Gestrodrive- Hand Gesture Controlled Robotic Car

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1. Abstract

The Gestrodrive project is a gesture- and app-controlled robotic car designed to showcase innovative user interaction and modern IoT integration. Using ESP32 microcontrollers, an MPU6050 motion sensor, and an ESP32-CAM module, the car responds to real-time hand gestures and streams live video to a web interface. Key features include automatic headlights triggered by an LDR, a buzzer horn for alerts, and an ultrasonic sensor for obstacle detection. Communication between the wearable gesture unit and car unit is handled via ESP-NOW for low-latency control, while the car's onboard Wi-Fi enables live video streaming and manual web-based controls.

The hand unit is a compact wearable device powered by a 3.7V LiPo battery with TP4056 charging. It integrates an MPU6050 for motion sensing and a 0.96" OLED display for feedback. The car unit is powered by a 7.4V 2S LiPo battery regulated using LM2596 buck converters. Dual L298N motor drivers control four DC motors, enabling precise movement.

Throughout the project, we built custom PCBs for better wiring management and implemented a lightweight IoT dashboard that combines video, joystick, and sensor data. The system was optimized for stable video streaming while handling simultaneous sensor inputs and motor control. With its modular design and clear power distribution, Gestrodrive demonstrates a robust and scalable approach to remote-controlled robotics.

2. Introduction

The Gestrodrive project is a hand gesture- and app-controlled robotic car that combines modern IoT features with embedded system design. The main goal of the project is to create an innovative user interface for controlling a car without traditional remotes. By using a wearable gesture controller, the user can guide the car's movement simply by tilting their hand. At the same time, the car streams live video to a web interface, allowing the user to monitor its surroundings in real-time.

The project is built using ESP32 microcontrollers as the core of both the car unit and the hand gesture unit. The gesture control unit uses an MPU6050 gyroscope and accelerometer to detect hand movements, while the car unit interprets these commands to control its motors via L298N motor drivers. Additional features such as an ultrasonic sensor for obstacle detection, an LDR-based automatic headlight system, and a buzzer horn enhance the car's functionality. A lightweight IoT dashboard is hosted on the ESP32-CAM module, enabling users to control the car using a smartphone or PC, even when gestures are not being used.

This project demonstrates key concepts in embedded systems, wireless communication, IoT dashboards, and real-time video streaming. It highlights how hardware and software can be integrated to create responsive and interactive robotics solutions. Our design also focuses on power management, with the car powered by a 7.4V 2S LiPo battery regulated by a buck converter, and the hand unit powered by a 3.7V LiPo battery with a TP4056 charging module.

The Gestrodrive project offers a unique approach to controlling robotic vehicles, making it suitable for tasks such as exploration of hard-to-reach places, real-time inspection, and hands-on learning of robotics technologies.

3. Background Research & Development

The Gestrodrive project brings together modern embedded hardware, IoT capabilities, and robotics. We researched and selected components that provide reliable performance for gesture recognition, wireless communication, and real-time video streaming.

3.1 ESP32 Microcontroller

The ESP32 is a dual-core microcontroller with built-in Wi-Fi and Bluetooth, making it ideal for IoT and robotics projects. We use two ESP32 boards:

- **ESP32 DevKitC (WROOM-32U)** in the hand gesture unit for gesture detection and wireless communication.
- **ESP32-WROVER CAM** in the car unit for motor control and live video streaming.

The ESP32 offers:

- Up to 240 MHz clock speed for fast processing.
- PWM, ADC, and I2C interfaces for controlling motors and sensors.
- ESP-NOW protocol, which provides low-latency, peer-to-peer wireless communication.

Reference: Espressif Systems. *ESP32 Series Datasheet.*

3.2 MPU6050 IMU Sensor

The MPU6050 combines a 3-axis accelerometer and a 3-axis gyroscope. It communicates via the I2C protocol and is used in the gesture controller to detect tilt angles (X and Y axes). We apply threshold-based logic to interpret hand movements (forward, backward, left, right) and send commands wirelessly.

Reference: InvenSense. *MPU-6000 and MPU-6050 Product Specification.*

3.3 ESP32-CAM and Video Streaming

The ESP32-CAM module integrates the ESP32 microcontroller with an OV2640 camera, capable of capturing images and streaming MJPEG video over Wi-Fi. We configured the camera to provide 10–15 FPS at VGA resolution while simultaneously processing motor and sensor data.

Reference: Ai-Thinker. *ESP32-CAM Development Board Specification.*

3.4 Motor Control (L298N Driver)

We use two L298N dual H-bridge motor drivers to control four DC motors. These modules allow forward and backward motion, as well as turning, using PWM signals from the ESP32.

Reference: HandsOn Technology. *L298N Motor Driver Module Datasheet.*

3.5 Power Systems

- **Car Unit:** A 7.4V (2S) LiPo battery powers the motors and electronics. A LM2596 buck converter steps down the voltage to 5V and 3.3V for the ESP32 and sensors.
- **Hand Unit:** A 3.7V (1S) LiPo battery powers the ESP32 DevKitC through an MT3608 boost converter (3.7V → 5V). A TP4056 charging module safely charges the battery.

3.6 Sensors and Additional Features

- **HC-SR04 Ultrasonic Sensor:** Detects obstacles up to 4 meters and triggers the buzzer if an object is closer than 10 cm.
- **LDR (Light-Dependent Resistor):** Automatically turns on headlights in low-light conditions.
- **Buzzer Horn:** Provides audible alerts triggered by gesture commands or proximity events.

3.7 Research Outcome

Our research confirmed that ESP32 modules can handle gesture recognition, motor control, and video streaming simultaneously with proper task prioritization. The combination of ESP-NOW (for gesture commands) and Wi-Fi (for the video stream and web interface) ensures smooth operation without significant delays.

4. System Functional Features & Specifications

The Gestrodrive robotic car is designed to showcase gesture-based control, real-time video streaming, and IoT integration. It is built around two core units: the gesture control hand unit and the car unit. Below are its main features and technical specifications.

4.1 Functional Features

1. **Gesture-Based Control**
   - The hand unit detects hand tilt using the MPU6050 sensor.
   - Tilting forward, backward, left, or right sends corresponding commands to the car via ESP-NOW.
   - Response time is under 200 ms, ensuring smooth control.
2. **Obstacle Detection**
   - The car unit uses an HC-SR04 ultrasonic sensor to detect objects up to 4 m.
   - If an obstacle is detected within 10 cm, the car stops and the buzzer is triggered.
3. **Automatic Headlights and Taillights**
   - A Light Dependent Resistor (LDR) monitors ambient light.
   - Headlights and taillights (white and red LEDs) turn on automatically in low-light conditions.
4. **Buzzer Horn**
   - A passive buzzer acts as a horn.
   - It can be activated via a gesture or from the web dashboard.
5. **Live Video Streaming (FPV)**
   - The ESP32-CAM streams video at 10–15 FPS (VGA 640x480).
   - The feed is accessible through a browser at http://cam.local/stream.
6. **IoT Web Dashboard**

- Provides virtual joystick buttons and toggle controls for lights and horn.
- Displays sensor readings such as ultrasonic distance.
- Embedded directly into the ESP32-CAM web server.

