UNIVERSITY OF NAIROBI

FACULTY OF SCIENCE AND TECHNOLOGY

Department Of Computer Science

# In-vehicle RFID and GPS-based Device for Real-time Identification of Road Speed Limit Violators

By

Ongwae Mathew Teya

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**Supervisor:**

Dr. Evans K. Miriti

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*A Project Submitted to the Department of Computer Science in Partial Fulfilment of the Requirements of the Degree of Master of Science in Computational Intelligence of the University of Nairobi*

**August, 2022**

## DECLARATION

I declare that this project is my own work and has not been submitted to any other university or institution for consideration. The research work has been complemented by references which have been duly acknowledged.

**Signature** ______ ________ **Date** ___8th August, 2022_____

**Name:** Ongwae Mathew Teya

**Reg. No.:** P52/85621/2016

**Supervisor:**

This project report has been submitted for examination with my approval as the university supervisor.

**Signature** ________________ **Date** ___08-08-2022____________

**Name:** Dr. Evans K. Miriti

Department of Computer Science.

## ABSTRACT

Road speed limit violations have been classified among the major causes of road accidents in developing countries including Kenya. As much as there have been many technological solutions that have been developed to curb vehicle speeding, still cases of road speed limit violations that lead to road accidents continue to rise. However, research has shown that drivers are more responsible on observing road speed limits when they are aware of being monitored. Thus to curb the vehicle speeding problem, a solution for real-time monitoring and identification of driver details could help.

The objective of this project was to design and develop a prototype for an in-vehicle Radio Frequency Identification (RFID) and Global Positioning System (GPS)-based device that can be used for real-time monitoring and identification of drivers violating road speed limits. Thereafter the RFID and GPS functionalities of the prototype were tested and analysed.

Prototyping methodology was used in the system development. The developed prototype comprises of the following critical parts: an embedded system that was deployed in a test vehicle and a web application for remote real-time monitoring and identification of drivers. The development of the solution was done using readily available off-the-shelf electronic components that were integrated by C programming using the Arduino Integrated Development Environment (Arduino IDE). The web application was done using python programming and PostgreSQL database. An experimental approach was used to collect data by fixing the developed prototype in a vehicle and driving it along the identified test locations. The data (GPS coordinates, RFID identities and Vehicle Speed) was sent to a remote server for analysis to ascertain the proposed system's functionality and reliability.

A total of 60 speed violation tests were done and an impressive 53 speed violation instants were successfully detected and updated on the web application within 3 seconds of violation detection. The instances of failure on speed violation updates were occasioned by poor GSM network connectivity in the areas where failure was detected. This could be rectified by including redundancy connectivity using a satellite module that would provide connectivity in case of poor GSM connectivity. This can also be solved by integrating the embedded solution with an internal storage that will store violation data wherever there's poor GSM connectivity then transmit the data to the remote server when better GSM connectivity is restored.

***Keywords:*** *GPS Module, GSM Module, RFID reader*, Electrically Erasable Programmable Read-Only Memory (*EEPROM), Embedded Intelligent System (EIS), Radar Technology, LiDAR Technology*

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Many thanks to my classmates who were always willing to be consulted and offer support when called upon. Their teamwork was a blessing to me.

Lastly, I thank God for having given me the resources and good health that I much needed through this period.

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## ACRONYMS

| | |
|---|---|
| **EEPROM** | Electrically Erasable Programmable Read-Only Memory |
| **EIS** | Embedded Intelligent System |
| **GPRS** | General Packet Radio Service |
| **GPS** | Global Positioning System |
| **GSM** | Global Systems for Mobile Communication |
| **IDE** | Integrated Development Environment |
| **LiDAR** | Light Detection and Ranging |
| **NTSA** | National Transport and Safety Authority |
| **PCB** | Printed Circuit Board |
| **PSV** | Public Service Vehicle |
| **Radar** | Radio Detection and Ranging |
| **RFID** | Radio Frequency Identification |
| **WHO** | World Health Organisation |

# CHAPTER 1: INTRODUCTION

## 1.1. Background of the Study

Vehicle speeding has been classified as a major cause of road accidents, injuries and loss of lives. According to the World Health Organization (2021), 40% to 50% of drivers in the whole world drive above the speed limit, and research has shown that the higher the speed of a vehicle, the higher the risk of injury and death. Approximately 1.35million people globally lose their lives annually through road accidents. 93% of the live losses through road accidents happen in low and middle in-come countries and more than half of these deaths and injuries are among the most vulnerable road users; pedestrians, cyclists and motorcyclists (WHO, 2020). In Kenya, monthly deaths caused by road accidents increased by 26% from January 2015 to January 2020 while injuries increased by 46.5% over the same period. The trend is projected to continue unless action is taken to curb speeding on the Kenyan roads (Muguro et al., 2020).

The National Transport and Safety Authority (NTSA) has over the years tried to enforce the road speed limits by traffic officers physically being on the Kenyan roads but still cases of road accidents continue to rise each year (Kajilwa, 2016). This continuous increase of road accidents has been attributed to irresponsibility by the drivers who as much as they are aware of road speed limits and the presence of law enforcers' on the roads, they only observe the speed limits in locations where they know traffic officers are present but knowingly break the speed limits in areas where they know no one is monitoring them (Yannis et al., 2013). In other cases of being caught speeding by traffic officers, the drivers always bribe their way out of the hands of the traffic officers (Transparency International, 2018). Some drivers on being stopped by traffic officers, they either speed away with the vehicle or run away on foot leaving behind their vehicle. This is attributed to the fact that there will be no evidence available to link the driver to the speed violations. Also, traffic officers are sometimes scared of impounding speeding vehicles because they belong to high ranking people in society (The Standard Media, 2017).

Over the years, several embedded intelligent systems (EIS) have been developed to curb vehicle speeding in several countries. These EIS solutions are using different technologies to curb speeding. Radar technology, Global Positioning System (GPS), Global Systems for Mobile Communication (GSM) and General Packet Radio Service (GPRS) technologies. These technologies are able to identify a speeding vehicle but they still have fallen short of identifying in real-time the details of drivers violating road speed limits (Jeddi et al., 2013).

## 1.2. Problem Statement

There lacks in Kenya an effective road speed limit monitoring system that can be used to enhance road safety by monitoring and identifying drivers violating speed limits in real-time. The National Transport and Safety Authority (NTSA) has put in place measures like speed governors with 80km/h speed limits but they have not been effective in real time identification and keeping records of the drivers violating speed limits. The speed governors have also not been effective in ensuring drivers observe speed limits in places with speed limits of below 80km/h. NTSA has also used Light Detection and Ranging (LIDAR) speed guns to monitor and identify speeding vehicles but these speed guns are only limited to identifying one vehicle at a time and are only effective to certain areas of the roads where traffic officers are physically present on the road. These two solutions, speed governor and speed gun, are also not able to identify the details of the specific driver driving a vehicle at a particular time with real-time remote monitoring. The systems also put much focus on identifying the vehicle rather than the driver who is solely responsible for speeding.

Sometimes drivers run away and leave vehicles behind when stopped by traffic officers for speeding. Vehicles like Public Service Vehicles (PSVs) are driven by many drivers in a particular day and thus it becomes difficult for traffic officers to identify which driver was driving the PSV at a certain time when it was stopped for speeding.

Thus, to ensure responsibility among drivers in observing road speed limits and curb road accidents, there's need to implement a system that is able to identify in real-time the details of drivers violating road speed limits.

### 1.3. General Objective

To design and develop an in-vehicle RFID and GPS Based system that can be used to monitor and identify drivers violating road speed limits.

### 1.4. Specific Objectives

a) To gather and analyse system requirements.

b) To design and develop a GPS and RFID based embedded device for speed violation detection.

c) To design and develop a web application for monitoring and recording speed violations

d) To test the functionalities of the GPS and RFID based speed detection system.

### 1.5. Significance of the Research

The study aimed at providing a better understanding about various embedded solutions used in monitoring and identifying road speed limit violators. The findings of this research would help the National Transport and Safety Authority (NTSA) and other stakeholders in the transport sector to put in place an effective road safety enforcement system that will help to identify drivers breaking road speed limits in real time and thus reduce road accidents caused by speeding.

This project would also help to bridge the technology gap in existing road safety enhancement solutions and architectures. It hopefully could also add new information to existing research on enhancing road safety through technology.

Implementation of an effective road safety solution could be a boost to Kenya’s Gross Domestic Product (GDP) which has often been affected by the government spending millions of Kenya Shillings in treating victims of road accidents and losing productive human resource to injuries and deaths caused by road accidents.

# CHAPTER 2: LITERATURE REVIEW

## 2.1. Introduction

This chapter looks at vehicle speeding and the problems it comes with, then explores speed detection and object identification technologies and how they have been applied in monitoring vehicle speeding. It then discusses various embedded intelligent systems that have been developed to help with monitoring vehicle speeds and the technology solutions that are being used in Kenya for vehicle speed monitoring. It also contains the proposed speeding detection model.

## 2.2. Vehicle Speeding Problems

40% to 50% of drivers drive at speeds higher than the set limits yet vehicle speeding has been classified as a leading major cause of road accidents, deaths and injuries (World Health Organization, 2021). Approximately 1.35million people globally lose their lives annually through road accidents. 93% of the road fatalities occur in low and middle in-come countries and more than half of these deaths and injuries affect the most vulnerable road users; pedestrians, cyclists and motorcyclists (WHO, 2020). In Kenya, monthly deaths increased by 26% between January 2015 and January 2020 while injuries grew by 46.5% during the same period. This tendency is predicted to continue unless urgent intervention is taken to curb speeding on the Kenyan roads (Muguro et al., 2020).

Drivers have been known to speed when not under surveillance by the enforcers of traffic laws but drive at the recommended speeds when they are aware of being monitored (Yannis et al., 2013). Some drivers when caught speeding, most of the time they speed away when stopped by traffic officers. Other drivers even abandon vehicles by the roadside and run away by foot just to avoid being held responsible for speeding offences.

### 2.3. Speeding Detection Technologies

#### 2.3.1. Radar Technology

Radio Detection and Ranging (Radar) is a speed detection technology that applies radio wave beams directed at an object whose speed is to be measured. The radio wave beams land on the object at a specific frequency and are reflected back at a different frequency. The difference in frequency is then used to determine the speed of the object (1sixty8, 2017).

Radar technology is only limited to identifying the vehicle speeding and cannot identify the details of the driver who is responsible for the speeding. This technology also needs the physical presence of traffic officers on the roads so as to enforce the speed limits. It is also limited to just identifying speeding vehicles at certain sections of a road where traffic officers are present (Jeddi et al., 2013).

#### 2.3.2. LIDAR Technology

Light Detection and Ranging (LIDAR) is a technology that uses pulsed laser light directed at an object to calculate its speed. The laser light pulse is mostly generated from a handheld device, mostly known as speed gun, that is held and directed to the object whose speed is to be determined (Sharma, 2021). Being mostly a handheld device, it requires the presence of traffic officers on the road and can only identify road speed limit violators at specific sections of the road where there are traffic officers. It also does not solve the problem of identifying the driver details of who are solely to blame for speeding and not the vehicle.

#### 2.3.3. Image processing

Image processing uses a camera to estimate the speed of a vehicle. This is achieved by tracking the motion of the vehicle through captured video frames. The speed of the vehicle is then calculated using distance travelled by the vehicle and the frame rate of the video. Image processing is affected by factors such as illumination, camera noise and interference by other road objects thus making it unreliable at times (Suresh et al., 2016). Image processing has also not been able to identify the details of the drivers violating road speed limits in real-time.

#### 2.3.4. Global Positioning System (GPS) with Accelerometers

A combination of GPS data (speed and elevation) with accelerometer data helps to monitor the activities of a moving object in terms of speed, elevation and orientation (Allahbakhsi et al., 2020). This helps to identify the speed of a vehicle at a specific time and thus remote monitoring is possible. This technology also helps to monitor multiple vehicles concurrently. Its limitation however is identifying driver details in real time.

### 2.4. Personal Details Identification Technologies

#### 2.4.1. Facial Recognition

Facial recognition is a biometrics technology that uses facial landmarks to identify an individual. It has been applied in access control systems, airport visa processing and many other identity recognition applications. This technology has been found to be reliable in many of the applications it has been used. It has however been found not to be entirely fool proof, it has sometimes been hacked by use of face masks and look-alike persons (Thales, 2021).

This technology has been applied in intelligent vehicles in the vehicle start mechanism, but only limited to a few faces of people authorised to drive the car. The computing power needed for a facial recognition system and its cost implications limits it for implementation or integration into an in-vehicle embedded device (Edgell, 2013).

#### 2.4.2. Fingerprint Recognition

Fingerprint recognition is a biometrics technology that uses comparison of fingerprints to countercheck if the taken fingerprints are of the details of the person whose fingerprints are already stored in a database (Sarfraz, 2020).

Fingerprint recognition sensors are prone to lose sensitivity caused by human body oils and temperature variations. It is also easy to steal fingerprints considering fingerprints are always left in all kinds of surfaces due to the normal human life occurrence of always touching surfaces (Erickson, 2020).

