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Designing a Smart Hand Gesture Robotic Car Receiver for Achieving Transformative Transportation

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ABSTRACT

This paper explains the design and performance of a hand gesture robotic car receiver aiming to provide an easy-to-use solution for mobility so that paraplegics can have some aid in their daily routines. Through the integration of gesture recognition and robotics technology, this system is designed to enable users to independently move through their environment with natural hand gestures. A MPU6050 added to the transmitter of the car makes it easy to control and communicate with the car using real-time hand gestures. The microcontroller processes these gestures and converts it to angles that control the movement of the car. In all, the system translates five crucial hand gestures into correlating vehicle movements such as forward movement, reverse direction, turning left, turning right and stopping. The classified commands are sent to the microcontroller which controls motors and moves respective parts as requested. The receiver uses NRF24L01 radio module to wirelessly communicate with the transmitter. Arduino IDE is the key software stack used to operate the system configuration and integration. The average response time for five different observations of the forward, backward, right, left and break movement of the robotic car was recorded as: 106.4ms, 106.2ms, 99.2ms, 97.4ms and 102.2ms. The experimental results show that the robotic system is able to detect and control a car with accurate gesture recognition in real time, with a total average response time of 102.28 ms, resulting to 95% accuracy.

Keywords: *Hand Gesture, Micro Controller, MPU6050, NRF24L01, Receiver, Robotic*

1 INTRODUCTION

A good robotic system must have human-machine interaction as a key component. Early on, the only means of communication with a robot was through programming, which took a lot of effort. The advancement of science and robotics led to the creation of gesture-based recognition. Though they can start from any physical state or motion, gestures most frequently come from the hands or face. Gesture recognition is one approach toward making computers capable of reading human body language. As a result, there is now less demand for GUIs (Graphical User Interfaces) and text interfaces (RCCIIT, 2023).
In this world of advanced technology, various types of technology have been created to facilitate the Inter networking of physical devices that are embedded with electronic devices, software, sensors, or actuators that can make the data transfer possible. IoT can help paraplegic people in several ways. At its most basic level, it can help the disabled people to carry out everyday tasks in a simple manner without the involvement of humans. This eliminates the need for a helper throughout the day and can do simple tasks like object picking and placing for the disabled people. This can be introduced in the medical field for efficient operations and maneuverability in tasks (Venugopal and Balu Adityan, 2023).

Hand gesture controlled robotic cars have emerged as an innovative field in human-computer interaction and robotics. This technology aims to provide intuitive and natural ways for users to control vehicles, potentially enhancing accessibility and user experience.

This work is on a Hand gesture robotic car receiver which aims at providing an easy-to-use solution for mobility so that paraplegics can have some aid in their daily routines. This reduces the complexity encountered in existing systems. The NRF24L01 wireless module used in the system provides reliable and fast communication between the robotic car and the control system, allowing smooth and precise control compared to using Bluetooth modules like HC-05 or HC-06 that have been used in previous works. The low power consumption of NRF24L01 makes it suitable for battery-powered robotic cars, enabling longer operation times compared to using Wi-Fi modules like ESP8266 or ESP32 which consumes more power. Finally the system discussed in this work - Hand gesture robotic car receiver – reads all round gesture (360^0) unlike previous work that could read in specific directions but not in all directions.

Wadaye et al. (2023) presents an innovative integrated system combining a hand gesture-controlled robotic arm with an all-terrain surveillance car. The study showcases the potential of accelerometer-based gesture recognition for dual control of both the robotic arm and car movement, while also incorporating surveillance capabilities through an integrated camera. This multi-functional approach demonstrates the versatility of gesture-controlled systems in complex, all-terrain environments. However, the research has several limitations. These include potential constraints in gesture vocabulary complexity, challenges associated with wearable sensor dependence, and a lack of clarity regarding the system's operational range and environmental robustness.

In the research made by (Neto et al., 2019), a gesture recognition system was designed using a depth sensor and machine learning algorithms. The system was integrated with a robotic arm for tasks such as pick-and-place and assembly. The system's performance was also evaluated in terms of accuracy, efficiency and user experience. The system's accuracy being affected by variations in lighting and environmental conditions in the study is a significant limitation.

Agarwal et al. (2016) presented a gestured-controlled robotic car whose hand gesture interface was integrated with a digital system which makes the system's performance in terms of accuracy and efficiency to be analyzed. The system was limited to recognizing a specific set of pre-defined gestures and the system's accuracy was affected by noise and interference in the signals.

