ISSN 2735-4792 (Print); 2735-4806 (Online)
International Journal of Artificial Intelligence and Emerging Technology
Available online at : https://ijaeur.journals.ekb.eg/

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Keywords:
gyroscope sensor; DC motor; Arduino Uno.

Article History:
Received: xxxx xx, 20xx
Accepted: xxxx xx, 20xx
Available Online: xxxx xx, 20x

Head Gesture Controlled Robotics Wheelchair Design and Implementation

ABSTRACT
Physically disabled people face several obstacles in their everyday lives because of illnesses, accidents, or congenital conditions. The goal of this study is to create a robotic wheelchair that can be controlled using head motions for those with limited mobility. The medical equipment used to help handicapped people nowadays is sometimes more costly and sophisticated. An MPU 6050 accelerometer sensor, gyroscope sensor, ultrasonic sensor, relay, battery, DC motor, and Arduino Uno are all included in the proposed head motion-controlled robotic wheelchair. To explain head motions for operation, the prototype makes use of a microcontroller. for head gesture-operated mobility aid. An MPU 6050 accelerometer processes data, and the controller filters signals to allow for robotic wheelchair navigation. Obstacle avoidance is aided by an ultrasonic detector. We have made this technology affordable so that everyone may use it, even though it is usually costly.

DOI :

1 Introduction

A. BACKGROUND AND MOTIVATION

The purpose of traditional wheelchairs is to be used by those who can move them with a working arm. Some people, such amputees and others with paralysis, are unable to use these wheelchairs.

Quadriplegia is the term used to describe the paralysis of the body from below the neck, which results in immobilization of the hands, legs, and torso. Quadriplegia can result from strokes, cerebral palsy, and injury to the spinal cord. Sensation and movement are compromised when the spinal cord is damaged because the brain cannot communicate with it effectively. The easiest movement for a quadriplegic patient is through the head because their hands and legs can no longer move at all, making it impossible for them to do even simple tasks like gripping objects or moving about. Over 2 million individuals in Egypt have movement impairments, some of whom are quadriplegic. This condition typically suggests further damage to the cervical spinal cord; however it can also be caused by injuries to the brain or peripheral nerves [1].

A person who has quadriplegia can move their head in a problem-loose way by tilting their head. Through efficient component use, our wheelchair aims to be both affordable and powerful, enabling the maximum number of quadriplegic patients—particularly those from rural areas—to utilize this equipment. Today, 650 million individuals worldwide are living with physical disabilities, accounting for 10% of the world's population.

B. OBJECTIVES

This paper's primary goals are to assist quadriplegic patients in moving freely from one location to another using a wheelchair by utilizing a tilt sensor to detect head movements and implementing an ultrasonic sensor to steer clear of obstructions like stairs or edges.

C. LITERATURE REVIEW

In the case of non-straight roads and approaching ramps, Ruzaij et al. [2] Provide and put into practice a speed-adjusting technique that enhances the functionality of the head tilt controller. It is designed to compensate for the speed loss in one or both wheelchair motors, depending on the user's weight and the degree of the road slope angle.

An IMU was utilized by Marins et al. [3] to operate a wheelchair and capture head motions. Data extraction and processing were done using an Arduino Uno, while data categorization was done using MATLAB. The accelerometer and gyroscope of an IMU are used to collect data on roll and pitch angles. The x and y axes are employed as the yaw angle information is not needed. The prototype or wheelchair that represented the design was never produced.

On the other hand, a sensory-headwear-based system for self-access to environmental control was proposed by Errico et al. [4]. The system includes hardware actuators, motion sensors, radio frequency transceivers, electrical components for transmission and receiving, software with a simplified graphical user interface, and more. Inter-Integrated Circuit (I2C) connections provide communication between the Multipoint Control Unit (MCU) and sensors. The RF transmission chip and the MCU communicate via in-circuit serial programming (ICSP). An MT3608 runs at a steady frequency of 1.2 MHz and a current mode step-up converter regulate the 4.5 V supplied by a battery pack. The MT3608's output voltage was five volts. The wireless transmission takes place on a dedicated conduit at 2.4 GHz [4].

