An Arduino-Based Automated Multi-Tiered Car Parking System for University of Lagos and Expected Financial Gains

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Abstract
Insufficient parking spaces in public places sometimes lead to untoward behaviours, traffic jams, loss of man-hour, security issues, stress and environments that are generally not congenial. The University of Lagos is not exempt and this is evident in the chaotic traffic situations on campus, especially when there is a special event. This paper intends to point out the gains of automated/semi-automated multi-tiered car parks in the University of Lagos, which include a tidier environment, reduction of stress, better security and extra funds for the institution. Also, merging parks close to each other by employing the multi-tiered system would release spaces for other uses. Three Sample car parks were "merged" in a multi-tiered building, releasing two parking spaces; the financial benefits were realized by using released spaces as fee-paying car parks. A prototype of Arduino-based automated two-tiered car park was designed and produced which allows entry/exit to only authorized users with radio frequency identification (RFID) cards. A liquid crystal display (LCD) shows the available number of parking spaces and locations.

Keywords: Arduino, automated, car park, funds, multi-tiered

1.0 INTRODUCTION

Commercial areas, higher schools of learning and teaching hospitals are usually characterized by many activities; consequently, car parking in these areas could be challenging. For ease, security and economic reasons, it is necessary to have sufficient parks with proper access controls and automated multitier car park lends itself here. Multitier structures are a way of increasing parking spaces without occupying more land spaces and many types with different automation now exist. The first known multi-tiered car park with seven floors was commissioned in 1901 by City and Suburban Electric Carriage Company in London. In the US, the first multi-tiered car park was built in 1918 for the Hotel La Salle in Chicago (Multistorey car park, 2020). Since then, advances have been made in many parts of the world.

The early systems were mainly vertical elevator modules that placed cars on upper levels to be moved by attendants and/or other mechanical devices into "slots". In the slightly advanced form, the driver leaves a car at the entrance to be transported to a parking space by a robot trolley (Albgul, 2012; Papacostas and Prevedouros, 1993). Automated car parks operate from this foundation and have been achieved by various means that include electrical, electronic and mechanical methods aided by appropriate software. Some of the methods improve automation of car parking, especially the entry and exit control systems by indicating available spaces and providing direction to available parks (Hanche *et al.,* 2013; Mamun *et al.,* 2015; Yanfeng and Christos, 2013; Bonde *et al.,* 2014). Researchers have used programmable logic controller (PLC) in a multilevel parking system to provide control of entry and exit points. Singh *et al.* (2019) included extra features that conserve energy while the system designed by Sheng-Wei *et al.* (2013) includes Human-Machine Interface (HMI) touch panel for parking data collection. In Mamun *et al.* (2015) infrared (IR) sensor sends signals to a PLC to count the vehicles entering and leaving the park. The system can automatically monitor and restrict vehicles to certain parts in the park.

In another development, automatic parking and electronic parking fee collection system uses image processing for vehicle number plate recognition, without magnetic cards and accompanying devices and guides to available spaces. It is run with a pre-programmed controller to substantially reduce human involvement (Rashid *et al.*, 2012). The system of Harishraghav and Chaitanya (2014) includes an IR transmitter and receiver in every lane and light-emitting diode (LED) display outside the gate to automatically show which lane is vacant for parking. The RFID technology used in Hanche *et al.*(2013) adds video surveillance to reduce waiting at entry-point and exit-point consequently reducing air pollution. Another advance that utilizes the capability of cloud based smart parking system is presented by Pham *et al. (*2015) where the network architecture is based on Internet of Things (IoT) technology. The system makes use of a vehicle's Global Positioning System (GPS) location, the distance between car parks and the number of vacant spaces in car parks and runs with a pre-programmed controller which denies access to some parts of a park. A Raspberry Pi-based parking sensor with pi-camera detects available parking spaces and sends this data to a server that can be accessed by users. This reduces the search for available car parks nearby. The IoT allows nearby environmental things to be connected to the network and provides easy access to those that cannot be connected directly to the internet from any remote location (Basavaraju, 2015). A Smart parking system (SPS) based on Optimal Resource Allocation and Reservations was implemented for cities with the ability to assign and reserve a space for a driver depending on his distance from the parking area. The approach solves a Mixed Integer Linear Program (MILP) problem at each decision point in a time-driven sequence (Yanfeng and Christos, 2013). The system of Kepuska and Alshamsi (2016) allows parking administrators and managers to get real-time information about the parking field and parked cars can be seen by other drivers with the help of a sensor placed above each car and another in front of the car.

