International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Implementation of Micro-Electro-Mechanical Systems Based PID-Gesture Controlled Wheelchair

Mohammed Aminu [a]*, *Jibril Danladi Jiya* [a], *Mohammed Ahmed Bawa* [b]

[a] *Department of Mechatronics and Systems Engineering, Abubakar Tafawa Balewa University, Bauchi, 740272, Nigeria*
[b] *Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi, 740272, Nigeria*

ABSTRACT

Wheelchairs support individuals with locomotive disabilities by facilitating mobility. However, movement can still be challenging, as many wheelchairs are either manually operated or motorized with basic control mechanisms, such as keypads and joysticks, which limit precision in navigation. This study presents the development of a wheelchair enhanced with a micro-electro-mechanical system (MEMS)-based proportional-integral-derivative (PID) control system, allowing smoother movement through hand gesture recognition. A MEMS sensor, incorporating both an accelerometer and gyroscope, detects the user's hand gestures and converts them into control commands for the wheelchair. The PID controller was implemented to ensure precise and responsive control, promoting smooth and stable wheelchair movement. An H-bridge driver, employing a MOSFET transistor for high power capability, was integrated for effective bidirectional control of the DC motor under nominal operating conditions. The system's algorithm was evaluated with various human weights (48.8 kg, 50.1 kg, 50.9 kg, 64.9 kg, 78.8 kg, and 82.6 kg), achieving corresponding speeds of 0.862 m/s, 0.839 m/s, 0.826 m/s, 0.648 m/s, 0.547 m/s, and 0.509 m/s, respectively. Results demonstrate that the developed wheelchair provides more efficient control and navigation compared to conventional designs.

Keywords: MPU6050-gyroscope/accelerometer, H-Bridge Driver (power transistors), NRF24L01-tranciever module, Micro-controller.

1. Introduction

Currently, approximately 1.85% of the global population, particularly the elderly and those with disabilities, require wheelchairs (Singh et al., 2019). As the world population grows, so does the demand for wheelchairs to assist individuals with mobility impairments. A wheelchair is an essential device that enhances personal mobility, allowing elderly and disabled individuals to navigate their environment more conveniently. It can be manually pushed by another person, self-propelled, or powered electronically. However, traditional wheelchairs present limitations in terms of flexibility, bulkiness, and restricted functionality (Shaari et al., 2017). With advancements in computational technologies, enhancing quality of life through natural human-computer interaction has become increasingly important. In a smart environment, individuals prefer intuitive, convenient ways to communicate and interact with their surroundings. While button pressing on remote control panels has been the most traditional approach, this method is often cumbersome and unnatural, particularly for the elderly or visually impaired who may struggle to identify buttons. Gesture-based interaction provides an alternative, offering a more intuitive way to engage with technology. Various assistive systems, including Smart Wheelchair systems with joysticks, and even voice recognition-based systems, have been developed to aid users (Paulose and Mohan, 2014). Gesture recognition has emerged as a key research area within human-computer interaction (HCI) and image processing. As human-machine interaction becomes more common, user interface technologies play an increasingly vital role. Physical gestures, being intuitive expressions, simplify interactions and allow users to more naturally command machines. Today, robots are often controlled via remote, cell phones, or direct wired connections (Sakpal et al., 2016). The rapid development of techniques for human-robot interaction (HRI), including hand gesture recognition, has led to increased interest in their advantages, such as enhanced intuitiveness and ease of use. Hand gesture recognition is now widely applied in diverse areas, including virtual reality, gaming, healthcare, and robotics (Su et al., 2020). This approach allows patients and elderly individuals to use hand gestures to control wheelchair movement, enhancing comfort and accessibility. In the biomedical sector, wheelchairs play a crucial role, and the rising number of physically disabled and elderly people calls for more advanced technology in these devices (Vernekar et al., 2020). Using a gesture-based controller, such as a hand glove or wheelchair handle, patients can improve their quality of life. The proposed system has two main components: the gesture controller and the robotic wheelchair (RW). Through sensor-based hand gestures, users can easily control the robotic wheelchair, reducing the physical effort required—especially beneficial for paralyzed or elderly users. Our system can achieve around 94% accuracy with minimal delay (Sabuj et al., 2019). While keyboards and mice are currently the primary input methods, alternative options—such as grasping virtual objects, using hand, head, or body gestures, and eye tracking—are becoming popular, driven by ubiquitous devices like digital TVs and gaming consoles. The demographic shift towards an aging population will likely increase the demand for such accessible technologies (Bhuiyan and Picking, 2019).