### 2.4.3. Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is an automatic identification system that uses exchange of information between an RFID tag and an RFID reader by use of the radio wave communication. RFID has been used in intelligent autonomous vehicles for various functions such as underground location recognition and vehicle starting mechanism integration (Gaba et al., 2012). RFID is a relatively affordable technology to implement in in-vehicle embedded devices since it does not require much computing power and of course due to its affordability. The disadvantage of RFID technology is that the RFID cards can easily be copied and cloned (Morse, 2017). However, this can be avoided by using encryption while writing information into the RFID cards or tags (Balluff, 2020).

### 2.4.4. Smart Cards

A smart card has a microprocessor which is embedded into a plastic enclosure that is used for data storage and provides additional computing capacity (Eze et al., 2018). The embedded microprocessor has a programmable memory that is used for recording user defined data. Different encryption technologies are used for the protection of the user data stored in the smart card. Smart cards are widely used in the financial sector for making less expensive and safe financial transactions. However, maintenance of the smart card technology is expensive and it is very sensitive to corrosion and dirt (Weldemedhin, D., 2016).

## 2.5. Technological Solutions Used to Curb Vehicle Speeding in Kenya

### 2.5.1. Speed Governors

Speed governor also known as Road Speed Limiter (RSL) is an embedded system device that is used to regulate the amount of fuel into a vehicle engine with the aim of limiting the vehicle speed to a pre-set value. In Kenya, RSLs are mandatory for all commercial vehicles and Public Service Vehicles (PSVs). They limit the speed of these category of vehicles to a maximum of 80km/h (Pinnacle Systems, 2014).

**Figure 2.5:** Speed Governor. *Afrika (2018)*

These speed governors are limited to a pre-set speed of 80km/h, only applicable to commercial and PSV vehicles and currently they cannot remotely monitor and identify driver details in real-time in all road sections. They also do not provide the capabilities to monitor all vehicles on the road in real-time.

### 2.5.2. Speed Guns

Speed guns also known as Light Detection and Ranging (LIDAR) Speed Guns is a technology that uses pulsed laser light directed at an object to calculate its speed. The laser light pulse is mostly generated from a handheld device, mostly known as speed gun, that is held and directed to the object whose speed is to be determined (Sharma, 2021). Being mostly a handheld device, it requires presence of traffic officers on the road and can only identify road speed limit violators at specific sections of the road where there are traffic officers. It also does not solve the problem of identifying the driver details of who are solely to blame for speeding and not the vehicle.

**Figure 2.6:** A Traffic Officer Using a Speed Gun. *Mwangi (2018).*

## 2.6. Related Works on Vehicle Speed Monitoring

### 2.6.1. Pay-As-You-Drive Vehicle Insurance System

Bolderdijk et al. (2011) developed an in-vehicle GPS system with the aim of controlling vehicle speeding among young drivers. The speed of the vehicle was monitored remotely and the driver who respected the speed limits would be rewarded by getting discounts on their motor vehicle insurance. The experiments on the speed compliance were quite impressive as drivers observed speed limits to earn the incentives. The system however did not have the monitoring capabilities of identifying the driver details in real-time, it was limited to just identifying the vehicle not taking into consideration that a vehicle can be driven by different drivers at different times.

### 2.6.2. Traffic Radar Verification System

In Jeddi et al. (2013), a GPS-Doppler module is placed in a vehicle to estimate the vehicle's speed. The speed data is then sent to a nearby police car to analyse any violations of speed limits. This embedded system is limited to having a nearby police car fixed with a radar system and it only provides the details of the car and not those of the driver who is responsible for speeding.

### 2.6.3. Cruise Control with GPS and Radar System

This is an embedded device installed in a vehicle to limit the vehicle's speed to a pre-set speed using GPS. The system also uses radar technology to limit the speed of the vehicle installed with the device by measuring the speed of a vehicle in front of the vehicle with the device using Doppler Effect (Nissan Global Corporation, 2020).

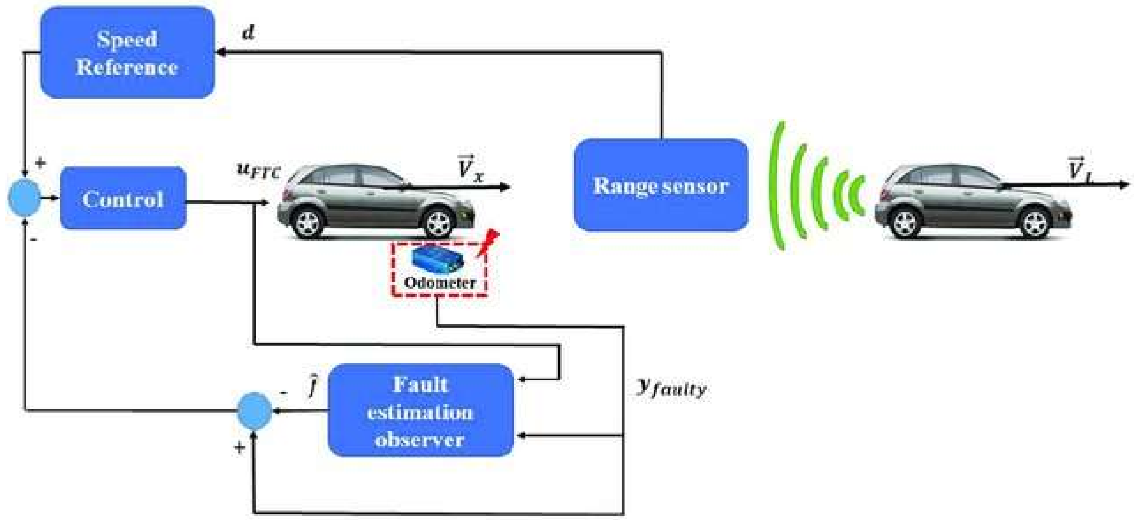


**Figure 2.7:** Intelligent Speed Control System. *Boukhari (2018).*

### 2.6.4. In-vehicle Intelligent Speed Advisory System

The intelligent speed advisory system is an in-vehicle device that helps to remind drivers of road speed limits to avoid accidents (Baten et al., 2009). But many drivers still ignore these speed reminders because they are aware no one is monitoring them and there are no adverse consequences for ignoring the system speed reminders.


**Figure 2.8:** In-vehicle Intelligent Speed Advisory System. *Baten et al (2009).*

### 2.6.5. Embedded System for Automatic Traffic Violation Monitoring and Alerting

This system is an in-vehicle system that is used to monitor violations at the road intersections. It monitors speed violations and cross line violations at the road intersections then sends any violations to a nearby traffic officer who is monitoring the intersection (Ramya et al., 2012). The system is limited to identifying vehicle details and is limited to only monitoring and detecting traffic violations at road intersections.

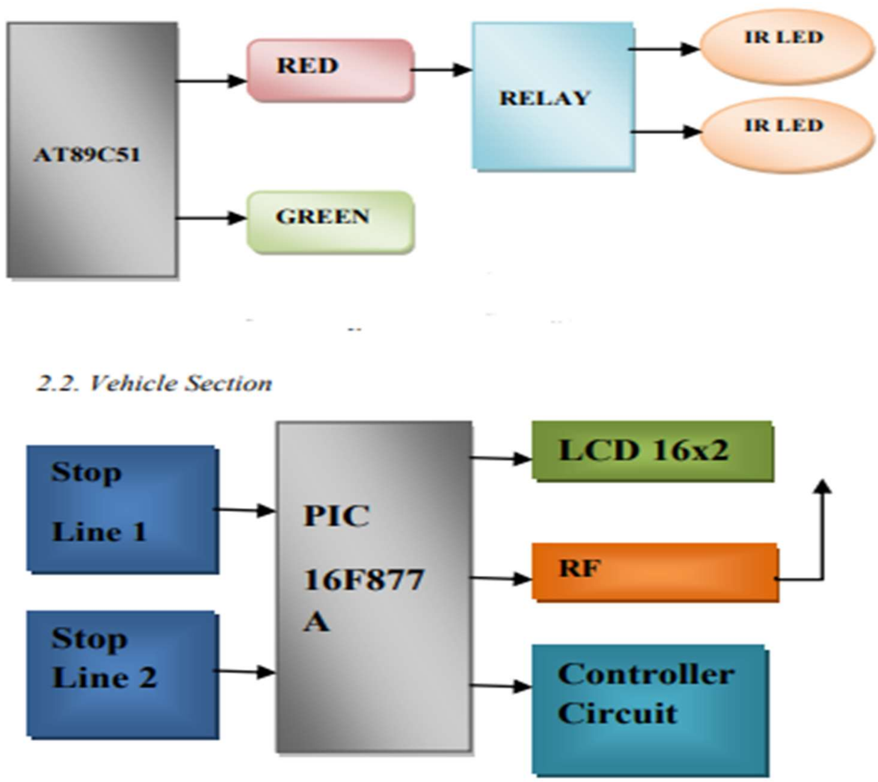


**Figure 2.9:** Automatic Traffic Violation Monitoring and Alerting Embedded System. *Ramya et al. (2012).*

### 2.6.6. GPS-Based Solution for Speed Limit Indicator

This is a solution that was developed to provide installable speed limit indicator devices in a vehicle to help remind drivers of road speed limits. This solution was implemented using Field Programmable Arrays (FPGAs) with the C programming language (Khan et al., 2009). This gives the driver of the vehicle a leeway to either obey the speed limit indicators or ignore them.

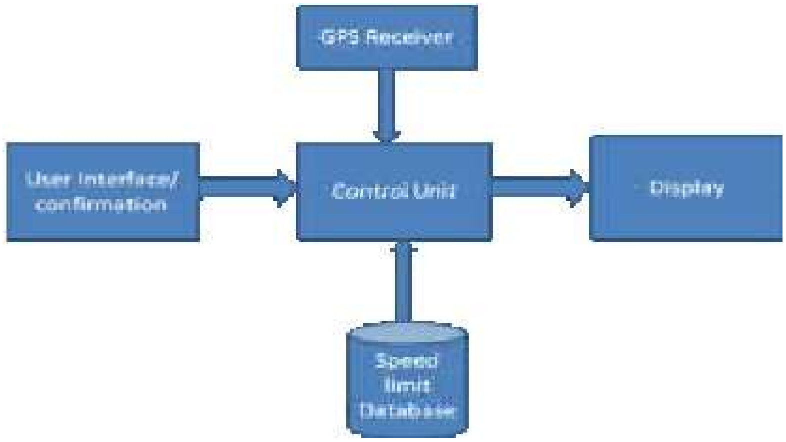


**Figure 3**: GPS Based Speed Limiter. *Khan et al. (2009).*

**2.7. Research Gap Analysis**

The in-vehicle embedded systems discussed in this literature review have been found to be effective in speed monitoring and identification of vehicles violating speed limits. However, these solutions fall short of identifying in real-time the details of drivers who are mainly responsible for the speed violations. As identified in the literature review, drivers are more responsible with observing road speed limits when they are aware of being monitored.

Therefore, to enhance responsibility among drivers and bring down cases of vehicle speeding, there's need to implement an in-vehicle RFID and GPS-based embedded intelligent system (IES) that is not only able to identify vehicles speeding but also constantly monitor and identify drivers breaking road speed limits in real-time.

