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A Hand Gesture Controlled Vacuum Cleaning Robot

TANSHI, F.[1,*], *OBI, N. O.*[2], *OHWO, R. O.*[1], *HOLT-EMERAH, J. O.*[1]

[1]*Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources, Effurun, Delta State*

[2]*Department of Computer Engineering, Federal University of Petroleum Resources, Effurun, Delta State*

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ABSTRACT

This contribution describes the design and construction of a semi-autonomous robot vacuum cleaner which can be controlled by hand gestures. The robot vacuum cleaner is controlled with the use of a gesture control system consisting of an Arduino Nano microcontroller for gesture recognition as well as control value assignment and an Arduino UNO for coordination and navigation. The microcontrollers are interfaced with a MPU6050 Accelerometer for gesture detection and RF module for communication. The hand gesture control system is designed to demonstrate how gesture-control can be utilized as a means of navigation with respect to domestic robots as well as the simplification of human-machine interaction in domestic contexts.

1. INTRODUCTION

Robotics has long been employed to assist humans with hazardous tasks in various applications in medicine, military operations, manufacturing, security, and other sectors (Ziefle and Valdez, 2017). Robots are now integral to major industries and driving societal progress. Domestic settings are seeing a growing number of robots. (Mouroutsos and Mitka, 2012). These "domestic robots" are designed to perform household chores such as cleaning, cooking, and laundry.

A significant demographic for domestic robot impact is the elderly. Traditionally, elderly care relies heavily on human caregivers. Domestic robots can complement or even replace some caregiver tasks (Ziefle and Valdez, 2017).

This review examines contributions demonstrating the role of gesture control in human-robot interaction and the importance of domestic robots, specifically vacuum cleaning robots, in improving household quality of life. Many contributions utilize accelerometers to detect hand motions which offers reasonable motion sensitivity across various applications, and the gestures are then used to control robot movements (Kiran et al., 2019).

*Corresponding author, e-mail: tanshi.foghor@fupre.edu.ng
DIO

(Hande and Chopde, 2020) described a gesture-controlled robotic arm for industrial automation using an accelerometer interfaced with an Arduino microcontroller. The accelerometer detects human arm gestures and angular positions, providing orientation data for dynamic gesture recognition. A low-quality MEMS chip was interfaced with an Arduino microcontroller. While effective for industrial tasks, the study did not explore domestic applications. (Asafa et al. 2018) and (Yatmono et al. 2019) developed robotic vacuum cleaners with autonomous navigation and remote-control capabilities. Neither study integrated gesture control into the navigation system. The system comprises three parts: the accelerometer, robotic arm, and platform.

(Kiran et al. 2019) implemented a robotic vehicle controlled via hand gestures using an Arduino Uno and an ADXL335 accelerometer fitted on a haptic glove. The system can read hand gestures based on angular displacement. The accelerometer input was encoded (HT21E) and transmitted via RF to the robot, where it was decoded (HT21D). The robot then responded by moving accordingly. (Atimati et al. 2021) expanded on this by integrating ultrasonic sensors and Bluetooth modules for dual-mode operation (autonomous and semi-autonomous) including advanced control using tilt angles for motion and speed. In semi-autonomous mode, the robot responded to glove tilt levels, while ultrasonic sensors controlled it in autonomous mode. Signals were transmitted via the HC-05 Bluetooth module. Motion and speed control in forward and reverse directions were achieved using accelerometer tilt angles. This study demonstrated how ultrasonic sensors and gesture control could create flexible navigation systems. This research highlights accelerometer utility in human-robot interaction but lacks exploration of domestic robot integration.

(Asafa et al. 2018) designed a compact robotic vacuum cleaner powered by a 2200mAh lithium-ion polymer battery. Equipped with four ultrasonic sensors (HC-SR04) for high-accuracy, non-contact obstacle detection, the robot utilized the Arduino Mega 2560 microcontroller for autonomous navigation and simple routine updates upon encountering obstacles. (Yatmono et al. 2019) introduced a vacuum cleaner robot controlled wirelessly via Bluetooth using an Android smartphone. The robot could switch between remote control and autonomous modes. However, neither research explored integrating gesture control for robot navigation and control.

