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Development of an IoT Smart Parking System Lot

[1]Umar B., [2]Zainab M. A., [3]Shittu S. S.
[1]*Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.*
[2]*Department of Computer Engineering, Ahmadu Bello University, Zaria, Kaduna State Nigeria*

ABSTRACT
This paper presents the development and implementation of an Internet of Things (IoT)-based smart parking system designed to enhance efficiency, security, and real-time monitoring in parking lot management. The proposed system integrates Radio Frequency Identification (RFID) technology and Number Plate Recognition (NPR) to enable automated vehicle detection, identification, and access control. The system architecture leverages IoT communication for seamless data exchange and centralized monitoring. Experimental evaluation of the developed system demonstrates a high level of performance. The RFID subsystem exhibited 100% robustness under varying environmental conditions, ensuring reliable vehicle authentication. The NPR subsystem achieved an accuracy of 95%, with an average processing time of 13.60 seconds, while the RFID anti-pass-back mechanism recorded a faster response time of 5.47 seconds. Additionally, the system maintained a low detection error rate of 1.66% for heavy vehicles. Overall, the smart parking system attained an efficiency of 93.72%, indicating its effectiveness in real-world applications. The results confirm that the integration of IoT, RFID, and NPR technologies provides a robust and efficient solution for modern parking challenges. The proposed system reduces manual intervention, improves operational efficiency, and enhances security, making it suitable for deployment in smart cities and intelligent transportation systems.

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INTRODUCTION

The Internet of Things (IoT) is the concept of connecting any device (physical objects) to the Internet and to other connected devices, for the purpose of exchanging data. These devices range from ordinary household objects like home appliances, cars, etc. to more sophisticated industrial tools such as power grids, smart cities, etc. [1], [2]. The types of network connections can include Wi-Fi connections, near-field communication (NFC), Bluetooth connections [3], [4].

The number of cars on the roads has increased dramatically, and keeps rising yearly and creating a daily chaos for parking. These congestions cause lots of issues, wastage of time along with excess fuel consumption due to stoppage and waiting time, harmful effect on the environment due to emission of pollutant gases, etc. [5], [6] Additionally, the noise pollution cause by the vehicle horns is a problem too in some countries. In recent times, the number of systems using IOT are increasing as the information is brought directly to the fingertips. A multitude of devices are expected to be involved in IOT, which provide a rich source of information. Cloud computing is basically the usage of cloud storage area that combines devices and virtual environment to monitor and store data.

There are many parking related problems that remain unsolved. Firstly, the longtime taken to wait and search for parking spots, that result as an inconvenience to the drivers by delaying their set schedules[7], [8].

Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

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Next, traffic congestions caused inside parking areas due to heavy vehicles entering into parking lots and occupying wrong sized parking spots. Then, the lack of availability of intelligent reservations for parking spots and access of their information remotely to the drivers [9], [10]. Additionally, there is the huge manpower costs, effort, discomfort, potential quarrelling of drivers while searching for parking spots, etc.

Finally, the problem of security at the parking bays to prevent unregistered entry of vehicles, keeping customers safe along with remote monitoring of their parking bays for the owner to keep track of their vehicle [9], [11], [12]. The main objective for the developed article is to develop a system that comprises of a smart parking prototype showcasing the parking lots with the effective cloud records and system linkage via IoT technological features. Also, featuring a systematic procedure of booking, parking and monitoring vehicles remotely, in addition to enabling access of the parking lot to the permitted cars only.

The outline of the article is as follows; section one is the introduction, while section two shows the materials and methods used, while section three shows the results and discussion. Finally, section four gives the conclusion.

Materials

This section elaborates on the materials used for the successful completion of this article. It can be categorized into hardware based and software based.

Node MCU

This chip has been selected as the controller for this system due to its compact size, compatibility, easy interfacing over several other type of controller including Programmable Integrated Circuit (PIC), Programmable Logic Controller (PLC) and others [11], [12]. ESP8266 is an opensource firmware that is built on top of the chip manufacturer's proprietary SDK. The firmware provides a simple programming environment, which is a very simple and fast scripting language TheESP8266 chip incorporates on a standard circuit board. The board has a built-in USB port that is already wired up with the chip, a hardware reset button, Wi-Fi antenna, LED lights, and standard-sized General Purpose Input Output (GPIO) pins that can plug into a bread board. It has Processor called L106 32bitRISC microprocessor core based on the Tensilica Xtensa Diamond Standard 106Micro running at 80MHz and has a memory of 32 Kbit instruction RAM, 32 Kbit instruction cache RAM, 80 Kbit user data RAM and 16 Kbit ETS system data RAM. It has inbuilt Wi-Fi module of IEEE 802.11b/g/n Wi-Fi [13]. Figure 1 shows the diagram of NODEMCU (ESP8266) [14], [15].