2. Literature Review

David et al. (2019) designed a head motion-controlled wheelchair using MEMS technology to assist paraplegic and quadriplegic patients in moving independently. The wheelchair movement is controlled by the user's head and neck motions, with the system translating head position into directional control. The design comprises a MEMS sensor unit and a programmed PIC16F73 microcontroller unit. The MEMS sensor detects head movements and sends signals to the microcontroller, which then directs the wheelchair accordingly. However, the PIC16F73 microcontroller, being an 8-bit device, has a relatively low processing speed, and encoder/decoder elements are not included in this design. Singh et al. (2019) developed a hand gesture-controlled wheelchair using an ADXL335 accelerometer, which provides analog signals when moved along the X and Y axes. An LM324 operational amplifier acts as a comparator, converting the analog signal to a digital one. To transmit signals wirelessly, a radio frequency (RF) transmitter is used, encoding data via the HT12E encoder IC with a secure address to minimize interference. Once received, the signal is decoded and processed by an Arduino Uno. If the received input matches preloaded data, it activates the L293D IC to control relays, initiating wheelchair movement. Although the ADXL335 accelerometer is sensitive to minute movements, its analog nature necessitates an analog-to-digital converter (ADC), leading to slower processing due to signal conversion. Mistry et al. (2018) designed a voice and gesture-based wheelchair using an AVR microcontroller and Android, allowing elderly or physically challenged users to navigate their homes independently. Through the Home Navigation System (HNS), users can move to specific locations within the house by either speaking the direction or moving an Android device. The system includes an obstacle-avoidance feature for situations where the user cannot provide timely commands. A security alert can also be sent to a predefined contact if the user feels endangered. However, the study only involved simulation, indicating potential difficulties in real-world implementation. Rahul (2014) developed a prototype for an accelerometer and voice-controlled wheelchair, operating based on head or hand movements. An accelerometer (motion sensor) detects these movements, and the HM2007 voice recognition module recognizes voice commands. The sensor, attached as a band to the hand or head, sends signals to a conditioning circuit, which processes them and controls the wheelchair's movement accordingly. Since the study focused on a prototype, there was no detailed design for the electromechanical interface. Goyal and Saini (2013) designed a system using voice and gesture control to operate a wheelchair. The setup included a speech recognition unit with an HM2007 voice recognition module, a MEMS sensor to detect hand angles, and a control unit for wheelchair movement. Using a Hidden Markov Model for voice recognition, the system interpreted voice and gesture commands to control DC motors through motor drivers, directing the wheelchair's movement. However, the HM2007 module has limitations with noise interference and supports only single voice commands. The motor driver interface was not implemented in this study. Eddy et al. (2016) designed a hand gesture-operated wheelchair using a MEMS-based accelerometer. The MMA7660FC accelerometer, a small, low-cost, ±1.5 g 3-axis accelerometer, measures acceleration and provides digital output, allowing easy attachment to the user's fingertips or back of the hand. The RF module transmits and receives signals at a 433 MHz frequency, at a rate of 1-10 Kbps, to communicate between the controller and wheelchair. The study noted a low scale factor for accelerometer calibration, and the design lacked implementation of an electromechanical interface.

3. Block Diagram

The block diagram of the system, as shown in Figure 1, illustrates the basic functionality of the design. The Arduino Uno microcontroller serves as the system's core, processing inputs and generating the required outputs.

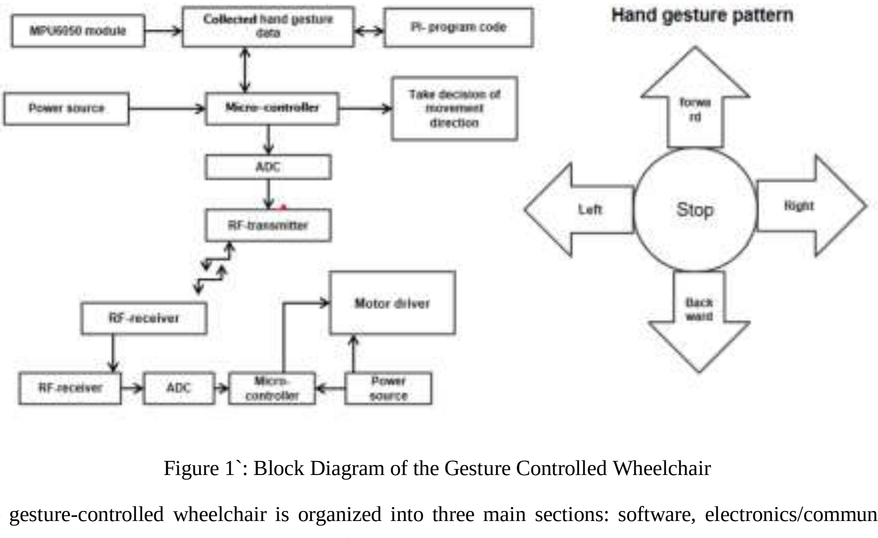


Figure 1`: Block Diagram of the Gesture Controlled Wheelchair

The development of the gesture-controlled wheelchair is organized into three main sections: software, electronics/communication, and mechanical components. The system is designed to control the movement of a standard adult-sized motorized wheelchair by interpreting gestures detected by the MEMS-based MPU6050 sensor. These signals are processed through a Proportional-Integral-Derivative (PID) control algorithm to ensure smooth and precise motion control. The wheelchair operates in five primary modes: moving forward, moving backward, turning right, turning left, and stopping.