Literature abounds on several research outcomes for managing floor space by use of multitier car parks and management of entry and exit points by automation but a generally missing element is the economic benefits in numerical terms. Though this work aims at solving a local problem of inadequate parking space that has persisted for long, it equally considers the financial gain that can be realised. Such financial gains enhance the attractiveness to prospective investors in car parking, especially where local resources are not readily available. It also intends to spur interest in research for local production and maintenance of entry/exit control systems to address the challenges in their supply chain.

Automation of the prototype of the parking system was achieved mainly with Arduino Nano which was programmed using the C++ programming language. It also demonstrates the ability to use available low-cost materials to produce control systems. In the proposed system, a user will be issued a RFID Card properly documented to serve a dual purpose - ensures the holder has satisfied requirements for accessing the park to avoid unauthorised parking and allows exit after validation as a means of checking theft.

2.0 IMPLEMENTATION OF THE MULTITIER AUTOMATED SYSTEM

2.1 Design of the Entry/Exit Point Control System

Arduino Nano is the brainbox of the automatic entry/exit system and was chosen due to its small size, low cost, easy adaptability to connectors and breadboard. It also has enough input/output terminals to take-in all necessary signals. The system was designed with Proteus Design Suite (Proteus 8.1) based on the technical expectations. It has the basic parts shown in the block diagram of Figure 1, translated into the required circuit in Figure 2. The physical circuit was implemented as described by the design; Figure 3a shows the microcontroller with its interconnection, the switch mode, power supply and the voltage regulator for the RFID reader. Figure 3b shows the interconnection between the RFID reader, the *liquid crystal display* (LCD) and the push button. The following is an overview of the main parts of the circuit.

a. Microcontroller Section

This section contains Arduino Nano 3.1 which is a microcontroller board based on the ATmega328. It has a total of 30 pins, of which 14 are digital input/output pins and 6 analog inputs. Each of the 14 digital pins on the Nano can be used as an input or output, using pinMode, digitalWrite, and digitalRead functions which operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor of 20-50kΩ (disconnected by default). Also, some pins have specialized functions and these can be found in many materials including COMPONENTS101 (2019). There is also a16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. The required Arduino Nano specifications that formed the basis of the design are in Electronics Source Co., Ltd, (2019). The board can be reset electronically or by programming. The source code is in C++ and uses the basic Arduino Library for LCD, Servo Motor and RFID. Users only need to define two functions to execute a program that is, *setup()* and *loop().* There is also a bootloader function that permits the upload of new codes to it without the use of an external hardware programmer.

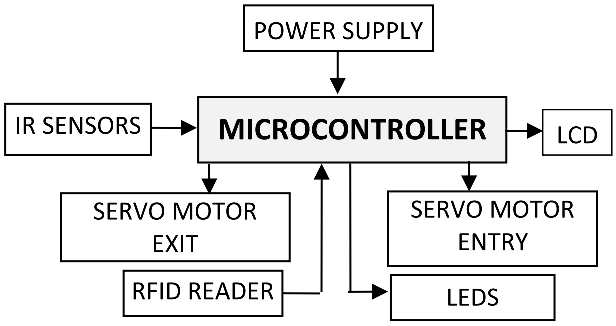

Figure 1: Block diagram of the entry/exit system

b. Power supply section

The power supply energizes all other sub-units and is rated 5V. It comprises a 12Vac step-down transformer, a bridge rectifier circuit, a 1000µF capacitor for input filtering, LM7805 linear regulator to stabilize the dc voltage to 5V dc, 4700µF capacitor for further filtering of the dc line. Power can also be supplied via USB connection or with an external power supply. Arduino board can operate on an external supply of 6 to 20V but the recommended range is 7 to 12V because if supplied with less than 7V, the 5V pin may supply less than five volts resulting in instability. If voltage is greater than 12V, the voltage regulator may overheat and damage the board (Lextrait, 2016). The linear regulator can be bypassed by supplying directly via the 5V pin but an unstable supply can destroy the Arduino.

