Development of Wearable eBand Tracking System
Stage 4 and Final Project Report

Submitted to

Nigerian Communications Commission (NCC)

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1. Introduction

The proposal for this project was submitted in May 2016 and awarded on May 16, 2018. We commenced work immediately after the award. We submitted the Project Kick Off Report along with Stage One deliverables as well as request for 40% payment on August 8, 2018. However, due to lack of communication from the NCC on this payment, the project was stalled for about seven months, as we only received 10% payment on March 12, 2019. When we received a letter from NCC on February 25, 2019 informing us that the project was running behind schedule, we responded that we were awaiting release of fund based on our August 8, 2018 request. Thereafter, NCC wrote to inform us that they had made payment of the 10% and 30% into the account of our University much earlier. We then followed up, got the money and resumed the project.

We submitted Stage Three Progress Report and a request for 45% payment on August 20, 2019. There were back-and-forth observations and responses by NCC and the project team up to June 2020. Our team eventually received the 45% payment requested in the Stage Three Report in May 2021. The last communication we received from NCC was dated June 17, 2021 with reference NCC/R&D/ABU/015. In that communication, we were reminded that the Commission had disbursed the sum of ₦5,945,903 (five million, nine hundred and forty-five thousand nine hundred and three naira only) being 85% of the Research Grant for the Stages 1, 2 and 3.

We submit this updated Stage Four Report as the final and project completion report and, with it, seek audience to present and demonstrate the system built. Section 2 of this report restates the aim and objectives of the project, as originally conceived. Section 3 summarizes the two earlier reports submitted to NCC. Section 4 discusses the three objectives of the project, how they were implemented and the deliverables therefrom. Section 5 presents a response to the two minor observations made during the demonstration of the prototype to visitors from NCC. Section 6 presents expenses on the project. The appendix contains some illustrative images.

2. Aim and objectives of the project

The aim of the project is to develop a wearable eBand for tracking pilgrims during the annual Hajj exercise, which, occasionally, leads to eventualities that call for such a solution. The specific objectives of the research are:

a. Design and implement an online real-time system for capturing bio-data during registration of pilgrims and store them in a central database, which can be accessed whenever needed and from any location.
b. Design and implement an electronic wrist band (eBand) that can be used to facilitate pilgrims' identification. Specifically, a configurable wearable eBand that contains pertinent information about the pilgrims would be worn by the pilgrims in order to easily identify or obtain the geographical positions of the persons wearing them.
c. Design and implement an electronic wrist band reader that can read the information stored in the wrist band in order to identify the wearer.

3. Summary of Earlier Reports

Two progress reports were submitted in the course of this project. The first, Project Kick Off and Data Collection Report, was submitted on August 6, 2018. This report contained elements of Stage One deliverables on the first objective—design of a central database of pilgrims bio-data (name, state, gender, height, hajj agency). We reported on the data modeling, analysis as well as data collection for the system. That report also contained review of the literature on the design considerations and communication options of the eBand with the central server. Literature review of the design options for tagging the eBand (using NFC, RFID, Barcodes or Bluetooth) to inform the cost-effective design of the reader was also presented.

The second Stage Three Progress Report, was submitted on August 20, 2019. It highlighted the percentage of work completed for the major work elements of the project including a Financial Report. It also contained:

- The data model of the application,
- Sample user interfaces implemented for the central server application,
- Sample Google Map interfaces,
- Sample interfaces for the Mobile Application reader, and
- Sample snapshots of the eBand components.

By the time of the second progress report, requirements gathering, data collection and data modeling had been completed. Interface design and implementation as well as design, construction and programming of the controller and reader had reached 60%.

At the time of writing this report, all the eleven (11) major tasks of the project, as reported in the second report, have been completed, as summarized in the next section.

4. Project Objectives Accomplished

The following sections summarize how the three objectives of the project have been accomplished and the deliverables from each objective.

4.1. Online Pilgrim Registration

Stage One of the project deliverables, Data Collection and Modeling have been accomplished and reported in our communication of August 6, 2018.

The conduct of *Hajj* and *Umrah* requires movement of people across and within borders; and based on the International Laws and treaties between nations, passport and visas are required for transborder movements. As such, the registration component of the project captures basic data available on the data page of a pilgrim's international passport. Other information components captured include basic medical data, next of kin, registration with a pilgrim agency and eBand identification information.

Pilgrim biodata is centrally maintained so that an intending pilgrim is issued a unique identifier. The identifier becomes the intending pilgrim's permanent identity in the system. Items of information that remain constant for a person are captured followed by other information that change from time to time. Information items that are considered changing

include next of kin, medical and passport. Others are allocation of seat for a particular *Hajj* or *Umrah* and mapping a wearable eBand to intending pilgrims. eBand mapping is done when a seat is confirmed for an intending pilgrim. It is important to note that wearable eBands are replaceable, much as they can be reused by different persons (though not within the same *Hajj* or *Umrah* year).

The system supports the following features:

- Capturing biodata during registration of pilgrims and storing them in a central database
- Configuring wearable eBands for each pilgrim after data capturing
- Configuring the eBand reader
- Resetting the eBand (for reuse purpose or any reason that necessitates resetting)
- Generating reports (e.g., list of eBands at a locality at a given time, location history of a given eBand over time, etc.)

Sample figures that show features of the system through the Web interface are shown in Appendix B.

4.2. Wrist-wearable eBand

The block diagram, circuit diagram and the final PCB design of the wearable eBand are shown, respectively, in Figures E.1, E.2 and E.3 in Appendix E. As mentioned earlier, each eBand identifies a pilgrim and periodically sends location information of the owner to the central database. An eBand also has an NFC tag that is readable by the mobile reader. Communication between the wearable-band, mobile application and the control server requires the eBand and the mobile app sending small-sized messages (pilgrim's location) to the server.

Figure E.3 of Appendix E shows that the level of integration in the final eBand design is high with a GSM/GPS module, microcontroller and other supporting components. Fabricating this design in a small space (wearable), including the battery and antenna, requires advanced PCB fabrication facility and is beyond the capacity of manufacturers that we have contacted offering low-cost production.

We spent the last few months exploring the possibility of fabricating the final eBand design in China and then Dubai and finally in Malaysia without success. To avoid further delay in the project, we resorted to building the eBand prototype by assembling off-the-shelf components.

The following are the components used to build the prototype wrist-wearable eBand:

- SIM module (Sim800l)
- GT-U7 GPS module
- Arduino Pro Microcontroller
- 3.7v battery

- TP4065 charging module

Fig. 1.1 is the SIM module (Sim800l) which is responsible for transmitting the location retrieved from the GPS module through the general packet radio service (GPRS) medium. It has a slot for a SIM card to be inserted into it in order for the device to access the internet to enable sending of locations to the server.

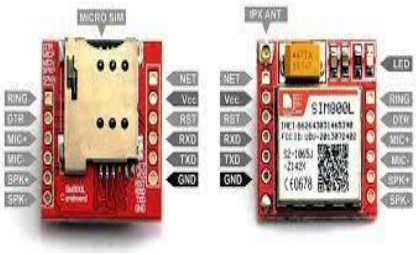


Fig. 1.1: Sim800l

Fig. 1.2 is the GPS module which is responsible for getting the set of geographic coordinates of the user. It retrieves the location from the satellite in NMEA format which then will be processed by the Arduino Pro Micro to separate the latitude, longitude, altitude, date etc. from the whole NMEA stream of data.

Fig. 1.2: GT-U7 GPS

The Arduino Pro Micro is the brain of the GPS tracker as it is the main component that communicates with and commands all other devices in the system. It is the device that is programmed to execute various functions of the system. Fig. 1.3 is the snapshot of the device. Fig. 1.4 shows the battery that powers the entire system and the TP4065 which is responsible for charging the battery is shown in Fig. 1.5.

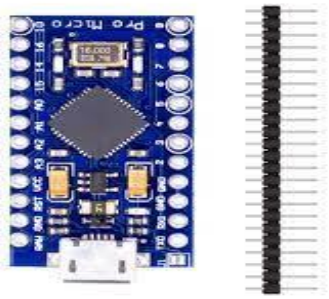


Fig. 1.3: Arduino Pro Micro

Fig. 1.4: 3.7v Battery

Fig. 1.5 Tp4065 Battery Charging Module

The assembled device is programmed to retrieve NMEA data streams provided by the GPS module, parsed using the NMEA parsing library. Then the device position, comprising the exact location of the device, date, time and altitude, is extracted and sent to the designated database by the SIM module at a given interval.

Fig. 1.6: Prototype eBand

The assembled components are formed into a wearable eBand as shown in Fig. 1.6. The eBand provides the desired functionality of sending the exact location of the owner in form of longitude and latitude to the designated database at an appropriate interval (e.g., 10 seconds).

The assembled eBand prototype provides the required functionalities undertaken by the project.

4.3. Mobile eBand Reader

This section highlights the design options, functionalities, design choices and justification of some of our choices with regards to the mobile eBand reader. Some screenshots of the developed mobile eBand reader are provided in Appendix D.

Design and Development

The Mobile eBand reader has been designed to allow *Hajj* officials to easily identify and track pilgrims, and report incidences that may occur by scanning the wearable eBand on their wrist. As stated in the objective, Near Field Communication (NFC) technology was utilized for the identification of the pilgrims. To achieve this identification, NFC tags with unique identifiers were embedded in the wearable bands. The mobile eBand reader has been developed using a cross-platform framework. This was done in other to make the app readily available on all platforms (mainly Android and ios).