1. Software Implementation

The software component consists of programming the RF-Nano microcontroller using C language in the Arduino IDE and Virtual Studio Code. The RF-Nano was selected due to its compact size, low power consumption, and integrated radio frequency communication capabilities.

a. PID Control Algorithm

The PID control algorithm is implemented in the software to ensure smooth movement of the wheelchair, minimizing overshoot and oscillation. The MPU6050 sensor captures the orientation and tilt of the user's hand, and the PID controller adjusts the speed and direction of the motors accordingly. The proportional (P) term is responsible for addressing the present error, the integral (I) term accounts for past errors, and the derivative (D) term anticipates future errors, all of which contribute to efficient and responsive control.

b. Gesture Recognition

The MPU6050 accelerometer and gyroscope are used to recognize hand gestures. These gestures correspond to the intended wheelchair movements:

Moving forward: Tilting the hand forward.

Moving backward: Tilting the hand backward.

Turning right: Tilting the hand to the right.

Turning left: Tilting the hand to the left.

Stop condition: Holding the hand level or in a neutral position.

The raw sensor data is processed and mapped to specific motor commands via threshold values in the software.

2. Electronics and Communication

The electronics and communication system integrates the RF-Nano microcontroller, MPU6050 sensor, motor driver, and DC motors.

a. RF-Nano Microcontroller

The RF-Nano receives data from the MPU6050 sensor and processes it to determine the necessary motor commands. It communicates wirelessly with the motor controller via the integrated radio frequency (RF) module, allowing the system to operate without the need for wired connections between the sensor and the motors.

b. MPU6050 Sensor

The MPU6050 sensor captures the orientation of the user's hand, translating the tilt and rotation into control signals. It combines a 3-axis accelerometer and 3-axis gyroscope, providing precise measurements of angular velocity and acceleration.

c. Motor Driver and Motors

The motor driver circuit is used to control the speed and direction of the DC motors based on the control signals sent by the microcontroller. The motors are connected to the wheelchair's wheels, enabling motion in the desired direction.

3. Mechanical Components

The mechanical structure of the wheelchair remains largely standard, with minor adjustments to accommodate the new motor and control system. The wheels are connected to DC motors that drive the movement of the wheelchair. The wheelchair frame and seating are designed to ensure user comfort and safety.

4. Operational Modes

The wheelchair operates in five primary modes, triggered by the corresponding gestures:

i. Moving Forward

When the user tilts their hand forward, the MPU6050 detects the inclination, sending a signal to the RF-Nano, which in turn instructs the motor driver to move the wheelchair forward. The PID controller regulates the motor speed to ensure smooth and gradual acceleration.

ii. Moving Backward

A backward tilt of the user's hand signals the system to reverse the wheelchair. The PID algorithm controls the motors to prevent abrupt changes in direction, providing a comfortable and controlled reversal of movement.

iii. Turning Right

Tilting the hand to the right results in a signal being sent to the motors on the left side of the wheelchair to move faster, while the right-side motors slow down or stop, causing the wheelchair to turn right.

iv. Turning Left

A leftward tilt of the user's hand instructs the left-side motors to slow down or stop while the right-side motors increase in speed, facilitating a smooth left turn.

v. Stop Condition

When the user's hand is held in a neutral or level position, the motors are stopped, bringing the wheelchair to a complete halt. This condition is monitored continuously to ensure the safety of the user and prevent unintended movement.

Circuit Diagram and Components

Figure 2 shows the circuit designed using the software proteus

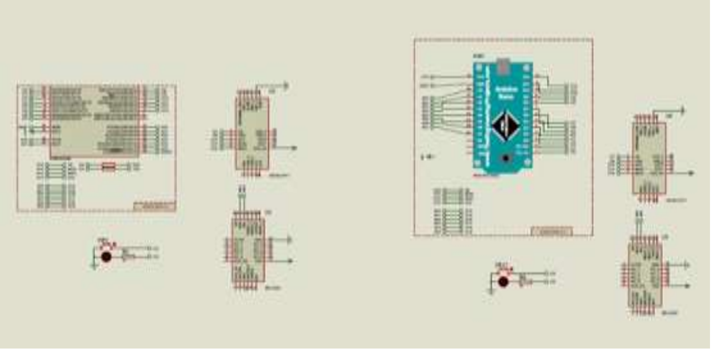


Figure 2(a) Transmitter Circuit Diagram Contained: MPU6050, RF-Module and Microcontroller.

