Vol 8. No. 3 Issue 2 – October, 2015
African Journal of Computing & ICT

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Design and Construction of a Battery-Powered Microcontroller-based Wheelchair

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ABSTRACT

In response to the prevalence of lost limbs in our society due to accidents, health problems, wars and age, this work is aimed at designing and constructing a battery-powered microcontroller-based wheelchair for paraplegics, which will alleviate the difficulty users experience when using crutches or manually operated wheelchairs. Such wheelchairs, commonly called power wheelchairs, are not uncommon in the society today. The system components draw power from a rechargeable deep-cycle battery which is designed to be discharged to up to 20% of full charge without damage and to be used in recreational vehicles (RVs). The Microcontroller Unit is the hub of the system as it receives input commands from the Drive Input Unit, processes these commands and issues appropriate control signals to the Motor Driver Units which drive the DC motor actuators. The microcontroller is programmed using Assembly Language which is a low-level programming language. The mechanical section of the project is comprised of the chair frame, rear and front DC motor compartments, circuit compartments, wheels, axles, gears and peripheral casing.

Keywords: Wheelchair, microcontroller, DC motor, assembly language, programming, deep-cycle, battery.

African Journal of Computing & ICT Reference Format:
S.U. Ufoaroh., O.S. Nnamonu, A.N. Aniedu & G.N. Okechukwu (2015): Reverse Probability Weight (RPW): Design and Construction of a Battery-Powered Microcontroller-based Wheelchair. Afri J Comp & ICTs Vol 8, No.3 Issue 2 Pp 153-162

1. INTRODUCTION

It is quite appalling the prevalence of lost limbs today due to accidents, health problems, wars and age. Victims of such circumstances cannot comfortably move from one location to another, be it indoors or outdoors. There is therefore the need to solve this problem by designing an alternative means of transport. This is the idea behind the design and construction of a battery-powered microcontroller-based wheelchair for paraplegics. A paraplegic is one who is paralyzed from the waist downwards, and can thus make use of the upper limbs. The proposed project solves the problem of indoor and outdoor movement the paraplegics have by providing a medium-power, easy-to-control wheelchair.

2. BACKGROUND OF PROJECT

The proposed project consists of electronic and electromechanical sections. The electronic section is pivoted on the microcontroller Integrated Circuit (IC) which receives input commands from buttons on a keypad, processes them, and issues out appropriate control signals. Also included is a charge controller that prevents the battery from overcharging beyond a certain predefined extent. The electromechanical section is comprised of two worm geared, brushed DC motors with their interfacing circuitry. One DC motor for the forward/reverse direction of the rear wheel and the other for the left/right direction of the front wheel. The frame of the wheelchair shall be a chair of light weight metallic material modified by welding to support the battery and control circuitry. (See Fig.1)

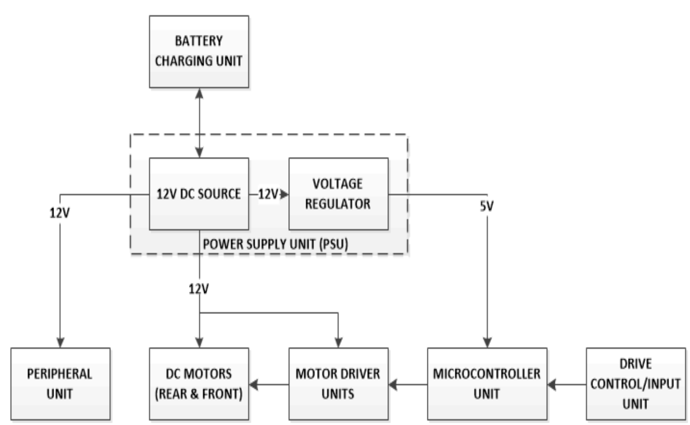

Fig. 1: The block diagram of the proposed wheelchair.

The block diagram explains the principle of operation of the project: The Battery Charging Unit (BCU) consists of a rectifier circuit that converts 240V AC mains to 14V DC sufficient to charge the 12V deep cycle battery. Also included in the BCU is a Charge Controller that prevents the battery from overcharging. The Power Supply Unit (PSU) is made up of the 12V battery and a voltage regulator. The output of the regulator is used to power the microcontroller. The Drive Control/Input Unit comprises buttons and levers for direction and speed control. The Microcontroller Unit (MCU) is comprised of the microcontroller IC and the required circuit components for its proper functioning. The Motor Driver Units (MDU) consist of transistors, diodes and relays. The MDU receives signals from the MCU, amplifies them and finally drives the DC motors accordingly. The MCU receives signals from the Drive Input Unit (DIU). The Peripheral Unit consists of a horn and a bright LED light source for improved vision when wheelchair is driven in poorly lit areas.

