Byte Rider

Version

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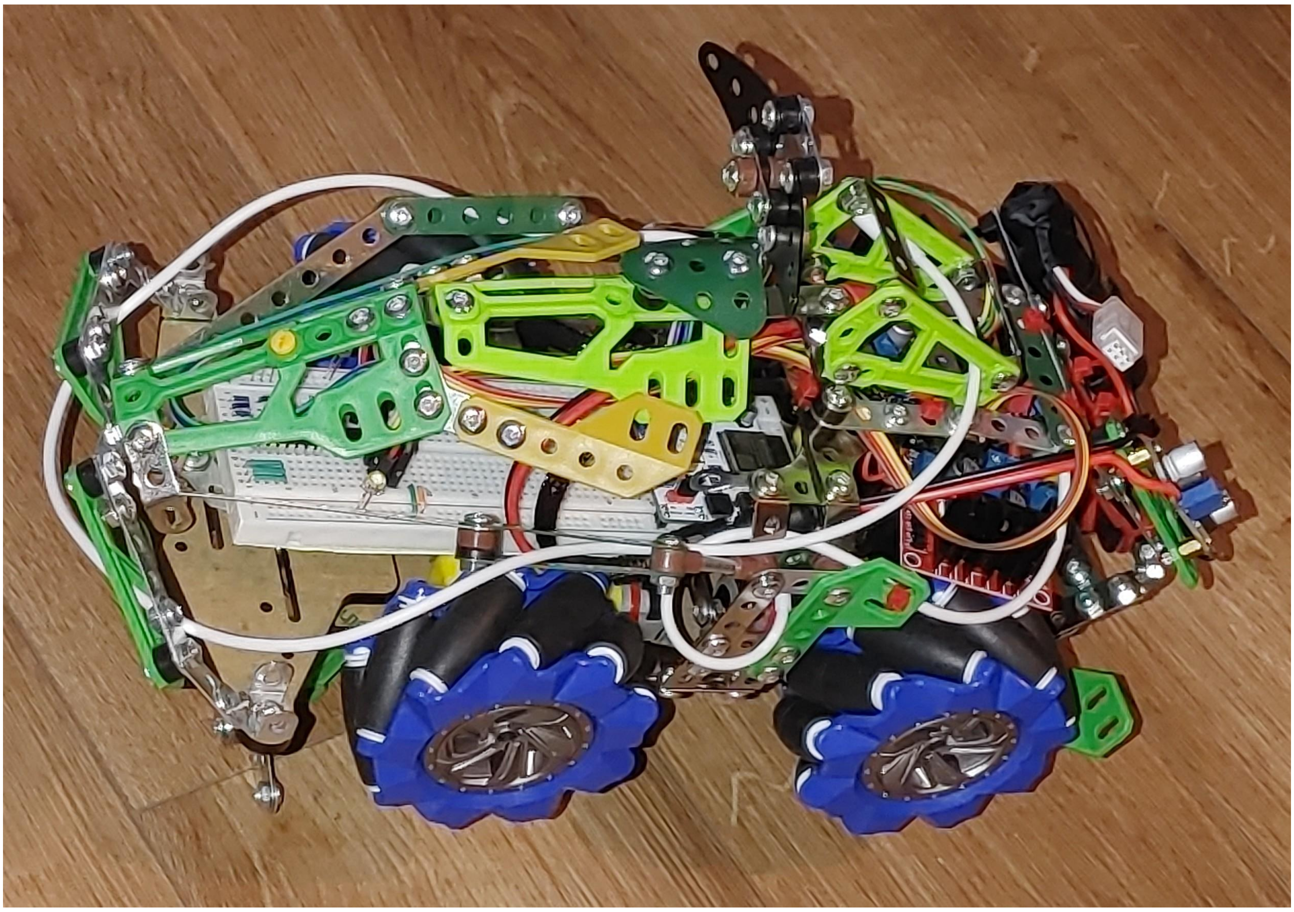
ByteRider documentation



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.

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.

HOW DOES IT WORK?

The bitByteRider RC car is powered by ESP32-C3 bitBoard. The Schematic and KiCAd PCB board files are available on GitHub : https://github.com/alexandrebobkov/ESP32-C3_Breadboard-Adapter

The bitByteRider RC car operates using two main units: the *transmitter* , which reads and sends the joystick's X and Y values, and the *receiver* , which interprets these values and converts them into PWM signals to control the DC motors. Both units communicate via **ESP-NOW** , a low-latency, connectionless wireless protocol that requires no Wi-Fi network or pairing.

