# Byte Rider

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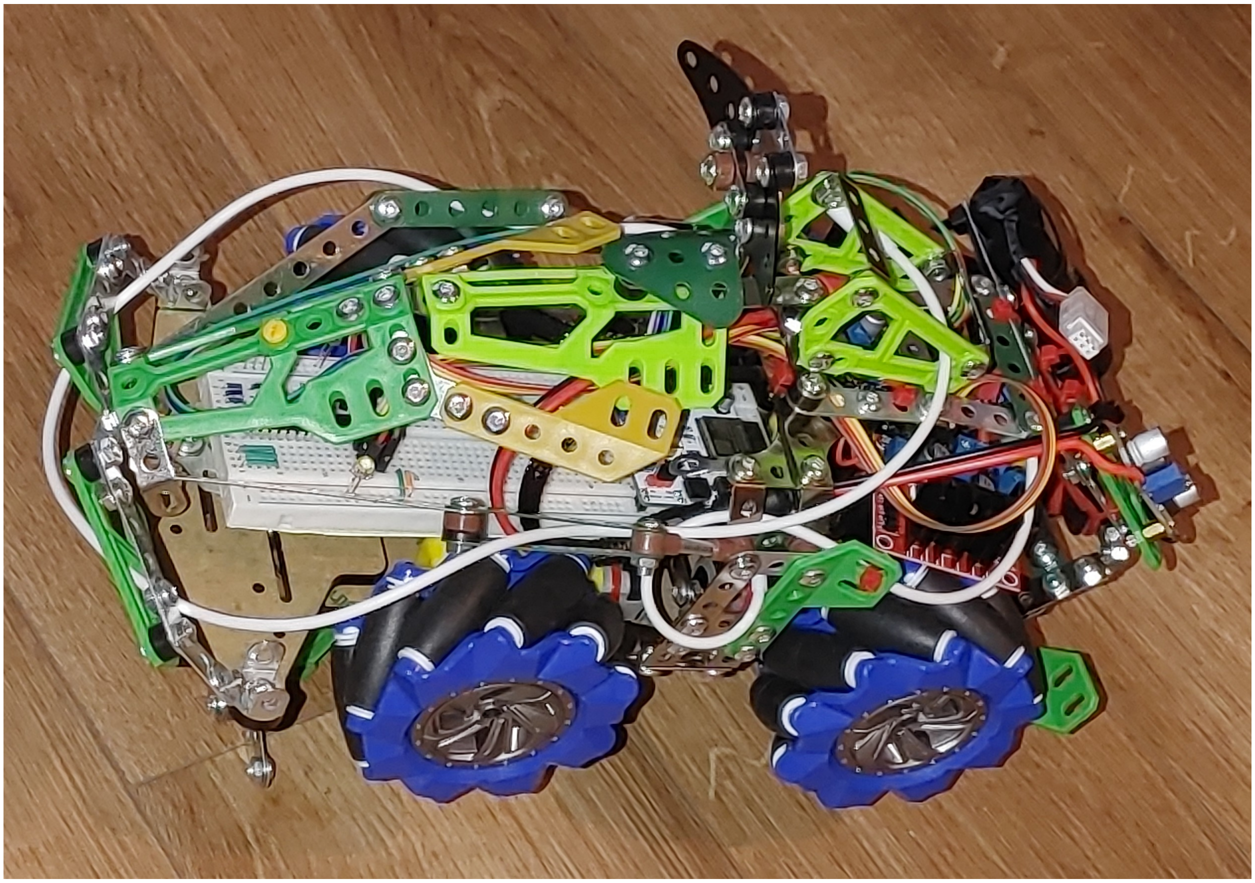

CHAPTER

# ONE

# OVERVIEW

At the heart of this project is a customizable remote-controlled car that responds to real-time control inputs, capable of handling speed adjustments, directional changes, and even extended features like lights or sensors. The foundational setup uses ESP-NOW for transmitter and receiver devices, allowing you to wirelessly guide the car's behaviour. While the design and physical appearance of the RC car can vary wildly depending on your creativity and available hardware, the control system remains elegantly efficient. To facilitate wireless communication between devices, the system employs ESP-NOW , which is a lightweight and connection-free protocol ideal for fast, low-latency data transmission between ESP32 microcontrollers. Though ESP-NOW is used under the hood, the spotlight remains on the RC car itself.