7. **Dual Control Modes**
   - Gesture Mode: Controlled via hand unit.
   - Web/App Mode: Controlled via the web dashboard.

4.2 Technical Specifications

COMPONENT	SPECIFICATION
MCUs	ESP32 DevKitC (Hand Unit), ESP32-WROVER-CAM (Car Unit)
Sensors	MPU6050 (gesture), HC-SR04 (distance), LDR (light)
Motors	4 x TT DC Geared Motors, controlled by 2 x L298N drivers
Camera	OV2640 (via ESP32-CAM) – 10-15 FPS at VGA resolution
Communication	ESP-NOW (gesture) + Wi-Fi (video stream & web control)
Power (Car Unit)	7.4V 2S LiPo battery (2200 mAh) with LM2596 buck converter
Power (Hand Unit)	3.7V 1S LiPo battery (300 mAh) with MT3608 boost converter
Lighting	2 white LEDs (headlights), 2 red LEDs (taillights)
Dimensions	Car chassis: 4WD DIY Kit, Hand Unit: 3D printed enclosure
Response Time	Gesture-to-action < 200 ms

5. System Design and Layout

The **Gestrodrive system** is divided into two main units:

1. **Gesture Control Hand Unit** – a wearable device that detects hand movements and transmits commands.
2. **Car Control Unit** – a robotic car platform that receives commands, streams live video, and controls movement and sensors.

The design integrates microcontrollers, sensors, motor drivers, and power management circuits to achieve smooth operation.

5.1 System Overview

- **Gesture Unit:**
  - Equipped with an ESP32 DevKitC (WROOM-32U) for gesture detection and wireless command transmission.
  - Uses an MPU6050 (3-axis gyroscope + accelerometer) to detect hand orientation.
  - A 0.96" OLED display provides real-time feedback (e.g., battery level or connection status).
  - Powered by a 3.7V LiPo battery with a TP4056 charging module and MT3608 boost converter (3.7V → 5V).
- **Car Unit:**
  - Controlled by an ESP32-WROVER-CAM, which handles video streaming, sensor data, and motor control.
  - Two L298N dual H-bridge motor drivers control four DC geared motors.
  - HC-SR04 ultrasonic sensor detects obstacles.
  - LDR sensor automatically switches headlights and taillights (white and red LEDs).
  - A buzzer acts as a horn for alerts.
  - Powered by a 7.4V 2S LiPo battery regulated through an LM2596 buck converter.

5.2 Communication Architecture

□ **ESP-NOW Protocol**

- Low-latency wireless communication between the hand unit and car unit.
- Allows gesture commands to be sent almost instantly (<200 ms).

 Wi-Fi Interface

- The ESP32-CAM streams live video over Wi-Fi.
- A web dashboard provides virtual joystick control and sensor data display.

6. Hardware Components & Specifications

The Gestrodrive system is built using carefully selected components for both the gesture control unit and the car control unit. Each component was chosen for reliability, ease of integration, and compatibility with the ESP32 microcontrollers.

ESP32 Microcontrollers

Car Unit: Freenove ESP32-WROVER-CAM with built-in OV2640 camera for video streaming and motor control.

Hand Unit: ESP32 DevKitC (WROOM-32U) for gesture sensing and wireless ESP-NOW communication.

Key Features:

  - Dual-core Xtensa 32-bit LX6 processor, up to 240 MHz.
  - Built-in Wi-Fi (2.4 GHz) and Bluetooth.
  - Multiple GPIOs, ADCs, PWM, UART, and I2C interfaces.

Motion & Gesture Sensor (MPU6050)

A 6-axis IMU combining:

- **3-axis accelerometer** (for tilt detection).
- **3-axis gyroscope** (for rotation).

Communicates with the ESP32 hand unit via I2C (SDA, SCL).

Detects tilt angles for directional commands: forward, backward, left, and right.

Camera Module (OV2640)

- Integrated into the ESP32-CAM board.
- Provides MJPEG video streaming at 10–15 FPS (VGA resolution 640x480).
- Used for FPV (First-Person View) through the web dashboard.

Motor Drivers (L298N)

- Dual H-Bridge design to control 4 DC motors.
- Supports forward, reverse, and speed control (via PWM).
- Logic power: 5V (from buck converter).
- Motor power: 7.4V (from 2S LiPo battery).

Motors

- Voltage: 3–6V DC.
- Speed: ~150–300 RPM (gear reduction for better torque).
- Drive: Each motor is connected to the wheels for 4WD operation.

Ultrasonic Sensor (HC-SR04)

- Measures distance using sound waves.
- Range: 2 cm – 400 cm.
- Accuracy: ±3 mm.
- Connected to ESP32 car unit (Trigger and Echo pins).
- Stops car and activates buzzer if an object is <10 cm away.

Light Sensor (LDR) & LEDs

- LDR detects ambient light.
- Automatically turns **headlights** and **taillights** when it's dark.
- LEDs are standard 5mm, current-limited using 220Ω resistors.

Buzzer

- A 5V passive buzzer used as the car horn.
- Controlled via GPIO (digital HIGH/LOW).

Power Components

- **Car Unit:**
  - **Battery:** 7.4V 2S LiPo (2200 mAh).
  - **LM2596 Buck Converter:** Steps down 7.4V to 5V for logic circuits.
  - **Fuse:** 6A slow-blow glass fuse for protection.
- **Hand Unit:**
  - **Battery:** 3.7V 1S LiPo (300–1200 mAh).
  - **TP4056 Charging Module:** For safe LiPo charging.
  - **MT3608 Boost Converter:** Boosts 3.7V to 5V for ESP32 and OLED.

OLED Display

- 0.96" I2C-based OLED display (SSD1306 driver).
- Displays system feedback (battery level, connection status).
- Resolution: 128 x 64 pixels.

Connectors and Wiring

- **Barrel Jack (5.5 x 2.1 mm):** For charging and power input.
- **16 AWG Wires (Male-Male/Female):** For prototyping.
- **TRX Connectors:** Used with the LiPo battery for reliable high-current connections.

7. Theory of Operation

The Gestrodrive system combines a gesture control hand unit and a car control unit to achieve smooth, wireless control and real-time feedback. Each unit is powered independently and communicates using the ESP-NOW protocol, while the car's camera provides live streaming over Wi-Fi.

7.1 Gesture Interpretation and Wireless Control

The hand unit reads tilt data (X and Y angles) from the MPU6050 sensor using I2C. Threshold values are applied to determine direction:

Threshold Logic Example:

```
If tilt_x > +15° → Move Forward

If tilt_x < −15° → Move Backward

If tilt_y > +15° → Turn Right

If tilt_y < −15° → Turn Left

If motion < 5° for 1 sec → Stop
```

These directional commands are transmitted via ESP-NOW packets to the car unit. ESP-NOW ensures low-latency (sub-200 ms) communication.