c. Liquid Crystal Display Section

A counter is implemented to monitor the cars going in and out of the car park and indicates this through a16X2 HDD44780 LCD that uses a serial adapter to makes connection and communication to the screen much easier. Serial data is sent to the MCP23008 which is converted and fed into the ports of the LCD for display. The MCP23008 is a port expander chip used when additional input/output ports for a microcontroller are needed. The LCD is connected to the Arduino via its standard inter-integrated circuit ports (port A5 and port A4).

d. Radio Frequency Identification Section

The MFRC522 based radio frequency identification (RFID) reader module is a highly integrated reader/writer integrated circuit for contactless communication at 13.56 MHz. It is cheap and can be used in many applications. It requires 3.3V and 13 –26mA and the maximum data transfer rate is 10Mbit/s.

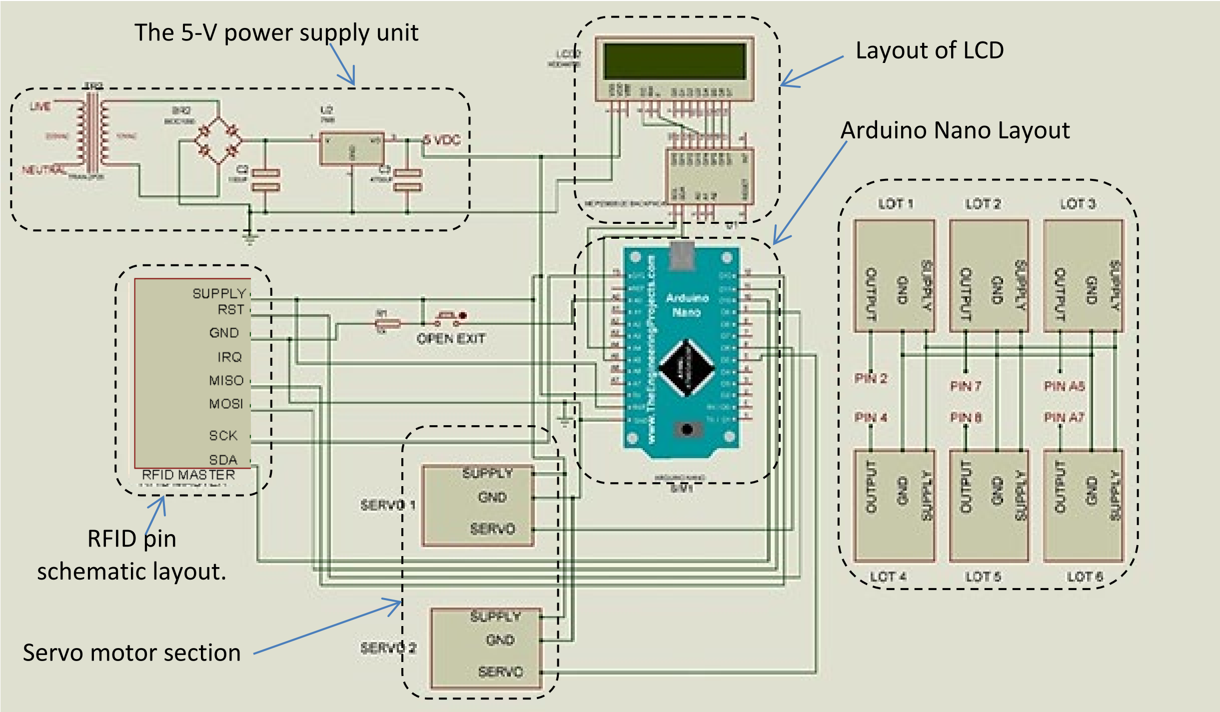

Figure 2: Circuit design of the Arduino-based entry/exit system with Proteus Design Suite (Proteus 8.1)