The researchers used an accelerometer built into an Android smartphone to sense the user's hand movements and control a 4-wheeled robot car. The smartphone application translates these physical gestures into digital signals transmitted via Bluetooth to an Arduino microcontroller. The microcontroller then instructs the robot's motors to move accordingly. The robot's movements in response to the user's hand gestures were in four directions which include forward, backward, right and left tilts respectively.

2. METHODS

2.1 System Design

The build of the vacuum cleaner robot itself is 3D printed using PLA Filament because of the lightweight and durable properties of the material. The design and fabrication of the chassis was by Cesar Nieto (Nieto, 2017). The system has been divided into two main sections for simplification: the **Transmitter section** and the **Receiver section**. Each section is further broken down into individual components. The transmitter section is where instructions are encoded and transmitted via RF transmission to the robot, realized by utilizing an Arduino Nano microcontroller, MPU 6050 Accelerometer sensor, the RF Transmitter module, and power supply. While the receiver section is where instructions are received from the transmitter section and decoded to be implemented by the robot. This section consists of the Arduino Uno microcontroller, RF receiver module, L298N motor driver, motors, fan blower and power supply. The block diagrams of the Transmitter and Receiver section are depicted in fig 1 and 2 respectively. While the circuit diagrams for both the transmitter and receiver section are shown in fig 3 and 4 respectively.

2.2. Flowcharts

Before writing the program required for the robot vacuum cleaner to function effectively, the algorithm for assigning control values based on tilt angle values and the algorithm for navigation based on control signal values were designed and visualized in the form of pseudo-code and flowcharts. This allowed for quick detection of flaws in the control sequences early on in development. Figures 5 and 6 depict the flowcharts for both control and navigation respectively.

