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DESIGN AND DEVELOPMENT OF RADIO FREQUENCY IDENTIFICATION (RFID) CAR PARKING MANAGEMENT SYSTEM

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ABSTRACT

The rapid growth of urban populations and vehicular density in developing cities has intensified the demand for efficient parking management systems. This study presents the design and development of a Radio Frequency Identification (RFID)-based car parking management system aimed at making parking more efficient, access more controlled, and traffic better regulated. The system was developed using an Arduino-based microcontroller integrated with RFID reader modules for vehicle identification, infrared sensors for vehicle presence detection, a servo motor for automated barrier control, and a liquid crystal display interface for user feedback. Hardware prototyping was carried out on a scaled testbed, while system logic and control algorithms were implemented and programmed using the Arduino Integrated Development Environment (IDE) in C/C++. The prototype was evaluated under varying traffic scenarios by measuring identification accuracy, response time, and reliability of real-time parking space monitoring. Experimental results from the prototype demonstrate reliable performance in vehicle identification, real-time parking space monitoring, and automated barrier control. The system effectively reduces human intervention, mitigates congestion during peak periods, and improves overall parking space utilization. Furthermore, it enhances security through user authentication and data logging capabilities. The proposed solution is cost-effective, scalable, and suitable for deployment in urban and semi-urban environments, contributing to the advancement of intelligent transportation and smart city infrastructure.

1. INTRODUCTION

Global increase in industrialization and the steady growth in the number of vehicles on roads and high ways has contributed significantly to the rising demand for parking space (Cohen, 2023). Poor urban planning is another reason that this problem has become more serious (Chen et al., 2024). Difficulty in finding parking has a myriad of effects, such as reducing work hours and economic productivity, increasing cost, and hindering social interactions (Flack et al., 2022). Recent statistics reveal that in modern urbanization, especially in highly populated cities like Lagos and its suburbs with an estimated population of 13.4 million (Auwalu and Bello, 2023), about 23% of commuters use public transport systems while the remaining 77% utilize private vehicles to commute. Heavy vehicular traffic has made it imperative to established transport management systems such as Lagos State Transport Management Authority (LASTM) among others.

Various technology applications have been developed to indirectly assist daily tasks and thereby improve efficiency and productivity in dealing with traffic and parking challenges (Elgazzar, et al., 2022). Although many technologies incorporate wireless capabilities, Radio Frequency Identification (RFID) serves as a

specific example: it is a communication technology that uses radio waves to identify individual items (Phillips et al., 2007). In the last few decades, RFID technology has been a growing development for different industries all over the world. Common applications of RFID are in the areas of inventory management, tracking a products throughout its manufacturing processes, access and control of parking facilities, containers or pallets monitoring, authentication of identity tags/badges, tracking hospital equipment and managing personnel (Shimi et al., 2022).

A typical RFID system consists of three significant components; tags, readers and database (Weis, 2007). Passive RFID tags are common and affordable. However, its low frequency is limited to a communication range of 3 meters and the data storage capacity is only 128b. Parking systems based on RFID technology require high frequencies, which apart from providing more data transfer rates, can cover larger distances (Hou et al., 2026). In practical working principle RFID reader creates a low-frequency electromagnetic field around it, which activates the tag. Upon activation, the tag emits a unique identification code through radio frequencies. The reader sends the decoded data to an interface layer that transmits it to the application system. The application system then authenticates the identity code by comparing it with entries in the host database. Access or rights may be granted or denied based on this (Mohamed et al., 2025).

Apart from car parking, RFID is also being used in toll collection system, transportation payment and conventional systems for logistics management. The potential of RF communication has been sufficiently established from literature, enabling further development in the field. By leveraging its capabilities and inherent properties, RF communication can support the development of innovative systems that ensure security, enhance performance, improve convenience and promote environmental sustainability (Olaleye et al.,2024).

According to a recent survey, the global number of cars is predicted to exceed 1.6 billion units by 2035, aggravating parking issues (Cardi, 2025). The manual operation and action of drivers based on human judgment is still one of the most common causes leading to road congestion and vehicle collision. Several vehicle technologies have been developed for parking monitoring, anti-collision warning and navigation toward parking facilities (Li et al., 2022; Park et al., 2017). The primary objectives of such systems are to relieve driver predicament, increase traffic flow capacity, and enable safe and reliable operation of vehicles (Hosseinian, 2024).

