Hand Gesture Controlled Robotic Car Using ESP32

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***Abstract*—The primary aim of this project is to design and implement a real-time, intuitive control system for a robotic car using hand gestures. Traditional control methods, such as joysticks or remotes, are replaced with a wearable gesture-recognition transmitter utilizing the wireless capabilities of the ESP32 microcontroller. The system integrates an MPU6050 accelerometer and gyroscope to accurately capture and process hand-tilt gestures. A low-latency wireless communication link is established using the ESP-NOW protocol, chosen for its speed and efficiency over standard Wi-Fi. The robotic chassis features a receiver ESP32 and a motor driver to translate these gestures into precise vehicle movements. This project not only validates the responsiveness of gesture based control but also introduces a hybrid control mechanism featuring a web based backup interface, ensuring system reliability and redundancy for assistive technology applications.**

***Index Terms*—ESP32, MPU6050, ESP-NOW, Hand Gesture Control, Robotics, Embedded Systems.**

I. Introduction

A. Background of Study and Motivation

The development of intuitive Human Machine Interaction (HMI) has increasingly shifted focus from traditional remote controls toward more natural interfaces, such as hand gestures. While vision based gesture recognition is an option, it often suffers from computational overhead [1]. An alternative for wearable applications is the use of Inertial Measurement Units (IMUs), such as the MPU6050, which effectively translates physical hand tilts into directional commands [2]. This project is motivated by the need for low-latency, connectionless control systems that can be applied to assistive technology, entertainment and industrial usage.

B. Project Objectives

The specific objectives of this project are as follows:

- To design and build a wearable transmitter module integrating an MPU6050 accelerometer and gyroscope with an ESP32 to accurately capture hand-tilt gestures.
- To develop a robotic car chassis incorporating a second ESP32 as the receiver and a motor driver for precise vehicle movement control.
- To establish a low-latency wireless communication link between the transmitter and receiver modules, preferably using the ESP-NOW protocol for its speed and efficiency [3].
- To design and implement a secondary web based control interface using the Wi-Fi Access Point Mode of the ESP32, providing a fail-safe mechanism for redundancy and reliability.
- To write and implement embedded software that translates specific gestures into corresponding robotic car movement commands.
- To test and validate the system's responsiveness, accuracy, and reliability in controlling the robotic car, ensuring a user-friendly and effective interaction [2].

II. Literature Review

The development of intuitive Human Machine Interaction (HMI) has driven research away from traditional remote controls toward more natural interfaces. Shinde et al. explored gesture controlled mecanum wheel cars using ESP32 and MPU6050, highlighting the effectiveness of these components for omnidirectional movement [3]. Similarly, Udugampala et al. focused on the development of accelerometer based data acquisition systems, validating the precision of IMUs in capturing hand gestures [2].

In the context of IoT robotics, Bhimashankar et al. demonstrated IoT based hand gesture control robots, though such systems often rely on Wi-Fi infrastructure [1]. In contrast, the ESP-NOW protocol used in this project offers a distinct advantage by bypassing central routers or TCP/IP stacks for lower latency [3].

Applications extend beyond just movement; Al-Ali et al. developed a smart wheelchair control system using hand gestures, emphasizing the potential for assistive technology for individuals with motor disabilities [4]. Furthermore, Mydin et al. reviewed the effectiveness of such robotics projects in STEM education, improving technological literacy and engagement [5].

III. Methodology and Modeling

A. Introduction

The system architecture consists of two main units: a wearable Transmitter Unit and a Receiver Unit mounted on the robotic car. The system relies on the interpretation of hand gestures (tilt) to generate PWM signals for DC motors, with a secondary web interface for redundancy.

B. Working Principle of the Proposed Project

The working principle involves three stages: data acquisition, transmission, and execution. The MPU6050 sensor reads the acceleration and gyroscope data from the user's hand gestures. This data is processed by the transmitter ESP32 to determine the orientation (forward, backward, left, right). The command is sent wirelessly via ESP-NOW to the receiver ESP32. The receiver decodes the signal and drives the L298N motor driver to actuate the DC motors. Simultaneously, the receiver acts as a Wi-Fi Access Point, allowing a smartphone to connect and send control commands via a web browser if the controller is unavailable. Additionally, for safety the transmitter unit has a latching push switch for locking or unlocking the controller, such that the conmmands could be paused momentarily.

C. Process of Work

The workflow began with project planning and component procurement, followed by circuit design and simulation. The software was developed to implement the hybrid `Wi-Fi_AP_STA` mode, enabling both ESP-NOW and standard Wi-Fi simultaneously. Finally, the hardware was assembled, and the system underwent testing and debugging to ensure accurate mapping of gestures and web commands to car movements.