Gomes et al. [5] developed a user interface that employs head motions to continually regulate a wheelchair's speed and direction based on the user's head null position and natural posture. The I2C bus connects the IMU (BNO055) and WIFI module (ESP8266), which together comprise the Head Motion Unit (HMU). A wheelchair processing unit (WPU) consists of an Arduino Mega, an IMU, a WIFI module, and many range sensors for the safety modules. Infrared sensors are utilized to determine the distance between the head and the headrest, and two tiny laser sensors (VL53L0X) are used to identify frontal objects in the wheelchair's path. The device also incorporates a biaxial joystick that is connected to the analog ports of the Arduino. The components of the power system include

Dey et al. [6] developed a novel accelerometer-based gadget that, in response to varying head movements, could propel a wheelchair in five distinct directions. To move the wheels in various locations, two DC motors have been added. The direction of the wheelchair is controlled by the Arduino UNO using relays as the motor driver. Utilizing sustainable energy sources is highlighted by the wheelchair's solar-powered drivetrain. A light-dependent resistor (LDR) can be used, for example, to detect a sensor when there is not enough light for the wheelchair user to control it. To improve mobility safety, an ultrasonic sensor has been used as an obstruction detector.

Mahmud et al. [7] developed a multi-modal human-machine interface to control wheelchairs for a greater number of disabled people. A joystick, smart hand gloves, a head movement tracker, and an eye tracker make up the interface. The Raspberry Pi device serves as the main controller for this multi-modal interface. The device has a very accurate and efficient 2-axis joystick. The hand glove's flex-sensors assess the amount of deflection or deviation. The Arduino Nano linked to the hand gloves uses the resistance value of the flex sensors to track hand motions. A camera detects changes in eye gazing. The system is processed using the Convolutional Neural Network (CNN) architecture. Head motion is tracked using an IMU. The Arduino Nano, which is connected to the IMU, decodes the signals it gets and gives the Raspberry Pi the final command to operate the wheelchair. The Raspberry Pi and the Arduino module may link wirelessly thanks to the Bluetooth module that is affixed to the Arduino Nano.

A head motion-controlled semi-autonomous wheelchair was created by Kader et al. [8] utilizing two DC motors, a 3-axis accelerometer, sonar sensors to detect obstacles, and location-based SMS sent by a GSM modem. On top of the head, in its usual orientation parallel to the earth's surface, is the motion sensor. When a person tilts their head in different directions, it changes their orientation. The device takes data from the Atmega328P (Arduino Nano) microcontroller. The GSM modem receives attention (AT) commands from the microcontroller using the Universal Asynchronous Receiver and Transmitter (UART) communication protocol. The serial transmission speed is 115,200 bps. The system also has a Bluetooth (BT) module that provides the microcontroller with the data it receives about head direction.

However, the literature research offers the findings about fuzzy logic controllers that were used in various wheelchair systems, including those found in [9], [10], and [11]. Zhang et al. [9] developed a fuzzy logic framework using an iterative linear matrix technique for an electric wheelchair. The control reduces the unknown nonlinearity of the dynamical systems. The system's output serves as the control option after the fuzzy controller evaluates inputs such as speed and acceleration mistakes. The wheelchair's position and velocity tracking stabilized after 65 seconds.

A fuzzy wall-following control utilizing ultrasonic sensors and distance conditionals for every fuzzy rule was put into practice by Lee et al. [10]. The wheelchair angle was the fuzzy output, and the distance was the fuzzy input. To control the wheelchair, Maatoug et al. [11] created a fuzzy logic controller with inputs for angle and distance. The mistake forms the basis of the fuzzy variables.