## 2.8. Model of the Proposed System

The proposed speeding detection model consists of the following modules:

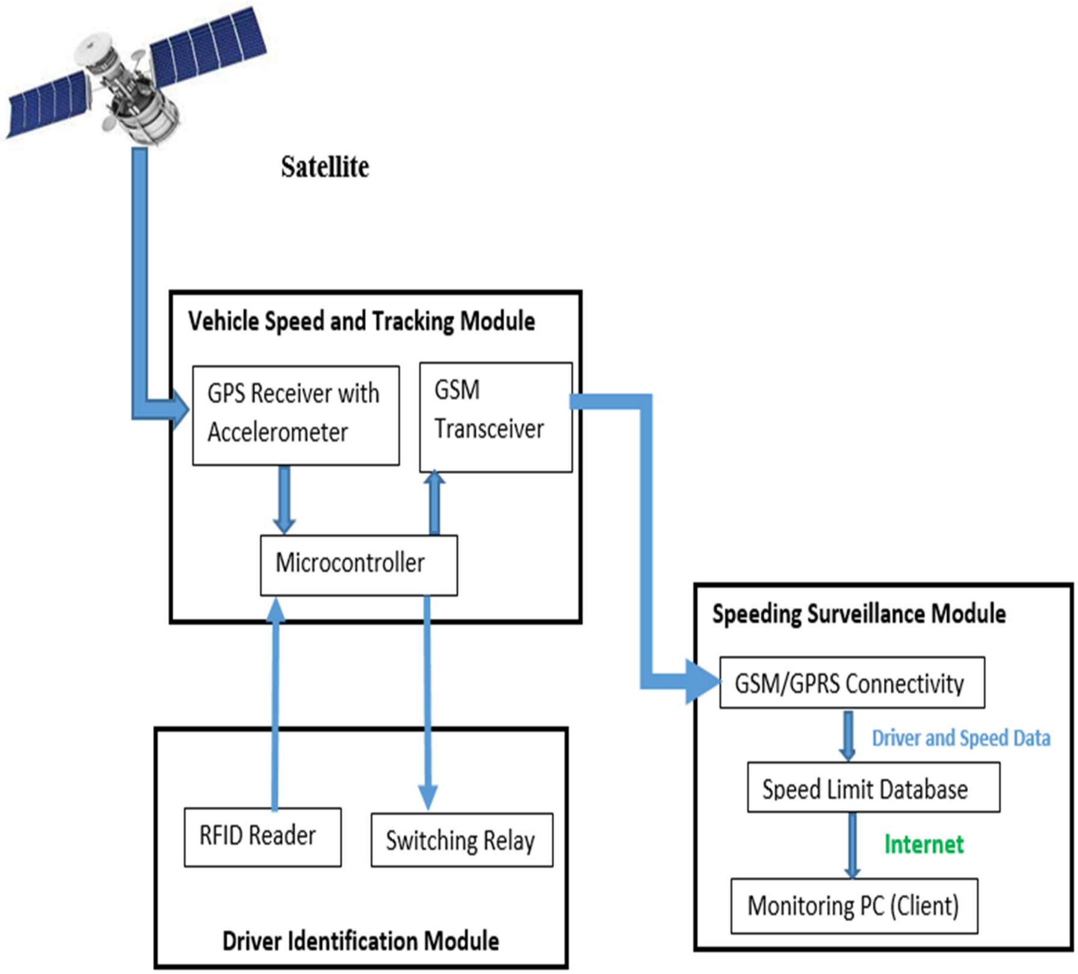


**Figure 3.1:** Model of Proposed System

Figure 2.8 above shows the model of the proposed system.

1. **Vehicle Speed and Tracking Module;** consists of GPS receiver that will be the main source of speed and location data for the proposed system and a microcontroller that will give intelligence to the embedded in-vehicle RFID and GPS based device.

2. **Driver Identification Module**; consists of the RFID reader and a switching relay that will help to ensure no vehicle is started unless the correct RFID card is sensed by the RFID reader.
3. **Speeding Surveillance module;** consists of a web application with speed limit database for real-time speeding alerts and driver details.

# CHAPTER 3: METHODOLOGY

## 3.1. Introduction

This chapter looks at the project processes in terms of the system development methodology and system evaluation. The methodologies for each of the project components are all outlined.

## 3.2. System Development Methodology

Prototyping methodology was used for this system development. This methodology was used for this development because it allows for experimentation of the system thus making it easier to spot bugs earlier in the system development and allows for visualization on how any change will impact the final product. The methodology also made it easier to change the design approach where the initial proposed design did not work as anticipated (Intergy, 2021). Figure 3.2 illustrates the prototyping development methodology that was used for the implementation of the system (Aman et al., 2018).

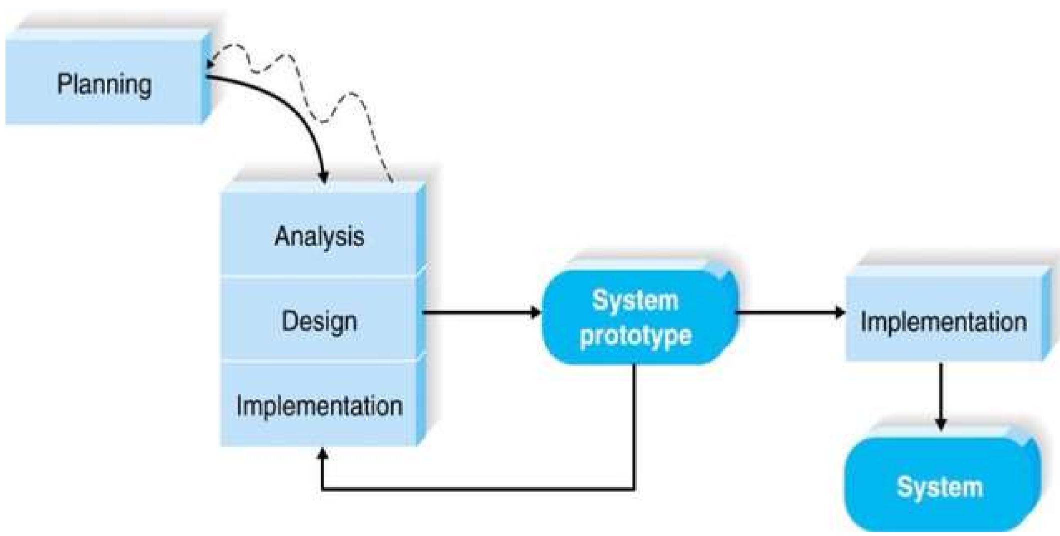


**Figure 3.2**: System Development Methodology. *Aman et al. (2018).*

### 3.3. Requirements Gathering and Analysis

The system requirements were gathered through reference on research documents on the existing in-vehicle embedded systems, and identifying the hardware and algorithm gaps that needed to be improved. Stakeholders in the transport industry; personal vehicle driver, PSV driver, NTSA and police officers were interviewed using informal interview questions to gather information on their experience with the existing speed detection technologies and their suggestions on what improvements can be made. Their responses were analysed and used to find the improvements that that were needed on the existing speed detection systems.

#### 3.3.1. System Specification

The system requirements were categorised into two, functional and non-functional requirements. The functional requirements detail what the system must perform and non-functional requirements have outlined the quality levels of the system.

#### 3.3.2. Functional Requirements

1) The device should only allow for vehicle ignition once an RFID card is swiped to ensure drivers do not by-pass the RFID authentication needed before ignition.

2) The web application should allow for registration of drivers and their RFID details at the issuance of the driver's card to ensure correct mapping of driver names with RFID numbers.

3) The web application should be able to show on the map the location of a vehicle at any particular time when ignited using GPS coordinates sent from the embedded device.

4) The web application should be able to update on the map the vehicle speed, driver name and ID, and also notify and record speed violations.

5) The web application administrator should be able to update speed limits in various road sections on the map, this will allow for any road speed limit updates at different road sections.

6) The web application should allow for user authentication to access speed monitoring and violation details.

### 3.3.3. Non-Functional Requirements

1) The system data should be accurate and reliable.

2) The monitoring interface should be easily accessible and user-friendly.

## 3.4. System Design

This involved the design and development of the hardware components and software components of the system using the Prototyping Methodology. The system adopts the below architecture;

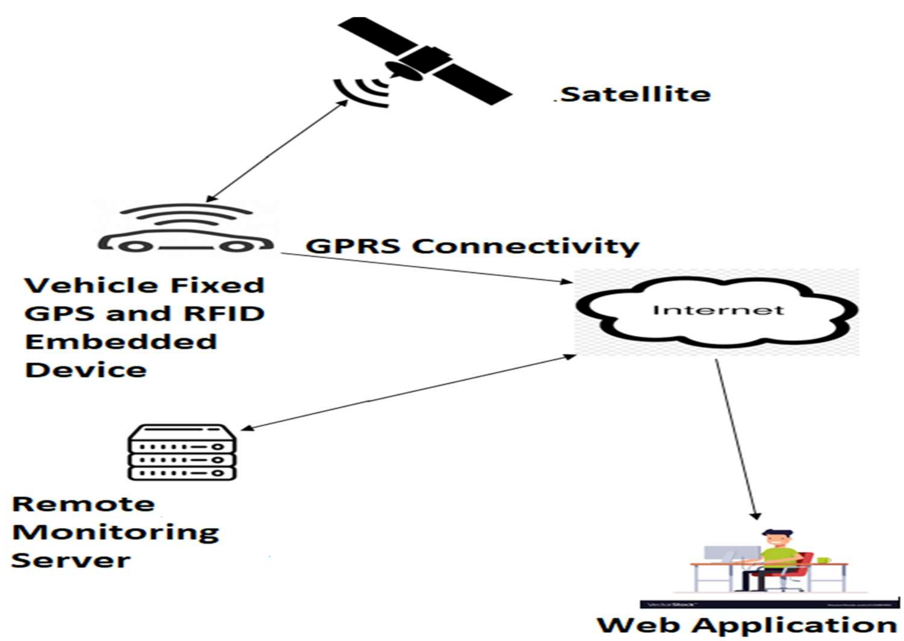


**Figure 3.3:** System Architecture.

The System design consists of three main sections;

i. Hardware Design

ii. Embedded System Software Design

iii. Web Application Design

### 3.4.1. Hardware Design

The hardware components were designed and interfaced as indicated on Figure 3.4 below;

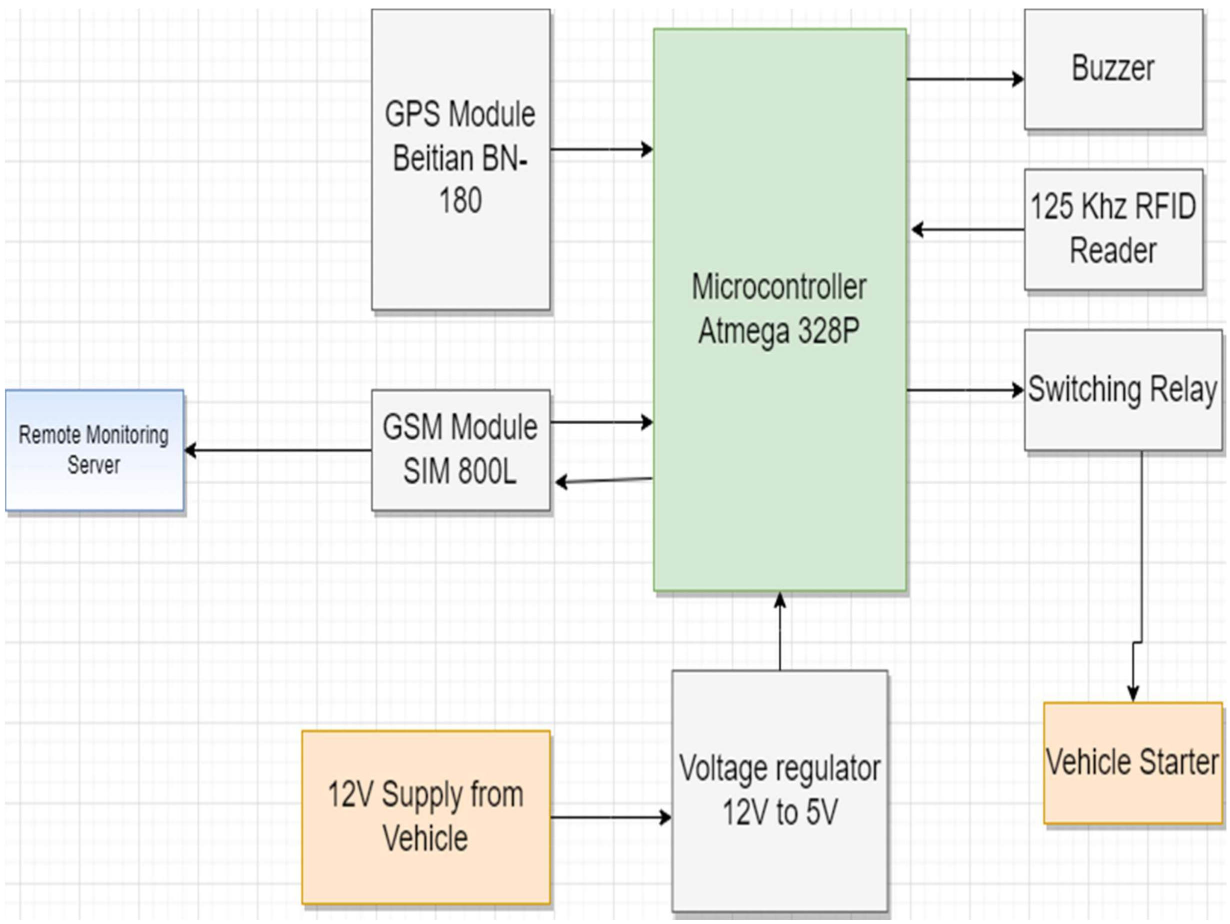


**Figure 3.4:** Hardware Design

### 3.4.2. Embedded System Software Design

This is the software that integrates and controls the in-vehicle embedded hardware. Figure 3.5 below illustrates the data flow diagram for the embedded software.