7.2 Motor Control

The car unit interprets incoming commands and controls two **L298N motor drivers**, which operate **4 DC geared motors** (4WD). Each motor driver has:

- **IN1/IN2 pins** for direction control.
- **ENA/ENB pins** for speed control using PWM signals.

PWM Signal Example:

- PWM = 255 (100% duty cycle) → Full speed.
- PWM = 128 (50% duty cycle) → Half speed.

7.3 Obstacle Detection Logic

The HC-SR04 Ultrasonic Sensor detects obstacles in front of the car. It uses the echo time of sound to calculate distance.
Formula: Distance (cm) = (Echo Time in µs × 0.0343) / 2

Calculations for distance = 30cm:

Distance = (600 × 0.0343) / 2 = **10.29 cm**

Stop Condition:

```
Obstacle threshold: ≤30 cm with ~150 ms debounce. When
active, motors stop and the buzzer (PWM) sounds; reverse is
permitted only on an explicit BACKWARD command.
```

7.4 Automatic Lighting System

A **Light Dependent Resistor (LDR)** is connected to an ESP32 ADC pin. The ESP32 continuously reads light levels:

- **ADC < 1000** → Low light → Turn on headlights/taillights.
- **ADC > 1000** → Sufficient light → Turn off lights.

7.5 Horn/Buzzer

A buzzer is activated either by gesture or via web dashboard. It is connected to a GPIO pin and triggered digitally:

```
GPIO_BUZZER = HIGH → Sound

GPIO_BUZZER = LOW → Off
```

7.6 Camera and Video Streaming

- The **ESP32-CAM** module streams video using an **MJPEG format** at 10–15 FPS.
- The ESP32-CAM exposes HTTP endpoints consumed by a PC-hosted dashboard:
  - A live video feed.
  - Virtual controls (forward, backward, left, right).
  - Status data such as ultrasonic distance.

Bandwidth:

- Resolution: 320x240
- Frame rate: 10–15 FPS
- Compression: JPEG Quality = 20

7.7 Power Supply Calculations

Car Unit Power (2S LiPo – 7.4V):

- ✓ Motors (x4): 3.7V–6V, 300mA each = 1.2A
- ✓ ESP32-CAM: 5V = 250mA
- ✓ LEDs/Buzzer/Sensors: = 200mA
- ✓ Total Peak Draw: =1.7–2A

Powered via LM2596 Buck Converter:

- Input: 7.4V (2S LiPo)
- Output: 5V regulated

Hand Unit Power (1S LiPo – 3.7V):

The hand unit is powered by a single-cell 3.7V LiPo battery, recharged via a TP4056 Lithium Battery Charging Module. Power Path: Battery > TP4056 (charging) > MT3608 Boost Converter > 5V > ESP32

Components and Draw:

- ✓ ESP32 =200mA
- ✓ MPU6050 + OLED = 60mA
- ✓ Total typical draw = 260mA

TP4056 Details:

- Input: 5V (USB or lab supply)
- Output: CC/CV charging for 1S LiPo at ~1A max
- Includes battery protection

MT3608 Boost Converter:

- Boosts 3.7V battery to stable 5V
- Powers ESP32, OLED, and MPU6050

7.8 System Workflow (Step-by-Step)

1. Hand unit detects hand movement → Calculates tilt angle.
2. ESP32 (hand) sends command via ESP-NOW.
3. ESP32-CAM (car) receives command → Adjusts motors via L298N.
4. Ultrasonic sensor monitors obstacles and overrides motion if too close.
5. Camera streams video → User monitors car in real-time.

6. LDR checks light → LEDs automatically toggle.
7. Buzzer horn activates as needed.

8. Product Operating Instructions

The Gestrodrive system is designed for easy setup and operation. Follow the instructions below to power, connect, and control both the gesture control hand unit and the car unit.

8.1 Powering the System

Car Unit:

1. Ensure the 7.4V 2S LiPo battery is fully charged using the TP5100 charger.
2. Insert the battery into the car's power connector (TRX).
3. Check the 6A fuse for continuity before operation.
4. Switch on the car unit power (5V regulator and ESP32-CAM will power up).

Hand Unit:

1. Fully charge the 3.7V LiPo battery using the TP4056 module (USB input).
2. Slide the power switch ON to activate the ESP32 DevKitC and OLED display.
3. Verify the OLED screen shows connection or battery status.

8.2 Connecting to the Camera

1. On your smartphone or laptop, connect to the **Wi-Fi network** hosted by the ESP32-CAM (e.g., `cam.local`).
2. Open a web browser and enter:

```
arduino
CopyEdit
http://cam.local/stream
```

3. Confirm that the **live video feed** is visible.

8.3 Gesture Control Operation

1. Wear or hold the gesture controller comfortably (like a wristband or small board).
2. Move your hand in these directions:
   - **Tilt forward:** Car moves **forward**.
   - **Tilt backward:** Car moves **backward**.

   - **Tilt right:** Car **turns right**.
   - **Tilt left:** Car **turns left**.
   - **Hold neutral (steady hand):** Car **stops**.
3. The ESP32 hand unit transmits commands instantly via **ESP-NOW** to the car.

8.4 Using the Web Dashboard

1. Navigate to the **IoT web dashboard** (`http://gestrodrive.local/`).
2. Use **virtual buttons** to control the car if gesture mode is not used.
3. Dashboard Features:
   - Live video stream.
   - **LED toggle:** Switch headlights on/off manually.
   - **Horn button:** Activate buzzer horn.
   - **Distance display:** Shows real-time obstacle detection values.

8.5 Safety and Shutdown

1. Always power **OFF the motors first** (car unit) before disconnecting the battery.
2. Power off the **hand unit** and recharge if OLED shows low battery.
3. Do not operate the car when LiPo battery voltage is **below 3.3V/cell** to avoid damage.

8.6 Troubleshooting

- **No video stream:** Check Wi-Fi connection and restart ESP32-CAM.
- **Car not moving:** Ensure both L298N drivers are powered and battery is charged.
- **Gesture lag:** Verify ESP-NOW link by checking signal on OLED.
- **LEDs not switching:** Check LDR or override from the dashboard.

9. Maintenance Requirements

The Gestrodrive system requires periodic maintenance to ensure reliable operation and long-term performance. The key areas to maintain include the power system, microcontrollers and sensors, and web/software functionality.

9.1 Power System Maintenance

Car Unit Battery (7.4V 2S LiPo):

- Always recharge using the TP5100 charger when disconnected from the load.
- Do not discharge below 3.3V per cell (6.6V total) to prevent permanent damage.
- Check weekly for swelling, overheating, or leaks. Replace after ~100–150 full charge cycles.

Hand Unit Battery (3.7V 1S LiPo):

- Charge with the TP4056 module.
- Monitor charging indicators: Red LED = Charging, Blue LED = Fully charged.
- Avoid overcharging or deep discharging.