Automatic Vehicle Management (AVM) systems and other systems have been proposed in previous studies. AVMs, utilizes ultrasonic sensors to identify availability of parking spaces in automated parking systems. The AVM gives a near 360^{O} view getting to areas that are not easily visible to drivers and helps identify objects near the vehicle. AVM detects markings of slots through a method based on tree

structure and various image registration methods. (Li et al., 2022).

Kamble and Dehankar (2019), created a Parking Indicator System using Global System for Mobile (GSM). The system indicates the availability of a free space and the intended user must send time and duration required for parking. The modem then gives a password and parking slot number to the user that can be used for access. From then on, the reservation counter starts ticking down by itself.

In another study, Kamra and Dagar (2022) developed a system that detects an object (in this case, the vehicle) through an infrared (IR) subsystem and requires the driver to provide a valid key and select either parking or picking up. Every key is verified and associated with a particular parking space. After the details are entered correctly, a robotic device lifts the car and its pallet to store them in their assigned location. On retrieval, it cross references the key with the database and returns the car back to the driveway. Using a stacking system, each pallet is repositioned to make way for new stock.

Oguta (2023) described a system, in the paper Automated Car Parking, controlled by microcontroller (89S51), providing individual ID for each user along with the allocated trolley. The ingenious design allowed for a car to be parked or retrieved without moving other parked cars. Patel et al. (2015) in their article Rotary Automated Car Parking System based on RFID, proposed a solution where, based on the RFID tags obtained by vehicle owners when they are registered for an automated parking card, they would be able to park at locations equipped with RFID readers. On the gate, scanning a tag upon entry deducts payment automatically and lifts the barrier while updating parking count. When exiting the gate opens again and the count reduces as well.

Feng and Yi (2017) described a Mechanical Parking Garage which utilized a rotary mechanism that ensures cars move in circular motion. This rotation allowed vehicle loading and unloading, making it fit for 8 to 12 cars. The system proved simple to operate, but required rotating each and every vehicle just to access a single one, incurred high installation and maintenance costs, and was complex in design. Shimi et al. (2022), designed an intelligent system by implementation of RFID sensors to identify the car or obstacles in reserved areas. Occupancy was then communicated to drivers. However a main drawback was that it can only detect nearby cars as the system did not have GPS capability to find parking lots far away.

Zayed et al. (2022) proposed a system in which preregistered IP camera(s) read the vehicle registration numbers and provided access. The system logged information like approximate parking time and user destination. For preregistered individuals, parking fees were deducted from their e-wallets, followed by a confirmation notification of the transaction. New users had a similar pricing scheme but paid offline. The key limitation of this system

was that it cannot handle more than 80 vehicles.

Alsheikh et al. (2022) proposed an open parking lot system based on smart sensors, vision system, neural network and multi agents systems on open parking lots. The method was seen as inexpensive and adaptable to shifting climate circumstances. However, helping drivers select available spaces was still a challenge because open lots are not bookable.

Alam et al. (2023) focused on parking management using Wireless Sensor Networks (WSNs). Wireless sensor networks (WSNs) have become a prominent area of interest in both academia and industry due to their inherent flexibility that allows monitoring and collecting data from varied environments. Low-cost sensors were built into every parking space in their design to observe the occupancy. Collected data are transmitted in a periodic manner using the WSN gateway to a storage central database. The management system had access to this database allowing it to perform multiple functions such as identification of vacant spaces, automated collection of tolls, security monitoring and statistical report generation.

The study aims to develop a cost effective RFID-based car parking management system using a microcontroller platform for automated operation. The system combines RFID- based access control, real time parking space detection and automated gate control. The system is intended to enhance parking efficiency, improve security, and support traffic management by reducing human intervention, minimizing congestion, and restricting access to authorized users.

2. MATERIALS AND METHODS

An IoT-based RFID car management system was developed using Arduino. The systems's Code was implemented and executed on the Arduino platform. Key components such as sensors, motors and display units are interfaced with the Arduino UNO microcontroller. The hardware and software components of the system are described as follows:

2.1 Software Component Arduino IDE

The Arduino Integrated Development Environment (IDE) works on Windows, macOS, and Linux. Built using C and C++, it has a text editor for code, a message area and a console window for text output as its interface. Arduino IDE is an open source software application that provides comprehensive facilities to computer programmers for software development. Various programming languages, especially without discriminating on syntax, use IDEs to develop their applications, drivers or utilities. Arduino IDE also recognizes and flags errors such as syntax issues or memory warnings to help debug codes and write in a more secure manner.