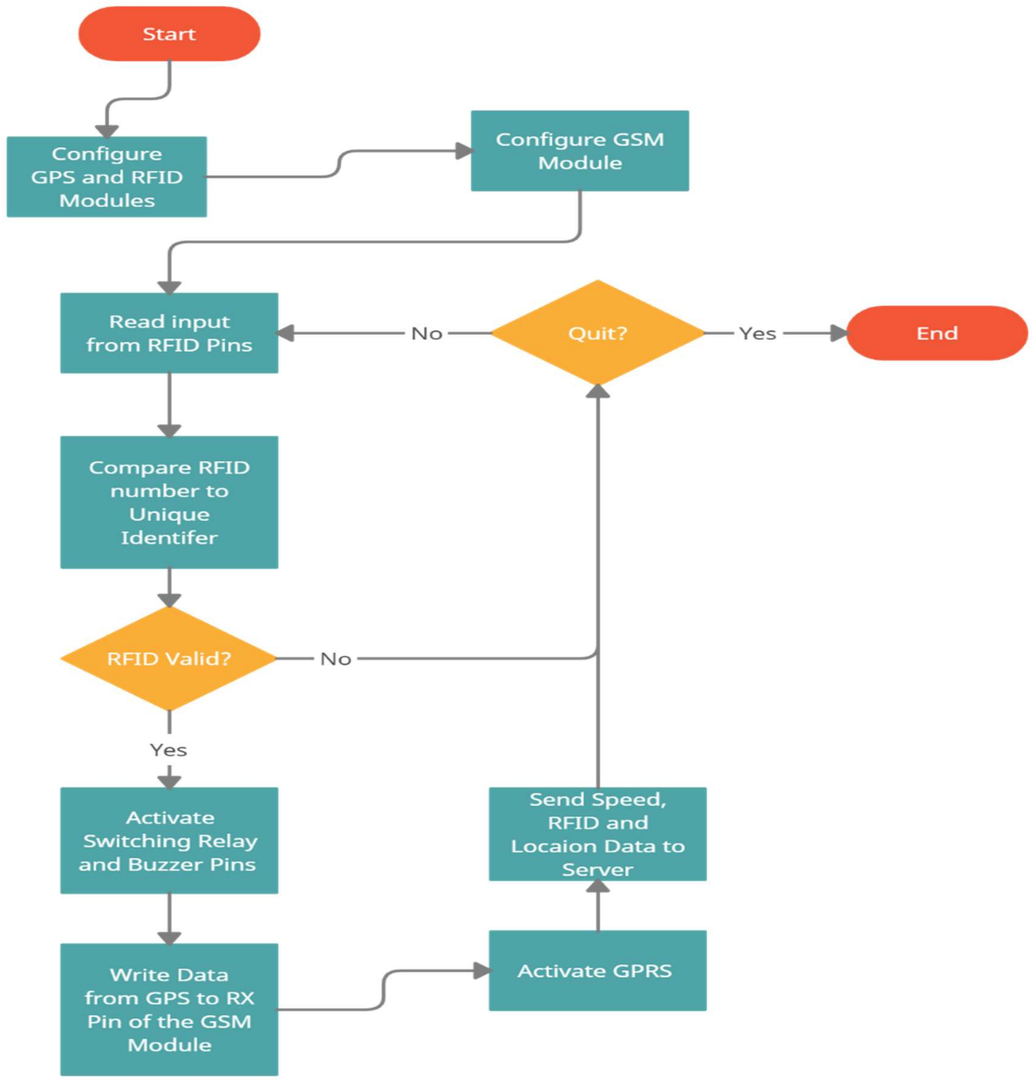


**Figure 3.5** Embedded System Software Design

### 3.4.3. Web Application Design

This is the design of the speed monitoring application to track movement and speed of vehicles and give notification on driver details in case of over speeding.

#### 3.4.3.1. Objects

These are the key ideas that characterize the design of the web application. The key objects in this system include:

**Vehicles;** Moving objects whose speed is being monitored.

**Speed Limit;** Speed of vehicle beyond which a notification is displayed.

**Drivers;** Associated with a particular vehicle. Each driver is identified with a unique RFID card which is used for vehicle ignition.

**Tracker Devices;** The tracker devices transmit the geographical data, vehicle speed and RFID number. Tracker devices are identified with a unique IMEI number in the web application.

#### 3.4.3.2. Features

The following are the key areas of functionality offered by the web application: Adding drivers, adding vehicles, and adding trackers, setting new speed limits on road sections, notification and recording of speed violations. A user has to be registered to perform the above functions. The features have been designed and analysed using context diagram, data flow diagram, use case diagrams and database design as outlined below;

#### 3.4.3.3. Context Diagram

The following diagram shows the external interfaces and gross data flows in the system.

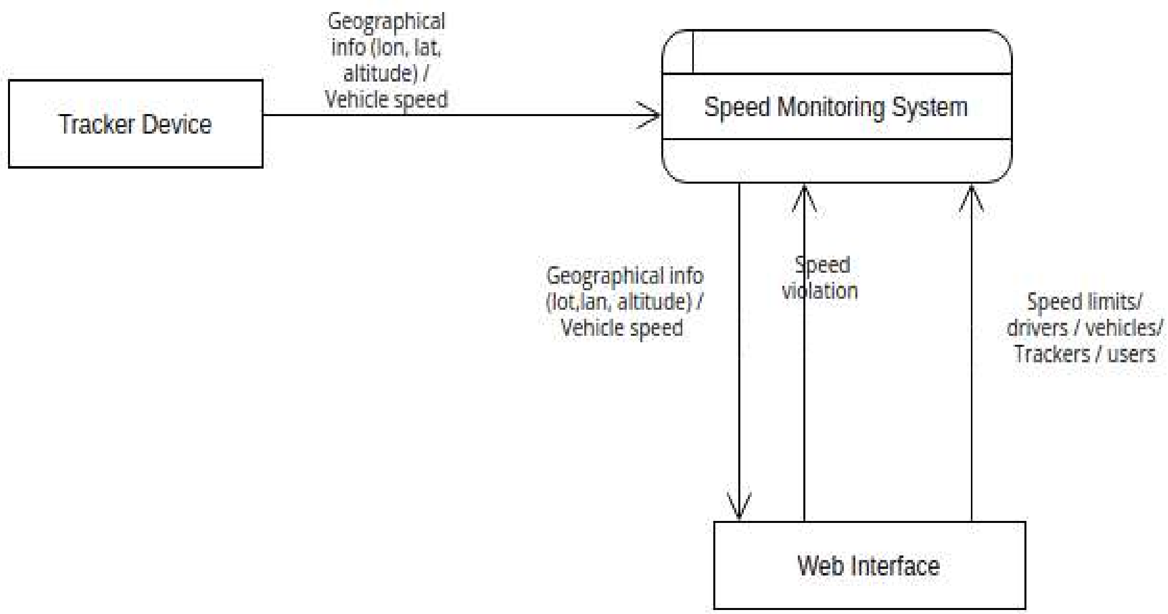


**Figure 3.6:** Context Diagram

#### 3.4.3.4. Data Flow Diagram

This a user interface input and output representation of the state within the system. It is represented by figure 3.7 below.

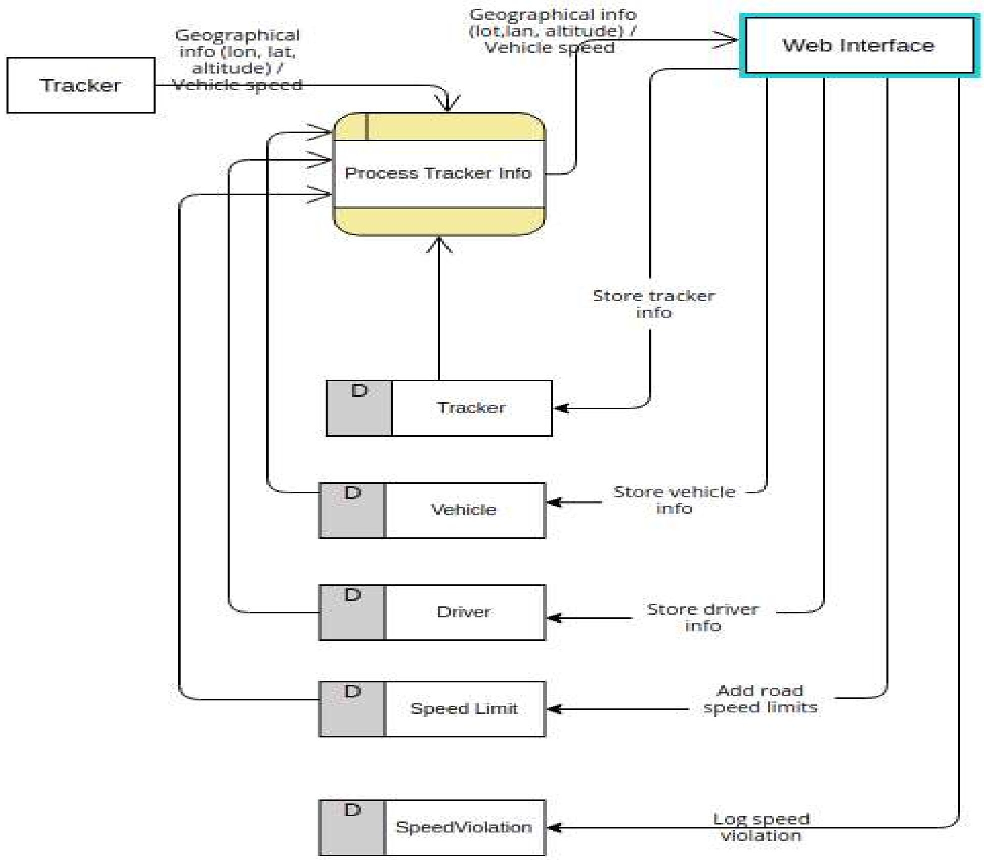


**Figure 3.7:** Data Flow Diagram

#### 3.4.3.5. Database Design

The database design took into consideration the interrelationship between the speed limits, tracker, vehicle and driver, and how they relate with the speed violations. Figure 3.8 below illustrates these entities' relationship.

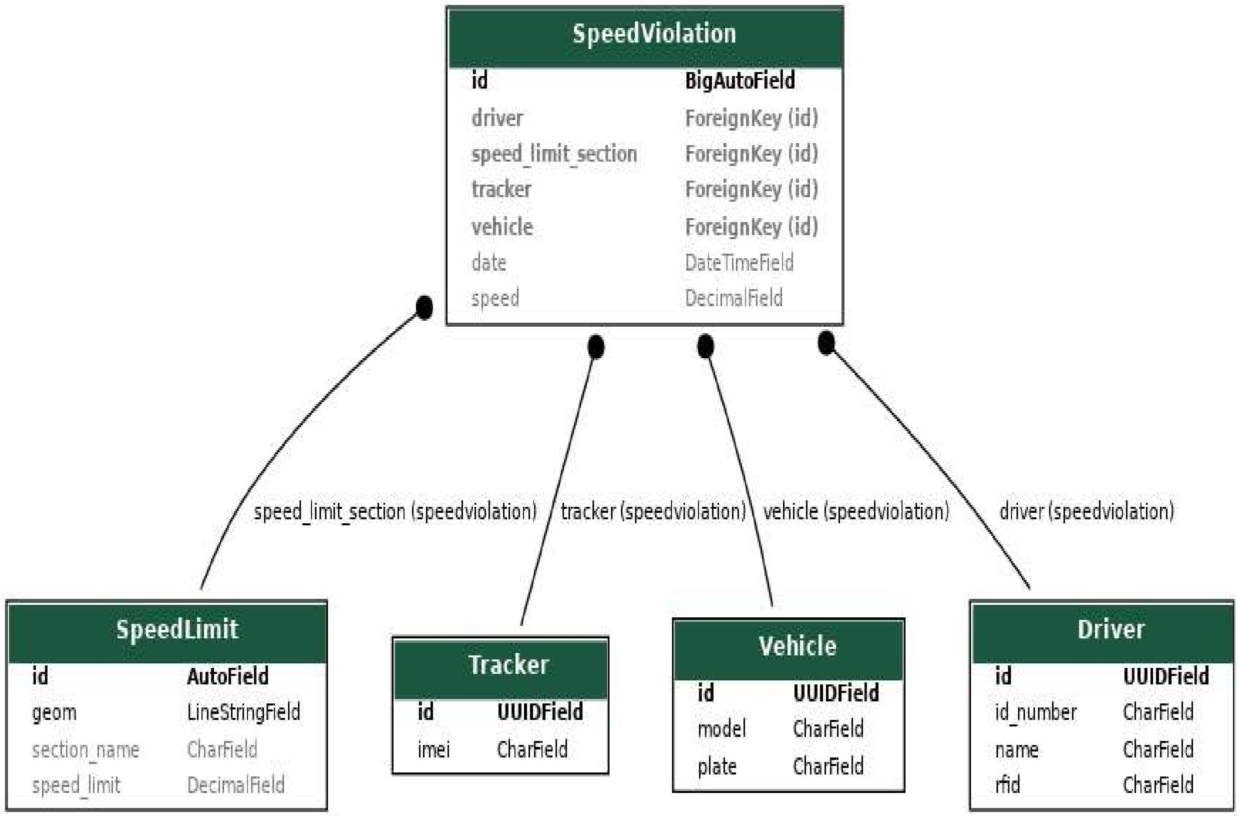


**Figure 3.8:** Entity Relationship

#### 3.4.3.6. Use Case Diagrams

The following are the use case diagrams for adding drivers, vehicles and speed limits along road sections;

