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Design and Development of Hand Gesture Controlled Robot Using an IMU Based Transmitter

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Abstract- *This paper focuses on establishing a natural synergy between human movements and robotic actions. Eschewing the use of traditional buttons or joysticks, this robot is controlled entirely through hand gestures. To achieve this, the 'MPU6050' a sensor based on MEMS (Micro-Electro-Mechanical Systems) technology is employed to accurately detect hand tilt and three-dimensional movements. This system is broadly divided into two main components: The Transmitter (Glove Unit): This unit utilizes an 'Arduino' or 'ESP32' microcontroller to process sensor data, while a 'smoothing algorithm' is applied to ensure stable and fluid robotic movement. The Receiver module: This unit receives data RF technology and with the aid of an 'L298N' motor driver, controls the direction and movement of the robot's wheels. The primary objective of this technology is to alleviate physical strain on human operators and to simplify the operation of robots in remote or hazardous environments. This system can prove immensely beneficial for individuals who face difficulties in handling traditional remote controls due to physical limitations. The main advantage of this mechanism is the car with this mechanism can take sharp turn without any difficulty. The design and implementation of a gesture control robotic arm using flex sensor is proposed. The robotic arm is designed in such a way that it consists of four movable fingers, each with three linkages, an opposing thumb, a rotating wrist and an elbow. The robotic arm is made to imitate the human hand movements using a hand glove.*

Keywords - Arduino Nano, IMU, MPU6050, Arduino UNO, RF Communication, Hand Gesture, L298N Motor Driver, Wireless Communication, Ultrasonic Sensor (for obstacle detection).

I -INTRODUCTION

Robotics has emerged as one of the most rapidly advancing fields in modern technology, playing a vital role across industries such as automation, healthcare, defense, and construction. A robot is an electro-mechanical system that operates through programmed instructions and can function either autonomously or semi-autonomously. Autonomous robots make decisions independently based on environmental sensing, whereas semi-autonomous or human-controlled robots rely on external inputs for operation.With the evolution of human-machine interaction, traditional control methods such as switches, joysticks, and wired systems are gradually being replaced by more intuitive and efficient techniques. Among these, gesture-based control has gained significant attention due to its simplicity, flexibility, and real-time responsiveness. A hand gesture-controlled robot enables users to interact with machines naturally, eliminating the need for physical contact or complex control interfaces.

Earlier robotic systems relied heavily on wired communication or image-processing techniques using cameras and gesture libraries. However, these approaches had limitations such as restricted range, high computational requirements, and delays caused by image processing and gesture recognition. Maintaining large gesture databases and ensuring accurate real-time matching also posted significant challenges.

To overcome these limitations, accelerometer-based gesture control systems have been introduced. In this approach, a wearable transmitting device equipped with an accelerometer sensor detects the tilt and movement of the user's hand. These analog signals are processed using a microcontroller and transmitted wirelessly through RF communication modules. At the receiver end, the signals are decoded and interpreted by another microcontroller, which controls the movement of the robot accordingly.

The primary objective of this project is to design and implement a reliable, efficient, and user-friendly gesture-controlled robotic system using accelerometer-based motion sensing. This system enhances human-robot interaction and finds applications in areas such as assistive technologies, surveillance, industrial automation, and disaster management, including fire-fighting operations.

Modern robotics is shifting away from rigid button-based interfaces toward more intuitive human-robot interactions. In this paper [1], the theoretical framework is established that natural hand gestures provide a more ergonomic and human-centric way to interact with machines, improving user efficiency and control flow. In this paper [2], it is demonstrated that micro-electro-mechanical systems (MEMS) like accelerometers are highly effective for translating physical hand tilts into robotic movement, bypassing the need for complex, high-overhead camera systems.

In this paper [3], the technical specifications for a 6-axis motion tracking device are defined, providing the raw motion data necessary for accurate gesture detection and orientation sensing. In this paper [4], the mathematical necessity for advanced filtering is detailed, which is vital for smoothing noisy inertial data and accurately calculating the pitch and roll required for stable robotic control. Finally, in this paper [5], the use of compact, low-power microcontrollers is justified as being ideal for the wearable transmitter unit due to their small form factor and ease of sensor interfacing in real-time applications.