2.2 Hardware Components

The following hardware components were utilized in the development of the car parking system

2.2.1 Arduino

Arduino (Figure 1) is a prototyping microcontroller board. It features 14 digital I/O pins and 6 analog inputs, allowing for flexible hardware interfacing. The board is connected to a computer via USB for power and programming using the easy-to-use Arduino IDE compiler.

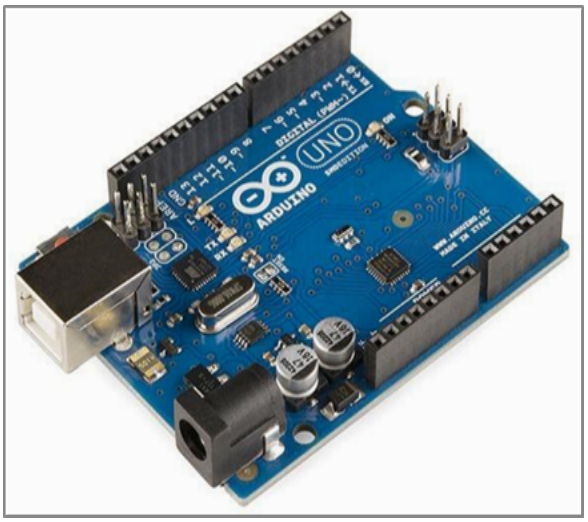

Figure 1: Arduino Development Board (Cameron *et al.,* 2019)

2.2.2 Breadboard and jumper wire

For the assembly of the circuit, breadboard and jumper wires were utilized (Figures 2 and 3). By using the breadboard, component and modules were connected without soldering. Interconnections between the circuit elements were made using jumper wires. This was done by inserting each jumper wire into the breadboard slots and the header pins of the modules or controllers.

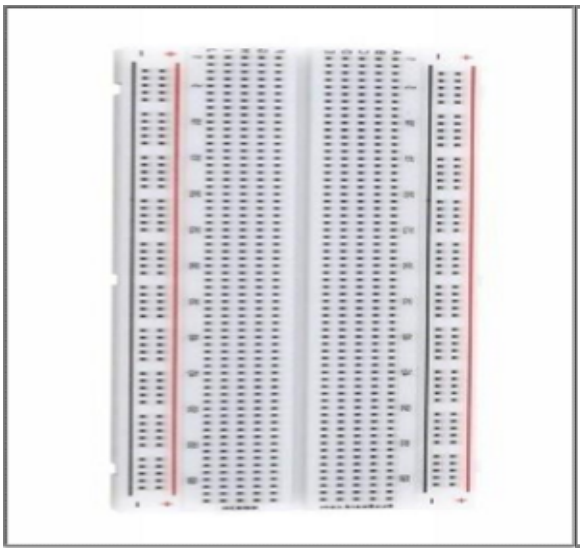

Figure 2: Bread Board (Fox, 2023).

Figure 3: Jumper wire (Fox, 2023).

2.2.3 12v Lithium Battery

Lithium-ion batteries were used to power the Arduino and other system components (Figure 4). They served as a reliable source of energy, ensuring continuous operation without interruption. The system was powered by a 12 V Lithium Battery.

Figure 4: 12v Lithium Battery (Zayed *et al.,* 2022)

2.2.4 Buzzer

A buzzer (Figure 5) generates sound from an electrical signal. Powered by a DC voltage source, it is utilized in devices like timers, alarms, printers, and computers. The device consists of two terminals, positive and negative. The positive pin is usually indicated by a '+' symbol or represented by the longer lead.

