UNIVERSITY of RWANDA

ACEIoT

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COLLEGE OF SCIENCE AND TECHNOLOGY

Research thesis title:

DESIGN OF AN IOT-BASED SEAT OCCUPANCY MONITORING SYSTEM FOR PUBLIC TRANSPORT

Case Study: RWANDA

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Award of Masters of science degree in Internet of Things/ Wireless Intelligent Sensor Networking.

Submitted by

NIYIGENA Issa

PG:213001736

January 2022

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Supervised by

Dr. Jimmy NSENGA

and

Dr. Gerard RUSHINGABIGWI

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Bonafide Certificate

This is to certify that the research task "Design of an IoT-Based Seat Occupancy Monitoring System for Public Transport" is an original report completed by Issa NIYIGENA with registration number 213001736 in partial fulfillment of the requirement for the award of masters of sciences in Internet of Things in the College of Science and Technology, University of Rwanda, for the Academic year 2020/2021.

This project was completed under the supervision of Dr. Jimmy NSENGA and Dr. Gerard RUSHINGABIGWI

Main Supervisor: Dr. Jimmy NSENGA

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Dr. James Rwigema

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Date: ……………………………………

Declaration

I hereby declare that this report on a research study titled "**Design of an IoT-Based Seat Occupancy Monitoring System for Public Transport "** is my original work and has never been submitted for the granting of any degree or diploma at the University of Rwanda or any other educational institution, except where due acknowledgement is made in the thesis.

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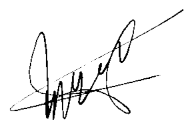
Signature: 

Date: 28/12/2021

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Abstract

As the world's population grows, the number of public transport users increases almost at the same rate, which creates a need for a higher offer in terms of the number of public transport vehicles, thus ensuring the best traveler's experience. However, transportation companies still have the challenge to control the correct money made by their vehicles due to some unfair drivers who steal part of the income for their personal use as a traditional solution, Supervisors are engaged to guarantee that the buses are used properly. Most particularly in Rwanda's public transportation sector, unfair public transportation drivers have been boarding people after leaving the departure station but before reaching the destination station. In this research, an analysis of the public transportation business in Rwanda has been done to understand the ecosystem of public transportation service providers in Rwanda; key operational difficulties from discussions with public transportation company owners and managers have also been carried out. The findings from an interview with 20 public bus owners and 18 public transportation company managers showed that most drivers claim less income than is actually earned, and the claim is likely much higher, that is according to 98 percent of the bus owners and 90 percent of the managers questioned. An IoT-based seat occupancy monitoring system has now been designed and prototyped for public transport vehicles to improve and facilitate companies to know all their income without being misled by their staff by detecting seat occupancy, computing a passenger's distance traveled, and calculating the distance fee in real time. Indeed, the system prototyped in this project can be installed in each company's vehicle to daily monitor and report various events that occur within vehicles during service, allowing an alternative estimation of revenues generated by the vehicle based on seat occupancy as a function of passenger distance traveled. And costs which were spent on paying the supervisors will be spared in the long run by increasing the company's return on investment. A collection of future works and views has been assessed as a result of this research project, including vehicle mechanical condition monitoring in order to ensure timely vehicle repair. In contrast to the existing literature, this mostly focuses on smart transportation; this study resulted in an innovative use of seat weight sensor and Hall Effect sensor to provide a solution to address the issue. A smart phone's application that allows passengers to see available free seats as well as their exact location in the coming bus is suggested, and also a leveraged artificial intelligence is necessary after gathering enough data for the system to be smarter than its current version.

Keywords: Internet of Things (IoT), Public transport; thefts; frauds; monitor; report, seat sensor, GSM/GPRS, Arduino

List of Acronyms

CCTV: Closed-circuit television

DC: Direct Current

DIP: Digital Image Processing

EEPROM: Electrically Erasable Programmable Read Only Memory

GSM: Global System for Mobile Communications

GPRS: General Packet Radio Service

IC: Integrated Circuit

IDE: Integrated Development Environment

LED: Light Emitting Diode

IoT: Internet of Things

LRT: Light Rail Transit

MCU: Microcontroller Unit

MRT: Mass Rapid Transit

NFC: Near-field communication

PHP: Hypertext Preprocessor

PIR: Passive Infrared Sensor

POC: proof of concept

POS: A point of sale

RFID: Radio Frequency Identification

RTC: Real-Time Clock

SQL: Structured Query Language

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1. INTRODUCTION

As the years go by, the world's population continues to grow, cities in general continue to expand and the world's population continues to spread to other parts of the world to find where to live, travel, visit, etc.. In most cases, people have to travel a long distance to access different daily life infrastructures such as schools, clinics, football stadiums, entertainment houses, work offices and so on. That is why many people need vehicles for daily commuting to save time. Because it is practically impossible for all of us to own our cars due to insufficient ability and infrastructure, the solution to the problems is public transportation.

Buses, MRTs, LRTs, and taxis are all examples of public transportation [1]. It is typically a low-cost, regulated alternative for individuals to get mobility and access to jobs, education, retail, health, and recreational services, as well as community facilities.

This sector is very big in terms of revenues because almost all of us need this service in our daily life. However, most of the company's owners regularly complain due to mismanagement of the income caused by some drivers and operation managers with fraud or using the income for their own purpose. This causes a big loss to the companies and also the country because of unrealized taxes compared to what would be paid if the exact money earned is correctly reported and therefore known by Revenue authorities. This is often the reason for these companies to increase fare costs due to all those losses in order to compensate for the small income with respect to their investment in buying cars, paying their employees, daily operation costs and finally taxes.

Kevin Ashton came up with the term "Internet of Things" (IoT) to describe supply chain management in 1999.Since then; it has been expanded to include various applications such as healthcare, utilities, and bio-sensing [2].

The IoT solution proposed in this research project aims at solving the income tracking challenge raised by company’s owners because it will enable them to detect theft done by some of their employees; This would enhance the way these companies operate and keep public transportation cheap, making it a more appealing choice to driving a private automobile in terms of passenger usage and customer satisfaction. This improvement will not only cover the transport modes themselves, but also all intermediate and end-point facilities, such as link ways, service information, customer service, etc.

1.1. Problem statement

After a survey at Rwandan public transport in 2019 in different companies, it was found that there are some problems that managers and owners of companies face such as not knowing the exact income generated by their bus vehicle services due to the problem of unfair drivers that do fraud. This fraud likely happens during duty after for instance a bus leaves a given bus terminal with some free seats and passengers are boarded on the way. In this scenario, unfair drivers do not declare such income which fails under unrealized income.

In the past, Companies have tried to find solutions such as Tap and Go Technology that uses NFC technology with POS machines, Infrared based system for counting entering and leaving passengers in the bus and Closed-circuit television CCTV to monitor activities in buses, however those existing solutions are not reliable, because Even if it is restricted to pay fare in hands ,It is easy to cheat the systems, passengers sometimes pay fare in hand and because Companies have many buses ,It is not easy for CCTV System Operators to monitor the whole buses. Still causing most companies to lose a lot of money and take that as an excuse to increase fare costs due to all those losses and small income compared to their investment in buying cars, paying many employees and paying taxes.

With the system designed and prototyped in this Master Thesis project, it will be easier to know the exact money earned every day by each bus. The system will efficiently solve the problem of residential theft by drivers on the road where managers are unable to access local information.

In addition, the system will enhance the way these businesses operate and keep public transportation affordable, making it a viable alternative to private automobiles. Not only that but the system also helps to solve other challenges or enable just open up new opportunities of services for car owners. They can be able to add/remove vehicles in some directions because there is more/less enough unrealized revenues. Seat monitoring in real-time can enable the development of services for travelers to know if a nearby public transport system has free seats and so on.

1.2. Research aim & Specific objectives

1.2.1. Aim

This study aims to prototype an IoT-based seat occupancy monitoring system for public transport vehicles as a way to improve and facilitate owners/managers in tracking unrealized income that would be generated by passenger’s onboarding during journeys outside bus stations and not reported by some unfair drivers.

1.2.2. Specific Objectives

The following are the specific goals for this master's research project that have been established in order to achieve the intended outcome.

- Understand the business challenges of unrealized incomes dues to unfair public transport drivers
- Understand the failure reasons of existing monitoring solutions
- Review the literature of IoT solutions for seat occupancy monitoring
- Make an architecture and a design of an IoT-based seat occupancy monitoring tailored to public transport in Africa
- Prototype in hardware the on-bus IoT system network
- Set Up an overall proof of concept (POC) environment to show live collected data

1.2.3. Study Scope

The overall technology solution for this problem is large including components deployed in the vehicle (edge layer), gateways, and backend/cloud services. This master's project focuses particularly on the edge layer with the development of the in-bus embedded IoT network composed of seat sensors, speed sensors, and local edge computing gateway. The one-year study focused on vehicles issued to drivers by public transportation companies. This focuses on tracking all activity in company vehicles while they are on the road for various business insights. This will allow the data on bus abuse to be transferred to the company that keeps all vehicle records and monitors all activity in the buses.

1.3. Summary

The introduction section discusses how public transportation is critical due to the large number of people living in areas with inadequate infrastructure, how it is a large financial sector, the field investors' challenges, such as losing money due to employee theft, and the proposed solution to solve the theft problem, as well as other management challenges.

2. RATIONALE AND LITERATURE REVIEW

2.1. Rationale

Public Transport companies do invest a lot in the supervision of the company buses to assess their rightful usage which includes monitoring of the passengers inside the buses. This cost manifests through facilitating the supervisors and managers for the daily activities. This raises the question of whether these companies can use IoT solutions instead of human supervisors to remotely monitor passengers inside the buses and get a report of the real revenue generated by the buses, allowing them to get the entire revenue, including the one that was previously misled by those employees, including drivers, potentially with the complicity of their in-bus supervisors.

2.2. Literature review

A literature review has been done about the existing related systems, to explore the potential solutions for the aforementioned problems as well as compare the technologies used and how they relate with and differ from our proposed system in this project. This will be discussed in five sections which include a) Public Transport in Rwanda b) Public transport without IoT enabled seat management system c) Seat sensors d) GSM/GPRS and e) Cloud platform.

2.2.1. Public Transport in Rwanda

In contrast to private transportation, public transportation (also known as public transportation, public transit, mass transit, or simply transit) is a system of public transportation for passengers that is managed on a schedule, operates on established routes, and charges a posted fee for each trip [8]. In Rwanda, licensed public bus and minibus companies and cooperatives, motorbike cooperatives, vehicle rental firms, and taxi cab companies and cooperatives provide road transportation for people [9].