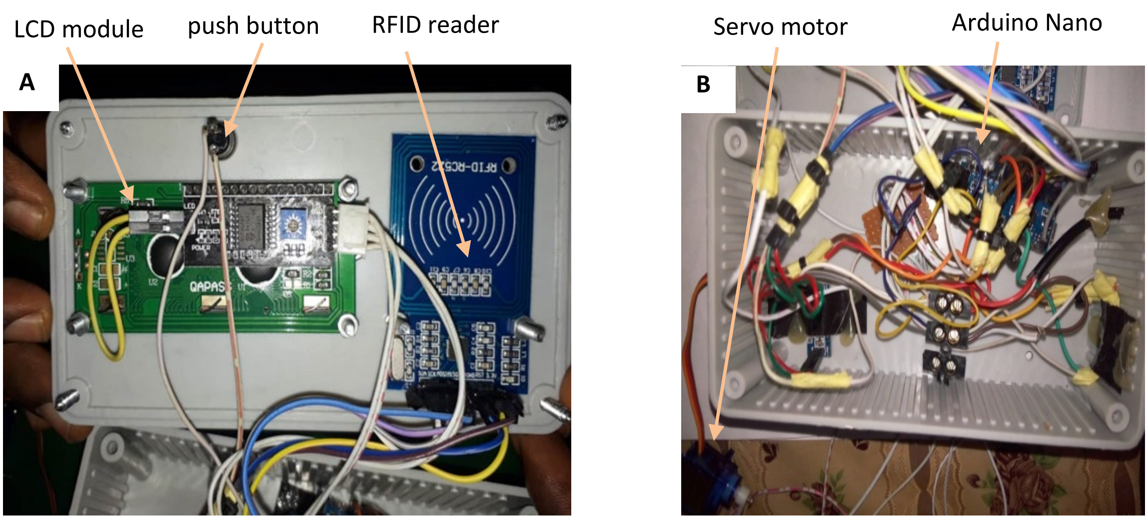

Figure 3: Physical circuit of the Arduino Nano-based entry/exit system (A) LCD and RFID reader (cover case), (B) Microcontroller and servo motor (bottom case)

e. Servo Section

There are two units of servo motors and each has four main components - a dc motor, a gearbox, a potentiometer and a control circuit. Arduino controls the servo motor by sending a series of pulse width modulated (PWM) signals. This is done with codes and the width of the pulse determines the angular position of the servo. When it rotates to 90^o the gate opens and when it goes back to 0^o the gate closes. Minimum and maximum duration of the pulses vary slightly with different brands but generally pulses of 1ms duration correspond to 0 degrees position, 1.5ms to 90 degrees and 2ms to

180 degrees.

f. Sensor Section

This section is made up of 6 units of Infrared Sender Receiver Circuit. Each parking space is equipped with an IR sensor that sends messages to the Arduino to check if a car is already parked and with the LCD module visually displays a vacant space. When all spaces are engaged, the Arduino will not enable the servo motor to open the entrance gate anymore and "FULL" will be displayed.

3.0 PHYSICAL SURVEY OF CAR PARKS

A survey was conducted by taking measurements of each car park in square meters and actual counting of vehicles in each car park, excluding extra cars that obstruct other cars. The result of the survey is provided in Table 1 based on their closeness to each other. The obstruction of other cars is termed *"inconvenience parking"* for this work because of the inconveniences usually experienced.

