Intelligent Hand Gesture Controlled Wheelchair for Mobility-Impaired Patients

[1]Eweoya Ibukun, [2]Amanze Ruth, [3]Ominu Daniel, [4]Beulah Victor, [5]Adebamowo David, [6]Adekola Olubukola, [7]Akande Oyebola, [8]Udosen A. Akpan, and [9]Akinola Ayomide
[1,3,4,5] Department of Software Engineering, Babcock University, Ogun State, Nigeria.
[2,6,7,8,9] Department of Computer Science, Babcock University, Ogun State, Nigeria.
eweoyai@babcock.edu.ng|amanzer@babcock.edu.ng|ominudaniel@babcock.edu.ng|beulah.umoren@babcock.edu.ng|adebamowodavid@babcock.edu.ng|adekolao@babcock.edu.ng|akandeo@babcock.edu.ng|udosena@babcock.edu.ng|akinolaa@pg.babcock.edu.ng

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ORIGINAL RESEARCH

Abstract— With the growing demand for affordable and accessible assistive mobility devices for individuals with physical disabilities, this paper presents the design, implementation, and experimental evaluation of an Intelligent Hand Gesture Controlled Wheelchair for Mobility-Impaired Patients. Mobility-impaired individuals in Nigeria face a dual barrier: severe motor conditions such as quadriplegia, muscular dystrophy, and spinal cord injury that preclude conventional joystick operation, and the prohibitive cost of imported powered wheelchairs, which effectively excluding the vast majority of disabled individuals from powered mobility solutions. This project designed, fabricated, and tested an intelligent hand gesture-controlled wheelchair prototype using locally sourced components to address both constraints simultaneously. The system employs an ADXL345 three-axis accelerometer worn on a glove to detect tilt-based directional gestures, an ATmega328P microcontroller for gesture classification via empirically calibrated threshold logic, a 433MHz RF transmitter-receiver pair with HT12E/HT12D encoding for wireless command transmission, and an L293D H-Bridge motor driver for differential drive control of two DC gear motors. A Seeed Grove infrared obstacle sensor provides automatic collision avoidance by overriding motion commands when an obstacle is detected within 40cm. Both circuit nodes were designed in Eagle CAD and fabricated on custom PCBs. In an experiment done in a controlled environment, performance evaluation across 300 gesture trials yielded an overall gesture recognition accuracy of 94.0%, a mean system response time of 239ms, 100% RF command reliability at indoor distances up to 8 metres, and 100% obstacle detection reliability at the recommended 40 cm threshold. All components were sourced from the Nigerian electronics market. These results confirm that reliable, affordable gesture-based wheelchair control is achievable in low-resource settings, providing a replicable and scalable foundation for further assistive mobility development.

Keywords— Accelerometer, Assistive Technology, ATmega328P, Gesture Control, H-Bridge, L293D Motor Driver, LiPo Battery, Obstacle Sensor, PCB, RF Module, Wheelchair

1 INTRODUCTION

The Physical disability remains one of the most significant barriers to independent living worldwide. The World Health Organization (2023) estimates that about 15% of the world's population has some type of disability, and more than 131 million people use wheelchairs to get from place to place. This is exacerbated by the high cost of powered wheelchairs in Nigeria, thereby ruling out the vast majority of people living with disabilities from having access to powered mobility solutions. This is an economic problem and a systemic problem, not only a technical problem, as there is a gap between the availability of assistive technology globally and its local accessibility which requires solutions locally-constructible.

Manual hand-rim and electric control by a joystick requires hand strength and upper limb dexterity that are often lacking in persons with quadriplegia, muscular dystrophy, advanced arthritis, or spinal cord injury. (Sadi et al., 2022). These individuals often require full-time caregiver assistance for mobility, which significantly compromises their independence, dignity, and quality of life. Research into alternative control modalities including head tracking, sip-and-puff interfaces, and wearable accelerometer-based gesture recognition has established the feasibility of non-contact wheelchair control, but most published systems rely on components that are either expensive or unavailable in developing-country electronics markets (Patil & Kale, 2015; Saini, 2019)

The ADXL345 three-axis digital accelerometer, manufactured by Analog Devices, has emerged as a widely adopted platform for low-cost gesture-based embedded control. Its digital I2C/SPI interface, programmable ±2g to ±16g measurement range, 13-bit resolution, and ultra-low power consumption of 23 μA in measurement mode make it highly suited to battery-powered wearable applications (Analog Devices Inc., 2015). When combined with the ATmega328P microcontroller, the processing core of the Arduino Uno platform (ADXL345) provides a straightforward, well-documented path to wrist-tilt gesture classification suitable for undergraduate-level embedded systems research (Asadullah & Raza, 2016).