An ESP-NOW-based remote controller sends control data wirelessly using the ESP-NOW protocol to the remote-controlled car. ESP-NOW enables fast and efficient communication between ESP32 devices without the need for a Wi-Fi router, network, or pairing. The provided tutorial demonstrates a functional setup where a transmitter sends data to a receiver to define the car's speed and direction, forming the core communication loop. While the baseline implementation focuses on movement, additional features like lights, sensors, or telemetry can easily be integrated by expanding the source code. This modular design gives users the freedom to customize both the appearance and behaviour of their RC car, resulting in endless creative possibilities.

## 1.1 ABSTRACT


To enable real-time remote operation of the RC car, the system translates joystick x- and y- axis inputs into PWM (Pulse Width Modulation) signals that control the DC motors. These PWM values are stored in a predefined data structure, which is then transmitted wirelessly using ESP-NOW — a low-latency, connectionless communication protocol developed by Espressif. Both the transmitter and receiver modules are based on ESP32-C3 microcontrollers.

On the transmitter side, the joystick's X and Y coordinates are continuously monitored and converted into PWM parameters. These values are packed into the data structure and sent via ESP-NOW to the receiver.

The receiver module listens for incoming ESP-NOW packets, extracts the PWM control data, and applies it directly to the DC motors. This communication flow allows the RC car to respond instantly to user input, managing speed and direction without any physical connection between the devices.

CHAPTER

# TWO

# HOW DOES IT WORK?

The BitByteRider RC car is powered by ESP32-C3 Breadboard & Power adapter developmemt board. The Schematic and KiCAd PCB board are available on GitHub: https://github.com/alexandrebobkov/ESP32-C3_Breadboard-Adapter

## 2.1 Reserved Pins & GPIOs

The following table summarizes GPIOs and pins reserved for operations purposes.

The GPIO numbers correspond to those on the ESP32-C3 WROOM microcontroller. The Pin number corresponds to the pin on the Breadboard and Power adapter development board.

### 2.1.1 x- and y- axis

The **GPIO0** and **GPIO1** assigned to measuring the voltage of x- and y- axis of the Joystick. Lastly, there is a group of GPIO pairs responsible for PWM for DC motors.

### 2.1.2 Direction and Speed

The pairs of DC motors on the left side are wired to the dedicated PWM channels. This means that *ESP32-C3 Breadboard DevBoard* can control rotation speed and direction of DC motors in pairs only (i.e. left and right side). Consequently, only four PWM channels are sufficient for controlling the direction of the RC car. Based on this constraint, the RC car can only move front, back, and turn/rotate left and right. Any other movements are not possible (i.e. diagonal or sideways).

**What is PWM?**

**PWM** stands for Pulse Width Modulation. It is a technique used to simulate analog voltage levels using discrete digital signals. It works by rapidly switching a digital GPIO pin between HIGH (on) and LOW (off) states at a fixed frequency (often, at base frequency of 5 kHz). The duty cycle—the percentage of time the signal is HIGH in one cycle determines the effective voltage delivered to a device. A higher duty cycle increases the motor speed, and a lower duty cycle decreases the motor speed. This allows for fine-grained speed control without needing analog voltage regulators.

A pair of PWM channels are used per DC motor for defining their rotation speed and direction on each side. In particular, **GPIO6** and **GPIO5** provide PWM to the left- and right- side DC motors to rotate in a **clockwise** direction. Similarly, **GPIO4** and **GPIO7** provide PWM to the left- and right- side DC motors to rotate in a **counter-clockwise** direction. Changing PWM on each channel determines the speed and direction of the RC car.

The table below summarizes the GPIO pins used for PWM to control the direction of the DC motors in the remote-controlled car.

| GPIOs | State | Description | Function |
|---|---|---|---|
| GPIO6, GPIO4 | PWM | Left & Right DC Motors spin clockwise | Forward |
| GPIO5, GPIO7 | PWM | Left & Right DC Motors spin counterclockwise | Reverse |
| GPIO6, GPIO7 | PWM | Left DC Motors spin clockwise. Right DC Motors spin counterclockwise | Left |
| GPIO4, GPIO5 | PWM | Left DC Motors spin counterclockwise. Right DC Motors spin clockwise | Right |

The following images illustrate various PWM duty cycles registered by oscilloscope (duty cycles 0%, 48% and 91%, resp.).