2. PROBLEM STATEMENT

In conventional robotic systems, control is primarily achieved using wired connections, remote controllers, or complex interfaces such as joysticks and computer-based systems. These methods often limit the flexibility, range, and ease of operation, making human-robot interaction less intuitive and more time-consuming. Additionally, wired systems restrict mobility, while remote-based systems require continuous manual input and can be difficult to operate in real-time applications.

Existing gesture recognition systems based on cameras and image processing also face several challenges, including high computational requirements, dependency on lighting conditions, delays in processing, and the need for large gesture databases. These limitations reduce system efficiency and reliability, especially in dynamic or real-world environments.

There is a need for a more efficient, low-cost, and user-friendly system that enables real-time robot control without complex hardware or processing requirements. The system should provide accurate and quick response to human gestures while maintaining flexibility and reliability. Therefore, the problem addressed in this research is the design and development of a hand gesture-controlled robot using an accelerometer-based transmitter that can wirelessly transmit motion data and enable precise and intuitive control of robotic movement

3. PROPOSED DIAGRAM (CIRCUIT DIAGRAM, BLOCK DIAGRAM)

The proposed hand gesture-controlled robotic system is designed to enable wireless control of a robot using human hand movements. The system is divided into two main sections: the **Transmitter Unit** and the **Receiver Unit**, which communicate through RF (Radio Frequency) modules.

3.1 Transmitter Section

The transmitter unit is responsible for capturing hand gestures and converting them into control signals.

- The **Arduino Nano** acts as the main controller in the transmitter section. It reads input data from sensors and processes it.
- The accelerometer (such as MPU6050, if used) detects hand movements and tilt in different directions. These movements generate analog/digital signals.
- The processed signals are then encoded and sent through the **RF Transmitter** module.
- The RF transmitter converts the signals into radio waves and transmits them wirelessly to the receiver section.

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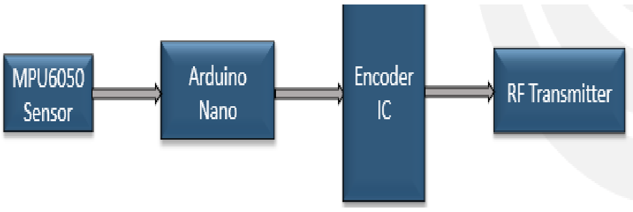

Fig 3.1 Block diagram of Transmitter Section

3.2 Receiver Section

The receiver unit receives the transmitted signals and controls the robot accordingly.

- The **RF Receiver** module receives the radio signals sent by the transmitter.
- These signals are then given to another **Arduino Nano**, which acts as the main processing unit.
- The Arduino decodes the received signals and determines the required motion of the robot (forward, backward, left, right, stop).

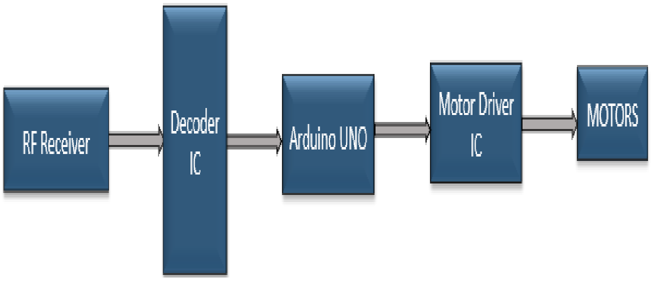

Fig 3.2 Block diagram of Receiver Section

3.3 Motor Control System

- The **L298 Motor Driver** is used to control the motors of the robot.
- Since Arduino cannot supply sufficient current to drive motors directly, the motor driver acts as an interface between Arduino and motors.
- Based on the commands from Arduino, the L298 driver controls the direction and speed of the motors.

3.4 Ultrasonic Sensor Integration

- The **Ultrasonic Sensor** is used for obstacle detection.
- It continuously measures the distance between the robot and nearby objects.
- If an obstacle is detected within a certain range, the sensor sends a signal to the Arduino.
- The Arduino then stops or redirects the robot to avoid collision.