D. Description of the Components

- **ESP32 Microcontroller:** Acts as the central processing unit for both transmission and reception.
- **MPU6050 Sensor:** A 6-axis Motion Tracking device that combines a 3-axis gyroscope and a 3-axis accelerometer to detect hand tilt.
- **L298N Motor Driver:** An H-Bridge motor driver for bi-directional controlling of the wheels.
- **DC Motors and Chassis:** Provide the physical movement for the robotic car.
- **Power Supply:** 3.3V sources for microcontrollers and a 7-12V source for the motor driver.

E. Experimental Setup

The experimental setup includes a small breadboard fitted with the Transmitter Unit (ESP32 + MPU6050) powered by a portable battery. The Receiver Unit is mounted on a 4-wheel drive chassis. The ESP-NOW protocol is configured to pair the MAC addresses of the two ESP32 units, establishing a dedicated communication channel on Wi-Fi Channel 1.

IV. Results and Discussions

A. Simulation

The logic for gesture recognition was analyzed by defining threshold angles for the MPU6050. For example, a forward tilt exceeding 15 degrees triggers the "Forward" command. This threshold based logic ensures that minor, unintentional hand movements do not trigger the motors, preventing erratic behavior.

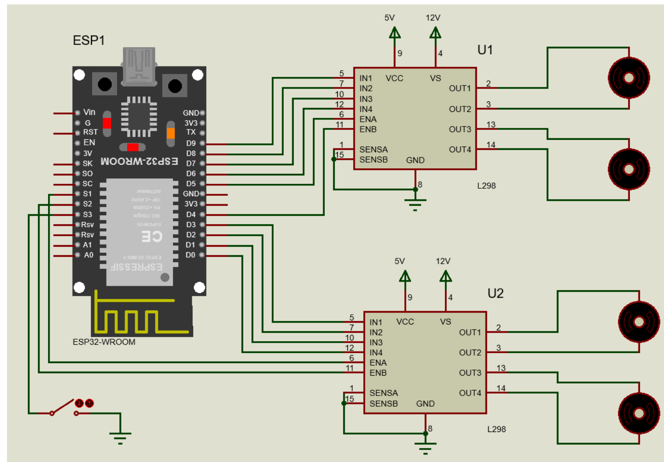

Fig. 1. Circuit schematics for the Receiver Unit

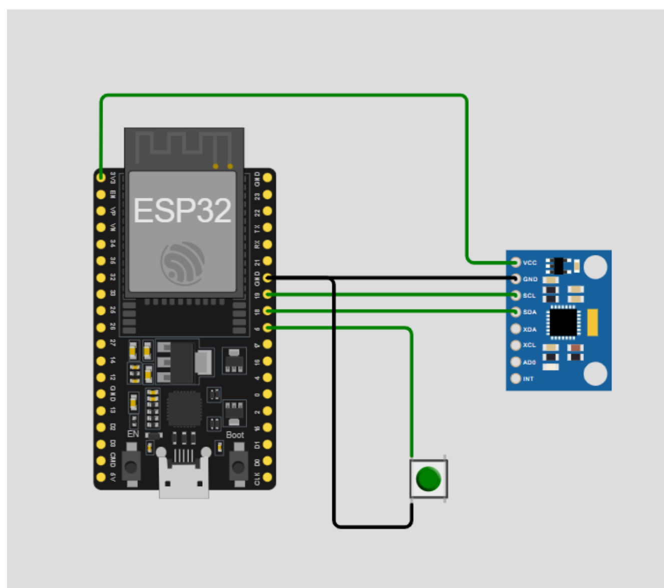

Fig. 2. Circuit schematics for the Transmitter Unit

B. Experimental Results

During testing, the robotic car successfully responded to four distinct hand gestures:

1) **Forward Tilt:** Car moves forward.
2) **Backward Tilt:** Car moves backward.
3) **Left/Right Tilt:** Car turns in the respective direction.

4) **Flat/Neutral:** Car stops.

The latency was observed to be minimal due to the connectionless nature of ESP-NOW.

C. Web Interface & Hybrid Mode Tests

To enhance system reliability, a secondary web interface was developed. The ESP32 hosts a lightweight web server on `192.168.4.1`, allowing control via any smartphone browser. Testing confirmed that the system successfully prioritizes controller input (ESP-NOW) while maintaining the Web Access Point in the background. A push button was added on top of the car to switch between the two modes, If pressed for 1 second the reciever ESP32 takes conmand from the web interface and vice versa.

D. Comparison between Numerical and Experimental Results

The experimental response matched the logic defined in the numerical thresholds. However, real-world testing required calibration of the MPU6050 offsets to prevent drift, ensuring the ”Stop” state was reliably detected when the hand was neutral.

