facilities, large area of lands will be needed to construct parking structures to accommodate the growing population in urban areas. Automated multi-level car park will be best solutions for areas with shortage of land and illegal parking because they need less ground area and building volume to provide adequate parking slots than conventional car parks [1, 6].

2. MATERIAL AND METHODS

The procedures for development of the automated vehicle parking system involves design calculations for mechanical and electrical components selection, electrical circuit design implementation, fabrication process and testing of the system.

2.1 Material Selection

Mechanical and electrical components were specified based on design calculation and used in the development of the automated multi-level car parking system. Mechanical components used in the fabrication of automated multi-level car parking system are: metal sheet, coupling, threaded rods, ball bearing slide, bolts and nuts. And the electrical components used are: NEMA-17 stepper motor, stepper motor driver, microcontroller, power supply, sensors, display unit and keypad.

Table 1: Description of Mechanical Components

S/N	Components	Functions	Material	Size	Reason for selection
1	Metal sheet	Used in the construction of the multi-level car park.	Mild steel	7mm	-Cheap -Malleable
2	Coupling	It transmits the torque from the stepper motor to the threaded rods.	Steel	5mm	Effective
3	Threaded rods	Used in the fabrication of the storage and retrieval system.	Mild steel	8 mm	-Cheap -Suitability -Availability
4	Bolts and nuts	Used in the assembly of the multi-level car park	Mild steel	M6	-Suitability -Necessary
5	Ball bearing slide	Used for smooth storage and retrieval process	Stainless steel	R6	Reduces friction

Table 2: Description of Electrical Components

S/N	Components	Functions	Material	Size	Reason for selection
1	NEMA-17 Stepper motor	To move the storage and retrieval machine in X, Y and Z axes	Bipolar (6Wires)/ Unipolar (4Wires)	12V, 1.7A, 0.42 Nm	-High torque -Precise
2	Stepper motor Driver	Control the NEMA-17 stepper motors	Pololu with built-in translator	A 4988	Cheap -Easy operation -Easy to Program
3	Micro-controller	To develop Automated system. Control the parking process.	Arduino	MEGA 2560	-- Easy to Program -Multi I/O pins Availability
4	Power supply	Supplies electrical power to the stepper motors.		12V	-Suitability -Necessary
5	Sensor	Converts physical action to electrical signals. Notify driver that a vehicle has been parked	Infrared sensors		- Cheap - Sensitive Availability
6	Display unit	For viewing information	Liquid Crystal Display	16 rows X 2 c/n.	- Cheap - Easy to Program -Clear Display Compatible
7	Keypad	Data input device for computers.		4x3 matrix	- Cheap Availability - Sensitive Compatible

Figure 1: NEMA-17 Stepper Motor

Figure 2: Infrared Proximity Sensor

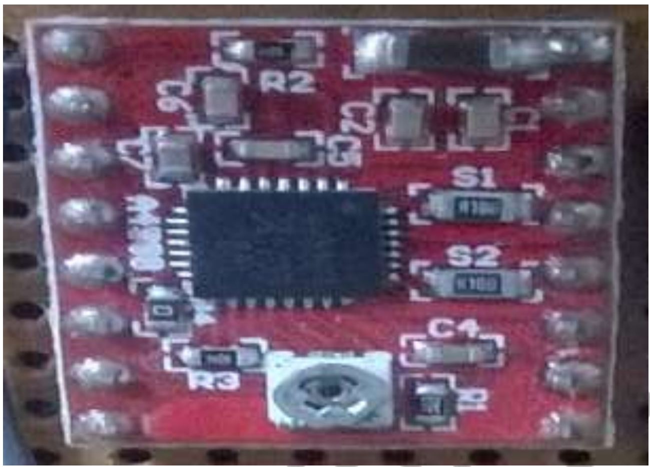

Figure 3: A4988 Pololu Stepper Motor Drive

Figure 4: Arduino MEGA 2560

2.2 *Design Calculation*

The nine slots multi-level car park dimensions were computed for power estimation for the storage and retrieval system.

a) Multi-level car park frame dimensions

Space of the multilever car park

$$V_{mcp} = L_P \times B_P \times H_P \quad (1)$$

Where, L_P is the length of the multi-level car park, 92 B_P is the breadth of the multi-level car park, 42 cm