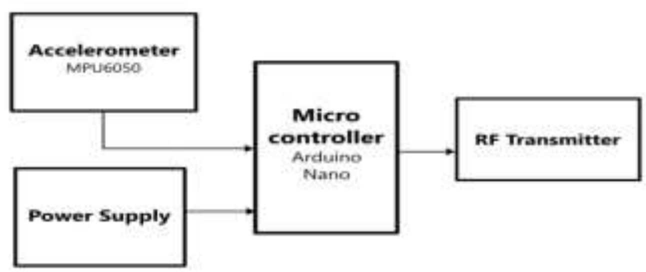

Figure 1: Block Diagram of the Transmitter Section

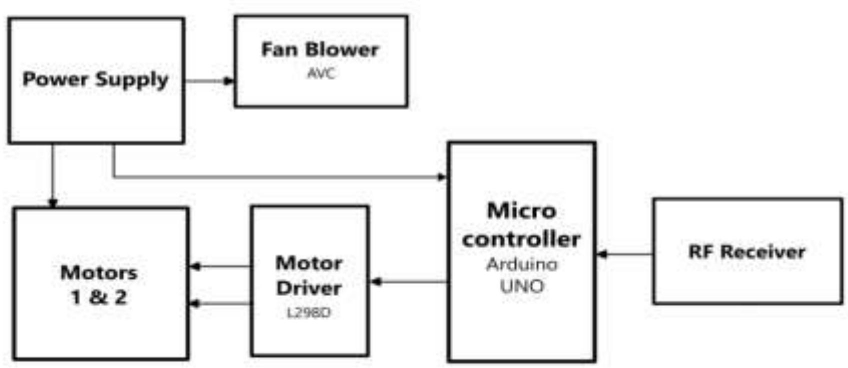

Figure 1: Block Diagram of the Receiver Section

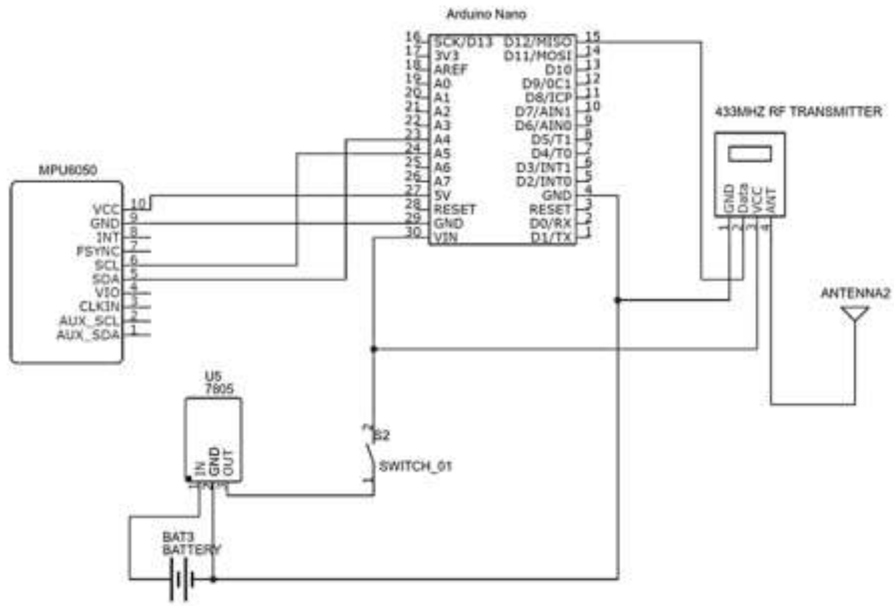

Figure 3: Circuit Diagram of the Transmitter Circuit