In addition to enabling real-time control, using ESP-NOW introduces to key networking concepts such as **data encapsulation** and structured communication. By using data structures to group control variables, you gain hands-on experience with how information is packaged and transmitted — laying the groundwork for understanding the fundamentals of network communication in embedded systems.

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.

Reading the Joystick x- and y- axis

To determine the position of the Joystick, the BitRider RC car uses ADC to measure voltage on two GPIOs connected to the joystick x- and y- axis potentionometers (**GPIO0** and **GPIO1**).

Controlling the Direction and Speed

To set any desired speed of BiteRider RC car, the *ESP32-C3 Breadboard Adapter DevBoard* uses PWM to control the rotation speed of DR motors. Similarly, to set the direction of the RC car, the rotation speed of corresponding DC motors is changed as required.

Due to the design and limited number of available GPIOs, the *ESP32-C3 Breadboard DevBoard* can control rotation speed and direction of DC motors in pairs only (i.e. left and right side). Consequently, this means that the four PWM channels used 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).

PWM of DC Motors	Direction
PWM(left) = PWM(right)	Straight
PWM(left) > PWM(right)	Left
PWM(left) < PWM(right)	Right

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.

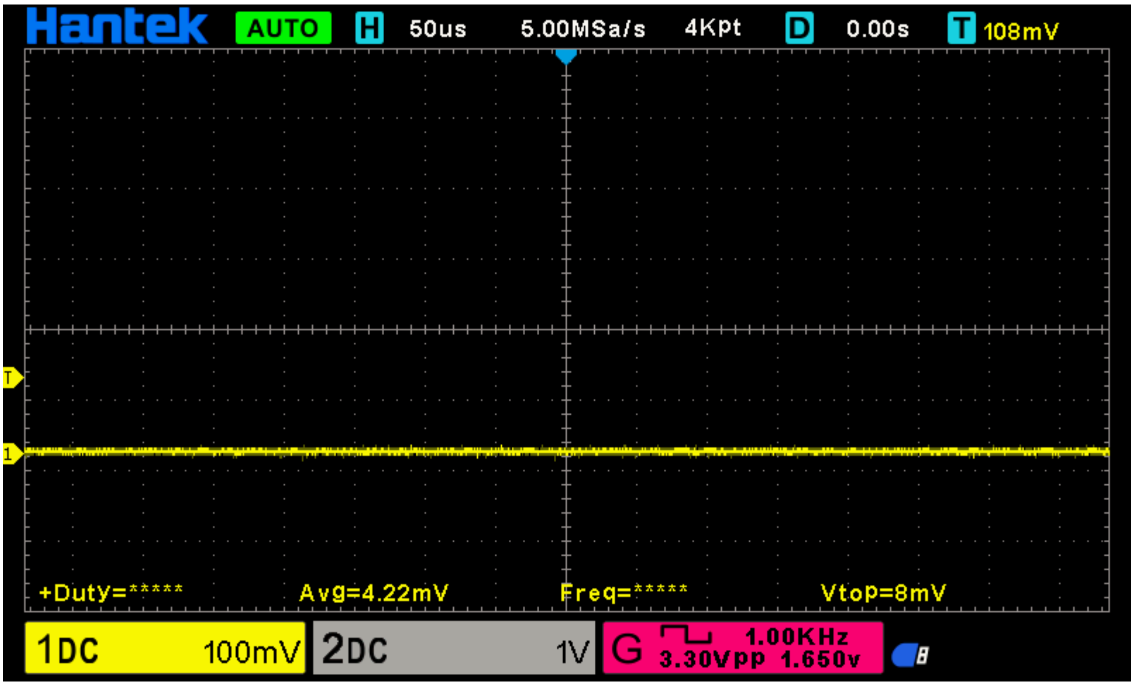
A pair of PWM channels are used per DC motor for defining their rotation speed and direction on each side. In particular, **GPIO6** and **GPIO5** provide PWM to the left- and right- side DC motors to rotate in a **clockwise** direction. Similarly, **GPIO4** and **GPIO7** provide PWM to the left- and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