H_P is the height of the multi-level car park, 70 cm $Thus, V_{mcp} = 92 \times 42 \times 70 = 270{,}480\ cm^3 = \mathbf{0.27m^3}$

For each parking slot, $V_{ps} = L_{ps} \times B_{ps} \times H_{ps}$ (2)

Where; the length, breadth and height of the car slot are all equal to 20.5 cm

$$V_{ps} = (20.5)^3 = 8615.125\ cm^3 = 0.0086\ m^3$$

Total space for the nine (9) car slots = 9× 0.0086 m^3

$$= \mathbf{0.0774\ m^3}$$

b) Design calculations for the storage and retrieval system

i. Lead of threaded rods

The lead of a threaded rod is the axial distance a nut moves in one revolution. Mathematically lead of a threaded,

$$L = n\ X\ p \quad (3)$$

Where; L = the lead of the threaded rods (mm); n = the number of starts; p = the pitch of the threaded rods *(mm).*

For four (4) threaded rods of the same size of threaded rods used in the fabrication of the storage and retrieval system; the number of start on the threaded rods is 1

$$p = \frac{1}{threads\ per\ inch\ (TPI)} = \frac{1}{30} = 0.762\ mm$$

Substitute the values, n = 1 and p = 0.762 mm in eqn. 3

$$L = 1 \times 0.762 = 0.762\ mm$$

Thus the lead of each threaded rods = 0.762 mm.

ii. Torque required for moving the vehicle in the X axis

The torque required by the stepper motor to move the vehicle left and right in the X-axis in the automated multi-level car park is expressed mathematically as

$$T = F_t.r \quad (4)$$

Where T is the torque required to move the vehicle (Nm); F_t is the total force acting on threaded rod 3 (N) and $\boldsymbol{r}$ is the radius of threaded rod 3, (0.004 m).

Total force acting on threaded rod 3 is expressed mathematically as

$$F_t = F_f + F_a + F_e \quad (5)$$

Where; F_f = the frictional force (N); F_a = the force due to acceleration (N) and F_e = the external forces (N)

Mathematically, frictional force is defined as

$$F_f = \mu \times W_t \times g \quad (6)$$

Where W = the total weight of the object acting on threaded rod 3 (N) μ = the co-efficient of friction; and g = the acceleration due to gravity (9.81 m/s^2)

Total mass of the object acting on threaded rod 3,

$$m_t = m_v + m_{tz} \quad (7)$$

For an estimated mass of the vehicle, m_v of 0.05 kg and the mass of components in the Z-axis m_{tz} is 5.2 kg, and the co-efficient of friction (μ) between the threaded rod and the nut is 0.25

$m_t = m_v + m_{tz}$ = 0.05 + 5.2 = 5.25 kg.

Thus $F_f = \mu \times W_t \times g$ = 0.25 × 5.25 × 9.81 =12.88 N

The force due to acceleration, $F_a = m_t \times a$ (8)
For object to reach a desired velocity, v of 0.05 m/s in 0.5 s

Also $F_a = m_t \times \frac{v}{t}$ = 5.25 × $\frac{0.05}{0.5}$ = 0.525 N
The external force, F_e acting on threaded rod 3 is the total weight of the object acting on threaded rod 3,

$$F_e = W_t = 51.5\ N$$

Using values, F_f = 12.88 N, F_a = 0.525 N and F_e = 51.5 N in eqn. (5)

$$F_t = F_f + F_a + F_e$$

$$F_t = 12.88 + 0.525 + 51.5 = 64.9\ N$$

Mathematically

$$d_m = 2 \times \left(\frac{d_{major} + d_{minor}}{2}\right) = d_{major} + d_{minor} \quad (9)$$

Where d_m the mean diameter of the threaded rods (m); d_{major} and d_{minor} are respective diameters of threaded rod1.
The major diameter and minor diameter of threaded rod 1 is 0.008 m and 0.00635 m respectively

Substituting the values d_{major} = 0.008 m and d_{minor} = 0.00635 m in (9) $d_m = 0.008 + 0.00635 = 0.014\ m$
Thus, $r_m = 0.007m$ and when r = 0.007 m,

$$T = F_t . r = 64.9\ X\ 0.007 = 0.4543\ Nm$$

iii) Torque required to move the vehicle in the Y-axis

Two stepper motors are used for providing the torque required to move the vehicle in the Y-axis which is the sum of the torque required for raising the vehicle and the torque required to lower the vehicle.