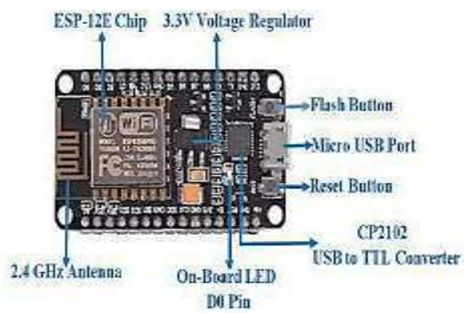

Figure 1: Node MCU [13], [16]

Infrared Obstacle Sensor

An Infrared (obstacle sensor) uses to detect the presence of the object or any other reflective surface in front. Its package has a Photodiode that uses to generate an IR signal and a Phototransistor which can be used to read the IR signal that is reflected[17]. The obstacle detected if the reading of the IR sensor is "0 [18]. This is shown in Figure 2.

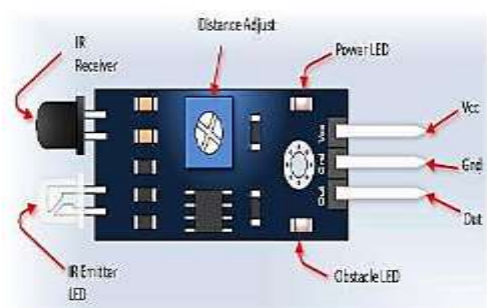

Figure 2. Infrared Obstacle Sensor [19], [20]

Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

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Power Supply

This is a regular 5v 2amp power supply, a phone charger would work well A power supply is an electrical device that supplies electric power to an electrical load [21], [22]. The primary function of a power supply is to convert electric current from a source to the correct voltage, current, and frequency to power the load. As a result, power supplies are sometimes referred to as electric power converters. Some power supplies are separate standalone pieces of equipment, while others are built into the load appliances that they power.

Examples of the latter include power supplies found in desktop computers and consumer electronics devices [23]. Other functions that power supplies may perform include limiting the current drawn by the load to safe levels, shutting off the current in the event of an electrical fault, power conditioning to prevent electronic noise or voltage surges on the input from reaching the load, power-factor correction, and storing energy so it can continue to power the load in the event of a temporary interruption in the source power (uninterruptible power supply) [24], [25]. This is shown in Figure 3.

Figure 3. Power Supply [25]

Arduino Uno

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals [26]. Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, etc. An Arduino Uno microcontroller board is shown in Figure 4.

Figure 4: Arduino Uno [27]

In Figure 4, an Arduino Uno microcontroller board which is based on the ATmega328P is shown. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-DC adapter or battery to get started [28].

Hardware Design and Implementation

The block diagram for the design is shown in Figure 5.

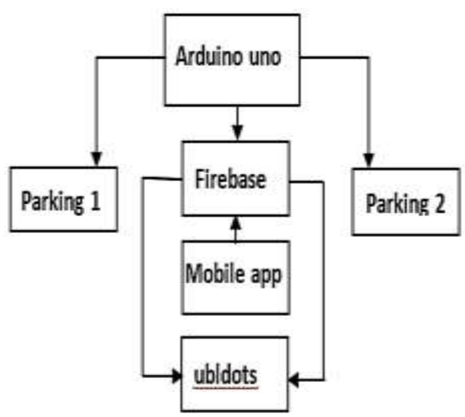

Figure 5. Block Diagram of the Circuit

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umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

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In Figure 5, the different components that were interfaced in the hardware design are shown. It consisted of the Arduino Uno board, ubldots, pulse rate parking zone, firebase, mobile app, NodeMCU ES8266, etc.

The components at Parking 1 (CP1) and Parking 2 (CP2) are two Arduino UNO, one each at the entry and exit of CP1 and CP2. Further, the added IR sensors in place of Ultrasonic sensors can also be seen. The Arduino UNO at the entrance controls the RFID tags and the servo motor to lift the gate if the scanned RFID tag is authorized. It also scans the vehicle length and displays messages on the different LCDs. The Arduino UNO at the exit has similar features but does not have the length sensor. The Arduino UNOs connects with RPi3 serially to exchange information with regards to the number plate authentication and RFID anti pass-back values.