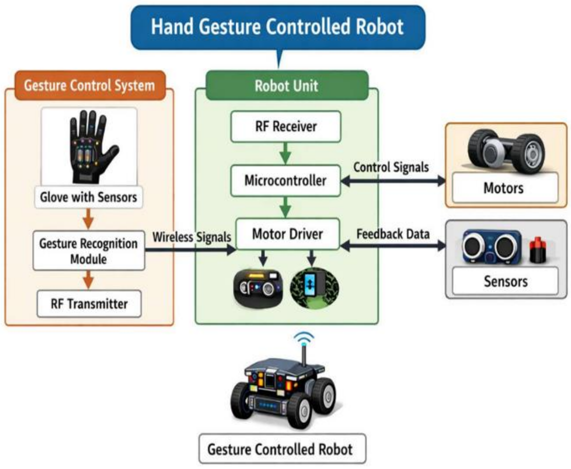

Fig 3 Block diagram of hand gesture controlled robot

4. PROPOSED SYSTEM ANALYSIS AND COMPONENT SECTION

4.1 Proposed System Analysis

The proposed system is a hand gesture-controlled robotic platform that enables intuitive human-machine interaction through wireless communication. The system is divided into two major units: a **transmitter unit (gesture glove)** and a **receiver unit (robot platform).**

In this system, the user wears a glove embedded with sensors and a microcontroller. Hand movements are detected and converted into electrical signals, which are processed and transmitted wirelessly. The robot receives these signals and performs corresponding movements. This approach eliminates the need for traditional wired or button-based control systems and provides real-time, efficient operation.

The transmitter section uses an **Arduino Uno**, which processes gesture data and sends control commands via an RF transmitter. The receiver section uses an **Arduino Nano**, which receives and interprets these commands to control the robot's motion through a motor driver. Additionally, an ultrasonic sensor is integrated into the robot for environmental awareness and collision avoidance.

4.2 Components Description

4.2.1 Arduino Uno (Transmitter - Glove Unit)

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The Arduino Uno is a microcontroller board based on the ATmega328P. In the proposed system, it is used in the transmitter unit mounted on the glove.

The Arduino Uno reads input signals from the gesture sensing device (accelerometer). It processes these signals and converts them into predefined digital commands corresponding to different hand movements such as forward, backward, left, and right. After processing, the Arduino sends these commands to the RF transmitter for wireless communication.It serves as the main control unit in the glove, handling signal acquisition, processing, and transmission.

4.2.2 **Arduino Nano (Receiver - Robot Unit)**

The Arduino Nano is a compact microcontroller board also based on the ATmega328P. It is used in the receiver section of the robot.The Nano receives encoded signals from the RF receiver module and decodes them into meaningful commands. Based on these commands, it generates appropriate control signals to drive the motors via the motor driver.Its small size, low power consumption, and sufficient processing capability make it suitable for embedded robotic applications.

4.2.3 RF Transmitter

The RF transmitter is used in the glove unit to send control signals wirelessly. It operates on radio frequency waves (commonly 433 MHz).The transmitter receives digital signals from the Arduino Uno and converts them into radio signals. These signals are then broadcast through an antenna and travel through the air to the receiver module.It acts as the communication bridge between the user and the robot.

4.2.4 RF Receiver

The RF receiver is placed on the robot side and is responsible for receiving signals sent by the RF transmitter.It captures the transmitted radio waves and converts them back into electrical signals. These signals are then passed to the Arduino Nano for further processing and execution.The receiver ensures reliable wireless communication between the transmitter and the robot.

4.2.5 Ultrasonic Sensor

The ultrasonic sensor is used for distance measurement and obstacle detection. It works on the principle of sound wave reflection.The sensor emits ultrasonic waves and measures the time taken for the echo to return after hitting an object. Based on this time, the distance is calculated.

The Arduino Nano continuously monitors this data. If an object is detected within a predefined distance, the robot can be stopped or redirected to prevent collision.

4.2.6 L298N Motor Driver

The L298N motor driver is a dual H-bridge motor driver used to control the direction and speed of DC motors.Since microcontrollers cannot provide sufficient current to drive motors directly, the L298 acts as an interface between the Arduino Nano and the motors. It receives control signals from the Arduino and accordingly drives the motors in forward or reverse direction.The driver enables precise control of motor operations required for robot movement.

