T.C.

MARMARA UNIVERSITY

FACULTY of ENGINEERING

COMPUTER ENGINEERING DEPARTMENT

CSE 4197 - Analysis and Design Document

Title of the Project

BLUETOOTH LOCALIZATION

05.01.2020

Group Members

150113066 - Erkan GÜNGÖR
150114051 - Mehmet MUM

Supervised by

Assoc. Prof. Müjdat SOYTÜRK

1. Introduction

1.1 Problem Description and Motivation

Due to the increase in the number of large and complex buildings such as malls, companies, museums, warehouses and airports, security and wayfinding are starting to become enormous problems. In a company, a visitor may enter an unauthorized area. In this case, a security guard can observe the behavior of the visitor, take the necessary action and/or report the visitor. It is a well known fact that in malls, people are wasting too much time to find the specific store they are looking for.

"Indoor localization is the process of obtaining a device or user location in an indoor setting or environment [1]." Many systems have been developed since this problem arose. Such systems are based on several technologies like Wi-Fi, computer vision, and sound waves. Each technology has some disadvantages. Computer vision based systems are too expensive. Systems that use sound waves for localization have short range. Although a Wi-Fi based system uses many access points, it still has low accuracy. Another approach to this problem is combining some systems in order to achieve higher accuracy. But these systems tend to become more complex and expensive. Bluetooth Low Energy technology has recently started to be used with IPS. Being highly cost-effective and more accurate, such innovation has pleased this part of the field. This advantage distinguishes it from other systems.

1.2 Scope of the Project

A real time positioning system has to locate assets in a duration that varies depending on the environment. If the system is an IPS, it also has to have high accuracy. Thus, the capability of an IPS can be evaluated under two headings; reliability and speed of the communication methods that are used in the system, accuracy of the indoor positioning algorithms. In our project, we want to design a cost effective IPS that satisfies these terms using Bluetooth 4.1.

Accuracy is the key point of an IPS. Therefore, we want to improve the system's accuracy as much as possible. But we do not want to increase the cost too much. Thus, while improving the system's accuracy, we do not plan to design or enhance any kind of hardware. Instead, we will focus on designing more efficient and more accurate indoor positioning algorithms than previously proposed algorithms.

The system will not be useful if it can not locate assets in a reasonable duration even though it can locate them with perfect accuracy. Therefore, we plan to improve the communication methods by:

- Increasing size of the packets which are sent from transmitter to receiver.
- Choosing more feasible communication technologies.

In the real world, there are many complex buildings that are challenging for indoor positioning. We may face lots of issues when setting up an IPS to these kind of buildings. Depending on the building structure, we may not be able to put the receivers at desired locations or due to the high signal interference, indoor positioning algorithms may have lower accuracy. In order to avoid these problems, we will design the IPS for a simple room. Therefore, our IPS may not be sufficient for such complex buildings.

When the localization part is done, we will have an IPS that produces valuable data. The data can be used for many purposes such as optimization and security. We plan to process the data in order to obtain:

- A heatmap that states crowded areas.
- Trace of individual users.

At this point, we will have three outputs: heatmap, user traces and real time locations. In order to make them easily observable, we will design a web page as a user interface.

Besides the main goals, we also have some claims:

- Assuming we get a Bluetooth 5.1 Angle of Arrival development kit for at least two months before the project's deadline, we will implement an algorithm that can find the position of the target with 1 meter error margin.

- Assuming we managed to develop a position estimation algorithm for the IPS that uses Bluetooth 4.1, create heat map & detailed user traces, and design Web UI in planned time, we are planning to implement an Android application to display current location to user and provide way-finding feature.

1.3 Definitions, Acronyms, and Abbreviations

IPS	: Indoor Positioning System
BLE	: Bluetooth Low Energy
RSSI	: Received Signal Strength Indicator
AoA	: Angle of Arrival
AoD	: Angle of Departure
ToA	: Time of Arrival
TDoA	: Time Difference of Arrival
UWB	: Ultra Wideband
UI	: User Interface

2. Literature Survey

In the work of Chouchang Yang and Huai-Rong Shao [2], authors worked on Wi-Fi based IPS. In this system, devices that are desired to locate should have Wi-Fi capabilities. For positioning, they have used two types of localization approaches: Angle of Arrival (AoA) and Time of Arrival (ToA). If there is one Access Point (AP) nearby, they applied the ToA method. Otherwise, they applied AoA method to obtain higher accuracy. They used Round Trip Time to measure distance between transmitters and receivers. On the other hand, they obtained the angle via AP which has multiple antennas. Performance of the AoA method increases with respect to number of antennas.

In the work of Cheng Zhou, Jiazheng Yuan, Hongzhe Lou and Jing Qui [3], the authors proposed an indoor positioning algorithm based on Bluetooth Low Energy 4.0. They divided the problem into three phases: Collecting Bluetooth signals, Bluetooth signal propagation model, real-time position output. In the first phase, they are collecting Bluetooth signals and calculating the distance between receiver and transmitter using RSSI values. Main idea of the second phase is improving accuracy. They erase obvious errors and smooth the RSSI using Kalman Filters. In the third phase, using Kalman Filters, weighted least square and four border positioning they estimate the positions.

In the work of Cemin Zhang, Michael Kuhn, Brandon Merkl, Aly E. Fathy, Mohamed Mahfouz [4], authors worked on Ultra Wideband (UWB) IPS utilizing time difference of arrival (TDoA). They experienced this system for both 1D and 2D localization. In the 1D experiment, using 1 receiver and 1 transmitter they located the assets with less than a millimeter error. In the second experiment, they used 3 receivers which are put at known positions and 1 transmitter. They used TDoA technique and triangulation method to indicate the position. For the 2D experiment, they located the transmitter with an error of 1.68mm.