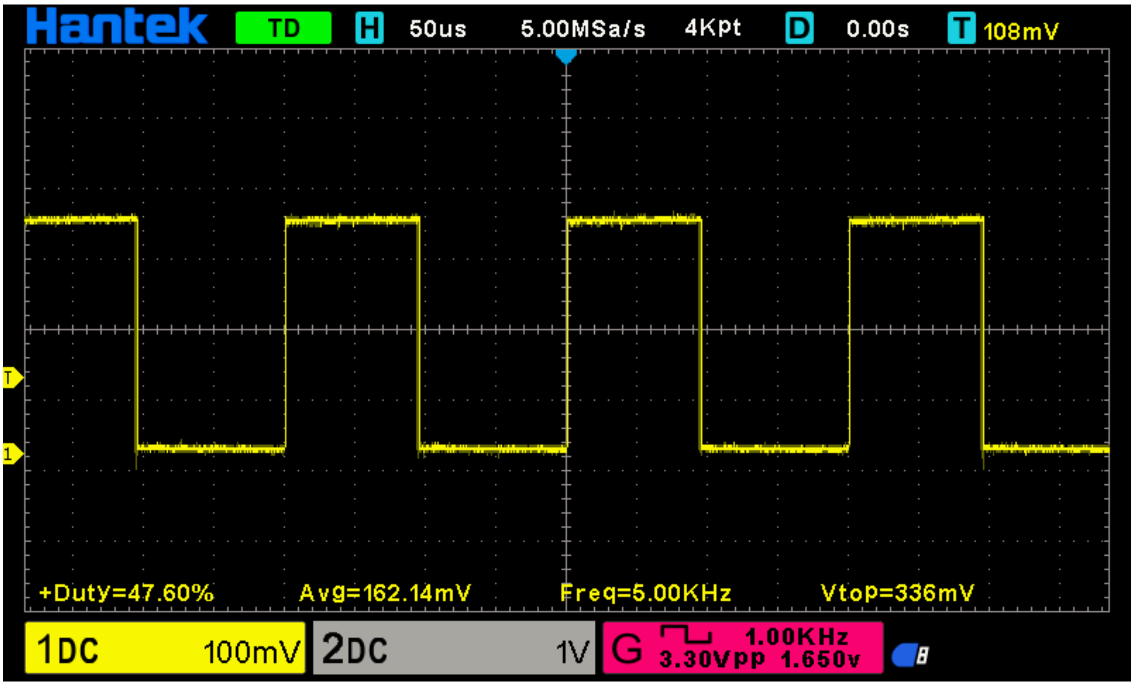
GPIOs	State	Description	Function
GPIO6, GPIO4	PWM	Left & Right DC Motors spin clockwise	Forward
	PWM	Left & Right DC Motors spin counterclockwise	Reverse

GPIOs	State	Description	Function
GPIO5, GPIO7			
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

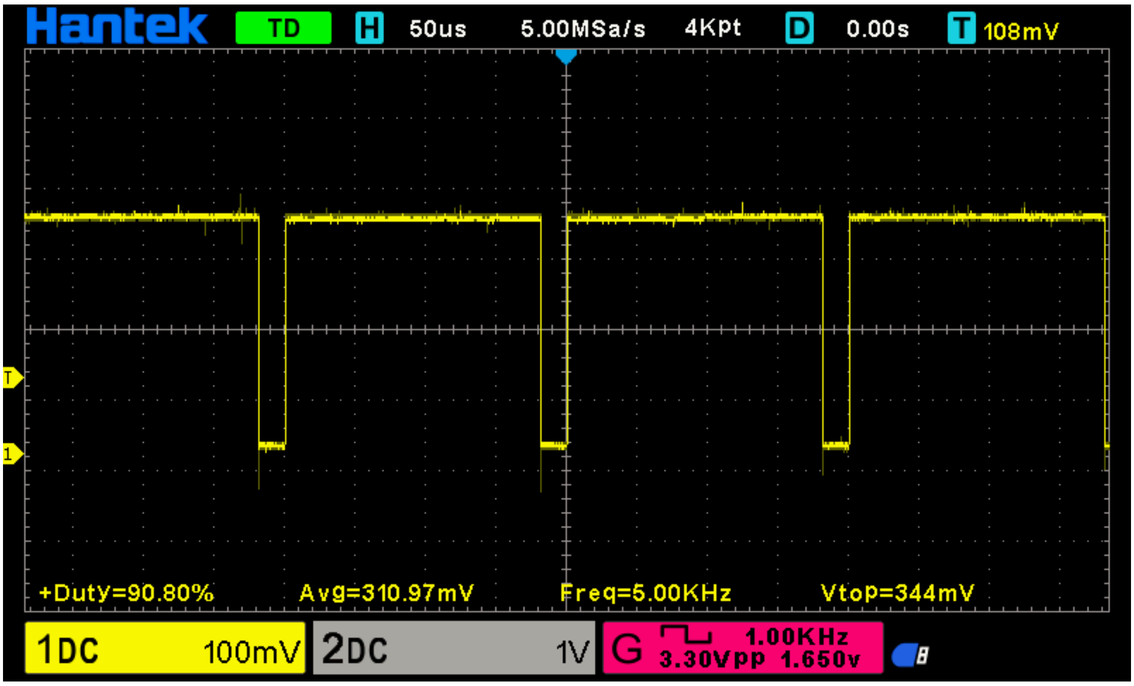
The following images illustrate various PWM duty cycles registered by oscilloscope (duty cycles 0%, 48% and 91%, resp.).



