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Integration of Personnel Tracking in an Augmented Reality Environment

Design Document

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List of Definitions

CSI/Channel State Information: Properties of a communication link, including information that describes how a signal propagates from the transmitter to the receiver and represents the combined effect of, for example, scattering, fading, and power decay with distance (Wikipedia)

RSSI/Received Signal Strength Indicator: a measurement of the power present in a received radio signal (Wikipedia)

Megaproject: large-scale, complex ventures that typically cost $1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people (Wikipedia)

1 Introduction

1.1 Acknowledgement

We would like to thank our advisor, Dr. Daji Qiao, for pointing us in the right direction when it comes to wireless communications technologies and helping us come up with viable tracking solution.

We would also like to acknowledge our client Andrew, CEO of Optical Operations. He always believes in us and gives us hope whenever we would meet. He is the ideal client, giving the team concise requirements and being understanding of our lives outside of senior design.

1.2 Problem and Project Statement

Problem Statement:
There are inherently a lot of problems with not knowing where people are located at. Whether they are in the location they say they are, or if they are missing and others are trying to find them. When workers can not be located, there are safety concerns. If you are working with something dangerous that could harm somebody such as demolition on a building. It can also mean people can get hurt doing something they shouldn't be and lie because you have no way of seeing where they were and what they were doing. Specifically for this project, Optical Operations LLC wants to solve the problem of general contractors not having access to their personnels' locations for construction megaprojects (projects costing upwards of $1 billion). Not having accountability for workers leads to loss of money and time on these projects and can make a huge difference in budget and schedule.

Project Statement: The goal of the project is to create a Microsoft Hololens application that shows a live map of where different people are at any given time. The personnel are tracked through a small token, which is attached to issued Personal Perspective Equipment (PPE). This small token communicates with a distributed tracking system that relays data to the Hololens, and a supervisor will utilize this Hololens application for monitoring purposes.

1.3 Goals

Our team would like to have a finished, working, tracking system and Hololens application that can accurately track 6 or more people in a playground-sized (20 meter x 20 meter) environment. Our accuracy goal is to have no more than a 5 meter differential between token reported location and actual location.

We want to also be able to provide our customer with a realistically-sized token that can be attached onto a belt clip. This would allow users to wear it without it interfering with other protective gear. This is an alternative to putting it onto a hard hat, since construction workers often throw their hard hats on the ground, and we would not want to break the device.

1.4 Operational Environment

There will be two specific environments where the system will be in. There will be one where the personnel who will be wearing the token device. This environment will be outside in a construction site. This construction site will have fast wifi throughout the entire site. The speed of the wifi will be 60 Mb/s and above. The second environment will be the Microsoft Hololens setting. The people using the Hololens will be in an office setting, specifically there should be a large table where the hologram will be displayed on. This room must have high availability wifi.

1.5 Intended Users and Uses

The primary intended user for this product is a supervisor on a construction site. They will be using the Hololens application to view the workers on their site. The secondary users will be the construction workers who are wearing the token on their belt clips. The comfort and satisfaction of both types of users are important to us because we want to make sure the token does not interfere with their equipment they are required to wear or with their daily tasks. Since the companies will be investing a significant amount of money in the Hololens to use the product, we want to make sure they are investing in a product that is useful for them and provides a pleasant experience for the user.

The primary intended use is to allow a construction supervisor to visualize where their workers are at a given time and to be able to play back a visual to see data within the day. This use represents the core functionality of the product we will be building.

The aforementioned use is primarily for productivity purposes. Having real time locations and saved daily locations of all personnel on a megaproject can hugely help increase productivity. It is estimated that every day that a mega project goes over the allotted time scheduled costs an average of 3.3 million dollars. Therefore, increasing productivity can save construction companies massive amounts of money.

Secondarily, the Hololens application will be used for safety purposes. One in Five worker deaths in 2015 occurred in a construction work environment [1]. These numbers could be decreased if supervisors were able to know where their employees were to avoid dangerous situations.

