Design and fabrication of solar powered smart prototype wheelchair for quadriplegic (disabled) persons

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Research Article

Keywords: wheelchair, control buttons, voice module, micro-controller, solar-powered

Posted Date: September 23rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2049030/v1

Abstract

Background

Disabled persons with weak limbs and joints find it impossible to manoeuvre a manual wheelchair which is abundant in some countries for long distances leaving them with the option of an electric wheelchair which are very costly. This paper focuses on achieving seamless control of a smart wheelchair via voice command and control buttons for easy and convenient movement of people with quadriplegic problems thereby, the design of a cost effective, sustainable and efficient solar powered wheelchair.

Methods

Materials used included mild steel, aluminium, galvanized pipe, backrest, seat, leg rest, foot rest, headrest, DC battery, solar module, panel for control buttons and DC motors. The 3D modelling and assembling was carried out using CREO parametric software and a dummy of 85kg was used to test run on a loop to arrive at findings.

Results

The maximum speed reached was 12.55 ± 0.44 km/h while the minimum speed was 6.23 ± 0.09 km/h. The total cost of the wheelchair was ₦ 174,000.00, this shows a sharp contrast to the cost of the imported ones in the market which is about ₦ 600,000.00. ($1 = N 450.00).

Conclusion

The wheelchair which is cost effective responded to commands issued, and also can allow for long distance travels as a result of the solar panel for charging.

1.0 Background

The number of physically challenged persons either by birth or as a result of accident or old age is increasing at a rapid rate; it is estimated statistically that about 15% of the world population belongs to these category of persons [1]. A study by [2], (2017) present that there are over 2 billion disabled persons world-wide and most of them are from developing countries; the Nigerian National Assembly in 2013, estimated that there are about 20 million disable persons in the country [3].

Following nine years of tireless advocacy by disability rights groups and activists, Nigeria's President signed the discrimination against persons with disabilities (Prohibition) Act, 2018, into law on January 23, despite this, many of them continue to face human rights violations such as stigma, discrimination, violence, and lack of access to healthcare, housing, and education. Such persons find it very difficult to move from place to place. In developing countries, they resort to the use of crutches or manual wheelchair which are often times assisted by their family members or guardians for mobility [4]. Furthermore, some of the disabled are physical weak, thereby making it is impossible for them to impel a manual wheelchair for long distances [5]. Smart wheelchairs are electric powered wheelchairs with many extra components such as a computer and sensors which help the user or guardian for easy and efficient handling of the wheelchair. Based on the technological and scientific progress, from manual to electric powered wheelchairs that uses joystick as controller, which have gone a long way to assist disabled persons, but this will not in all cases be suitable for some disable persons; therefore, based on the Human Machine Interfaces (HMI), joysticks controller, voice recognition, eye-gaze tracking etc. which are inputted to make up for lapses in manual wheelchair have evolved [6]. Wang and Chiang [7]; Li and Wang [8]; Thomas [9] and Brown [10], all worked on design and control of a proton exchange membrane fuel cell (PEMFC) powered electric wheelchair, their aim was to minimize air pollution and global warming. Gurram et al [11]; Quaglia and Nisi [12], worked on design of a self-leveling cam mechanism for a stair climbing wheelchair. Their aim was to improve wheelchair performance in terms of stability and smoothness during stair movement. Saharia et al [13] and Gurram et al [11] worked on controlled mechanism for ease of forward, backward, sideward movements. Joysticks were mostly mounted at arm-rest of the wheelchair, but for those without fingers, other choices were available such as sip-and-puff controllers. Wallam and Asif [14]; Asgar et al [6]; Chowdhury et at [15] all worked on finger movement tracking of wheelchair. Mazo et al [16]; Meena et al [17] and Aktar et al [18] saw the need of users without fingers, such users can communicate with the system by giving voice command. Lin et al [19] and Wanluk et al [20] worked on eye-controlled wheelchair. Different techniques and measurement for this type of systems include coil searching method etc. were used.

Badejpko-Okunade et al [21], worked on development of an Automator (ergonomically attached) that converts a manual wheelchair into an electric wheelchair for domestic use by physically impaired persons in Nigerians who cannot afford the exorbitant cost of a ready-made motorized or electric powered wheelchair. Ogbonna et al [22] in their work, development of solar powered electric wheelchair for physically challenged persons proposes a solar power assisted wheelchair for the disabled low-income persons living in developing countries like Nigeria. Ajibola and Iyonmahan [23], in their work, design and fabrication of bi-directional electronic driven wheelchair, accessed the possibility to domesticate the technology and making it available for investors involvement and ultimately affordable to cater for the growing population of the disabled persons in Nigeria. Peter et al [24] and Ajibola et al [23] both considered cost and source of power in their separate works solar powered wheelchair for lower limb amputee and design and fabrication of indigenous electronic driven wheelchair. The above works took advantage of availability of enough solar irradiation in Nigeria, and the low income of disabled persons in the country. This paper aims to design a cost effective solar powered wheelchair with a dual control system; button and voice control for disabled persons in Nigeria. The automation of the wheelchair was achieved by the process of hardware programming, using Arduino platform. The development of voice recognition device will be carried out using the software, ‘Arduino Studio’. Comfort of the user, durability, simplicity and cost were highly considered and given attention in designing the smart wheelchair.