iv) Torque required to raise the vehicle, T_r is computed using equation,

$$T_r = \frac{F \times d_m}{2}\left[\frac{l + \pi\mu d_m}{\pi d_m + \mu l}\right] \quad (10)$$

Where; T_r = the torque required to raise the vehicle (Nm); μ = the coefficient of fr d_m= the mean diameter of the threaded rods (m); l = the lead of the threaded rods (m), F = the total force acting on the threaded rods (N).
Therefore when $L = 0.762$ mm $= 0.000762$ m; $F_t = 64.9\ N;\ and\ d_m$= 0.014m in (10)

$$T_r = \frac{64.9 \times 0.014}{2}\left(\frac{(0.000762) + (0.25\pi \times 0.014)}{(0.014\pi) + (0.25 \times 0.000762)}\right) = 0.181\ Nm$$

v) Torque required for lowering the vehicle,

$$T_l = \frac{F \times d_m}{2}\left[\frac{\pi\mu d_m - l}{\pi d_m + \mu l}\right] \quad (11)$$

$$T_l = \frac{64.9 \times 0.014}{2}\left(\frac{(0.25\pi \times 0.014) - (0.000762)}{(0.014\pi) + (0.25 \times 0.000762)}\right) = 0.151\ Nm$$

vi) Torque required for moving the vehicle in the Z-axis and X-axis

The torque required for moving a vehicle X-axis into the slot and out of the slot Z-axis when $F_t = 64.9N\ and$ R= 0.007 m
Thus T= 64.9 × 0.007 = 0.4543 Nm.

2.3 **Fabrication of Automated Vehicle Parking System**

Procedures for fabricating the storage and retrieval system involve drilling holes at both corners of the roof and base of the multi-level car park. The holes at the roof and base aligned with each other for both corners. The two stepper motors for the Y-axis were inserted into the holes at the corners. Two nuts were fixed into threaded rods 1 and 2 (TR1 and TR2) each. Threaded rods 1 and 2 (TR1 and TR2) were coupled to each stepper motor for the Y-axis. A steel rod with the length of the multi-level car park was cut out and a sleeve was inserted into the steel rod as shown in figure 5.

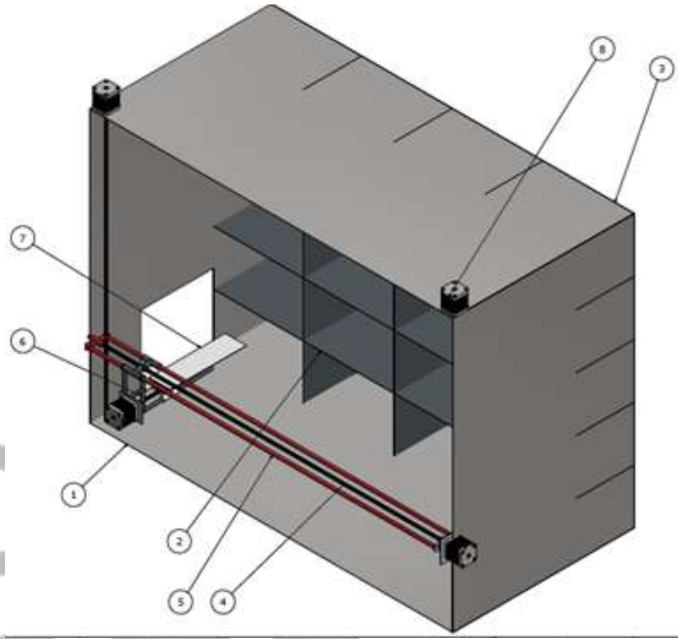

Figure 5 Automated Vehicle Parking System

Table 3: Component Description List

Item	Quantity	Part list
1	1	Base
2	20	Car Compartment
3	1	Back Cover
4	4	Threaded Rod
5	2	Threaded Rod Support
6	1	Face Plate Support
7	1	Lifting Arm
8	4	Stepper Motor NEMA-17