In these works, the authors have focused on only positioning. In our work, we will find positions, store them in a database. And then, we will interpret this data for creating heatmap and user traces. In addition to these, we will visualize the positions, create heatmap and the user traces.

3. Project Requirements

3.1 Functional Requirements

- The system should provide a registration/login service.
  There are three types of users:
  - Moderator
  - Administrator
  - Security guard
- Moderators should be able to only register a user to the system.
- Administrators should access heat map, real time locations, and user tracking.
- Security guards should access real time locations and user tracking.

3.2 Nonfunctional Requirements

3.2.1 Performance

- Real time locations should be updated every 3 seconds.
- Heat map should be updated every 3 seconds.
- User tracking service should be displayed on the screen when it requested. It should be updated every 3 second when it is open.

3.2.2 Reliability

- We should update the database before displaying any data in the real time location system. Not displaying data in the database for real time location system may be tolerable, but displaying data which is not in the database can cause problems.

3.2.3 Usability

- The interface should be clear and easy to use. In case of any emergency situation, users should not face any difficulty using the user interface.
- User interface should be updated automatically.

3.2.4 Security

- We are using Django for web user interface. Django handles encryption of the passwords for us.

4. System Design

4.1 UML Use Case Diagrams

Moderator can make all possible actions. User A (security guard) can view live locations, heatmap, user trace and person details. User B is visitor or employee, he can not make any action.

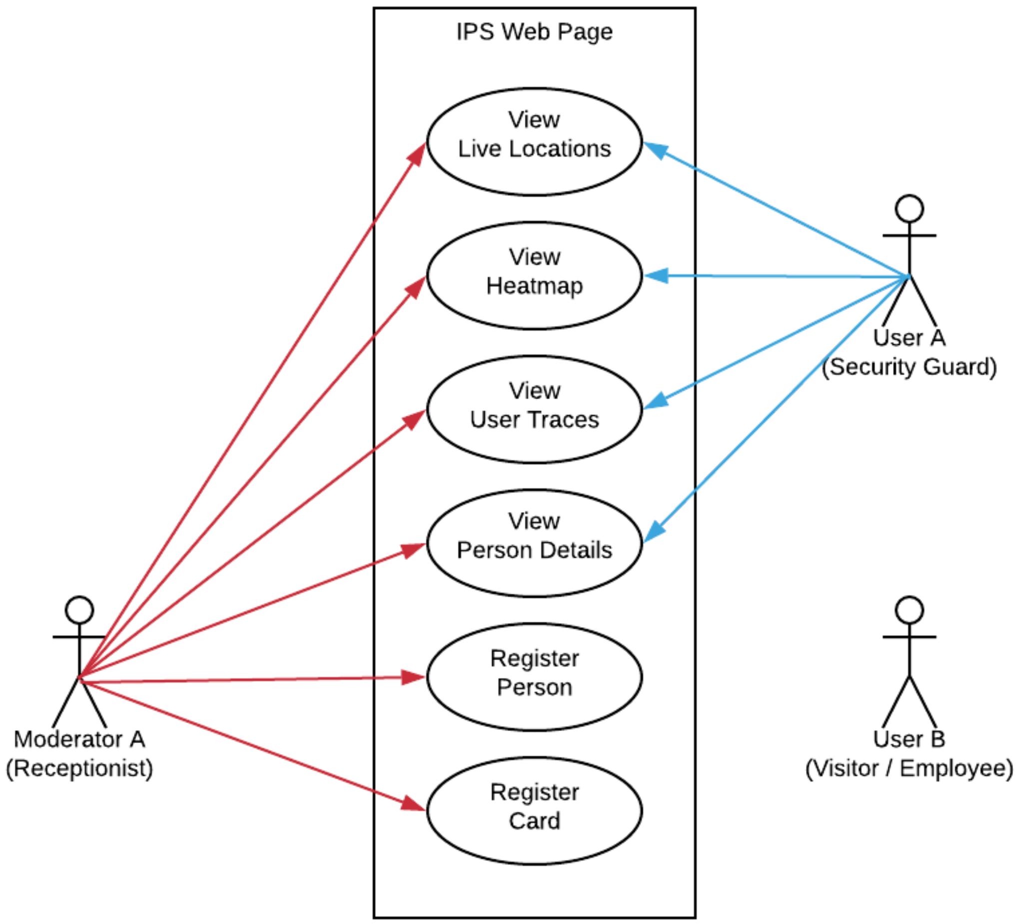

Figure 1: IPS Web Page Use Case Diagram

Android App is developed for visitors. A visitor can display the map or his own location. Also, he can set a navigation to somewhere on the map.