Arunkumar, Gautham, et al. [12] suggest that the freedom of mobility is the challenging issue that disabled people face. To do their daily duties, they need outside help. The main objective of this research is to rehabilitate disabled people who are unable of moving voluntarily. As a mobility assistance, the wheelchair's hardware implementation will help patients with severe quadriplegia. The wheelchair will work according to the user's head movement. The recognized motions provide motion control signals to the controller, which enables it to control the wheelchair's movements as the user wishes. Head movement is one of the simplest natural motions to observe. Individuals with quadriplegia who have paralyzed parts of their bodies below the neck are able to move their heads. Patients are therefore able to move their heads. An accelerometer sensor that detects head motions is included into the wheelchair. In order for the wheelchair to maneuver, the controller decodes the signal and transmits it to it. For the patients who are suffering from this sickness, this will offer a little sense of relief. The wheelchair's cost-effective execution reduces the complexity of the design. Its user-friendly interface makes it possible for people with disabilities and the elderly to

D. PROBLEM FORMULATION

To control the movement of the wheelchair the wheelchair can be controlled in two methods.

I. The wheelchair can be moved in all four directions using a tilt sensor. The tilt sensor recognizes the direction of neck movement and moves accordingly.

II. The wheelchair can also be moved using the app. The user can move the wheelchair by pressing the app button.

The robotic wheelchair employs an ultrasonic sensor to identify obstacles on the way and steer clear of them. Larger obstructions, which are always apparent to humans, are the primary target of the ultrasonic sensor. Obstacles such as stairs or edges in the wheelchair's path can be avoided by employing ultrasonic sensors.

1.1 Materials

I. MATERIALS AND METHODS

The design of a power wheelchair with control systems for those with lower limb injuries or those with combined lower limb and upper limb injuries was the focus of this research. It also included rehabilitation facilities to help the crippled regain their function. Thus, the entire system is separated into two halves. The mechanical part is the first, and the regulating part is the second.

A. DESCRIPTION OF THE ROBOTICS WHEELCHAIR

As seen in Figure 1, the suggested wheelchair solution was created using Solid Works. After choosing appropriate motors and achieving the synthesis of the transmission chain ratio to wheels, the required torque and angular speed of propulsion motors were determined based on wheelchair dynamics. Two servomotors with reduction gears and a duty torque of 12 Nm at 30 rpm are used in the wheelchair driving system.

Chain transmissions are used to transfer motion to the wheels. The angular velocity is decreased by the chain transmission, which doubles the motor torque. Figure 2 shows the experimental model of the robotic wheelchair that was put together at MHIET.

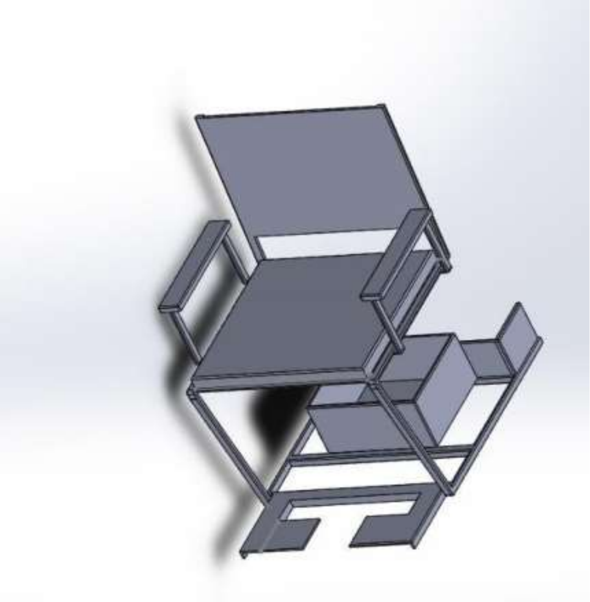


Figure “1”:Robotics Wheelchair designed in Solid Works.