1.6 Assumptions and Limitations

- Assumptions
  - The product must be wearable.
  - The tracking device casing should be IP67.
  - The tracker should be able to relay info to our service.
  - The product should be protected from unauthorized users.
  - The product service should be scalable to fit as many users realistically as possible.
  - The product should be able to be viewed on a website and Hololens

- Limitations
  - The end product shall be no bigger than an iPhone 8.
  - The end product must track at least 6 people in playground-sized environment (20 x 20 m).
  - The end product must be accurate within 5 meters.
  - The end product must be able to last a work day (at least 8 hours).
  - The end product shall have a sensor communication range of within 10m.
  - The end product shall track with a delay at most 1 second.
  - The end product shall track moving people at maximum 5 mph.
  - The end product shall work in all outdoor environments.
  - The end product shall be droppable by at most 3 meters.
  - The product budget shall not exceed $5000.
  - The product shall have a proof of concept before the end of May, 2018.

1.7 Expected End Product and Deliverables

- The end product shall have a tracking service.
- The end product shall be a scalable outdoor personnel device.
- The end product shall have documented source code.
- The end product shall be a Proof of Concept for the client to showcase to investors.
- The end product shall have an UI for tracking for Microsoft HoloLens and possibly Web interface.
- The end product shall have some possible casing for the product.

- The end product shall have reliable communication between devices.
- The end product shall be demonstrable by the end of the project (April 2017).

2. Specifications and Analysis

2.1 Design Specifications

The main focus of the project is to get a system in place to track multiple personnel and display their locations on a virtual map. The initial product should be able track up 6 people on the worksite in real time with a same delay. Another design specification is the accuracy of our tracking. We would like to make our solution as accurate as possible, with a minimum accuracy of less than 5m in error.

In addition, the tracking token that will be placed on each personnel must last at least an average work day (10 hours). It also has to be able to relay readable data to the hololens to be displayed.This token has to be able to withstand rough conditions, must be water resistant, and reasonably sized so it will not hinder the worker wearing it. We would like it to attach to PPE so it must always be worn. The relay will also be secure so unauthorized users cannot access the information or create false data. The final requirement is that the system must be scalable, so it will be able to handle more people at larger construction sites, as well as maintainable to last the length of the construction project.

Functional Requirements:

- Must track at least 6 people in a playground-sized environment (20 x 20 m): the end goal is to be able to track our group successfully in a small, coned-off simulated outside work environment.
- Must accurately localize personnel within 5 meters: the tracking must show the avatar as accurately as possible to track people in real time.
- Token relays information in a readable format to Hololens.
- If active sensor, battery life = 1 work day (10 hours): needs to be able to last an entire workday without being charged.
- Sensor communication range: 10 m: must have a minimum range of 10 m to limit the number of sensors needed.
- Real time tracking: acceptable delay of 1 second: if there is too long of a delay, the positioning will not be accurate on a moving target.
- Track people moving at maximum of 5 mph: this will allow the positioning to still be accurate on someone moving at a reasonable speed.

Non-Functional Requirements

- Must track at least 6 people in a playground-sized environment (20 x 20 m): the end goal is to be able to track our group successfully in a small, coned-off simulated outside work environment.
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possible to track people in real time.

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- Track people moving at maximum of 5 mph: this will allow the positioning to still be accurate on someone moving at a reasonable speed.

2.2 Proposed Design/Methods

The design that our team has chosen is using RSSI and active tokens to track the personnel, and then send that information to our server and display it for the user. The job site will be completely covered in WiFi with an appropriate amount of access points to guarantee anywhere the personnel go they will be in the range of at least three access points. The token will be a Raspberry Pi Zero, which will be attached to the belt of the worker. This token will gather the RSSI data, and send it through the network to a hub that will use known algorithms to convert the RSSI data into a relatively accurate location for the multiple tokens. Once it generates the location of the tokens, it will send this data to an offsite server. From this server we will get the information, and generate avatars at the locations on a 3d mapping of the site on the Hololens.