To use the mobile eBand reader, the *Hajj* official has to install the application from the Google or Apple app store and obtain login credentials from the agency. The official can then activate the app on the device by filling in the login credentials. It is the duty of the agency to then activate the official's device in order to access the application. This mechanism has been put in place in order to prevent unauthorized access to the mobile app. It is important to note that each official can only have the app active on a single device at a time.

An official can identify a pilgrim by simply placing the pilgrim's mobile device on the wearable eBand of the pilgrim. The mobile eBand reader will read the ID of the NFC tag embedded in the pilgrim's wearable eBand and use this ID to retrieve the pilgrim's information from the central server. The official can then perform other operations using the mobile app as described in the next section.

A mobile app has been developed as against the use of custom hardware readers because these readers largely do not have screens to make usage easy. Also, adopting such readers will mean we would have to trade off portability. The official may have to carry this custom hardware along with the mobile device to use the app. With our solution, an official does not need to carry any other additional hardware aside the mobile device.

Functionalities

The mobile eBand reader communicates with the central server via an internet connection. Therefore, a good internet connection is a prerequisite for the reader to perform its functionalities effectively. The mobile eBand reader has five major functionalities as follows:

1. **Display all pilgrims on a Map**

   On successful login into the mobile eBand reader, an official sees a Map that displays the current location of all pilgrims in the current pilgrimage. We use an icon to display these locations on the map. From this view, an official can click on a pilgrim and a popup window will be shown with a brief information about the pilgrim on it. The official can then either dismiss the popup or choose to see the detailed information of such a pilgrim.

2. **Identify a Pilgrim**

   This feature allows an official to identify a pilgrim by scanning the wearable eBand on their wrists. If the official knows the ID of the eBand (which we suggest should be printed somewhere on the wearable when deploying), he can also key in the ID to identify the pilgrim. On successful identification of a pilgrim, an official can see the

pilgrim's basic information, track the pilgrim's previous movements, report an incidence and also send the pilgrim's current location to the server. However, for any functionality that requires the location of a pilgrim to be sent to the server, the wearable eBand must be scanned by the mobile eBand reader to achieve that.

3. **Track a Pilgrim**
   This functionality allows an official to visualize the history of a pilgrim's movement over a period. The option is available after successfully identifying a pilgrim. The official is to supply the period over which the tracking should be done and the result is displayed on a map.
4. **Report Incidences**
   Incidences that may require urgent attention do occur during a pilgrimage. This feature allows the *Hajj* officials to capture these incidents and send them along with the location where they occurred to the central server.
5. **Send Location to Server**
   Sometimes, it may be desirable to explicitly send the location of a pilgrim to the server, which ideally is to be sent periodically from the wearable eBand. The feature allows an official to do so. Upon successful scanning of the wearable eBand, this option is made available.

5. Observations after Prototype Demonstration

Following our letter to NCC dated October 14, 2021 requesting for a visitation from for demonstrating capabilities of the developed prototype from the project, a team of the following three persons came on November 12, 2021 for the exercise:

1. Dr. Mohammed Kyari
2. Dr. Lawal Moriki
3. Mr. AbubakarDaudu

Our team successfully demonstrated the developed prototype resulting from the project during this interaction. At the end of the presentation that lasted more than one hour, two minor observations were made:

1. What is the estimate cost of messages sent by the eBand per day and/or per month?
2. How can the battery life of the eBand be enhanced?

We respond to these observations briefly in the following subsections.

5.1. Cost Estimate of eBand Messages

As mentioned earlier, an eBand identifies a pilgrim and periodically sends small-sized location information of the owner to the central database. The geographic location of a pilgrim consist of the latitude and longitude of the current location of the eBand wearer. Cost estimates of the eBand messages given below are based on the following assumptions:

1. The location (coordinates) is sent via GPRS.
2. Messages are sent at 5 minutes intervals
3. The size of the message is 22 Bytes.
4. As of February 2021, 1Gb cost an average of ₦364 in Nigeria (https://www.statista.com/statistics/1181410/price-for-mobile-data-in-nigeria/) and ₦609 in Saudi Arabia https://www.atlasandboots.com/remote-work/countries-with-the-cheapest-internet-world/).

Based on these assumptions, 288 messages will be sent per day with an estimated daily cost of ₦0.00216 in Nigeria and ₦0.0036 in Saudi Arabia.

5.2. Enhancing Battery Life of eBand

The assembled eBand consists of a 3.7v rechargeable battery that powers the entire system and a TP4065 charging module responsible for charging the battery. This module is made for charging rechargeable lithium batteries using the constant-current/constant-voltage (CC/CV) charging method. In addition to safely charging a lithium battery the module also provides necessary protection required by lithium batteries. The module uses a very small amount of current (in the micro amps) whenever it is connected to a battery. It is fine to leave it connected to a battery for long periods, but if the plan is not to charge the battery within four months then disconnecting the module from the battery is recommended.

The charge voltage is fixed at 4.2V, and the charge current can be programmed externally with a single resistor. The TP4056 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

Based on these futures of the battery and charging module, there are ways of enhancing the battery lifetime, if the same battery and charging module are to be adopted in the production eBand. Alternatively, the production eBand may be based on a solar rechargeable battery.

6. Project Expenses

Expenses on the project since inception include those shown in Table 1.

S/N	Item description	Quantity	Rate	Amount
	Computer Hardware and Accessories			
1	Lenovo G50-80 Intel Core i5-1.9Hz (6GB,1TB HDD) 15.6-Inch Windows 8.1 Laptop	5	150,000	750,000.00
2	HP 2025 LaserJet Printer	1	50,000	50,000.00
3	Additional toner cartridges	5	12,000	60,000.00
4	Internet Modem	5	5,500	27,500.00
5	External HDD (1TB)	3	15,000	45,000.00
	Computer Software			
6	One year antivirus (Norton) subscription license	5	6,000	30,000.00
7	Google Map Service	1	355,000	355,000.00
	Chip (controller and reader) components			
8	First Invoice with 21 components (1,779 Saudi Riyals at 93 Naira to Riyal). Please see attached invoice.	93	1,779	330,894.00
9	Second Invoice with 9 components (1,622 Saudi Riyals at 93 Naira to Riyal). Please see attached invoice.	93	1,622	301,692.00
10	Shipping cost (425 Saudi Riyals at 93 Naira to Riyal)	93	425	79,050.00
	Logistics			
11	Travels	1.00	355,000	355,000.00
12	Conference attendance	100,000	2	200,000.00
13	Web hosting (Cloud hosting plan with Gold support)	250,000	1	250,000.00

14	Books	250,000	1	250,000.00
15	Software testing (Beta-testing)	50,000	1	50,000.00
16	Internet access subscription @ N3,000/month	15,000	6	90,000.00
17	Stationary	1.00	120,000	120,000.00
18	Project meetings	12	11,000	132,000.00
	Research and Field Assistants			
19	Research Assistants (50,000 x 2 x 12)	100,000	9	900,000.00
20	Field Assistants (40,000*3*12)	120,000	9	1,080,000.00
	Accounting and Secretarial Services			
21	Secretary, Accountant, Driver	60,000	9	540,000.00
	Estimate for System Development			**5,996,136.00**

Table 1: Financial Expenses to Date.