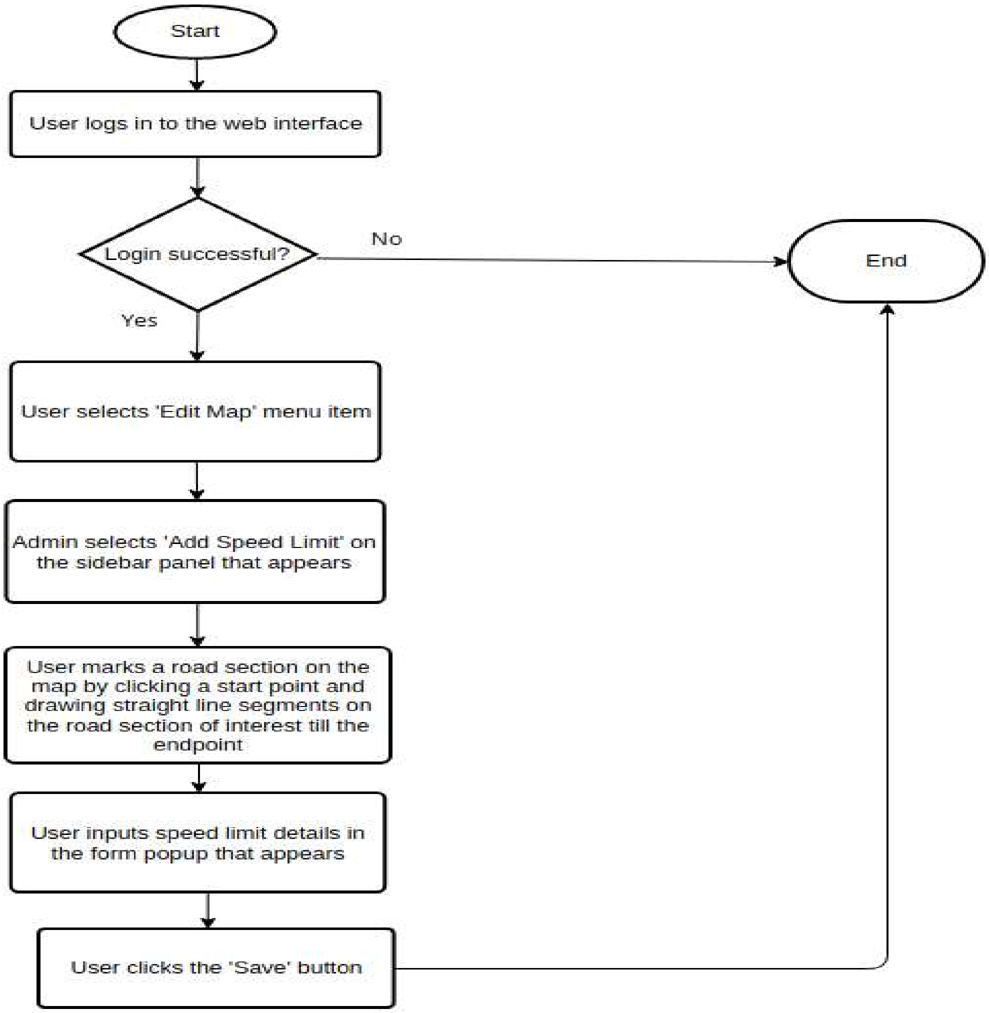


**Figure 3.9:** Add Speed Limit

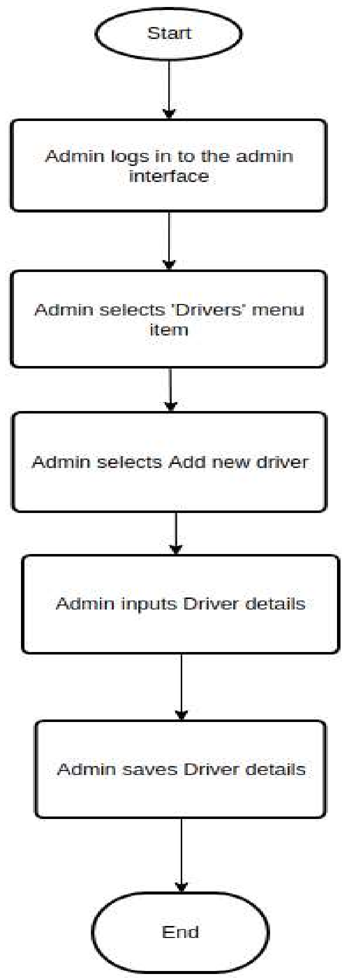


**Figure 4.0:** Add Driver Details

### 3.4.4. Embedded Hardware Implementation

The hardware implementation was done through procurement of the necessary hardware components; one piece of 125 Khz RFID reader, three pieces of 125 Khz RFID cards, one piece of SIM 800L GSM module, one piece of CIROCOMM GPS Module, one piece of Atmega 328p microcontroller, resistors and capacitors, etched PCB board, one piece of voltage. The following hardware components were used for the development of the embedded device;

#### 3.4.4.1. The Control Unit (Atmega 328P)

The control unit consists of Atmega 328P microcontroller. The microcontroller provides the integration platform for all the electronics components and also the control unit for the interfaced components. It was preferred for this development because of its availability, affordability and also relatively easy to programme using the Arduino Integrated Development Environment (Arduino IDE), the microcontroller also provides a miniature Real-time Operating System (RTOS) that perfectly fits into the real-time needs of the embedded device and minimal use of space at deployment stage.


**Figure 4.1:** Atmega 328P. *Oemsecrets (2021).*

#### 3.4.4.2. The GPS Module

Beitian BN-180 GPS module was used for the development of the solution. This module was preferred for this development because it has up to 72 channels for satellite searching, making it more accurate and quick in location fixes. It also has an inbuilt accelerometer that makes it easy to get speed data that is critical for the project. It is also reasonably priced and easily available.


**Figure 4.2:** Beitian BN-180 GPS Module. *Amazon (2021).*

#### 3.4.4.3. The GSM Module

SIM800L GSM module is used to provide GPRS connectivity in the developed solution. It has GPRS capabilities, low power consumption and easy to programme and integrate with the other modules using the Arduino IDE.


**Figure 4.3**: SIM800L GSM Module. *MakePro (2021).*

#### 3.4.4.4. The Voltage Regulator Module

LM2596S DC to DC voltage step down module was used for the system development. This module is able to step down 12V to 5V. This makes it easy for in-vehicle deployment since the vehicle voltage is at 12V and the embedded system need 5V for normal operation.

**Figure 4.4:** LM2596S DC to DC voltage step down module. *Xcluma (2021).*

#### 3.4.4.5. Switching Relay Module

A 12v and 80A Switching relay was used for this implementation. This module is able to withstand the heavy current of a vehicle ignition system.


**Figure 4.5:** Switching relay. *Ebay (2021).*

#### 3.4.4.6. Hardware Simulation and Fabrication

The interoperability of the hardware components shown in Figure 3.4 above were designed, modelled and simulated using the free Trial Version of Proteus Software. Proteus Modelling and Simulation tool is a software used for electrical and electronics circuit design, the simulated circuits are as shown on Figure 4.6 and Figure 4.7. The simulated and integrated design files were then generated from the Proteus Software and used for the fabrication of the Printed Circuit Board (PCB) electronics circuit. The electronic components and modules were then soldered onto the PCB to get a complete assembled RFID and GPS-based embedded device ready for integration with the software component of the proposed system.

The fabrication of the prototype was done in a well-equipped electronics lab at Envision Technologies Ltd.

The integration of the hardware components involved the following outlined procedures below;

1) Etching of PCB board using laser engraving and UV light exposure.

2) Stencil printing using Stencil Printer machine.

3) Component placing using automatic Pick and Place Machine.

4) Component soldering using Oven and Soldering iron.

5) Programming of the assembled embedded device using Arduino IDE, Arduino Nano as ISP programmer and C programming language.

6) 3D printing of casing and lid.

In accordance with the Prototyping methodology used in the development of the system, iterative prototyping and testing of the hardware was done to ascertain the functionalities of the proposed embedded solution.

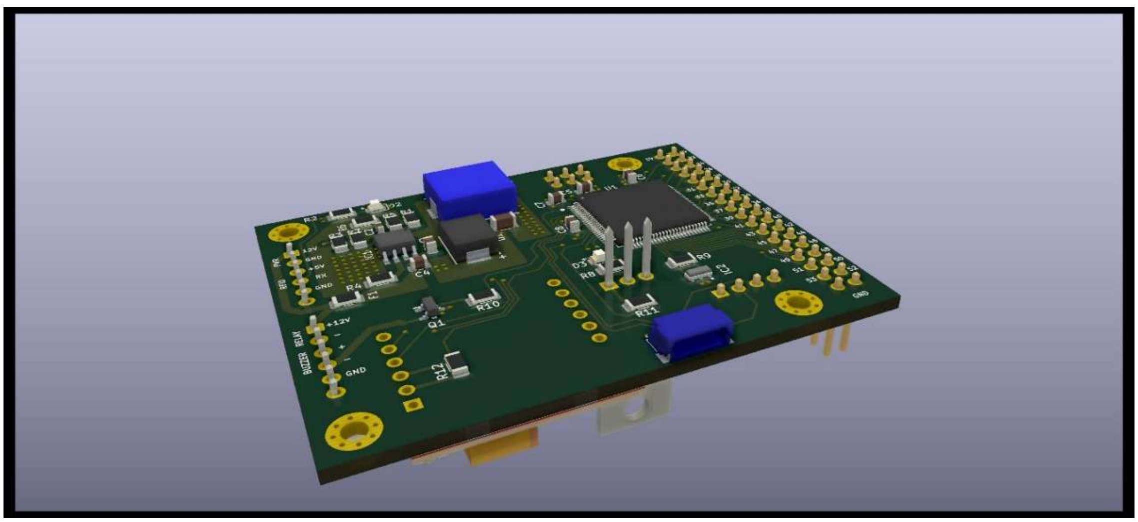

**Figure 4.6:** Hardware Design and Simulation on Proteus software

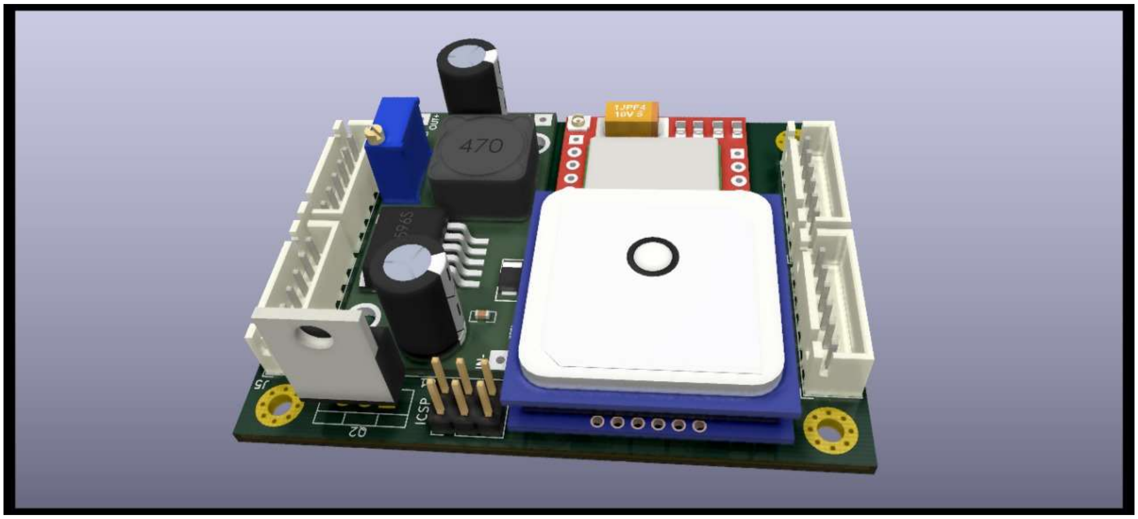

**Figure 4.7:** Fine-tuned circuit Design using Proteus Software

### 3.4.5. Embedded Software Implementation

The software for integration and controlling of hardware were developed using Arduino IDE. This programming was done using C programming and simulation of each module was done using the Arduino IDE terminal. Different libraries were used to integrate the three main modules as described below:

**RFID Module;** rdm6300 and the EEPROM libraries were used to integrate the RFID module.

**GPS Module;** TinyGPS++.h library was used to integrate the GPS module with the main embedded software.

**GSM Module;** SoftwareSerial Library was used for the integration of the GSM module.

### 3.4.6. Web Application Implementation

The application was built with the client and server as separate entities. The client/frontend is in charge of visual representation. The server processes data and uses a PostgreSQL database server for data persistence

#### 3.4.6.1. Client/Front-end

The client communicates with the server backend over HTTP to add/update data.

The following technologies and tools were used to build the client application:

- JavaScript - Programming language
- ReactJs - a JavaScript library for building user interfaces
- NodeJs - a JavaScript runtime that makes it possible to execute JavaScript code in a non-browser environment.