2.0 Materials And Method

By the use of anthropometry parameters from the works of Ajibola et *al* [23], quality, cost, availability of local materials and their mechanical properties were considered for the design. The basic materials used included mild steel, aluminium, galvanized pipe for the frame work, backrest, seat, leg rest, foot rest, headrest, DC battery, solar module, panel for control buttons, DC motors and other basic electrical components. The 3D modelling and assembling was carried out using CREO parametric version 6.0 application software in order to have accurate dimension and visual illustration of the proposed model as shown in Fig. 1(a, b, c and d comprising of side, front, top and general view respectively) while Fig. 2 represents the exploded view. The prototype of the wheelchair was then fabricated and assembled using locally available materials.

2.1 Design considerations/methods

A 0.5-inch galvanized steel pipe was used for the frame which form the skeleton of the wheelchair, it was cut into different lengths and arc welded, with a half inch sheet of mild steel for covering the base and half-length of angle bar for housing both the solar panel and batteries, while 1 ft sq. fibre for padding the button control. The design specification of polycrystalline solar panel with length, width and depth of 36.6 inch, 12.4 inch and 0,8 inch respectively having a wattage of 50 W, amperage of 2.8–2.95 A and voltage of 17.8 V was chosen. Other factors that were considered in the design was load, and speed. Table 1 shows some other technical specifications of the wheelchair. The maximum speed of the wheel chair was 8.33 km/h (Chien 2014), weight on each wheel, torque, power, energy of the battery and time of its charging were calculated as shown below:

Table 1

Technical specifications of the wheelchair

Specifications of the wheelchair	**Details**
Size:	0.84 by 0.58 by 1.45 m
Weight with system	40 kg
Seat	Cushioned
Braking system	Disc brake
Max load weight capacity	125 kg
Tyre size	0.19m (rear wheel)
	0.10m (caster)
Solar panel	50 W (17.8 V, 2.8 A)
Batteries	Lead acid battery, 12v – 18A-hr
Motor	0.335 Hp (DC), 24 V
Charge controller: Solar based (MPPT)	Multi Point Power Tracking

Taking the maximum speed of the wheelchair as 8.33 km/h, and using the relationship between linear and angular speed, the speed of the wheel required to achieve a desired speed is given as:

Taking max speed of wheelchair as = 8.33 km/h

RPM of shaft wheel (let say N) = (8.33x 1000)/ (60 x 60) = (3.14 * 0.669 * N)/6

RPM = 66

Where d is 0.669 m, the diameter of the rear wheel of the wheelchair, n is the speed of the rear wheel of the wheelchair (rpm).

Weight (on each wheel) = 20 x 9.81 = 196.2 N;

where 20 is an assumed weight on a wheel

Torque (T) = 196.2 x 0.19 = 37.28 Nm; where 0.19m is the radius of the rear wheel

Power = (2 x 3.14NT)/60 = (2 x 3.14 x 66 x 37.28)/60 = 258 W

Energy of Battery = 216 W/hr

Time of Charging = 216/258 = 0.8 hrs

2.2 Connection Procedure

The control system for the wheelchair was designed on a computer using fritzing software so as to validate connections. The control components and modules were then assembled according to the appropriate method of connection represented on the computer design. An Arduino sketch was written in Arduino programming language that was meant to control the module in a required manner. Figure 3 shows the circuit connection for the control panel. However, the voice command was programmed and synchronized with the voice recognition device and then a Bluetooth connection was used to pair the connections.

2.3 Description of the voice controlled and solar assisted wheelchair.

The wheelchair consists of the battery housing, wheels, driving motors, 12 v batteries, solar panel, etc. The front and rear wheels carry the entire components of the wheelchair with the rear wheels fastened to the driving motor. The battery housing carries the fabricated frame upon which the rechargeable 12v batteries sits. The batteries supply electrical energy to the motors, electrical and automation components.

2.4 Principle of Operation

The principle of operating the wheelchair was achieved by the conversion of energy by different components that had been used in the course of its fabrication. The electrical energy of the battery was converted to mechanical energy through the two D.C. motors to the rear wheels for driving the wheelchair. The electric circuit ensures power transfer from the battery to run the D.C. motor, whilst the solar panel powers the wheelchair when in use and help store energy to the battery hence compensating for its discharge. The voice interface was programmed, designed and 3D printed to be held handy by the user while in operation or by a third party to help the disabled. The voice module device had the power button incorporated in it and thus the user receives a welcome message when powered on. The voice module automatically pairs with the wheelchair and recognizes the following commands; forward, backward, left, right and stop. When the user issues a recognized command, the voice module picks the command and transmits to the wheelchair which it is paired to and hence the wheelchair obeys the commands in splits of seconds. However, when the user issues an unrecognized command, the wheelchair sends feedback to the user by making a different beep sound from the recognized command beep. The wheelchair was programmed to accept English and four (4) other local languages. This means, the user will train the voice module on the particular language (using the manual) he/she will want to be using so as to make them recognized commands. The various languages incorporated include the three major languages in Nigeria; Hausa, Igbo and Yoruba or any language of the user’s choice. The system also responded perfectly to the buttons control which was designed as well. A flow chart of the control is as shown in Fig. 4.