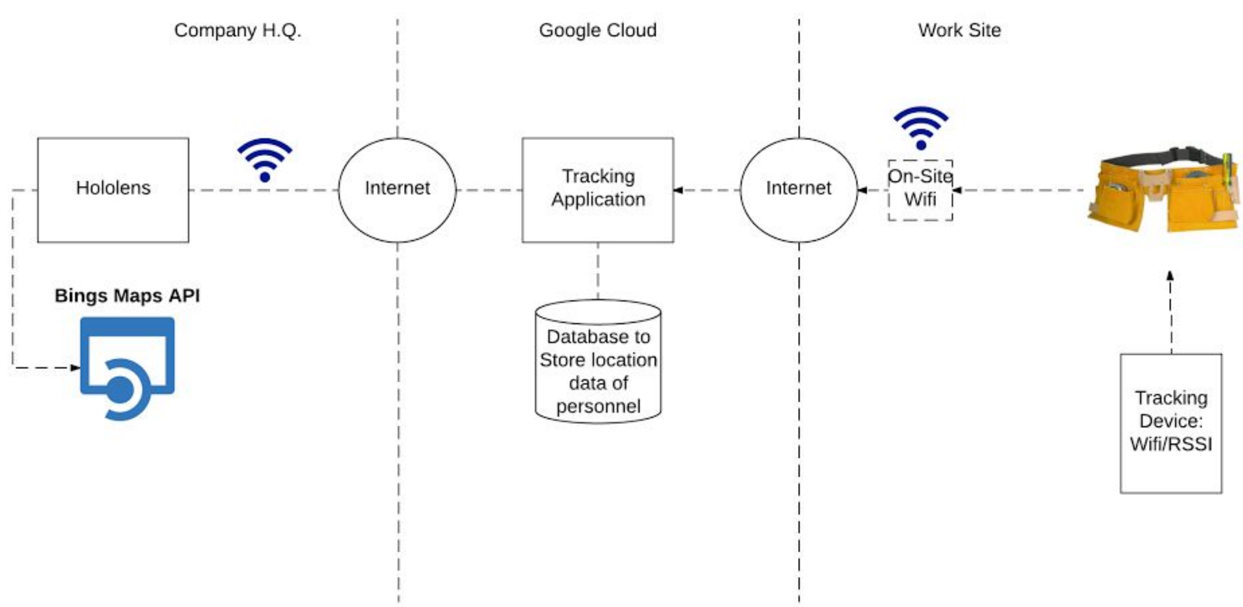

Figure 1: Architecture Diagram of Proposed System

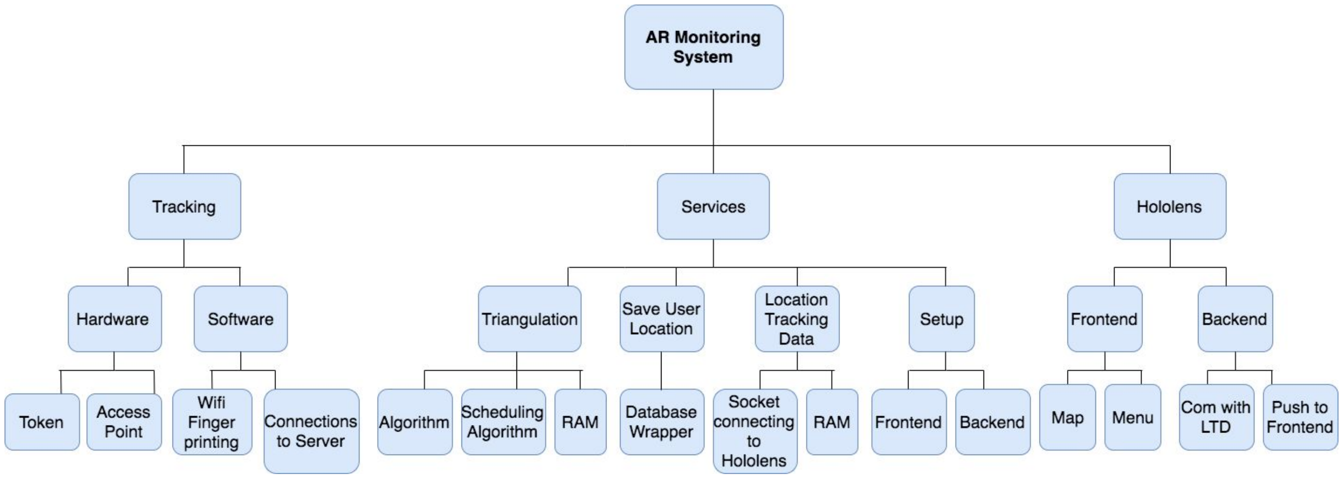

Figure 2: Functional Decomposition Diagram of System

2.3 Design Analysis

Our original plan for the localization solution for this project was to use CSI, Channel State Information, due to it having accuracy within 5 meters. We have decided to change this plan to a different technology. After collecting data using Intel's 5300 CSI tool, we came to the realization that this technology will only work to track one person and not a large group of personnel, which is the intended goal of this tracking system. This prompted us to start pursuing an alternative solution, Received Signal Strength Indicator (RSSI). We also changed our plan of using CSI based on the need for CSI data to be collected over an open Wi-Fi network, which is a major security concern for our client.

We have compiled the areas of weakness and strength of this proposed design:

- Areas of Weakness
    - Accuracy: The accuracy of our tracking with RSSI will not be as strong as with CSI. It will likely be within 5 m, whereas CSI could have provided us with less than 1 m accuracy.
        - We can improve our accuracy by using wifi fingerprinting once we obtain the RSSI data.
    - System component dependency: Many of our components rely on each other, so when one component goes down, it will likely impact another.
        - We can fix this weakness by making an effort to modularize our Triangulation Service by decomposing them into more services.
    - Setup may be long and error-prone: Our setup for a work site's users and access points for gathering data can be complex and may leave a general contractor who is setting it up feeling puzzled or may lead to them making errors.
        - We can help to reduce these errors and confusion in setup by creating out website for management setup in accordance with the proper setup

process.

- Areas of Strength