Figure “2”: Robotics Wheelchair experimental

B. HEAD ORIENTATION

The head orientation can be categorized into 3 angles Pitch angle, the X-axis, Roll angle, the Y-axis and the Yaw angle, the Z-axis. The orientation of the head is shown in Figure 3 [13] The algorithm creates the control signal for robotic wheelchair mobility by utilizing the x, y, and z-axis data to calculate the head's orientation. Wheelchair locomotion control signals would be provided by the pitch angle for forward and backward motion, the roll angle for front left and forward right motion, and the yaw angle for rear left and back right motion.

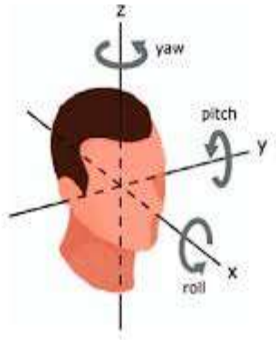


Figure “2”: Three degrees of freedom in head orientation: yaw (head rotation), roll (head pivot), and pitch (head tip) [13].

The variation in the head orientation angles would determine the optimal threshold, at which the robotics wheelchair should locomote. Figure 4. shows the flowchart of the system locomotion.

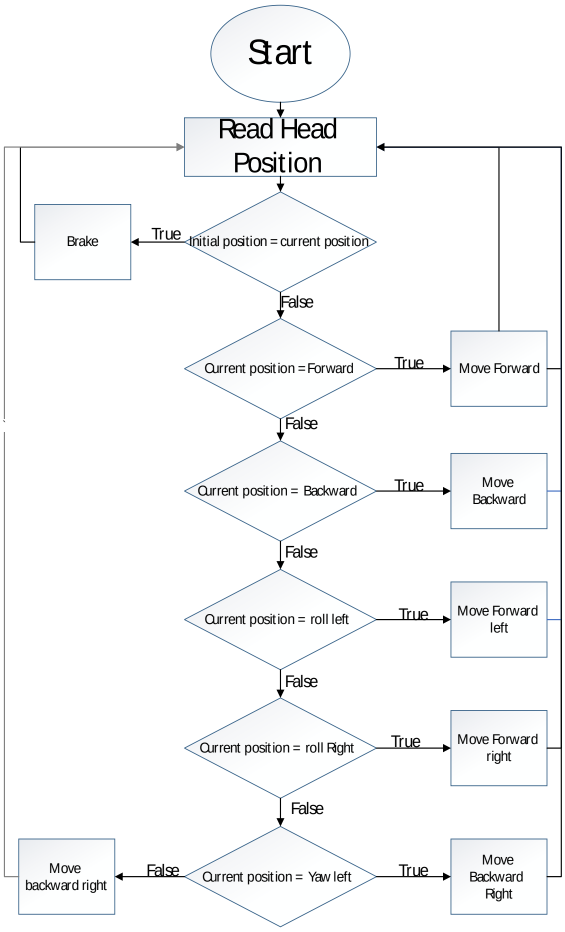


Figure “4” : Flowchart Diagram

C. ROBOTICS WHEELCHAIR DESIGN

The prototype wheelchair's mechanical design is described in the robotics wheelchair design. The manual wheelchair is 950 mm in length, 700 mm in width, 923 mm in height, and features a footrest that can be raised or lowered. The flywheel was used to design the gears. The wheelchair's inner rim held the Flywheel in place. As seen in Figure 5, the manual wheelchair was converted into an electric wheelchair with a 1:6 gear ratio (spur gear).