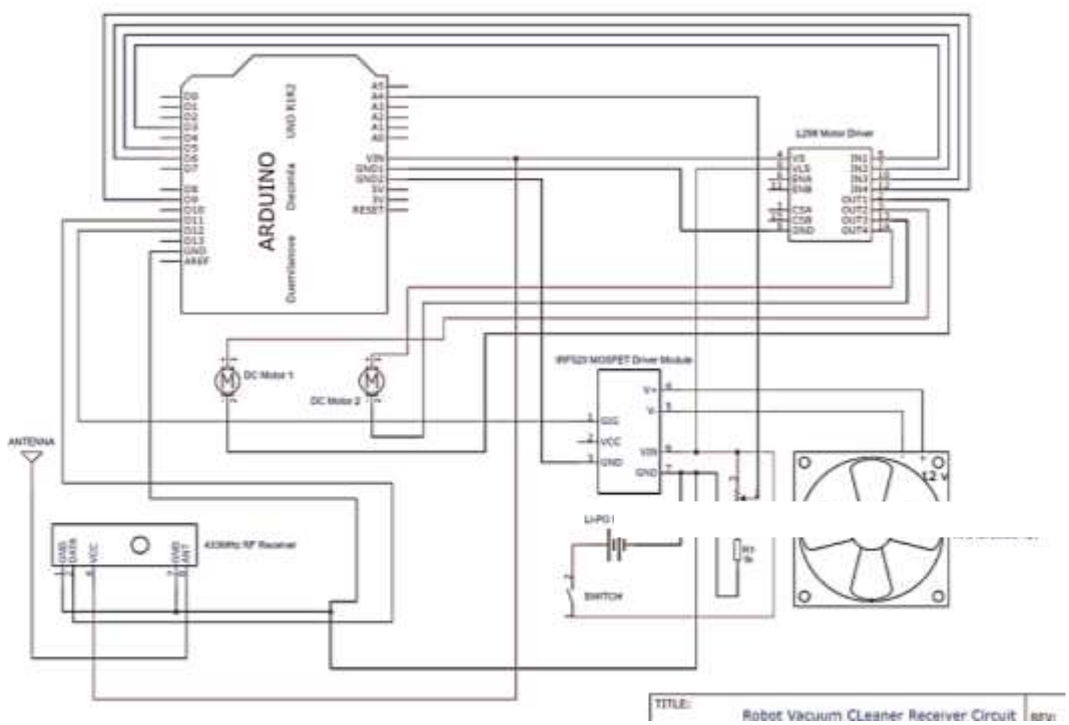

Figure 4: Circuit Diagram of the Receiver Circuit

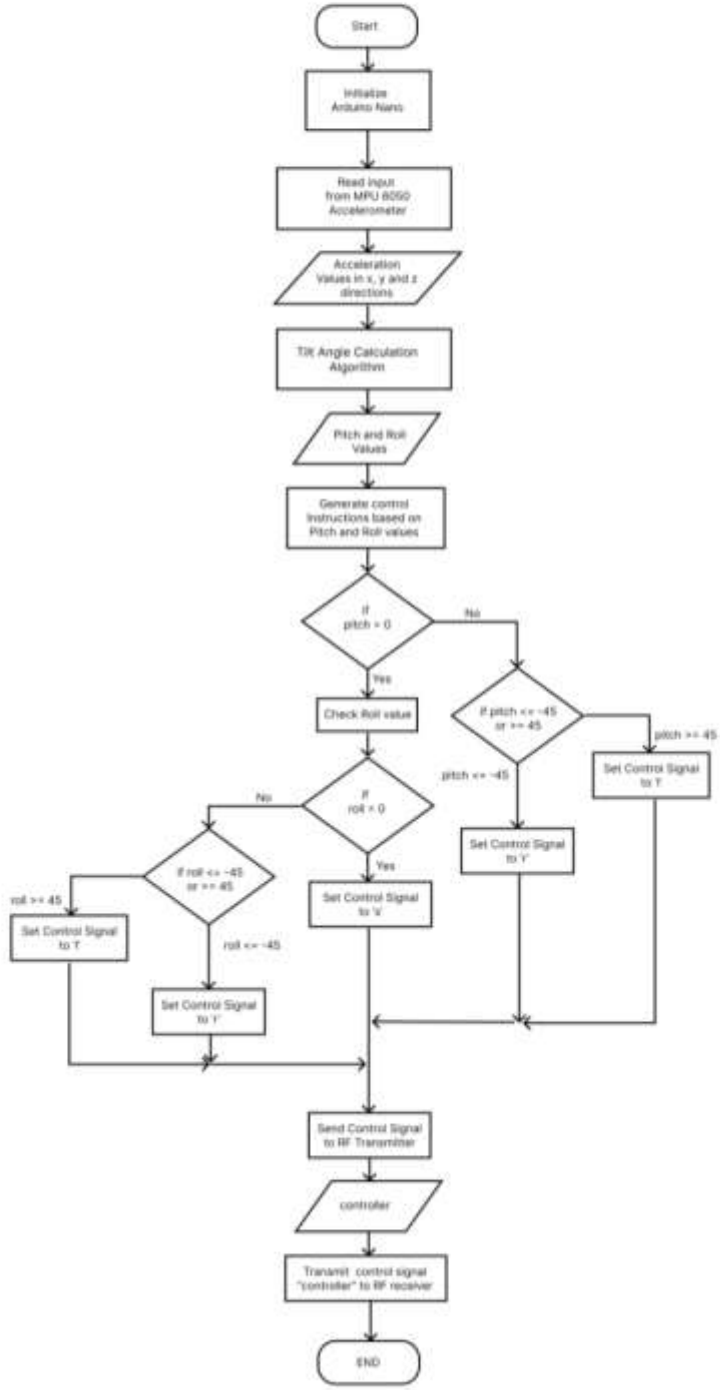

Figure 5: Control Value Assignment Algorithms

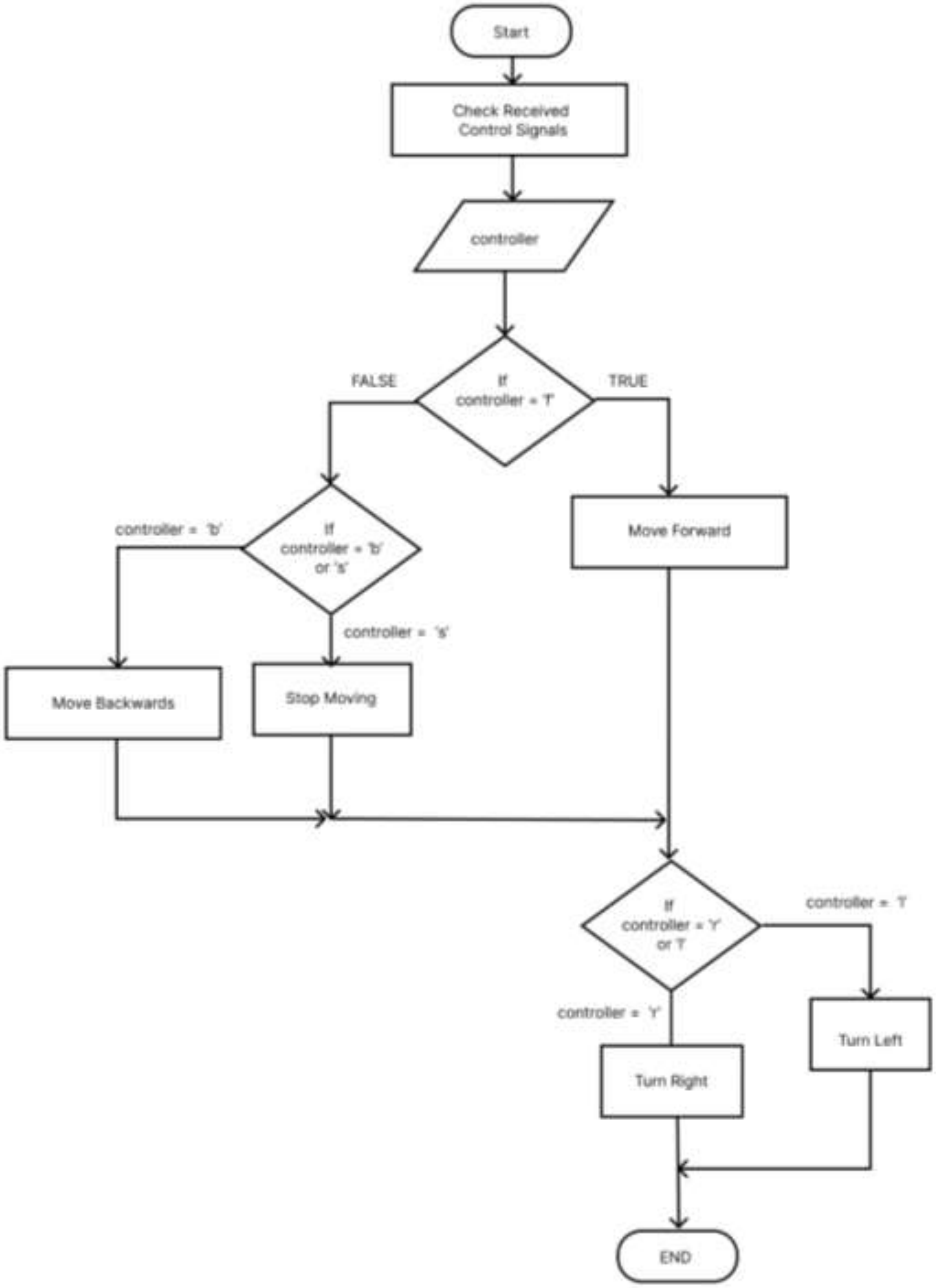

Figure 6 Navigational Algorithm

2.3 Software implementation

The design of this system was done using Easy EDA online electronic work bench. Easy EDA was used due to its simplicity when simulating and its vast collection of electronic components, both analogue and digital. The main goal for the simulation is providing an overview of problems that may occur during hardware implementation.