In Kigali City, selected public transportation options include bus and taxi cabs as illustrated in Table 2.1.

(a) Buses

(b) Taxi Cabs

Figure 2.1: Selected types of public transport in Kigali (a) Buses; (b) Taxi Cabs

2.2.1.1. Express Bus

They travel between large towns on a regular schedule (typically every 30 minutes), stopping only at designated points near the station. Even if you exit earlier, The fare to the next major stop must be paid.. Almost all routes in Kigali pass via Nyabugogo.

Private companies operate the buses, which sell tickets in advance at a government-set fare (RURA). A conductor is not required to collect money on the bus. Due to the fact that tickets are collected and printed in offices at bus terminals or by an employee on the side of the road (minor stops). Because tickets can be purchased in advance, they may sell out rapidly during peak times (such as Fridays, Sundays, and at the beginning and end of the school semester).

Unlike Shared Taxis, this mode of transportation runs on time and does not wait until it is full. Similarly, they are almost never overcrowded and always leave early.

The vehicles range in size from Toyota Coasters to large buses. Ritco, in which the government owns a stake, operates a small number of buses. It's also the only operator that has bus stops across the country, whilst private rivals are limited to certain regions. When it was created, it took the place of Onatracom, a publicly traded company [14].

In certain rural areas, share taxis are still the primary mode of transportation, but Express Buses are employed wherever possible. According to the express's nearly comparable price, enhanced comfort and speed.

Since 2011, the number of public transportation vehicles (buses) registered in Rwanda has increased from 5,597 to 8,092 buses in 2016 [9]. It should also be highlighted that the number of users is steadily expanding, as the AC Group, a Rwandan tech firm that enables payment in public transportation, recently announced that it has 2 million customers and sells 300,000 tickets every week. The AC Group collaborates with 19 bus companies in Rwanda, who operate a total of 1633 vehicles of various models and sizes across the country [10]. The demand for public transportation is growing and will continue to grow in the coming years as the number of people using it grows.

In the following, we present the different public transportation service providers in Rwanda organized by geographical boundaries of their transportation services.

2.2.1.1.1. Intra-District

As stated in Table 2.1, Kigali City has four main public transportation zones. Zone 1 is served by Kigali Bus Service. Zone 2 is served by Royal Express. Rwanda Federation Transport Cooperatives operate Zones 3 and 4 (RFTC). Three bus companies have been given a contract of five years to operate in their own zones. [12]

Table 2.1: Four exclusive public transportation zones summary

Zone	**Company**	**Coverage Area**
Zone 1	Kigali Bus Service or KBS	Remera,Kanombe,Kabeza,Nyarugunga,Rusororo (Kabuga),Masaka and Ndera Sectors
Zone 2	Royal Express	Niboye,Kicukiro(Sonotubes,Centre),Gahanga,Gatenga,Gikondo and Kigarama.
Zone 3	Rwanda Federation Transport Cooperatives or RFTC	Kimironko,Kinyinya(Kagugu-Dutchwelle),Gisozi,Kacyiru,New & Gakinjiro,Batsinda,Kibagabaga,Kimihurura,Nyarutarama
Zone 4		Kimisagara,Nyakabanda,Nyamirambo,Mageragere,Kigali,Gatsata,Karuruma,Jabana,Nyacyonga

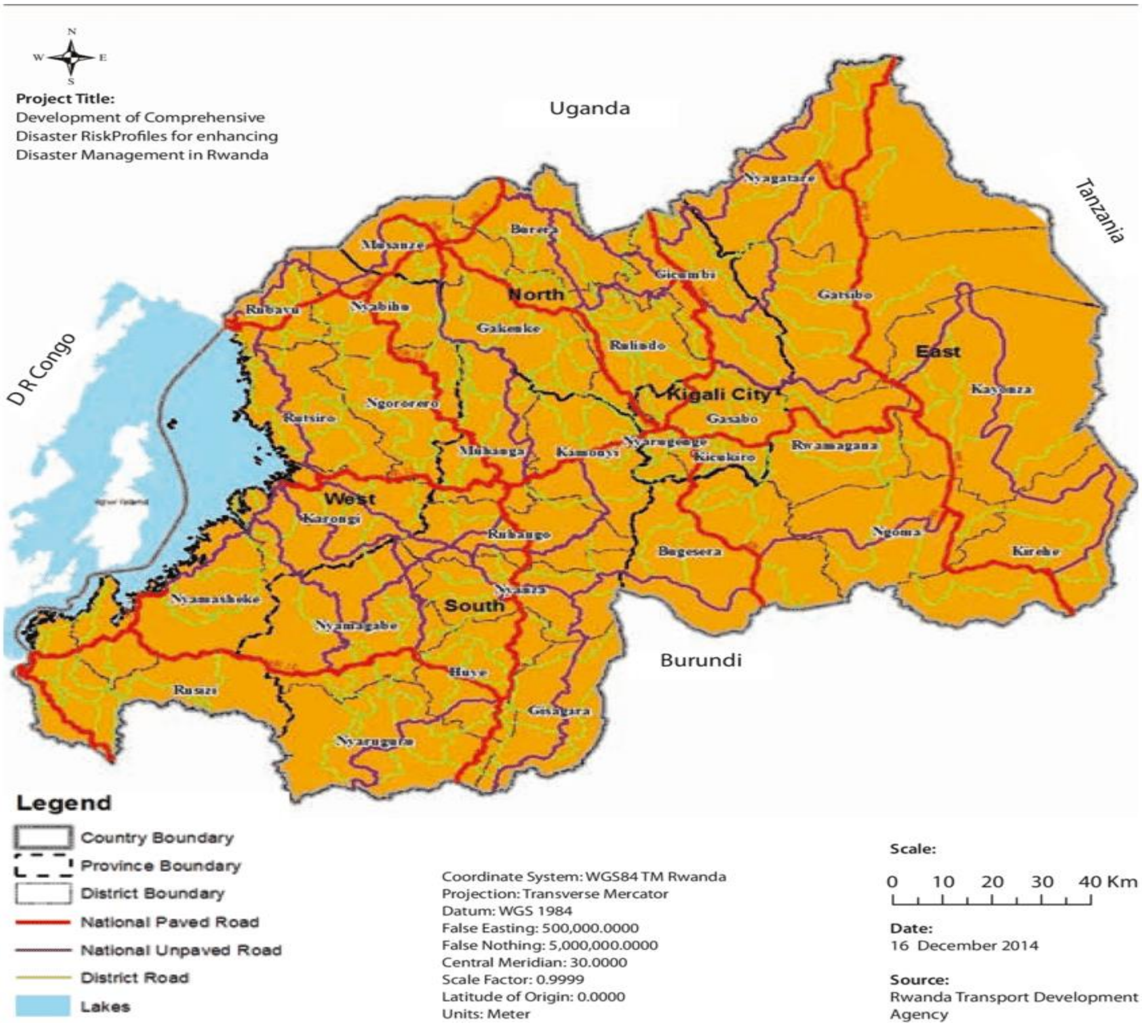
2.2.1.1.2. Inter - District

Kigali has a well-developed radial road system. RN1, RN3, RN4, and RN5 are the major radial roads. RN1 connects Kigali to Butare (Burundi), RN3 connects Kigali to Byumba (Uganda) and Rwamagana (Tanzania), RN4 connects Kigali to Ruhengeri (DRC), and RN5 connects Kigali to Bugesera (Burundi). The map below [12] depicts the key road network.

Table 2.2: Kigali's Major Roads and Connected Cities or Areas

Road Class	**Road Name**	**Connected Major Cities**	**Remarks**
National Highways	**RN1**	Butare (Burundi) West direction of Kigali	Butare (Burundi) West direction of Kigali
	RN3	Byumba (Uganda) North direction of Kigali	Byumba (Uganda) North direction of Kigali
		Rwamagana (Tanzania) East direction of Kigali	Rwamagana (Tanzania) East direction of Kigali
	RN4	Ruhengeri (DRC) Northwest direction of Kigali	Ruhengeri (DRC) Northwest direction of Kigali
	RN5	Bugesera (Burundi) South direction of Kigal	Bugesera (Burundi) South direction of Kigal

The principal routes of Rwanda are shown on the map in the figure 2.2 below



Source: Rwanda Transport Development Agency

Figure 2.2: Map showing principal routes in Rwanda

As stated in table 2.3, there are several daily transport options provided from Kigali to various parts of Rwanda.

Table 2.3: Inter-District Public Transport

Departure Bus Terminal/District	**Destination Bus Terminal/District**	**Roads**	**Transport Company**
Nyabugogo/Kigali City	Huye bus Terminal/ Huye/Nyamagabe	Nyarugenge, Kamonyi, Muhanga, Ruhango,Nyanza, Huye, Nyamagabe	Horizon, Sotra Tours,Volcano

Nyabugogo/Kigali City	Rulindo/Gakenke/Musanze/Nyabihu/Rubavu	Nyarugenge, Kigali, Rulindo, Gakenke, Musanze, Nyabihu, Rubavu	Virunga, Ritco, la colombe, International,Volcano, Excel, Stella
Nyabugogo/Kigali City	Rwamagana/Kyonza/Gatsibo/Nyagatare	Rwamagana, Gasabo, Kyonza, Gatsibo, Nyagatare, Kagitumba border	Ritco, Ruhire, RFTC, International, Excel, Stella
Nyabugogo/Kigali City	Kicukiro/Bugesera	Nyarugenge,Kicukiro,Bugesera border	RFTC, International, Excel
Nyabugogo/Kigali City	Gicumbi/Gatuna border	Nyarugenge,Gicumbi,Gatuna border	RFTC,International,Excel
Nyabugogo/Kigali City	Gasabo/Rwamagana/Kayonza/Ngoma/Kirehe Rusumo	Gasabo, Rwamagana,Kayonza, Ngoma, Kirehe, Rusumo order	Ritco, Ruhire, RFTC, International, Excel, Stella, Select

2.2.1.1.3. International Travel

As stated in table2.4, there are also several daily transport options provided from Rwanda to places in the African Great Lakes:

Table 2.4: International travel from Rwanda to its neighboring countries

Departure city / Country	**Destination city/ Country**	**Roads**	**Transport Company**
Kigali/Rwanda	Bujumbura/ Burundi	Butare (Burundi) West direction of Kigali	Yahoo Car Express,Venus Express
Kigali/Rwanda	Kampala / Uganda	via Gatuna(road 1) or via Kayonza and Kagitumba(roads 2 and 2a)	Jaguar, Volcano, Horizon, Mosh Power, Trinity Coach
Kigali / Rwanda	Nairobi / Kenya Kampala / Uganda Dar es Salaam /	via the Gatuna border crossing	Trinity,Matunda xpress,Select,Regional Coach Services

	Tanzania		
Kigali/Rwanda	Goma/DRC Kampala/Uganda Nairobi/Kenya	Gisenyi / Goma and Kigali to Kampala and Nairobi via Gatuna	Kampala coach, Simba, Mash Cool , Modern coach

Furthermore, national express sharing taxi services from Cyangugu and Gisenyi frequently to get to the DRC, Transport passengers need to cross the DRC border to Goma and Bukavu [13].