Despite this commitment, Usman et al. (2024) found in a study of 280 stroke survivors in Kano, Nigeria, that only 41% were using any assistive technology, with wheelchairs being the most common device cited. Youssef and Morsy (2023) further noted that assistive technology remains critically underutilised in low-income settings, reinforcing that policy frameworks alone have not closed the affordability gap and that locally constructible prototypes are essential.

Recent advances further validate this approach. Bouyam

Corresponding Author: udosena@babcock.edu.ng
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et al. (2025) demonstrated that piezoelectric sensors and MEMS accelerometers serve as effective hands-free human-machine interfaces for simulated wheelchair control in older adults and persons with physical disabilities, with participants achieving reliable directional control after minimal familiarisation. Erturk et al. (2024) proposed a LiDAR-based driving assistance system for electric wheelchairs that achieves comprehensive obstacle avoidance — a capability that the present prototype partially addresses with a forward-facing infrared sensor, and which points to a clear upgrade path for future iterations.

This paper makes the following contributions: (1) a complete, documented design of a dual-node gesture-controlled wheelchair system using the ADXL345, ATmega328P, 433 MHz RF modules, and L293D motor driver, all of which were commercially available in the Nigerian electronics market at the time of construction; (2) empirically calibrated ADXL345 gesture classification thresholds derived from systematic Serial Monitor data collection across 30 readings per gesture orientation; (3) PCB-fabricated transmitter and receiver circuits integrated into a functional wearable glove and wheelchair chassis prototype; and (4) quantitative performance evaluation across 300 gesture trials and multiple communication range and obstacle detection tests.

The remainder of this paper is organised as follows. Section 2 reviews the background and related literature. Section 3 presents the system architecture and hardware design. Section 4 describes the firmware methodology and gesture classification approach. Section 5 presents experimental results and discussion. Section 6 concludes the paper and identifies directions for future work.

2 LITERATURE REVIEW

2.1 Review of Related Works

Patil and Kale (2015) presented a wheelchair prototype which used a 433MHz RF link and recognized gestures with an accuracy of nearly 90%, but they also identified a problem of sensor drift and pointed out that obstacle detection was completely absent. Similarly, Saini et al. (2019) used an accelerometer with 433 MHz RF communication based on HT12E and HT12D encoder-decoder ICs, and they reported good results for transmission in indoor environments, but noted problems with RF interference in dense wireless environments. The authors designed an IoT integrated gesture wheelchair which used APDS-9960 infrared sensor with Bluetooth and connected to the ThingSpeak cloud, and the results they achieved are competitive, though with the drawback of relying on the internet infrastructure that cannot be guaranteed in low-resource locations. Huda et al. (2025) showed that machine learning can be applied to the MPU6050 IMU and a k-NN classifier, obtaining almost 96% accuracy, but they needed to train the machine learning algorithm with data from a particular user that cannot be embedded in low-cost microcontrollers. Bangali and Shaligram (2013) analyzed and discussed the use of an alert system for a remote user to alert the caregiver using a GSM based system, but they did not offer any gesture-based directions for the wheelchair.

Gesture wheelchair research has been continued in complementary directions in more recent research. This paper's sensor approach was validated by Bouyam et al. (2025), who showed that these piezoelectric sensors and MEMS accelerometers are suitable hands-free HMI for a simulated wheelchair control system. While the prototype employed only one forward-facing infrared sensor for obstacle detection, Erturk et al. (2024) proposed a LiDAR-based driving assistance system for electric wheelchairs that enabled comprehensive obstacle avoidance. Rabhi et al. (2018) created a visual joystick wheelchair control system which was tested on a real patient in a clinical environment, where they found that non-conventional control interfaces are feasible in practice but require computational hardware not available in the component market in Nigeria. An obstacle avoidance system for a low cost motorised wheelchair conversion using cheap embedded hardware is presented by Arboleda et al. (2015) and is very similar to the present design. Additionally, Islam et al. (2026) used a multi-sensor health monitoring system, implemented deep learning obstacle detection, and combined them with gesture control to achieve a single platform, showcasing the cumulative effect of such features added to a base wheelchair controlled by gestures. Nguyen et al. (2025) used a YOLOv8n model for vision-based gesture recognition on a smart wheelchair that costs less than USD 300, which further reinforced the trend of reducing the cost of the hardware for the gesture interface. For classification of all the above, the taxonomy of smart wheelchair control modalities, sensing strategies and navigation architectures by Simpson (Rehan et al., 2005) is used. With the development of a vision-based hands-free interface by Ju et al. (2009) using the inclination of the human face and the shape of the mouth, it has been shown that a variety of non-contact methods can be implemented on a typical embedded device.