The code for the hand gesture controlled vacuum cleaner was written in C++ and compiled within the Arduino IDE. The architecture of the code was implemented by following the design of the algorithm and the flow of the pseudo-code. Libraries for components were included in the implementation of the program to shorten the amount of code that needed to be written. Libraries used include the following:

1. L298NX2 Library for initializing and controlling two motors at once using the L298N motor driver
2. Adafruit MPU6050 Library for initializing the MPU6050 accelerometer chip and retrieving measurements from the IC.
3. RadioHead ASK Library for initializing the RF Transmitter and Receiver modules and declaring them as Amplitude Shift Keying objects.

2.4. Mode of Operation

The operation of the gesture control vacuum cleaner robot can be broken down into 3 phases: Gesture Detection, Communication and Execution of Instructions. The robot is divided into two sections; the transmitter section and receiver section (see Fig 1.1 and Fig 1.2). These two sections work together to ensure the completion of cleaning tasks via hand gesture control. The transmitter section consists of an accelerometer, a microcontroller, and a RF transmitter, all of which are fitted on to a hepatic glove worn by the user. The accelerometer serves to read predefined hand gestures by detecting the change in acceleration of the hand in the x, y and z directions as it moves. The readings are fed into the microcontroller which then computes the value of pitch and roll to assign the control instructions and sends them through the transmitter to the receiver section.

The receiver section consists of the RF receiver, a decoder, a microcontroller, and the drive unit of the vacuum cleaner. The transmitted signal is received by the RF receiver module and sent into the microcontroller. The microcontroller then decodes the instructions received and sends them to the drive unit consisting of the motor drivers and motors. The drive unit then executes the instructions given by moving in accordance with the gesture performed.

3. RESULTS AND DISCUSSION

The table below shows the results obtained from the final operational test and program code test. The results were obtained by observing the serial monitor of the Arduino IDE as well as the actual motion of the vacuum cleaner and recording the corresponding values in Table 1.