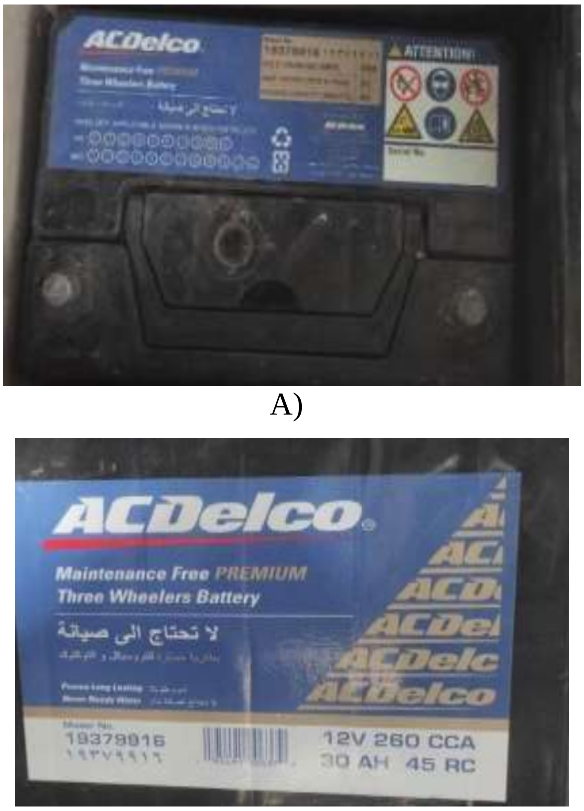
Figure “5” :Gearbox Motor

Figure “6”: Installing motors

Figure “7” :position of the wheel

Figure “8”: Final form of the robotics wheelchair

The wheels are controlled via a DC motor using two Battery 12v 30ah & 12v7AHa. The power motors of a robotics wheelchair are 250W. The data obtained using both the accelerometer and gyroscope sensor are processed using algorithms in the Microcontroller.



A)

B)

Figure “9” :A) Battery 12v 30ah & B) Battery 12v 30ah

D. ROBOTICS WHEELCHAIR MATHAMATICS MODELING

The primary component of the robotics wheelchair simulator is a rolling bench that has a wheelchair attached to it. To guarantee precise reference speed monitoring in real-time, a controller for the haptic interface must be included, which makes wheelchair mobility easier. The wheelchair model, which is then utilized as a reference model for the MRAC control, and the dynamic modeling of the roller bench are presented in this part.

E. WEELCHAIR-ROLLER MODELLING

Consider the dynamic model of the Weelchair-Roller [14] illustrated in Figure ١. In this study, we assume that each rear wheel of WCS is placed on one roller instead of two and each roller is independent of the other. We also suppose the no-slip rolling condition while movement. Thus, the governing equations of the dynamic system are described as follows.

$$\{I_L \dot{\omega_{el}}(t) - F_L\big(\omega_{eL}(t)\big) = N\,T_{M_L}(t) + \tau_{h_L}(t) \tag{1}$$

$$\{I_R \dot{\omega_{eR}}(t) - F_R\big(\omega_{eR}(t)\big) = N\,T_{M_R}(t) + \tau_{h_R}(t) \tag{2}$$

Where $I_i \dot{\omega_{el}}$ and $\dot{\omega_{el}}$ are respectively the inertia, angular acceleration and velocity of each roller bench. τ_{h_i} is the human torque exerted on each wheel and τ_{M_L} represents the roller bench motor torque.

Assuming that there is a perfect speed reducer between the roller motor and the wheelchair wheels, then N is the torque reduction and can be calculated as follows.

$$R_T = \frac{R_r}{R_W} = \frac{\omega_s}{\omega_e} = \frac{1}{N} \tag{3}$$

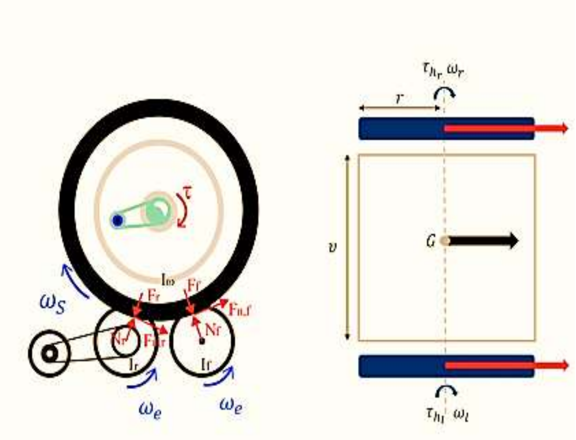


Figure “10” : (A) Schematic description of the involved forces in the wheelchair-ergometer dynamics. (B) Schematic description of the wheelchair dynamics [15].