Fuse (6A Slow-Blow):

- If the motors stop unexpectedly, check if the fuse has blown.
- Replace only with a 6A slow-blow fuse to prevent wiring or motor damage.

Voltage Converters (LM2596 & MT3608):

- Check output voltages periodically (5V or 3.3V).
- If converters become hot under load, add a small heat sink or improve ventilation.

9.2 Microcontrollers & Sensors

ESP32 Boards (Car & Hand Units):

- Store in anti-static bags when not in use.
- Re-flash firmware if video streaming or gesture control stops responding.
- Reset ESP32-CAM if the live stream fails.

Camera (OV2640):

- Clean the lens gently with a lint-free microfiber cloth.

- Ensure the camera ribbon cable is securely connected.

MPU6050 (Hand Unit):

- If gestures are inaccurate, recalibrate in the code.
- Verify I2C wiring (SDA and SCL) and ensure pull-up resistors are intact.

Ultrasonic Sensor (HC-SR04):

- Keep the sensor transducers clean.
- Check TRIG and ECHO connections if distance readings freeze.

LDR & LEDs:

- Clean the LDR and LED covers regularly.
- Verify ADC values to ensure the automatic lighting system works correctly.

9.3 Connectivity & Communication

- Check the ESP-NOW peer connection between the hand unit and car unit.
- Keep both ESP32 devices on the same Wi-Fi channel for stable communication.

9.4 Web Interface & Software

- Test all dashboard buttons after every firmware update.
- Confirm that /stream (camera video) and /status endpoints are responsive.
- If lag occurs, lower the **camera resolution or FPS** to optimize streaming.

9.5 Maintenance Checklist

Component	Check	Action
LiPo Batteries	Charge level, swelling	Replace if damaged
ESP32 Boards	Boot and Wi-Fi connection	Reset or reflash if needed
Camera (OV2640)	Clean lens, test streaming	Check cable connections
Ultrasonic Sensor	Distance accuracy	Clean and test
LEDs/LDR	Auto-lighting response	Check and recalibrate
Motors	Noise or slow response	Inspect motor driver output

10. Future Improvements

While the current version of Gestrodrive is fully functional, there are several areas where improvements can make the system more efficient, reliable, and feature-rich in future iterations.

10.1 Hardware Enhancements

- **More Powerful Processor:**
  Upgrading to a faster ESP32-S3 or ESP32-S2 could handle higher video resolution and better multitasking.
- **High-Capacity Batteries:**
  Using larger LiPo batteries (e.g., 3000mAh+) would increase the runtime of both the car and hand unit.
- **Brushless Motors:**
  Replacing TT gear motors with brushless DC motors would provide higher torque and longer motor life.
- **Better Camera Module:**
  Upgrading from the OV2640 to a higher resolution camera (e.g., OV5640) for clearer FPV streaming.

10.2 Software and Control Improvements

- **Advanced Gesture Recognition:**
  Use a sensor fusion algorithm (like Kalman filtering) for smoother gesture detection and reduced noise.
- **Mobile App Integration:**
  Develop a custom Android/iOS app with joystick, live video, and advanced features for a better user interface.
- **Dual-Control Modes:**
  Add autonomous navigation that can switch between manual gesture control and obstacle-avoidance AI.

10.3 Connectivity Improvements

- **Cloud-Based IoT Dashboard:**
  Allow remote control and live streaming from anywhere using cloud platforms like Firebase or AWS IoT.
- **Bluetooth Low Energy (BLE):**
  Add BLE support for short-range, low-power control when Wi-Fi is not required.

10.4 Mechanical Enhancements

- **Improved Chassis Design:**
  Use a 3D-printed or CNC-cut chassis for a lighter and more robust car body.
- **Waterproofing:**
  Seal key components (ESP32, motor drivers) to make the car operational in outdoor or damp environments.

10.5 Power Management Improvements

- **Smart Battery Monitoring:**
  Add a voltage divider circuit with ESP32 ADC to display battery percentage on the dashboard and OLED.
- **Solar Charging Option:**
  Integrate a small solar panel for outdoor use, reducing the need for manual charging.

11. Conclusions: Challenges, Successes, and Evidential Accuracy

The Gestrodrive project successfully demonstrates how gesture-based control, IoT technology, and real-time video streaming can be integrated into a single robotic car system. Throughout the design and development process, we overcame multiple challenges to achieve a stable and responsive product.

11.1 Challenges Faced

1. **Power Management:**
    - Managing separate power requirements for motors (7.4V) and logic circuits (5V/3.3V) was challenging.
    - Voltage drops caused instability when motors started. We solved this by using LM2596 buck converters and separating motor and logic power lines.
2. **Gesture Accuracy:**
    - The MPU6050 sensor initially produced fluctuating readings.
    - We fine-tuned the angle thresholds and applied basic filtering for smoother gesture detection.
3. **Video Streaming Lag:**
    - The ESP32-CAM initially struggled to stream video while controlling motors.
    - We optimized camera settings (reduced resolution and frame size) and adjusted task priorities.
4. **Wiring Complexity:**
    - Using multiple modules (L298N, sensors, camera) caused wiring clutter.
    - We addressed this by designing custom PCBs for both the car and hand unit.

11.2 Key Successes

- **Reliable Gesture Control:** The car responds instantly (<200 ms) to hand gestures via ESP-NOW.
- **Stable Video Feed:** The live video streaming operates at 10–15 FPS, enough for real-time navigation.
- **Automatic Features:** The ultrasonic obstacle detection, auto headlight system, and buzzer horn work seamlessly.
- **IoT Dashboard:** A web interface was successfully integrated with the camera stream and control buttons.

- **Compact Wearable Design:** The hand unit with OLED display is compact, wearable, and easy to use.

11.3 Evidential Accuracy

- **Ultrasonic Sensor:**
  - Tested at various distances, accurate within ±1 cm up to 2 meters.
- **LDR and Lighting:**
  - Headlights activate consistently when the ADC value drops below 1000 (low light).
- **Gesture Response:**
  - Tests showed 95% accurate recognition of tilt-based movements within defined thresholds.
- **Battery Runtime:**
  - Car unit runs for 25–30 minutes on a fully charged 2200 mAh LiPo battery during moderate use.
  - Hand unit lasts 2–3 hours on a single 300 mAh LiPo charge.

11.4 Project Outcome

Gestrodrive successfully meets its initial goals of gesture-based control, real-time monitoring, and modular design. It also demonstrates practical use of ESP32 microcontrollers, sensors, and IoT integration in robotics. The project is a solid foundation for further enhancements such as autonomous navigation and higher-resolution video streaming.