2.2.1.2. Taxi Cab

A taxi, often known as a taxicab or cab, is a form of private vehicle with a driver that is frequently used for non-shared transport by a single passenger or small number of people

Taxicabs transport clients to their preferred destinations. This is in contrast to public transportation, where the service provider, rather than the consumers, selects the pick-up and drop-off locations. However, responsive transportation is required, and shared taxis give a bus/taxi hybrid option. And passengers pay a charge based on the distance traveled (money is counted according to the number of kilometers traveled).

2.2.1.3. Moto Taxi

Moto-taxis make up a major fraction of the vehicles on Rwandan roadways, particularly in Kigali. A single person can board and disembark from the back of a motorcycle or scooter and pay the required payment for the voyage.

2.2.1.4. Bicycle Taxi

Bicycle taxis are a type of small-scale local transportation. It's a type of bicycle designed to transport passengers for a fee. Bike taxi, velotaxi, and other similar terms have been used to describe it. Rwandan roadways do not feature bicycle lanes, unlike pedestrian walkways. Passengers in bicycle taxis pay the required fee based on the distance traveled.

2.2.2. Traditional and IoT solutions for counting the number of passengers in a public transport

2.2.2.1. Human driver assistant supervisor

Private persons own the vehicles, which are operated and maintained on a daily basis by a driver and an in-car supervisor or conductor.

The conductor is in charge of the main sliding door's opening and shutting in addition to taking money from customers. If all seats are taken, the conductor will stand at the door. Tickets are provided by POS machines in this type of taxi, although the conductor sometimes accepts payment in hand and does not reveal it. This approach has numerous flaws, such as paying another conductor's salary, occupying one less seat not paid for by a customer, and partnering with the driver to falsify data regarding the number of passengers.

2.2.2.2. E-ticketing system

Smart cards (also known as "Tap & Go") are used by passengers to board buses. With POS machines, the system use NFC technology (Smart card tag and Card reader)

Smart cards are available for purchase at the bus station store. Smart cards with a RWF 500 pre-loaded balance are marketed for RWF 1,000. When the amount runs out, It needs to be recharged before it may be reused, and there is a recharging store near the bus terminal/station. When a passenger boards the bus, he or she pays the fare by swiping their card via a card reader installed inside the vehicle.

The smart cards and the card reader are designed by AC Group. The system vendor, AC Group, receives a 5% commission on gross revenue collected per bus. AC Group collaborated with the Rwandan government and the bus company to develop the smart cards and card reader. The system vendor is AC Group, which is part of the DMM Group in Japan. Previously, bus operators had to collect cash payments, necessitating the hiring of conductors. Revenue leakage to the crews, on the other hand, was an issue.

As a countermeasure, bus companies implemented a smart card-based automatic payment system. As a result, bus owners' revenues have soared by 50%, according to reports.

The gross revenue collected per bus earns AC Group a 5% commission [15].

Figure 2.3: Tap & Go Smart card

Figure 2.4: Tap & Go Smart card Reader

When it comes to the real data from public transport companies in terms of money and real number of passengers, this system has weaknesses. It can't provide the real data, because even if it is restricted to pay fare in hand, it is easy to cheat the system, passengers sometimes pay fare in hand.

2.2.2.3. Smart Ticket Management System

In Turkey,Akilli Bilet developed the Smart Ticket Management System, and The system was introduced jointly by AC Group and Akilli Bilet.

RURA collects bus location information, in addition to the number of passengers and the amount of money received every bus and per bus ride, using the Smart Ticket Management System. The system has yet to be updated to reflect changes in bus routes. As a result, It is impossible to collect precise, relevant data that represents actual bus operations, Because it just takes data from POS machines rather than the genuine ones from the bus, it may obtain the number of passengers and the amount collected per bus at bus terminals and bus stops, which is a problem.

2.2.2.4. Closed-circuit television (CCTV) camera

AC Group said the practice was making a loss of about 26% of the revenues collected from fares. It had emerged that some passengers were sneaking into the bus, taking a seat and leaving without paying their fare.

The company’s CEO, Patrick Nsenga Buchana, said that drivers were also receiving cash in hand and not declaring it.

AC Group decided to install CCTV Cameras In Public Buses to avoid Tricks of marauding passengers, to check on the behavior of drivers and for the safety of passengers and properties and the system serve as a security precaution.

AC group said, no one will do such a thing and go unnoticed. They said the footage from the cameras in each bus will be monitored in real time.

The Rwanda Regular (RURA) Spokesperson, Tony Kulamba Said that cameras will also help identify drivers who were overloading and breaking traffic rules [16].

This solution also has weaknesses. Because Companies have many buses, It is not easy for System Operators to monitor the whole buses via one screen.

2.2.3. Monitoring seat occupancy in public transport vehicles using IoT

2.2.3.1. PIR

Currently IoT is not being used to monitor buses seat occupancy in Rwanda with public transport companies unless seat occupancy system is being used in new private cars by airbag system and vehicle seat belt sytem but in some abroad countries, IoT seat occupancy system are used for different purposes as reported in literature review

Routing, navigation, safety, and tracking have been the main applications of IoT in public transportation [17–19]. Wireless sensor networks, on the other hand, Seat occupancy detection systems have been used in large halls, film halls, and festivals [20]. To identify seat occupancy for massive systems, Massive inter networks with a hybrid architecture are used in these solutions.. However, the application of such technologies in public transportation is still in its early stages and has yet to be extensively explored.

Different methods for estimating crowding in public transportation have been proposed [21],[22]. These systems primarily employ Digital Image Processing (DIP) with surrounding(s) subtraction to assess bus crowding using the pixel density of the removed image [17]. In a crowd control system based on IoT which is low-cost [23], Rajesh Agarwal, Aditya Varma, Hari Charan, S. Renuga Devi, and Sachin Vidyasagaran. Employed a velostat piezo resistive sensor to sense seat occupancy. However, these sensors have some drawbacks, such as being too sensitive to pressure and recording inessential changes in resistance [24], The Prototype Bus Passenger Monitoring System Using PIR Sensor to determine seat occupancy. [25], which also has some drawbacks, such as not operating above 35 degrees C.Snoozing is another issue with PIR sensors. It is insensitive to the slow movement of the items. Even when there isn't much movement in a crowded area, PIR sensors may switch off [26].

This method, however, has a number of drawbacks. To begin with, because it can only determine if the bus is completely occupied, somewhat occupied, or unoccupied, the system's accuracy is restricted. The number of people in each seat isn't stated. Furthermore, Lighting, weather, and time of day are all factors which affect such systems. DIP processing necessitates a huge increase in compute power, reducing the system's lifespan. As a result of these observations, it is possible to affirm that a more robust, long-lasting, and accurate system is necessary. Because the application of IoT in managing passengers with paid public transportation fares has not been adequately studied, the suggested IoT system aims to offer a framework for the same.

2.2.3.2. Passenger Seat Occupant weight Sensor/ Hall Effect wheel speed sensor

When they are placed in vehicle seats, some applications employ the weight seat sensor-based approach to determine whether a seat is occupied. Capacitive sensing is a term that refers to a variety of ways for determining the capacitance of an electrode in relation to its surroundings [27]. The rest of these occupancy sensing devices have been industrialized and are now used in smart airbag solutions [28], [29], [30]. As well as monitoring drivers' vital signs [31], [32]. Capacitive sensing has shown to be a powerful and dependable measuring technique with minimal power consumption, making it appropriate for the fast-paced automotive environment. As a result, several investigations have been conducted on Seat occupancy monitoring with capacitive sensors, with various prototypes constructed. Many of these occupancy sensing devices have been industrialized and used in smart airbag technologies [28], [29],[30], as well as for monitoring drivers' vital signs [31], [32]. The above-mentioned sensors place a premium on performance (quick response time) and sensitivity.

Three alternative capacitive sensing approaches are described in [32] and [33]: which are transmit, shunt, and loading modes. The shunt mode approach is used by said referenced sensors. The body effectively becomes grounded in shunt mode, The field is screened, and the current observed at the receiving electrode is reduced.

This approach, as stated by [32], cannot tell the difference between a larger mass far away and a smaller mass close by, but many transmitter or receiver electrodes can compensate for this deviancy. In transmit mode, the body acts as a virtual extension of the transmitter to the receiver electrode, which is inefficient for sensing occupation. In loading mode capacitive detecting, the difference in capacitance between a single electrode and ground is detected. Transmit and shunt mode are used to detect a single person. Several electrodes are placed on the seating area and backrest in capacitive sensing techniques.

Putting sensors on each seat on the bus to sense all passengers' motions inside the bus is reliable ways that will assist the system generating the intended output without error. Magnetic sensors are solid-state components that are gaining popularity due to their use in a variety of applications, including sensing position, speed, and directional motion. Their non-contact wear-free method, easy maintenance, and strong architecture, as well as the fact that sealed Hall Effect devices are resistant to vibration, dust, and water, make them a popular sensor choice for electronics designers [34].

A Hall Effect sensor is a transducer that responds to a magnetic field by changing its output potential difference. The size and direction of the magnetic field, as well as the electric current, influence the Hall voltage (power supply). The Hall plate detects the magnetic field, and a "Hall" voltage corresponding to the induced magnetic flux is formed across the biased Hall plate. This sensor is an analog transducer, which means it returns a voltage in its most basic form. The distance between the Hall plate and a known magnetic field may be calculated. A set of sensors may be used to compute the magnet's relative position. Hall Effect sensors can be used in proximity switching, positioning, speed sensing, and current sensing applications [35].