7. Appendix A—Updated System's Data Model

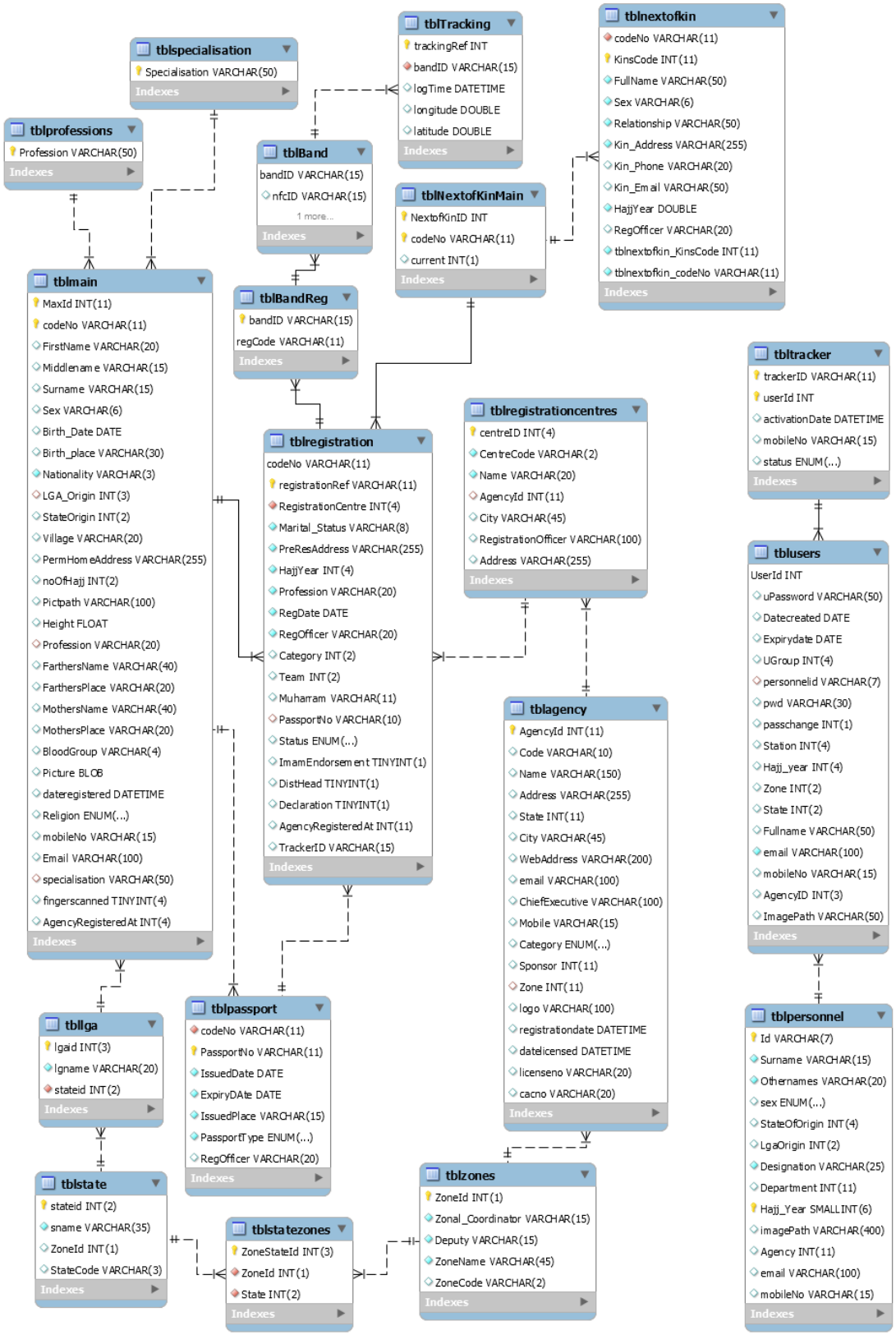


Figure A.1: Simplified Data Model of the System

8. Appendix B—Updated System's Sample User Interfaces

Figures B.1 – B.7 show sample user interfaces of the eBand controller web interface.