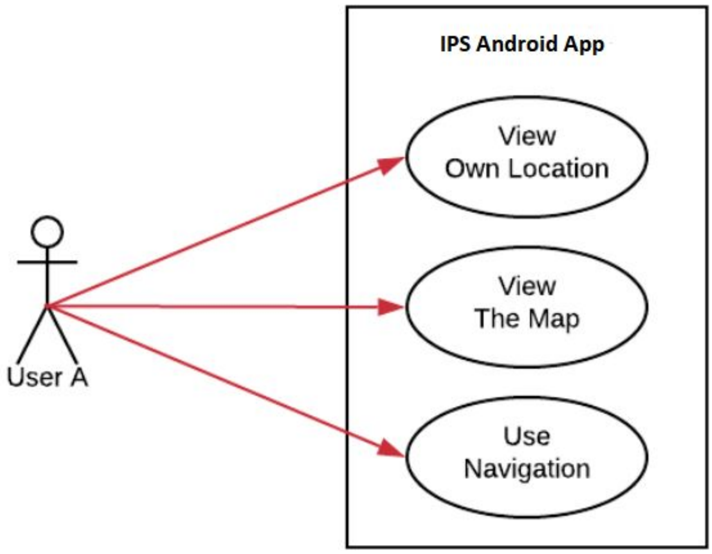

Figure 2: IPS Android App Use Case Diagram

4.2 UML Class and Database ER diagrams

4.4.1 UML Class Diagram

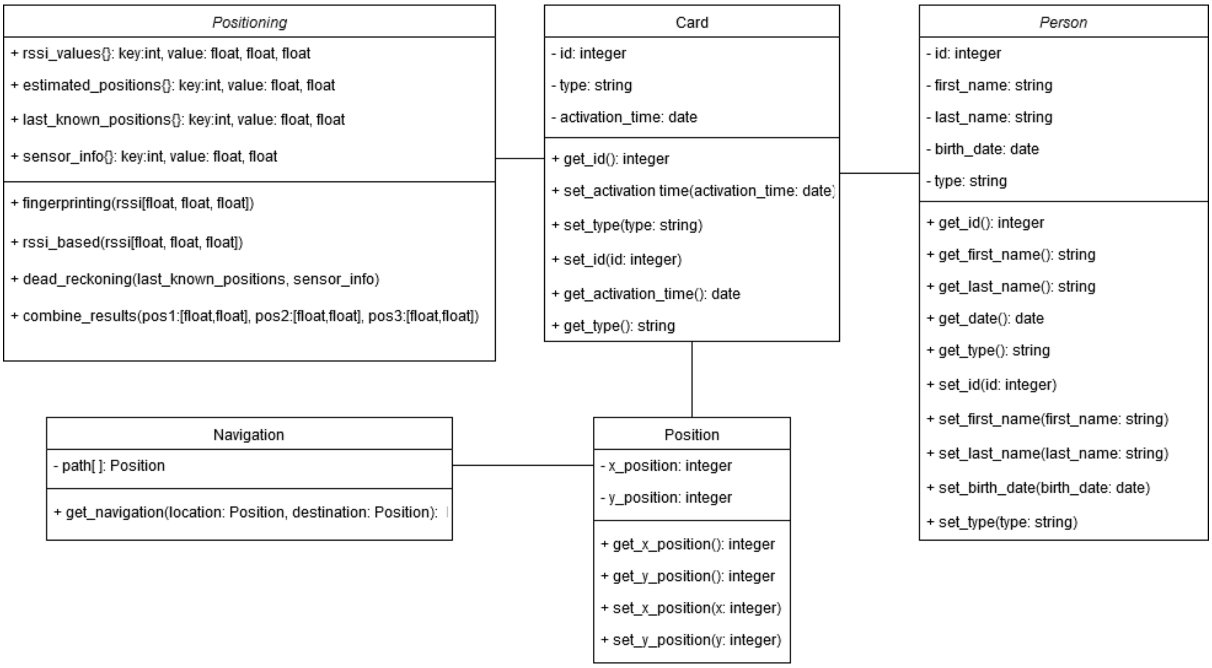

Figure 3: IPS UML Class Diagram

4.2.2 Database ER diagram

In the database we will store personal details, card details, and estimated positions.. For personal information, we will store first name, last name, birth date and card id which is given to the person. For card information, we will store card id, activation time and type of card. For log information, we will store coordinates of positions and the time.

In addition to these, we will also store heatmap information in database. In this part, we will store coordinates of positions and the number of visitors who has visited that position.

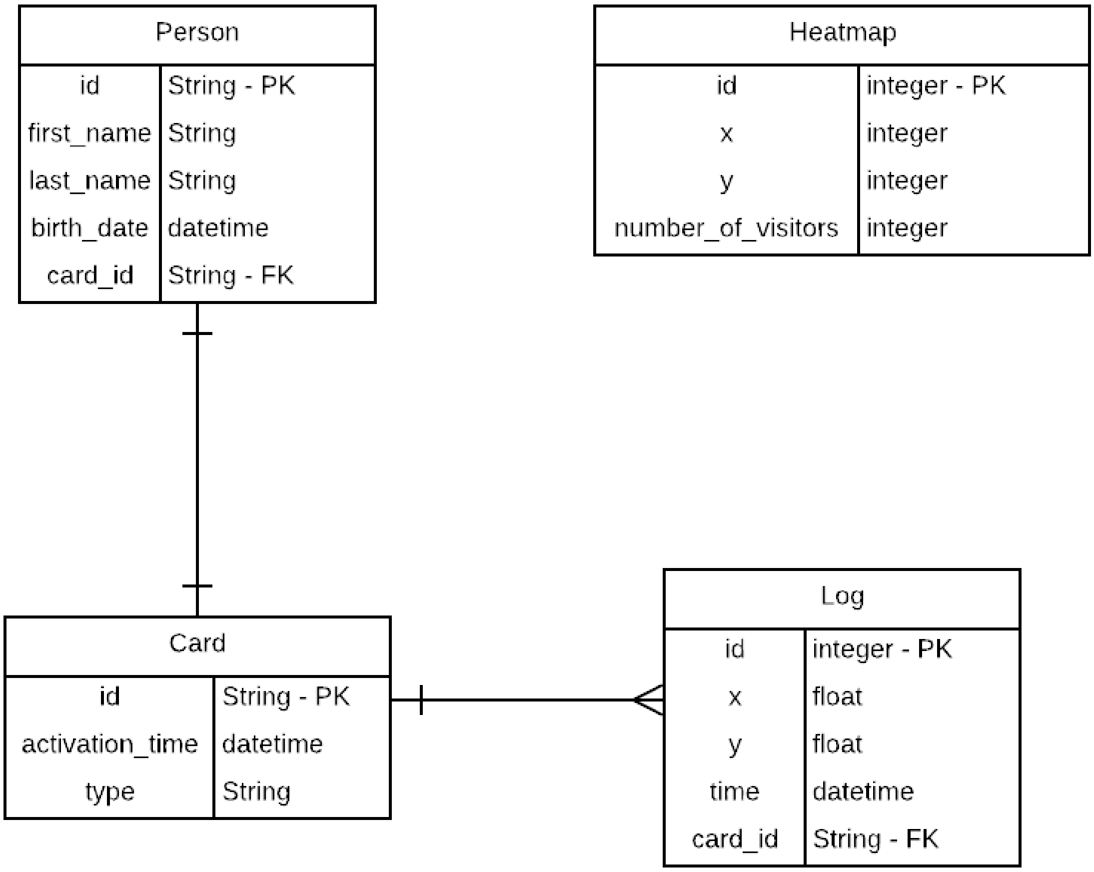

Figure 4: IPS Database ER Diagram

4.3 User Interface

Web user interface includes real time locations, heatmap and user trace.