The Hall Effect sensor is titled after Edwin Hall, who discovered in 1879 that a potential difference occurs across a current-carrying conductive plate when a magnetic field passes across it in a direction perpendicular to the plate's plane. Due to advancements in enabling technology, Hall-effect (magnetic field) detection applications have recently become useful. It's possible that Hall Effect sensors don't have analog circuits that can connect to microprocessors. These interface examples include input diagnostics, fault prevention for transient conditions, and open circuit detection. It may also supply current to the Hall Effect sensor and monitor it. Accurate integrated circuits (ICs) are available to hold these features.

In this system I will use the Hall Effect sensor in simulation only because once the system is done by installing it in the car the Hall Effect will not be needed because I will use an ignition motor cable which is also used when installing a tachometer in vehicles to measure vehicle speed.

2.2.4. Summary

This section discusses the current state of the chosen mode of public transportation in Rwanda, as well as Kigali's main roads and surrounding cities/areas, as well as their service provider companies, challenges, and existing traditional and IoT solutions to address those challenges in Rwanda and around the world.

3. RESEARCH METHODOLOGY, ROADMAP AND TIMELINE

This research combines both qualitative and quantitative approaches. On the one hand, the qualitative approach consisted of investigating existing systems to find their merits and weaknesses as a basis to set up requirements for a suitable and valuable system for the public transport business.

On the other hand, the quantitative approach relied on experimentation using both virtual and prototyped hardware to collect data from a public transport-like vehicle setup, analyze them and evaluate the effectiveness of our solution from data. The following presents the defined research tasks and timeline to complete the project

3.1. Research Tasks

The different tasks to be carried out have been organized into work packages (WP) as follows:

- WP1: Analysis of the Public Transport Business in Rwanda
    - T1.1: Understand the ecosystem of Public Transport Service Providers in Rwanda
    - T1.2: Understand main operational challenges from discussion with public transport company owners
    - T1.3: Define business requirements for seat occupancy monitoring
- WP2: Literature review of seat occupancy monitoring solutions
    - T2.1: Review of traditional solutions for counting the number of occupants in a vehicle
    - T2.2: Review of IoT-based seat occupancy monitoring technologies
- WP3: Public Transport Seat Occupancy Monitoring Solution Design
    - T3.1: High-level architecture of an IoT-based seat occupancy monitoring service
    - T3.2: System-Level Design of the on-board seat occupancy system (sensors & local gateway)
- WP4: Rapid Prototyping of an IoT-based seat occupancy monitoring service
    - T4.1: Hardware Development of Sensors
    - T4.2: Hardware Development of the on-board edge gateway
    - T4.3: Setting up a backend for Data Storage and Visualization
- WP5: Reporting
    - T5.1: Writing Thesis
    - T5.2: Writing Conference Paper

3.2. Research Timeline

The timeline of executing the above research tasks

Table 3.1: Scheduled Research Activities

Work Package	**2021**			
	January - March	**April - June**	**July - September**	**October - December**
WP1: Analysis of the Public Transport Business in Rwanda	■			
WP2: Literature	■			

review of seat occupancy monitoring solutions				
WP3: Public Transport Seat Occupancy Monitoring Solution Design				
WP4: Rapid Prototyping of an IoT-based seat occupancy monitoring service				
WP5: Reporting				

3.3. Summary

This section explains the approach utilized in the research activities that led to the discovery of the study topic. It also lists the various actions completed, ranging from an analysis of Rwanda's public transportation business to investigating the ecosystem of public transportation service providers and their issues, system prototype, and the schedule for completing the above research tasks.

4. RESEARCH RESULTS

This section presents the prototyping work done during this thesis including system-level design and also the output proof of concept (POC) system for monitoring seat occupancy in real-time within public transportation vehicles.

4.1. System-Level Design

The overall system is organized in 3 layers as follows as seen in Figure 4.1 bellow:

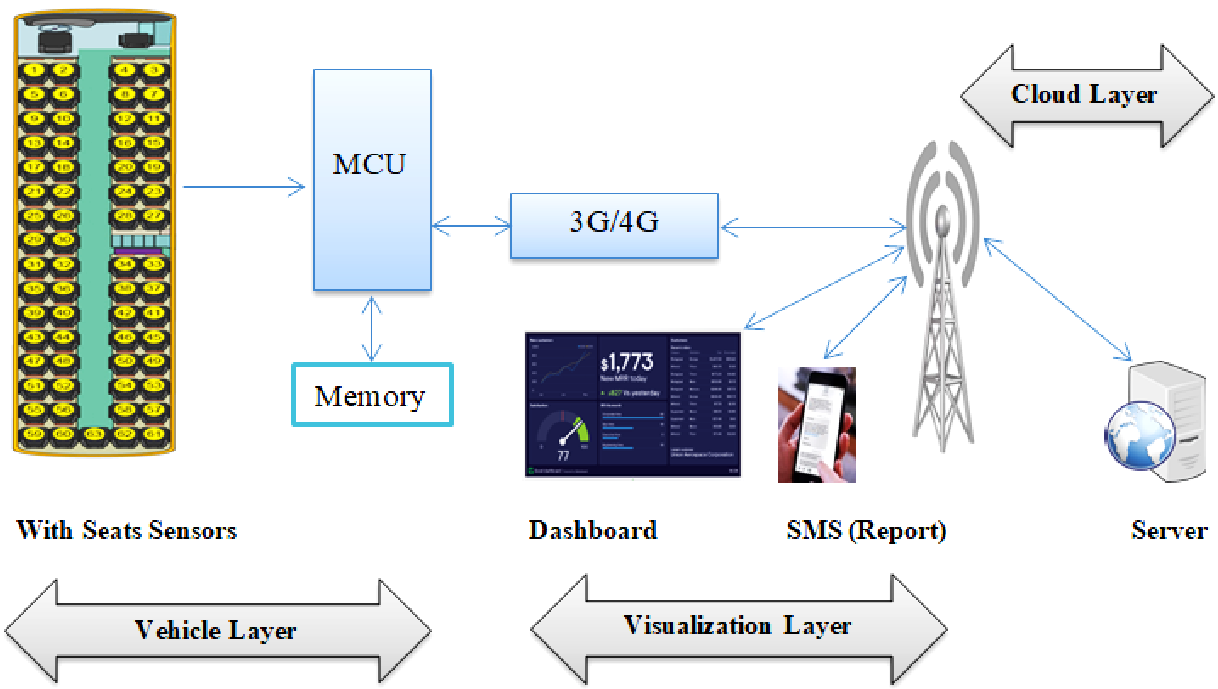


Figure 4.1: System Block diagram

1. **Vehicle Layer:** includes all components that are deployed in the public transport vehicle. These are:
    a. Sensors such as seat occupancy and speed
    b. Edge Computing Gateway gathering all raw sensor data and compute time-based geo-localized seat occupancy information
2. **Cloud Layer**: receives data sent by the on-board edge computing gateway via mobile Internet over cellular networks. The cloud layer includes the server infrastructure to store collected data into a database and some analytics to generate for instance alerts from the data.
3. **Visualization Layer:** This layer includes user interface (UI) components that facilitate end-users to view and interpret the collected data. These components are UI dashboard and short messaging reports via either SMS.

4.1.1. Vehicle Layer

4.1.1.1. Sensors

There are two main type of sensors used to control real-time geo-localized seat occupancy within a public transport vehicle:

1. Seat sensors are placed at each seat of the vehicle to measure the pressure on the seat via weight changes. A minimum weight value has been defined to avoid confusing passengers with their hand bags etc.
2. Vehicle speed sensor measures the distance traveled for each occupied seat.

In the following, more information about each type of sensor is provided.

4.1.1.1.1 Seat Occupant weight Sensor

As shown in Figure 4.3, the car seat sensor is a film-type contact sensor. The contact points of the seat sensor are equally distributed across the strained surface of the seat. When the seat receives pressure from the outside, the seat sensors generate a trigger signal [36].

Figure 4.2: Seat sensor

Up circuit layer, between gluey layer, down circuit layer, and back gluey layer are the four layers that make up most automobile seat pressure sensors. Wire cables and connectors are examples of other fixtures.

The seat surface is put under pressure when a person sits in a vehicle seat. As a result of this pressure, the top and lower circuit layers of the seat sensor come into contact. The circuit loop is then made conductive in order to send a signal to other devices. Indicating that someone is seated in the vehicle's passenger seat other systems in the automobile then utilize this signal in their processes. The seatbelt alerting system, for example, will identify whether or not the passenger in the vehicle seat has buckled up.

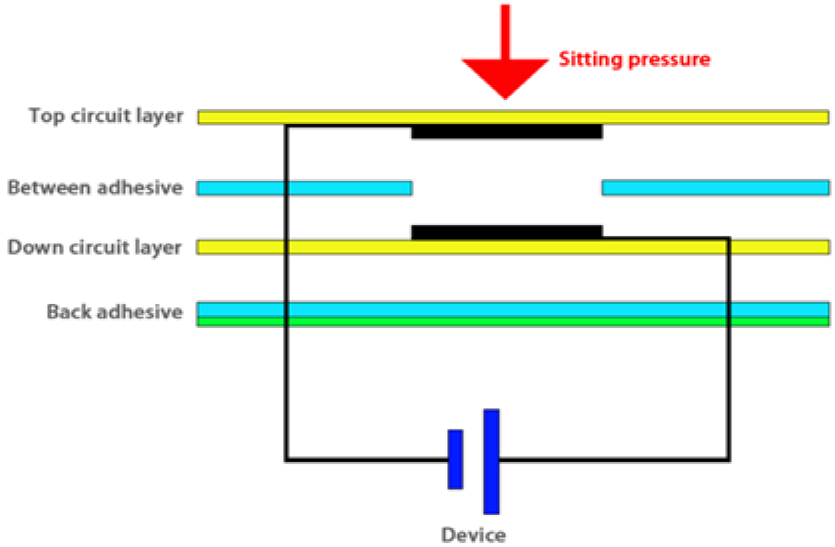


Figure 4.3: Working Structure and Principles

4.1.1.1.2. Hall-effect sensor

Vehicle speed detection, vehicle distance traveled, and estimating the distance traveled with passengers are all achieved using the Hall Effect sensor. Hall Effect sensor components are an example of the several forms of magnetic sensors that employ semiconductors. The Hall Effect is a Galvano magnetic effect that is used in Hall components. Because Hall components can only produce very modest voltages, Amplifiers, such as operational amplifiers, are virtually always required. The number of externally connected components is reduced, and circuit design is simplified, because a Hall Effect IC contains both a Hall component and an operational amplifier [35].