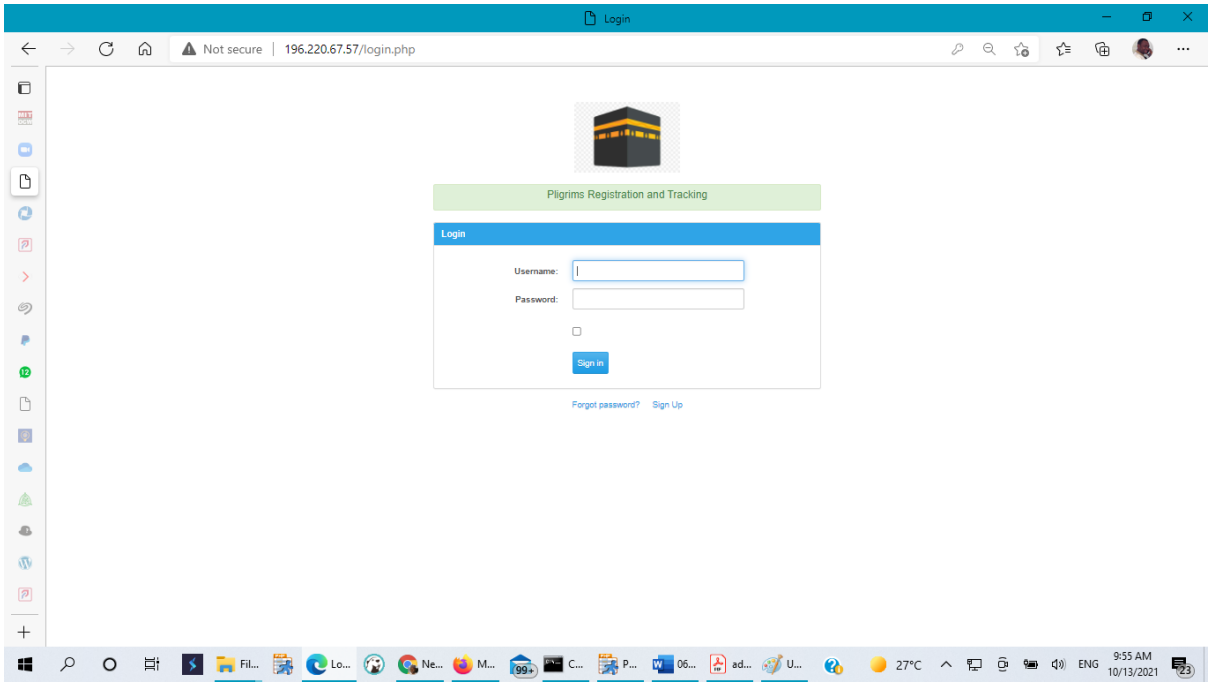


Figure B.1: Login Page of the eBand Controller

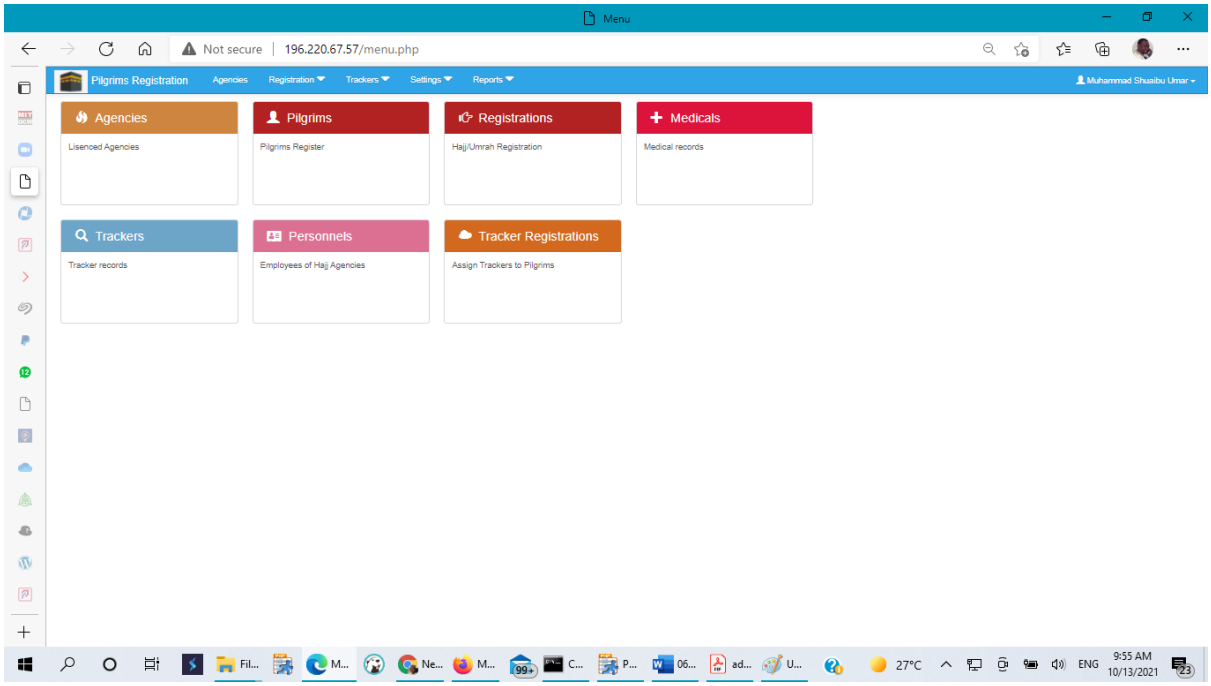


Figure B.2: Main Menu of the eBand Controller

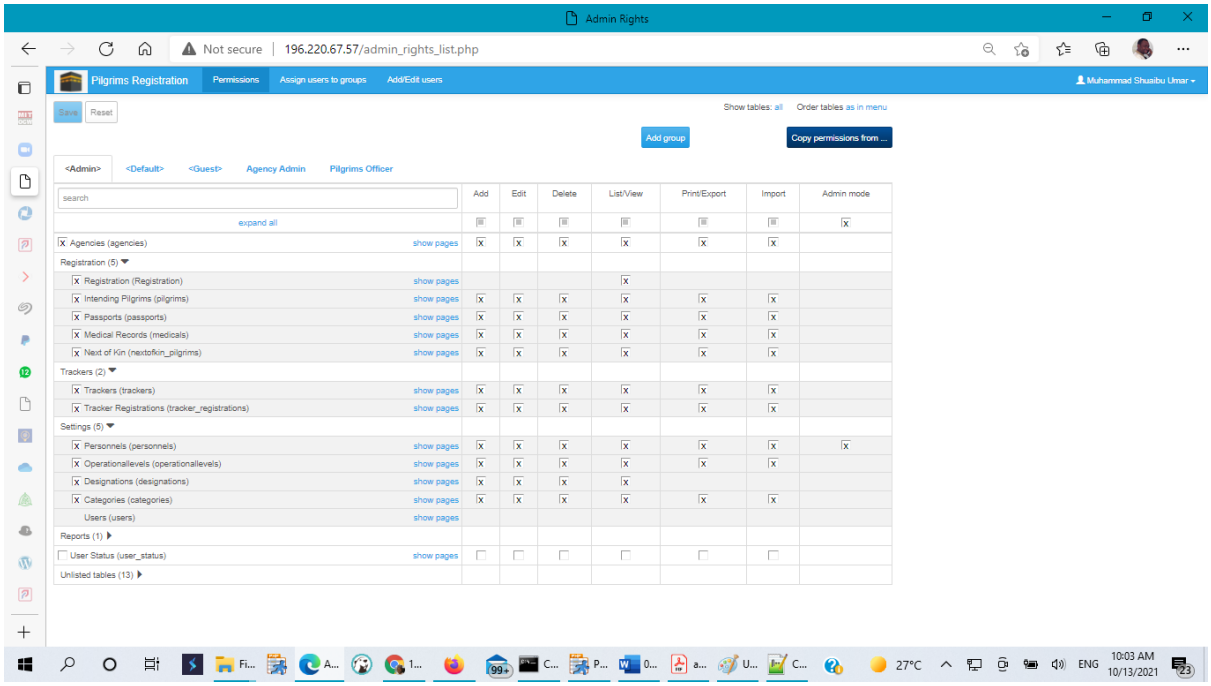


Figure B.3: Admin Console of the eBand Controller

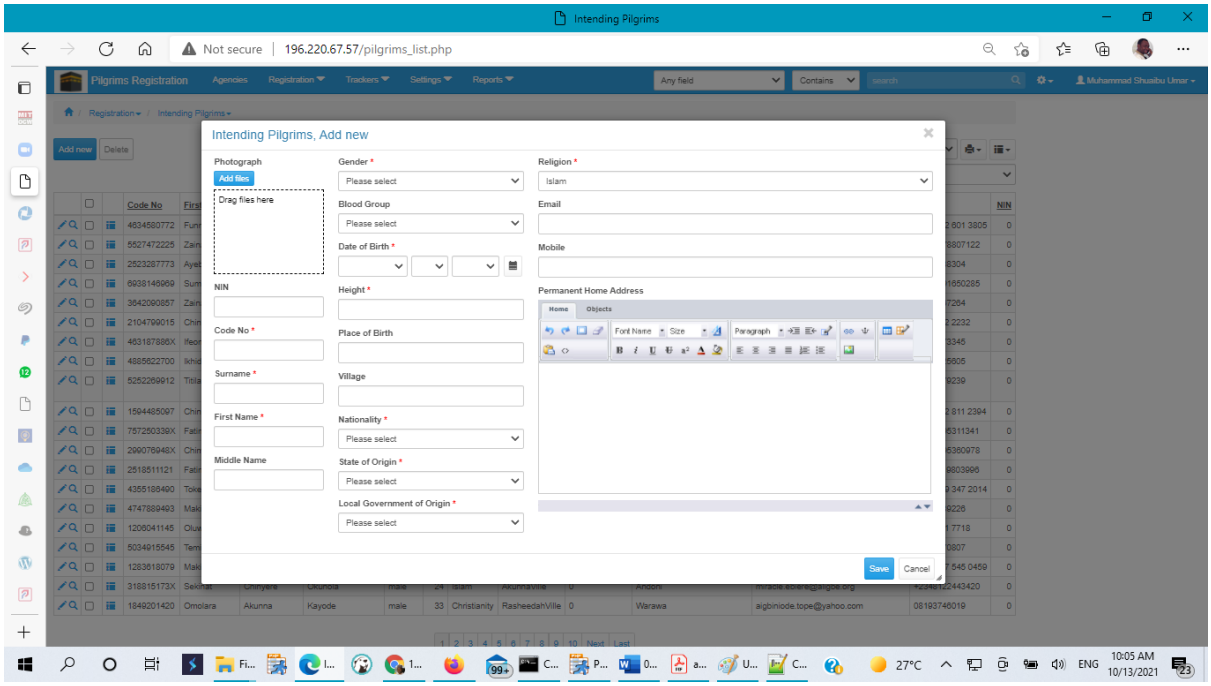


Figure B.4: New Pilgrim Record Form

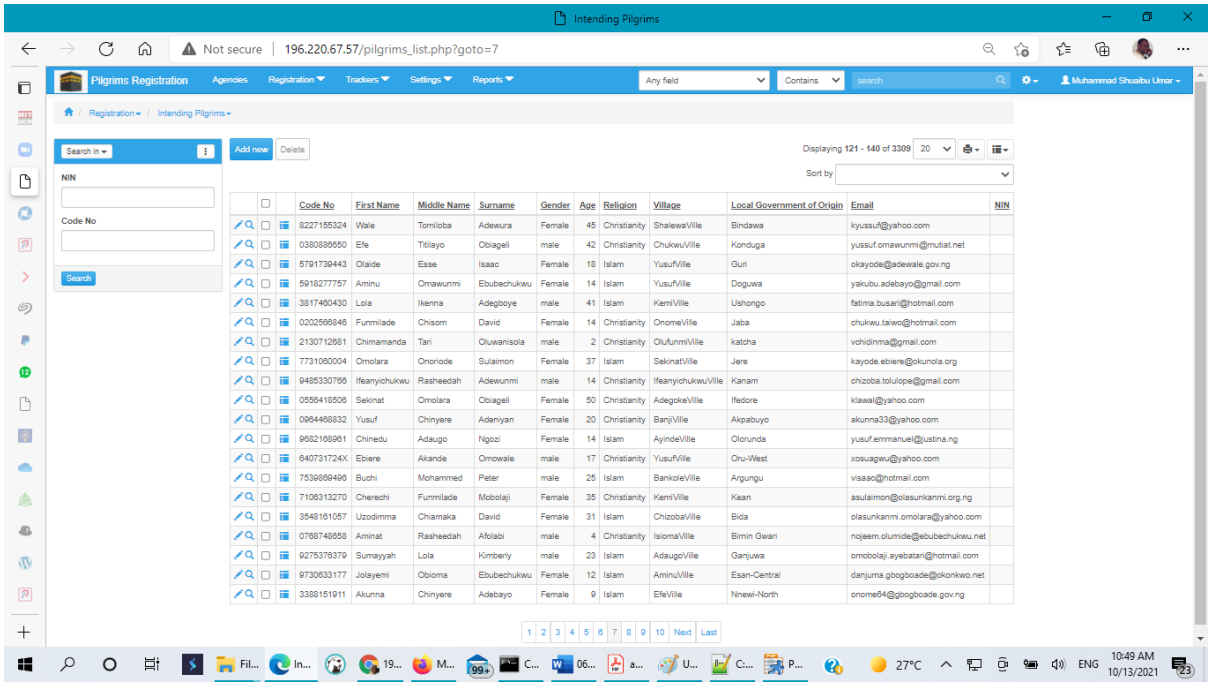


Figure B.5: Pilgrim Search Web Interface

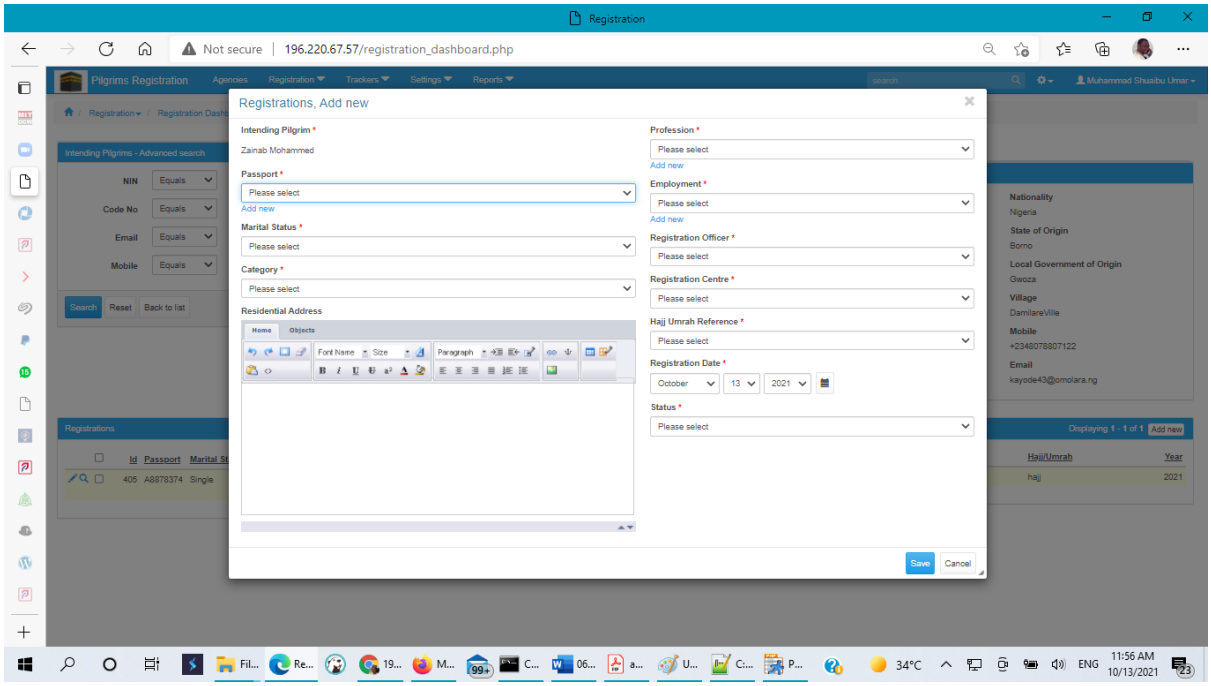


Figure B.6: Registration for Hajj

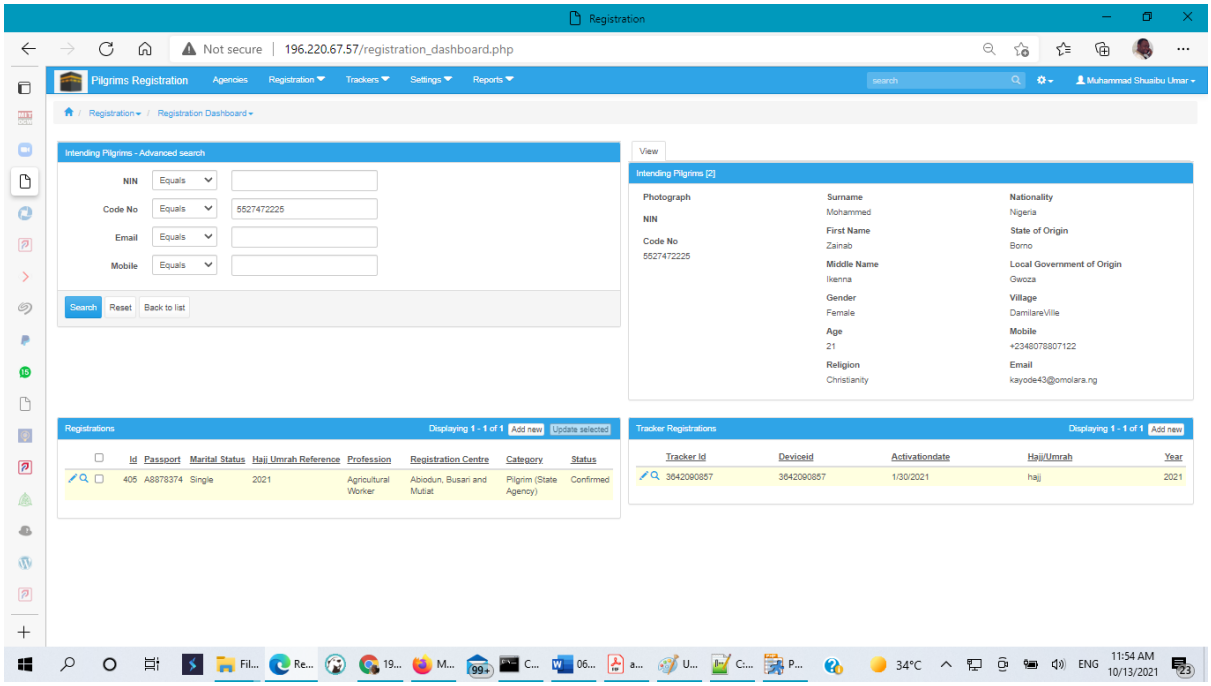


Figure B.7: Registered Pilgrim

9. Appendix C—Google Map Interfaces

Figures C.1 - C.5 show sample Google Map interfaces.

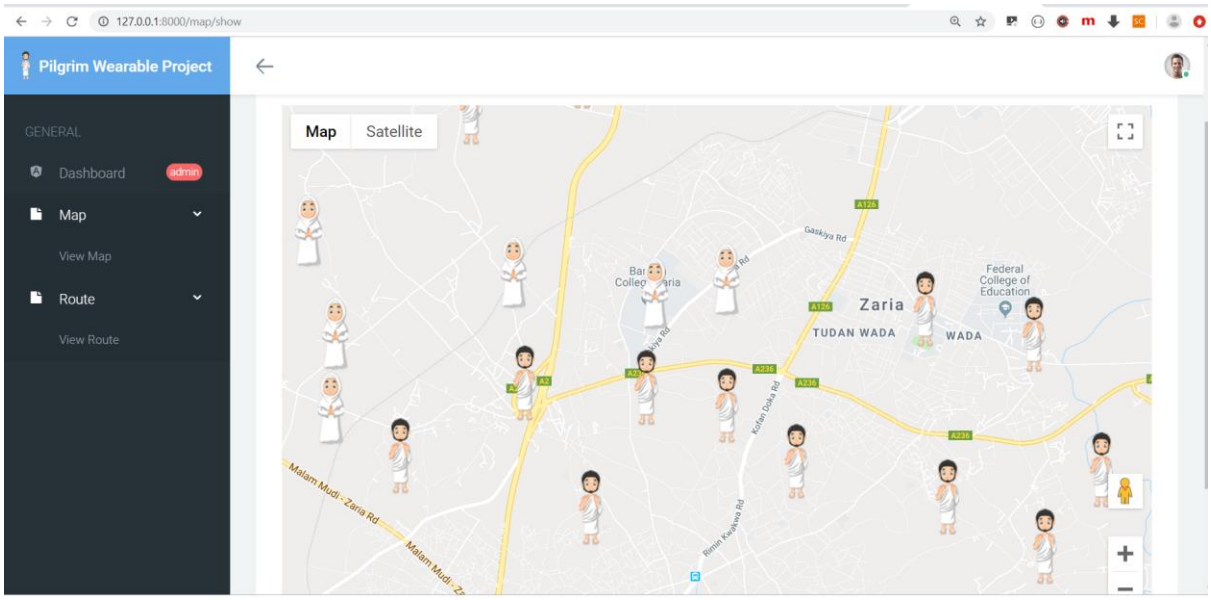


Figure C.1: Road view of Map Interface

Figure C.1 shows the Central Controller Map Interface that captures a specific area of interest with multiple location markers. A location in this context represents a coordinate of interest that depicts a pilgrim. From the map, pilgrims are marked by gender-like icons and distributed according