#### 3.4.6.2. Server/Back-End

The backend was built as an API (Application Programming Interface) based on REST architectural style.

The purpose of the API is to provide data to clients that access it over an HTTP connection. The data provided is then used to power the front-end pages.

The backend server sends the speed and location data it receives from the tracker to the frontend using a Web Socket API. The Web Socket API makes it possible to open a two way interactive communication session between the frontend and the backend server. This way, the frontend does not have to explicitly request for data from the server every time it needs it, rather, a persistent connection is established that the server then uses to send the data whenever it receives from the tracker. Overall, this allows us to establish a real time monitoring of speed and location of vehicles.

### 3.5. System Testing

The system testing was done on the two main system components;

i. Embedded Device testing
ii. Web Application Testing

### 3.5.1. Embedded Device Testing

Before deployment into a vehicle, functionalities of the hardware were tested in the Envision Technologies Lab using a lab power supply and Digital Multi-meter as shown below. The power supply was used to test the capabilities of the voltage regulator and what voltage range it could withstand. It was able to take an input of up to 32Volts and step it down to 5 Volts that is needed to power the embedded device. The GPS module was also able to lock location coordinates (longitude and latitude) within 5 seconds and display them on the Arduino IDE terminal, and the GSM module transforming into the GPRS module by changing from blinking once in every 3 seconds to once in every second hence able to provide internet connectivity for the developed embedded system. The calibration of the vehicle speed and the GPS generated speed was done using the vehicle's speedometer in comparison with the speeds from the GPS module. Comparison of the speeds was found to provide satisfactory values for the project. The RFID reader was also able to read the RFID cards swiped and this was confirmed promptly using buzzer alerts, display of the RFID number on the Arduino IDE terminal and the switching click sound of the switching relay.

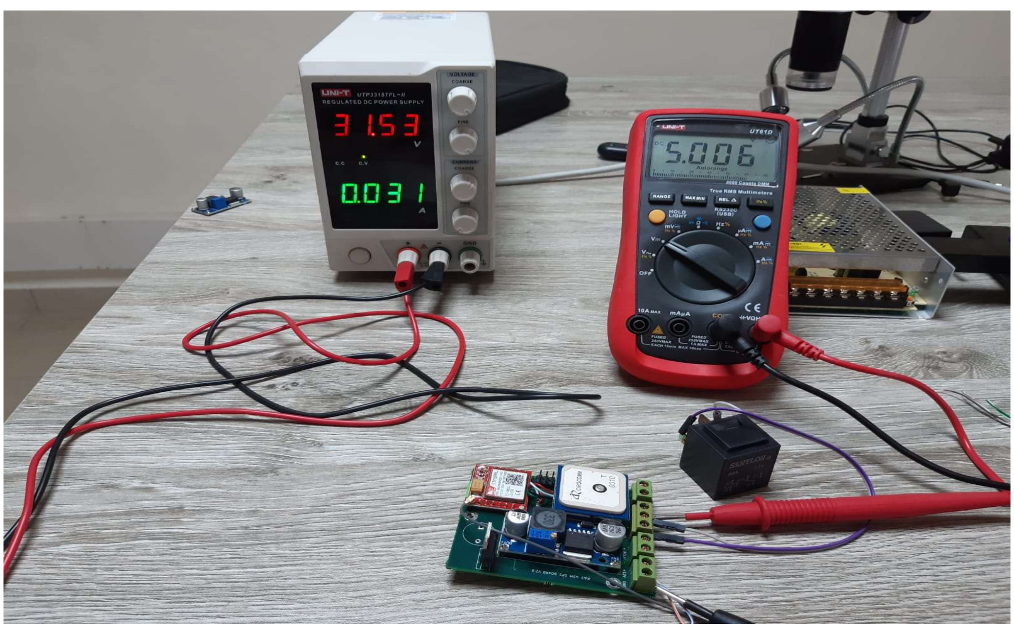


**Figure 4.8:** Embedded Device Testing

After successful lab tests, the device was placed in personal vehicle and powered using the vehicles cigar lighter for further testing and collection of data (RFID number, GPS coordinates, Vehicle Registration number) from different road sections within Nairobi.

The testing and collection of road speed limit data was done along the Northern Bypass between Kiambu Road Overpass and Marurui shopping center, and the Kiambu Road between Northern Bypass Road Underpass and the AAR Hospital along Kiambu Road. These road sections were chosen for testing because they offer a diverse range of road speed limits, between 30km/hr and 110km/hr. The road sections also made it easier to get more accurate results due to minimal vehicle traffic disruptions along the routes.

Figure 4.9 and Figure 5.0 below show map sections of the testing locations

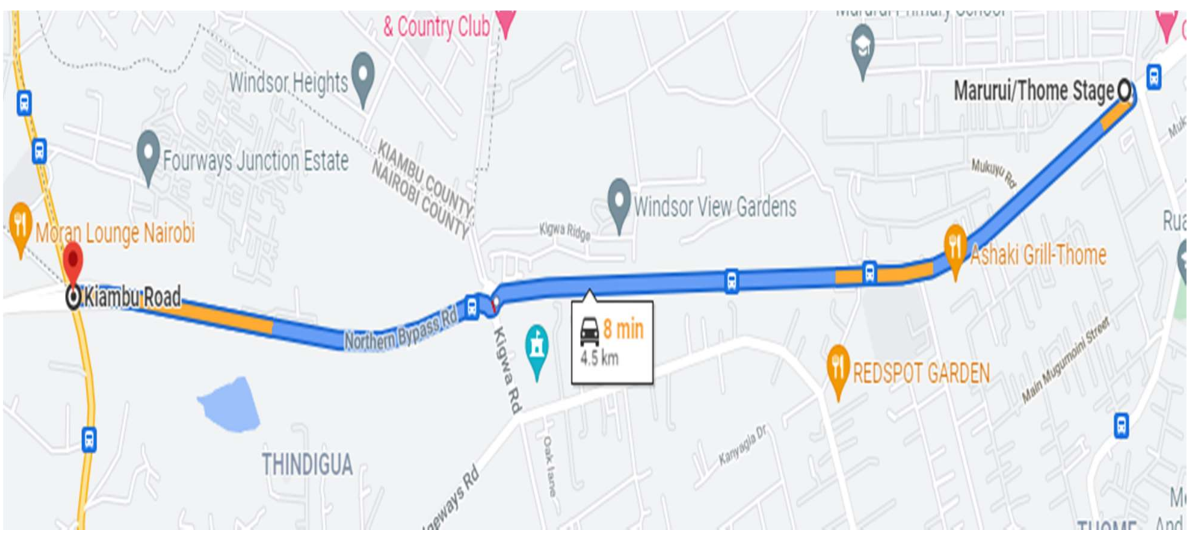


**Figure 4.9:** Location 1 of the System Testing

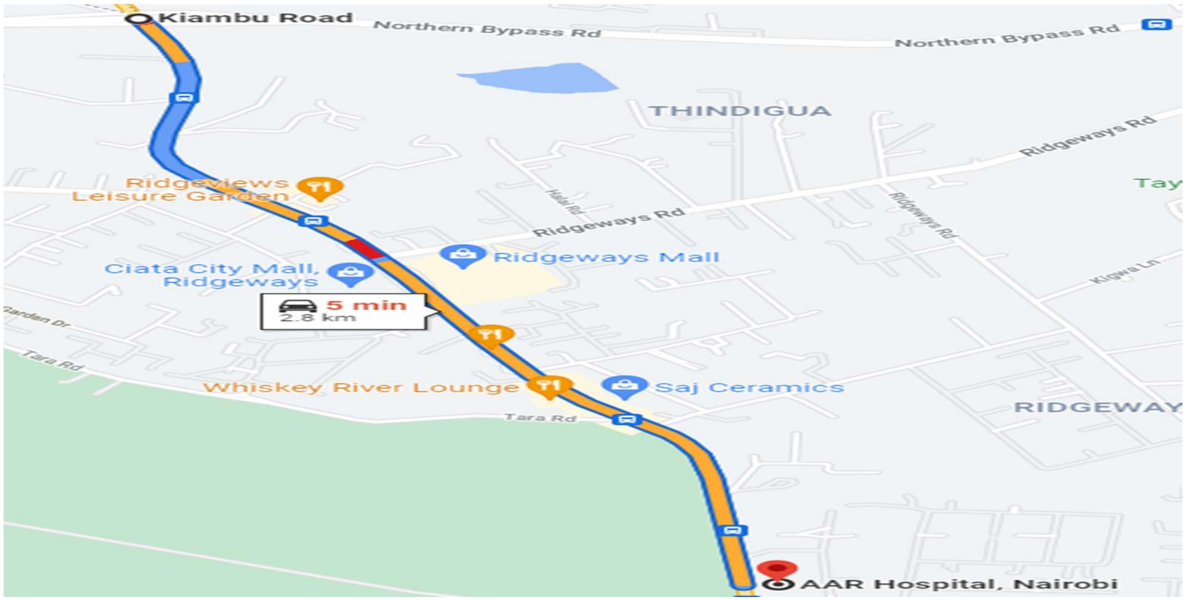


**Figure 5.0:** Location 2 of the System Testing

### 3.5.2. Web Application Testing

The web application was deployed in the open source Herokuapp platform for web connectivity. Various aspects of the functionalities of the web application were tested:

1) Ability to log into the Administration panel of the application using authorised credentials
2) Ability to log into the maps monitoring interface/client interface using authorised credentials.
3) Ability to add speed limits along different road sections.
4) The ability of the web application to update status on speed limit violations along different road sections.

The results of these tests have been shared and evaluated in Chapter 4 with screenshots showing the results.

### 3.6. Ethical Considerations

Prior to conducting informal personal interviews on the identified respondents (drivers, traffic police officers and NTSA officers), the respondents were informed of what the research is about, its tentative research goals and objectives. Additionally, all respondents were assured of confidentiality during this process. Information collected has been kept confidential and only used for purposes of system requirements gathering and analysis.

Request for approval to use the hardware fabrication site, Envision Technologies' electronics lab, was sought from its management before use of their facility.

# CHAPTER 4: RESULTS AND DISCUSSION

After the research, development and testing of the RFID and GPS-based system, evaluation was done to ascertain the functionalities of the solution in terms of the embedded device functionalities and the web application functionalities.

## 4.1. Embedded Device Testing Results

### 4.1.1. Testing the RFID Functionality of the Embedded Device

To ascertain the possibility of using RFID for vehicle ignition and real-time remote monitoring of driver details, iterations on RFID card swipes were done to check whether the switching relay will be activated every time the RFID card will be swiped. The response time of between swiping and the activation of the Switching relay was also measured. The results were recorded as indicated in table 4.1 below.

**Table 4.1: Test Data Results Collection Template**

| **No. of RFID Swipe Experiments Done** | **No. of Successful Relay Switching** | **Average Response Time Between RFID Card Swiping and Relay Switching (Seconds)** | **Switching Relay Failures** | **No. of RFID Identity Update Success on Web Application** |
|---|---|---|---|---|
| 60 | 60 | 1 | 0 | 60 |
| **Success Rate (%)** | **100** | | | |

The system success rate and reliability was calculated using equation 4.1 below;

$$System\ Accuracy = \frac{Total\ No.of\ Successful\ RFID\ Web\ Updates}{\text{Total No. of RFID Swipes Done}}\ x\ 100$$

**Equation 4.1:** Driver Identification Success Rate Equation

The higher the success rate scores the higher the system reliability, the system gave the best success rate response that guarantees the system performance in real-life deployment.

### 4.1.2. Testing the GPS Functionality of the Embedded Device

To ascertain the possibility and reliability of monitoring vehicle speed and remote monitoring, the RFID swipe iterations that were done in table 4.1 above were used to record the number of times successful GPS coordinates, vehicle speed and RFID identity were reflected on the web application. The results were recorded in table 4.2 below.

**Table 4.2: Vehicle Tracking Data**

| **No. of RFID Swipe Experiments Done** | **No. of Successful GPS Coordinates, Speed and RFID Identity Alerts updated on the Web Application** | **No. of GPS Coordinates, Speed and RFID Identity Alert Failures** |
|---|---|---|
| 60 | 53 | 7 |
| **Tracking Success Rate (%)** | **88.3** | |

The vehicle tracking success rate was calculated using equation 4.2 below:

$$Tracking\ Acc. = \frac{Total\ No.\ of\ Successful\ Web\ Alerts}{\text{Total No. of RFID Swipes done}}\ x\ 100$$

**Equation 4.2:** Tracking and Remote Monitoring Success Rate Equation

The tracking success rate was found to be at 88% from the expected 100%. This was attributed to loss of GSM connectivity and also sometimes inaccurate GPS coordinates due to limited number of satellites locked by the GPS antenna.

## 4.2. Web Application Testing Results

### 4.2.1. Ability to Log into the Administration Panel using Authorised Credentials

The administration panel for the web application was accessed using the link (https://speed-monitoring.herokuapp.com/admin/). Successful log into the administration panel was achieved only using authorised credentials as shown by the screenshots below.