Where R_r and R_W are respectively the roller radius and the rear wheel radius and ω_s denotes the wheelchair’s wheels speed. As described earlier, the simulator consists of a roller bench on which a wheelchair is fixed. As the wheels encoders are faster than the motor speed sensor, we consider that the output measurement of the simulator comes directly from the wheels.

Finally, friction force dynamics generated during the wheelchair - roller system interaction is expressed by a nonlinear model as a function of wheel speed $F_i\big(\omega_{ei}(t)\big)$

$$F_i\big(\omega_{ei}(t)\big) = \theta_1\big(\tanh(\theta_2\omega_{e_i}) + \tanh(\theta_3\omega_{e_i})\big) + \theta_4\tanh(\theta_5\omega_{e_i}) + (\theta_6\omega_{e_i}) \tag{٣}$$

F. WHEELCHAIR REFERENCE MODEL

As stated in the introduction, the level of realism envisaged to replicate the wheelchair behavior in the virtual environment, requires a complex mechanical model that faithfully represents the subject-WC-environment interactions [16]. However, it is practically impossible to use a very accurate modeling of the wheelchair dynamics, since a nonlinear modeling always raises many complex issues in the control design level. [17]. To this end, a simplified wheelchair model including only the rear wheel dynamics is used in this study [18], [19]. Thus, the relation between the angular velocities $\omega_{eL,r}$ of the left and right wheels and the human torques $\tau_{h_{L,r}}$ applied to its wheels is described by the following dynamics. $A = k\,J^{-1}$ and $B = J^{-1}$.

$$\begin{bmatrix}\dot{\omega}_R\\ \dot{\omega}_L\end{bmatrix} = -A\begin{bmatrix}\omega_R\\ \omega_L\end{bmatrix} + B\begin{bmatrix}\tau_{h_R}\\ \tau_{h_L}\end{bmatrix} \qquad (٤)$$

$$J = \begin{bmatrix}\frac{Mr^2}{4}+\frac{I_G r^2}{v^2}+I_w & \frac{Mr^2}{4}-\frac{I_G r^2}{v^2}\\ \frac{Mr^2}{4}-\frac{I_G r^2}{v^2} & \frac{Mr^2}{4}+\frac{I_G r^2}{v^2}+I_w\end{bmatrix} \qquad (٥)$$

Where:

J= the equivalent inertia matrix of the system

M= the mass

Ig and Iw= the inertia at the Centre

II. CONTROLLER OF THE ROBOTICS WHEELCHAIR

The main concept behind this Head Motion controlled wheelchair is the use of an accelerometer and gesture detection. To detect head motion in all directions, an accelerometer is included within the earpiece. Our electric wheelchair is controlled by an Arduino microcontroller. There are two components to this head motion-controlled wheelchair technique. The transmitter is on one side and the receiver is on the other. From the transmitter side to the receiver, the accelerometer data is sent via radio frequency. The three main parts of the transmitter side are the Arduino Nano, Accelerometer MPU6050, and RF transmitter.

A. ACCELEROMETERS

An electromechanical device called an accelerometer is used to measure acceleration capabilities. These forces could be static, like gravity's continual pull at your feet, or they may be dynamic, brought on by the accelerometer's movement or vibration. An instrument that gauges the acceleration or vibration of a structure's motion is called an accelerometer.

The mass can "squeeze" the piezoelectric material, producing an electrical charge equivalent to the force applied to it, thanks to the force created by vibration or a change in motion (acceleration). The charge is proportional to the acceleration since the mass is constant and the charge is equal to the force.