The major shortcomings in the various systems are; components that are not available in the Nigerian electronics market; lack of integration of obstacle detection; lack of documentation to enable the replication of the system independently and no evaluation in a low-resource environment. All 4 gaps are addressed directly in this project: firstly, local sourcing of components; secondly, integrated obstacle avoidance using the Seeed Grove IR sensor; thirdly, systematic threshold documentation for the ADXL345 sensor; and finally complete disclosure of the firmware.

3 METHODOLOGY

3.1 System Overview

The proposed system is a dual node, unidirectional wireless control system made up of a Transmitter Node (wearable glove assembly) and a Receiver Node (wheelchair chassis unit). The Transmitter Node is equipped with an ADXL345 accelerometer module and a

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first ATmega328P microcontroller which is used to read the axis values of the gestures, to classify them, to encode the command using the HT12E IC and to send the command through a 433 MHz RF transmitter module. The Receiver Node is built using a second ATmega328P, an HT12D decoder IC, a Seeed Grove infrared obstacle sensor and an L293D H-Bridge motor driver with two DC gear motors. The full hardware BOM for both nodes is listed in Table 1.

Table 1. Hardware Bill of Materials

Component	Model / Specification	Qty
Microcontroller	ATmega328P (Arduino Uno)	2
Accelerometer	ADXL345, ±2g–±16g, I2C	1
RF Transmitter	433 MHz ASK, 3–12V	1
RF Receiver	433 MHz superheterodyne	1
Encoder/Decoder	HT12E / HT12D ICs	1 each
Motor Driver	L293D Dual H-Bridge	1
DC Gear Motor	12V, high-torque, gear-reduced	2
Obstacle Sensor	Seeed Grove IR proximity	1
Battery	12V, 5Ah LiPo pack	1
Caster Wheel	360° swivel front wheel	1

3.2 ATmega328P Microcontroller

The Microchip ATmega328P is an 8-bit AVR RISC microcontroller with up to 16 MHz frequency, 32KB of in-system programmable Flash memory, 2KB of SRAM and 1KB of EEPROM. It supports 14 digital input-output (I/O) pins, 6 analogue input channels and offers hardware UART, SPI, and I2C (TWI) interfaces. The ATmega328P is used in the Transmitter Node to read data from the ADXL345 axis using the I2C (SDA on A4, SCL on A5) protocol, classify the gestures, and control the RF transmitter with digital output pins 8-11. The second ATmega328P in the Receiver Node receives the decode signal from the HT12D IC, checks a dedicated digital input of the obstacle sensor and controls the L293D motor driver using four digital output pins. The ATmega328p was chosen for its reliability, the availability of an Arduino IDE toolchain, and being readily available from most electronics suppliers in Nigeria.

3.3 ADXL345 Tri-Axial Accelerometer

The ±2g range of the ADXL345 is measured on three orthogonal axes with 13-bit resolution, which gives a sensitivity of around 4 mg per least significant bit (LSB) (Analog Devices Inc., 2015). When the SDO pin is grounded, it communicates on I2C bus at address 0x53. In measurement mode, it draws just 23 μA of current, and can provide user-programmable activity and inactivity detection interrupts, tap detection, double-tap detection and free-fall detection. In this system, the sensor is attached to the back of the glove with the Z axis perpendicular to the hand plane, which means wrist flexion mainly deflects the Y axis, wrist extension mainly deflects the X axis and lateral tilts affect the relationship between X and Z axis. After testing three different orientations and observing the separability of the gesture clusters based on the output in the Serial Monitor, this mounting orientation was chosen. The ±2g range was chosen to achieve greatest sensitivity for the small tilt angles which are common for wrist gesture navigation.