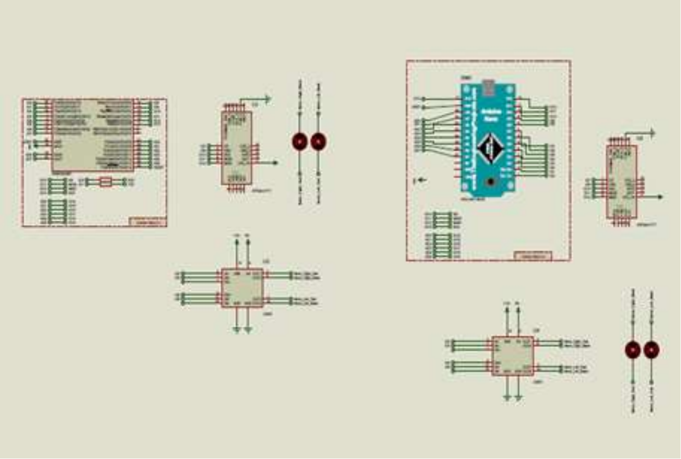


Figure 2(b) Receiver Circuit Diagram Contained: H-Bridge Circuit, RF-Module, and Microcontroller

The list of components used in the work is shown in Table 1. These components were selected based on their availability in the market, their specifications, power consumption, and reliability to meet the demand.

Table 1: List of Components

S/N	Type	Components
1	MPU6050	Gyroscope/accelerometer
2	Arduino Nano	Microcontroller
3	TIP42/TIP41	High-power transistors (H-bridge driver)
4	NRF2401L	Transceiver module
5	DC- motor	12 Volts Geared DC-motor
6	Resistors	1kΩ, 220kΩ, 330kΩ, 47kΩ
7	Capacitors	1μF, 10μF, 220μF,470μF, 1000μF, 2200μF
8	DC fam	12 Volts DC fan

9	Heat sink	Aluminium Heat Sink
10	Tyres	Wheelchair two tyres

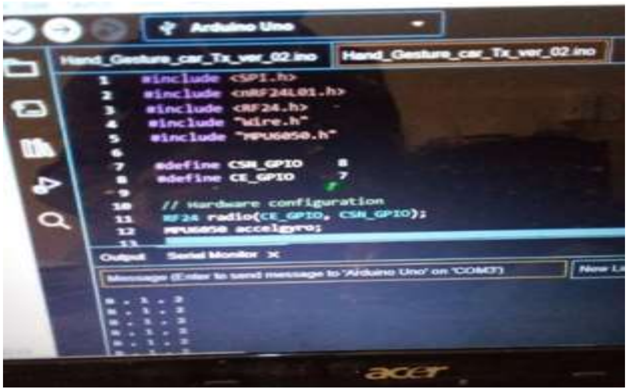
5. Results

This section presents results obtained during the simulation, implementation, and testing of the hand gesture hardware with the output result from the wheelchair's DC motor.

5.1 Simulation Result

The hand gesture training for the gesture-controlled wheelchair was implemented using the MPU6050 MEMS sensor module in conjunction with the Arduino microcontroller and RF communication module. The Arduino IDE, utilizing C-based programming, enabled the development of the proportional-integral (PI) controller, hand gesture recognition, and transceiver programs. The corresponding libraries for the MPU6050 and nRF24L01 modules were integrated for real-time gesture tracking and transmission. Upon uploading the code, the system was successfully tested on the computer screen, with the wheelchair's movement accurately controlled through various hand gestures. These gestures were used to simulate wheelchair direction and speed, confirming the system's responsiveness and stability during simulation.

A screenshot of the simulation is shown in Figure 3.



```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include "Wire.h"
#include "MPU6050.h"

#define CSN_GPIO    8
#define CE_GPIO     7

// Hardware configuration
RF24 radio(CE_GPIO, CSN_GPIO);
MPU6050 accelgyro;
```

Figure 3. Debugging Simulation Code Programming on Arduino Platform

5.2 Testing of the Electronic Circuit on Prototype Board

The connection of the circuit is shown in Figure 3, MPU 6050 module was connected to the Arduino development board, and NRF24L01 module which consists of the ATMega328p microcontroller with a 16MHz crystal oscillator. The MPU 6050 Gyro/accelerometer module receives a Hand gesture recognition command which is referred to as Human-computer interaction (HCI) and is sent via a wireless communication protocol with the use of a microcontroller for processing. It then sends the control signal to the electromechanical interface for the motion of the wheelchair in compliance with the said command.

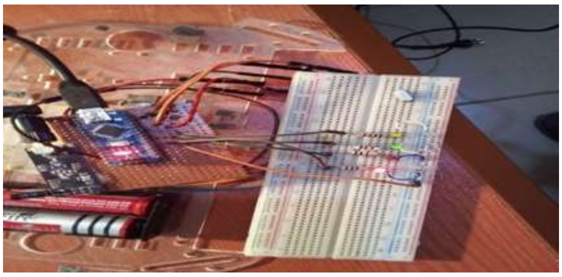


Figure 4. Circuits Connection on Prototype Development for the H-bridge Control Signals