E. Cost Analysis

The project was designed to be cost-effective. A breakdown of the approximate component costs is provided below:

TABLE I
COST OF COMPONENTS

Component	Price (BDT)	Quantity	Subtotal (BDT)
ESP32 ESP-32S 30P NodeMCU	630	2	1,260
4WD Robotics Wooden Chassis With Motors & Wheels	990	1	990
L298N H-Bridge Dual Motor Driver	168	2	336
MPU6050	690	1	690
14500 Rechargeable Lithium Battery 3.7V	80	4	320
Jumper Wires	130	1	130
7x7mm latching Push	10	2	20
Battery Holder	18	1	18
Breadboard Full Size	150	1	150
Breadboard Half Size	90	1	90
Total			**4,004**

F. Limitations in the Project

While functional, the system has limitations. The range of ESP-NOW is limited compared to long-range RF modules. Additionally, the system currently lacks obstacle avoidance sensors, meaning the user must maintain visual line-of-sight to prevent collisions.

V. CONCLUSION AND FUTURE ENDEAVORS

This project successfully demonstrated the design and implementation of a hand gesture controlled robotic car using the ESP32 and MPU6050. By leveraging a hybrid communication architecture, the system achieved low-latency gesture control via ESP-NOW while providing a fail safe web interface for manual override. The intuitive, low effort control system could empower users to operate electric wheelchairs or robotic assistance arms, promoting greater independence [4]. Additionally, it creates a maker culture, which is a proven method for improving engagement and technological literacy in STEM education [5].

Future endeavors will focus on integrating obstacle avoidance sensors to enhance safety and autonomy. Furthermore, the principles developed here can be scaled for industrial applications, such as remotely controlling machinery in hazardous environments.

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APPENDIX

The program and other related materials for the project can be found in the following Github repository. https://github.com/r2sakib/esp32-gesture-rc-car

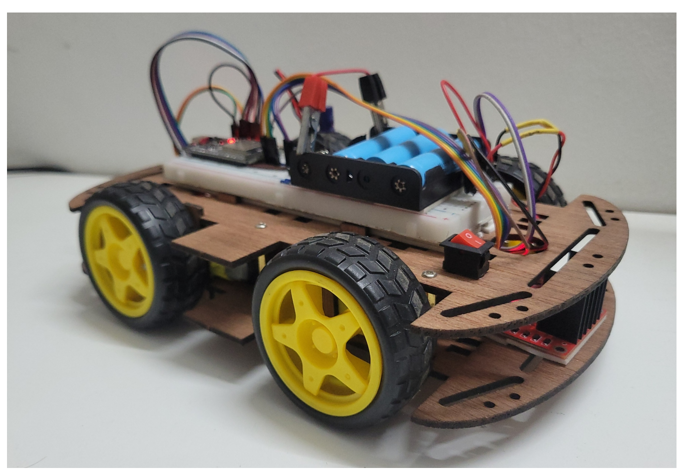

Fig. 3. Side view of the build car

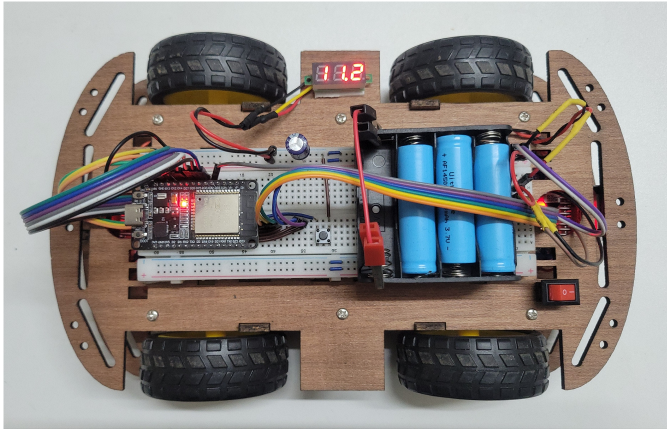

Fig. 4. Top view of the build car

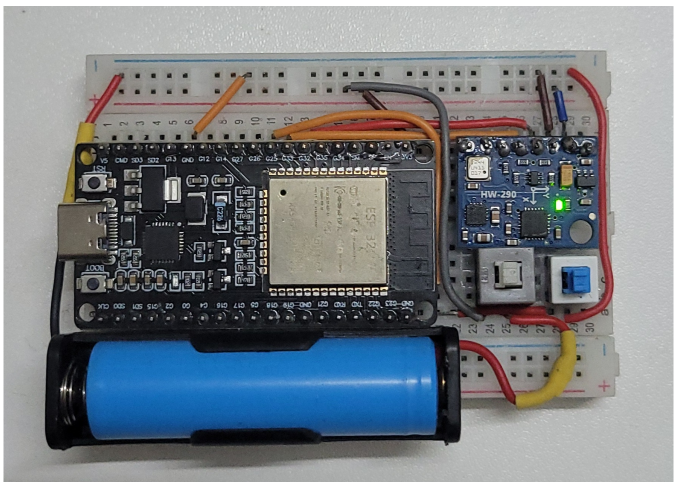

Fig. 5. The Transmitter Unit (Controller) build on a breadboard