Table 1: Data of the car parks based on proximity (without blocking any car)

SECTION A					
S/N	**Car Parks**	**Length(m)**	**Width (m)**	**Area (m²)**	**Capacity (cars)**
1	Faculty of Engineering	38.1	31.4	1,196.34	46
2	Institute of Maritime Studies	35	13.7	479.5	21
3	Senate Building	47	20	940	40
	TOTAL			2,615.84	107
SECTION B					
S/N	**Car Parks**	**Length (m)**	**Width (m)**	**Area (m²)**	**Capacity (cars)**
4	Faculty of Law	56	37	2,072	80
5	Faculty of Business	46	38	1,748	70
6	Guest House	31	17	527	22
	TOTAL			4,347	172
SECTION C					
S/N	**Car Parks**	**Length (m)**	**Width (m)**	**Area (m²)**	**Capacity (cars)**
7	Faculty of Science	114	11	1,254	50
8	Jaja Hall	89	24	2,136	89
9	Chemical Engineering	44	14	616	25
	TOTAL			4,006	164
SECTION D					
S/N	**Car Parks**	**Length (m)**	**Width (m)**	**Area (m²)**	**Capacity (cars)**
10	Distance Learning Institute	103	39	4,017	150
11	Honours Hall	44	33	1,452	60
	TOTAL			5,469	210
SECTION E					
S/N	**Car Parks**	**Length (m)**	**Width (m)**	**Area (m²)**	**Capacity (cars)**
12	Chapel	50	24	1,200	48
13	Mosque	60	15	900	37
	TOTAL			2,100	85

3.1 Merging Car Parks in Multitier Structure

Car parks can be "merged" by building a multitier car park in one of the spaces of car parks close to each other. Some parks were theoretically merged in the proposed course of action and financial gains were determined.

3.1.1 *Case Study*

Faculty of Engineering, Institute of Maritime Studies and Senate Building car parks were chosen as a case study; the required data is summarised in in Table 2. Using Engineering car park as a benchmark, let the number of cars without obstruction be C_{cE} and number of cars with inconvenience parking be C_{iE}; then extra cars, C_{xE} can be calculated using Eq. 1. The per-unit value of extra cars, χ is given by Eq. 2.

$$C_{xE}= C_{iE}-C_{cE} \tag{1}$$

$$\chi = \frac{C_{xE}}{C_{cE}} \tag{2}$$

Table 2. Data of the sample car parks

Park (with identifying subscripts)	REAL DATA		
	Floor Space (m^2)	No. of cars during Convenient Parking	No. of cars during Inconvenient parking
Engineering ($_E$)	1,196.34	46	57
Maritime ($_M$)	479.5	21	-
Senate ($_S$)	940	40	-
Combined Parks ($_T$)	2,615.84	107	-

Let the total number of cars that the three sample parks can conveniently accommodate be C_{cT} and total number during inconvenience parking be C_{iT}. Then the total cars with inconvenience parking can be obtained by Eq. 3.

$$C_{IT}= C_{cT}+\chi C_{cT} \tag{3}$$

Substituting the required data from Table 2 into Eqs. 1-3 gives the total number of cars in the three car parks with inconvenience parking, to the nearest whole number, as C_{iT} = 133.

3.1.2 *Determination of Number of Tiers*

Any of the sample car parks can be chosen as the site for the multitier car park. However, the number of tiers that would accommodate 133 cars conveniently would vary because the floor spaces are not equal. Let the floor spaces of Maritime, Engineering and Senate car parks be ς_M, ς_E and ς_s respectively, then the total floor space is $\varsigma_T =(\varsigma_M + \varsigma_E + \varsigma_s)$. The number of tiers at any particular park that would give the equivalent floor space when merged is given by Eq. 4, where ς is the floor space of any chosen park.

$$\tau = \frac{\varsigma_T}{\varsigma} \tag{4}$$

Inconvenience parking is factored in using Eq. 5, where τ_i is the number of tiers that would sufficiently cater to all cars including those that cause obstructions and the total numbers of cars with and without inconvenience parking are C_i and C_c respectively.

$$\tau_i = \frac{\tau C_{iT}}{C_{cT}} \quad (5)$$

Substituting Eq. 4 in Eq. 5 yields;

$$\tau_i = \frac{\varsigma_T C_{iT}}{\varsigma C_{cT}} \quad (6)$$

Let $\left(\frac{\varsigma_T C_{iT}}{C_{cT}}\right) = k$, which is a constant. Using in Eq. 6 yields Eq. 7.