Fig. 1: DC Motor PWM duty cycle 0%

Fig. 2: DC Motor PWM duty cycle 47.6%

Fig. 3: DC Motor PWM duty cycle 90.8%

| GPIO | Pin | Function | Notes |
|---|---|---|---|
| 0 | 16 | Joystick x-axis | ADC1_CH0 |
| 1 | 15 | Joystick y-axis | ADC1_CH1 |
| 8 | 5 | Joystick push button | |
| 6 | 4 | PWM for clockwise rotation of left-side motors | LEDC_CHANNEL_1 |
| 5 | 3 | PWM for clockwise rotation of right-side motors | LEDC_CHANNEL_0 |
| 4 | 2 | PWM for counter-clockwise rotation of right-side motors | LEDC_CHANNEL_2 |
| 7 | 6 | PWM for counter-clockwise rotation of left-side motors | LEDC_CHANNEL_3 |

## 2.2 Fusion of Software with Hardware

The *struct* for storing motors PWM values.

```
struct motors_rpm {
    int motor1_rpm_pwm;
    int motor2_rpm_pwm;
    int motor3_rpm_pwm;
    int motor4_rpm_pwm;
};
```

The function for updating motors' PWM values.

```
// Function to send data to the receiver
void sendData (void) {
    sensors_data_t buffer;              // Declare data struct

    buffer.crc = 0;
    buffer.x_axis = 0;
    buffer.y_axis = 0;
    buffer.nav_bttn = 0;
    buffer.motor1_rpm_pwm = 0;
    buffer.motor2_rpm_pwm = 0;
```

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```
    buffer.motor3_rpm_pwm = 0;
    buffer.motor4_rpm_pwm = 0;

    // Display brief summary of data being sent.
    ESP_LOGI(TAG, "Joystick (x,y) position ( 0x%04X, 0x%04X )", (uint8_t)buffer.x_axis,␣
↪(uint8_t)buffer.y_axis);
    ESP_LOGI(TAG, "pwm 1, pwm 2 [ 0x%04X, 0x%04X ]", (uint8_t)buffer.pwm, (uint8_
↪t)buffer.pwm);
    ESP_LOGI(TAG, "pwm 3, pwm 4 [ 0x%04X, 0x%04X ]", (uint8_t)buffer.pwm, (uint8_
↪t)buffer.pwm);

    // Call ESP-NOW function to send data (MAC address of receiver, pointer to the␣
↪memory holding data & data length)
    uint8_t result = esp_now_send(receiver_mac, &buffer, sizeof(buffer));