The user issues a command using the Sparkfun PID 15453 voice module which is paired to the Arduino Uno R3 board carrying the Atmega328 microcontroller via the ESP8266 HC05 Bluetooth module, it is received as bits by the voice module from the user and then transmitted to Arduino Uno R3; it uses C++ programming language and has its own Integrated Development Environment where the codes were written hence its converts the transmitted audio to signals and sends it to the 12V – 10A electric DC motors passing through the 5 v relay modules where it is interpreted and acted upon to obey the command issued. The DC motors converts the electrical energy supplied from the battery to mechanical energy thereby providing motion which makes the wheelchair move. The 50 W polycrystalline solar panel was connected to a 12 V PWM charge controller which regulates the voltage entering the 12-v battery so as to avoid overcharging or discharging. However, same applies to the system when the user issues a command using the control button. The control buttons were built using resistors of varying capacities which include (10, 8.2, 6.8, 4.7, 3.3, and 33) k Ω. Veroboard was used to connect the various components together. The block diagram for the control algorithm is shown in Fig. 5 below.

3.0 Results

Speed is one of the critical performance factors for maximizing wheelchair configuration, according to Mason et al. [26]. Level, incline, and decline roads served as the basis for the performance analysis. Ten (10) separate tests were used to collect all the data, analyze and statistically expressed each result using its average. The highest acceleration was 0.74 ± 0.09 m/s^2 at a maximum driving current of 18.5 A, and the maximum speed reaches 8.33 ± 0.15 km/h in steady state at an average driving current of 6.0 A when an 85 kg driver propels the wheelchair on a flat road. The wheelchair slows down throughout this time, stopping within 2 seconds of its full speed. The braking distance was around 0.82 ± 0.05m and the greatest deceleration was 1.26 ± 0.12m/s^2. When the wheelchair was moving up at an angle of 10.5 degrees on a hilly road, the maximum acceleration was 1.40 ± 0.60m/s^2 with a maximum driving current of 22A, and its maximum speed reaches 6.23 ± 0.09 km/h in steady state at an average driving current of 12A. This test was done to determine the wheelchair's maximum torque and power capacity. It was found that propelling the wheelchair uphill needed more thrust force and current during the soft-starting mode, which resulted in a larger start-up acceleration. The maximum acceleration during the uphill test was also higher than that on the level road. The wheelchair stopped after traveling roughly 0.51 ± 008m during the braking period, with an average deceleration of 1.62 ± 0.22m/s^2. A downhill test was performed to evaluate the wheelchair's braking capacity. The wheelchair could go at a top speed of 12.55 ± 0.44km/h on a slick, 10.5 degree slopy road. The average deceleration was 1.83 ± 0.21m/s^2 and the average braking distance was 2.0 ± 3 0.22m during the braking time. The driving range test was performed around a square loop of a level road of 200 m by an 85 kg dummy. Figure 6 shows the plot of velocity vs time for the various road test carried out.

4.0 Conclusion

The current design integrates sustainability, cost effectiveness, and a seamless control of a smart wheelchair. The disabled in Nigeria can now afford a smart wheelchair; the design and fabrication also seek to support the implementation of the Bill of Act 2019 passed into law by the Nigerian presidency for inclusion of disabled persons into the society. The smart solar powered wheelchair responded to commands issued, and also can allow for long distance travels as a result of the solar panel for charging. In Nigeria, the potential of this product to deliver a significant number of persons and make them independent is eminent. This work if supported by the Government, can go a long way to solving the mobility problems of the physically challenged persons in the country. Figure 7(a) presents summary of the cost analysis of components, design and fabrication of the wheelchair, while 7(b) is the final assembly of the fabricated solar/voice-controlled wheelchair.

Due to the increase in the exchange rate of naira to dollar as at the time of research, the total cost of the wheelchair as shown in Fig. 7 (b) above was ₦ 174,000.00, this shows a sharp contrast to the cost of the imported ones in the market which is about ₦ 600,000.00 [23].

Abbreviations

D.C – Direct Current

₦ - Naira sign

$ - Dollar sign

V - Voltage

W - Watts

PID - Parameter Identification

A - Amperes

PWM - Pulse Width Modulation

m/s - Meter per second

km/h - Kilometer per hour

Declarations

Ethics Approval

Not Applicable

Consent for publication

Not Applicable

Availability of data and materials

The data that support the findings of this study are available from Dr. Victor Achrigbenda but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Achrigbenda Victor (achirgbenda.victor@uam.edu.ng).

Competing interests

The authors declare that they have no competing interests

Funding

This work was supported by the Forging Africa’s Future Mechanical Engineers under the Nigerian Institution of Mechanical Engineers (NImechE) auspices of the Royal Academy of Engineering UK. Grant awardee: Engr. Oduwa Agboneni, FNIMechE 2020.

Authors' contributions

VA ensured the overall result of the work meets international standard. He contributed immensely to the literature and general overview of the work. He was the principal investigator of this work as the work was developed in his lab.

KO carried out the CAD designs, technical analysis and prototype developments to achieve the desired result.