2 METHODOLOGY

In this Section the different modules that form the entire system are discussed and the steps taken to achieve the assembly of the system are underlined.

2.1 BLOCK DIAGRAM OF THE SYSTEM

Figure 1 illustrates several components of the receiver design and the way they are connected. The receiver is composed of Arduino Uno microcontroller, Radio Module NRF224L01, l298 Motor Driver and Motors.

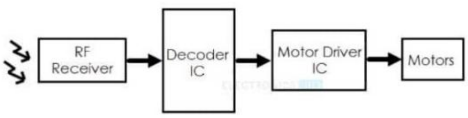

Figure 1: Block Diagram Of the System

The receiver of the hand gesture-enabled robotic car is a crucial component that enables the robotic car to receive and respond to hand gestures wirelessly. The Arduino Uno which is the Control unit of the system receives input in the form of signal from the Radio module NRF24L01 which is the wireless communication component. The Radio module connected to the Arduino Uno microcontroller is used to enable wireless communication, receive and decode commands, and provide reliable connectivity for remote control of the robotic car.

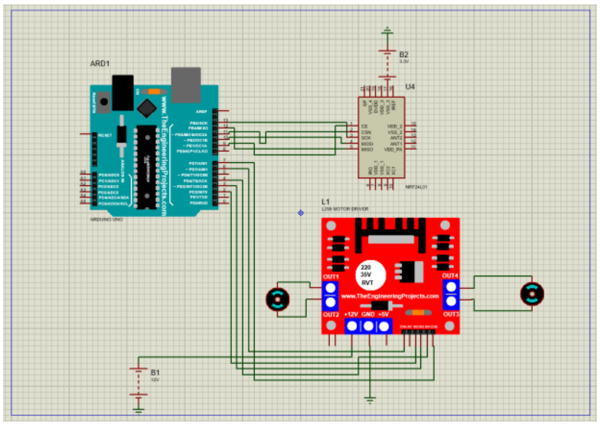

Figure 2: Circuit Diagram of the receiver of hand gesture-enabled robotic car

2.2 HARDWARE COMPONENTS

The system Consists of the following hardware:

1. Wireless Communication Unit
2. Motor Control Unit
3. Control Unit
4. Power Management Unit

2.2.1. WIRELESS COMMUNICATION UNIT:

The NRF24L01 radio module is a wireless component that serves as the wireless communication unit of the receiver. The NRF24L01 is a low-power, high-data-rate, and long-range wireless module that is small, cost-effective, and easy to use, making it a popular choice for wireless communication in various applications.

In the system, NRF24L01 radio module receives and decodes radio frequency (RF) signals, enabling wireless communication between the transmitter and receiver, and providing a reliable link for controlling the robotic car. The NRF24L01 radio module have a frequency range of 2.4 – 2.5Ghz ISM band, data rate of 250kbps , and it's Operating Voltage is 1.9 – 3.6V with Max. operating current of 12.3mA.

The NRF24L01 radio module can cover up to 30-100 meters.

Figure 3 illustrates the wireless communication Unit of the Receiver of the hand gesture-enabled robotic car

Figure 3: NRF24L01 radio module

2.2.2. MOTOR CONTROL UNIT:

The Motor Control Unit is made up of the L298N Motor Driver which acts as an interface between the Arduino Uno and the motor, providing the necessary voltage and current to drive the motor. L298N Motor Driver Module is a high-power motor driver module for driving the DC and Stepper Motors.

The L298N is a dual H-Bridge motor driver that allows speed and direction control of two DC motors at the same time. The L298N can drive DC motors that have voltages between 5 and 35V. With a peak current up to 2A.