to their current locations, as tracked and stored on the system's database. In addition, the map depicts a road view with labeled locations. An alternate view can be accessed via the menu on the top left corner of the map.

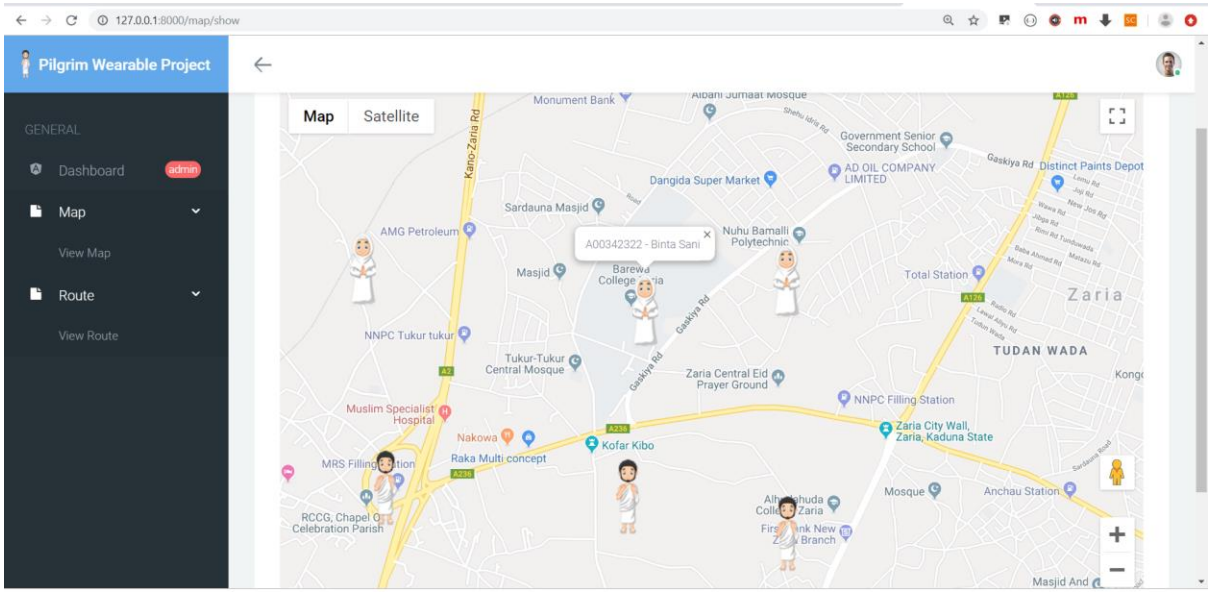


Figure C.2: Road view of map interface with profile information display

Figure C.2 shows the Central Controller Map Interface that captures a specific area of interest with multiple location markers and profile information for a selected pilgrim. A location marker in this context is a gender-like icon which, upon clicking, retrieves the basic profile information of the pilgrim, such as passport number and full name. In addition, the map can be zoomed in and out using the "+" and "– " buttons at the bottom right corner of the window.

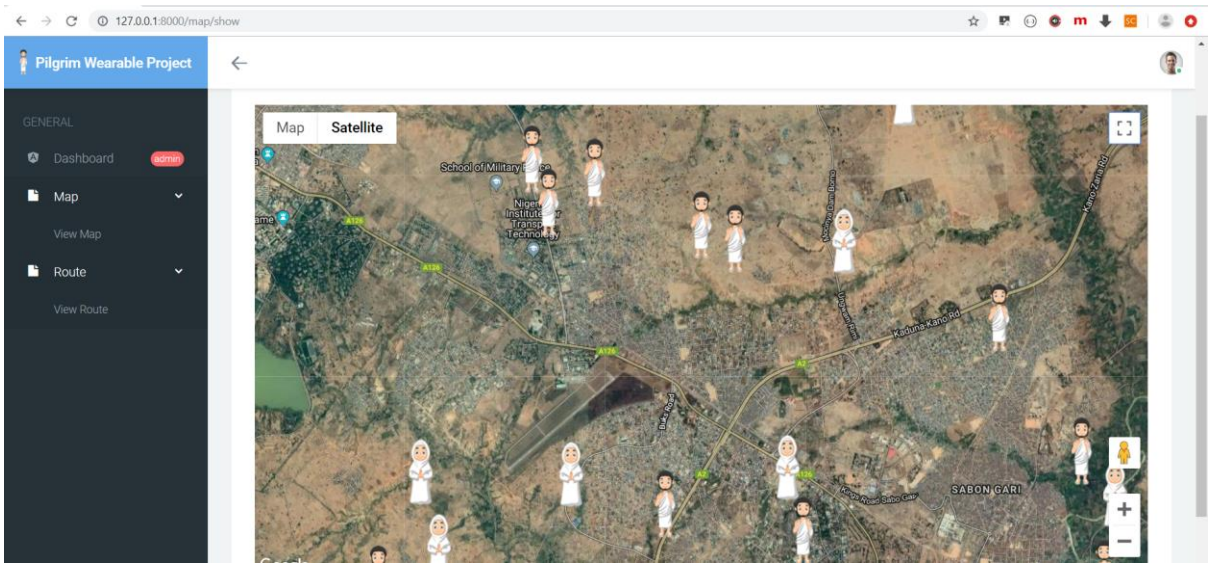


Figure C.3: Satellite view of Map Interface

Figure C.3 illustrates a satellite view of the Map with labeled locations. An alternate view can be accessed via the menu on the top left corner of the map.

