

Design and Fabrication Of Head Motion Control Based Wheel Chair

Mr. Kushal Gowda U¹, Mr. Linith R², Mr. Lokesh M E³, Mr. Madhu K R⁴

Guide: Mr. Syed Imran Ali Asst. Professor

Dept. of Mechanical Engineering, PES College of Engineering, Mandya

Abstract- This paper presents the design, fabrication, and experimental analysis of a Head Motion Control Based Wheelchair for individuals with severe motor disabilities. The system utilises an MPU-6050 three-axis accelerometer and gyroscope module mounted on the user's head to detect intentional head tilts — forward, backward, left, right, and neutral — and translates them into corresponding wheelchair drive commands via an ESP32 microcontroller and L298N motor driver. Experimental results across 300 trials yield an overall gesture recognition accuracy of 97.3%, average system latency of 124 ms, and successful multi-directional navigation in indoor environments. The system outperforms all prior comparable implementations in accuracy, latency, and is the only design to incorporate continuously variable speed control proportional to tilt angle magnitude.

Keywords: Head Motion Control, Accelerometer, MPU-6050, Wheelchair, Gesture Recognition, Tilt Angle, ESP32, Assistive Technology, Variable Speed Control.

I. INTRODUCTION

Severe motor impairments — resulting from conditions such as quadriplegia, ALS, muscular dystrophy, or high cervical spinal cord injuries — eliminate the ability to operate conventional joystick or hand-controlled powered wheelchairs. This restricts independent mobility and negatively impacts quality of life for millions of individuals worldwide.

Head-based interfaces present a compelling, non-invasive alternative since most individuals with the above conditions retain voluntary head movement. The MPU-6050 inertial measurement unit (IMU), comprising a three-axis MEMS accelerometer and three-axis gyroscope on a single chip, provides a cost-effective, accurate platform for capturing head orientation changes in real time.

The proposed system maps the continuous angular output of the accelerometer — specifically the pitch

axis (forward/backward) and roll axis (left/right) — to wheelchair movement commands and variable motor speed. This enables the user to steer intuitively through deliberate head gestures, without the need for hand, arm, or breath-based interfaces.

II. SYSTEM OVERVIEW

Hardware Architecture

The system uses the following hardware stack:

- MPU-6050 (3-axis MEMS accelerometer + gyroscope) — head-mounted sensor
- ESP32 Microcontroller — complementary filter, FSM, PWM generation
- L298N Motor Driver — dual DC motor control
- HC-SR04 Ultrasonic Sensor — obstacle detection
- 12V Li-ion Battery + 5V Buck Regulator — power supply
- Bluetooth Module — real-time mobile monitoring

Signal Processing

The MPU-6050 returns 16-bit signed integers (range -32768 to +32767) at ±2g sensitivity, sampled at 100 Hz over I2C. Pitch and roll angles are derived as:

$$\text{Pitch } (\theta) = \arctan\left(\frac{A_y}{\sqrt{A_x^2 + A_z^2}}\right) \quad | \quad \text{Roll } (\phi) = \arctan\left(\frac{A_x}{\sqrt{A_y^2 + A_z^2}}\right)$$

A complementary filter combines accelerometer-derived angles with gyroscope integration to suppress noise and drift, producing stable orientation estimates. Variable speed for forward/reverse is computed as:

$$\text{PWM } (\%) = \left[\frac{(|\theta| - 15^\circ)}{45^\circ - 15^\circ} \right] \times 100$$

Angles below 15° activate a dead zone (STOP). Angles above 45° are clamped to 100% PWM. Left/right turns use a fixed 60% PWM for stable arc trajectories.

III. HEAD GESTURE TO DIRECTION MAPPING

Five discrete directional states are defined based on pitch and roll angle magnitudes. Thresholds were determined experimentally to balance sensitivity and resistance to unintended activations:

Table 1 – Head Gesture to Directional Command Mapping

Head Gesture	Axis	Angle Range	Wheelchair Command	PWM / Speed
Tilt Forward	Pitch (-θ)	15° – 45°	FORWARD	Proportional to θ
Tilt Backward	Pitch (+θ)	15° – 45°	REVERSE	Proportional to θ
Tilt Left	Roll (-φ)	15° – 45°	LEFT TURN	Fixed 60% PWM
Tilt Right	Roll (+φ)	15° – 45°	RIGHT TURN	Fixed 60% PWM
Neutral / Centre	Both axes	< ±5°	STOP	0% PWM

IV. RESULTS AND ANALYSIS

Accelerometer Output vs Head Tilt Angle

The MPU-6050 returns 16-bit signed integer values (range -32768 to +32767) for each axis at ±2g

sensitivity. These raw values are converted to g-units (divide by 16384) and then to angles using the arctan equations. Table 2 characterises the accelerometer output across the full operational range for the pitch axis (forward/backward):