The steel rod was welded in between the nuts on both TR1 and TR2 using the electric arc welding machine. The nuts on both rods of the same height measured from the base of the threaded rods were attached. Three steel rods of 1 cm long were cut out and welded at the center of both nuts in TR1 and TR2 and the last one at the center of the sleeve. Eight (8) nuts were fixed into threaded rod (TR3) with two nuts each at both ends and the remaining four at the center. These nuts were welded to the other ends of the welded steel rods each.

ii) **Assembly of X-Axis Stepper Motor to the Face Plate**
A faceplate was fabricated for the X-axis stepper motor and attached to the X-axis stepper motor as shown in figure 6. The X-axis stepper motor was coupled to threaded rod 3 (TR3) with the faceplate attached to the nuts at the right hand side of TR3 with a flat bar. The Z-axis stepper motor was attached to its face plate identical the X-axis faceplate with a nut fixed into the fourth threaded rod (TR4).

iii) **Attachment of Ball Bearing Slide**
A ball bearing slide was fitted to the nut in TR4 using an L–shaped metal plate. The base of the L-shaped steel plate was joined to the nut in TR4 with the aid of a bolt and nut and was welded to the side of the L-shaped steel plate shown in Figure 6. The Z-axis stepper motor was coupled to TR4 and the ball bearing slide was welded to the nuts at the center of TR3.

Figure 6: Ball Bearing Slide Attached to TR4.

IV. Electrical Circuit Design

The electrical circuit implemented in the development of the automated car parking system consists of the Arduino MEGA 2560, infrared proximity sensors, LCD, stepper motors and stepper motor driver. A motor driver circuit board was connected to both the microcontroller and stepper motors for motor movement control circuit as depicted in Figure 7.

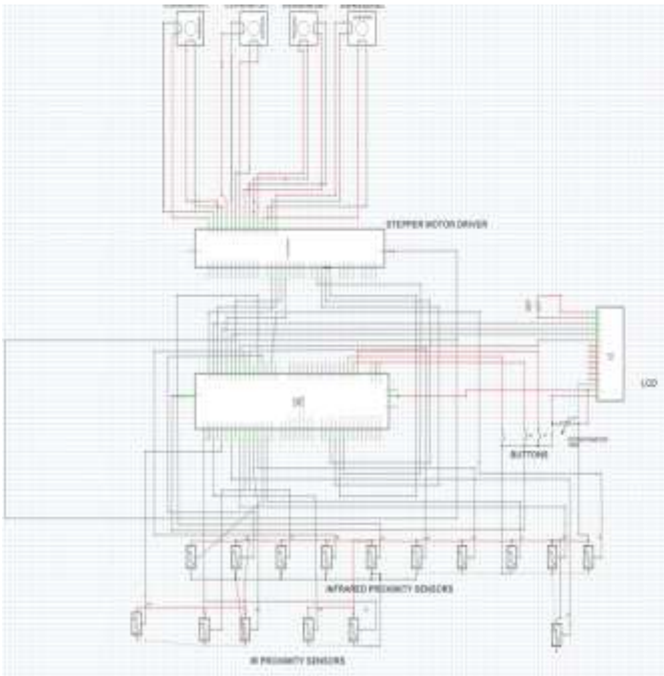

Figure 7: Electrical Circuit Design for the Automated Vehicle Parking System

3. RESULTS AND DISCUSSION

Figure 8 shows the developed automated vehicle parking system with nine parking slots.

Figure 8: Automated Vehicle Parking System

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3.1 Results

The results obtained from automated vehicle parking system sensor test is shown in table 6. The test showed that the infrared proximity sensors were at different sensitivity range for slots at varied time to ensure vehicles are correctly parked at available space.

Table 4: System Time –Slot Based Response

Slots Test	**LCD Response**	**Time to Respond (Secs)**	**RGD Response**	**Interpretation**
1	Available	4.12	Green	Parking slot empty
2	Available	5.32	Green	Parking slot empty
3	Occupied	10.35	Red	Parking slot occupied
4	Available	5.13	Green	Parking slot empty
5	Available	3.85	Green	Parking slot empty
6	Occupied	11.32	Red	Parking slot occupied
7	Available	4.85	Green	Parking slot empty
8	Available	5.12	Green	Parking slot empty
9	Occupied	10.27	Red	Parking slot occupied

The motor control circuit board was tested for continuity using a multi-meter to ensure that there was no mistake in the connection of the motor driver circuit board. The continuity test shows system reliability as there were no errors in connection.