3. REVIEW OF RELATED WORKS

This section is aimed at reviewing previous works done on microcontroller-based wheelchairs. In their design of a low-cost intelligent wheelchair, [1] built the control circuitry around the PIC16F877A microcontroller. They also included in their design a voice recognition system and an obstacle detection system. For their motor driver circuitry, they used the ULN2003A (Darlington Transistor array) IC and four relays to give all direction movements and also stop. The Darlington Transistor array circuit is responsible for converting the microcontroller's output signal of 5V to the relay operating voltage of 12V. They chose two DC motors each of which carry 25kg so the two collectively carry 50kg including the wheelchair components. They used a membrane keypad which made it easier for the buttons to be pressed. Also included in their design is a small Liquid Crystal Display (LCD, 2×16) used to display the command given by the user. It also shows the response of the intelligent wheelchair and gives feedback to the user regarding a scenario such as detection of an obstacle.

[2] did a similar work to [1] in their design of a Microcontroller-based intelligent wheelchair. The major difference being the use of a different microcontroller, the PIC18F452 and the use of four (4) stepper motors. In the works of [3] [4] and [5] it was gathered that they incorporated into their design, voice recognition systems. Oral commands are stored in memory using a keypad and uttered when a specific function is required. Various drivers were used to drive the DC motors; [3] used electromechanical relays, [4] used the L298 motor driver IC, [5] used the L293D motor driver IC. In the work of [6] on an automatic wheelchair for disabled persons, they used accelerometers as one method of direction control input to the system and speech recognition as the other. They also used ultrasonic sensors for automatic obstacle detection.

For the motor control assembly, they used the L293D dual H-bridge motor driver. It is dual in that with one IC, two DC motors can be controlled if they rotate in two directions (i.e. forward and reverse). However four DC motors could be driven by the same if the motors are to rotate in a fixed direction. They made use of an ARM 7[1] microcontroller which was programmed in C using Keil µVision4 Integrated Development Environment (IDE) and simulated on Proteus Virtual Systems Modelling (VSM) software. In the design of [7], the source of input to the system is a joystick. The PIC18F4520 microcontroller is used in their project to process inputs from the joystick and drive the geared DC motors. They also used optocouplers in-between the microcontroller and the H-bridge motor driver to prevent the higher voltage on the motor side from affecting the microcontroller.

4. METHODOLOGY AND SYSTEM OPERATION

4.1 Methodology

This project is comprised of two sections viz:

i. **Mechanical section;**
ii. **Electronic section.**

The mechanical section is comprised of the chair frame, rear and front DC motor compartments, circuit compartments, wheels, axles, gears and peripheral casing. The chair frame typically is made up of the headrest, backrest, cushion, leg rest and a panel for the control buttons. The motor compartment is a casing for the DC motors. There are two of such, one for the rear and the other for the front. The battery and Vero boards which make up the system circuitry are contained in the circuit compartment. The axle, gears and wheels are assembled in such a way that friction is reduced. This is achieved using bearings.

The chair frame and wheels were procured from Onitsha Main Market in Anambra State and reconstructed, by welding, into a standard wheelchair with the other compartments included. The system circuits were designed on Proteus Virtual Systems Modelling (VSM), a Computer Aided Design (CAD) system, which is comprised of, among other tools, the Schematic Capture Tool (SCT) as a means of design entry into the system as well as the Simulation Tool for verification of the modelled system under analysis. Afterwards, the components were bought. The different electronic units that make up the entire electronic part of the system were first constructed on a breadboard. After the various electronic circuits had been tested and certified to work, the circuits were soldered onto Vero boards.

The program that would drive the system, written in Assembly language, was burnt onto the microcontroller. Further tests for open and short circuits were carried out. After the construction of the mechanical and electronic sections of the system were certified to be working properly, they were assembled into a functional power wheelchair.