A single Hall Effect IC can be used to discriminate against the magnetic poles. These integrated circuits are utilized in a wide range of applications, including general and automotive.

Only a few of the major detection features of Hall Effect ICs include rotation detection, position detection, open/closed detection, current detection, direction detection, detecting vehicle height, speed and the number of motorcycles.

Figure 4.4: Hall Effect wheel speed sensor

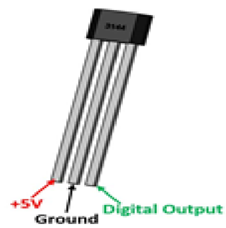


Figure 4.5: Hall Effect sensor

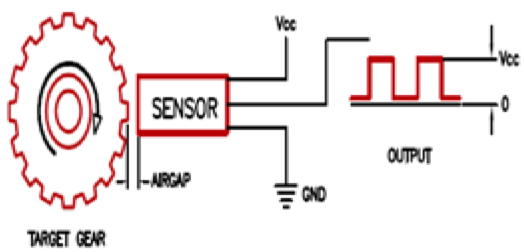


Figure 4.6: Hall Effect sensor output signal

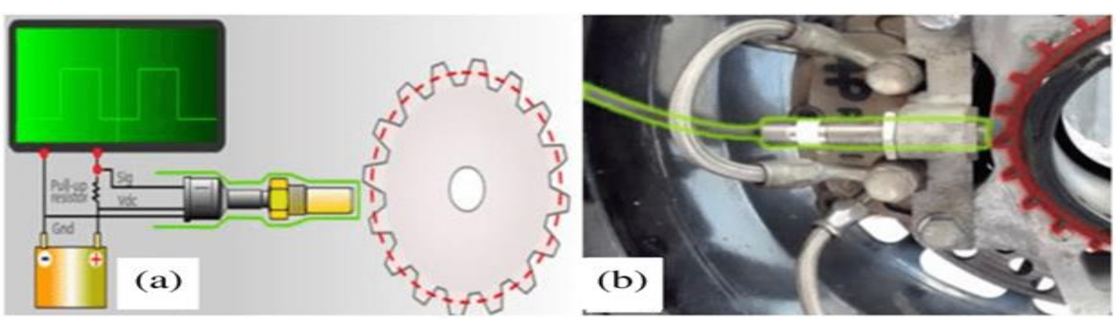


Figure 4.7: Wheel speed sensor with Hall Effect A schematic of the Hall Effect sensor for measuring vehicle speed (a) and a genuine shot (green) of the Hall sensor appropriately positioned for detecting wheel rotation speed (red) (b).

Static (non-changing) magnetic fields trigger Hall Effect sensors. This is a notable difference from inductive sensors, which only respond to field changes. This makes it suitable to the system.

4.1.1.2. Edge Computing Gateway

4.1.1.2.1. Control module

An Arduino Uno microcontroller is used to control the entire system. This is a microcontroller that receives and performs all system commands. It's a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (six of which may be used as PWM outputs), six analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53 - R0), and a USB connection (CSTCE16M0V53 - R0). A reset button, an ICSP header, and a power connector are all included.

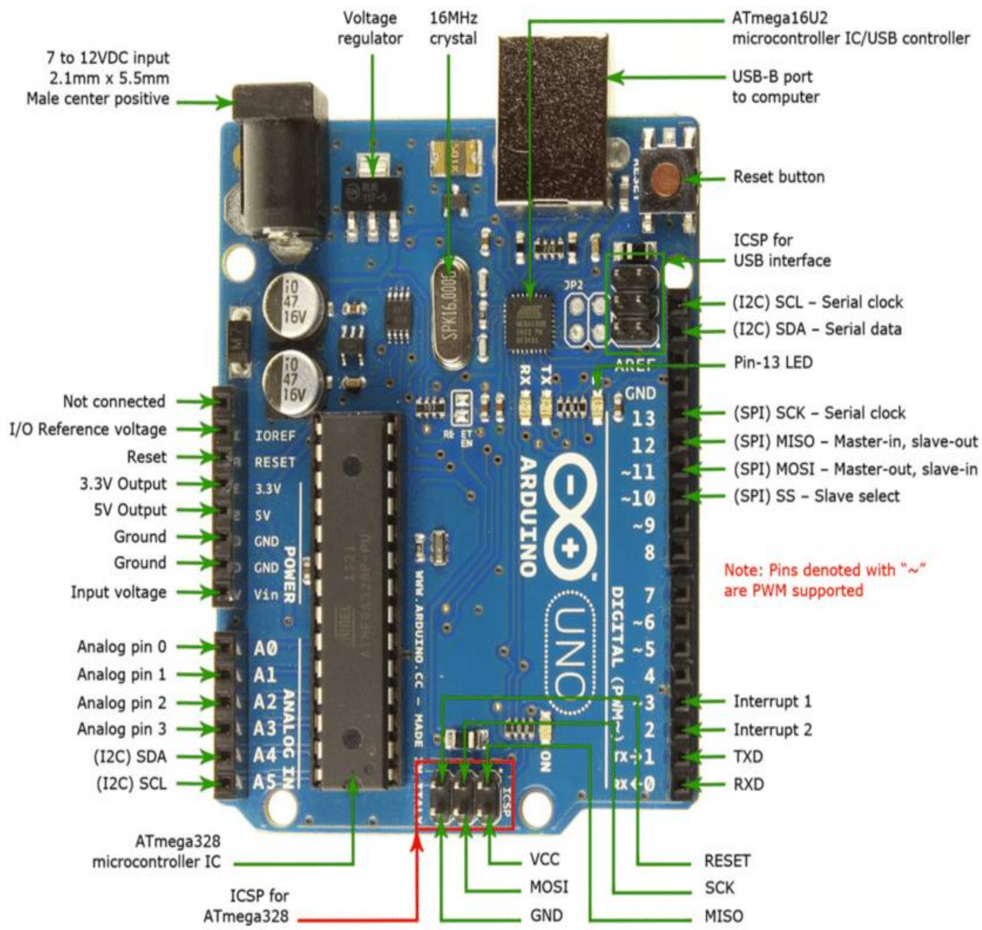


Figure 4.8: Arduino Uno

4.1.1.2.2. Communication

4.1.1.2. 2.1. SIM800L modem

A SIM800L modem is used to enable the system installed in the bus to communicate with the end-user, which is the public transportation operator. This allows data from the sensing module to be delivered to a distant database while still being accessible to the enterprise for monitoring.

GSM refers to a wireless modem that connects to a GSM network. The dial-up modem uses radio waves to transfer and receive data. A GSM modem requires a SIM card from a cellular carrier to function [37]. The SIM800L module is used in this project to remotely update the changes inside the buses.

A buck converter may be used in real-world implementation to step down from 12V to 5V for all system components since it requires 5V power.

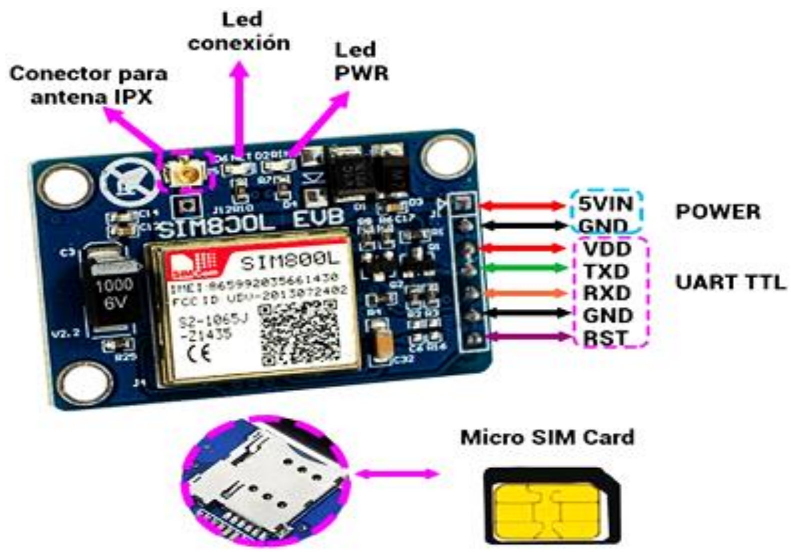


Figure 4.9: SIM800 GSM/GPRS modem

When the SIM has been fully registered to a network, Every two to three seconds, the onboard LED indicator will blink. The SIM800L is still seeking for a network to connect to if the LED indicator blinks every second. [38] If the LED indicator does not flash, double-check the power supply to ensure it can give enough current and the correct output voltage. A voltage of 3.4 to 4.4 volts is required for the SIM800L module. If there isn't enough voltage, the module will send out under- and overvoltage alerts.

I utilized the IPEX antenna to collect the GPRS network for the prototype. This is depicted in Figure 4.11.

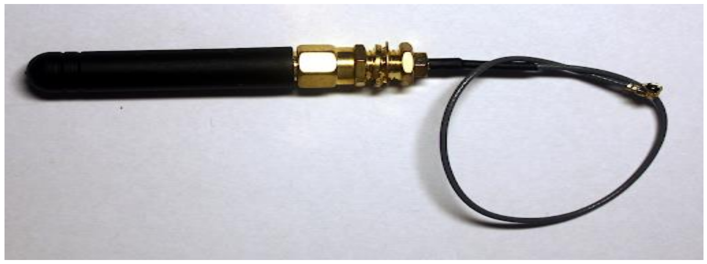


Figure 4.10: SIM800L circuit board antenna

4.1.1.2.2.2. Raspberry pi 3 model B

Because the cellular network coverage in the area where the prototype was developed was very poor, the Raspberry Pi 3 model B was used as the gateway in this prototype due to its ability to connect to wifi.It helps send data to the Node-RED dashboard and to the mongodb Atlas as a cloud database. However, when the system is implemented in a real bus, GSM will suffice.

In conjunction with Broadcom, the Raspberry Pi Foundation has developed a range of inexpensive single-board computers (SBCs) in the United Kingdom. [39] The Raspberry Pi project was launched with the intention of boosting basic computer science teaching in schools and underdeveloped nations.[40] [41] [42]

The most current model proved more popular than expected, [43] selling outside of its primary robotics industry. It is widely utilized in a number of sectors, including climate monitoring, because of its low cost, adaptability, and open architecture [44]. It is mostly used by computer and electronic professionals because of its support for HDMI and USB devices.