Table 2 – Accelerometer Output vs Left/Right Head Tilt Angle (Roll Axis)

Tilt Angle (°)	Ax Raw	Ax (g)	Az Raw	Roll (°)	Command
0° (Neutral)	0	0.000	16384	0.0°	STOP
5° Right	+1430	+0.087	16324	5.0°	STOP (Dead zone)
10° Right	+2845	+0.174	16120	10.0°	STOP (Dead zone)
15° Right	+4260	+0.260	15773	15.0°	RIGHT TURN (60% PWM)
25° Right	+6920	+0.422	14680	24.8°	RIGHT TURN (60% PWM)
35° Right	+9280	+0.566	13110	34.4°	RIGHT TURN (60% PWM)
45° Right	+11380	+0.694	11115	44.0°	RIGHT TURN (60% PWM)
15° Left	-4260	-0.260	15773	-15.0°	LEFT TURN (60% PWM)
25° Left	-6920	-0.422	14680	-24.8°	LEFT TURN (60% PWM)
35° Left	-9280	-0.566	13110	-34.4°	LEFT TURN (60% PWM)

45° Left	-11380	-0.694	11115	-44.0°	LEFT TURN (60% PWM)
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Table 3 presents the pitch axis (forward/backward) characterisation. Variable speed proportional to tilt magnitude is used for forward/reverse commands:

Table 3 – Accelerometer Output vs Forward/Backward Head Tilt Angle (Pitch Axis)

Tilt Angle (°)	Ay Raw	Ay (g)	Az Raw	Pitch (°)	Command
0° (Neutral)	0	0.000	16384	0.0°	STOP
5° Forward	-1430	-0.087	16324	5.0°	STOP (Dead zone)
10° Forward	-2845	-0.174	16120	10.0°	STOP (Dead zone)
15° Forward	-4260	-0.260	15773	15.0°	FORWARD (Slow — 0% base)

Variable Speed (PWM) vs Head Tilt Angle

The variable speed behaviour was characterised by measuring actual wheel velocity (cm/s) at each discrete tilt angle step. A digital tachometer measured shaft RPM, converted to linear speed via wheel circumference (54.0 cm for standard 8-inch

wheels). The measured PWM closely tracks expected values with a maximum error of 4.5% at minimum threshold tilt (17°), reducing to below 1.5% at higher tilt angles:

Table 4 – Variable Speed Characterisation: Tilt Angle vs PWM vs Measured Wheel Speed

Tilt (°)	Exp. PWM (%)	Meas. PWM (%)	L Motor RPM	R Motor RPM	Speed (cm/s)	Error (%)
15°	0	0	0	0	0.0	—
17°	6.7	6.4	11	11	3.1	4.5%
20°	16.7	16.2	28	27	7.8	3.0%
25°	33.3	32.8	55	55	15.7	1.5%
30°	50.0	49.5	82	82	23.4	1.0%
35°	66.7	66.0	109	110	31.2	1.1%
40°	83.3	82.9	137	136	39.0	0.5%
45°	100.0	99.1	163	163	46.5	0.9%

Directional Gesture Recognition Accuracy

Five head gestures were evaluated across 60 trials each (300 total) by three test participants. Gestures were performed at tilt angles of 20°, 30°, and 40° to

assess recognition consistency across varying intensities:

Table 5 – Directional Gesture Recognition Accuracy at 20°, 30°, and 40° Tilt Angles

Gesture	Trials @20°	Correct @20°	Trials @30°	Correct @30°	Trials @40°	Correct @40°	Overall Acc.
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Forward	20	19	20	20	20	20	98.3%
Reverse	20	19	20	19	20	20	96.7%
Left Turn	20	18	20	20	20	20	96.7%
Right Turn	20	19	20	20	20	19	96.7%
Stop (Neutral)	20	20	20	20	20	19	98.3%
TOTAL	100	95	100	99	100	98	97.3%

Recognition accuracy improves with increasing tilt angle: 95% at 20°, 99% at 40°, confirming robust operation at moderate-to-large intentional head tilts. At 20° tilt, marginal signal-to-noise ratio causes occasional misclassification, particularly for turning gestures.

System Response Latency Analysis

Response latency was measured from gesture onset (head tilt initiation) to motor shaft rotation using an oscilloscope trigger on the PWM output pin, across 50 trials per gesture:

Table 6 – Detailed System Response Latency Breakdown per Directional Gesture

Latency Component	Left Turn (ms)	Right Turn (ms)	Forward (ms)	Reverse (ms)
IMU Sampling Period	10	10	10	10
Complementary Filter	12	12	12	12
FSM Decision Time	8	8	9	9
PWM Update Cycle	10	10	10	10
Motor Driver Response	42	44	43	43
Mechanical Startup Delay	41	42	43	44
Total Average Latency	123	126	127	128
Max Observed Latency	141	144	148	147

Total system latency remains well below 150 ms across all gesture types. The dominant contributor is the combined motor driver response and mechanical startup delay (~83–87 ms), representing physical motor inertia rather than computational overhead. The microcontroller-side processing accounts for only ~40 ms, confirming efficient real-time performance.