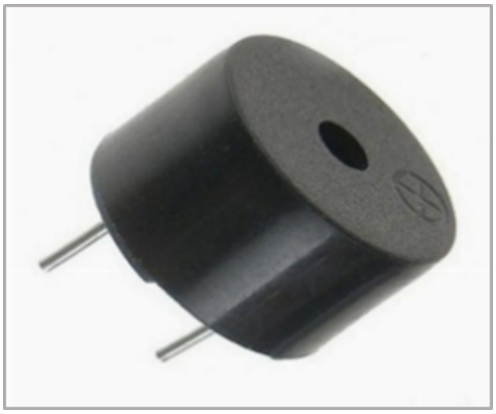

Figure 5: Buzzer (Cameron *et al.,* 2019)

2.2.5 Servo Motor

A servo motor (Figure 6) enables precise angular motion via a closed-loop control system. A servo motor works through Pulse Width Modulation, which means that the width of a control pulse determines angle the shaft would be. In order to do this, a servo consists of a motor, gear system and potentiometer. The potentiometer return position is continuously monitored by the internal control circle and this information received is used to adjust the movement of motor accordingly for stabilization and accuracy. The servomotor is used in the developed system to open and close the access gate to the parking slots.

2.2.6 IR Sensor

Infrared (IR) sensor detects how much heat an object releases. IR sensors are receivers that passively sense infrared radiation. A typical IR transceiver consists of a transmitter (LED) and receiver (photodiode). Characteristics like resistance and voltage of the photodiode varies according to the terms of received radiations when exposed to the IR light. The IR sensor (Figure 7) helps to detect if a parking space is empty or occupied.

Figure 6: Servo Motor (Kamra and Dagar 2022)

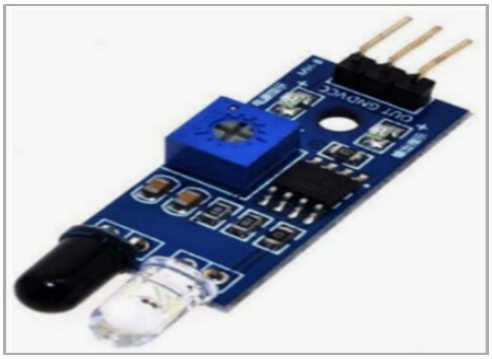

Figure 7**:** IR Proximity Sensor (Kamra and Dagar 2022)

2.2.7 Liquid Crystal Display (LCD)

The dot-matrix 16x2 LCD module (Figure 8) is used to display alphanumeric data and symbols. Its capacity is 32 characters arranged in two rows of 16 characters each. Each character is drawn from a 5x8 pixel character matrix, which provides a library of 224 pre-defined characters. The LCD provides information such as user information and available slots

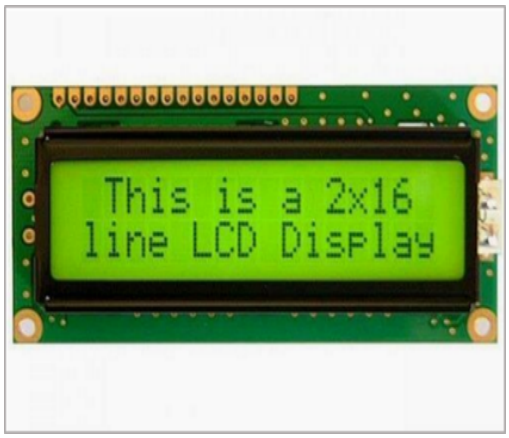

Figure 8**:** Liquid crystal display (Zayed *et al.,* 2022)

2.2.8 Radio Frequency Identification (RFID)

The Radio Frequency Identification system consists of a tag, a reader that acts as both transmitter and receiver, and an antenna. The reader triggers a tag and the tag sends information from its memory (for instance, an ID number) that can be utilized for inventory. The RFID tags (Figure 9) is passive (with no internal power) and powered from the reader.

Figure 9: RFID Module (Shimi *et al.,* 2022)

2.2.9 I2C Module

I2C bus (Figure 10) is a relatively easy and economical communication protocol that is used frequently in electronics. This allows a microcontroller to connect up to as many devices, including sensors, real-time clocks, DACs, ADCs and LCD displays with only two general-purpose I/O pins. In PC hardware, it is used in SPD EEPROMs on memory modules and EDID for monitors. The 12C Module was used to link the LCD to the Microcontroller.

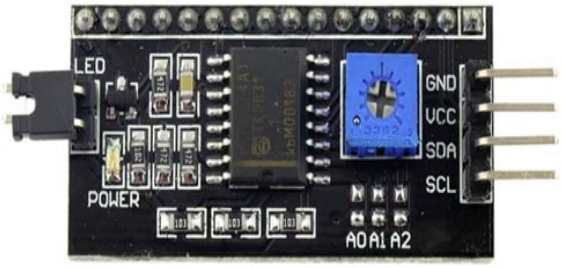

Figure 10: I2C Module (Zayed *et al.,* 2022).