[1] Advanced RISC Machine, RISC stands for Reduced Instruction Set Computer

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Other parts of this project follow the systematic way of achieving the aim of the project starting from component review and design, calculation of component values and their choice thereof, analysis and implementation (with simulations and schematic captures), assembling and packaging as well as the testing of the entire system. The choice of programming language to be used was determined by the AT89C51 microcontroller architecture; hence Assembly programming language was used in developing the firmware embedded in the microcontroller.

4.2 System Functional Operations

This section is aimed at presenting detailed and functional insight into the constituents of each of the blocks of the system (shown in Fig 1)

Battery Charging Unit (BCU): The Battery Charging Unit (BCU) is responsible for converting the 220V AC mains to 14V DC which is capable of charging the 12V DC battery. It is also responsible for increasing the lifetime of the battery; it does this by preventing the battery from overcharging.

The BCU is made up of a *rectifier* and a *charge controller*.
The **rectifier** circuit is responsible for converting the 220V ac mains supply to the 14V dc capable of charging the 12V battery. The block diagram is shown in Fig. 2
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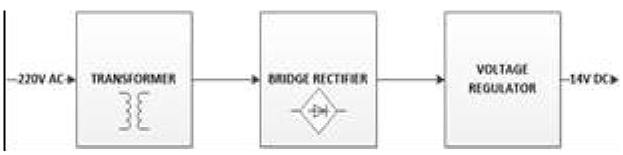

Fig. 2: The Block Diagram of the Rectifier

The Transformer block contains the transformer. It is wound in such a way as to accept 220V ac mains at its input and give out 20V ac at its output. This 20V is still alternating and is rectified by the bridge rectifier contained within the Bridge Rectifier block. The rectified 20V is still pulsating in the positive sense and is then smoothened by a smoothening capacitor connected in shunt before being regulated by the voltage regulator (LM338T). The capacitor and the voltage regulator are contained in the Voltage Regulator block. The regulator gives a regulated output of 14V DC which is then suitable for charging the battery. The rectifier circuit is shown in Fig.3.

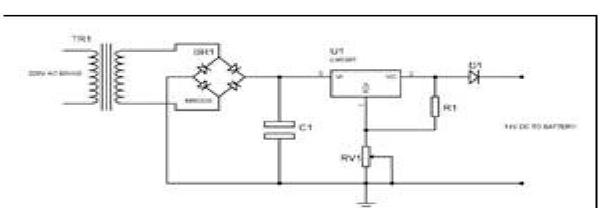

Fig. 3: The Rectifier Circuit

The **charge controller** circuit is responsible for preventing the battery from overcharging. The block diagram is shown in fig 4. .

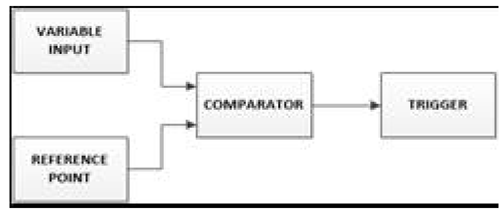

Fig. 4: The Block Diagram of the Charge Controller

The charge controller is a form of two-position control response where the controller compares an analogue or variable input with instructions (reference input) and generates a digital (or two-position) output. In this case, the controller is the comparator. It compares the variable input signal corresponding to the battery voltage level to the fixed reference input signal and generates an output based on the comparison. The trigger is the actuator and is responsible for turning off or on the charging of the battery. The circuit schematic is shown in fig 5..

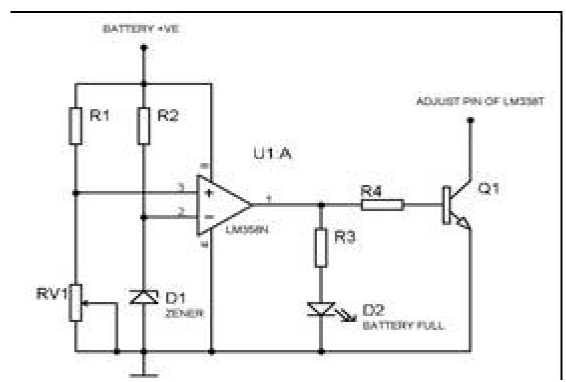

Fig. 5: Charge Controller Circuit

Here, the LM358N IC is configured as a voltage comparator. The fixed reference input is achieved using the zener diode. The value of the fixed reference signal is equal to the zener voltage (V_Z) rating of the zener diode. The potentiometer is used to calibrate the variable input signal in such a way that a little over the fixed reference input voltage value (V_Z) corresponds to about 12V indicating a full battery.