- Real time locations

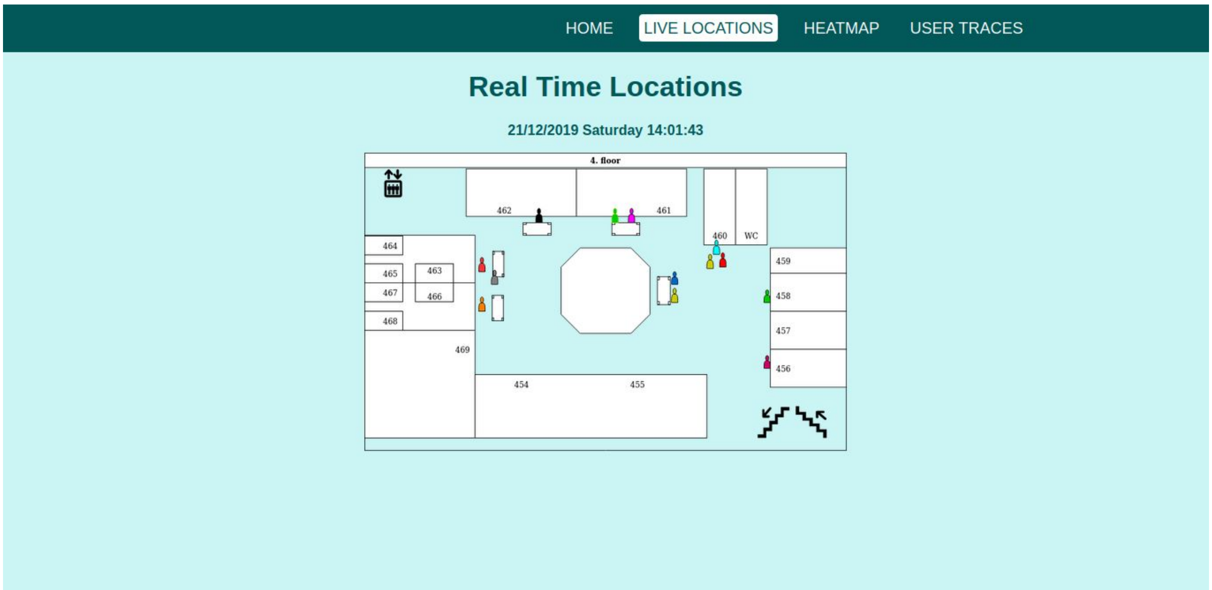

Figure 5: IPS Web Page Real Time Locations

- Heatmap

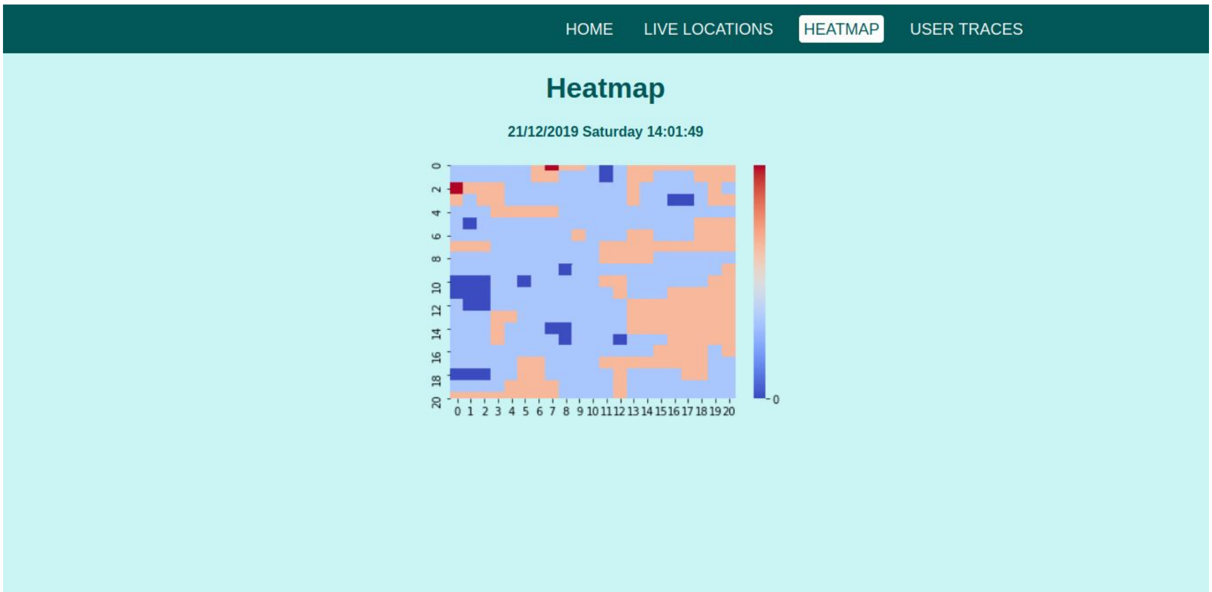

Figure 6: IPS Web Page Heatmap

- User trace

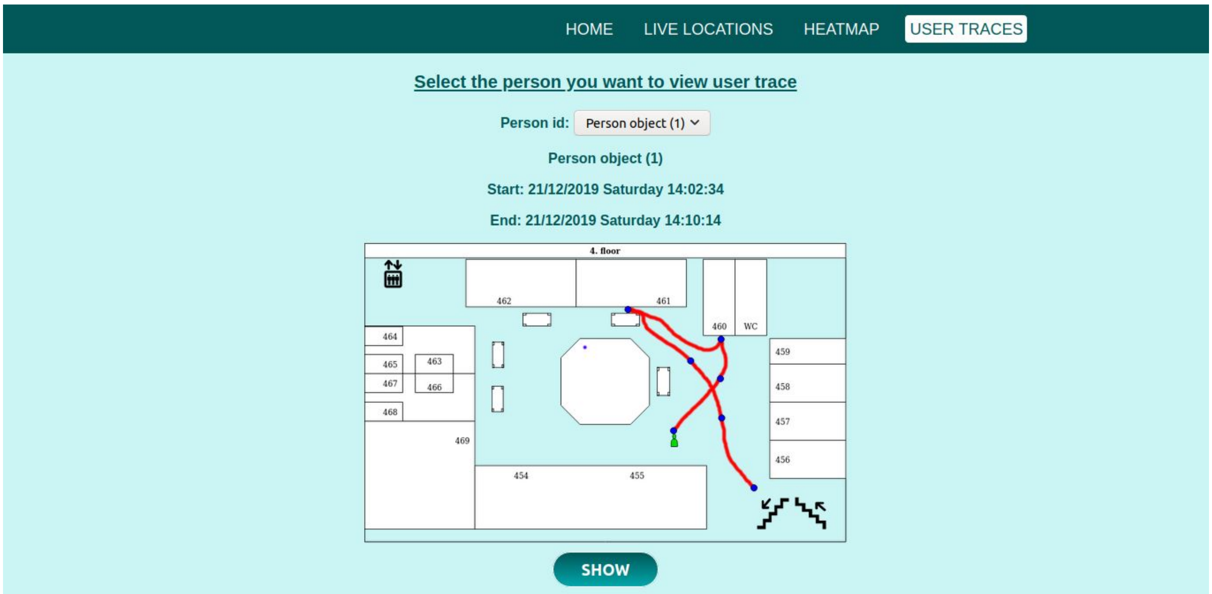

Figure 7: IPS Web Page User Trace

Android user interface:

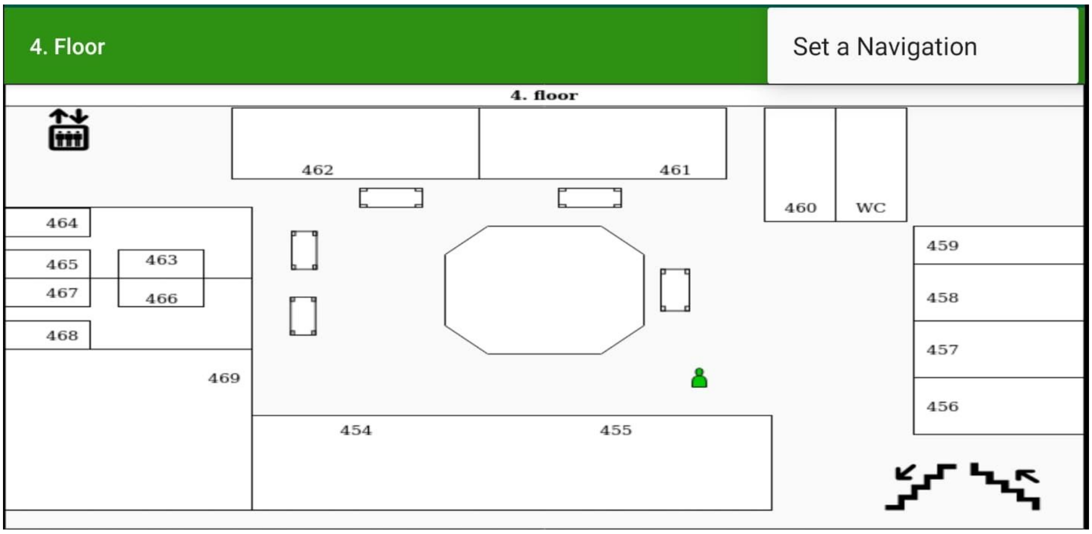