Acknowledgements

We’d like to acknowledge the efforts of David Daniel, Adu Lawrence and Lawal Samuel who aided in one way or the other to the development of this prototype.

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Figures

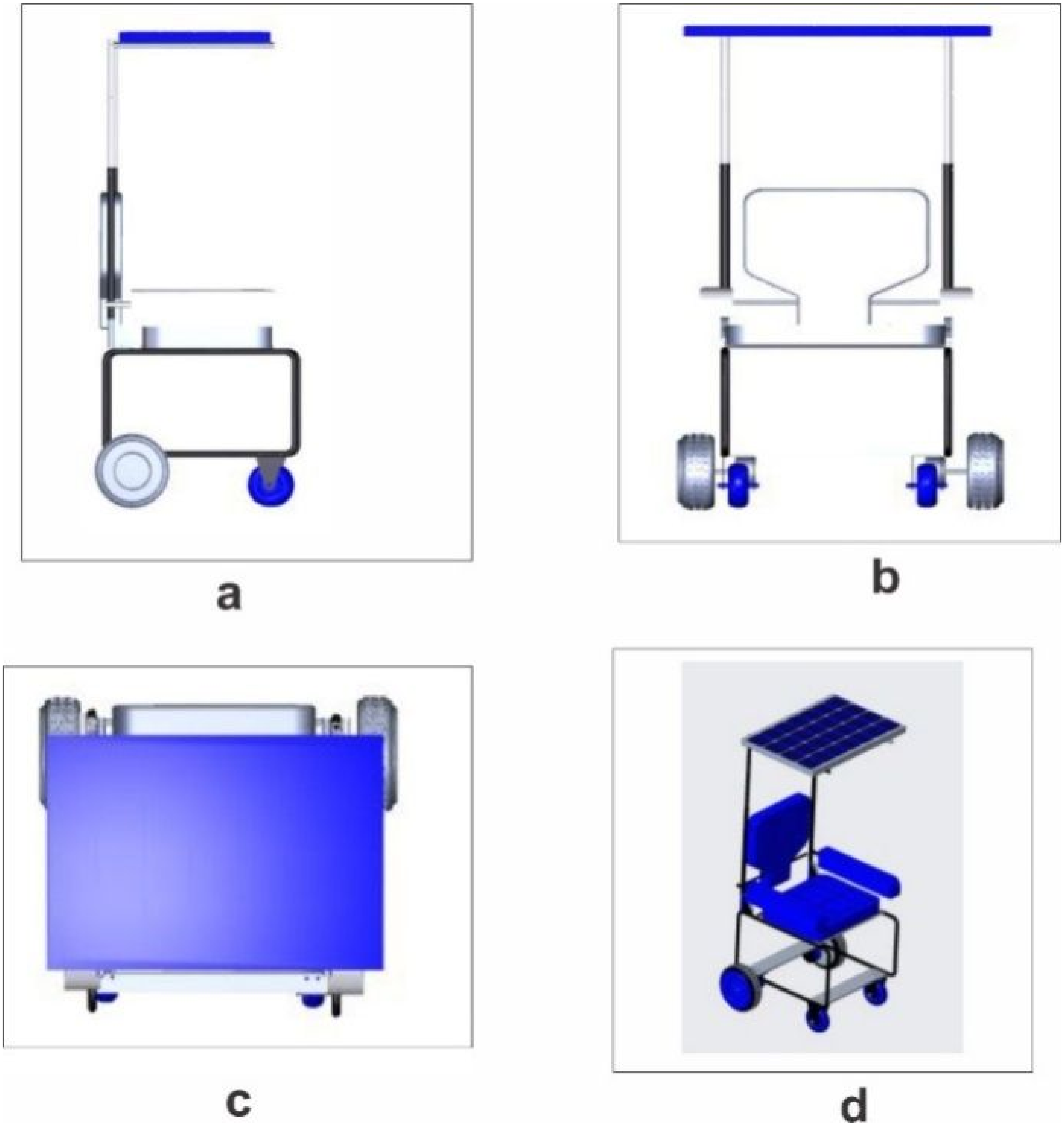
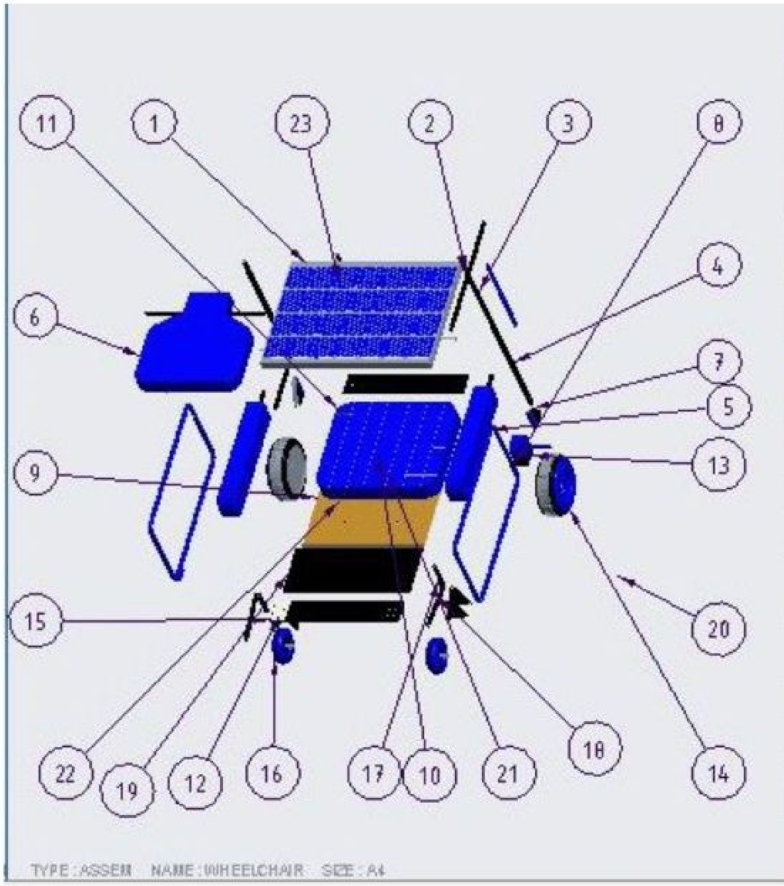