The mode of operation of the charge controller is based on the electronic shutdown characteristic of the LM338T adjustable voltage regulator [8]. When the battery is fully charged, the voltage at pin 3 of the op-amp exceeds the fixed voltage at pin 2. Thus a HIGH is obtained at the output of the op-amp.

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This signal biases the NPN transistor which then shorts the *ADJ* pin of the LM338T to GND. According to the electronic shutdown characteristic, when the *ADJ* pin is shorted to GND, it ceases to give output. This then discontinues the charging of the battery.

Power Supply Unit (PSU): The Power Supply Unit (PSU) is responsible for supplying regulated power to the various blocks of the system. It is comprised of the *12V DC source* and a *voltage regulator*.

The power wheelchair gets electrical energy from the **12V DC source**. This is a deep–cycle battery. Deep-cycle batteries are used where power is needed over a long period of time and are designed to be "deep cycled", or discharged down to as low as 20% of full charge (80% DOD, or Depth of Discharge) [9].
The deep-cycle battery used in this project is rated 12V, 62AH (amp-hour). The 62AH rating means that if 1A is drawn from the battery, it will last for 62 hours before being fully discharged.

The **voltage regulator** is responsible for converting the 12V DC from the battery to 5V DC capable of powering low voltage circuit components, which include the microcontroller and operational amplifiers. The voltage regulator circuit is pivoted on the LM317T adjustable voltage regulator IC. The circuit diagram is shown in fig 6..

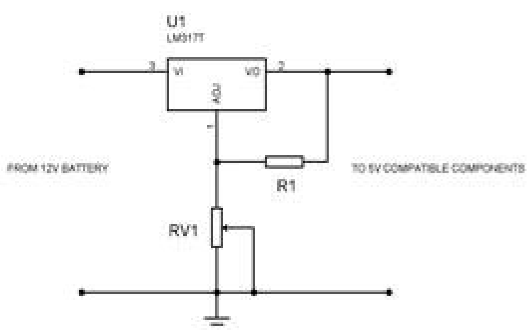

Fig. 6: The Voltage Regulator Circuit

The LM317T is a monolithic IC in TO-220 packaging intended for use as a positive adjustable voltage regulator. It is designed to supply more than 1.5A of load current with an output voltage adjustable over a 1.2 to 37V range. The nominal output voltage is selected by means of a resistive voltage divider, making the device exceptionally easy to use [10].

Peripheral Unit (PU): The peripheral unit (PU) of the power wheelchair is made up of a horn and a bright LED light source. These two draw power from the 12V dc source without any signal conditioning. The horn and light source are rated at 12V and so are connected in parallel to the battery. The circuit diagram is shown in fig. 7.

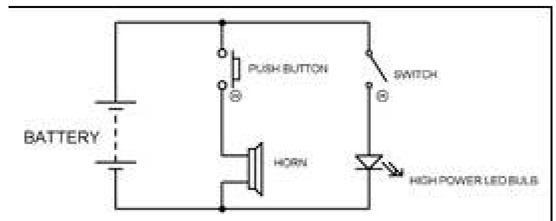

Fig. 7: The Peripheral Unit Circuitry

Microcontroller Unit (MCU): The microcontroller unit is the nucleus of the power wheelchair. The MCU receives input signals or commands from the Drive Control/Input unit, processes it according to the program burnt unto it, and gives out conditioned signals to the Motor Driver Unit. The MCU is made up of the *microcontroller IC* and other circuit components required for its proper configuration.

The **microcontroller** used is Atmel's AT89C51 microcontroller IC. It is a low-power, high-performance CMOS 8-bit microcontroller with 4 kilobytes of Flash programmable and erasable read only memory (EPROM) [11]. The AT89C51 is a 40-pin microcontroller numbered in an anticlockwise manner with reference to the notch. See fig 8.

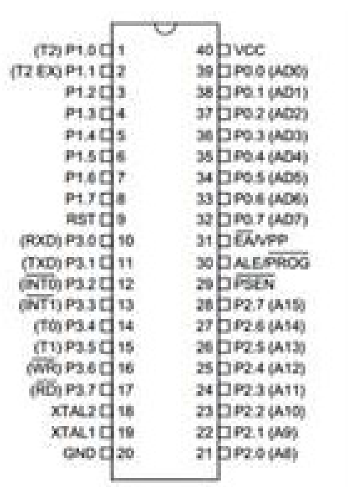

Fig. 8: Plastic Dual In-Line Package (PDIP) Pin Configuration of the AT89C51

The circuit connection is shown in fig 9. The values of the reset pin capacitor (C1) and resistor (R1) are chosen to enable a HIGH to be present on the reset pin for at least two machine

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cycles. This resets the microcontroller. The logic behind this is that the product of the capacitor and resistor is the time constant of the capacitor charging circuit.