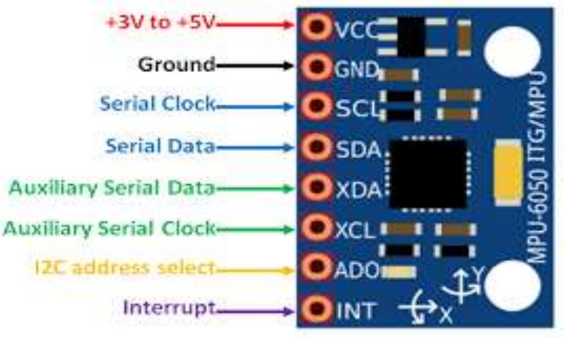
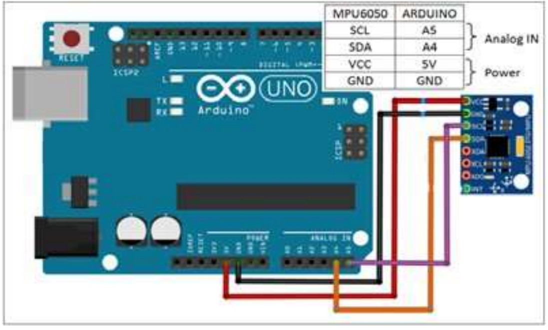


Figure "11": Accelerometer MPU6050 Module

B. ARDUINO UNO

The Microchip ATmega328P microprocessor, developed by Arduino.cc, serves as the foundation for the open-source Arduino Uno microcontroller board. Numerous expansion boards (shields) and other circuits can be attached to the board's set of digital and analog input/output (I/O) pins. The board features six analog I/O pins, fourteen digital I/O pins (six of which may produce PWM), and can be programmed using the Arduino IDE (Integrated Development Environment) via a USB type B connector. Despite supporting voltages ranging from 7 to 20 volts, it can be powered by an external 9-volt battery or a USB cable. It is also comparable to Leonardo and Arduino Nano. [20]

Figure "12" :Arduino UNO



MPU6050	ARDUINO
SCL	A5
SDA	A4
VCC	5V
GND	GND

Figure “13” :The connection between of Arduino uno and MPU6050

C. THE BTS7960 DRIVER

Stepper motors, DC motors, and 3-phase BLDC are examples of high-current loads that may be driven by the potent half-bridge output driver integrated circuit BTS7960. Two BTS7960B ICs are installed in the BTS7960 module, which is seen below, in an H-Bridge arrangement. Because the BTS7960 is rated for up to 43A (with adequate heat dissipation), it is perfect for driving DC motors that need a lot of current.

Figure “14” :BTS7960 driver

D. DC MOTOR

Electric motors power almost every technological innovation we encounter. Electricity can be transformed by electrical machines. Electrical energy is absorbed by motors and produces mechanical power. In our daily lives, we come across hundreds of pieces of equipment that are powered by electric motors. Direct current (DC) motors and alternating current (AC) motors are the two main types into which electric motors are often separated. The DC-motor is the name of the electric motor that runs on DC. This device converts DC electrical energy to mechanical energy. [21]

