with ATmega328 chip.</td>
</tr>
<tr>
<td>Nov.05</td>
<td>Continue to work on server integration, start working on map visualization.</td>
<td>Solder one transmitter and receiver module and test the performance</td>
<td>Solder Bluetooth to receiver.</td>
</tr>
<tr>
<td>Nov.12</td>
<td>Help Solder all five transmitters.</td>
<td>Solder all five transmitters</td>
<td>Help solder all five transmitters.</td>
</tr>
<tr>
<td>Nov.19</td>
<td>Test the performance of the receiver and verify if the localization works.</td>
<td>Test the performance of the receiver and verify if the localization works.</td>
<td>Test the performance of the receiver and verify if the localization works.</td>
</tr>
<tr>
<td>Nov.26</td>
<td>Finalize the hardware modification if any. Continue to work on map visualization.</td>
<td>Finalize the hardware modification if any. Assist the software side of the project.</td>
<td>Finalize the hardware modification if any. Assist the software side of the project.</td>
</tr>
<tr>
<td>Dec.03</td>
<td>Wrap up the project, prepare for the final presentation and start working on the final report.</td>
<td>Wrap up the project, prepare for the final presentation and start working on the final report.</td>
<td>Wrap up the project, prepare for the final presentation and start working on the final report.</td>
</tr>
<tr>
<td>Dec.10</td>
<td>Finish the final report.</td>
<td>Finish the final report.</td>
<td>Finish the final report.</td>
</tr>
</tbody>
</table>

### 5 Design Ethics and Safety

Compared to other works for similar purposes, our proposed design poses fewer potential safety hazards, partially because of the low-power nature of the product. Both the TX anchor the RX beacon are powered by 6V DC power source. Further, Bluetooth chip and microprocessor operates under 5V DC power source, diminishing the risk of electric shocks. However, electrostatic discharges can negatively affect the accuracy of localization results and even damage the chips. Therefore, when handling and testing our prototype, especially those exposed components, extra caution is advised to avoid electrostatic discharges.

Part of our design involves complex printed circuit board design. This is especially the case for RX module, which requires the receiver circuitry, microcontroller and Bluetooth chip to integrate on a relatively compact space. Therefore, we need to solder parts on the board with great care to prevent short circuitry.

More than one module requires wireless communication. This is either achieved by custom RF transmitter(s) with 433 MHz radio frequency, or low-power Bluetooth chip with 2.4 GHz frequency. These frequencies not only comply with Federal Communications Commission (FCC) standards [14], but also impose no threats...
to human bodies.

Despite various tolerance analysis and hardware/software validations, our product is high experimental, and is prone to errors or inaccurate results in different environments. We adhere to IEEE code of ethics #3 [15]: "to be honest and realistic in stating claims or estimates based on available data" and will not make dishonest or unrealistic claims regarding test results and estimated cost. We will also make hardware designs accessible and localization algorithms open sourced so that we make effort to "improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies" [15].
References