  - We are able to use any programming language for the backend services of the system.
  - With RSSI, every WiFi connected device can be tracked and see the data easier.
  - an be used with a closed wifi network
  - The solution with RSSI that we have designed is scalable for several worksites.
  - Our design is a platform that can be added on to in the future.
  - Since we are using the Microsoft Hololens over HTC Vive or Oculus Rift, the user will be using a mixed reality device, which is less draining and uncomfortable than a virtual reality device. The Microsoft Hololens allows users to still interact with their environment as well.

2.4 Technical Approach

Our technical approach was to find research, existing projects, and approaches to using CSI and RSSI wireless tracking technologies. The data used from these technologies will be given to our service to track locations of the nodes (Personnel) in a location / site. The location database on our service will then be pushed to our location tracking data service that will be in communication to our Hololens application.

We are going to split up our project into six separate parts in order to develop a software architecture that we can base our implementation off of:

1. Tracking Device Software
   a. Obtain RSSI values for all access points for a particular personnel device
2. Triangulation Service
   a. Processes devices' fingerprints (compilation of mac addresses and RSSI of APs)
   b. Runs triangulation algorithm
   c. Schedules data exchange between the service and tracking devices
3. LocationTrackingData Service
   a. Sends updates of user locations to the general contractor's view of the work site (via Web Application or Hololens) in real time
4. SaveUserLocation Service
   a. Sends user's latitude, longitude, work site, and time
5. Management User Interface to setup a work site
6. Hololens Application
   a. Views a work site through an augmented environment, allows bird eye view