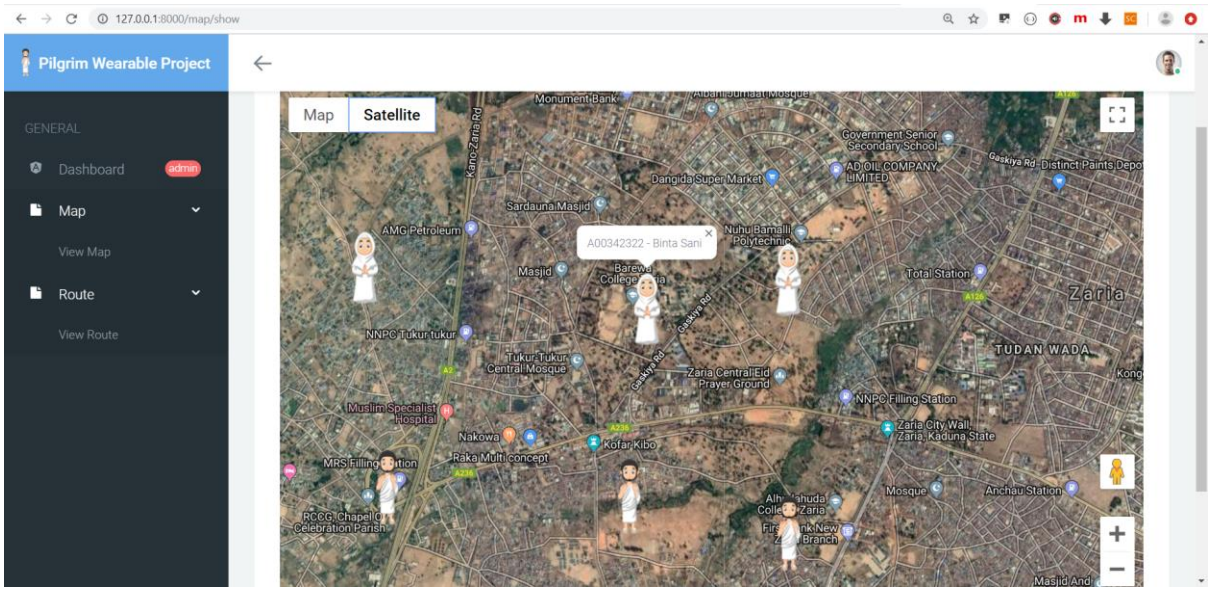


Figure C.4: Satellite view of map interface with profile information display

Figure C.4 illustrates a satellite view of the map with labeled locations and profile information display for a selected pilgrim. An alternate view can be accessed via the menu on the top left corner of the map.

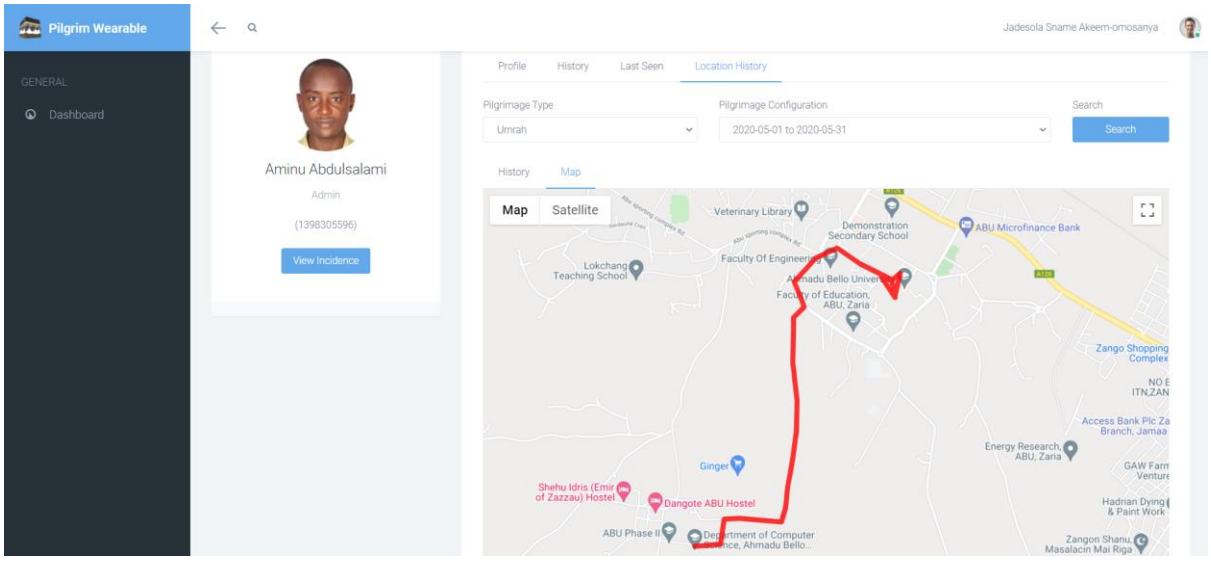


Figure C.5: Road map view with route followed from Point A to Point B

Figure C.5 shows the Central Controller Map Interface that captures the route followed by a pilgrim from Point A to Point B. The red line joins several intermediate points that exist between Point A and Point B. The arrow headed end of the red line depicts the destination point, while the other end depicts the beginning point of the route. Lastly, the route can be zoomed in and out using the “+” and “– “ buttons at the bottom right corner of the window.

10. Appendix D—Mobile Reader's Interfaces

Below are some screenshots from the mobile eBand reader demonstrating some of its functionalities.

Figure D.1: Login page where an authorized official logs into the app

Figure D.2: Landing page of the App that shows the official all pilgrims and their current locations

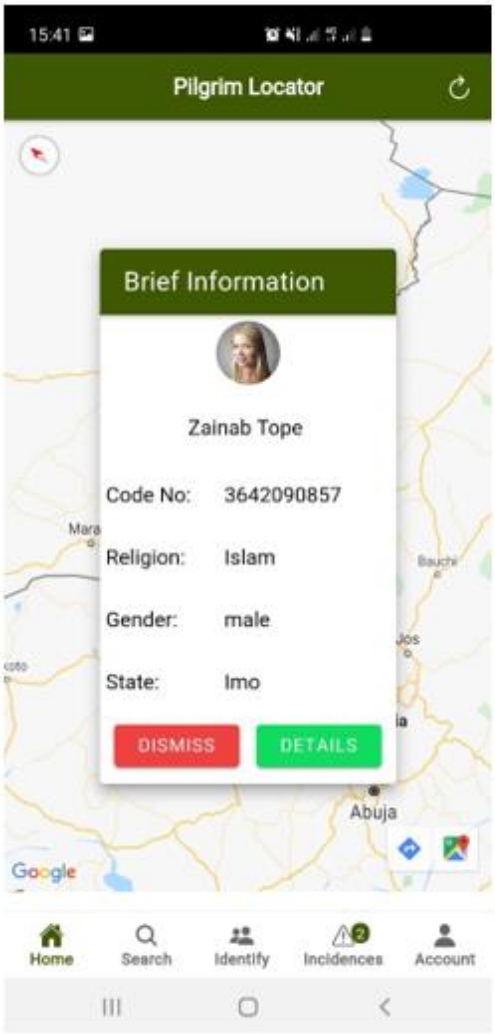


Figure D.3: Tapping on the icon of a pilgrim on the map shows a brief information of the pilgrim

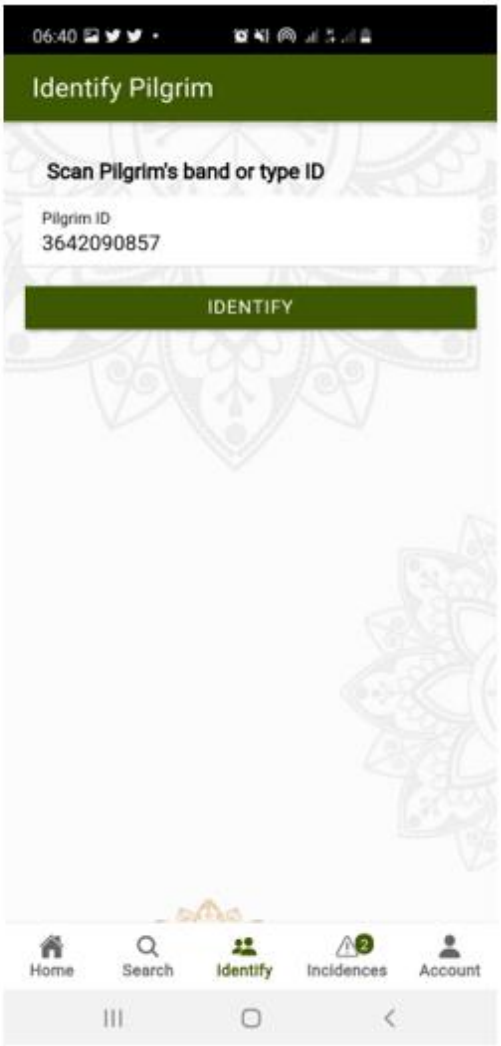


Figure D.4: A pilgrim can be identified by typing the wearable ID or scanning the wearable at any point on the app.