The DC voltage used to power the Motor driver is 11.1V

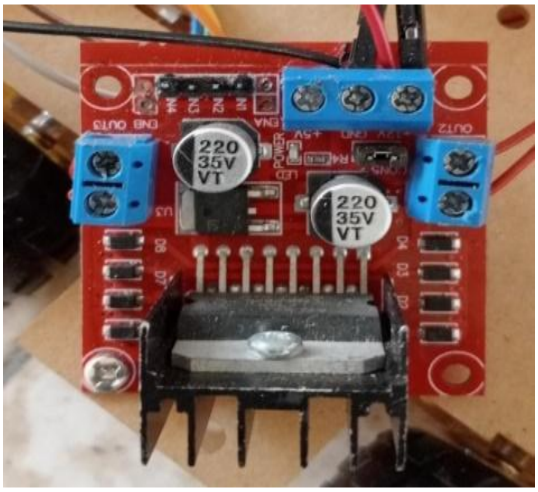

Figure 4: Motor Driver Used in the system

2.2.3. CONTROL UNIT:

The Arduino Uno is a microcontroller board that serves as the central processing unit of the System. In the system, the Arduino Uno is to receive the data of the hand gesture from Radio Module Nrf24l01 and recognize the gesture, also to process the signal and generate control signals to drive the motor drive.

Figure 5 shows the schematic design of Arduino Uno which has 14 pins used for digital input/output to read digital signals and 6 analog input pins for reading analog signal outputs which can control analog devices, a reset button for microcontroller reset. The connecting wire from Radio Module Nrf24l01 is connected to an analogue input and the Motor driver is connected to the output unit using connection wires.

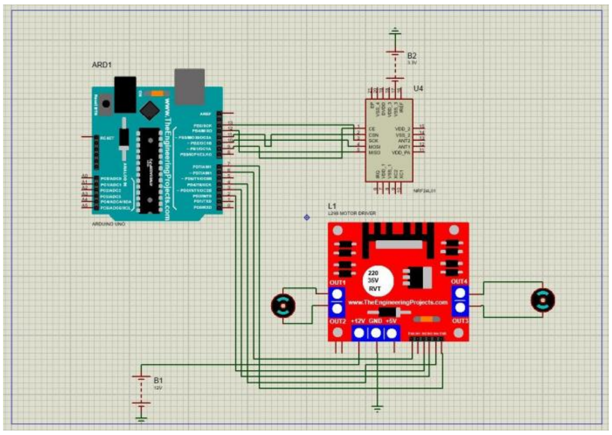

Figure 5: The Schematic diagram of the hand gesture robotic car comprising both the transmitter and receiver

2.2.4. POWER MANAGEMENT UNIT:

The Power Management Unit of the receiver of the hand gesture-enabled robotic car is responsible for managing the power supply to the various components of the car. The Power Management Unit consists of the battery, the voltage regulator and the capacitor. Though the Voltage regulator and the capacitor are secondary components of the receiver in the sense that the receiver will still function well without both, but it’s needed to make the system more efficient.

2.2.4.1. THE VOLTAGE SOURCE

The voltage source of the receiver of the robotic car is the battery, 3 batteries (rechargeable) with 3.7V was connected in series, making it 11.1V. The reason why the batteries were connected in series is to have a high Voltage that can power the Motor driver, microcontroller and the motors.

Figure 6: Lithium battery (Manthiram, 2017)

2.2.4.2. THE CAPACITOR AND THE VOLTAGE REGULATOR

The capacitor in this system serves to stabilize the power supply and reduce noise. It acts as a temporary energy storage device, smoothing out voltage fluctuations and providing a more consistent power flow to the components. The Capacitor used is 10UF, which makes the power supply to be stabilized.

The voltage regulator plays a crucial role in maintaining a stable and appropriate voltage level for the electronic components. It takes the input voltage from the battery (which may vary as the battery discharges) and converts it to a steady, lower voltage suitable for the microcontroller, Motor driver and motor. This is essential because the Arduino Uno and wireless module require a specific operating voltage of 5V. The voltage regulator ensures that these components receive the correct voltage regardless of fluctuations in the battery's output, protecting them from potential damage due to overvoltage and ensuring consistent performance. Figure 7 shows the connection of the capacitor and Voltage regulator on the board

Figure 7: Capacitor and Voltage Regulator used in the system

2.3 SOFTWARE COMPONENT

Arduino IDE is the programme used to operate the system's hardware components (Integrated Development Environment). The programme is written using this software, which then compiles it for the Arduino Uno Module Installed and running on the system of the constructed device. The software code used to program the Arduino Uno Microcontroller is written in the C++ programming language. Figure 3.11 shows the snapshot of the Arduino IDE when programming the microcontroller in what way to accept data from the radio module.