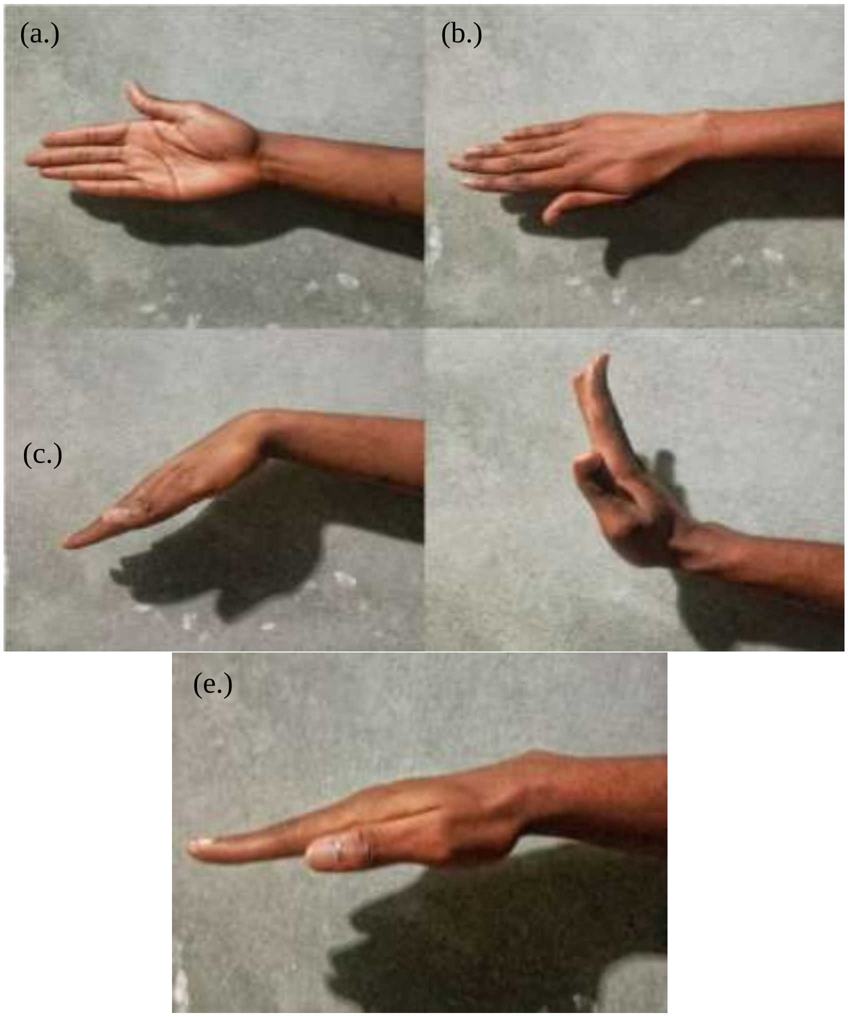

Figure 7 Hand Gestures for Control (a.) turn right (b.) turn left (c.) move forward (d.) move backwards and (e.) stop.

Table 1. Results For Hand Gesture Controlled Vacuum Cleaner

S/N	HAND GESTURE	TILT ANGLE /◦	CONTROL SIGNAL	ROBOT NAVIGATION
1	Forward	Pitch:0.0 Roll: <= -45.0	‘f’	MOVE FORWARD
2	Backward	Pitch: 0.0 Roll: >= 45.0	‘b’	MOVE BACKWARDS
3	Left	Pitch: <= -45.0 Roll: 0.0	‘l’	TURN LEFT
4	Right	Pitch: >= 45.0 Roll: 0.0	‘r’	TURN RGHT
5.	Flat	Pitch: 0.0 Roll: 0.0	‘s’	STOP MOVING

Results indicate that hand gesture control is a suitable application for robot vacuum cleaners in domestic settings. An accelerometer sensor enables precise control, directing the vacuum cleaner to the desired location. A gesture-based interface simplifies user-robot interaction by requiring only a set of predefined hand gestures. Simplifying Human-Machine Interaction (HMI) can be achieved by introducing control methods based on natural human motions, such as hand gestures.