Figure 1

Caption: Side, front, top and general view of the 3D model

Figure 1 Alt Text: ACAD drawing of the voice-controlled wheelchair using CREO PTC software for the different views. **Fig a**. Side view of the wheelchair CAD drawing. **Fig b**. Front view of the wheelchair CAD drawing. **Fig c**. Left to Right: Top view of the wheelchair CAD drawing. **Fig d**. General view of the wheelchair CAD drawing.



S/No	Name	Type	Quantity
1	SOLAR_PANEL	PART	1
2	SOLAR_PANEL_SUPPORT	PART	2
3	BACK_SUPPORT_1	PART	2
4	BACK_SUPPORT_DOWN	PART	2
5	ARM_REST	PART	2
6	BACK_REST	PART	1
7	JOINT	PART	2
8	BASE	PART	2
9	BATTERY_SEAT	PART	1
10	SPRING	PART	4
11	SEAT	PART	1
12	CASTER_TOP_SUPPORT	PART	2
13	DC_MOTOR	PART	2
14	TYRE_2	PART	2
15	CASTER_MAIN	PART	2
16	TEST	PART	2
17	LEG_REST_MAIN	PART	2
18	M8_BOLT	PART	40
19	LEG_REST_SUPPORT	PART	1
20	M8_SHORT	PART	8
21	M8_TYRES	PART	4
22	NUT_8	PART	40
23	ANGLE_SUPPORT	PART	2

Figure 2

Caption: Exploded view of the 3D model of the wheelchair.

Figure 2 Alt Text: A detailed assembly drawing showing the various components of the wheelchair CAD drawing using CREO PTC software with 23 components all exploded.