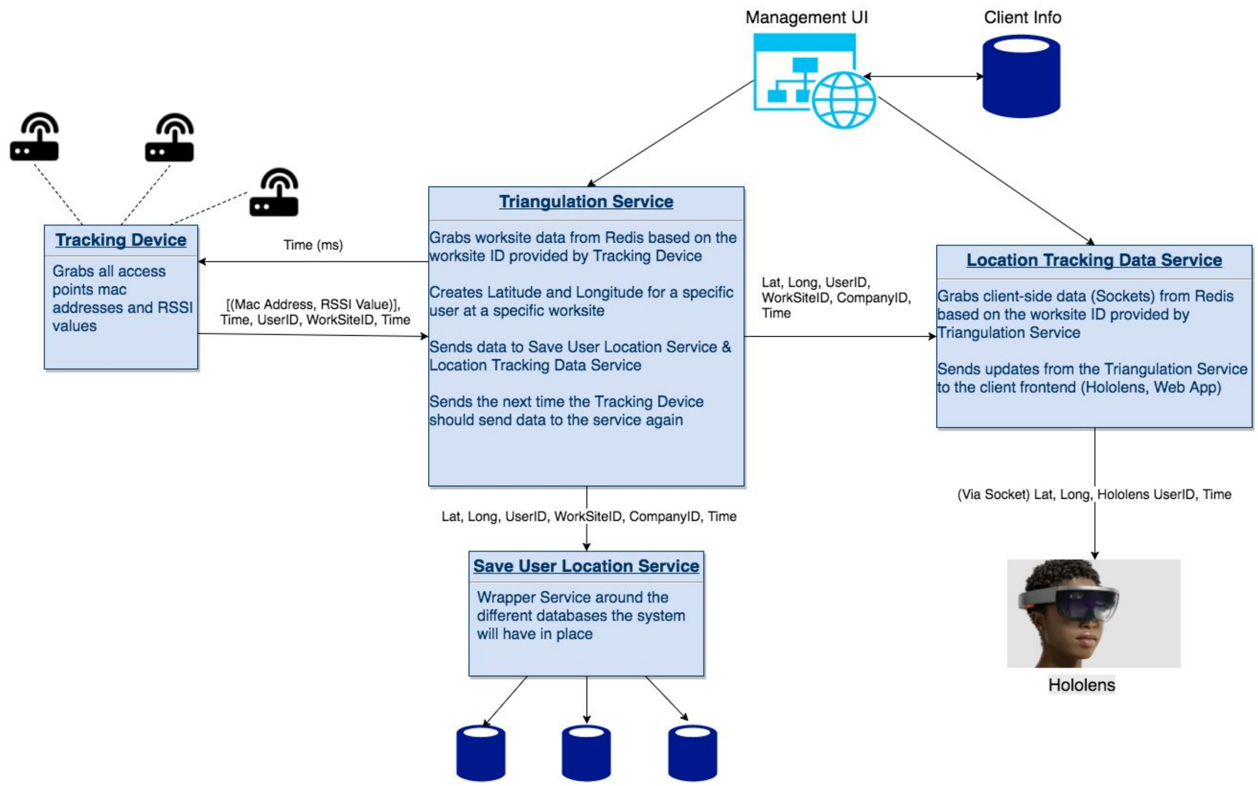

Figure 3: Block Diagram of Software Architecture

3 Testing and Implementation

3.1 Interface Specifications

- Hardware
    - Raspberry Pi Zero W (Token)
        - Will connect to wifi and send back through wifi to the RSSI Collection Service the tokens RSSI information
    - Microsoft Hololens
        - Will connect through wifi to the Hololens Map Creator to gather the bing maps to create 3D render of the location the personnel are at
        - Will connect through wifi to the Hololens Personnel Tracking Service that will feed in data about where people are located at
- Software
    - Tracking
        - Connection to Service
        - Wifi Fingerprinting
    - Services

                - Triangulation
                    - RAM redis server
                    - Algorithms
                    - Scheduling Algorithm
                - Save User Location
                    - Database Wrapper
                - Location Tracking Data (LTD)
                    - Socket Connection
                    - RAM redis server
                - Setup
                    - Backend
                    - Frontend
            - Microsoft Hololens
                - Frontend
                    - Menu display
                    - Display Map
                - Backend
                    - Communicate with LTD
                    - Push information to Frontend