2.3 System Implementation

Within the parking system, new users are registered and their info is written to an RFID tag that is then operated and accessed via the platform. The proposed approach consists of three non sequential steps: input, processing, and output to achieve its fundamental purposes. Figure 11 below is the block diagram of the system.

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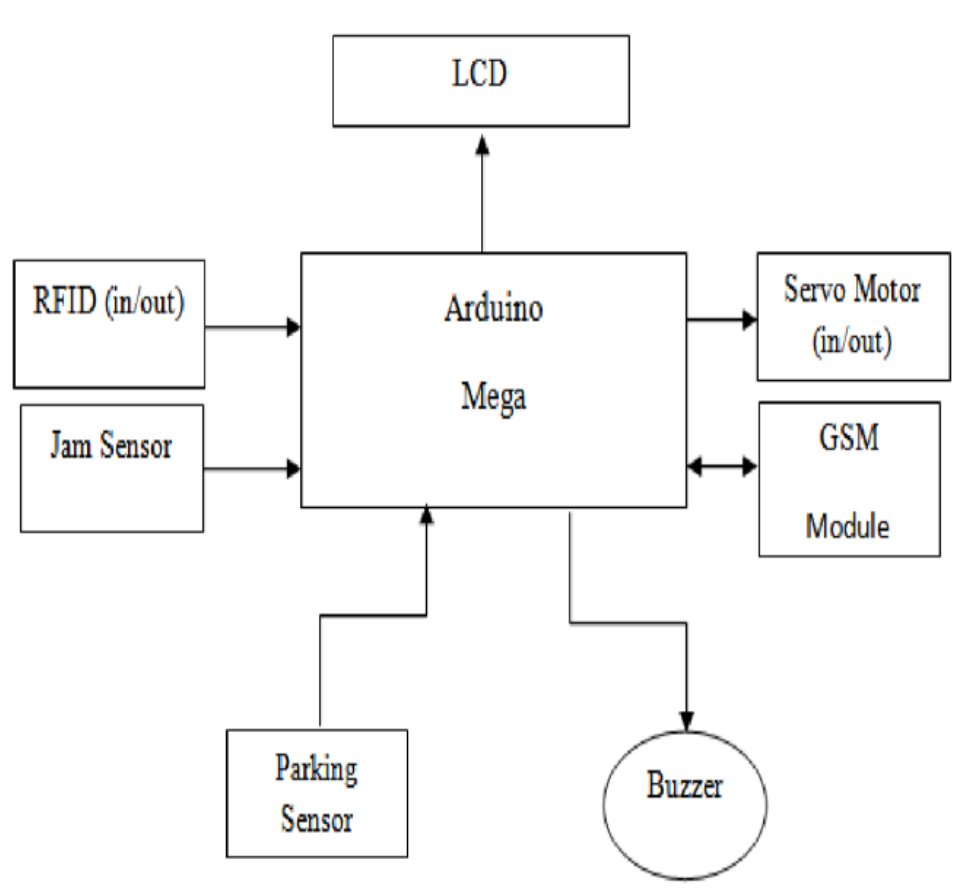

Figure 11: Block Diagram of the System

Unlike existing parking systems that often focuses on either access control, occupancy detection, or required complex and costly infrastructure, the developed system integrates RFID based authentication, real time parking space detection and automated gate control within a single low cost microcontroller platform. The system operates independently making it practically suitable for deployment in resource-constrained environments. The integration of multiple functionalities into a simple scalable and cost effective design represents a practical advancement towards accessible smart parking spaces.

2.3.1 Arduino Setup

Coding for the RFID car parking management system was carried out using the Arduino software. The Arduino software was downloaded from the official website and installed on the computer. The Arduino Uno board was then connected to the computer using a USB cable. After establishing the connection, the appropriate microcontroller was selected from the tools menu, followed by selection of the correct COM Port to enable communication. A microcontroller- based program was subsequently loaded onto the Arduino board to verify proper operation (Figure 12 a and Figure 12 b). Pins 13, 7 and 9 were used to interface components such as RFID sensors, buzzer, LED and servo motor. The complete circuit diagram of the connected components is presented in Figure 13.