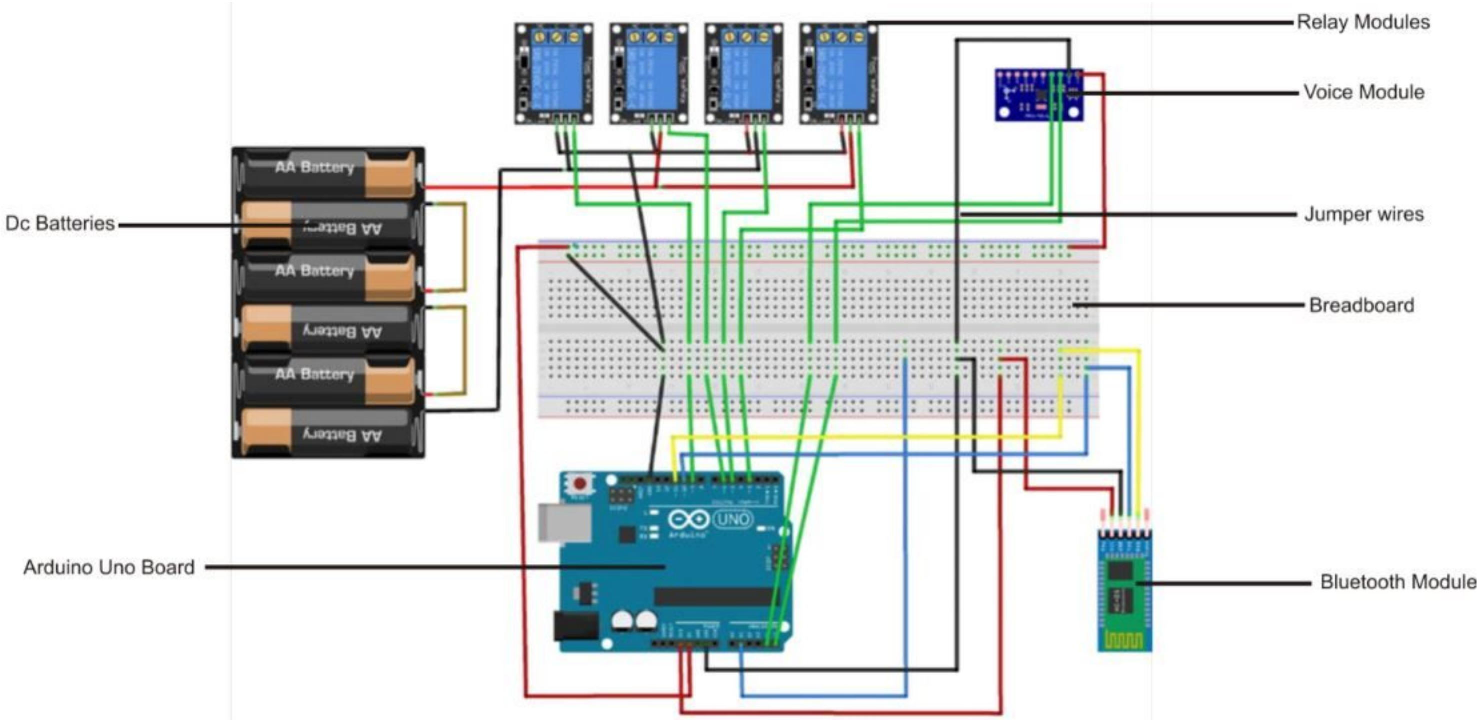


Figure 3

Caption: The circuit connection of the control panel.

Figure 3 Alt Text: The circuit connection of the various electronics components for the control panel which was designed using Fritzing software for connection check and connection flow.

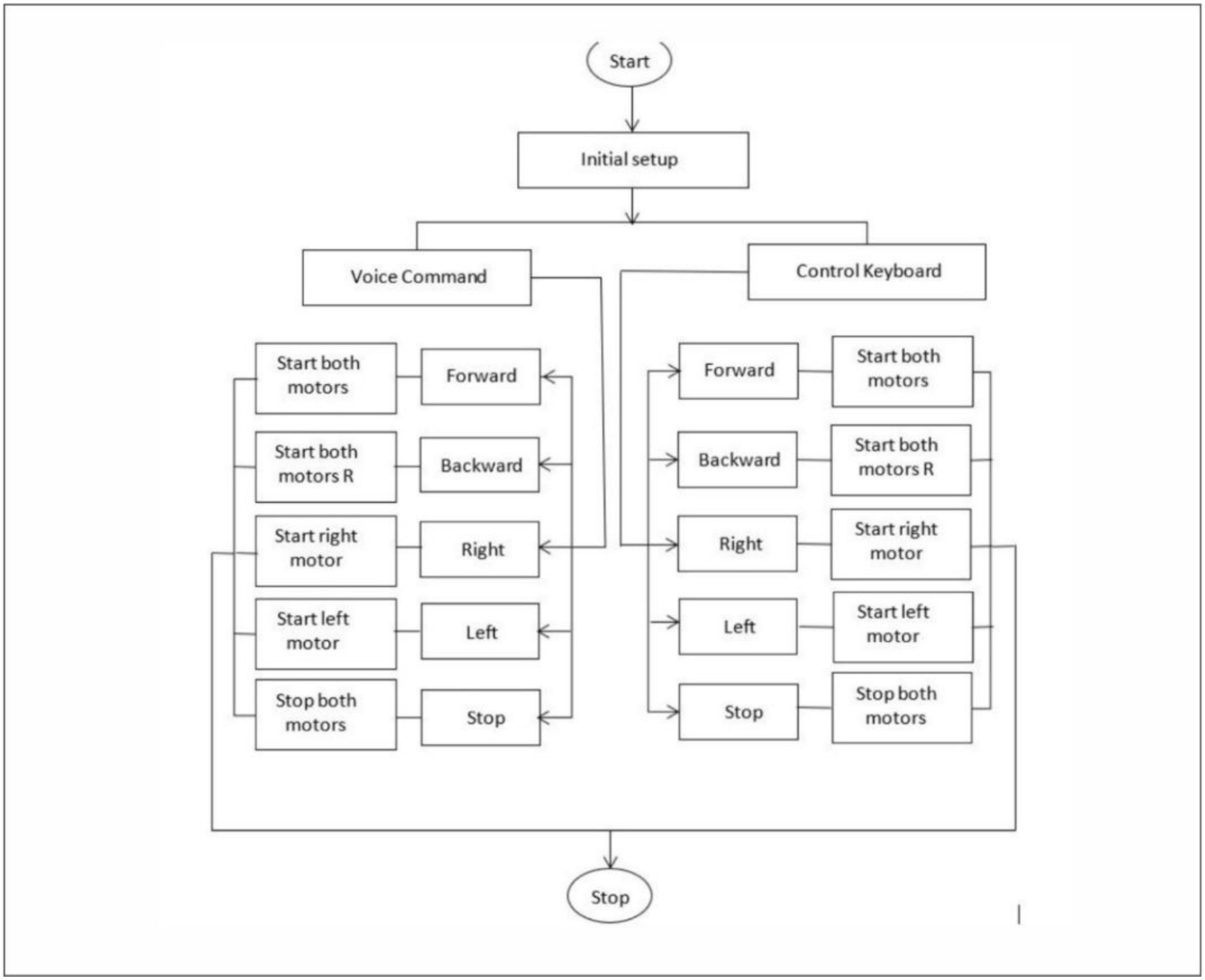


Figure 4

Caption: Flow chart for wheelchair control systems.