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13. Appendices

13.1 System Block Diagram (SBD)

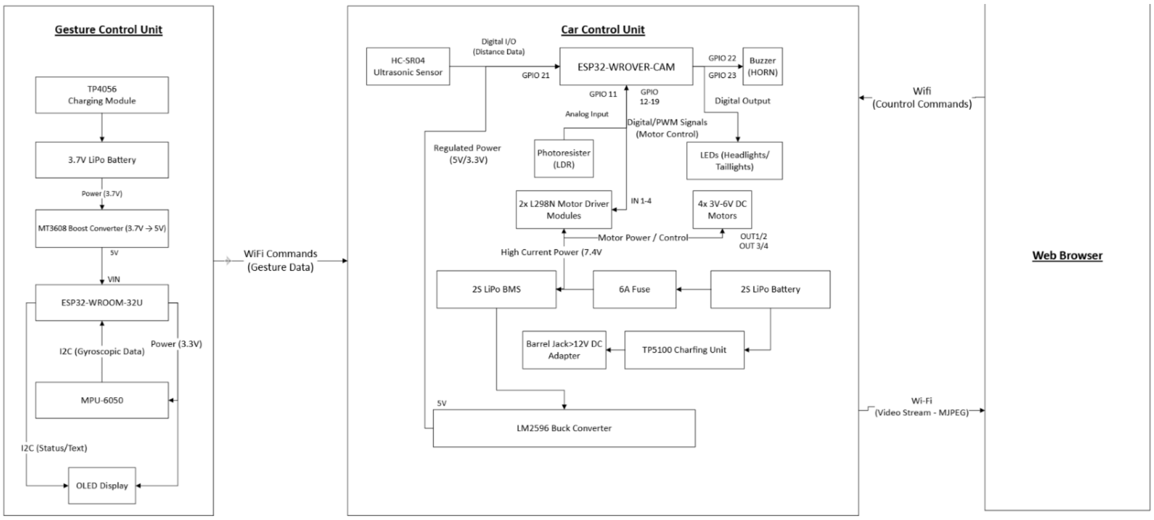


Figure 1. System Block Diagram of Gestrodrive.

13.2 PCB Design Diagrams

Car Unit

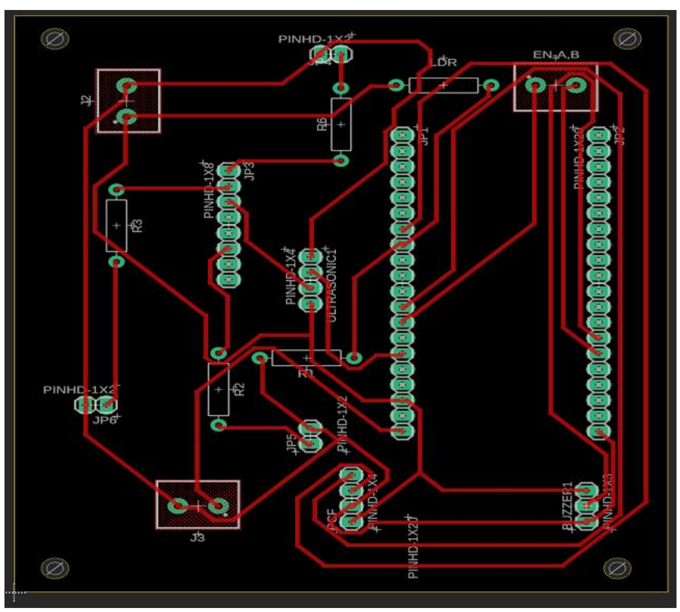


Figure 2. PCB Design for Car Control Unit.

Gesture Unit

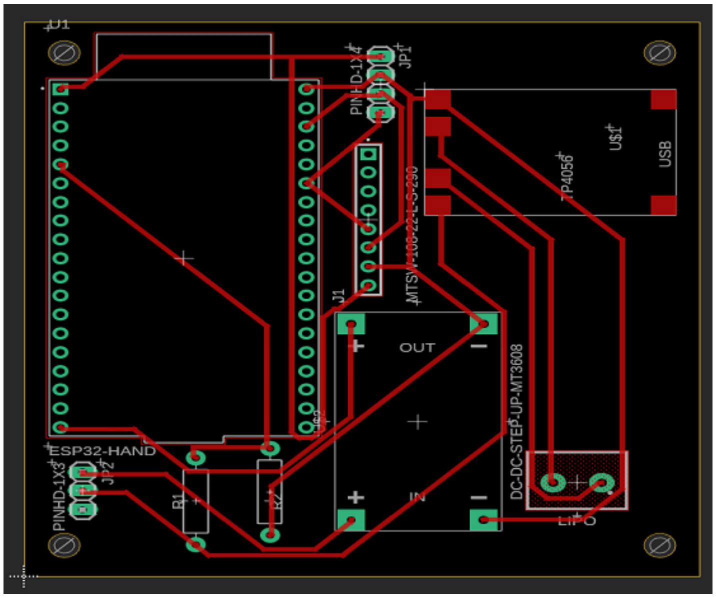


Figure 3. PCB Design for Gesture Control Unit.