The overall visual block diagram in Figure 3.1 represents the developed system being more integrated and connected to each other using serial and cloud connectivity. The more details workings of the system are elaborated in Figure 6.

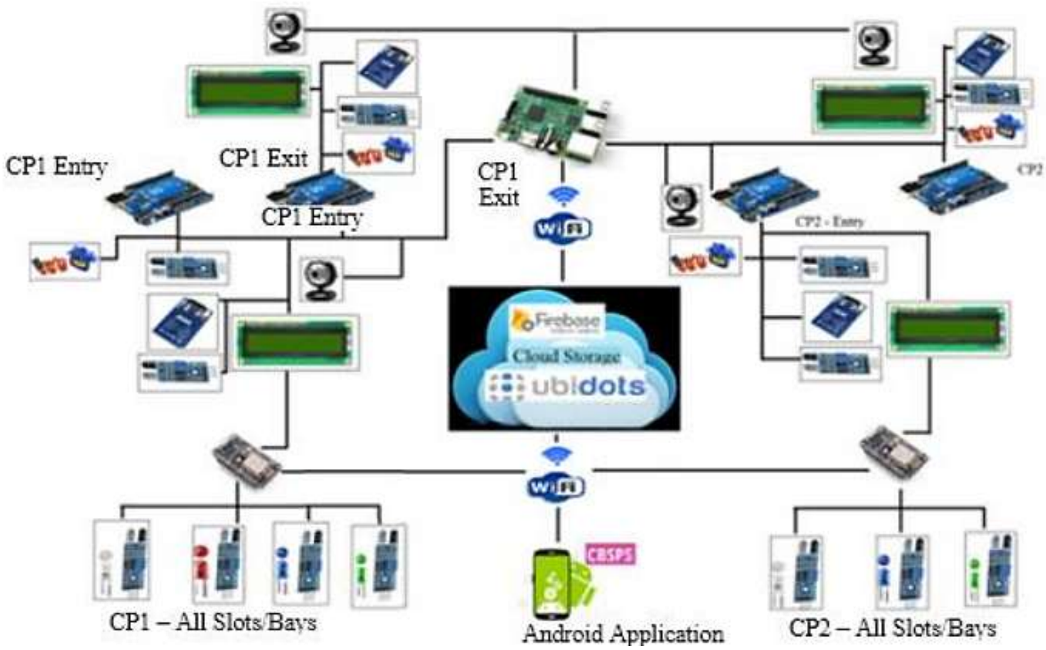

Figure 6. Visual Representation of the System

Once the car enters the car park and it is sensed as a light vehicle (based on length of the vehicle), the Arduino UNO with its RFID tag checks for the access card, whence if the card is flashed, the Arduino UNO checks with RPi3 on whether the card has been already used to enter the parking - if Yes, the gate is kept closed. This is the anti-pass back mechanism. Further, if the card is not flashed, the image processing part is triggered by the Arduino UNO by sending the "checking" command to RPi3. The connection for the RFID is shown using Arduino in Figure 7.

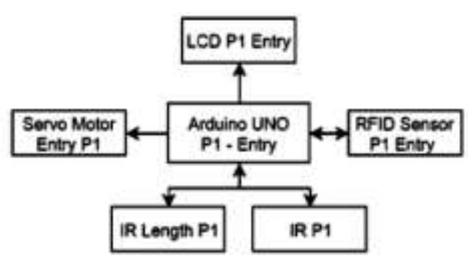

Figure 7. Entry Node

Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

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The IR sensor present at the parking slot detects the presence of the car in the slot and turns on the LED. Then, the NodeMCU updates the databases, which in turn shows on the application as connected as shown in Figure 8.

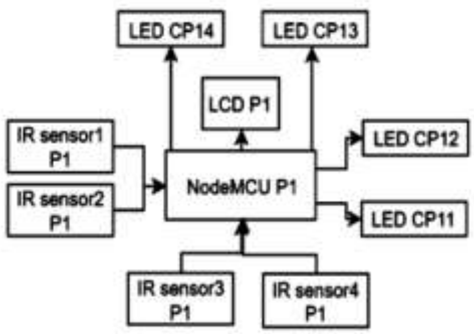

Figure 8. Slot Node

The cost is calculated between the entry and exit time, if these conform to the booking, then a fine is imposed and deducted from the card if the duration exceeds the booking.