Multi-Directional Navigation Path Test

A standardised navigation course was conducted in a 6m × 4m indoor space. The course required: forward 3m → right turn 90° → forward 2m → left turn 90° → reverse 1m → return to start. Results across 6 trials are presented below:

Table 7 – Multi-Directional Navigation Course Results

Trial	Part.	Completed	Collisions	Time (s)	Avg Tilt	Speed	Result
1	P1	Yes	0	48.2	28°	Medium	PASS
2	P1	Yes	0	44.7	33°	Fast	PASS

3	P2	Yes	0	56.1	22°	Slow	PASS
4	P2	Yes	1*	52.3	26°	Medium	PASS*
5	P3	Yes	0	42.9	36°	Fast	PASS
6	P3	Yes	0	50.5	25°	Slow-Med	PASS

All 6 trials successfully completed the navigation course. The single collision event in Trial 4 was attributed to late obstacle detection on a sharp 90° right turn where the front ultrasonic sensor had limited lateral coverage — identified as a hardware

limitation to address in future work. Average completion time varied from 42.9 to 56.1 seconds, directly reflecting participant speed preference.

Comparative Analysis with Prior Work

Table 8 – Comparative Analysis: Proposed System vs Prior Accelerometer-Based Wheelchair Systems

Author & Year	Sensor	MCU	Accuracy	Latency (ms)	Var. Speed	Obstacle	Dirs
Chau et al. (2014)	ADXL345	Arduino	92.0%	~250	No	No	4
Kumar et al. (2017)	ADXL335	Arduino	89.5%	~220	No	No	4
Saiteja et al. (2019)	MPU-6050	Arduino	93.5%	~200	No	No	4
Reshma et al. (2020)	MPU-6050	NodeMCU	91.0%	~180	No	No	4
Pradeep et al. (2023)	MPU-6050+ML	RPi	96.5%	~160	No	No	4
Anitha et al. (2024)	MPU-6050	Arduino	94.2%	~170	No	Yes	4
Proposed System	MPU-6050 IMU	ESP32	97.3%	~124	YES	Yes	5

The proposed system outperforms all referenced works in accuracy (97.3%) and latency (124 ms). It is the only implementation to support continuously variable speed control proportional to head tilt magnitude, combined with five-direction control (including reverse), real-time obstacle avoidance, and Bluetooth monitoring.

V. FUTURE RESEARCH ROADMAP

- **Diagonal Motion Support:** Combine simultaneous pitch and roll inputs to enable smooth diagonal movement, expanding navigable directions from 5 to 8.
- **Adaptive Threshold Calibration:** Implement per-session automatic calibration of activation

thresholds based on the user's natural head movement range and tremor characteristics.

- **Multi-Sensor Obstacle Coverage:** Add side-facing and rear ultrasonic sensors to provide 360° obstacle awareness, addressing the lateral blind spot identified in navigation trials.
- **Eye-Blink and Voice Multimodal Fallback:** Integrate EEG or EOG eye-blink detection as an alternative command modality for users with restricted head mobility.
- **AI-Powered Gesture Learning:** Develop on-device federated learning to personalise gesture classification for individual users, reducing false activations from involuntary movements.
- **Cloud Caregiver Dashboard:** Stream orientation data, speed, battery, and obstacle events to a cloud dashboard for real-time remote caregiver monitoring.

- **Clinical Validation with Motor-Disabled Participants:** Conduct IRB-approved trials with quadriplegic and ALS patients to gather clinical usability data.

VI. CONCLUSION

This report presented a comprehensive result analysis of a Head Motion Control Based Wheelchair driven by an MPU-6050 accelerometer and gyroscope sensor, processed by an ESP32 microcontroller. The key contribution is the systematic characterisation of accelerometer digital output across the full operational head tilt angle range (0° to $\geq 45^\circ$) and the demonstration that continuously varying the tilt angle produces proportional, predictable wheelchair speed modulation.

Experimental results from 300 gesture recognition trials confirm an overall accuracy of 97.3%, improving from 95% at 20° tilt to 99% at 40° tilt. The system achieves a total end-to-end latency of approximately 124 ms — significantly below the 200 ms threshold of prior comparable systems — and successfully navigates a multi-directional course in all 6 trials.

Compared to all prior accelerometer-based wheelchair systems, the proposed design is unique in combining: variable speed proportional to pitch angle, five-direction control including reverse, real-time obstacle avoidance, Bluetooth caregiver monitoring — all within an estimated component cost of USD 60–80. This work establishes a robust and extensible foundation for clinically deployable head-controlled mobility aids.

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