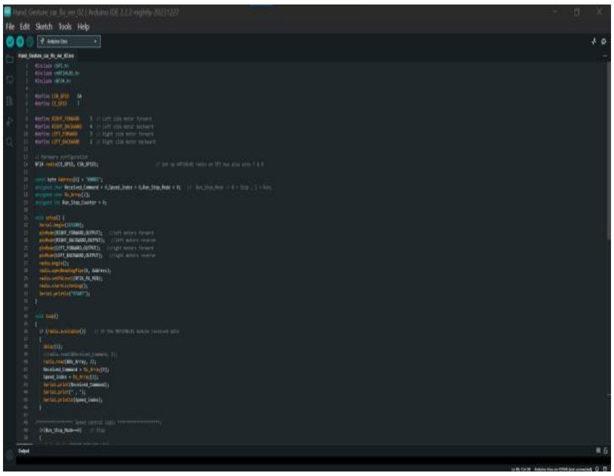

Figure 8: Snapshot of Arduino IDE

The Following was the Algorithm of the Coding Process of the Arduino Uno Microcontroller:

1. Include the nRF24L01.h library to the Arduino IDE.
2. Initialize the NRF24L01 radio module and set up the SPI bus and pins.
3. Set up the serial communication and define the pins for the motors.
4. Initialize variables for received command, speed index, run/stop mode, and counter.
5. In the loop function:
    a. Check if data is available from the NRF24L01 radio module.
    b. If data is available, read the received command and speed index.
    c. Print the received command and speed index to the serial monitor.
    d. Control the motors based on the received command and speed index.
    e. If the run/stop mode is stop, increment the counter and switch to run mode if the counter reaches a certain value.
    f. If the run/stop mode is run, increment the counter and switch to stop mode if the counter reaches a certain value.
6. Repeat the loop function continuously.

2.4. PRINCIPLE OF OPERATION

The receiver of the hand gesture-enabled robotic car is a crucial component that enables the robotic car to receive and respond to hand gestures wirelessly. The Arduino Uno which is the Control unit of the system receives input in the form of signal from the Radio module NRF24L01 which is the wireless communication component. The Radio module connected to the Arduino Uno microcontroller is used to enable wireless communication, receive and decode commands, and provide reliable connectivity for remote control of the robotic car.

The Arduino software (IDE) is used to program the Arduino Uno, communicate with the Radio module NRF24L01, control the motors, and debug the code, making it a crucial tool in the development of the hand gesture-enabled robotic car receiver. The Motor Driver is the output that is connected to the Arduino Uno and it plays a crucial role in controlling the motors of the robotic car, enabling it to move in response to hand gestures, and providing a reliable and efficient way to control the speed and direction of the motors. The Capacitor is connected to the L298 Motor Driver and the Arduino Uno, it helps in ensuring stable and reliable operation of the robotic car by filtering out noise, regulating voltage, and protecting the components from voltage spikes. The Voltage Regulator is also connected to the L298 Motor Driver, and it ensures a stable and consistent power supply to the components, protecting them from voltage fluctuations and spikes, and enabling reliable operation of the robotic car. The Motor is connected to the L298 Motor Driver and it is the actuator that enables the robotic car to move and perform various tasks in response to hand gestures, making it a crucial component of the hand gesture-enabled robotic car system.

The flowchart depicted in Figure 9 shows the steps involved in enabling the robotic car to receive hand gesture commands, control its movements, and adjust its speed accordingly.