    // If status is NOT OK, display error message and error code (in hexadecimal).
    if (result != 0) {
        ESP_LOGE("ESP-NOW", "Error sending data! Error code: 0x%04X", result);
        deletePeer();
    }
    else
        ESP_LOGW("ESP-NOW", "Data was sent.");
}
```

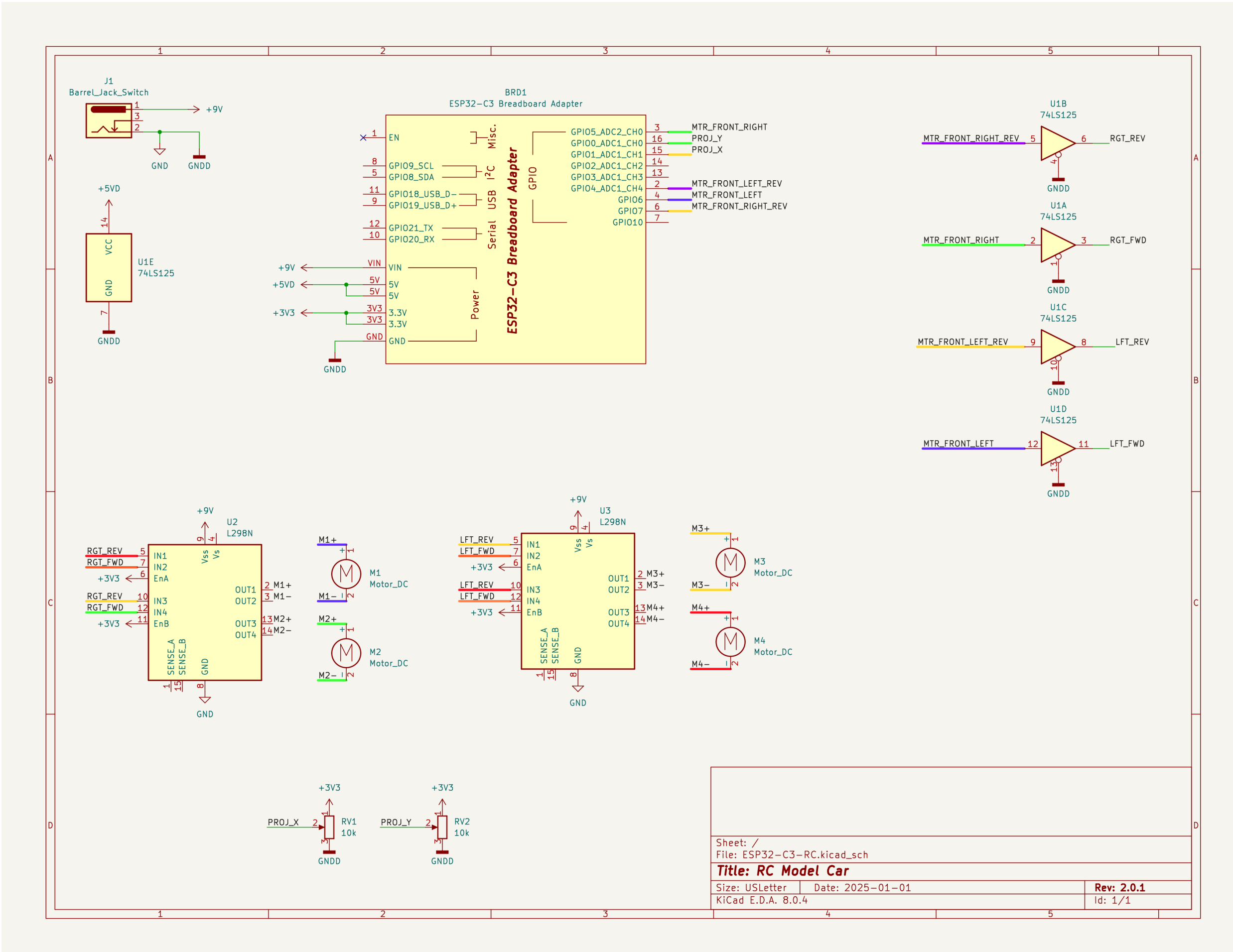
The onDataReceived() and onDataSent() are two call-bacl functions that get evoked on each corresponding event.

```
// Call-back for the event when data is being received
void onDataReceived (uint8_t *mac_addr, uint8_t *data, uint8_t data_len) {

    buf = (sensors_data_t*)data;                              // Allocate memory for␣
↪buffer to store data being received
    ESP_LOGW(TAG, "Data was received");
    ESP_LOGI(TAG, "x-axis: 0x%04x", buf->x_axis);
    ESP_LOGI(TAG, "x-axis: 0x%04x", buf->y_axis);
    ESP_LOGI(TAG, "PWM 1: 0x%04x", buf->motor1_rpm_pwm);
}

// Call-back for the event when data is being sent
void onDataSent (uint8_t *mac_addr, esp_now_send_status_t status) {
    ESP_LOGW(TAG, "Packet send status: 0x%04X", status);
}
```

The rc_send_data_task() function runs every 0.1 second to transmit the data to the receiver.

```
// Continous, periodic task that sends data.
static void rc_send_data_task (void *arg) {

    while (true) {
        if (esp_now_is_peer_exist(receiver_mac))
            sendData();
        vTaskDelay (100 / portTICK_PERIOD_MS);
    }
}
```

## 2.3 Schematic



CHAPTER

THREE

# DATA STRUCTS

The struct serves as the data payload for sending control signals from the transmitting device to the receiver using ESP-NOW. In addition, it may contain additional data such as telemetry, battery status, etc. The *sensors_data_t* struct encapsulates all control commands and sensor states relevant to the vehicle's operation. It's intended to be sent from a transmitting device (like a remote control) to a receiver (such as a microcontroller on board of the vehicle).

```
typedef struct {
    int         x_axis;             // Joystick x-position
    int         y_axis;             // Joystick y-position
    bool        nav_bttn;           // Joystick push button
    bool        led;                // LED ON/OFF state
    uint8_t     motor1_rpm_pwm;     // PWMs for 4 DC motors
    uint8_t     motor2_rpm_pwm;
    uint8_t     motor3_rpm_pwm;
    uint8_t     motor4_rpm_pwm;
} __attribute__((packed)) sensors_data_t;
```