3.4 RF Communication Modules and HT12E/HT12D Encoding

The wireless link between nodes is implemented using ASK RF transmitter/receiver (TR) pair at 433.92 MHz. The data is sent to the DATA input pin of the transmitter and the transmitter emits serial data with a maximum power output of 10 mW from 12V to 3V supply. The superheterodyne receiver module extracts data from the received signal and provides the output data of the demodulated signal on a 5V power supply. Under typical indoor multipath environment, the range of the effective indoor use of quarter wave wire antennas is 5–10 metres. The modules are matched with HT12E/TX12F address matched data encoding and decoding ICs, which greatly reduce the risk of receiving spurious commands from other RF sources, using a 4-bit address. The reason is that when purchased, the RF ASK module was available from at least three different electronics suppliers in Lagos, but Bluetooth was not available at that time, while at the time of purchase the HC-05 Bluetooth modules were not always available (there is no intention to impose this restriction on the reviewed similar works).

3.5 L293D Dual H-Bridge Motor Driver

The L293D is a quadruple half-H driver IC produced by Texas Instruments, which can drive two DC motors at a time in both directions (Texas Instruments, 2015). The continuous current for each channel is 600 mA (1.2 A peak) and the motor supply range is from 4.5V to 36V. All output pins are protected from inductive back-EMF voltage spikes and the IC is provided with built-in flyback protection diodes to protect.

The motor direction reversing forces do not damage the microcontroller. The logic state on IN1/IN2 (Channel A) and IN3/IN4 (Channel B) controls the direction of Motor: IN1=HIGH, IN2=LOW, Motor A is driven forward; IN1=LOW, IN2=HIGH, Motor A is driven in reverse; both LOW provides dynamic braking. In this prototype the Enable pins ENA and ENB are permanently set to HIGH, and speed modulation is left for future implementations using Pulse Width Modulation (PWM) on the enable pins as iterations.

3.6 Power Management and Safety Features

The 12V, 5Ah LiPo battery pack is the main power supply and feeds directly into the 12V rail, which powers the L293D motor driver circuit. The 5V rail is used by all logic and sensor circuits, and is regulated onboard using a linear regulator. Instead, sealed lead-acid chemistry was chosen in favor of LiPo. The weight penalty of a 5Ah lead-acid battery (~1.5 kg) was deemed too heavy for a small chassis prototype, while the LiPo pack weight is less than 400g. The LiPo battery current charger offers cell balancing and over discharge protection, thus increasing the life of the battery pack. During integration testing, it was discovered that the voltage drop from inrush current of the motors caused resets of the microcontroller, so a

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1000 μF electrolytic was installed across the 5V logic rail to prevent this. A 3 second timeout in the receiver. If there is no valid RF command, runaway motion is prevented when the RF link is broken by stopping the motors automatically when necessary.

4 GESTURE CLASSIFICATION METHODOLOGY

4.1 Threshold Calibration Procedure

Gesture classification is performed through a series of if-else conditional checks on the raw ADXL345 integer axis values read at each firmware polling cycle. Threshold ranges were determined empirically using a structured calibration procedure: 30 consecutive Serial Monitor readings were recorded for each of the five gesture orientations (FORWARD, BACKWARD, LEFT, RIGHT, STOP), and the minimum and maximum observed values on each relevant axis were identified. Non-overlapping threshold windows were then defined with a conservative deadband of 5 raw units between adjacent gesture regions to minimise misclassification at gesture boundaries. Table 2 summarises the resulting gesture-to-command threshold mapping embedded in the transmitter firmware.

Table 2. ADXL345 Gesture-to-Command Threshold Mapping

Gesture	Axis Conditions	Output Pins (8–11)	LED
STOP	x∈(10,30) AND y<1	LOW, LOW, LOW, LOW	OFF
FORWARD	y∈(50,200) AND z∈(150,250)	HIGH, LOW, HIGH, LOW	ON
BACKWARD	x∈(15,100) AND z∈(50,250)	LOW, HIGH, LOW, HIGH	ON
LEFT	x<1 AND z∈(50,250)	HIGH, LOW, LOW, LOW	ON
RIGHT	y∈(1,50) AND z∈(50,250)	LOW, LOW, HIGH, LOW	ON
Default	None of the above	LOW, LOW, LOW, LOW	OFF

4.2 Debouncing and Fail-Safe Logic

Two software debouncing mechanisms protect against spurious gesture commands. In the transmitter firmware, a 1500 ms polling delay prevents spurious detections from brief involuntary wrist movements between intentional gestures. Additionally, the receiver firmware requires three consecutive identical command reads before activating the motors, filtering single-occurrence RF noise events that could cause unintended wheelchair movements. The default STOP condition means that the wheelchair will not move if the hand is not in a flat position or if it is in an unrecognised position, giving a simple fail-safe against unwanted movement. On the receiver end, if no valid RF command is received for three consecutive polling cycles, the wheelchair automatically stops, so that if the transmitter battery dies or the RF link goes out, no damage will result. The STOP command is deliberately placed in a large and geometrically central part of the accelerometer output space, the flat-hand position, so that the wheelchair will naturally return to the stationary state when the hands are naturally repositioned. This design decision was made for the sake of safety versus responsiveness, given this is a prototype for use by users with less than full control of their upper limbs who may have involuntary wrist movements during the gesture transition. .