2.4.2 RFID Setup

The RFID RC522 Module consists of two main components : the RFID reader and RFID card (tags). These tags are ingeniously designed to work at a frequency of 13.56 MHz, where electromagnetic waves are produced and captured by the RC522 reader. The operating voltage level for this module is 3.3 V DC and as it provides only 3.3 V output, the module is compatible with Arduino. The RFID tags or cards are assigned a unique identification number. Once tagged is scanned (within about 1.5 cm of the reader), and verification succeeds, the barrier opens.

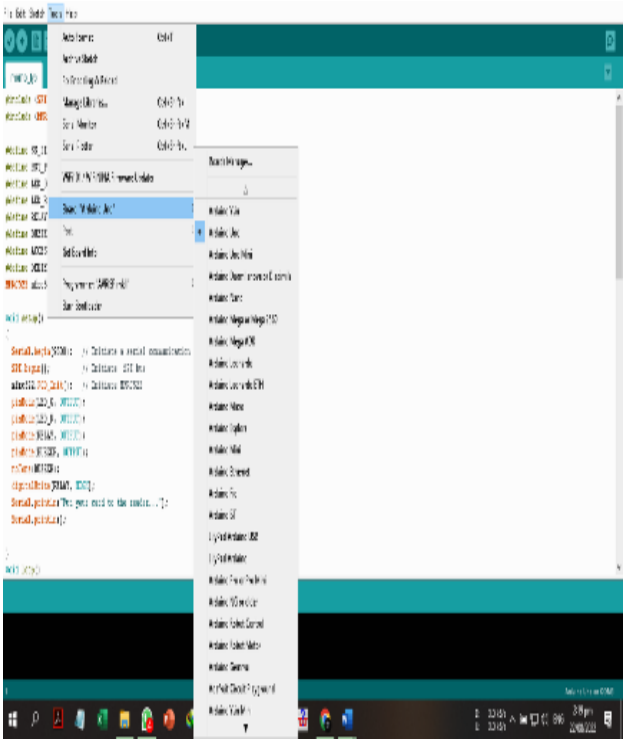

Figure 12: (a) Importing libraries for the project

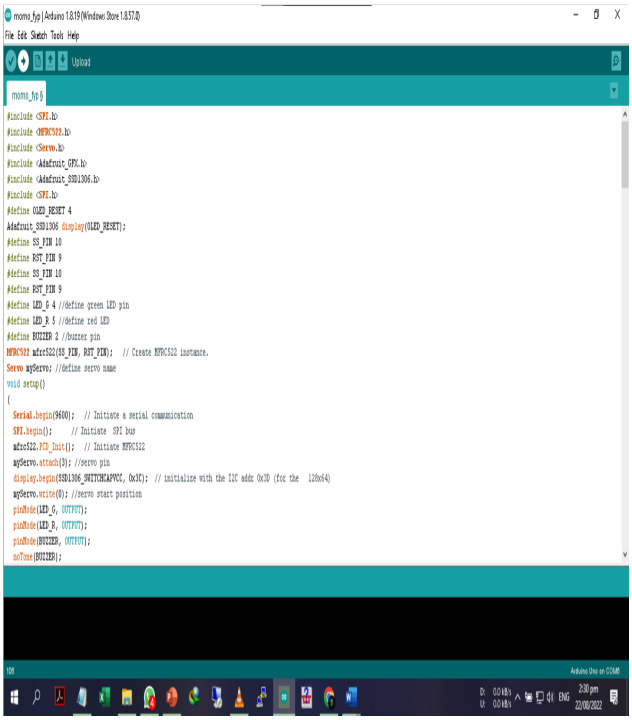

Figure 12: (b) uploading the code

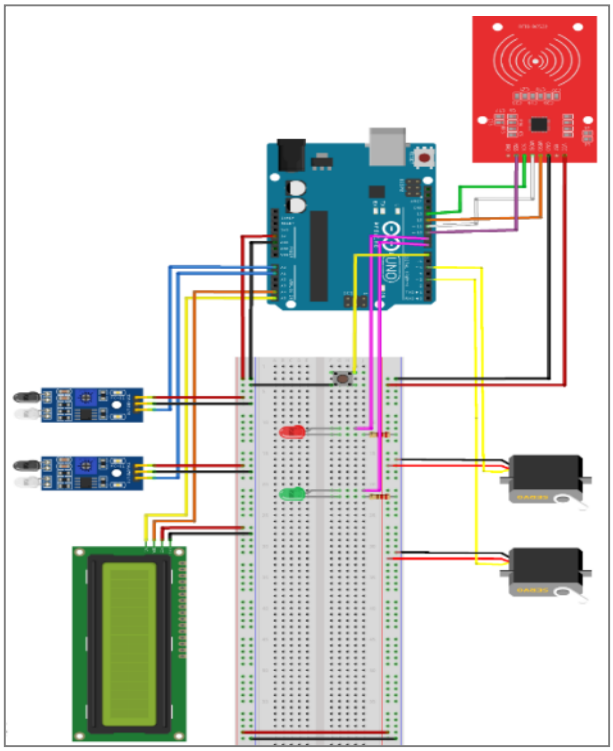

Figure 13: Diagrammatic Illustration of the Circuit Diagram

The system is powered by a 12 V lithium battery that runs the circuit and simultaneously executes specified coded instructions. Using jumper wires, the output and input pins are connected to the Arduino for receiving signals to control the servomotor. The IR proximity

sensor detects moving objects, and send signals to the microcontroller. Based on this, the microcontroller will ensure the servo motor keeps the gate either open or closed.

3. RESULTS AND DISCUSSION

The proof of concept for RFID-based car parking management system was simulated. Operations are depicted in Figures 14, 15 and 16. LED Status indicators are: Red (No Parking Space), Green (Parking Space Available). The buzzer makes a sound indicating that the barrier has opened when the servo motor lifts barricade to let a vehicle pass.