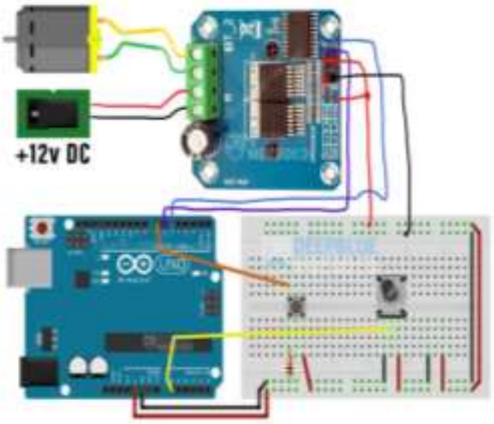
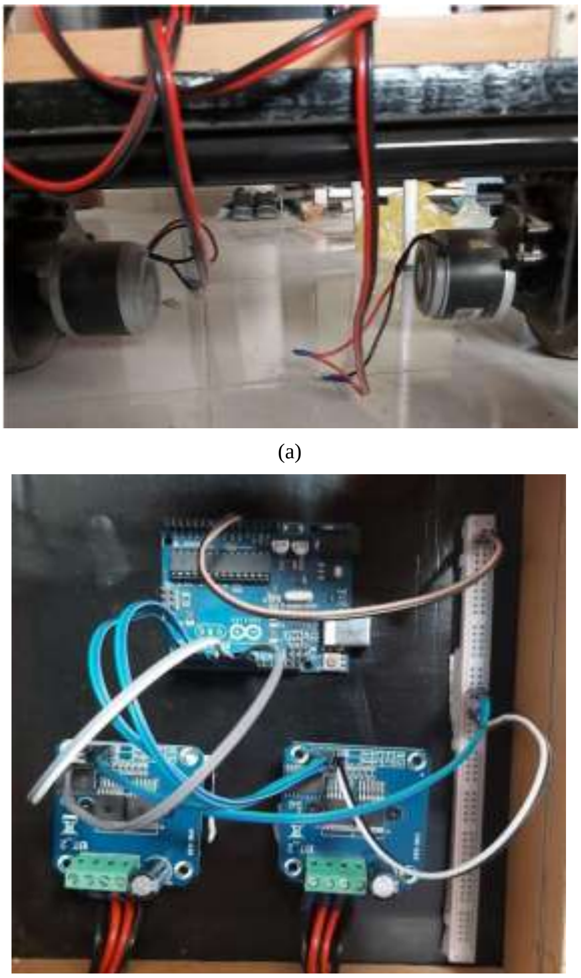


Figure “15” :Wiring BTS7960 Motor Driver With Arduino



(a)

(b)

Figure “16”: Full connecting of circuit drivers with motor

1.2 Results and discussion

A. RESULTS

An experiment was conducted in this study to evaluate the microcontroller system that was designed. There are two components to the experiment. ٢ impaired patients were given each of the four existing commands ٥ times in the first section. As a result, 40 commands were given by each impaired patient, for a total of ٨٠ commands. They then executed a predetermined set of ten head gestures in the second portion of the experiment, which included looking up, reading the text in front of them (looking down), and looking to the right. These motions were not intended to be used as commands. Because it is just as crucial to not recognize a command where it is not intended as it is to recognize a command where it is intended, this is done. Here, we looked at the worst-case situation, such as a sequence that goes down, up, and down. In ٩٥% of cases, the microcontroller system was able to recognize the command.

TABLE 1. RESULTS OF THE EXPERIMENT

		1	2	3	4	5
Case 1	Forward	Positive	Positive	Positive	Positive	Positive
	Back	Positive	Positive	Positive	Positive	Positive
	Right	Positive	Positive	Positive	Positive	Positive
	Left	Positive	Positive	Negative	Positive	Positive
Case 2	Forward	Negative	Positive	Positive	Positive	Positive
	Back	Positive	Positive	Positive	Positive	Positive
	Right	Positive	Positive	Positive	Positive	Positive
	Left	Positive	Positive	Positive	Positive	Positive

The sign **Positive** symbolizes a success in the intention (in Table 1 it means the system successfully recognized the command. The sign **Negative** symbolizes a failure to recognize the intention of the user.

The studies conducted demonstrate that a patient's psychological state has a significant impact on his wheelchair control. Adding an obstacle-detection subsystem to the wheelchair can boost self-esteem, according to [22]. Considering this research, we can conclude that some of the experiment's mistakes occurred because the examinees were using the wheelchair in an extremely unique manner and a very small indoor space without any form of protection.

Conclusion

In order to provide wheelchair control for quadriplegics, this article employs a unique head motion recognition technique. The technique is implemented as an algorithm of a microcontroller system. This system's prototype is put through experimental testing. The findings of the experiment were excellent. Specifically, following system adaptation and a brief learning period, two distinct patients were able to issue commands with 95% success.

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