3.2 Hardware and Software

- Hardware
    - Raspberry Pi Zeros W & Raspberry Pi 3s
    - GPS Hat (Backup)
        - Adafruit GPS Raspberry Pi Hat
        - Berry-IMU Raspberry Pi Hat
            - GPS
            - Temperature Sensor
            - Barometer
            - Gyroscope
            - Accelerometer
    - Microsoft HoloLens
    - MSI Gaming Laptop

We are using a Raspberry Pi Zero W as a main hardware tool for tracking. We will be the microcontroller's onboard Wifi chipset . We are using two chips for RSSI and CSI. We will be gathering RSSI on the Raspberry Pis. We are going to use a GPS Hat as backup technology for tracking. The Berry-IMU contains various chips and sensors to help determine our height and acceleration of the tracked object. The main UI will be through the Microsoft HoloLens. The MSI Gaming Laptop will help us run and build our code quickly for the Microsoft HoloLens.The two different Raspberry Pis' are to determine if the CPU on the RPI (Raspberry Pi) 3 is better than the Pi Zero.

- Software
    - Unity
    - Raspbian
    - Visual Studio
    - Atom
    - C# & Python
    - Git & Gitlab

Unity and Visual Studio are needed to run, build, and test the Microsoft HoloLens application. Raspbian is the base OS for Raspberry Pis. Atom will be our text editor for any code. C# and Python will be our languages for our projects. Git will be our version control software. Gitlab will store our repository and note delegations and todos.

3.3 Functional Testing

- Must track at least 6 people in a playground-sized environment (20 x 20 m): the end goal is to be able to track our group successfully in a small, coned-off simulated outside work environment.
    - We will test this by having 6 or more users wear the hardware token (Raspberry Pi Zero devices) in an area that is at least 20 x 20 m in size, and monitor the tracking data to ensure it fits within our accuracy.
- Must be accurate within 5 meters: the tracking must show the avatar as accurately as possible to track people in real time.
    - We will test this by having people carry the tokens in known locations, allowing us to compare the location we detect from the token and the location we know.
- Token relays information in a readable format to Hololens.
    - Will format the data that the token sends to match what our program for the hololens is looking for
- If active sensor, battery life = 1 work day (10 hours): needs to be able to last an entire workday without being charged.
    - Leave tester on for length of a work day with program running, see if it's still alive
    - Calculate power usage of program and compare it to battery life of token
- Sensor communication range: 10 m: must have a minimum range of 10 m to limit the number of sensors needed.
    - Create 10M area around an access point and make sure token can communicate with AP anywhere in the circle
- Real time tracking: acceptable delay of 1 second: if there is too long of a delay, the positioning will not be accurate on a moving target.
    - Track people as they walk around environment, making sure the location they are in is being represented within one second, given that we already know their location

3.4 Non-Functional Testing

- Realistically-sized token: wearable device attached to belt that is no bigger than a pager
    - We plan to test this by comparing the final product for the tracking token to a pager
- System secured so it is inaccessible to unauthorized users: must be secure so others cannot gain access and view positioning of workers, very negative consequences in future phases.
    - Can have multiple users outside of the network attempt to access and steal data in between multiple communication types
- Create a system that is scalable to megaprojects (projects greater than 1 billion dollars): must be able to scale for projects that have a lot more than six workers.
    - We will test this by attempting to connect to services with as many people as possible to get an idea of how many people can initially connect without it breaking
    - Also we will test code for design clarity and modifiability to make sure when the number of necessary users change, our code can be changed to fit needs
- Maintainable for length of project: for construction site, must be able to be easily maintained for length of construction project for at least five months at a time.
    - We will test this by doing a beta release of the product and after five months of use, testing that over this time, the product did not need maintenance to it and could be used as intended during the entire work period.

3.5 Modeling & Simulation

- Testing Scenarios
    - Hardware
        - Model 1: Tracking device hardware (Raspberry Pi Zero loaded with software written in Python)
            - Simulation: Test collection method of Wi-Fi RSSI fingerprints and transmitting method of data to server.
        - Model 2: Hololens loaded with application
            - Simulation: Do user testing of Hololens device and application to ensure the device configuration works well for this purpose.