```
struct motors_rpm {
    int motor1_rpm_pwm;
    int motor2_rpm_pwm;
    int motor3_rpm_pwm;
    int motor4_rpm_pwm;
};
```

When used with communication protocols like ESP-NOW, this struct is **encoded** into a byte stream, then **transmitted** at regular intervals or in response to user input, and finally **decoded** on the receiving end to control hardware.

**What is struct?**

In C programming, a struct (short for structure) is a user-defined data type that lets you group multiple variables of different types together under a single name. It's like a container that holds related information — perfect for organizing data that logically belongs together. Structs are especially powerful in systems programming, embedded projects, and when dealing with raw binary data — like parsing sensor input or transmitting control packets over ESP-NOW.

## 3.1 Data Payload

*x_axis* and *y_axis* fields capture analog input from a joystick, determining direction and speed. *nav_bttn* represents a joystick push-button.

*led* allows the transmitter to toggle an onboard LED and is used for status indication (e.g. pairing, battery warning, etc).

*motor1_rpm_pwm* to *motor4_rpm_pwm* provide individual PWM signals to four DC motors. This enables fine-grained speed control, supports differential drive configurations, and even allows for maneuvering in multi-directional platforms like omni-wheel robots.

### 3.1.1 Why use __attribute((packed))?

ESP-NOW uses fixed-size data packets (up to 250 bytes). The *__attribute__((packed))* removes compiler-added padding for precise byte alignment.

As *packed* attribute tells the compiler not to add any padding between fields in memory, this makes the struct:

- Compact
- Predictable for serialization over protocols like UART or ESP-NOW
- Ideal for low-latency transmission in embedded systems

This ensures the receiver interprets the exact byte layout you expect, minimizing bandwidth and maximizing compatibility across platforms.

CHAPTER

# FOUR

# TRANSMITTER

## 4.1 Configuration Variables

```
uint8_t receiver_mac[ESP_NOW_ETH_ALEN]  = {0xe4, 0xb0, 0x63, 0x17, 0x9e, 0x44};

typedef struct {
    int         x_axis;             // Joystick x-position
    int         y_axis;             // Joystick y-position
    bool        nav_btn;            // Joystick push button
    bool        led;                // LED ON/OFF state
    uint8_t     motor1_rpm_pwm;     // PWMs for each DC motor
    uint8_t     motor2_rpm_pwm;
    uint8_t     motor3_rpm_pwm;
    uint8_t     motor4_rpm_pwm;
} __attribute__((packed)) sensors_data_t;
```

## 4.2 Reading Joystick x- and y- Axis Values

## 4.3 Sending & Ecapsulating Data

```
void sendData (void) {

    ... ... ...
    ... ... ...

    buffer.x_axis = x_axis;
    buffer.y_axis = y_axis;

    // Call ESP-NOW function to send data (MAC address of receiver, pointer to the␣
↪memory holding data & data length)
    uint8_t result = esp_now_send((uint8_t*)receiver_mac, (uint8_t *)&buffer,␣
↪sizeof(buffer));

    ... ... ...
    ... ... ...
}
```

## 4.4 Main Function

```
#include "freertos/FreeRTOS.h"
#include "nvs_flash.h"
#include "esp_err.h"

... ... ...
... ... ...

void app_main(void) {

    ... ... ...
    ... ... ...

    // Initialize internal temperature sensor
    chip_sensor_init();

    // Initialize NVS
    esp_err_t ret = nvs_flash_init();
    if (ret == ESP_ERR_NVS_NO_FREE_PAGES || ret == ESP_ERR_NVS_NEW_VERSION_FOUND) {
        ESP_ERROR_CHECK( nvs_flash_erase() );
        ret = nvs_flash_init();
    }
    ESP_ERROR_CHECK( ret );
    wifi_init();
    joystick_adc_init();
    transmission_init();
    system_led_init();

    ... ... ...
    ... ... ...
}
```

# CHAPTER FIVE

# RECEIVER

## 5.1 Configuration Variables

```
uint8_t transmitter_mac[ESP_NOW_ETH_ALEN] = {0x9C, 0x9E, 0x6E, 0x14, 0xB5, 0x54};

typedef struct {
    int         x_axis;             // Joystick x-position
    int         y_axis;             // Joystick y-position
    bool        nav_bttn;           // Joystick push button
    bool        led;                // LED ON/OFF state
    uint8_t     motor1_rpm_pwm;     // PWMs for 4 DC motors
    uint8_t     motor2_rpm_pwm;
    uint8_t     motor3_rpm_pwm;
    uint8_t     motor4_rpm_pwm;
} __attribute__((packed)) sensors_data_t;
```

```
struct motors_rpm {
    int motor1_rpm_pwm;
    int motor2_rpm_pwm;
    int motor3_rpm_pwm;
    int motor4_rpm_pwm;
};
```

## 5.2 Receiving & Extracting Data

```
void onDataReceived (const uint8_t *mac_addr, const uint8_t *data, uint8_t data_len) {

    ... ... ...
    ... ... ...