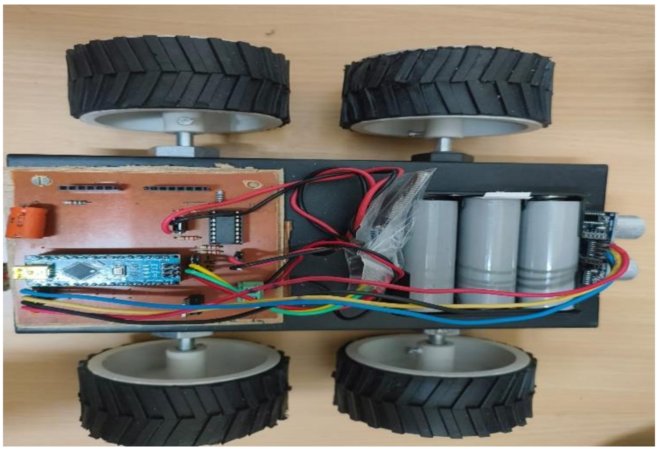

Fig 4.1 Hardware model of Receiver Section

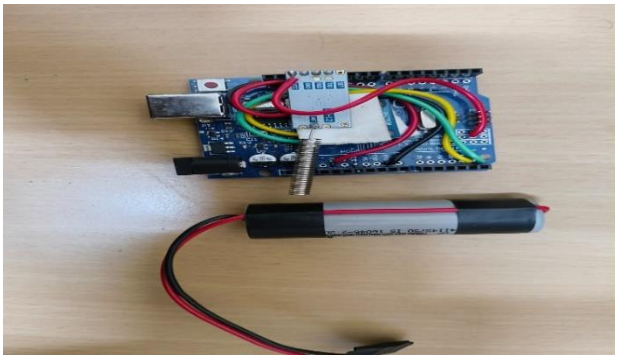

Fig 4.2 Hardware model of Transmittor Section

5. SIMULATION PARAMETERS AND RESULTS

The simulation of the proposed hand gesture-controlled robot was performed to check its performance under different conditions. Various parameters such as communication range, response time, input gestures, and sensor operation were considered during the simulation:

Table 5.1: Simulation Parameters

Sr. No.	Parameter	Value / Description
1	Microcontroller (Transmitter)	Arduino Uno
2	Microcontroller (Receiver)	Arduino Nano
3	Communication Type	RF Wireless Communication
4	Operating Frequency	433 MHz
5	Input Type	Accelerometer-based Gesture Input
6	Output Devices	DC Motors
7	Motor Driver	L298
8	Supply Voltage	5V – 12V
9	Communication Range	10–15 meters
10	Response Time	100–150 ms
11	Sensor Used	Ultrasonic Sensor
12	Obstacle Detection Range	2 cm – 400 cm

5.2 Simulation Results

The system was simulated for different gesture inputs and environmental conditions. The results obtained are as follows:

Table 5.2: Simulation Results for Gesture Control

Sr. No.	Input gesture	Robot action	Status
1	Forward Tilt	FORWARD	Success
2	Backward Tilt	BACKWARD	Success
3	Left Tilt	LEFT	Success
4	Right Tilt	RIGHT	Success
5	No Tilt	STOP	Success

Table 5.3: Obstacle Detection Results

Sr. No.	Distance Input (cm)	Expected Action	Obtained Result	Status
1	> 30 cm	Move normally	Moves normally	Success
2	20–30 cm	Slow/Alert	Slows down	Success
3	< 20 cm	Stop	Robot stops	Success

Table 5.4: Communication Performance

Sr. No.	Distance (m)	Signal Condition	System Response	Status
1	2 m	Strong	Instant response	Success
2	5 m	Strong	Smooth operation	Success
3	10 m	Moderate	Slight delay	Acceptable
4	15 m	Weak	Delay observed	Acceptable
5	>15 m	Very Weak	Signal loss	Failed

6. CONCLUSION

In conclusion, this research paper successfully demonstrates an intuitive hand-gesture-controlled robotic system that advances beyond the foundational methodologies of prior studies. While earlier work established basic motion using MPU6050 sensors and RF modules, this paper introduces critical enhancements in environmental awareness and operational stability. By integrating an ultrasonic sensor for real-time obstacle avoidance and implementing a specialized smoothing algorithm to process IMU data, the system achieves a more fluid and "intelligent" response compared to raw sensor mapping. Furthermore, hardware optimizations including the use of the L298N driver for high current handling and the Arduino Nano for a compact footprint result in a high-precision platform with a 100-150 ms response time. Ultimately, these advancements transform the robot from a simple locomotion device into a robust, reliable tool suitable for practical applications in hazardous or remote environments.

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