Figure 8: IPS Android App Home Page

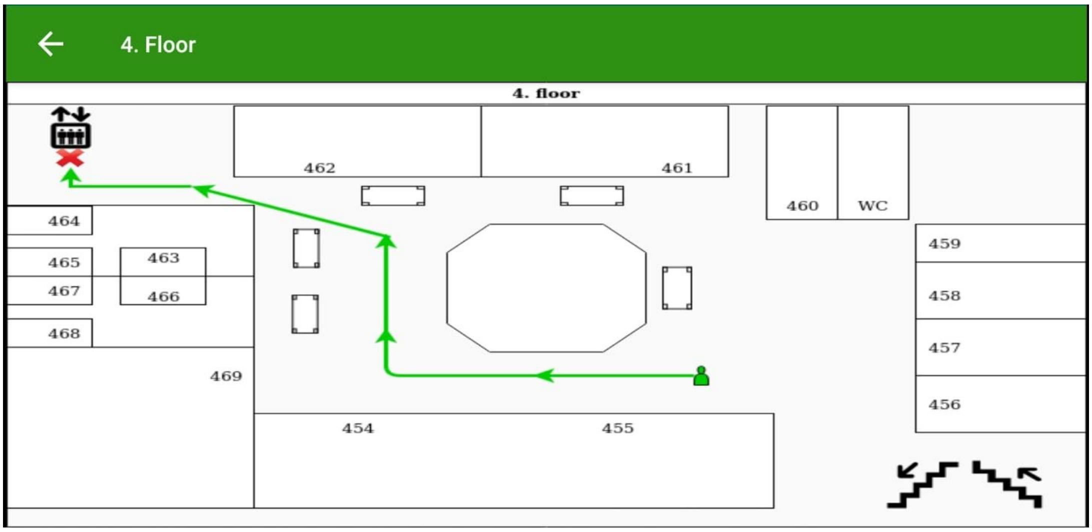

Figure 9: IPS Android App Navigation Page

4.4 Test Plan

In this section, we will describe how to test our system. We have divided our system into subsystems. Each subsystem should be tested individually. So, the tests will be applied in various times during the development cycle.

