ECE 445 Project Proposal
Hawkeye Keyfinders

Kexuan Zou, Mengze Sha, Zeran Zhu

TA: Nicholas Ratajczyk

ECE 445 Senior Design

September 2018

1 Objectives and Background

1.1 Goals and Benefits

- Implement an indoor positioning system using RF and triangulation.
- Design RX and TX prototypes so that the system can be up-scaled easily.
- Design communication networks using Bluetooth for RX devices to broadcast locations.
- Design small and energy-efficient RX devices that can be hooked up to target being tracked.
- Can be deployed to various conditions to satisfy different needs, from in-door localization to in-door navigation.

1.2 Background

- Imagine a scenario when you are about to leave the dorm but you cannot find the keys. You search everywhere in your dorm and feel really frustrated. Because 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.
- Several existing commercial products, such as Tile [1], aims to solve this problem. Tile utilizes GPS technology and low energy Bluetooth to track a small module attached to the key or whatever item to be located. The tile can provide audio feedback to alarm the users. We plan to improve this product by providing the user the key's exact location, mapped onto a confined space.
- Since the nature of our solution is about indoor positioning, 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.

1.3 High Level Requirements

1.3.1 Transmitters

- TX must be fixed and always transmit signal at fixed frequency.
- The strength of the signal transmitted must be strong enough that the receiver can identify it from noise.

1.3.2 Receiver

- RX must be able to monitor a frequency either constantly or upon request.
- RX must be able to either send RSS data to compute server or send computed data to visualization server.
- Accuracy must be guaranteed, depending on the scale of room.

1.3.3 Power Supply Unit

- TX power supply must be sustainable.

1.3.4 Other Specifications

- Total cost of each TX/RX device must be under $30 each.
- Localization algorithm must be fast enough to visualize position in real-time.
- Connection from the compute/visualize server to the Bluetooth must have low enough latency.
- The receiver's physical size should be small comparing to the key dimension and easy to carry.

2 Solution Overview

- The solution we come up with harnesses the wireless communication technology. We will attach a receiver to the key to be found. We will place several stationary transmitter towers for tracking purpose. The user will hand-held a device that is able to do real-time data processing. The receiver's can interpret the incoming signal strength information and hence can be triangulated by those transmitter towers. The users can read the receiver's location on their phone. The receiver also will give the users feedback if they are getting closer to the key.

3 Subsystems and Module Description and Requirements

3.1 RF Modules (PCB)

3.1.1 Transmitters

- We need 5 transmitters to conduct localization. The frequency of signal transmitted from different transmitters will have significant separation to avoid information interference. This can be realized by incorporating voltage controlled oscillator(VCO) in our design. By powering different voltage to the VCOs, the controllable output frequency will be achieved. Overall, the frequency of signal sent will fall into VHF spectrum range (30 - 300 MHz) to reduce the path loss.
- Apart from VCOs, the transmitters have the low noise amplifiers(LNA) and matching networks(MN) to maximize the signal strength and enlarge the signal propagation distance.
- Requirement: The frequency separation between different transmitted signal should be larger than 2 kHz.

3.1.2 Receiver

- The receiver splits the incoming signal spectrum into five bands, each corresponding to one frequency band of transmitter, and calculates the signal strength within that band. The signal strength information(SSI) detector will output the SSI as voltage to the data processing unit, in our case the Arduino board.
- The receiver is the circuit-heavy part of our project where we implement the MN, BPFs, and LNAs to maximize the signal to noise ratio(SNR) without introducing new unwanted signals.
- Requirement: The SNR of the signal after BPF and LNA should be larger than 30dB.

3.2 Communication

- 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.
- Requirement: The latency of the communication between receivers and hand-held device should be at ms level.

3.3 Servers

- We need servers because RSS are detected on the location to be tracked. Eventually the data collected must be sent through some wireless methods to a server, whether to compute the location or just visualizing the location.
- In both cases (evaluation and visualization), the server will just be a hand-held mobile device like a phone or an iPad, or even a laptop or we run out-of-time on mobile software development.