    ESP_LOGI(TAG, "Data received from: %02x:%02x:%02x:%02x:%02x:%02x, len=%d", mac_
↪addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr[4], mac_addr[5], data_len);
    memcpy(&buf, data, sizeof(buf));

    x_axis = buf.x_axis;
    y_axis = buf.y_axis;

    ... ... ...
```

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```
    ... ... ...
}
```

## 5.3 Main Function

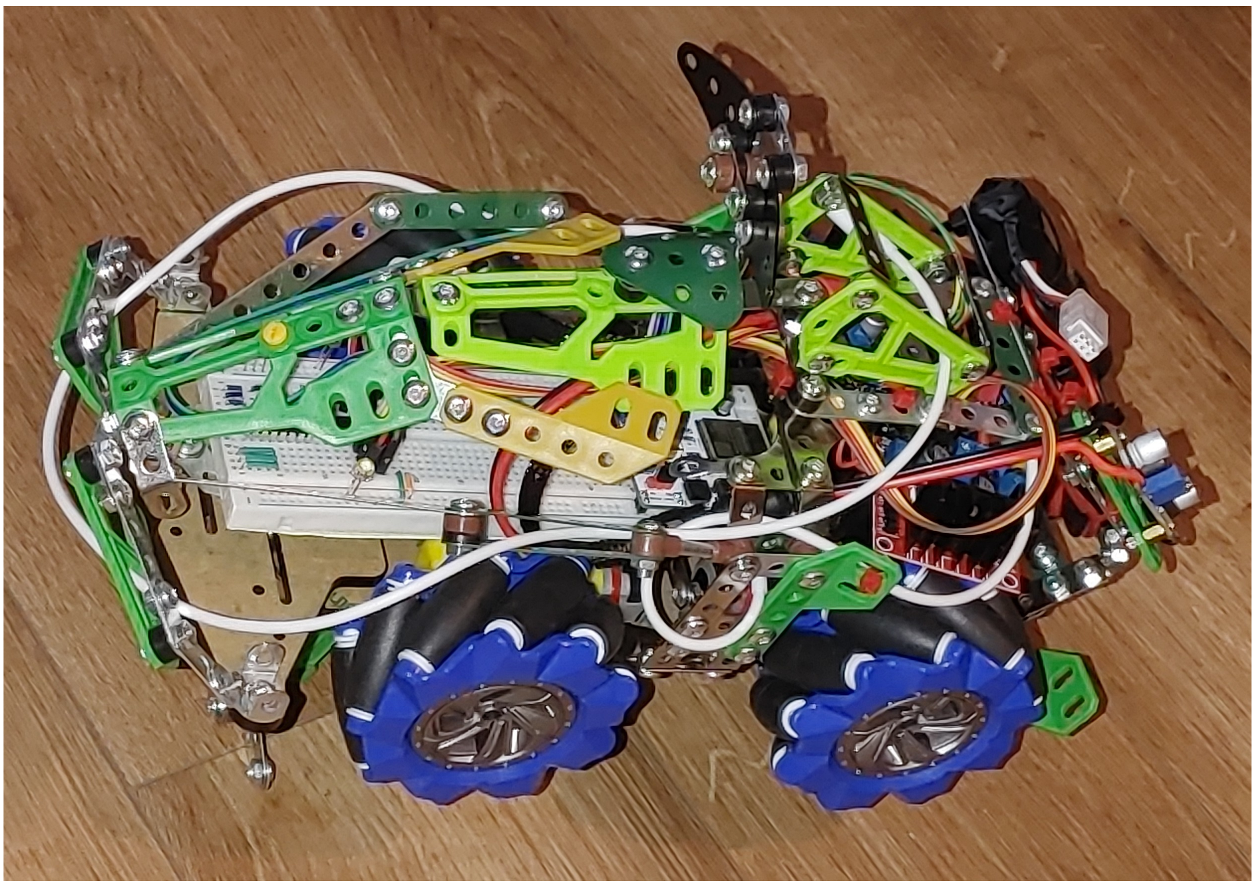
```
#include <string.h>
#include "freertos/FreeRTOS.h"
#include "nvs_flash.h"
#include "esp_err.h"

... ... ...
... ... ...

void app_main(void) {

    ... ... ...
    ... ... ...

    // Initialize NVS
    esp_err_t ret = nvs_flash_init();
    if (ret == ESP_ERR_NVS_NO_FREE_PAGES ||
        ret == ESP_ERR_NVS_NEW_VERSION_FOUND) {
        ESP_ERROR_CHECK( nvs_flash_erase() );
        ret = nvs_flash_init();
    }

    ESP_ERROR_CHECK( ret );
    wifi_init();
    ESP_ERROR_CHECK(esp_now_init());

    esp_now_peer_info_t transmitterInfo = {0};
    memcpy(transmitterInfo.peer_addr, transmitter_mac, ESP_NOW_ETH_ALEN);
    transmitterInfo.channel = 0; // Current WiFi channel
    transmitterInfo.ifidx = ESP_IF_WIFI_STA;
    transmitterInfo.encrypt = false;
    ESP_ERROR_CHECK(esp_now_add_peer(&transmitterInfo));

    ESP_ERROR_CHECK(esp_now_register_recv_cb((void*)onDataReceived));

    system_led_init();

    ... ... ...
    ... ... ...
}
```