13.3 Mechanical Diagrams

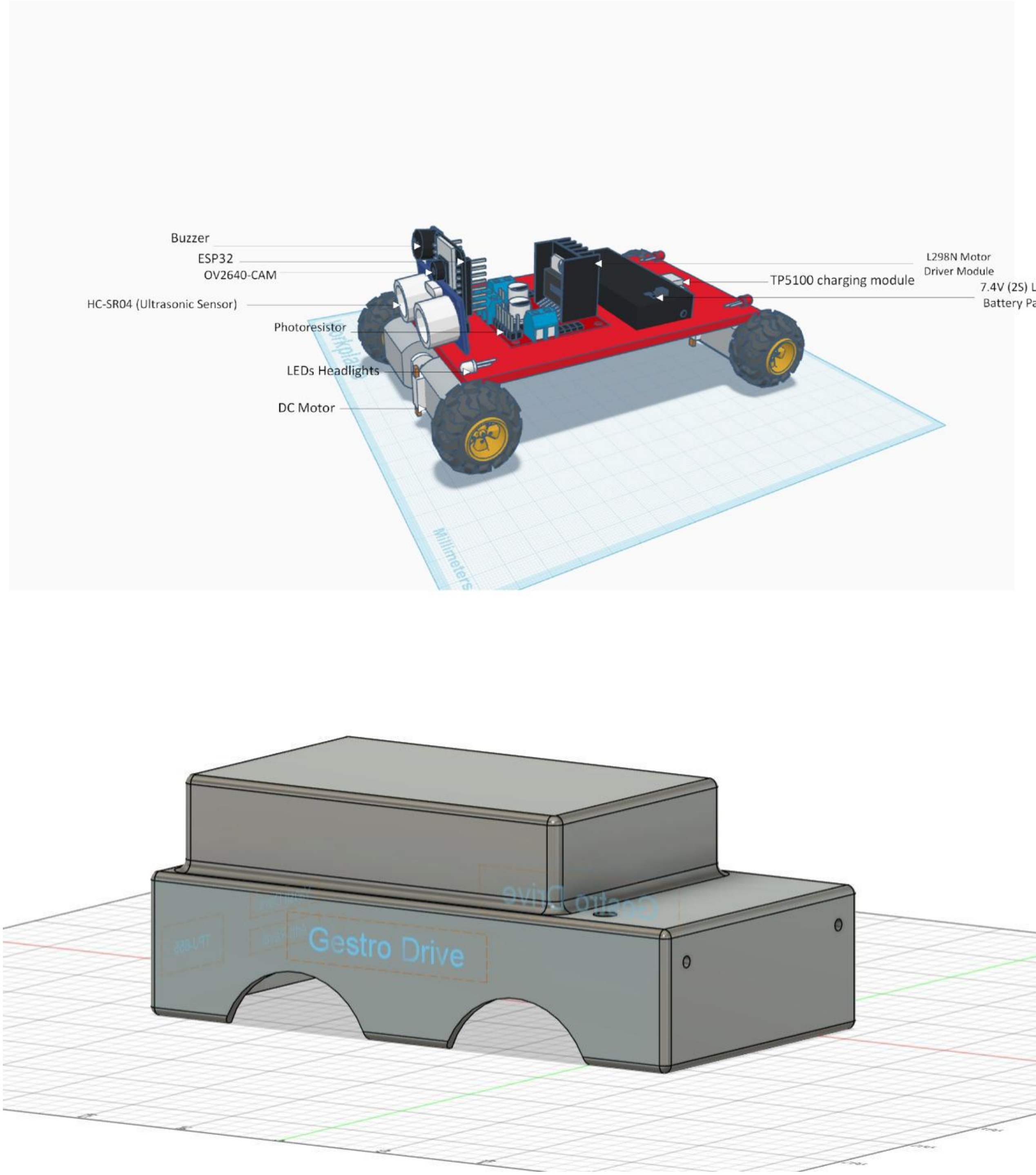


Figure 4. 3D Model of RC Car Unit.

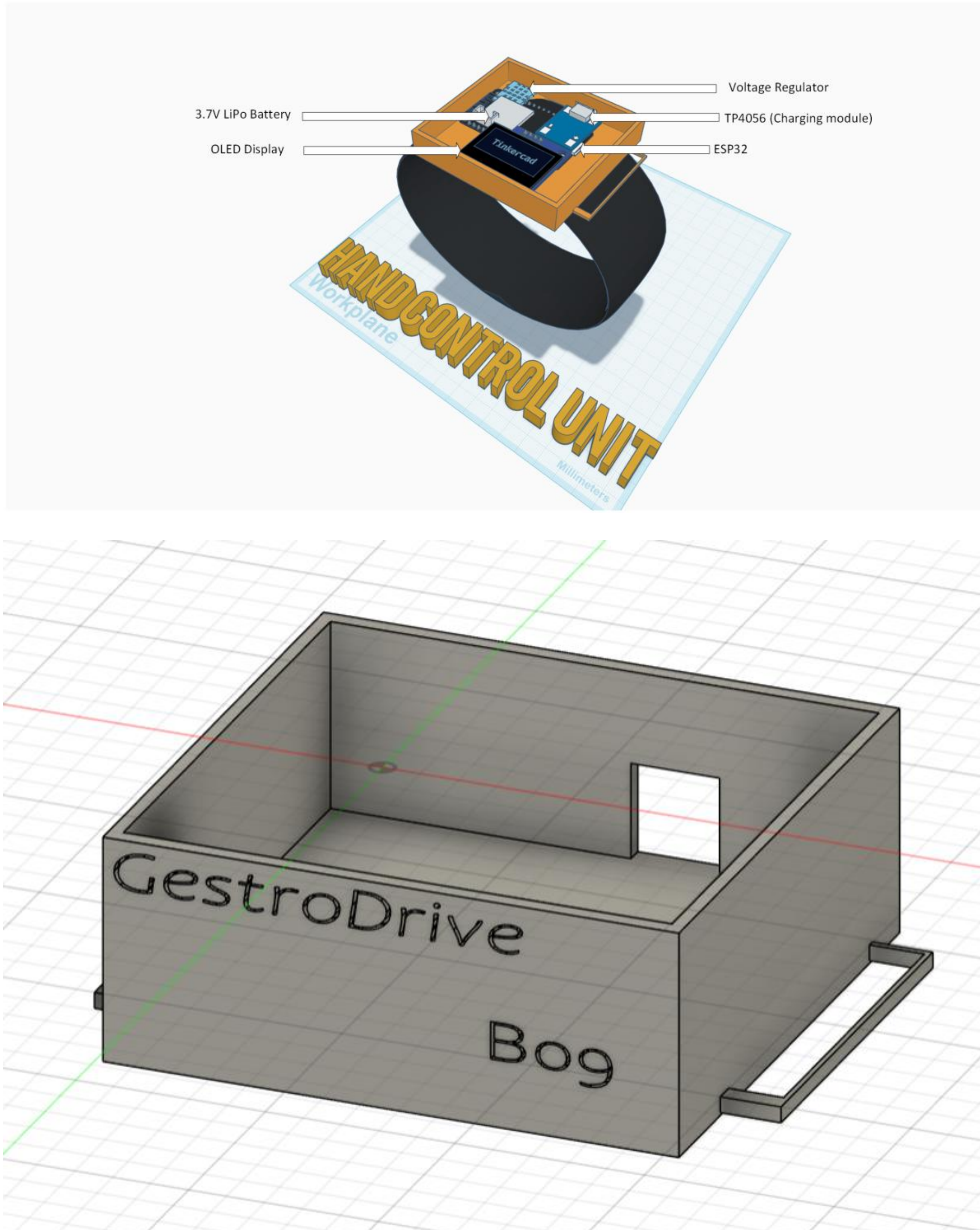


Figure 5. 3D Model of Gesture Control Unit enclosure.