3.2 Electrical components automation

The developed automated parking system uses power, program of instructions and control system for automation. Power drives the process and the control system while the program of instructions is pre-defined commands followed to accomplish a process. The control system manipulates the entire. process or system. The stepper motor driver used for the development of the automated system is the A4988 pololu stepper motor driver. It was used to control the NEMA-17 stepper motors. The A4988 stepper motor driver is a complete micro-stepping motor driver with built-in translator for easy operation. It is designed for bi-polar stepper motors like the NEMA-17 stepper motor used in the development of the automated multi-level car parking system.

The microcontroller used in the development of the automated system is Arduino MEGA 2560. Arduino MEGA 2560 is an open-source physical computing platform predicated on a simple input/output board and a development environment that implements the Processing/Wiring language. The board based on ATmega2560 microcontroller. It contains 54 input/output pins, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Arduino MEGA 2560 was used to control the parking process via the input devices and output devices. The display unit used in the development of an automated vehicle parking system is the Liquid Crystal Display (LCD). Its screen has sixteen (16) rows and two (2) columns for displaying data. Display units are output device used for viewing information in devices like alarm clocks, calculators, phones and other electronic devices. The flowchart of the processes and the operations taken to achieve the overall automated vehicle parking system implementation is shown in Figure 9.

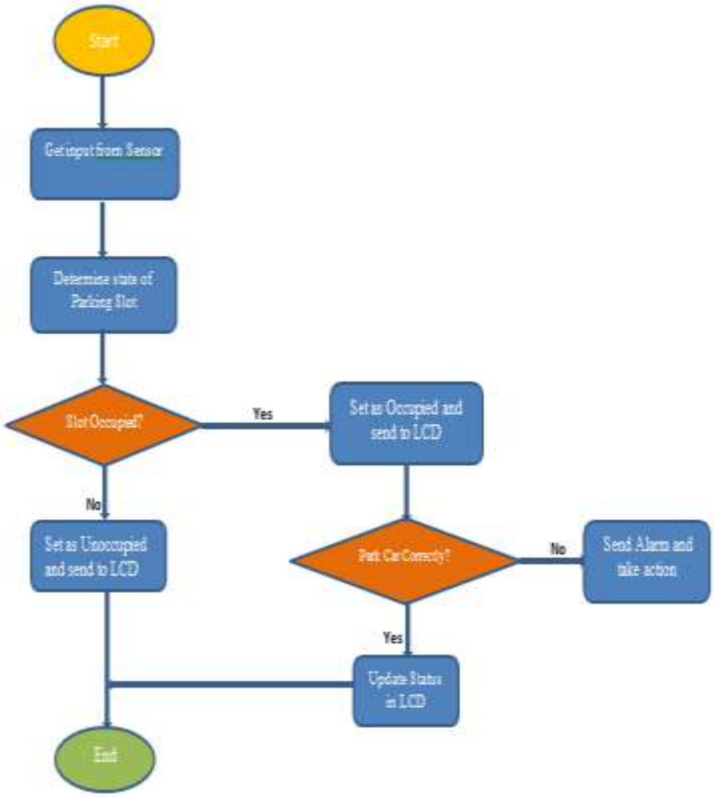

Figure 9: Smart Parking System flow chart

4. CONCLUSIONS

The development of an automated vehicle parking system is beneficial to every driver and vehicle owner as it provides parking spaces in areas faced with parking problems as a result of shortage of land, it promotes the security and safety of drivers and vehicles and it reduces traffic congestion by reducing illegal parking. The parking system for the safety of drivers and vehicles, reduction in traffic congestion and provision of adequate parking slots for vehicles. Arduino MEGA 2560 based smart parking system to efficiently address the issue of car parking has been developed. Testing and evaluation of the developed system has shown effective utilization of the motor control driver circuit to avoid system malfunction.

Developed of an automated vehicle parking system will provide solution to the problems of inadequate parking facilities, traffic congestion and insecurity of drivers and vehicles. The parking systems are less expensive per parking slots as they require less ground area and less building volume than a conventional car park of the same capacity. Thus they make efficient use of space, reduce traffic congestion, ensure vehicle security and ease of parking, eliminate air and noise pollution than a conventional park.

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