CHAPTER

SIX

# WORK-IN-PROGRESS WALK THROUGH

## 6.1 Finished Work



## 6.2 Chassis

## 6.3 Wiring

## 6.4 Motor Wires Harness

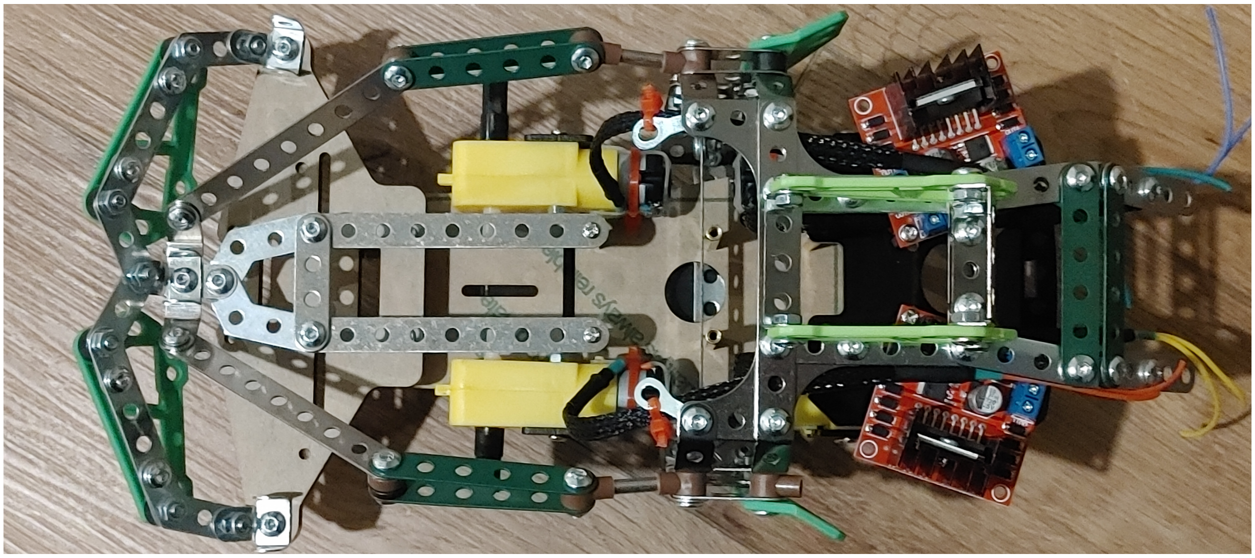


Fig. 1: Completed chassis with only DC motor controllers installed.