Figure 4 Alt Text: The various processes in which the wheelchair communicates with the board represented in a flowchart system from the start option to the end/stop option and various commands indicated in the square boxed.

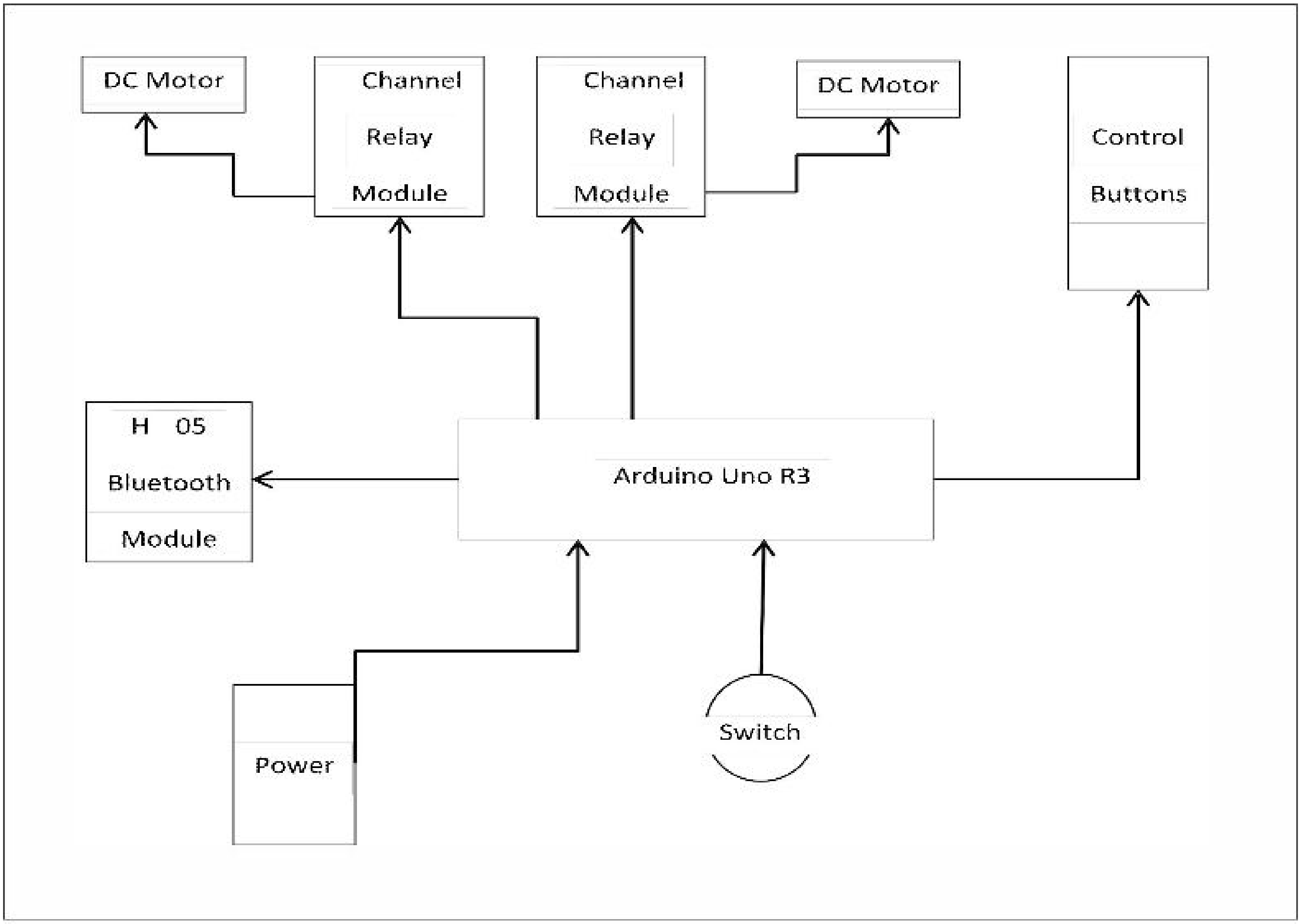


Figure 5

Caption: Block diagram for the Control Algorithm.

Figure 5 Alt Text: A diagram of which shows how the Bluetooth module communicate with the dc motor and actions occurs all represented in a flowchart system in boxes and circles.