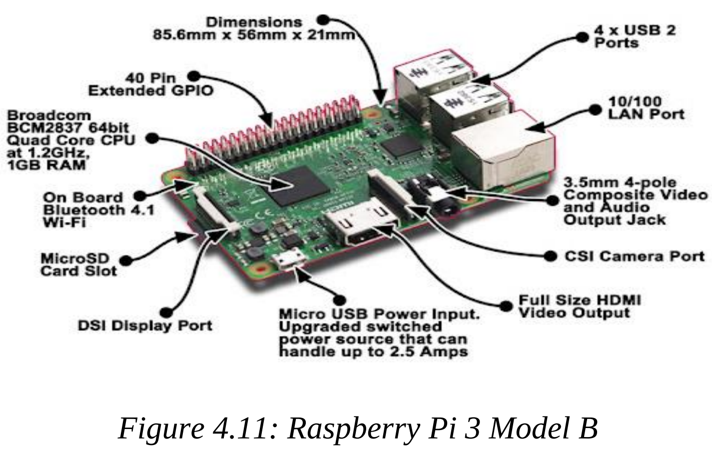


Figure 4.11: Raspberry Pi 3 Model B

The Raspberry Pi 3 Model B, with a 1.2 GHz 64-bit four core ARM Cortex-A53 CPU, on-board 802.11n Wi-Fi, Bluetooth, and USB boot capabilities, was introduced in February 2016. [45] The

Raspberry Pi 3 Model B+ was announced on Raspberry Pi Day 2018, with a faster 1.4 GHz processor, three-times faster gigabit Ethernet (throughput limited to around 300 Mbit/s by the inner USB 2.0 connection), and 2.4 / 5 GHz dual-band 802.11ac Wi-Fi (100 Mbit/s). [46] New features include USB boot, network boot (no longer requires an SD card), and Power over Ethernet (PoE) (with the add-on PoE HAT).

4.1.1.2.2.3. DS3231 RTC module

To transmit system reports to the authorized user at a specific moment, the system must work in real time. The DS3231RTC module will assist the system in operating in real-time. The DS3231 is an I2C real-time clock (RTC) featuring a temperature-compensated crystal oscillator (TCXO) and an extremely detailed crystal.

When the main power to the gadget is interrupted, the equipment has a battery input and keeps precise time. The use of a crystal resonator improves the equipment's long-term accuracy while simultaneously reducing the number of pieces in an assembly line.

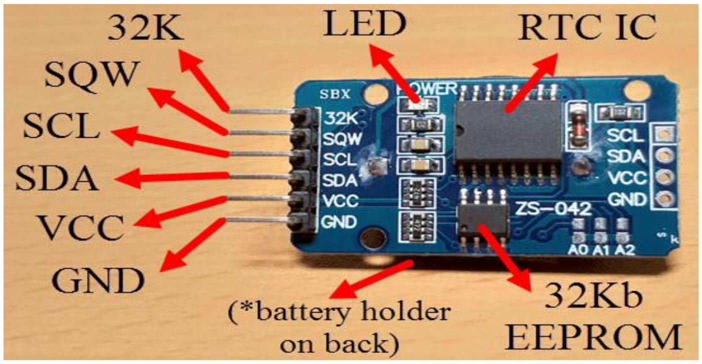


Figure 4.12: DS3231 RTC module

The Real Time Clock module keeps track of seconds, minutes, hours, days, dates, months, and years. The date at the end of the month is automatically altered for months with fewer than 31 days, including leap year adjustments.

The clock controls in either a 24-hour or 12-hour configuration with an AM/PM indication. Two programmable time-of-day alarms and a programmable square-wave result are featured. Addresses and data are serially transferred through an I2C bidirectional bus. This module is required for the system to operate at the vehicle layer in real time.

4.1.2. Cloud Layer

The remote database stores detailed information about each individual bus such as live number of passengers in the bus, vehicle speed, distance traveled by the bus, distance traveled by passenger each seat, total distance traveled on all seats and total money made by the bus. The document in figure below includes the registered bus and the corresponding details. The system prototype has 4 seat sensors, hence registering 4 seats of the bus as it is visible from the figure below.

The database was hosted at MongoDB Cloud during development, a fully managed cloud database for modern applications. MongoDB is the most widely used NoSQL database. It is an open-source document-oriented database. The word 'NoSQL' refers for 'non-relational SQL,' which indicates it isn't based on relational databases' table-like structure and instead employs an altogether other data storing and retrieval approach.. This storage format is known as BSON (synonymous with JSON) [47] [48].

The data is stored in a collection that is named as the plate number of the bus and each document of the collection contains all information of the bus at a certain time, here the time interval between documents is five minutes. The database is accessed through mongodb Atlas as shown in the figure 4.14 below.

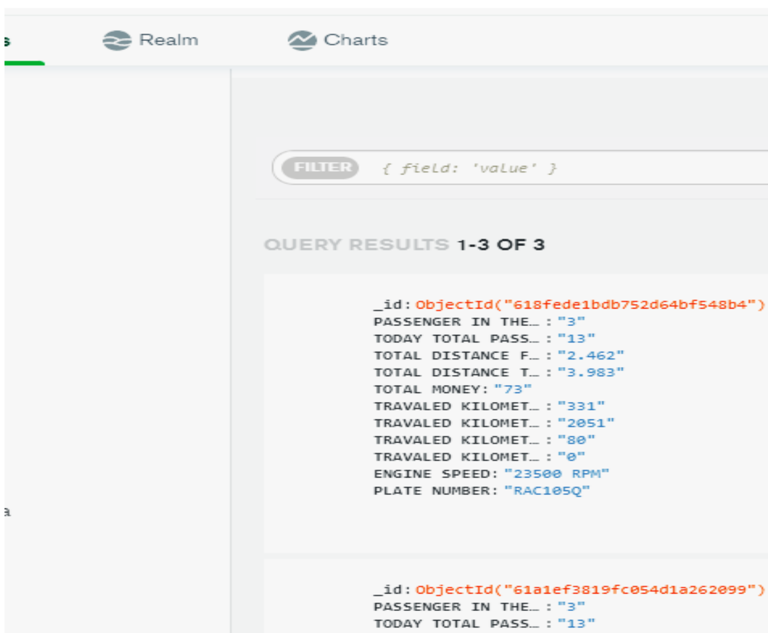


Figure 4.13: Bus database in mongodb Atlas

Future enhancements the technology will be able to send a notification to the company so that they can act as quickly as possible, reducing the need for supervisors to visit the drivers when it isn't essential.

4.1.3. Visualization Layer

4.1.3.1. Remote monitoring platform

This allows the company to access information about the bus's state remotely, such as the number of passengers on board, the status of the seats, and the expected revenue earned. The Node-RED platform is used to construct the visualization system. IBM is the creator of the platform. Node-RED is a free and open source logic engine that connects physical I/O, cloud-based systems, databases, and APIs using any level of programming. [49].

Data about the whole events occurring in the bus are stored in a database. Tracking the activities of buses helps to avoid misuse of public transport vehicles and future planning. Below figures 4.15 shows the user interface (UI) of the resulting monitoring dashboard