5 EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Experimental Setup

All test were performed on a fabricated prototype PCB in a controlled indoor laboratory environment at Babcock University. The glove was a transmitter worn by a single healthy test person carrying out similar wrist tilt movements. Performance metrics were recorded multiple times on three separate test sessions on different days, 20 trials per gesture direction per session (or 60 trials per command). The response times were measured using a digital stopwatch with a resolution of ±1 ms. The time elapsed between the initiation of the gesture and the actual movement of the motors. Each sequence of gestures was independently checked by reading the output data from the transmitter ATmega328P on the serial monitor to ensure that the commands were correctly transmitted. Radio Frequency range and obstacle detection tests were conducted. Measures were taken at set distances (measuring tape) and trials were randomly ordered across trials to avoid ordering effects.

5.2 Gesture Recognition Accuracy

The accuracy in gesture recognition is presented in Table 3 based on 300 trials in total (60 trials for each command in 3 different sessions, 20 trials per session). The overall gesture recognition accuracy of 94.0% is comparable to the reported accuracy by Patil and Kale (2015) (around 90%) which shows that ADXL345 threshold based classification can be used with a competitive accuracy when systematic threshold calibration is used. The accuracy of the gesture recognition is given in table 3.

Table 3. Gesture Recognition Accuracy Results

Gesture	Trials	Correct	Accuracy (%)
FORWARD	60	57	95.0
BACKWARD	60	56	93.3
LEFT	60	55	91.7
RIGHT	60	55	91.7
STOP	60	59	98.3
Overall	**300**	**282**	**94.0**

The command STOP had the best accuracy (98.3%) because its corresponding output of the accelerometer has the smallest overlap with all of the other command thresholds and is spread out in the output space. Forward also had a good performance (95.0%) due to a similar geometric effect, forward tilt always yields a large magnitude response in the Y-axis. LEFT and RIGHT commands had the lowest accuracy (91.7%) because the tilt axis value separation between both commands is smaller. This can be explained by the following results from Huda *et al.* (2025) that gesture pairs sharing the same primary detection axis are the main source of the threshold-based accelerometer systems, classification error. One practical mitigation not utilized in this prototype, but recommended for future prototypes is to increase the distance between the boundaries of LEFT and

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RIGHT to introduce a higher deadband, which will require the user to make a more pronounced wrist movement to activate the switch.

5.3 System Response Time

The response time results in Table 4 are shown for 20 trials for each gesture. The average time till full response of 239ms is within the 500ms limit for real-time assistive mobility control systems, confirming the response time and feedback of the system is responsive with no noticeable time delay when navigating the wheelchair.

Table 4. System Response Time Measurements (ms)

Gesture	Min (ms)	Max (ms)	Mean (ms)
FORWARD	180	330	242
BACKWARD	185	340	248
LEFT	190	350	255
RIGHT	190	345	252
STOP	145	280	198
Overall	—	—	**239**

The total latency is the combination of ADXL345 polling and classification (~10–20ms), the radio serial transmission at the HT12E/HT12D baud rate (~80-120ms) and the settling time of the L293D motors (~20-40ms). The firmware polling interval was chosen at 1500ms, which is the dominant cycle time consumption and is recommended to be reduced to 500ms (with a more aggressive 3-reading validation strategy) as a priority firmware refinement to achieve a worst case response time of under 200ms before any clinical use is made.

5.4 RF Communication Range

The test results of RF Communication Range are given in the table 5.

Table 5. RF Communication Range Test Results

Distance (m)	Trials	Successful	Rate (%)
1	20	20	100
2	20	20	100
4	20	20	100
6	20	20	100
8	20	20	100
10	20	19	95
12	20	14	70

100% delivery of commands was achieved at all indoor distances up to 8 metres, illustrating reliable wireless communications for all practical wheelchair use scenarios in which the user wearing the glove is likely to be within the range of 1–3 metres of the wheelchair. The degradation at 10m (95%) and 12m (70%) is representative of the specified indoor range of 433 MHz ASK modules and short wire antennas, and is caused by RF path loss and multipath reflections at extended distances. At all tested indoor distances up to 8 metres the system successfully delivered 100% of the commands, showing reliable wireless communication for all practical wheelchair usage scenarios where the person wearing the glove can be expected to be within 1–3 metres of the wheelchair. The degradation at 10 m (95%) and 12 m (70%) is as expected with an indoor range of 433 MHz ASK modules using short wire antennas due to the multipath reflections in the RF path loss at extended distances. During range testing, no spurious command activations were observed with the use of address-matched encoding by the use of HT12E/HT12D. For future iterations a visible signal strength indicator on the glove is recommended to alert users if they are approaching the reliability boundary.