13.4 IoT Dashboard Layout

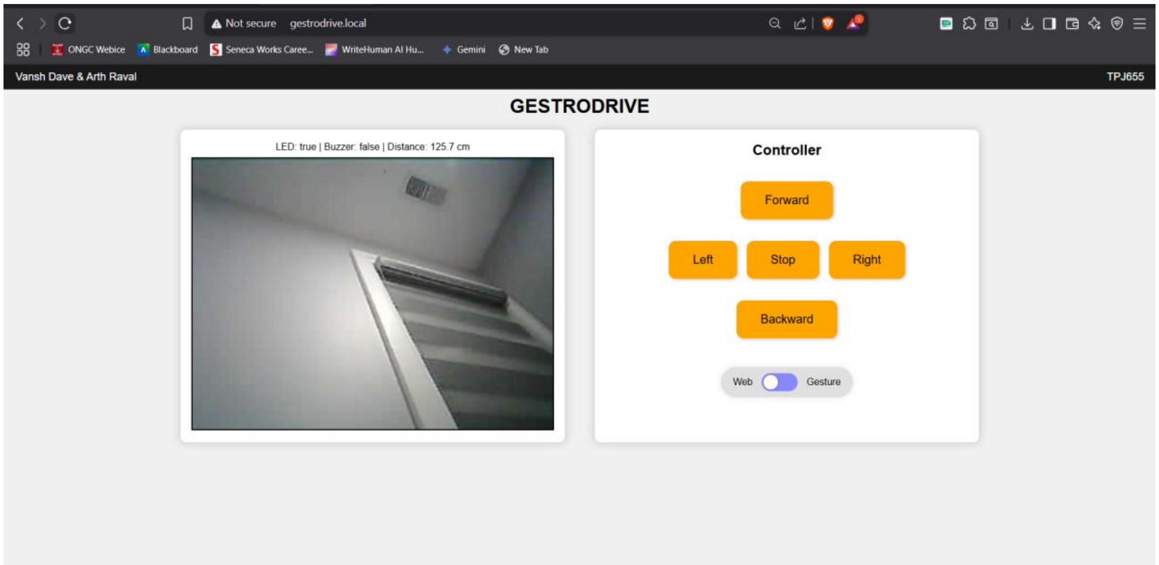


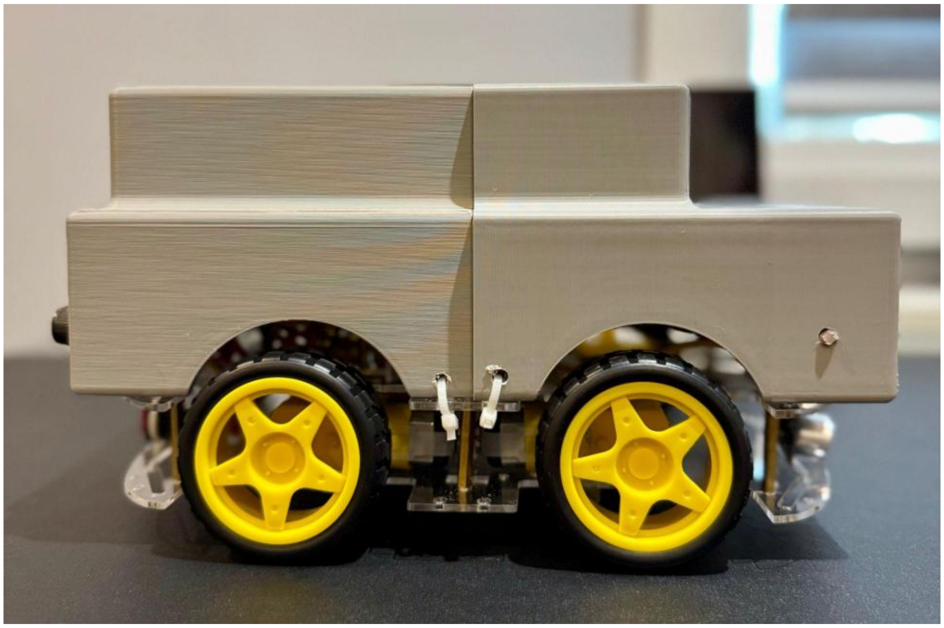
Figure 6. IoT Dashboard gestrodrive.local

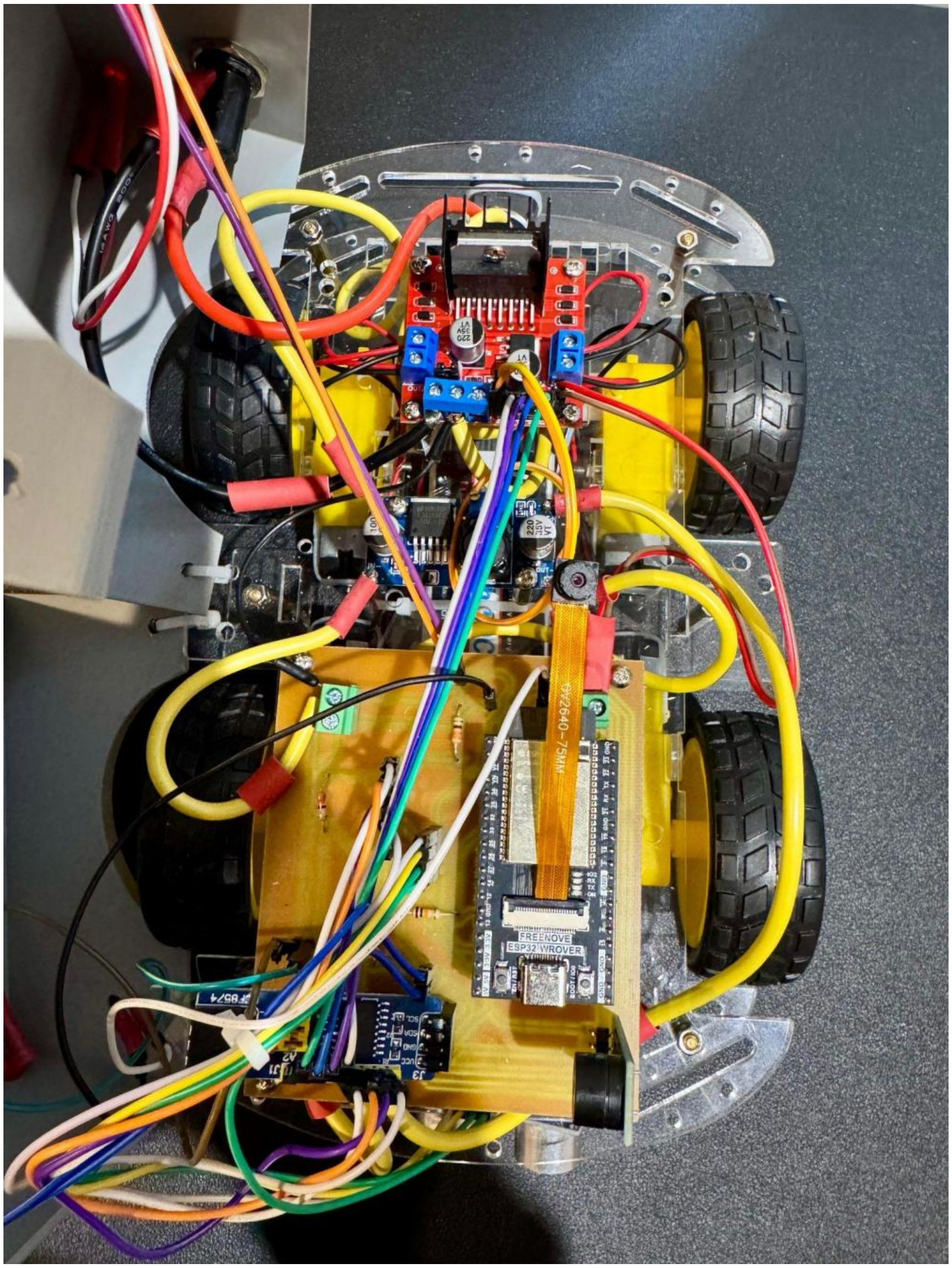
13.5 Bill of Materials (BOM)