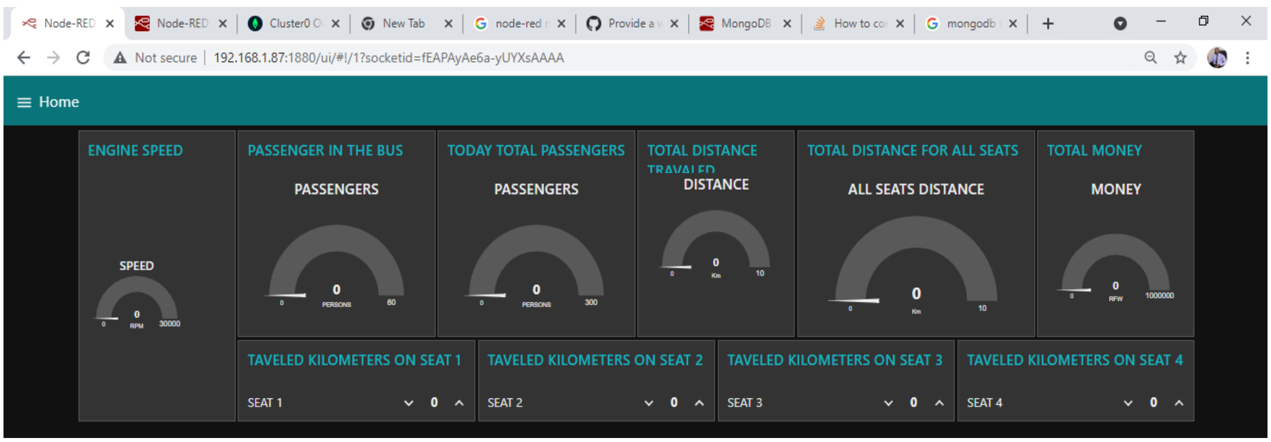


Figure 4.14: Dashboard from the node red Flow

The figure 4.16 below represent the Charts from the node red Flow

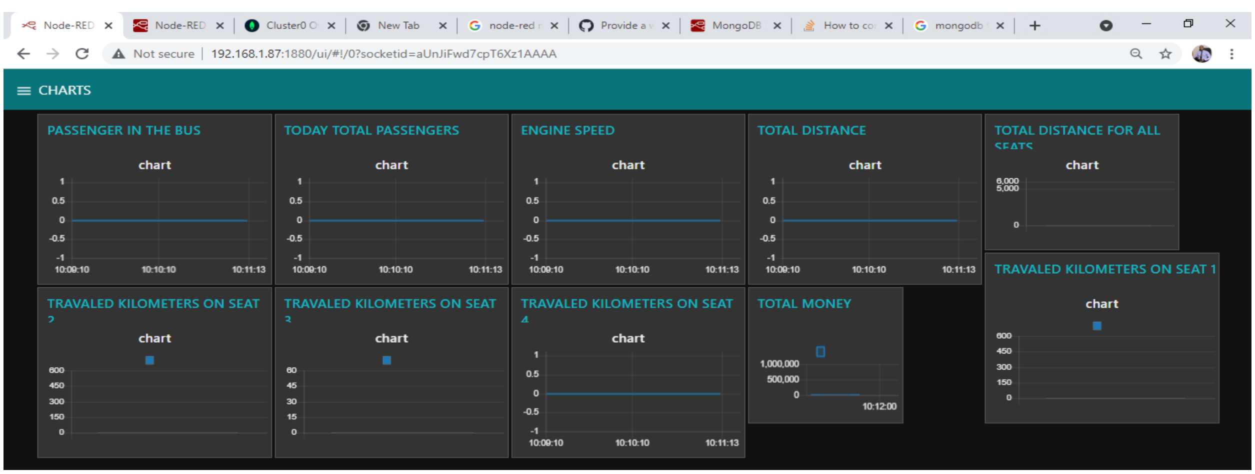


Figure 4.15: Charts from the node red Flow

4.2. Flow chart of the system

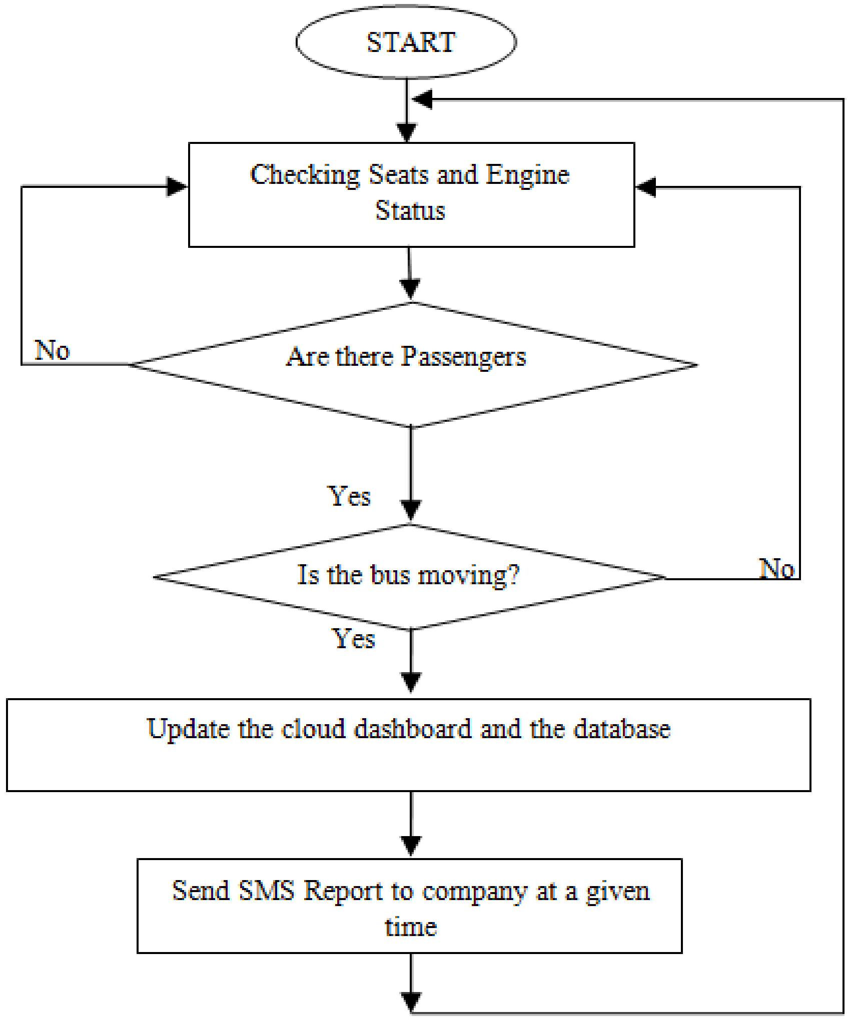


Figure 4.16: Flow chart for seats monitoring loop

This Flowchart of the system is showing how data flows in a system and how decisions are made to the control module.

4.3. Prototyping and Results Analysis

4.3.1 Simulation in Proteus

The virtual scenario was simulated in Proteus however it had some limitations such as simulating the engine speed with a Hall Effect sensor. From the list of needed components in this project, the only available simulation components in Proteus are GSM, Arduino board, DC Fans 120x120x25.4mm 12V (to model the vehicle wheel), Hall Effect sensor (to sense speed of the wheel to find the distance traveled by the vehicle) and push buttons (for Weight seat sensor for sensing passengers on seats). This did not produce satisfactory results, so I decided to do a prototype.

The project was simulated in Proteus software and Arduino IDE code. To simulate the project's components, the various libraries were downloaded and put to the proteus.

As shown in Figure 4.17, the system is designed and simulated in Proteus.

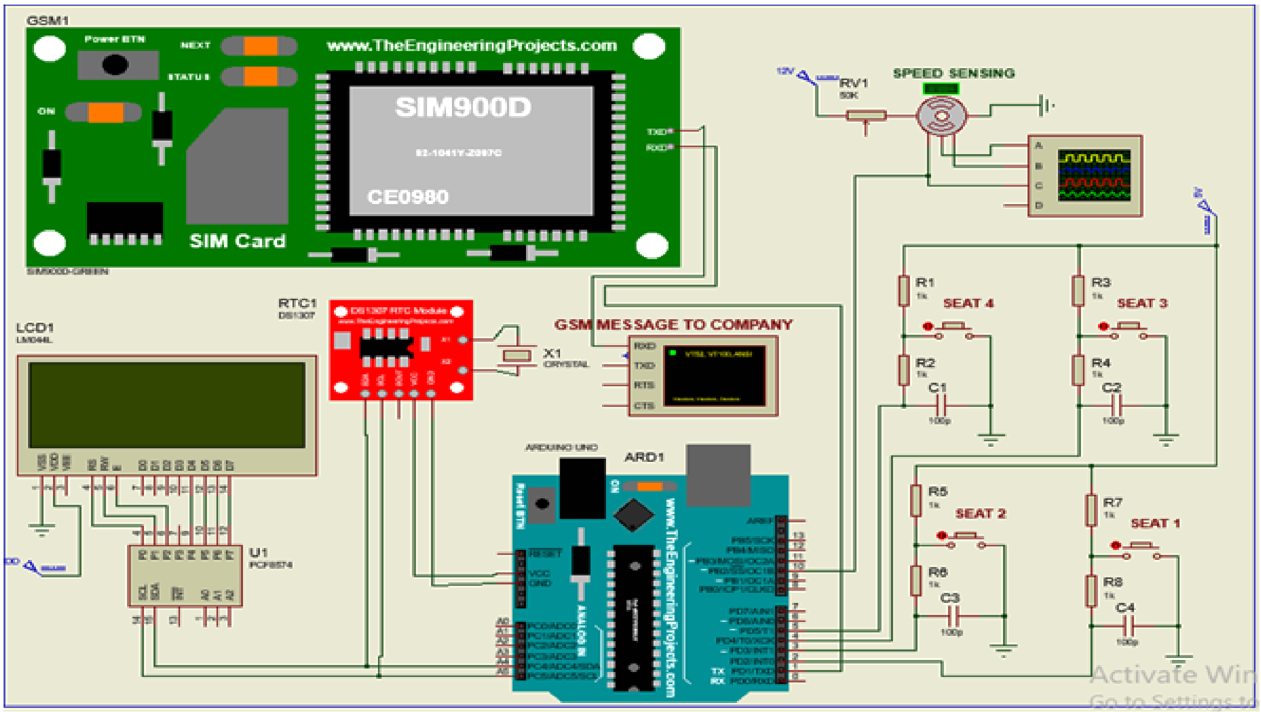


Figure 4.17: System Simulation

The code was written in Arduino IDE, Node-RED cloud platform with the database using mongodb Atlas. The system is to be installed in a public transport vehicle to monitor whole activities done during working hours. Also those activities will be recorded in a database and issued an SMS report after work every day. The company can take the necessary actions after receiving this information, as well as use the data for business insight and analysis.

Because some components, such as Engine speed, could not be replicated during simulation, a system prototype was done, as illustrated in figure 4.18 below.

4.3.2. Hardware Prototyping

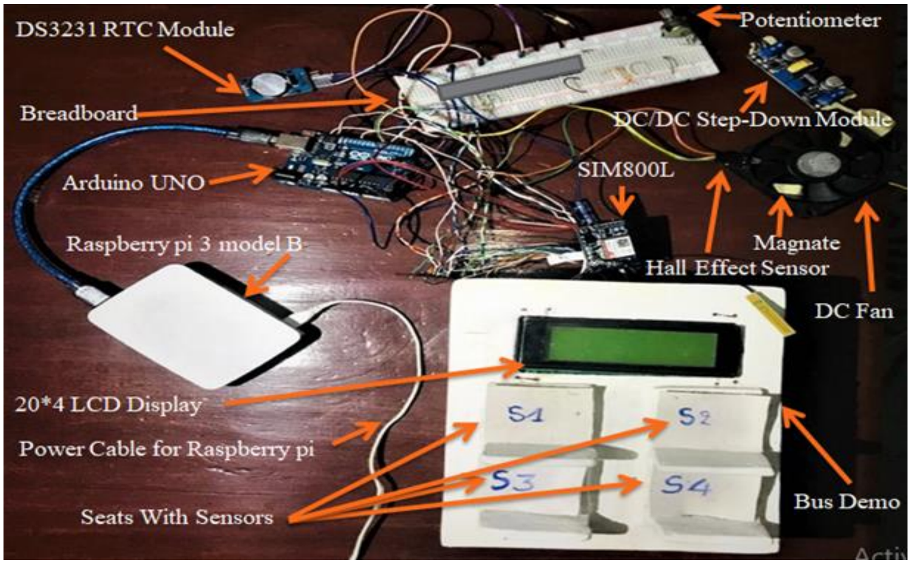


Figure 4.16: System Prototype

4.3.1. Seat Sensors

Seat Occupant weight Sensor for each seat detects whether a passenger is on the seat or not and the system decides whether or not to count the distance for the corresponding seat. If the sensor determines a weight on the seat is not a person, the system does not count the distance.