$$\tau_i = k\frac{1}{\varsigma} \quad (7)$$

Equation 7 gives the number of tiers, τ_i that would conveniently accommodate 133 cars in any car park. From Table 2, C_{cT} = 107, C_{iT} = 133, ς_T = 2,615.84, therefore, $k = \frac{(2615.84 \times 133)}{107}$ = 3251.4647. The numbers of tiers are computed specifically for Maritime Studies, Engineering and Senate House car parks using Eqs. 8-10.

$$\tau_{iM} = \frac{k}{\varsigma_M} \quad (8)$$

$$\tau_{iE} = \frac{k}{\varsigma_E} \quad (9)$$

$$\tau_{iS} = \frac{k}{\varsigma_S} \quad (10)$$

a) Building the Multitier Car Park in Maritime Car Park Space

Floor space of Institute of Maritime Studies is ς_M = 479.5m^2, using Eq. 8 the number of tiers is obtained as;

$$\tau_{iM} = \frac{3251.4647}{479.50} = 6.78 \approx 7 \text{ tiers}$$

b) Building the Multitier Car Park in Engineering Car Park Space

The Engineering floor space is ς_E = 1196.34m^2; substituting in Eq. 9, the number of tiers is obtained as;

$$\tau_{iE} = \frac{3251.4647}{1196.34} = 2.7178 \approx 3 \text{ tiers}$$

c) Building the Multitier Car Park in Senate House Car Park Space

The floor space of the Senate House car park is ς_S = 940m^2. Similarly, substituting in Eq.10, the number of tiers is;

$$\tau_{iS} = \frac{3251.4647}{940} = 3.4590 \approx 4 \text{ tiers}$$

The number of tiers that can be built in each of the sample car parks has been determined but the Senate House car park is the proposed site because of its strategic location. Though 4 tiers are required, a sample arrangement of a multitier car park is shown in Figure 4 incorporating the 2-tier prototype that was produced in the course of this work as an example.

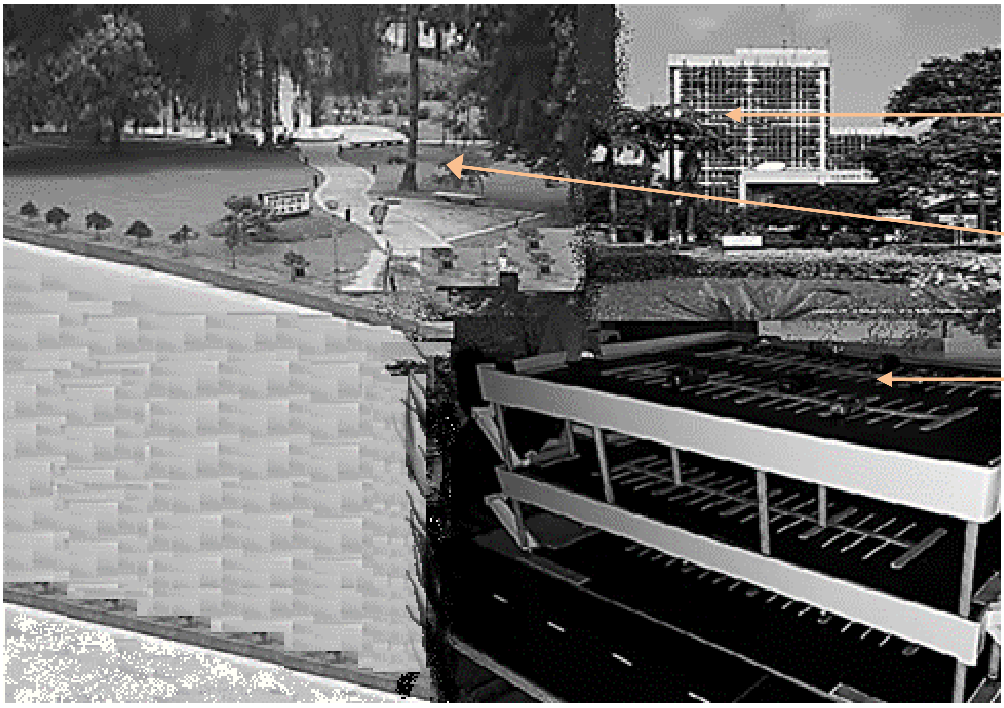

Figure 4: Proposed siting of the two-tier car park in the senate parking space

The system proposed is the open type with landscape gardening on top as in picture in duplipark-Synergy, (2019) which creates a beautiful and healthy environment. Also, it would look like an extension of Sofoluwe Park.