RESULTS AND DISCUSSION

This subsection discussed the results that was obtained from the analysis of this article.

Hardware Design

The overall prototype generated can be seen in Figure 4. The first image depicts a simulated layout of an area that contains a Mall, Sports arena, Food stalls, roads and pedestrian crossings. The top left open space is CP1 consisting of four parking slots and the bottom middle space is CP2 consisting of three slots. This is shown in Figure 9.

Figure 9. Protype (Top View and Side View)

The hardware prototype was made in accordance to the planned design. The LCDs, IR sensors, RFID scanners, servo motor barriers can all be seen in the second image of Figure 10.

Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

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Figure 10. Permanent Structure

Software Design

From Figure 11, it shows that the NPR process and approval message on the LCD for the respective RFID tags flashed, which is checked and approved based on the anti-pass back mechanism. The extracted number plate is recognized and displayed. Figure 12 shows a sample of the various screens of the application.

Figure 11. NPR Process

Figure 12. Sample Screens of the Application

After the testing of the system connection to the cloud storage was checked with different connection speeds to identify the update time taken. Figure 13 shows the results. The update time was found to be better than the benchmark.

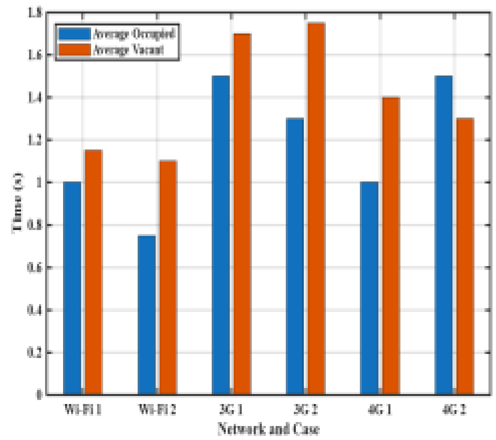
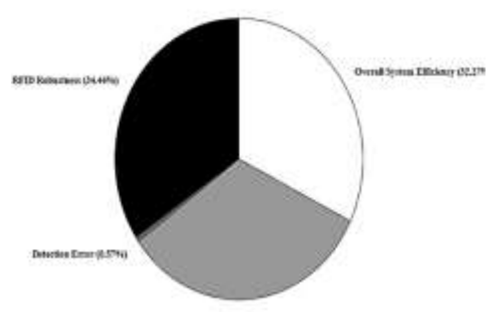


Figure 13. Updated Time Taken by the Cars

The developed system was checked for its overall efficiency by performing all the tasks. Figure 14 shows the efficiency test results achieved. The overall error in detecting a heavy vehicle was 1.66% and the robustness of RFID sensors was proven in different conditions with efficiency of 100%. The average time taken to detect a car by using NPR system was around 13.60 seconds and using RFID anti pass-back was 5.47 seconds. According to the mean value found the accuracy of the NPR was found to be 95% and the complete parking system had efficiency of 93.72%. Figure 14 shows the efficiency of the test result.



Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

CONCLUSION

The development of the IoT-based smart parking system demonstrated a high level of effectiveness in vehicle detection, identification, and access control. The experimental results revealed that the system achieved an overall efficiency of 93.72%, indicating reliable performance in real-time parking management. The integration of RFID technology exhibited excellent robustness, attaining 100% efficiency under varying environmental conditions, which confirms its suitability for secure and consistent vehicle authentication.

In addition, the Number Plate Recognition (NPR) subsystem achieved an accuracy of 95%, although it required a longer average processing time of 13.60 seconds compared to the faster RFID anti-pass-back mechanism, which recorded 5.47 seconds. The observed detection error of 1.66% for heavy vehicles further demonstrates the system's high precision. Overall, the results validate that the proposed IoT smart parking system effectively enhances operational efficiency, reduces manual intervention, and improves access control reliability. The combination of RFID and NPR technologies provides a balanced trade-off between speed and accuracy, making the system suitable for deployment in modern smart city infrastructures and intelligent transportation systems. Future improvements may focus on reducing NPR processing time and further minimizing detection errors to achieve even higher system performance.

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Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.

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Corresponding author: Umar B.
umarbagaye@gmail.com
Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna State, Nigeria.