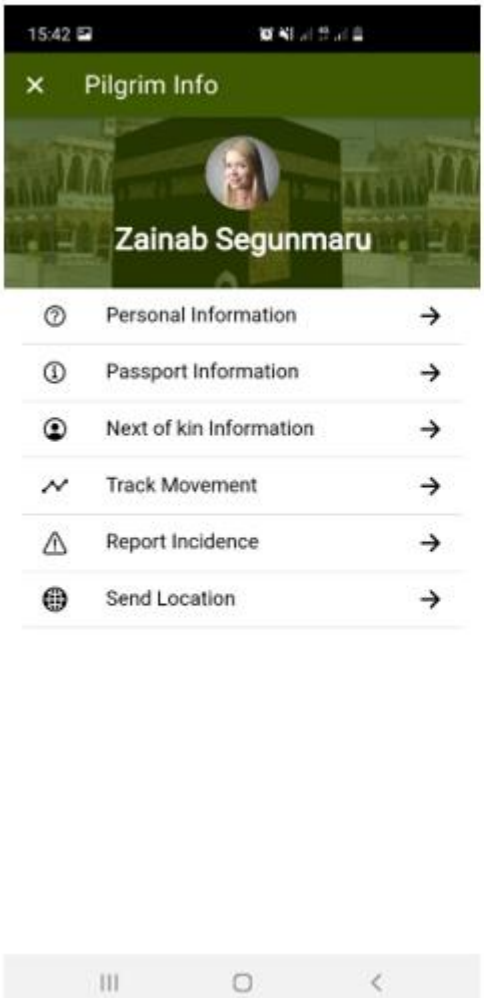


Figure D.5: Display upon successful identification of a pilgrim

Figure D.6: Display of a pilgrim's personal information

Figure D.7: Display of a pilgrim's passport information

Figure D.8: Display of a pilgrim's next of kin information

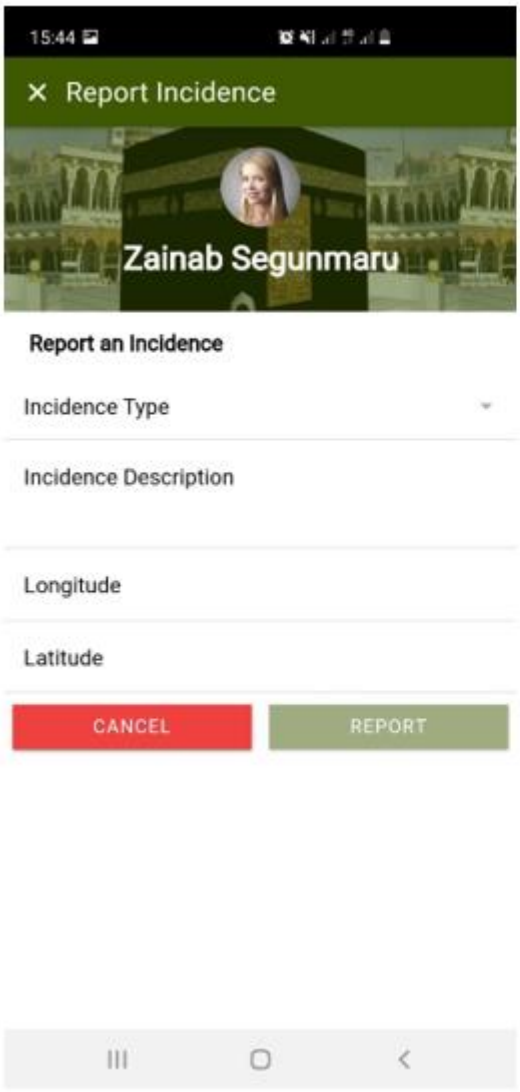


Figure D.9: Interface for reporting an incidence

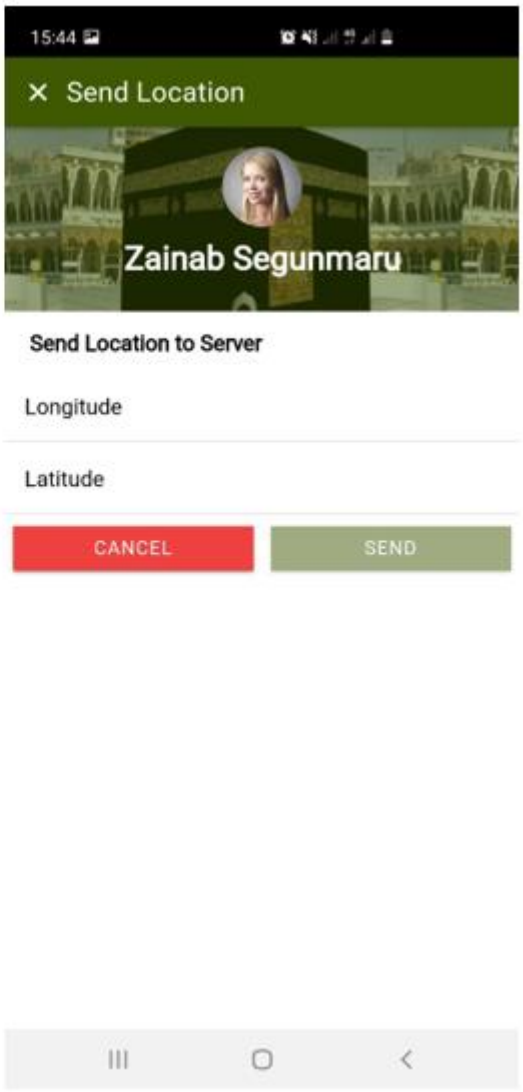


Figure D.10: Interface for sending a pilgrim's current location

Figure D.11: Interface for tracking a pilgrim over a period of time.

Figure D.12: Map showing a pilgrim's location over a period of time

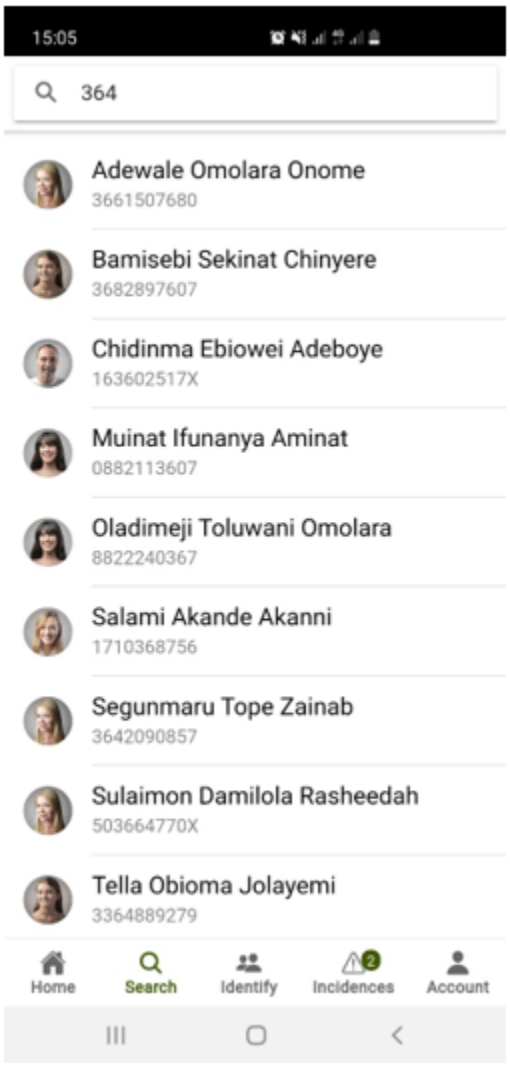


Figure D.13: Interface for searching for a pilgrim among all pilgrims.