During charging, a HIGH is on the reset pin. When C1 is fully charged, R1 acts as a pull-down resistor and pulls the reset pin low. The duration of the HIGH on the reset pin is the time constant τ.

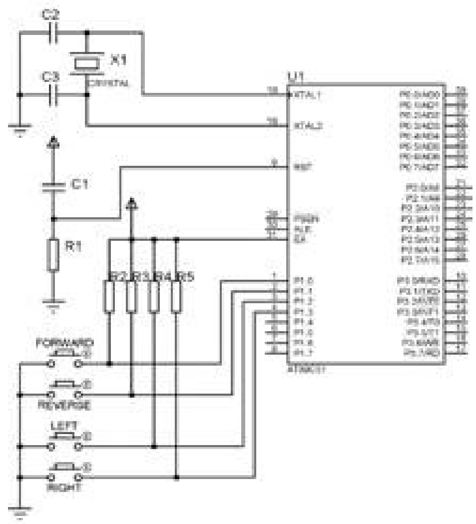

Fig. 9: Microcontroller Circuit Connection

The values of C2 and C3 (33pF each) are as recommended for use with a crystal from the AT89C51 microcontroller's datasheet [11]. This configuration is to configure the inverting buffer as an on-chip oscillator. The resistors R2, R3, R4, and R5 are connected as pull-up resistors. They also limit the current sunk into pins p1.0, p1.1, p1.2 and p1.3 respectively.

Motor Driver Unit (MDU): The Motor Driver Unit (MDU) is responsible for driving the DC motors; it is comprised of all circuitry used to interface the microcontroller unit to the rear and front DC motors. The MDU is made up of transistors, electromechanical relays and diodes. The circuit is shown in fig 10.

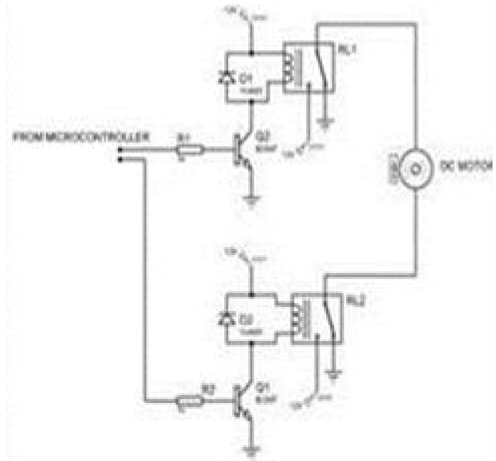

Fig. 10: Motor Driver Unit Circuit

It operates such that the Normally Closed (NC) terminals of the relays are both connected to GND, the Common (COM) terminals are connected to the DC motor and the Normally Open (NO) terminals are connected to the 12V source. Then for one direction of rotation of the DC motor, one transistor is biased by a signal from the microcontroller. This switches ON the corresponding relay which in turn allows power to the motor and the motor rotates. If the motor is to turn in the opposite direction, the other transistor is biased.

The diodes act as freewheeling or flyback diodes protecting the transistors from the voltage build-up when the relays are switched off.

Drive Control/Input Unit (DIU): The user gives direction and speed control commands to the wheelchair through the Drive Control/Input Unit. The unit comprises buttons and interfacing circuitry for direction and speed control. These commands are fed to the MCU which processes and issues out appropriate control signals to the MDU. See fig 9.