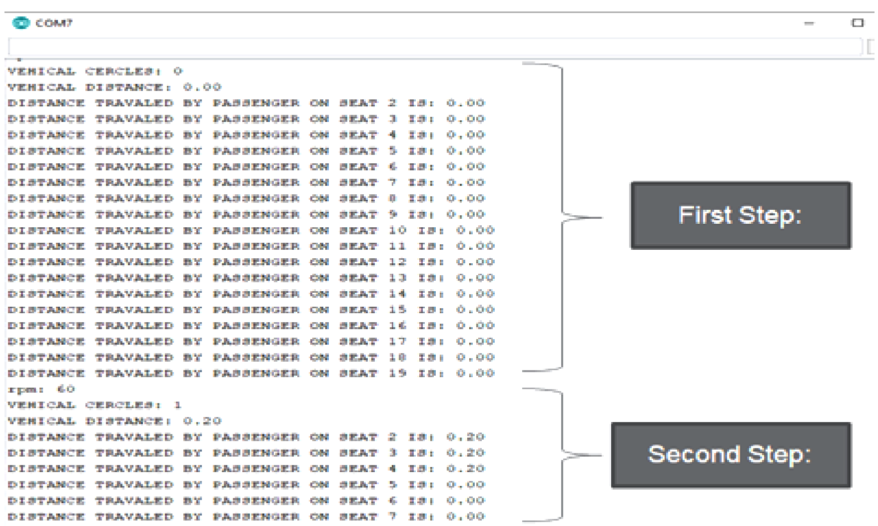


Figure 4.17: Serial Monitor reading for vehicle rpm, Vehicle Circles, vehicle distance and the distance traveled by passengers on each seat

- ***First step:*** Bus (fan) is not moving and there are no passengers in the bus.

- ❖ ***Second step:*** Bus starts moving (0.20 kilometers) and there are 3 passengers in the bus (on seat 2, 3 and seat4).

4.3.2. Hall Effect Sensor (Speed & Distance sensing)

In a Hall-effect sensor, a current is sent through a thin piece of metal. In the presence of a magnetic field, electrons in the bit of metal are deflected toward one end, resulting in a generating voltage across the short side of the strip (perpendicular to the feed current).

In internal combustion engines, hall sensors are frequently used to measure the velocity of wheels and shafts for engine speed, tachometers, and anti-lock braking systems.

Vehicle Speed and Distance sensing is made by 12V DC fan with magnet attached to its rotating part, the Hall Effect sensor attached to its static part and potentiometer for speed control. This helps to get the distance traveled with the fan (vehicle) when the rotating part of the fan is rotating and the side with attached magnet passes around where hall effect sensor is attached the system count one turn which is equal to 20cm (circumference of the rotating part of the fan) as it is shown in above figure 18, where vehicle circles is one and vehicle distance shows 0.20 meters.

4.3.3. SIM800L module

This is programmed to send an SMS report at a given time one a day, including the needed information like total money made by the bus during working hours the real time clock is maintained with DS3231 RTC module. The SIM800L includes an antenna to improve connectivity, and it uses an MTN SIM card because of its high coverage. For reception and transmission, it is connected to two Arduino pins. It establishes a GPRS connection whenever transmission is required and shuts the connection when transmission is not required to save electricity. For different connectivity statuses, the GSM LED lights up in different patterns.

4.3.4. Results Analysis

When passengers sit on seats in the bus with the system and the bus is moving, all information of the vehicle can be accessed from the dashboard including the speed of the bus, live passengers in the bus, Total passengers for today's trips, Travel Distance of the bus, Traveled distance for each seat, Total distance traveled for all seats and Total money made by bus, when one of the passengers leaves the bus, Both live passengers number decreases and the seat where he/she was sitting stops counting the distance automatically. As indicated in the dashboards below. And all this information are sent to a remote database for business insight for future plan

The system generates information about public vehicle movements in terms of traveled distance, carried passengers and money made by the vehicle. As illustrated in figure 4.20.

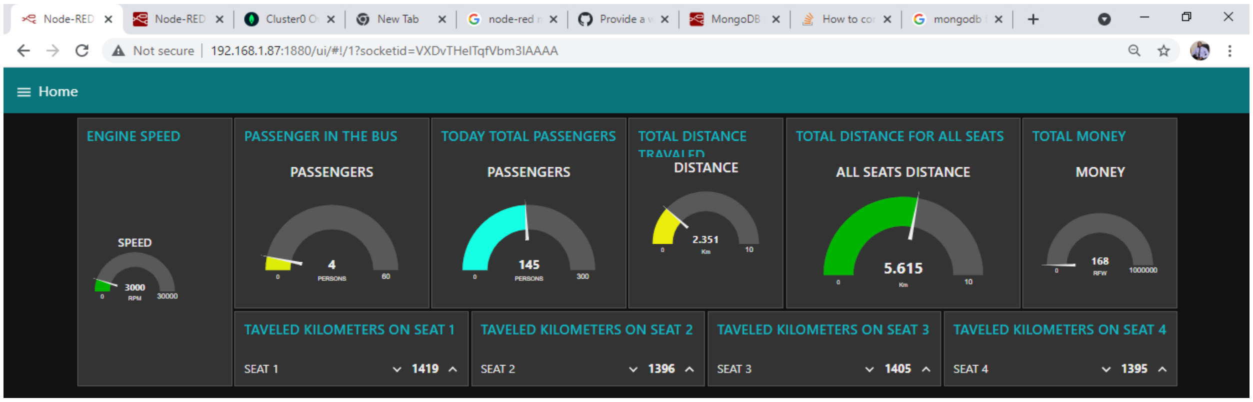


Figure 4.18: Bus monitoring dashboard

As seen in the illustration below, this data may be used to categorize the error rate of illegal activities committed by public transit staff, gain business insight for future improvement, and make it easier for both the Rwanda Utilities Regulatory Authority (RURA) and the Rwanda Revenue Authority to know the exact taxes from public transportation companies. The chart below gives visual representations for all of the vehicle's operations, which correlate to real-time readings detected by the system.

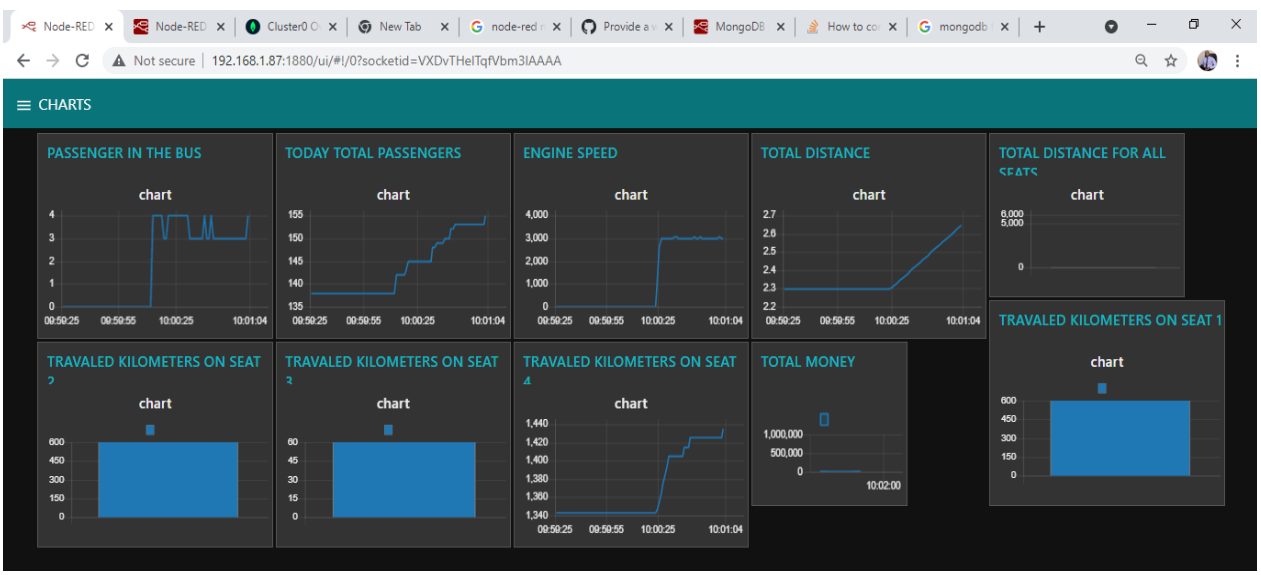


Figure 4.19: Bus monitoring charts dashboard

The dashboard and database are both updated in real time when a change is noticed. The company uses this to make business decisions based on client preferences. The company can use this information to determine which locations have a large number of passengers and make decisions based on that information.

When employing seat sensors, the system gets confused between bags and humans in seats. The precision of the readings is hampered as a result of this. It is unable to detect only passengers. These issues can be overcome in the prototype by employing weight seat sensors to set the reference weight so that the system does not confuse the bags with passengers.

4.4. Summary

This section describes the proposed solution's design, including system architecture and different layers of the system, ranging from the vehicle layer to the cloud layer to the visualization layer. It also lists appropriate devices to use in each layer, along with their working principles and functions within the system.

5. FUTURE WORKS AND PERSPECTIVES

From this research project, a set of future works and perspectives has been analyzed. These are summarized below:

1. Include vehicle mechanical condition monitoring in order to ensure timely vehicle maintenance. To avoid accidents due to mechanical issues with the car, such as a faulty brake or something else.
2. Create a smartphone application for passengers to be able to know available free seats and their exact location in the approaching bus for their preferences when they are at the bus stop for time management, for example people with disabilities have their specific preferable seats even people in general to feel comfortable for a long journey.
3. Enable remotely controlling the vehicle by switching it on and off when mechanical conditions are not good to prevent accidents because vehicle conditions are not monitored.
4. Leverage artificial intelligence. This is one of its limitations. Due to the fact that there is not enough data, this can be improved to have a more efficient system by referring to the stored data and providing some urgent decisions and notifications. For the system to be very smart.

6. CONCLUSION

The public transport business in Rwanda has been encountering an operational challenge of unfair public transport drivers who onboard passengers after leaving the departure station and before arriving at the destination station and never report the income of those passengers. Different solutions have been proposed in the past to overcome this problem but failed.

By leveraging IoT,Our research designs and prototypes a real-time monitoring of seat occupancy in public transport vehicles. With the proposed system, the Passengers, the distance made, and the total money made by the bus is recognized using the weight seat sensors and the Hall Effect sensor with the help of the microcontroller. The system delivers real-time information both when the bus is driving and when it is not, making it simple for the public transportation provider to keep track of the vehicles. The solution allows for remote monitoring of the buses, lowering supervision expenses and collecting data for business information. This project presents an interesting application of seat weight sensor and Hall Effect sensor in comparison to the existing literature, which primarily focuses on smart transportation. This allows transportation businesses to keep an eye on their vehicles from far.

This system has been shown to be more effective in terms of monitoring than previous systems by giving complete information about how public buses operate to public transportation companies. This also enables the data to be used to develop business insights.

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