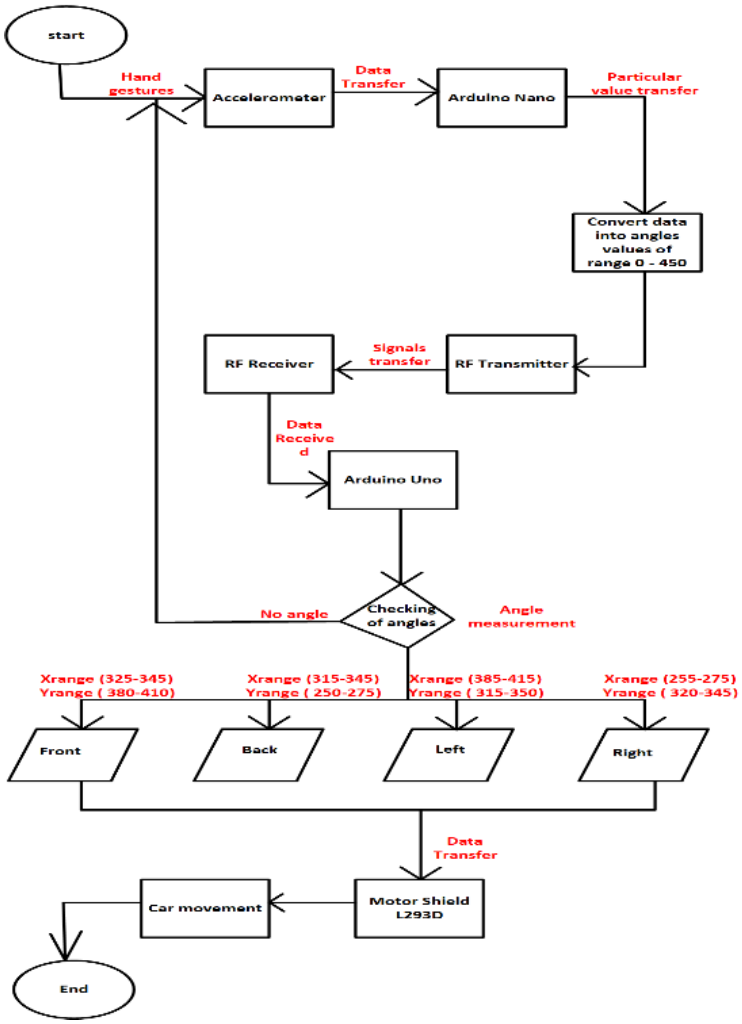

Figure 9: Flowchart of Hand gesture-enabled Robotic Car.

2.5. TESTING DURING METHODOLOGY AND CHALLENGES ENCOUNTERED DURING IMPLEMENTATION

To test the system, multimeter was used to check the voltage and current at each port of the board, and in every point during methodology to ensure accuracy. The response time of the receiver was gotten from the Arduino IDE which was displayed in real time and properly recorded. One of the challenges that was encountered during the implementation of the system was that the Arduino Uno was prone to quick damaged whenever there is high voltage, but it was checkmated by connecting a voltage regulator to the Arduino Uno and the L298 Motor Driver to regulate the power supply to the system. To avoid a break in communication, it was ensured that the pins were properly soldered, and they were well firmed to the board

3 RESULTS AND DISCUSSION

The tests carried out on the project work to determine the performance of the system were done by changing hand gestures to different positions and observing how quick the car responds. When the hand glove's accelerometer is in the straight position or the robot car does not receive any signal from it, it will initially remain motionless. However, if the hand palm glove is tilted in any direction, The Arduino will measure the angle of that tilt and send a command to the motor shield to turn on the corresponding motors, causing the robot car to begin moving in that direction.

Figure 10 illustrates the process of coupling the Radio Module NRF24L01 and the Motor Driver to the Arduino Uno on the Robotic Car .

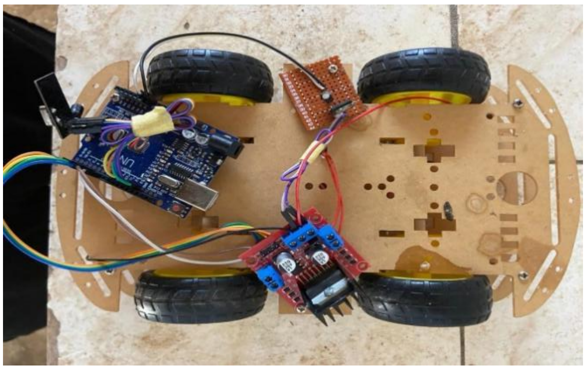

Figure 10: Coupling of the Receiver of the Car

3.1 TABULATION

This subsection delves into the analysis of the data obtained in the process of testing the accuracy of the axis on the receiver and the response time.

The inputs on the data pins of the Arduino uno determines the output of the motor drivers which gives the car its direction. The car moves according to the accelerometer orientation from the transmitter.

The Response time refers to the time it takes the car to respond to hand gestures. All movement of the car was observed 5 times each to get the average response time of each movement of the Robotic Car. Table 1,2,3,4,5 shows the response time of the car in different directions.