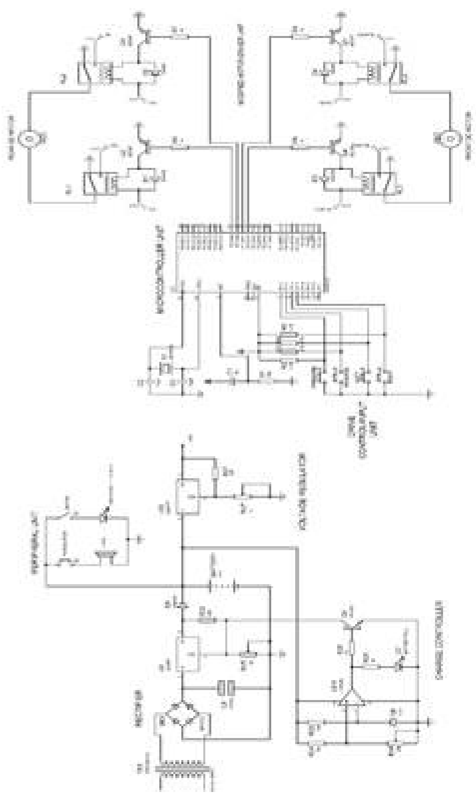

Fig. 11: System Circuit Diagram

DC Motors: In this project, two brushed DC motors are used. The front motor is for left and right directions whereas the rear motor is for forward and reverse directions.

The system circuit diagram is shown in fig 11and the program flowchart in fig 12.

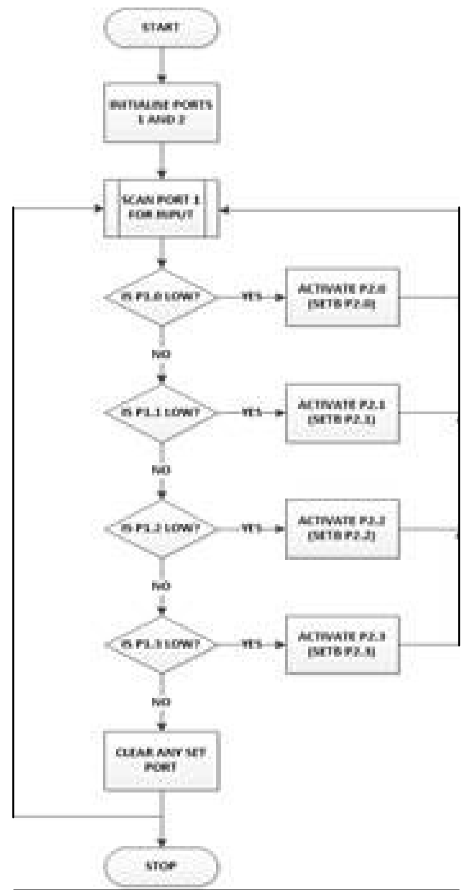

Fig. 12: Program Flowchart

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5. SYSTEM IMPLEMENTATION

This section is concerned with the stepwise approach to constructing the project. It is subdivided into *Mechanical* and *Electronic* subsections.

Mechanical subsection: The mechanical and structural components for the project were procured from markets in Anambra State. See Figure 3.

Figure 3: Mechanical and structural components

These components include the chair frame, rear and front wheels, rear and front DC motors, ball bearings, chains for linking gears, metal panels, hollow rectangular metal rods, nuts and bolts. First the rear wheel was put in place. Bearings, rear axle, nuts and bolts were used. The rear axle gear was affixed and the chain linking the rear DC motor to the gear was put in place..

Fig, 14: Rear Wheel Implementation

Then the front wheel was put in place. The front DC motor was affixed to the supporting frame and linked to the front wheel via pulley. See Figure 15.

Fig. 15: Front Wheel Implementation

Electronic subsection: The electronic section implementation of the project is subdivided into several sub-circuits namely: Battery Charging circuitry, Power Supply circuitry, Microcontroller circuitry, Direction Control circuitry and Motor Driver circuitry. All electronic implementation was carried out using a standard Vero board and all components where soldered onto the Vero board. for the circuit before the transformer was installed and was placed in its compartment. shows the composite circuit placed in its compartment.After the individual system components making up the design have been tested individually both through simulation and physically, the various sub systems were incorporated together and the final full system testing was carried out. This testing was also carried out through simulation first before physical implementation and testing. Several persons of varying weights were used to test how the overall system responded to various body weights and the system responded optimally. See for the final stages of implementation of the project.

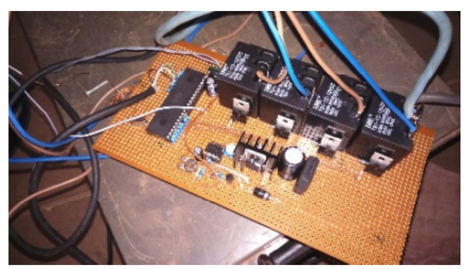

Fig. 16: Circuit on Vero Board

6. PERFORMANCE ANALYSIS

In this section, an account of the project is presented as being compared to the specific objectives of the project. Likewise, the performance of the system is obtained based on mass-current and mass-speed measurements.