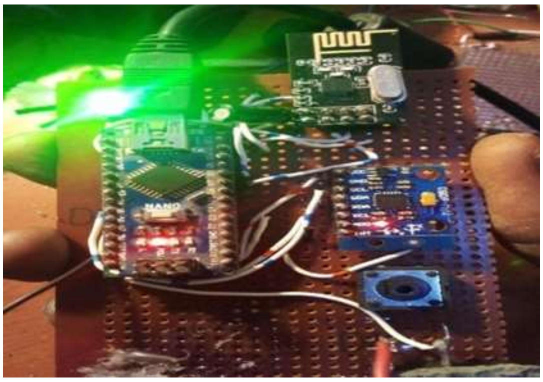
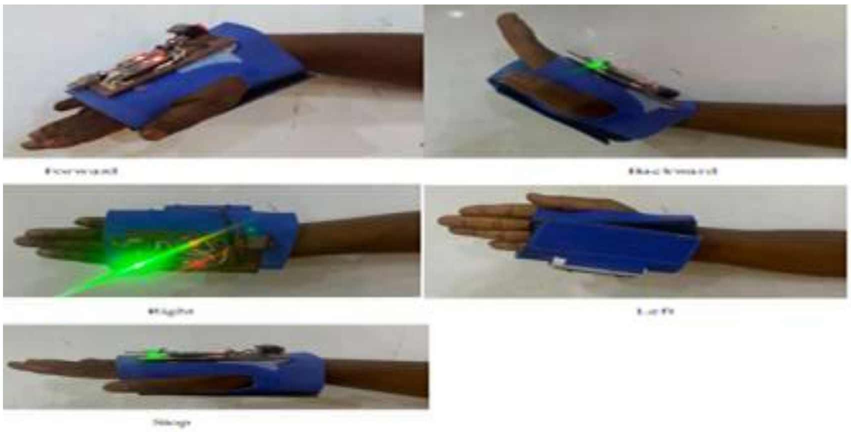


Figure 5. Circuits Connection on Prototype Development for the Hand Gesture

Figure 6 Construction/Soldering of H-bridge Driver Circuit



Forward

Backward

Right

Left

Stop

Figure 7. Gesture Notations on Forward, Backward, Left, Right, and Stop Command

5.3 The Assembled Wheelchair

The front view, side view, and controller box view of the assembled work are shown in Figures 8,9 and 10. The office chair was adopted to be part of the wheelchair. The optical encoder was used for the feedback control signal.

Figure 8: Front View of the Wheelchair

Figure 9: Side View of the Wheelchair

Figure 10: Controller Box of the Wheelchair

After assembling the Micro-Electro-Mechanical Systems (MEMS)-Based PID-Gesture Controlled Wheelchair, the project will transform into a functional assistive mobility device. This wheelchair utilizes the MPU6050 sensor to detect hand gestures—specifically, the movement of the user's hand—to control both the direction and speed of the wheelchair. The Proportional-Integral-Derivative (PID) controller ensures smooth and precise movements by dynamically adjusting the motor speed and direction in response to the input gestures, thereby providing stability and accuracy. This wheelchair enhances independence for users with mobility impairments, offering a more intuitive, gesture-based control mechanism compared to traditional joysticks or buttons.

5.4 Performance Test (Measurement of Percentage Accuracy of MPU6050 Module)

For the MPU6050 accelerometer, the sensitivity, as shown in Equation (1), is approximately 16,384 LSB per g (where g is the acceleration due to gravity, which is approximately 9.81 m/s² or 1 g). This means that for every 1 g change in acceleration along any axis (X, Y, or Z), the digital output of the accelerometer will change by approximately 16,384 counts or LSBs.

$$sensitivity = \frac{\text{Full scale range(LSB)}}{\text{Full scale range } (g)} = \frac{2^{16}}{FSR(g)} \quad \ldots(1)$$

Where;

Sensitivity (LSB/g) is the sensitivity of the accelerometer in LSB (counts) per g.

Full-Scale Range (LSB) is the total range of the sensor's digital output (16 bits, so 2^16).

Full-Scale Range (g) is the range of acceleration values the sensor can measure in terms of gravity (usually ±2g, ±4g, ±8g, or ±16g, depending on the selected setting).

5.5 Accuracy of MPU6050 Module from the Real World (Environment)

The accuracy of the MPU6050 accelerometer/gyro module, as used in this research, is taken as rough data from the serial monitor concerning the hand gesture-accepted commands. This is shown in Tables 1(a, b, & c).

Table 1(a): CASE I: MPU6050, 3-Axis X, Y, Z Real World Values

	X	Y	Z	Unit
Acceleration	1.19	3.42	8.83	m/s^2
Rotation	0.86	-0.02	-0.00	rad/s

Table 1(b): CASE II: MPU6050, 3-Axis X, Y, Z real world values

	X	Y	Z	Unit
Acceleration	0.97	3.30	9.36	m/s^2
Rotation	0.04	0.08	-0.02	rad/s

Table 1(c): CASE III: MPU6050, 3-Axis X, Y, Z real world values

	X	Y	Z	Unit
Acceleration	0.57	0.63	10.24	m/s^2
Rotation	0.08	-0.23	-0.023	rad/s

The range of output voltage of the axis at -2g, 0g, and 2g (±2g) is given in Table (2)

Table 2: Voltage Values at Different Orientations for all 3-Axis.