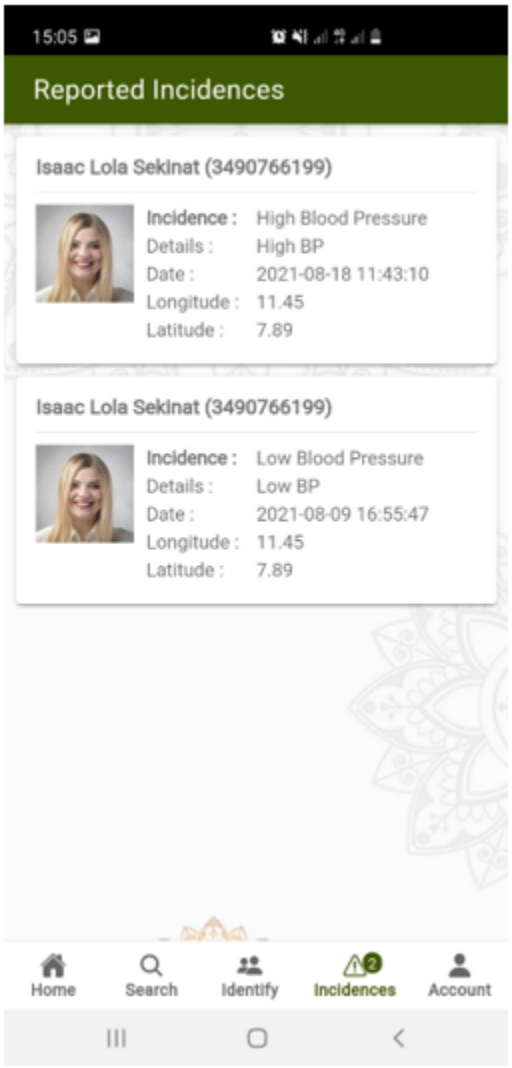


Figure D.14: Interface showing a list of incidences reported by an official

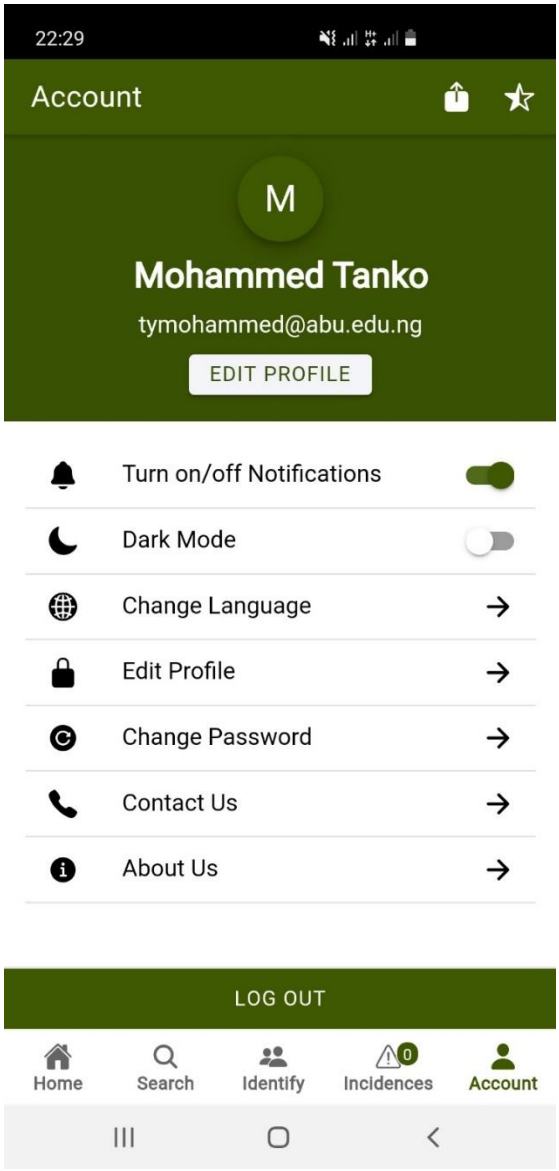


Figure D.15: Hajj official account interface for managing settings and preferences.

11. Appendix E—Designs of the wearable eBand

Figures E.1, E.2 and E.3, respectively, show the block diagram, circuit diagram and the final PCB design of the wearable eBand.

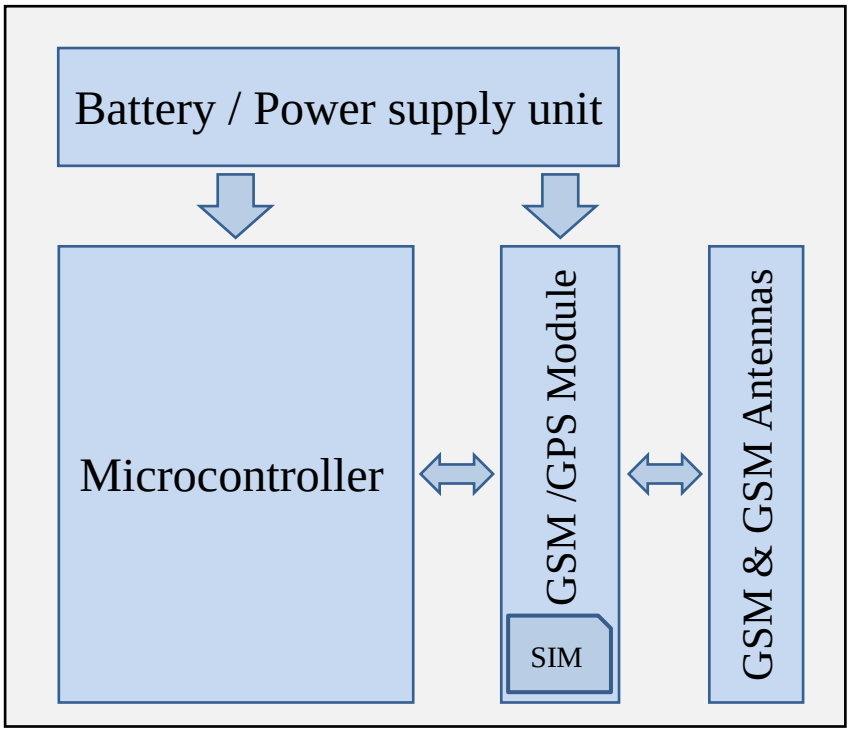


Figure E.1: Block Diagram of the eBand

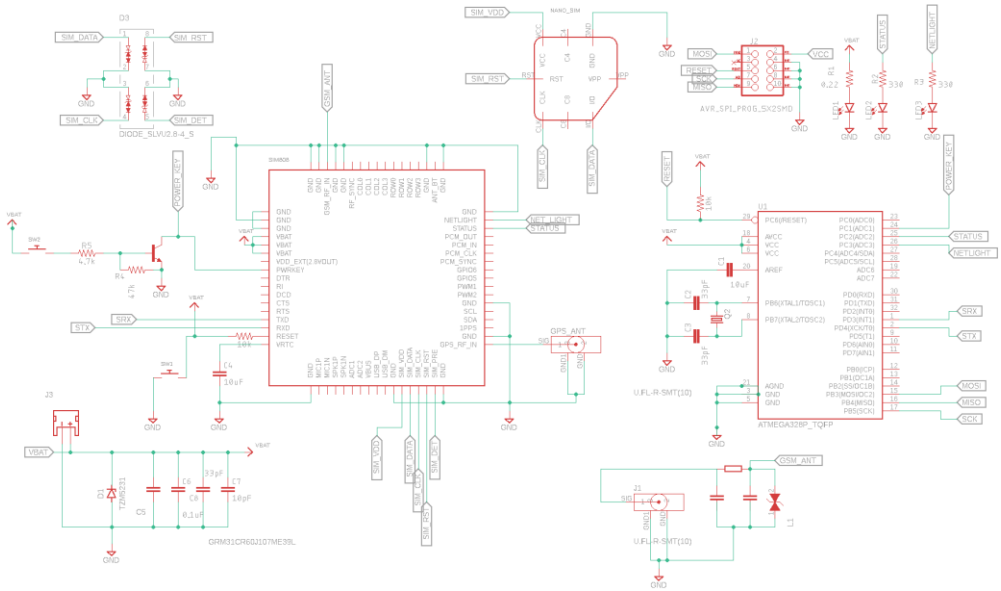
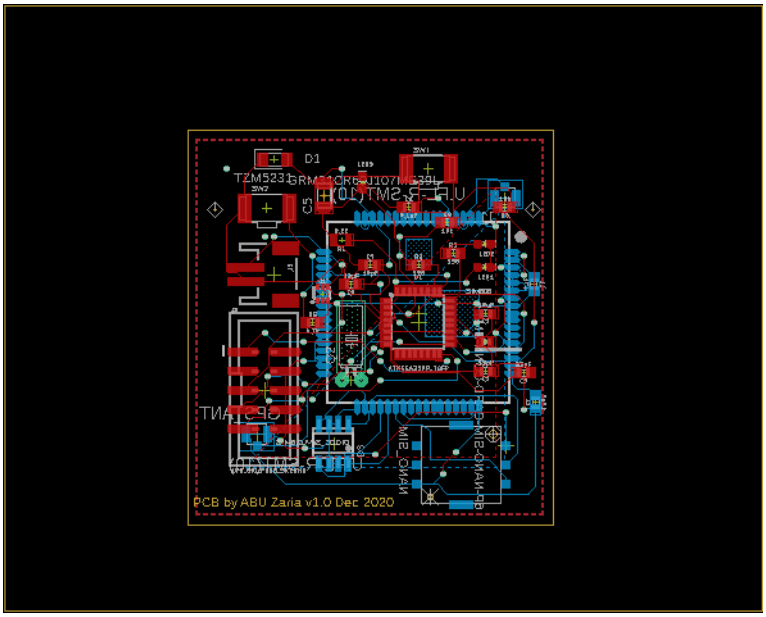


Figure E.2: Circuit Diagram of the eBand



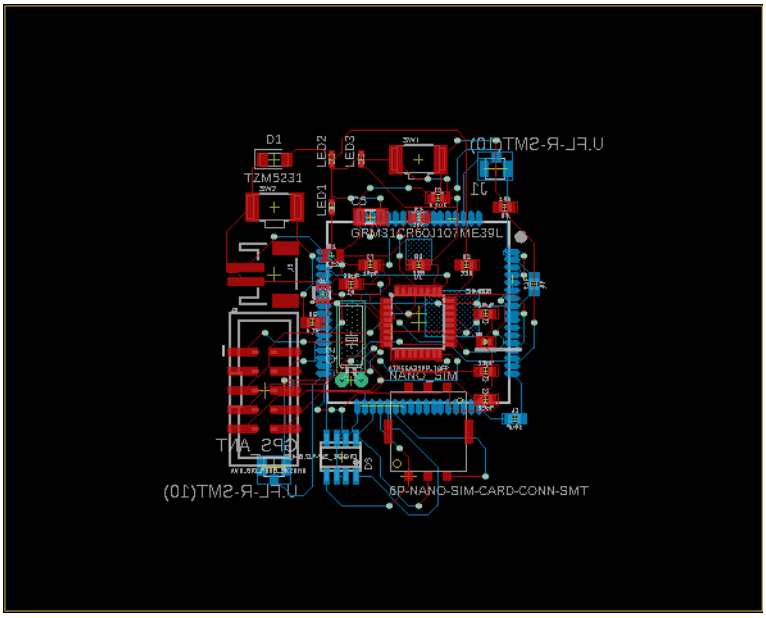


Figure E.3: PCB Design for the eBand