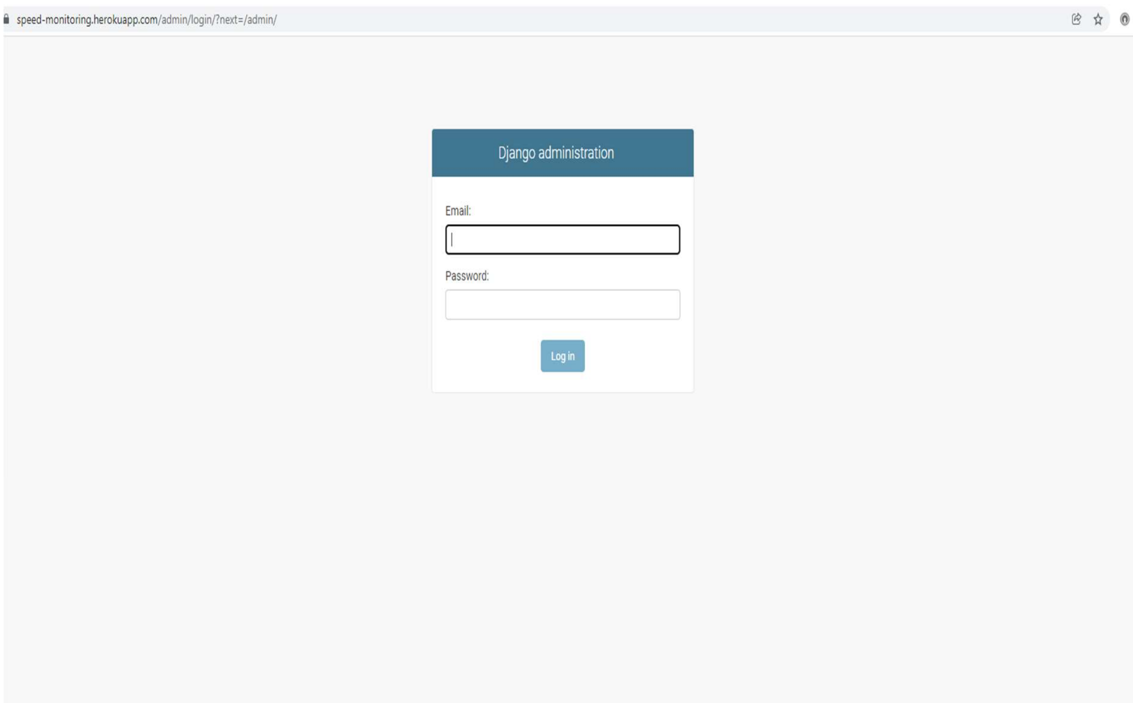


**Figure 5.1:** Login into the Administration Panel

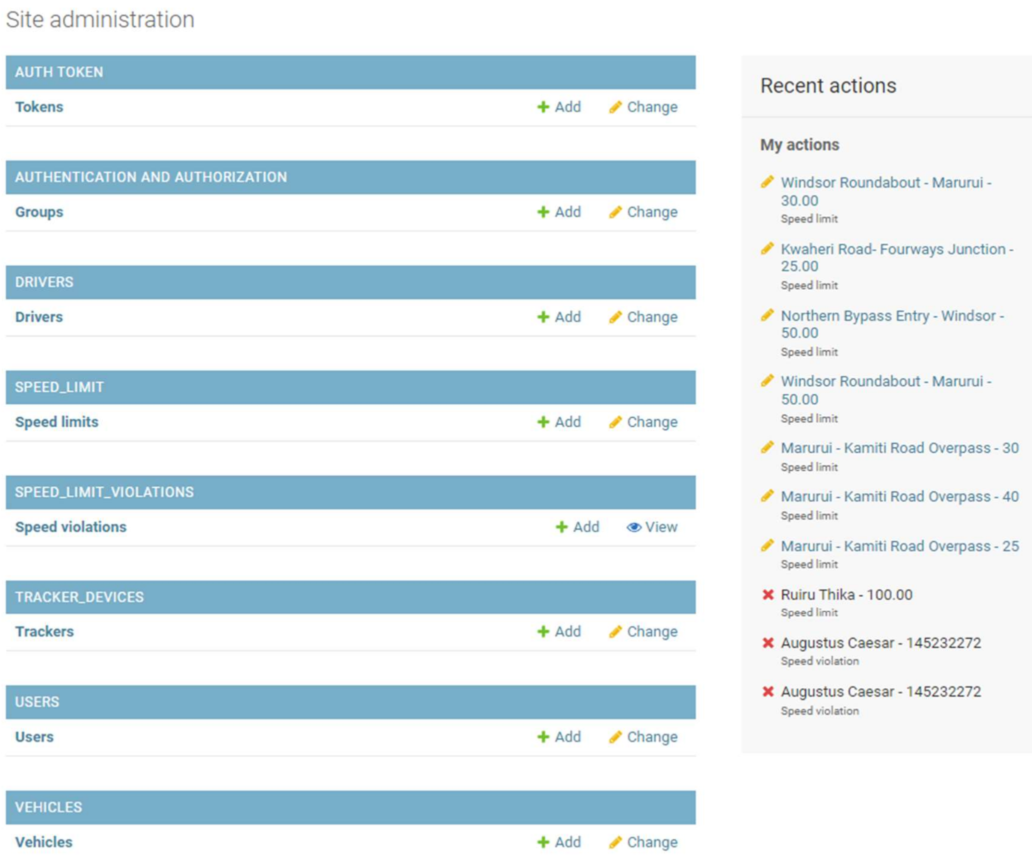


**Figure 5.2:** Administration Landing Page

### 4.2.2. Ability to Log into the Maps monitoring/ Client Interface using Authorised Credentials

The maps monitoring interface for the web application was accessed using the link (https://speed-monitoring-live.herokuapp.com/). Successful log into the maps interface was achieved only using authorised credentials as shown by the screenshot below.

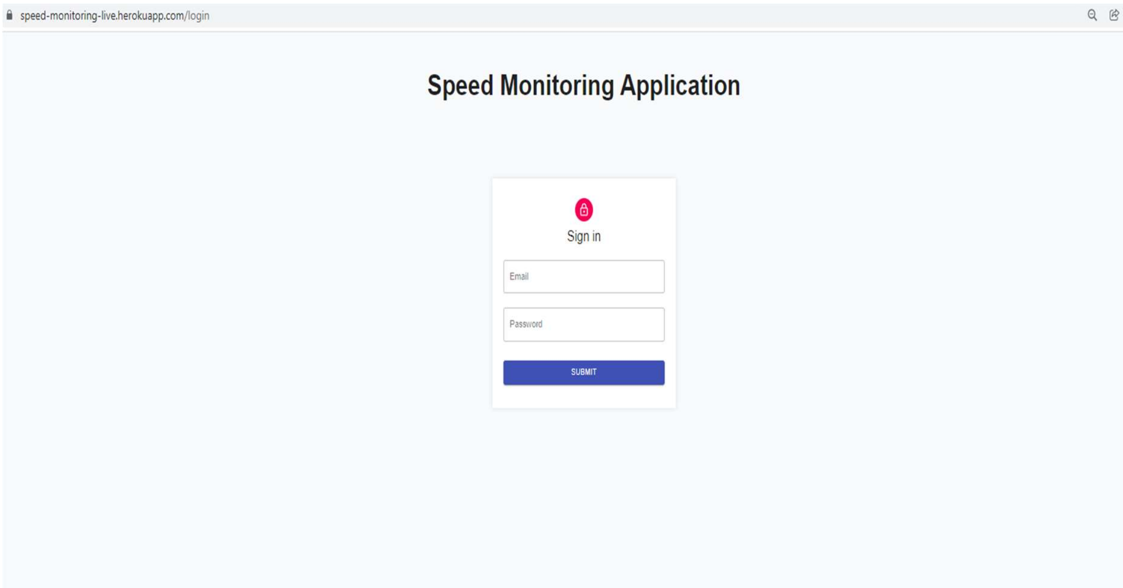


**Figure 5.3:** Login into the Client Interface

### 4.2.3. Ability to add Speed Limits along Different Road Sections

Adding of road speed limits was done successfully as shown on Figure 5.4 below;

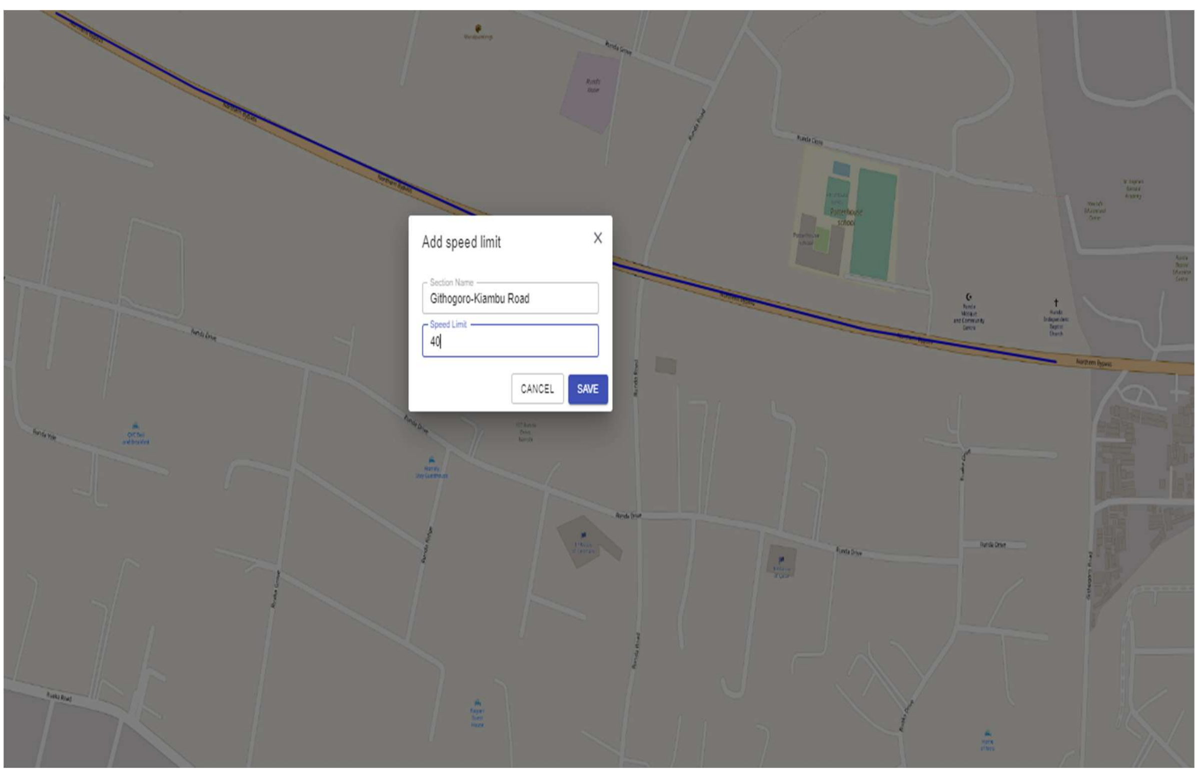

**Figure 5.4:** Adding Speed Limits along Road Sections

### 4.2.4. Ability of the Web Application to Update Speed Violations Details

The web application successfully updated speed limit violations with details of the driver, vehicle and the current speed as shown on Figure 5.6 below.

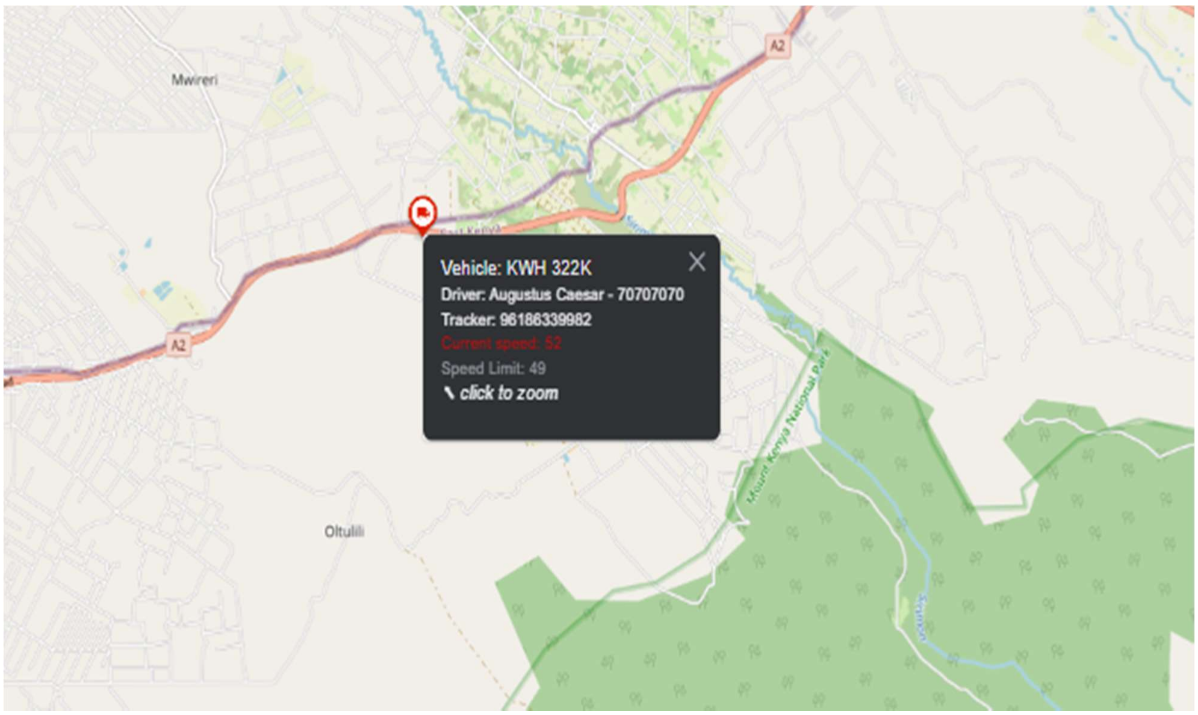


**Figure 5.6:** Maps Module and Alerts Notification Testing

### 4.2.5. Evaluation of the ability of the Web Application to Receive and Update Speed Limit Detection Data

Evaluation was done on the PostgreSQL server for the speed violations data that was updated on the map. Analysis was done on the data and the Table 4.3 below shows a summary of the results.