During operation, a vehicle drives down the entry trajectory until it confronts the closed barrier. The driver needs to authenticate using a valid RFID tag at this stage. After the RFID reader reads and verifies the tag, it saves the client's details in a database. If authenticated, the system sends a command to open the barricade allowing the vehicle access

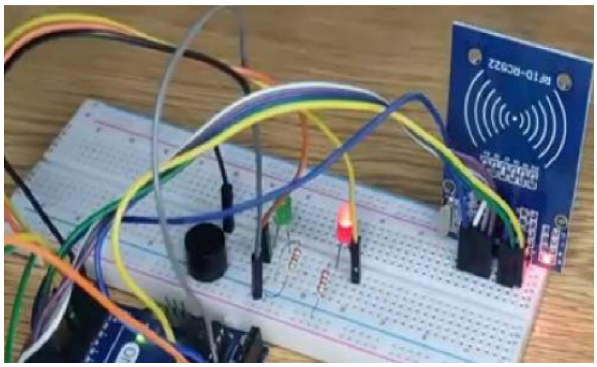

Figure 14: Testing the RFID reader before Opening Command Was Sent

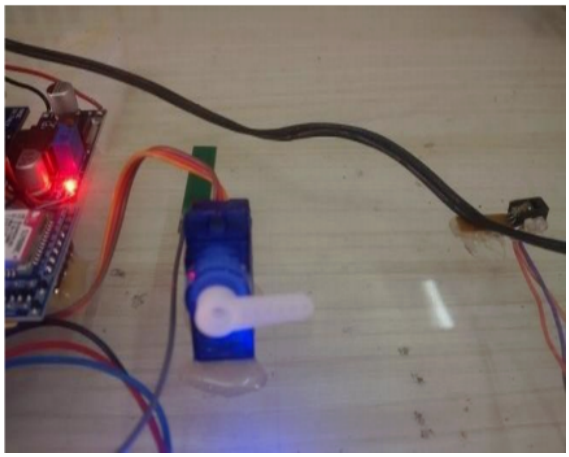

Figure 15: Plate Showing the Close Gate

Figure 16: Showing the Slots Availability Update

4. CONCLUSION

This study presented the development of an RFID based car parking management system aimed at improving parking efficiency, security and traffic control. The developed system successfully integrates RFID technology with a microcontroller platform to enable automated vehicle identification, access control and real time parking space monitoring. Experimental results demonstrate that the system effectively reduces human intervention, minimizes time and fuel wastage, and enhances convenience. The incorporation of RFID authentication improves security by restricting access to authorized users while maintaining a database of parking activities. The system is cost effective, scalable and suitable for deployment in urban and semi urban environments offering a particular solution towards the development of intelligent transport and smart parking structures.

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