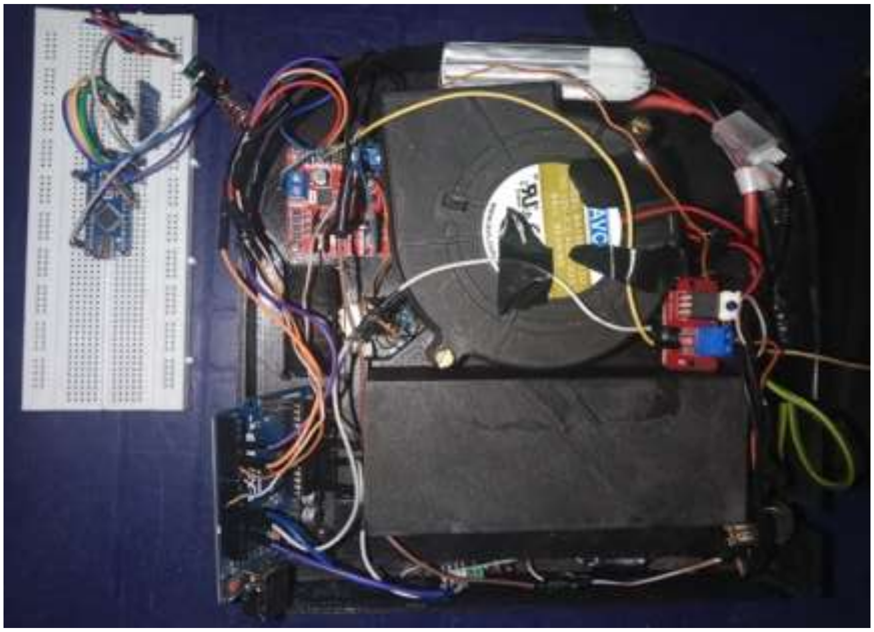

Figure 8 Hand Gesture Controlled Vacuum Robot

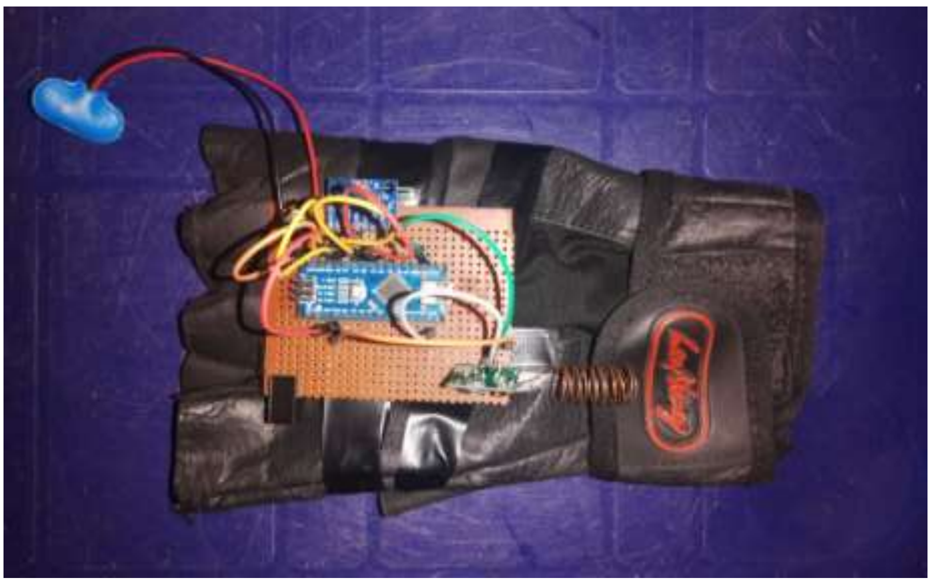

Figure 9 Hand Gloves used for control of vacuum robot

The findings presented in this study demonstrate the potential of gesture control to enhance the user experience and simplify human-robot interaction, particularly in the context of domestic robots such as vacuum cleaners. By leveraging intuitive human motions like hand gestures, we can create more natural and user-friendly interfaces for controlling robotic devices.

The use of accelerometers, as highlighted in various research studies, has proven effective in detecting and interpreting hand gestures for robot control. These devices offer a relatively simple and cost-effective means of capturing motion data, enabling the development of robust and responsive gesture-based control systems.

While this study has focused on the application of gesture control to a specific type of domestic robot, the principles and technologies explored have broader implications for other robotic applications. The integration of gesture control with other technologies, such as autonomous navigation and advanced sensor systems, holds significant promise for creating more intelligent and user-centric robotic systems.

Future research could focus on the following areas. Improving the accuracy and robustness of gesture recognition algorithms to ensure reliable and consistent robot control. Exploring innovative ways to integrate gesture control into user interfaces, such as haptic feedback or augmented reality displays. Evaluating the real-world impact of gesture control on user experience and satisfaction through rigorous user testing and feedback. Investigating the potential of combining gesture control with artificial intelligence, machine learning, and other advanced technologies to create even more sophisticated and intelligent robotic systems.

4. CONCLUSION

In conclusion, this study demonstrates the significant potential of gesture control to enhance the user experience and simplify human-robot interaction, particularly within the context of domestic robots. By leveraging intuitive human motions like hand gestures, we can create more natural and user-friendly interfaces for controlling robotic devices. The use of accelerometers has proven effective in capturing and interpreting hand gestures, enabling the development of robust and responsive gesture-based control systems.

While this study has focused on a specific application, the principles and technologies explored have broader implications for various robotic applications. The integration of gesture control with other emerging technologies, such as artificial intelligence, machine learning, and advanced sensor systems, holds significant promise for creating more intelligent and user-centric robotic solutions.

Future research should prioritize refining gesture recognition algorithms, developing more intuitive user interfaces, and conducting thorough user testing to evaluate the real-world impact of gesture control on user experience and satisfaction. By addressing these key areas, we can continue to advance the field of gesture-controlled robotics and pave the way for a future where human-robot interaction is more seamless, intuitive, and enjoyable.

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