5.5 Obstacle Detection

The test result for the obstacle Detection is displayed in table 6.

Table 6. Obstacle Detection Test Results

Threshold (cm)	Trials	Stops	Reliability (%)
50	20	20	100
40	20	20	100
30	20	19	95
20	20	17	85

At both 50cm and 40cm threshold distance, the Seeed Grove sensor stopped reliably, recording 100% stop reliability. Slight faults at 30 cm (95%) and 20 cm (85%) are related to motor braking distance when fully loaded.

In addition to the sensor detection failures, the obstacle stop threshold was set at at least 40 cm when actually using the system, reinforcing this recommendation. The multi-directional sensor array approach suggested by Erturk et al. (2024) would be useful to build to increase coverage beyond the single forward facing sensor included in this prototype.

5.6 Comparison with Related Work

Table 7 shows a comparison with related systems (where Obs. = Obstacle Detection, Comms = Communications)

Table 7. Comparison with Related Systems

System	Sensor	Comms	Acc.	Obs.
Patil & Kale (2015)	MEMS accel.	433 MHz RF	~90%	No
Saini et al. (2019)	MEMS accel.	433 MHz RF	N/R	No
Sadi et al. (2022)	APDS-9960	BT + Cloud	~95%	No
Huda et al. (2025)	MPU6050 IMU	Embedded	~96%	No
Proposed	**ADXL345**	**433 MHz RF**	**94%**	**Yes**

The proposed system is able to achieve competitive accuracy compared to (Sadi et al., 2022) with all local available components without relying on cloud services. It is seen that, it has an accuracy of gesture recognition of around 4% better than Patil and Kale (Patil & Kale, 2015) due to systematic ADXL345 threshold calibration and debounce validation for three consecutive readings implemented in this work. Most importantly, the proposed system is the only one that combines obstacle detection with RF-based gesture control, which is a necessity for safety issues as pointed out in literature review. The use of only available market components in Nigeria and complete disclosure of the system firmware also makes it the only replicable design to be directly available for low-resource engineering contexts.

6 CONCLUSION

This paper has proposed the design, implementation and experimental validation of an Intelligent Hand Gesture Controlled Wheelchair for Mobility Impaired Patient. The system comprises of a pair of ATmega328P microcontrollers, a 3-axis accelerometer (ADXL345), 433 MHz RF modules (which include HT12E and HT12D

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encoding), and an L293D H-Bridge motor driver, all purchased from the Nigerian electronics market, all combined into a fully functional dual-node wireless gesture control platform. The system successfully recognizes all the gestures, with an overall accuracy in gesture recognition of 94.0% for 300 trials, and a mean response time of 239 ms; the reliability of the RF communication is 100% at the recommended distance of 40 cm and 8 metres indoors, and the reliability of the obstacle detection is 100% at the recommended distance of 40 cm. The results validate the feasibility of reliable and cost effective gesture controlled wheelchair in a low resource engineering environment without reliance on cloud computing infrastructure or on expensive proprietary sensors and parts that are not available in Nigeria. The main drawback for the current prototype is the size of the motorised chassis, which has not been tested with the mechanical load of a normal full size wheelchair and an adult wheelchair user. All tests were performed on flat indoor surfaces and performance has not been tested under outdoor and inclined terrain conditions. The single forward facing obstacle sensor only detects in the direction of travel, not to the side or behind. Gesture detection thresholds were set on one test subject and could need to be adjusted for users with a much greater range of hand size or range of movement.

Further research is needed to implement a lightweight, deployable classifier, such as a k-Nearest Neighbour or Decision Tree, to replace the fixed-threshold classification on the ATmega328P with the EloquentML library, so that adaptive personalisation can be provided for individual users. Priority development extensions identified are lateral obstacle sensors, integration with IoT monitoring platforms, and scaling to a full-size 24V wheelchair platform. Finally, the structured usability trials with real wheelchair users supervised by occupational therapists is highly recommended prior to community or clinical use.

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