Axis orientation	-2g	0g	+2g
X-axis	2.10	2.62	3.30
Y-axis	2.07	2.59	3.10
Z-axis	2.08	2.60	3.20

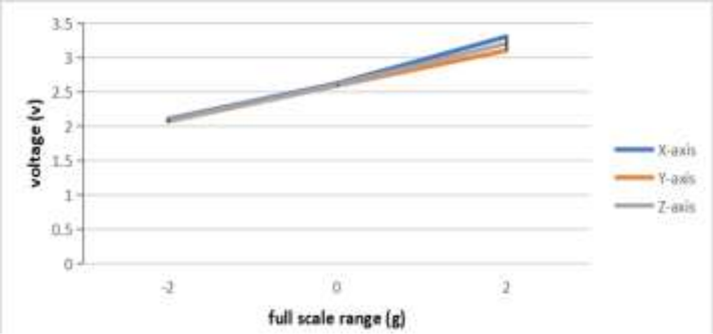


Figure 11: Plot of Analog Voltage Values of X, Y, & Z, Axis

Parameters to measure the performance of the hand gesture-controlled wheelchair using Equations (2) and (3)

…(2)

$$linearity = V0g - \frac{1}{2} * (V2g + V - 2g)$$

…(3)

$$sensitivity - (V2g - V - 2g)\frac{1}{2g}$$

Table 3: Linearity and Sensitivity Range for Different Axes

Parameters	X-axis	Y-axis	Z-axis
Linearity	-0.08	0.005	-0.04
Sensitivity	0.6	0.515	0.56

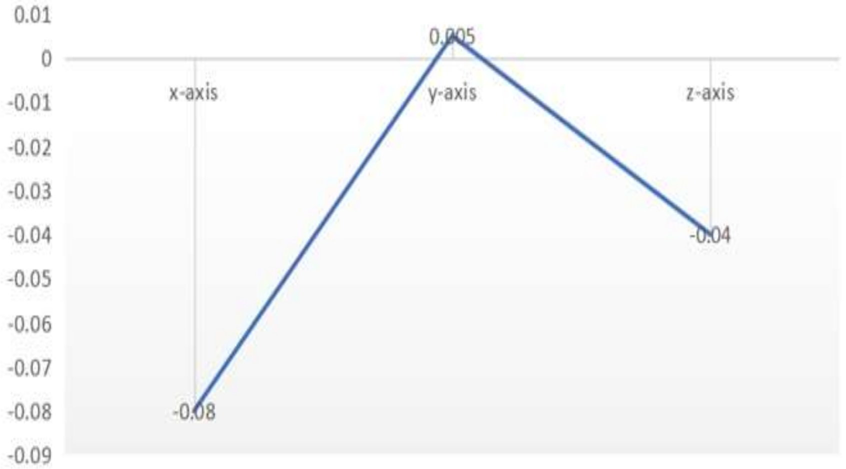


Figure 12: Plot of Linearity of Different Axes from Equation 1

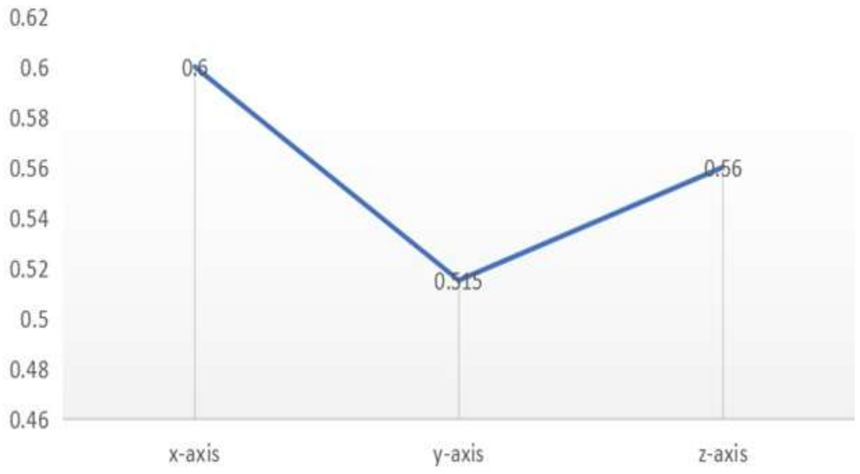


Figure 13: Sensitivity Plot of Different Axes on the Basis of Equation 2

6. Wheelchair Payload

The payload capacity of a motorized wheelchair refers to the maximum weight it can safely carry, including the user's weight and any additional items. This capacity varies depending on the make and model of the wheelchair. Generally, most basic wheelchairs have a standard weight limit that ranges from 113.398kg to 136.078 kg. The data in Table 3 were recorded from the performance evaluation of the wheelchair with different weights to obtain the time and speed for a fixed distance of seven meters

Weight of Wheelchair = 24.3kg

Weight of Battery used = 2.0kg

Battery Specifications: 12Volts/7Ah

Table 3: Shows the Result of Testing the Wheelchair with Different Weights to Obtain the Time and Speed for a Fixed Distance of 7 Meters.