- If raw RSS data is sent to the server, there will be algorithms developed by us to do multiple triangulation and location mapping.
- Requirement: For visualization, the software must draw the fixed TX stations on a map on the screen. Then, fit the triangulated target into the map with calculated coordinates.

3.3.1 Localization Algorithm

- The algorithm should take advantage of the RSS data from the back-up TX devices in the case when one or more TX device(s) is being blocked by an obstacle, so as to increase the robustness of the system. For example, in our proposed design there are 5 active TX devices sending RSS intensity $I_1, ..., I_5$ to the embedded chip and only 3 RSS signals are required to compute the exact location (x_c, y_c) of the tracker. There are $5C3 = 10$ possible combinations $(x^{(1)}, y^{(1)}), ..., (x^{(10)}, y^{(10)})$ of where the object might be. In this case we use majority voting to determine where most probable the object's location might be.
- The algorithm must map the intermediate results back to a pair of coordinates $(x_c, y_c) \in \mathbb{R}^2$ so they can be rendered on a map with precision of several centimeters that are comparable to the physical size of the receiver. In other words, for given localization error ϵ we have the probability density function of the location as
$$f_r(x_c, y_c) = \frac{1}{\pi\epsilon^2}.$$
- Requirement: Localization algorithm must be time-efficient enough to provide real-time results on a low-power embedded chip.

3.4 Power

3.4.1 Fixed Station Power Supply

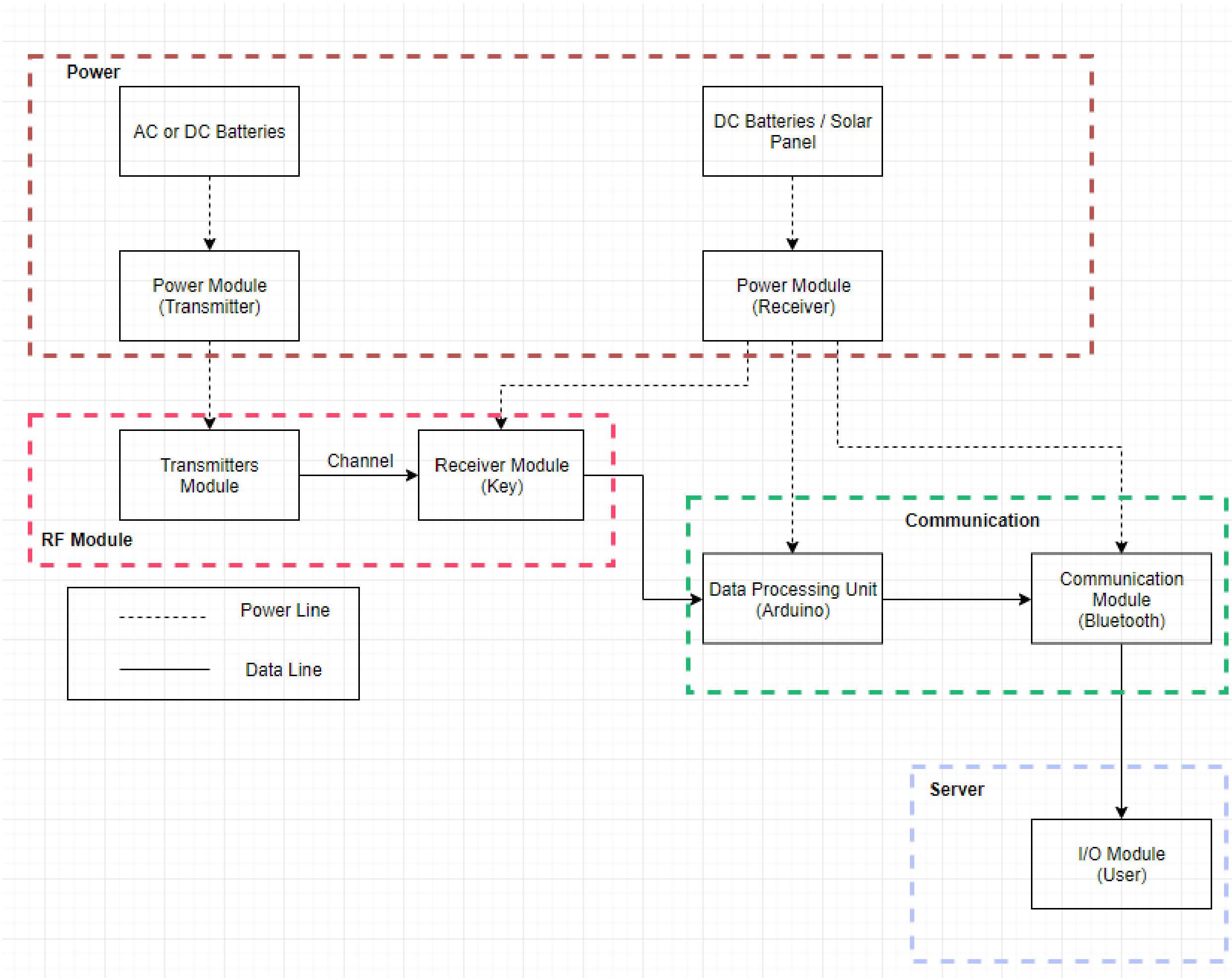
- TX stations are fixed, so we can use 110v adapters as power supply. The AC/DC converter will be necessary in that circumstances. However, maybe batteries should be enough unless we are transmitting over a very large space like a stadium.
- We plan to implement a voltage regulator to control the voltage feed into those VCOs. The voltage difference should be significant to reflect the separation between transmitted signal frequency.
- Requirement: The voltage regulator must regulate the voltage separation to be 0.8-1.2 V [2].