3.2 Economic Viability and Evaluation of the System

Engineering economics is fast gaining prominence in research activities because it gives a clear view of the economic benefits of a proposed solution to engineering problems. When determining the economic viability of a project, factors to be considered include the total cost of the project, financial gains, potential new jobs, sustainability and regulations, but this work considers mainly the financial gains.

Building the merged car park at Senate releases two spaces; two options can be explored - released spaces could cater for visitors at a fee but automated entrance should be in place to reduce manpower and ensure accountability; on the other hand, a two-tier open car park can be constructed in one released car park space for visitors. This can be replicated in several areas where events that attract non-members of the community are common, or where such non-members of the community with cars visit frequently for business with the university. This would yield considerable financial gains. The Senate House space would accommodate 133 cars in a 4-tiered structure as determined from Eq. 10. Most visitors do not stay long so if 200 cars visit per day, extra income can be realized (see Table 2).

4.0 RESULTS AND DISCUSSION

A physical assessment of the prototype was carried out after the design and construction to ascertain its successful operation.

4.1 Hardware Evaluation

The hardware was evaluated to validate that each stage of the system provides the required voltage. Measurements were done with digital multi-meter and the node voltages were compared to expected voltages as shown in Table 3.

Table 3. Measured node voltages relative to desired voltages

Parameter	Desired Voltage (V)	Measured Voltage (V)
Power Supply Section		
Transformer secondary Voltage	>12 ac	12 ac
Voltage after Rectification and Filtering	>12.5 dc	21.2 dc
7805 Voltage Regulator Output	5dc	5 dc
Microcontroller (Arduino Nano) Section		
Positive Power Supply to the Microcontroller(V_{DD})	5 dc	4.95dc
Negative Power Supply to the Microcontroller(V_{SS})	0 dc	0 dc
RFID Module Section		
V_{CC} Voltage	3.3 dc	3.28 dc
GND Voltage	0v dc	0 dc
INFRARED Module Section		
V_{cc} voltage	5 dc	4.99 dc
GND Voltage	0 dc	0 dc

4.2 Test-running the System

The following tests were performed to show the corresponding responses of the entry/exit control system to the control messages:

i. When a valid RFID card was swiped, the LCD displayed "***Access Allowed***" as in **Figure 5a**.

ii. In **Figure 5b** the LCD displayed ***"Access Denied"*** when an invalid RFID card was used.

iii. The availability of space is indicated by the LED's at the entrance (**Figure 5c)** when the first floor is fully occupied; the "red LED" turns on while the "green LED" turns off. The second floor has vacant spaces, so the "red LED" is off while the "green LED" is on.

Figure 1: Different displays at the entrance of car park (A) Valid RFID card, (B) Invalid RFID card, (C) Space availability

4.3 Entry and Exit Sequences

The sequences for moving in and out of the car park are illustrated in Figures 6. The database is updated each time a car enters or leaves the car park. When the driver places a valid RFID card on the reader, the entrance gate opens, the car enters the park and the counter increases by one. When a car is about to leave the car park the driver places a valid card on the reader, the exit gate opens, the car leaves and the counter decreases by one.