S/N	Weight (kg)	Wheelchair + load applied (kg)	Distance (m)	Time (s)	Speed (m/s)
1	26.3	-	7	6.16	1.1363
2	48.8	75.1	7	8.12	0.8620
3	50.1	76.4	7	8.34	0.8393
4	50.9	77.2	7	8.47	0.8264
5	64.9	91.2	7	10.81	0.6476
6	76.8	103.1	7	12.79	0.5473
7	82.6	108.9	7	13.75	0.5091

The graphs of weight applied against time and weight against speed of the wheelchair are shown in the Figures 14 and 15 respectively.

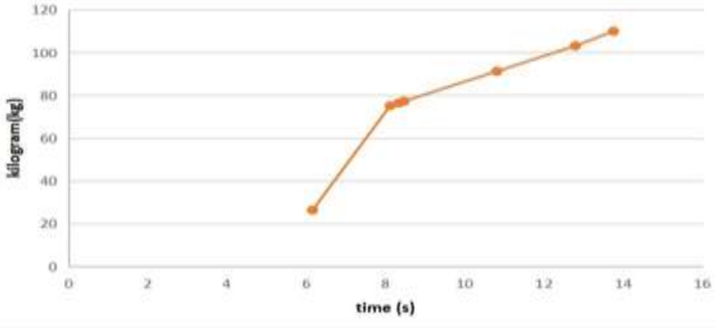


Figure 14: The Behaviour of the Wheelchair Due to Weights Applied with Time

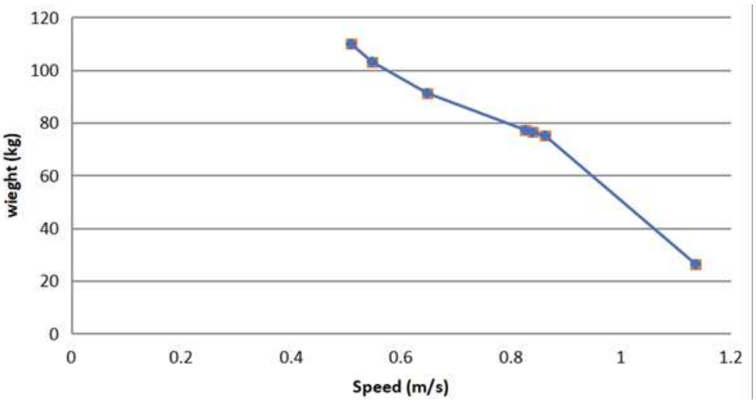


Figure 15: Graph of Weight Against Time to Reach 7 Meters (Distance)

7. SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 Summary

This research focuses on reconfiguring a standard adult-sized wheelchair into a hand gesture-controlled wheelchair designed for individuals who cannot walk and are too weak to operate a manually driven wheelchair. Hand gestures will serve as an alternative control mechanism for people with locomotor disabilities who are also deaf or mute, allowing them to use their body movements to control the wheelchair.

The standard adult-sized wheelchair has been integrated with the electronic and mechanical components of the system. The electronic components include the hand gesture control unit, which comprises an RF-Nano (a nano microcontroller combined with an NRF24L01 module), an MPU 6050 module for gesture recognition, an H-bridge driver for bidirectional current flow through the DC motors, and a 12V/7Ah battery that serves as the power supply. Additionally, a speed control unit and a PID controller are implemented within the program for digital speed and PID control.

The mechanical components consist of a geared drive and a DC motor. The electronic and mechanical systems are interconnected through a computer program written in the C programming language on the Arduino platform. The system is designed to execute five commands for wheelchair movement: i. Forward command, ii. Backward command, iii. Left command, iv. Right command, v. Stop command.

7.2 Conclusion

At the conclusion of this research, the objectives have been successfully achieved:

i. The gesture recognition protocol and Proportional-Integral (PI) algorithm for wheelchair control have been developed and implemented.

ii. ii. The electromechanical interface utilizing a solid-state H-bridge driver for bidirectional DC motor control with a high-power MOSFET has been designed and implemented.

iii. iii. The integration of the control algorithms into the hardware for operating the motorized wheelchair has been developed and successfully executed.

iv. iv. The performance evaluation of the hand gesture-controlled wheelchair has been conducted and analyzed using various weights applied to the system.

A standard adult-sized wheelchair has been designed and implemented, powered by a 12V, 7.0Ah battery. The system includes a hand glove equipped with a hand gesture sensor, an RF module, and a microcontroller.

7.3 Recommendations

As the aim and objectives of the research have been achieved, some limitations can be overcome in future design. These suggestions include;

1. Additional obstacle detection sensors on both sides to enable the wheelchair to respond to the action of an obstacle moving toward it..
2. Integrating a robust power management system into a motorized wheelchair, can give optimal performance, user safety, and extended battery life.
3. Motors with higher torque can be used to enable the wheels to move relatively easily.
4. Future research should focus on implementing an advanced closed-loop control strategy in set-point speed control systems to improve efficiency and performance.
5. it is recommended that further research should explore data augmentation techniques to simulate diverse hand gesture scenarios, enhancing the MPU 6050 sensor's generalization and recognition accuracy.