3.4.2 Sensor Power Supply

- RX stations can consume a little more power because apart from monitoring different frequencies and receiving signals, they also have to send data to servers using Bluetooth.
- The voltage regulator can be coded to Arduino board to regulate the voltage level of LNAs and SSI detectors.
- We plan to try to use button cell batteries, and switch to small volume Li battery packs if they are not enough. For extended battery life and reduce the overhead of changing batteries, we can incorporate tiny solar panels to charge the battery.
- Requirement: The Rx's battery life should be sustainable enough to last more than 1 month.

4 Design

4.1 Block Diagram



4.2 Risk Analysis

Since the success of our project heavily relies on whether the receiver can evaluate the signal strength information and output voltage, the RF modules where SSI detectors reside in must be fabricated and tested as early as possible to avoid delays of the project pace. We will first simulate the transceiver's' performance in SPICE software such as ADS and use through hole board to test them in real settings.

5 Ethics and Safety

5.1 Ethics of the Product

Due to the nature of this real-time localization system, user must utilize this product in a legitimate and ethical way. Further, if this product is employed in a location-based service, user should implement certain obfuscation scheme to mask the exact location of each object unless the object is being directly queried.

5.2 Safety Concerns

In lab environment, the device operates on low-power, DC power source that reduces the risk of electric shocks; however, electrostatic discharge can negatively affect the accuracy of localization results and even damage the chips.

References

[1] Tile Inc, ”Find Your Keys, Wallet & Phone with Tile's App and Bluetooth Tracker Device” , [Online]. Available: https://www.thetileapp.com/en-us/. [Accessed: Sept. 20, 2018].

[2] Texas Instruments, ”SN54LS624 THRU SN54LS629, SN74LS624 THRU SN74LS629, VOLTAGE-CONTROLLED OSCILLATORS” [Online]. Available: http://www.ti.com/lit/ds/symlink/sn74ls624.pdf. [Accessed: Sept. 20, 2018].