**Table 4.3: Test Data Results for Various Captured Data**

| Details Captured | Number of Tests | Successfully Updated | Unsuccessful Updates | Success Rate (%) |
|---|---|---|---|---|
| Driver Data | 60 | 60 | 0 | 100 |
| Location Data | 60 | 53 | 7 | 88.3 |
| Speed Data | 60 | 55 | 7 | 91.7 |
| Date and Time | 60 | 53 | 7 | 88.3 |
| RFID data | 60 | 60 | 0 | 100 |

## 4.3. Explanation of Results on Table 4.3

The location, speed and date data gave a success rate of less than 100% due to the following reasons;

1) GSM module losing GPRS connectivity due to some areas not covered by GSM network.
2) When the device is powered up, the GPS module took an average time of 40 seconds to lock location details and start sending the updates to the PostgreSQL server hence the delay in location data update on the map.
3) Also, for better success rate, the GPS module needs to receive 48 satellite channels at ago but due to sometimes thick cloud coverage and buildings interference, the GPS' signal became weak thus providing low success rate results.

# CHAPTER 5: CONCLUSION AND FURTHER WORK

## 5.1. Achievement of Research Objectives

This research had four (4) objectives as outlined in chapter 1 of this document. These objectives were achieved as outlined below;

### 5.1.1. Gathering System Requirements

This objective was successfully achieved by the literature review that was done on existing in-vehicle embedded solutions for speed monitoring and other literature materials that were referenced. The literature review helped to identify the research gap on whose basis this system development was done.

This objective was also achieved through informal interviews that were conducted on road safety stakeholders; personal car drivers, PSV drivers, NTSA staff and traffic police officers. Their input on experience with vehicle speeding and how best speed monitoring can be done on Kenyan roads helped to get more information on the system requirements.

### 5.1.2. Designing and Developing an RFID and GPS-based Embedded Device for Speed Violation Detection

The RFID and GPS-based embedded device was developed and its functionalities successfully tested. This was as illustrated in Chapter 3 and Chapter 4 of this report. The RFID reader was able to read RFID card details and send them to a remote server. The GPS data (longitude, latitude and vehicle speed) was also successfully received from the embedded device. The GSM module also successfully provided GPRS connectivity to the remote server.

### 5.1.3. Designing and Developing a Web Application for Speed Violation Updates.

The web application was successfully developed using python and PostgreSQL server. Updates on speed violations sent from the embedded device were successfully updated and recorded on the web application.

### 5.1.4. Testing the functionalities of the RFID and GPS-based Speed Violation Detection System

The RFID and GPS functionalities of the system were tested and analysed in chapter 4 of this research. The system was able to detect, notify and record details of drivers violating road speed limits with a success rate of 88.3%.

## 5.2. Research Contribution

The main contribution of this research is the development of a solution that is able to combine hardware and software to identify drivers responsible for vehicle speeding at any particular time and at different road sections with their designated speed limits. How to identify drivers in real time at any time of the day and road section was the main problem that this system development was trying to address and this was successfully demonstrated in the research.

## 5.3. Conclusion

The application of an in-vehicle RFID and GPS-based embedded system with remote monitoring capabilities provides the most practical solution to monitoring and identification of road speed limit violators. Existing systems in the market are only able to identify the vehicle speeding and end up missing on the identity of the drivers responsible for speeding. The solution developed here will help to curb speeding by drivers who this research identified that they are more careful and responsible on road speed limits when they are aware of being monitored.

## 5.4. Recommendations for Further Work

To enhance the functionalities of the system and enhance its stability and reliability, the following key areas can be researched further and implemented;

1) Integration of machine learning into the embedded system to enhance its performance and better analytics on the data collected.

2) Integration of the embedded device with a Satellite communication module for better and wider coverage in terms of connectivity to the remote server. Connectivity to the remote server was sometimes lost due to lack of GSM network coverage in some areas during testing.
3) The 125 KHz RFID card can be easily cloned thus possible cases of identity theft, therefore further research is recommended for possible use of a smart card, an RFID card with encryption capabilities or use of biometrics in place of the 125 KHz cards and readers.
4) Implementation of a system failover mechanism in case the RFID reader fails or the embedded device fails as a whole. The failover mechanism will ensure drivers are able to start their vehicle when the in-vehicle embedded device fails.

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## APPENDIX I: PROJECT SCHEDULE

| **Timeline**<br><br>**Tasks** | June 2021 | July 2021 | August 2021 | September 2021 | October 2021 | Jan-Feb 2022 | Feb-May 2022 |
|---|---|---|---|---|---|---|---|
| Gathering Proposal Background Resources | ■ | | | | | | |
| Literature Review Development | ■ | ■ | | | | | |
| Submission of Proposal Draft and Review | | ■ | | | | | |
| Methodology, System Design and Data Collection Tools Development | | ■ | ■ | | | | |
| Submission of Proposal Draft and Review | | | ■ | | | | |
| Milestone 1 Presentation | | | | ■ | | | |
| Piloting Data Collection | | | | ■ | | | |
| Procurement of Prototype Materials | | | | ■ | ■ | | |
| System Development and Testing | | | | | ■ | ■ | |
| Results Analysis | | | | | | ■ | |
| Milestone 2 Presentation and Review | | | | | | ■ | |
| Milestone 3 Presentation and Review | | | | | | | ■ |

## APPENDIX II: PROJECT COST ESTIMATES

| | **Item Description** | **Cost** |
|---|---|---|
| 1. | Hardware Components Acquisition | 10,000 |
| 2. | PCB fabrication and Integration | 4,000 |
| 3. | Internet Charges | 6,000 |
| 4. | Data Collection and System Test | 20,000 |
| 5. | Miscellaneous | 10,000 |
| | **TOTAL** | **50,000** |

# APPENDIX III: CODE SNIPPETS

Embedded_Device | Arduino 1.8.15 Hourly Build 2021/05/31 10:33

File Edit Sketch Tools Help

Embedded_Device

```
#include "TinyGPS++.h"
#include <SoftwareSerial.h>
#include <EEPROM.h>
#include <rdm6300.h>

#define RDM6300_RX_PIN 9
Rdm6300 rdm6300;
static const int RXPin = 2, TXPin = 3;
static const uint32_t GPSBaud = 9600;
static const int RX = 7, TX = 6;

// The TinyGPS++ object
TinyGPSPlus gps;

// The serial connection to the GPS device
SoftwareSerial ss(RXPin, TXPin);
// The serial connection to the GSM device
SoftwareSerial gsm(RX, TX);

char colon = ':';
char slash = '-';
char space = ' ';
byte buffer1[18];
byte buffer2[18];
const int upload_status = 13;
const int relay = 8;
const int buzzer = 4; //buzzer to pin 4
String id;
String id1;
String plate = "KCY 402T";
long previousMillis = 0;
//long interval = 7200000; //Read sensor each 10 minutes
long interval = 600000; //Restart system after every 5 minutes
String IMEI;
int user = 0;
String user_id = "1234567890,8910111,21314144,161718199,1623786#";//,1234567";//format is ac
//String user_id = "1623786,8910111,2131414,1617181,9202122#";//,1234567";//format is admin1
char user_id_array[55];
// Variables to store admin numbers and the gsm response.
String textMessage, admin1, admin2, admin3, admin4, admin5;

void setup() {
  pinMode(relay, OUTPUT);
  pinMode(buzzer, OUTPUT);
  pinMode(upload_status, OUTPUT);
  // Init Serial ports
  Serial.begin(9600);
```

Done Saving.

```
The sketch name had to be modified.
Sketch names must start with a letter or number, followed by letters,
numbers, dashes, dots and underscores. Maximum length is 63 characters.
```

```
void setup() {
  pinMode(relay, OUTPUT);
  pinMode(buzzer, OUTPUT);
  pinMode(upload_status, OUTPUT);
  // Init Serial ports
  Serial.begin(9600);
  ss.begin(GPSBaud);
  gsm.begin(9600);
  // Init RDM6300
  rdm6300.begin(RDM6300_RX_PIN);

  Serial.println("Setup done.");

  delay(500);
}

void loop()
{
  if (rdm6300.update())  //look for cards
  {
    Read_Tag();    //Read the detected card
    delay(1000);
    //Serial.println();
    //Serial.print(user_id);
    //Serial.print(id1);
    //Serial.println();
    int m = 1;
    if(m == 1)
    {
      buzz(1, 100);
      digitalWrite(relay, HIGH);   //disable the cut-out.
    }

    else {
      buzz(5, 100);   //sound buzzer to indicate that the read card is not for the required user.
    }
    user_id = "";
    gprs();   //enable gprs to be able to upload data to the server.
    while (1)
    {
      unsigned long currentMillis = millis();
      if (((currentMillis - previousMillis) > interval))  //check if ten minutes have expired.
      {
        previousMillis = currentMillis;  //reset the timer.
        gsm.listen();
        delay(200);
        at_command("AT+CFUN=0", "OK");
```

```
// This custom version of delay() ensures that the gps object is being '
static void smartDelay(unsigned long ms)
{
  unsigned long start = millis();
  do
  {
    while (ss.available())
      gps.encode(ss.read());
  } while (millis() - start < ms);
}

void at_command(String cmd, char *resp)
{
  boolean at_flag = 1;
  int x = 0;
  while (at_flag)
  {
    gsm.println(cmd);
    Serial.println(cmd);
    x++;
    delay(1000);
    while (gsm.available() > 0)
    {
      textMessage = gsm.readString();
      //Serial.print(textMessage);
      delay(10);
      if (textMessage.indexOf(resp) >= 0)
      {
        //if (textMessage.indexOf("+HTTPACTION: 0,200") >= 0)
        if (textMessage.indexOf("+HTTPACTION: 1,200") >= 0)
        {
          digitalWrite(upload_status, HIGH);
          delay(500);
          digitalWrite(upload_status, LOW);
        }
        textMessage = "";
        at_flag = 0;
        break;
      }
      //break;
    }
    if (x > 4)
      break;
    //delay(1000);
  }
}
```

```
void data()
{
  gsm.print("AT+HTTPPARA=\"URL\",\"http://speed-monitoring.herokuapp.com/tracker/?imei=");
  gsm.print(IMEI);
  gsm.print("&rfid=");
  gsm.print(id1);
  gsm.print("&lat=");
  gsm.print(gps.location.lat(), 6);
  gsm.print("&lon=");
  gsm.print(gps.location.lng(), 6);
  gsm.print("&timestamp=");
  gsm.print(gps.date.year());
  gsm.print(slash);
  if (gps.date.month() < 10) gsm.print("0");
  gsm.print(gps.date.month());
  gsm.print(slash);
  if (gps.date.day() < 10) gsm.print("0");
  gsm.print(gps.date.day());
  gsm.print(space);
  if (gps.time.hour() < 7) gsm.print("0");
  gsm.print((gps.time.hour() + 3));
  gsm.print(colon);
  if (gps.time.minute() < 10) gsm.print("0");
  gsm.print(gps.time.minute());
  gsm.print(colon);
  if (gps.time.second() < 10) gsm.print("0");
  gsm.print(gps.time.second());
  //gsm.print("&num_satellite=");
  //gsm.print(gps.satellites.value(), 3);
  gsm.print("&altitude=");
  gsm.print(gps.altitude.meters(), 2);
  gsm.print("&course=");
  gsm.print(gps.course.deg(), 2);
  gsm.print("&speed=");
  gsm.print(gps.speed.kmph(), 2);
  gsm.print("&plate=");
  gsm.print(plate);
  gsm.println("\"");
}

void gprs()
{
  gsm.listen();
  delay(200);
  at_command("AT", "OK");
```