Objectives: Specific objectives versus actual characteristics of the system are reported in Table **13**.

Table 13: Objectives compared with actual system characteristics:

Objectives	Actual characteristics
Battery-charging circuit and charge controller for recharging battery powering system.	Battery-charging circuit and charge controller working properly.
Use a suitable geared, brushed DC motor capable of carrying a mass of 80kg (approx. 800N).	This was achieved as the DC motor (Subaru WM-1220-2S) carried a mass of 90kg (wheelchair and user).
Use lightweight materials in wheelchair frame so as to reduce weight of system.	This was achieved as the wheelchair weighs about 7kg (without battery).

Performance: The mass-current relationship observed is reported in Table 2.

Table 2: Mass-current performance

Mass (kg)	Direction	Motor Current (A)
7 (no load, wheelchair only)	Forward	2.3
	Reverse	3.3
65	Forward	2.5
	Reverse	3.35
85	Forward	2.6
	Reverse	3.4

The performance in Table 2 is represented graphically in Error! Reference source not found.**17.**

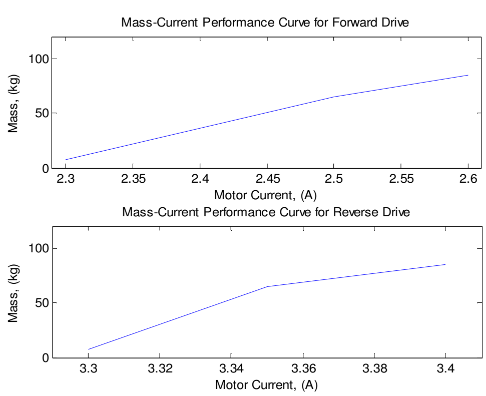

Fig.. 17: Mass Current Performance Curves

It is therefore observed that as the load on the wheelchair is increased, the motor draws more current from the battery source.
The mass-speed relationship observed is reported in Table .

Table 3: Mass-speed performance

Mass (kg)	Direction	Speed (m/s)
7 (no load, wheelchair only)	Forward	1.25
	Reverse	1.14
65	Forward	0.91
	Reverse	0.96
85	Forward	0.83
	Reverse	0.79

The performance in Table is represented graphically in 18.
From the foregoing analysis, it is observed that when a larger mass is placed on the wheelchair, a larger current is drawn by the rear motor. Also, a larger mass results in the wheelchair running at a lower speed.

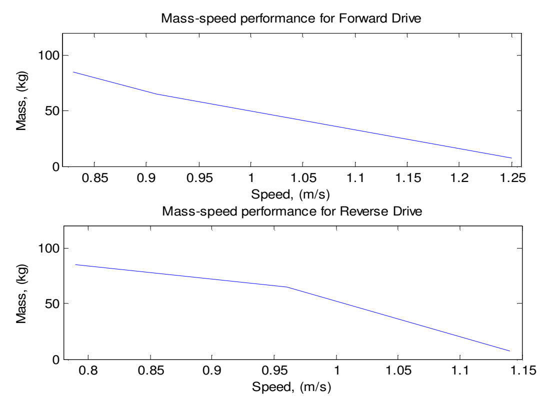

Fig. 18: Mass-speed Performance Curves

System Specifications: The system electrical and mechanical specifications are given in Table 4.

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Table 4: Sys4tem specifications

ELECTRICAL	INPUT:	
	220V-240V, 50Hz AC mains (charging).	
	OUTPUT:	
	12V, 90W (discharging or in use).	
MECHANICAL	LOAD:	
	100 kg (max.).	
	SPEED:	
	1.25 m/s (max.).	

7. CONCLUSION

In designing this project we set out to achieve some objectives, the core of which is to design a Battery-Powered Microcontroller-Based wheelchair that will be a low-cost alternative to the current market offerings. The idea is so that paraplegics in our society, especially those who cannot afford the expensive models currently available today, might have a chance at buying one if this project is commercialized. We achieved this primary objective hence showing that by using the components readily available to us in our environment today, we can manufacture these Battery-Powered Microcontroller-Based wheelchairs and hence give the paraplegics in our society a chance to live a better live.

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