REFERENCES

Aamir, M. (2013). On replacing PID controller with ANN controller for DC motor position control. International Journal of Research Studies in Computing, 2(1), 21–29. https://doi.org/10.5861/ijrsc.2013.236

Akmeliawati, R., Tis, F. S. B., & Wani, U. J. (2011). Design and development of a hand-glove controlled wheelchair. 2011 4th International Conference on Mechatronics: Integrated Engineering for Industrial and Societal Development, ICOM'11 - Conference Proceedings, May, 17–19. https://doi.org/10.1109/ICOM.2011.5937126

Bhuiyan, M., & Picking, R. (n.d.). Gesture-controlled user interfaces, what have we done, and what ' s next ?

David, N., Udengwu, C., & Onyia, O. (2015). A Gesture Controlled System. 6(11), 397–405.

David, S., Tharun, V., Reddy, D. M., & Vinay, A. U. M. (2019). Hand gesture controlling device. International Journal of Engineering and AdvancedTechnology, 8(4), 1439–1442.

Goyal, D., & Saini, S. P. S. (2013). Accelerometer-Based Hand Gesture Controlled Wheelchair. 4(2), 15–20.

Kushwah, M. & Patra, A. (2014). Tuning of PID controller using Ziegler-Nichols method for speed control of DC motor - Semantic Scholar. International Journal of Engineering and Advanced Technology, 03(13), 2924–2929.

Machangpa, J. W. & Chingtham, T. S. (2018). Head Gesture Controlled Wheelchair for Quadriplegic Patients. Procedia Computer Science, 132(Iccids), 342–351. https://doi.org/10.1016/j.procs.2018.05.189

Mahmud, S., Lin, X. & Kim, J. (2019). A Multi-Modal Human Machine Interface for Controlling a Smart Wheelchair. December, 13–14.

Maruthisagar, N. V. (2014). MEMS-Based Gesture Controlled Robot Using Wireless Communication. 14(4), 185–188.

Mems, P. U., Pande, P. V. V, Ubale, N. S., Masurkar, D. P., Ingole, N. R., & Mane, P. P. (2014). Hand Gesture Based Wheelchair Movement Control for Disabled. 4(4), 152–158.

Mistry, K. S., Pelayo, P., Anil, D. G., & George, K. (2018). An SSVEP-based brain-computer interface system to control electric wheelchairs. I2MTC 2018 - 2018 IEEE International Instrumentation and Measurement Technology Conference: Discovering New Horizons in Instrumentation and Measurement, Proceedings, 1–6. https://doi.org/10.1109/I2MTC.2018.8409632

Paulose, S., & Mohan, G. (2014). Automatic Wheelchair using Gesture Recognition Along with Room Automation. 2(5), 40–43.

R. C. M. (2014). Voice and Accelerometer Controlled Wheel Chair. International Journal of Research in Engineering and Technology, 03(15), 290–292. https://doi.org/10.15623/ijret.2014.0315056

Sabuj, B., Islam, M. J., & Rahaman, M. A. (2019). Human-robot interaction using sensor-based hand gestures for assisting disabled people. 2019 International Conference on Sustainable Technologies for Industry 4.0, STI 2019, 0, 1–5. https://doi.org/10.1109/STI47673.2019.9068087

Sakpal, V., Patil, O., Bhagat, S., Shaikh, B., & Mumbai, N. (2018). Hand Gesture Controlled Robot Using Arduino. International Journal of Recent Trends in Engineering and Research, 4(4), 336–342. https://doi.org/10.23883/ijrter.2018.4244.4ls6r

Shaari, A. R., Nordin, M., Jani, M., Syukri, A., & Yunus, M. (2017). A Smart Wheelchair Prototype Based On Hand Gesture Control. Journal of Engineering and Science Research, 1(2), 209–214. https://doi.org/10.26666/rmp.jesr.2017.2.31

Singh, R., Bhojwani, Y., Reddy, R., & Sultana, H. P. (2019). Hand gesture-based multi-purpose bot. International Journal of Innovative Technology and Exploring Engineering, 9(1), 4419–4423. https://doi.org/10.35940/ijitee.A5098.119119

Su, H., Ovur, S. E., Zhou, X., Qi, W., & Ferrigno, G. (2020). Depth vision guided hand gesture recognition using electromyographic signals. Advanced Robotics, 0(0), 1–13. https://doi.org/10.1080/01691864.2020.1713886

Sujant, K., & Reddy, G. (2016). Hand Gesture Controlled Wheelc hair using Raspberry Pi and Open CV. 05(29), 6117–6120.

Vernekar, P., Chougula, B., Pawar, M., Patil, A., & Hooli, K. (2020). Gesture-controlled wheel chair and convertible wheelchair into stretcher. 2020 International Conference for Emerging Technology, INCET 2020, 7–10. https://doi.org/10.1109/INCET49848.2020.9154172

Yadav, S., & Kumar, S. (2018). Design & Simulation of Speed Control for DC Drives using Smart Controller. 7(12), 210–213.