The following subsystems will be tested:

- Web UI
    - Real Time Location
    - Auto Update
    - Heatmap
    - User Trace
- Android App
    - Display Own Location
    - Navigation
- System setup (communication between devices)
- RSSI based positioning algorithm
- Dead reckoning based positioning algorithm
- Fingerprinting based positioning algorithm
- Combination algorithm
- Angle based positioning algorithm

4.4.1 Web UI

Test Case Name	Real Time Location
Requirement	UI shall display everyone's location
Procedure	Give positions as input
Expected Result	Display each person's location

Test Case Name	Auto Update
Requirement	Positions should be updated automatically every 3 seconds.
Procedure	Give new positions every 3 seconds as input.
Expected Result	Display updated positions automatically every 3 seconds.

Test Case Name	User Trace
Requirement	UI shall display the locations that visited by a person in a given time period.
Procedure	Give locations of a person with timestamps.
Expected Result	Display the locations that visited by a person in a given time period.

Test Case Name	Heatmap
Requirement	UI should display a smooth heatmap
Procedure	Give matrix as input
Expected Result	Display which areas were visited more by people.

4.4.2 Android App

Test Case Name	Display Own Location
Requirement	A user shall see his own location on the map.
Procedure	Give position as input.
Expected Result	The visitor sees his own location on the map.

Test Case Name	Navigation
Requirement	A user shall set a navigation to somewhere on the map.
Procedure	Give the user's location and target location as input
Expected Result	Display a path on the map.

4.4.3 System Setup

Test Case Name	Communication of Components
Requirement	Receivers and the access point should be connected.
Procedure	Give data as input to receivers.
Expected Result	Received data should be correct, delay should not be more than 2 seconds.

4.4.4 RSSI based positioning algorithm

Test Case Name	RSSI based positioning algorithm
Requirement	The algorithm shall find the position.
Procedure	Give RSSI values as input.
Expected Result	The algorithm should estimate the positions.

4.4.5 Dead Reckoning based positioning algorithm

Test Case Name	Dead Reckoning based positioning algorithm
Requirement	The algorithm shall find the next position.
Procedure	Give position, direction, average velocity and time duration as input.
Expected Result	The algorithm should estimate the next position.

4.4.6 Fingerprinting based positioning algorithm

Test Case Name	Fingerprinting based positioning algorithm
Requirement	The algorithm shall find the possibilities of chosen position
Procedure	Give RSSI values as input.
Expected Result	Class possibilities of the chosen positions.

4.4.7 Combination algorithm

Test Case Name	Combination algorithm
Requirement	The algorithm shall combine 3 estimated positions
Procedure	Give the positions which are estimated using RSSI based, dead reckoning and fingerprinting algorithms.
Expected Result	The algorithm should estimate the final positions with at most 2 meters error.

4.4.8 Angle based positioning algorithm

Test Case Name	Angle based positioning algorithm
Requirement	The algorithm shall find the position.
Procedure	Give angles between receiver and transmitter as input.
Expected Result	The algorithm finds positions with at most 1 meter error.

5. Software Architecture

5.1 Data Flow

In our application, users can display, register, edit and delete users and cards. Also, the real time location system will keep sending estimated positions to the server every 3 seconds. So, every 3 seconds estimated locations will be recorded to the database. And depending on the user's request, user interface should be updated.

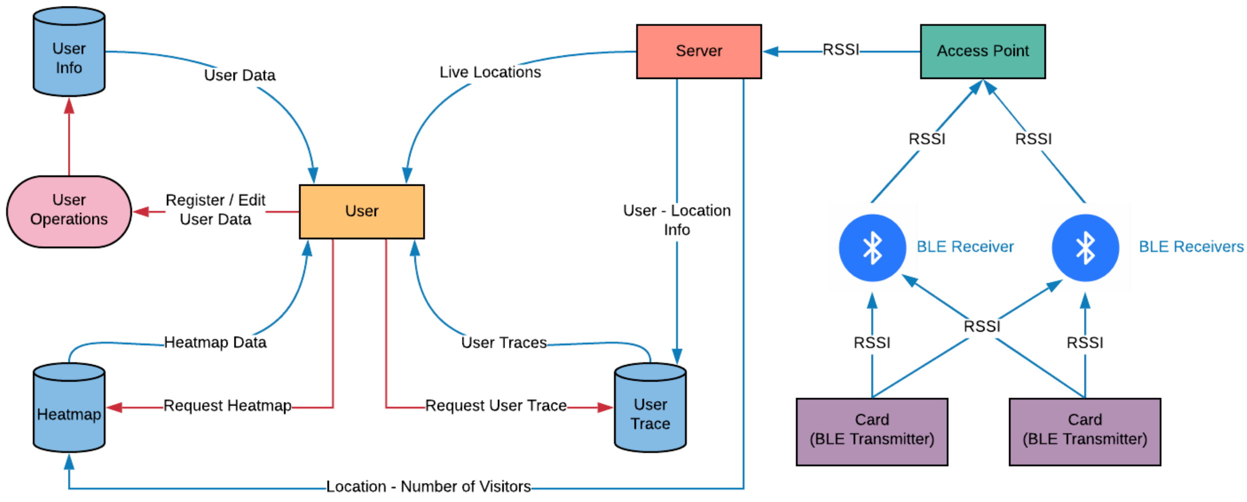

Figure 10: IPS Data Flow Diagram

5.2 Control Flow

The IPS that plan to design can be divided into three headings: Data collection, positioning and data interpretation. The system should wait until the receivers collect data which satisfies the expected format. If this data is successfully transmitted to the server, then the system can run positioning algorithms and estimate the positions of target devices. These positions should be recorded in the database, then Web UI can display new locations, new heatmap and updated user traces.