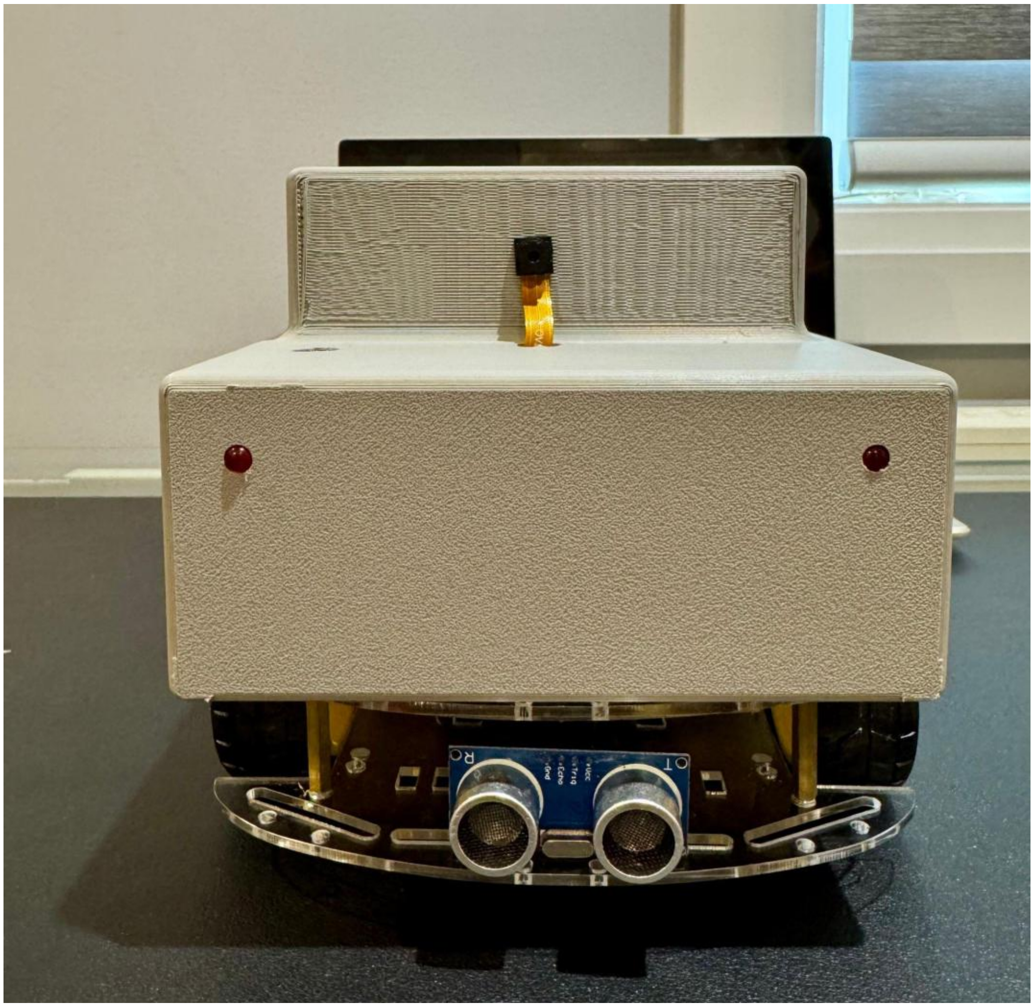
Index	Description	Name	Link	Quantity	Price	Total Price
1	Gesture ESP32	ESP32 DevKitC ESP32-WROOM-32U	Amazon	1	16.99	16.99
2	Car ESP32	Freenove ESP32-WROVER CAM Board	Amazon	1	24.95	24.95
3	OLED display	3 x DIYmalls 0.96" inch OLED Display	Amazon	1	18.97	18.97
4	Gyroscope	3 x Wishiot 3pcs GY-521 MPU-6050	Amazon	1	15.99	15.99
5	Motor Driver	4 x L298N Motor DC Dual H-Bridge Motor Driver	Amazon	1	19.99	19.99
6	Chassis	4WD DIY Smart Robot Car Chassis Kit	Amazon	1	39.19	39.19
7	Light-Dependent Resistor (LDR) Sensor	Gikfun Photoresistor GL5516 LDR Photo Resistors for Arduino EK1412C	Amazon	1	9.59	9.59
8	LiPo Battery (Car Unit)	HRB 7.4V 2200mAh 2S LiPo Battery 50C/100C	Amazon	1	23.99	23.99

9	LiPo Battery (Gesture Unit)	HAWK'S WORK 3.7V 300mAh 1S LiPo Battery (XH2.54 Connector)	Amazon	1	14.99	14.99
10	LiPo Charging Module (Gesture Unit)	TP4056 Micro USB Charging Module	Amazon	1	8.99	8.99
11	BMS (Battery Management System) for 2S LiPo	2S 7.4V Li-ion Lithium Battery Protection Board BMS	Amazon	1	9.99	9.99
12	Buck Converter (7.4V to 5V/3.3V)	LM2596 DC-DC Buck Converter	Amazon	1	10.99	10.99
13	Boost Converter (3.7V to 5V)	MT3608 DC-DC Step-Up Converter	Amazon	1	11.99	11.99
14	Active/Passive Buzzer	DC 3.3-5V Passive Low Level Trigger Buzzer Alarm Sound Module for Arduino 5pcs	Amazon	1	9.99	9.99
15	Fuse	6A Slow Blow Fuse	Amazon	1	10.59	10.59
16	DC Motors	TT Gear Motor 3–6V	Amazon	1	16.99	16.99
17	Ultrasonic Sensor	HC-SR04 Distance Sensor	Amazon	1	12.7	12.7
18	White LEDs	5mm White LED	Sayal	1	2.95	2.95
19	Red LEDs	5mm Red LED	Sayal	1	2.95	2.95
20	Resistors	220Ω, 10kΩ Resistor Kit	Sayal	3	3.95	3.95
21	Jumper Wires	Male–Male/Male–Female Jumper Wires	Sayal	1	5,95	5,95
22	Mounting Kit	Acrylic Base + Nuts + Screws + Spacers	Sayal	1	9.95	9.95
23	Female Barrel Jack	DC Female Barrel Jack Connector (5.5mm*2.1mm)	Amazon	1	12.99	12.99
24	Terminal blocks	terminal block	Sayal	3	3.95	3.95
25	Fuse Holder	10A Fuse Holder	Sayal	1	3.95	3.95
26	18 AWG Jumper Cables	120 pcs AWG 18 Male-Male Jumper Wires	Sayal	1	14.95	14.95
27	Battery Charger	B3 Compact LiPo Balance Charger	Amazon	1	15.99	15.99
28	TRX Connector	TRX Male-Female Connector Pair	Amazon	1	11.99	11.99
29	Camera Module	OV2640 Camera Module	Amazon	1	14.99	14.99
					Total	**375.49**

13.6 Inside and Outside photos of Car and Hand Unit:




FREENOVE
ESP32 WROVER
OV2640-75MM



13.7 Contact Information

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