    - Software
        - Model 1: Implemented Triangulation Service
            - Simulation: Take in RSSI data and run triangulation algorithm on data. Verify that data obtained is correct.
        - Model 2: Implemented Location Tracking Data Service
            - Simulation: Run service and verify that data being sent over to Hololens application is in real time and is accurate.

- Model 3: Implemented Save User Location Service
    - Simulation: Run service that saves user's latitude, longitude, work site, and time and verify that this data is correct (matches the actual correct).
- Model 4: Management User Interface
    - Simulation: Run through interface and ensure that access points can be added as well as other details need for proper usage

3.6 Implementation Issues

- Implementing our Hololens application without knowing the a real worksite map
- Time constraints with finishing the prototypes
- Constraints with finding open source algorithms for the method of tracking we choose
- Obtaining all of the hardware necessary for implementing the different location tracking methods while keeping the cost down
- Designing the software architecture using both RSSI and CSI
- Understanding how the towers will communicate with the access points and location tokens

3.7 Process

In regards to tracking in our first stage, using the CSI approach we have narrowed down the solutions to focus on the implementation of the solutions outlined in several papers. These papers are *SpotFI: Decimeter Level Localization Using WiFi* [2] and *Decimeter-Level Localization with a Single WiFi Access Point [3].* These papers focus on localizing devices using approaches based on used specialized algorithms that process the RSSI data and accurately compute location of the targets that they track. The algorithm that we choose to implement based off of the complexity of the algorithm, and which will be the most scalable solution. There will be comprehensive tests to figure out which algorithm will work the best. As our team consists of 6 members we will be able to split up the work between the different members of our team to streamline the testing process. Once we have the solution then we can start to introduce the solution to the other portions of our system including services that will turn the data into usable content to displayed on 2D and 3D maps over different interfaces such as the Microsoft Hololens and a web application.

After researching, the later stages of the project will be focused on getting our services up and running and getting our deliverables done. Based on our schedule, we want to split into three different groups for our project. In those groups, we are going to have general due dates that are based off of a two week sprint.

- Set up server, configure Raspberry Pis, start Hololens Application- Jan. 19th
- Complete proof of concept Wi-Fi triangulation localization solution - Feb. 9th
- Create Prototypes - Feb. 23rd
- Test and improve tracking system and Hololens application - Mar. 9th

- Integrate tracking system and Hololens application - April 13th
- Prepare for the final demo - April 20th

3.8 Results

At this point in time, we know that we are going to be using RSSI for our location tracking. Knowing this, we have begun splitting up the work that we will accomplish next semester. Our decision was to split up the work into 3 different parts. Each part will have a team of 2 working on it. There is the tracking portion which Chris and Logan will be working on. The next portion is the Services portion which Jason and Chandler will be working on. The last portion is the Hololens (UI) part which Josh and Victor will be working on.

Overall, this semester we spent the bulk amount of time researching Channel State Information. We eventually came to the conclusion that CSI will not be the optimal implementation for our specific solution that we are going for. We have learned very much about location tracking methods in that time. After coming to this insight, we have decided to move forward using RSSI, and we are ready to begin the implementation process beginning next semester.

4 Closing Material

4.1 Conclusion

This semester, we have extensively researched different location tracking methods and discussed specifications with our client to make a solid plan for development of our product. We initially attempted to implement a CSI-based solution, but ran into many different issues. Along the way, we have continued to learn more about our specific project, along with location tracking in general. We have also worked with our advisor, Dr. Qiao, to establish functional and nonfunctional requirements for the product after deciding what product we wanted to build: a hardware token and a Microsoft Hololens application. Our goals for this project are to enable our user, a construction general contractor, to visualize where their employees are at a given time. Our solution is to use a Raspberry Pi Zero for the hardware token and use RSSI to achieve tracking of personnel. It will allow us to get within our 5 meters error goal. Overall, we believe we have a strong plan going into the development of our product in the second semester of the project and will continue working diligently with the oversight of our client and the guidance of our advisor to
develop a product that solves this problem and accomplishes our goals.

4.2 References

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