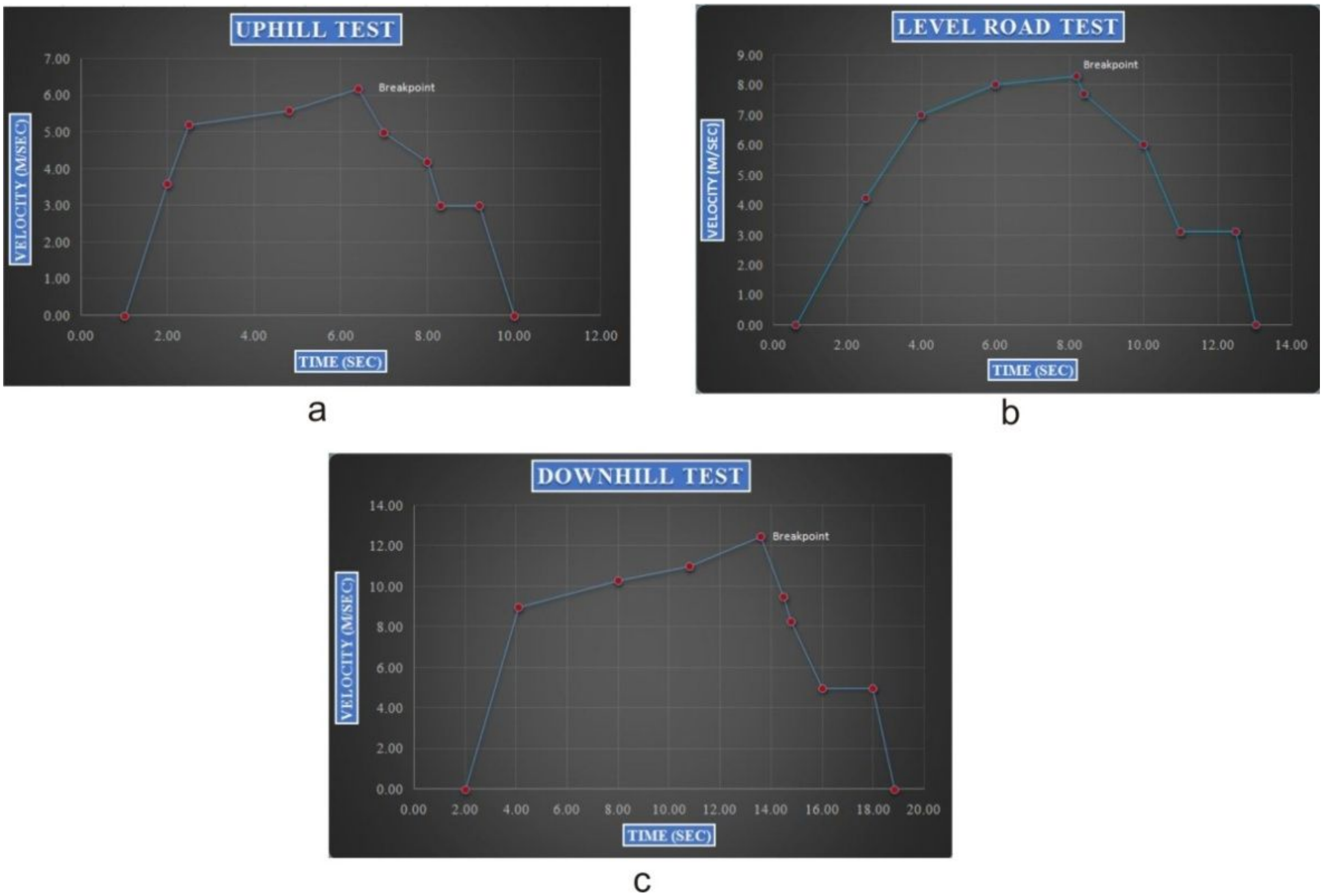


Figure 6

Caption: (a) Uphill test (b) Level Road test (c) Downhill test.

Figure 6 Alt Text: Fig a. The uphill test shown in graph with the maximum speed of 6.23 ± 0.09 km/h in steady state. **Fig b.** The level road test shown in a graph with a maximum speed of 8.33 ± 0.15 km/h in steady state. **Fig c.** The downhill test shown in a graph with a maximum speed of 12.55 ± 0.44km/h down at a sloppy road of 10.5 degrees

DESCRIPTION	QTY	PRICE (₦)
Voice Module	1	16,000
Arduino Mega 2560	2	20,400.00
Bluetooth Module	2	9,331.00
Bread Board MB102	3	1500
Casters and Rear Wheels	2 pairs	12,000
Length of Steel pipes for framework	4	10,750
Bending of steel pipes	1	2,200
1/2 inch of 3/4 galvanized steel pipe	1	1,500
1/2 inch galvanized steel pipe	1	3,000
Fabrication	1	11,500
Bolt and nut	20	2,600
Angle bar	1	1,000
cushion for seat	33 in	2,000
cushion covering	1	1,350
cushion for back rest	1	3,000
angle bar	1	1,800
soldering iron and lead	1	1,900
Jumper wires	bulk	2,700
Vero boards	2	800
speaker and lead for circuit	1	450
M13 bolts and nuts	2	50
Resistors	1	250
9v batteries	3	450
Battery connectors	bulk	300
M10 bolts, nuts and washers	bulk	880
Seat belt	1	580
circuit box	1	700
Battery wires	2 yards	570
Spanners and logistics	bulk	670
seat belt strap	1	200
Hot blue gun and filament	1	1,600
switches	2	100
Painting and spraying of frame work	1	7,600
50W panel and logistics	1	13,000
12v Dc battery	2	15,000
Electric Dc motors	2	22,000
Solar charge controller	1	5,000
TOTAL		174,731

a

b

Figure 7

Caption: Final assembly and cost summary of the solar/voice-controlled wheelchair.

Figure 7 Alt Text: A pictorial representation of the final constructed project in a stable condition and a table showing the various materials used with the cost implications in Naira (NGN).