TABLE 1: RESPONSE TIME FOR 5 OBSERVATIONS OF FORWARD MOVEMENT OF THE CAR

Observation	Response (ms)
1	112
2	92
3	125
4	79
5	124

Average Response time = (112+92+125+79+124)/5 = 106.4ms

TABLE 2: RESPONSE TIME FOR 5 OBSERVATIONS OF BACKWARD MOVEMENT OF THE CAR

Observation	Response (ms)
1	110
2	79
3	139
4	64
5	139

Average Response time = (110+79+139+64+139)/5 = 106.2ms

TABLE 3: RESPONSE TIME FOR 5 OBSERVATIONS OF RIGHT MOVEMENT OF THE CAR

Observation	Response (ms)
1	93
2	81
3	137
4	93
5	92

Average Response time = (93+81+137+93+92)/5 = 99.2ms

TABLE 4: RESPONSE TIME FOR 5 OBSERVATIONS OF LEFT MOVEMENT OF THE CAR

Observation	Response (ms)
1	123
2	79
3	81
4	121
5	83

Average Response time = (123+79+81+121+83)/5 = 97.4ms

TABLE 5: RESPONSE TIME FOR 5 OBSERVATIONS OF IDLE/BREAK MOVEMENT OF THE CAR

Observation	Response (ms)
1	92
2	87
3	130
4	73
5	129

Average Response time = (92+87+130+73+129)/5 = 102.2ms

Total Average Response time = (106.4+106.2+99.2+97.4+102.2)/5 = 102.28ms

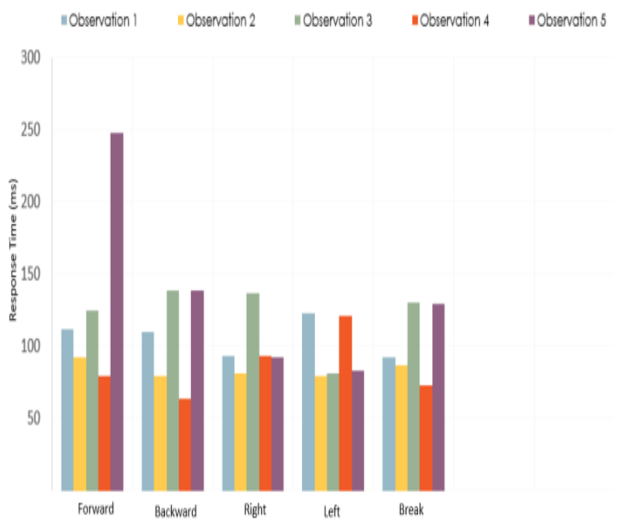

Figure 11: Response time for movements of the Car

3.2 DISCUSSION OF RESULT

The gesture recognition system achieved a commendable accuracy rate of approximately 85-90%, with the car responding correctly to most hand movements. The performance evaluation test shown in Table 4,5,6,7,8 reveals the response time of the system is 102.28 milliseconds on average, providing generally a smooth user experience. Wireless communication utilizing the NRF24L01 module, maintained reliable control up to distances of about 20-25 meters indoors and 50-100 meters in open spaces. Overall, the results indicate that while the hand gesture-Enabled robotic car successfully demonstrates the concept, there's room for improvement in accuracy, response time, and advanced control features. The paper not only achieved its primary goal of gesture-based control but also provided valuable insights into the challenges and potential of gesture recognition technology in consumer robotics.

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4 CONCLUSION

The research presented in this paper have demonstrated the design of a Smart hand gesture robotic car receiver for achieving Transformative Transportation for disabled (paraplegic) individuals to move to wherever they want to go with their hand gestures without the need of complex buttons or joystick controls. The Arduino Uno, a Radio module, L298 Motor Driver and Motor were all used in the construction of the receiver.

The system's ability to receive hand gestures and convert it to signals that can control the robotic car was archived with the help of Radio module Nrf24l01. The car shows proper movements for the pre-determined and calibrated different hand gestures. The data from the hand movements with the help of the accelerometer are fed into the Microcontroller. Then the values are transmitted with the help of Nrf24l01. Nrf24l01 receives the value in the receiver part, where it is decoded by Arduino Uno and sent to the motor driver L298D. Then motors are controlled with the data obtained from the motor driver. The car only moves when the accelerometer is moved in a specific direction as per the given values of the accelerometer.

The work is highly recommended because it is simple, reducing the complexity encountered in previously existing systems. It also recognizes and reads gestures in all directions. It requires low power consumption. These features make it promising when compared to existing systems.

This work could generate a new generation of small-scale automatic wheelchairs and exoskeletons, both devices to help paraplegics with their mobility challenges, making them less dependable on care givers or heavy bulky chairs; all these can be significantly improved upon

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