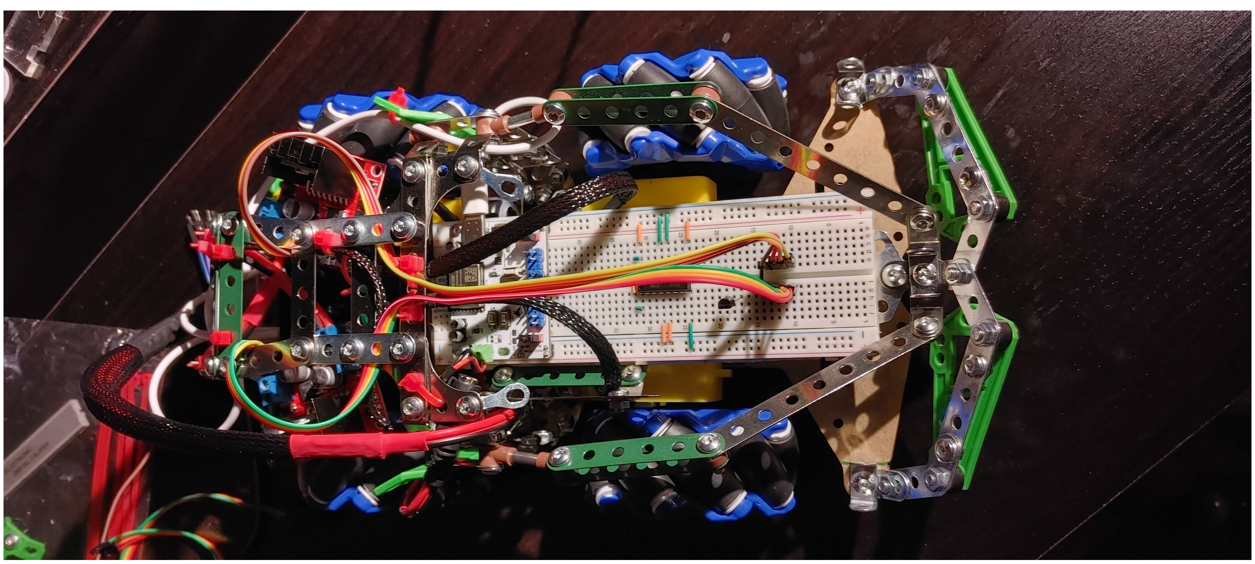


Fig. 2: Completed wiring.

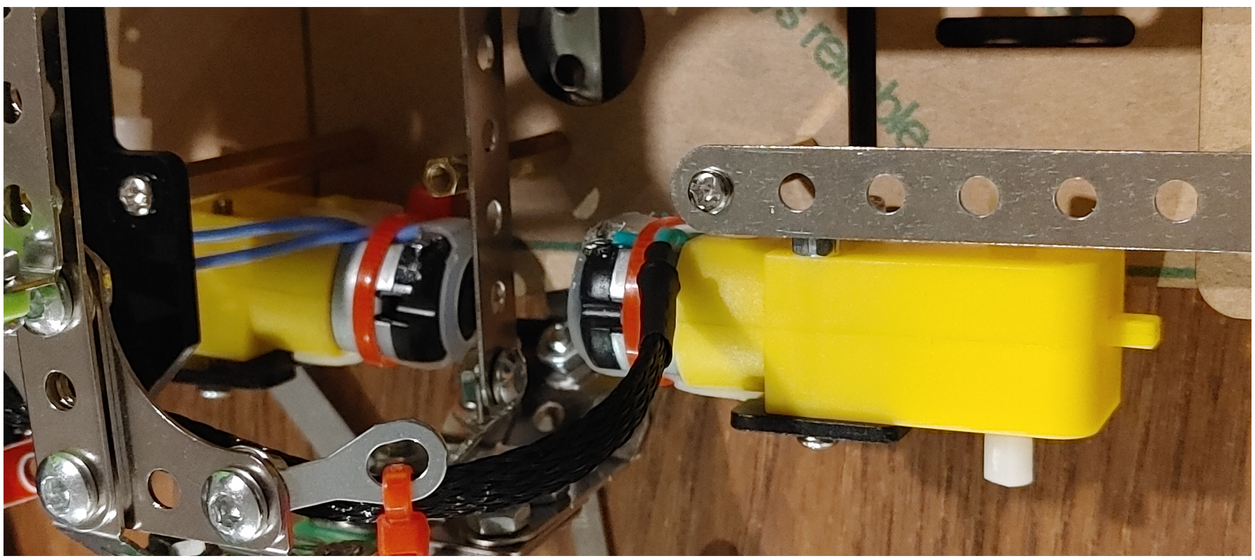


Fig. 3: DC Motors wires secured inside harnes.

CHAPTER

SEVEN

# REFERENCES

## 7.1 GitHub

Complete source code with README.md file: https://github.com/alexandrebobkov/ESP-Nodes/blob/main/ESP-IDF_Robot/README.md

KiCAd Schematic and PCB design: https://github.com/alexandrebobkov/ESP32-C3_Breadboard-Adapter