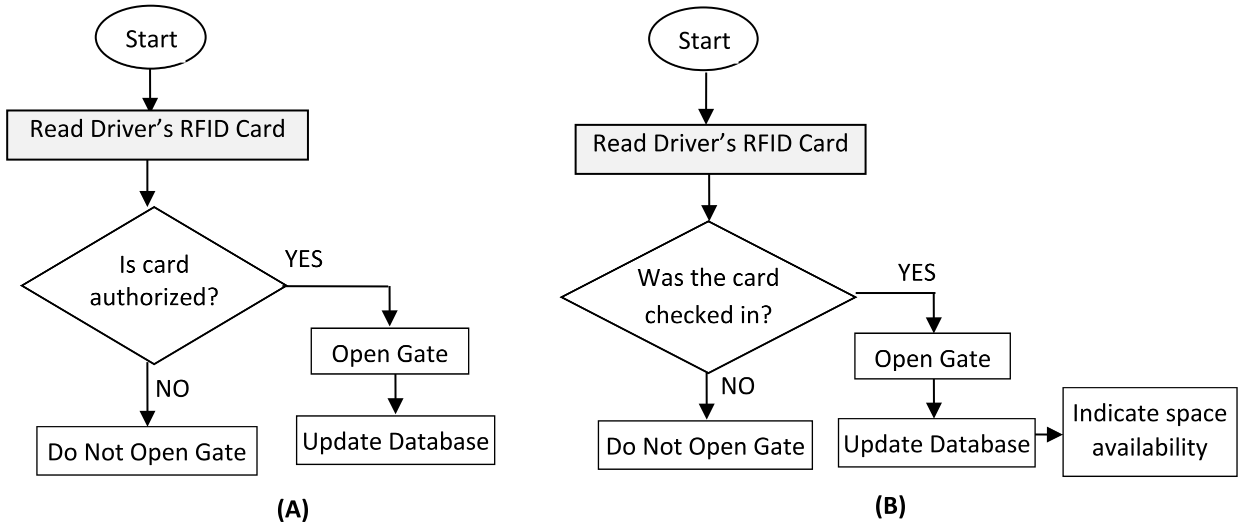

Figure 2: Automated car park gate entry and exit sequences. (A) Entry sequence, (B) Exit sequence

4.4 Number of Tiers

The number of tiers that would accommodate 133 cars in each sample space has been computed and the results are shown in Table 4. The seven-tier structure seems tall but the design of the proposed car park at Maritime Studies is of low ceiling clearances. Thus, the overall elevation for the structure will not be very high particularly, secondly, having a tall building there will not be obtrusive. Structures with low ceiling clearances are also ideal for Engineering and Senate car parks.

Table 4: **Parks floor spaces and Number of tiers**

Park	Floor Space (m^2)	No. of Tiers
Engineering ($_E$)	1,196.34	3
Maritime ($_M$)	479.5	7
Senate ($_S$)	940	4

4.5 Income Generation

The proposed system has no moving parts in terms of devices to move cars up and down so maintenance cost would be low. The income that can be generated from only one multitier car park is summarized in Table 5 where 8.2 million naira can be realized annually. The value assumes only 200 cars, which is low, given the influx of vehicles into the university and charge per car could be more so the expected income can be much higher. The number is reduced in this analysis to accommodate any uncertainty which cannot be avoided in any business venture. Also, since there is no need for land purchase, the total cost of implementation is reduced.

Table 5: **Fund that can be generated from an automated multitier car park**

Number of cars	Charge per car (₦)	Total amount realized per day (₦)	Total amount realized per annum (₦)	Salary of two workers (₦)	Maintenance cost per annum (₦)	Gain per annum (₦)
200	200	40,000	9,600,000	1,200,000	200,000	8,200,000

5.0 CONCLUSION

The original intent of this work was to proffer an effective solution to the problem of insufficient car parking spaces and the attendant challenges in the University of Lagos and similar places. Since the work is conceptual, only a functional prototype was designed and produced. The engineering bill of materials amounted to fifty-seven thousand, two hundred and seventy naira (₦57,270) only, but real-time applications can be derived from this based on standard practices. Also, the economic benefit is laid out numerically to show that car parking real estate is a worthwhile area to invest in, especially to generate extra funds for the university.

6.0 RECOMMENDATION

Though this attempt to address the issue of car parking and resultant traffic jams has limitations, it is recommended that the approach be followed but expanded to ensure full realization. Another recommendation is that a proper database containing all car parks and the number of cars should be created. In addition, the number of cars that pass through the gates should be ascertained during normal times and when there is an event that attracts more visitors to aid planning and give a clearer picture of expected income.

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