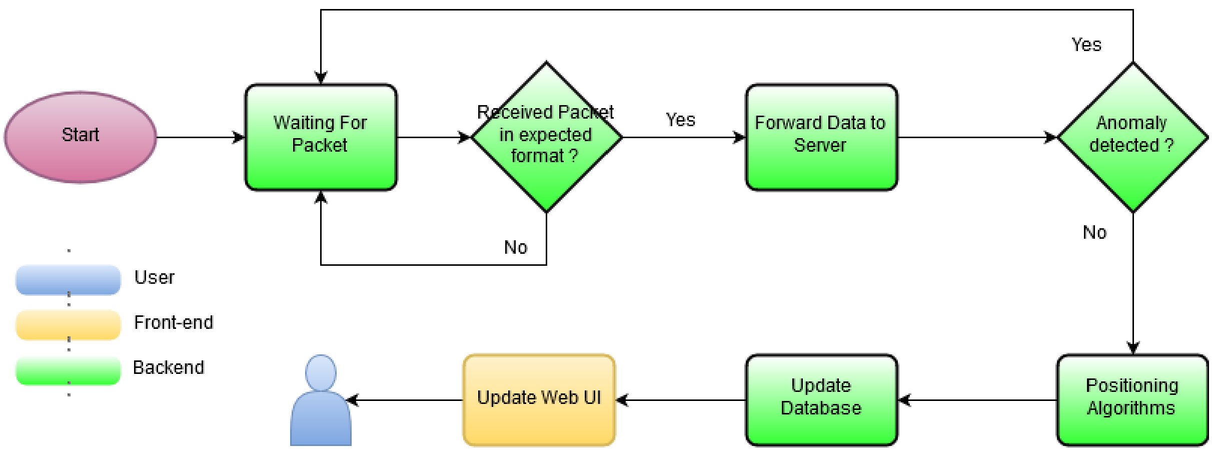

Figure 11: IPS Control Flow Diagram

5.3 Modular Design

This project will consist of three parts: UI/Front-End, Back-End components and the web application.

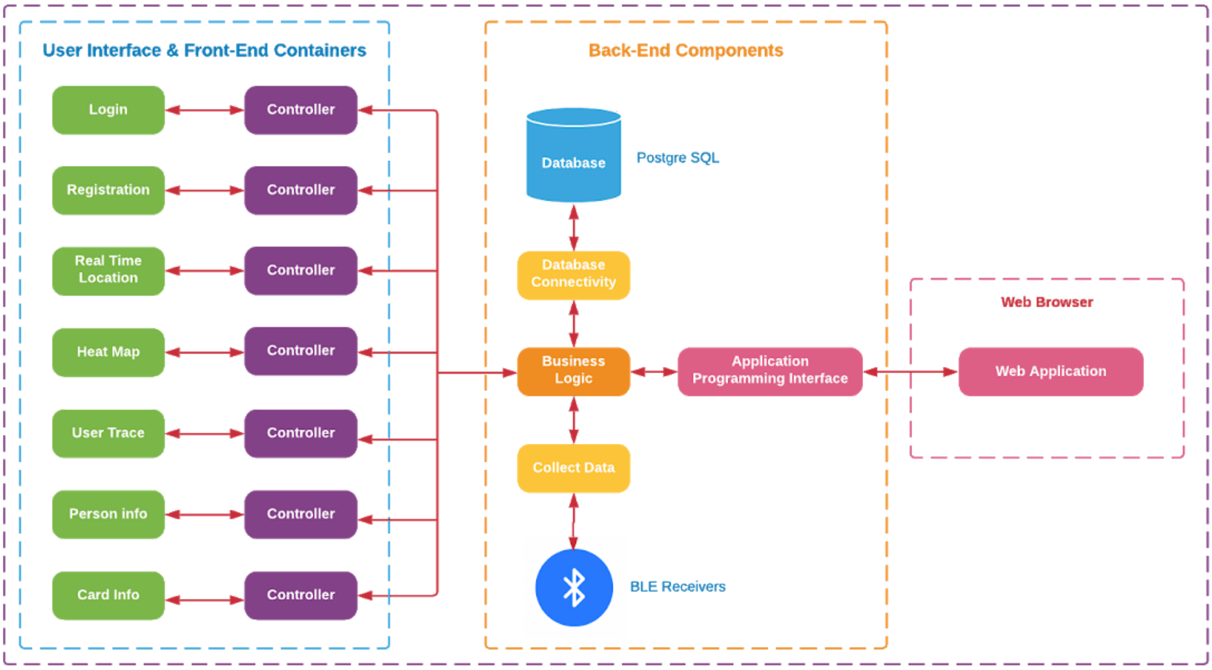

Figure 12: IPS Modular Design

5.4 Hardware - Software Interaction

The following diagram shows the data flow and interaction between hardware and software. Also, we plan to use MQTT and REST methods in data transmitting part. We will use three types of hardware in this project:

1. Transmitters: Android phones
2. Receivers and access point, Raspberry Pis
3. Server: A computer

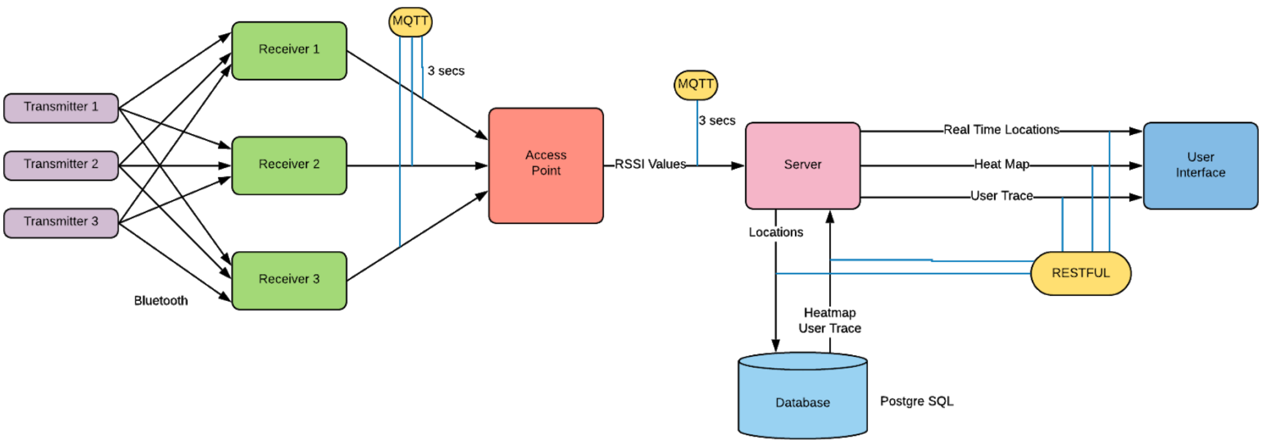

Figure 13: IPS Hardware-Software Interaction

6. Task Accomplished

6.1 Current State of the Project

In the current state of the project, these tasks were accomplished:

- Database design using postgresql
- Preliminary versions of the user interfaces (Web and Android)
- Dockerize the project and the containers are:
  - Database container which runs postgresql
  - Web container which runs django
- Preliminary version of the heatmap

6.2 Task Log

During this semester, we discussed the problems with our advisor in the meetings each week on Friday. Highlights of these meetings are listed below.

- We started with the system design and discussed which components should be used. The design that we settled on is shown in figure 13.
- We were not sure about the devices which will be used in the system. We settled on:
  - Raspberry Pi as receivers and the access point
  - Android phones as transmitters
  - A computer as the server
- We discussed the communication techniques which will be used for transmitting data between devices.
  - We plan to use MQTT between receivers and the access point. Also, it will be used between the access point and the server.
  - We plan to design Restful APIs to transmit data from the server to the database and vice versa. Also, it will be used between the server and the user interface.

6.3 Task Plan with Milestones

- **Work Package 1:** System Setup
    - **Task 1.1**: Put the receivers and the access point
    - **Task 1.2:** Adjust the communication between devices
- **Work Package 2:** Complete the designs of user interfaces
    - **Task 2.1:** Web UI
    - **Task 2.2:** Android UI
- **Work Package 3:** Implementation of algorithms
    - **Task 3.1:** Positioning algorithms
    - **Task 3.2:** Way-finding algorithm for navigation
- **Work Package 4:** Data collection and testing

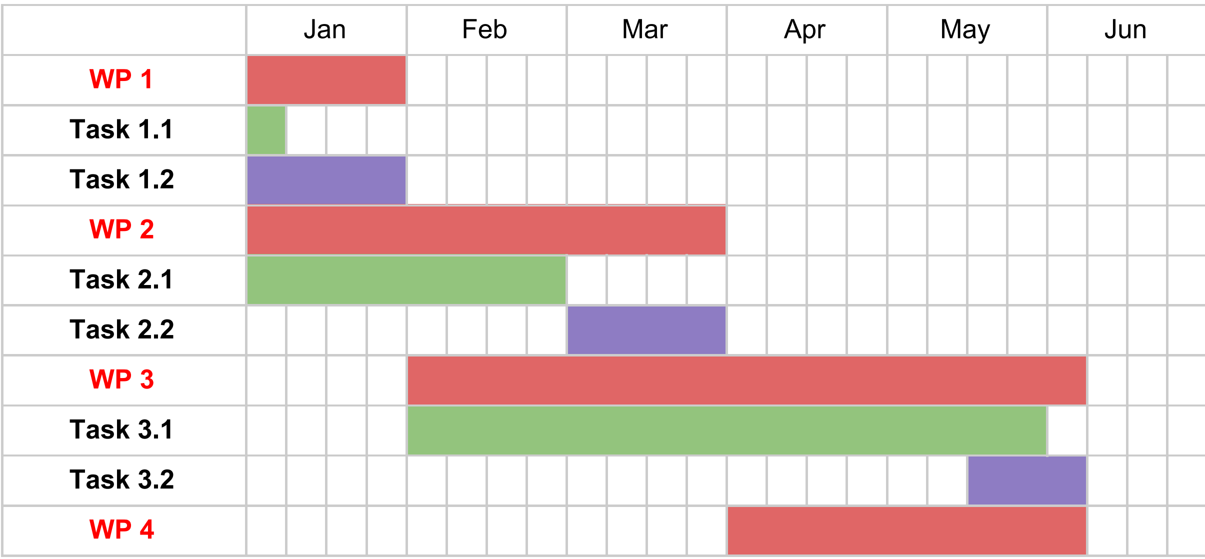

Figure 14: Task Plan and Milestones

7. References

[1] F. Zafari, A. Gkelias and K. K. Leung, "A Survey of Indoor Localization Systems and Technologies," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 3, pp. 2568-2599, 3rd quarter 2019.

[2] C. Yang and H. Shao, "WiFi-based indoor positioning," in *IEEE Communications Magazine*, vol. 53, no. 3, pp. 150-157, March 2015.

[3] Zhou, C., Yuan, J., Liu, H. et al. Wireless Pers Commun (2017) 96: 4115.

[4] C. Zhang, M. Kuhn, B. Merkl, A. E. Fathy and M. Mahfouz, "Accurate UWB indoor localization system utilizing time difference of arrival approach," *2006 IEEE Radio and Wireless Symposium*, San Diego, CA, 2006, pp. 515-518.