DC Motor PWM duty cycle 0%



DC Motor PWM duty cycle 47.6%



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	NC
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

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;
    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.");
}
```

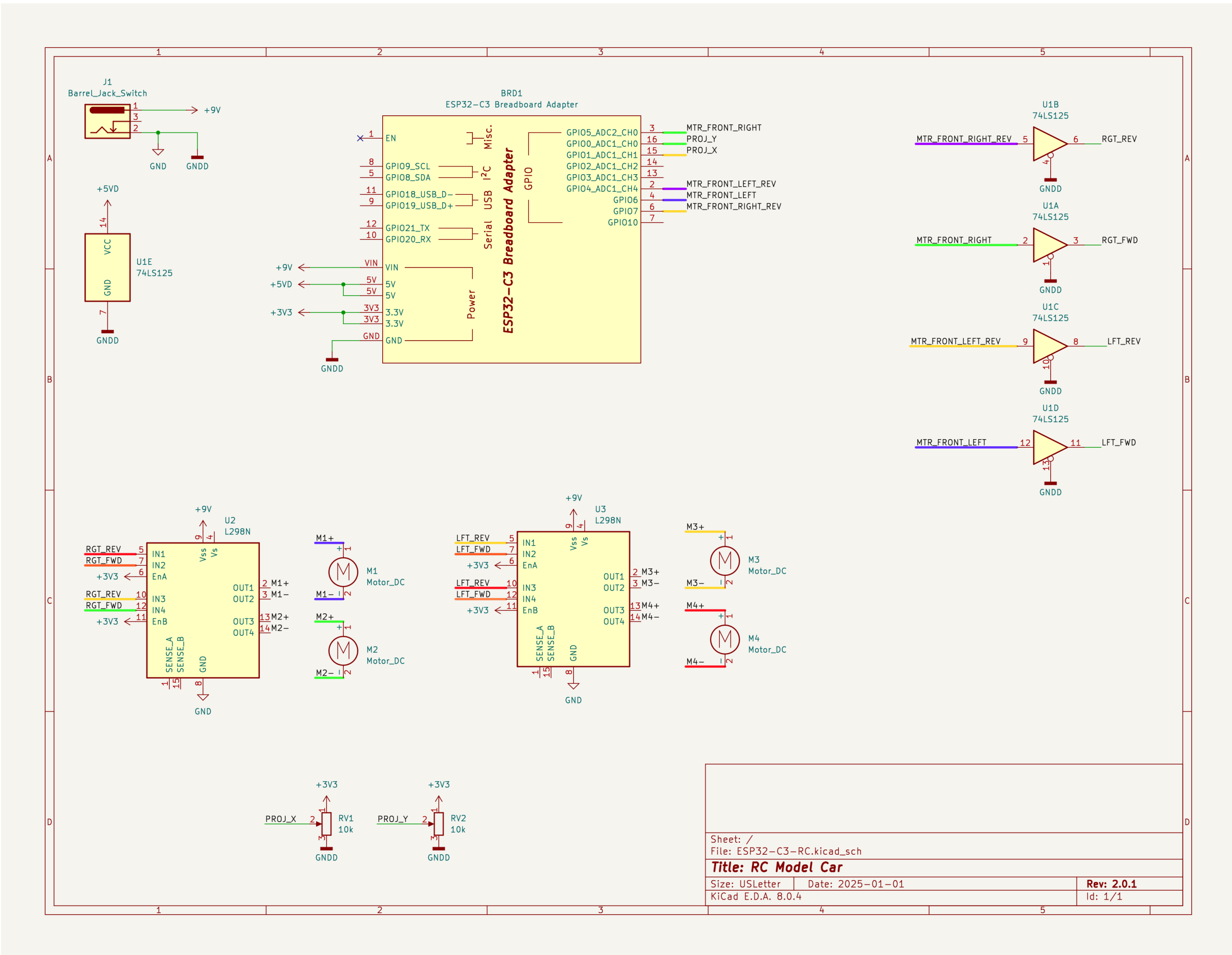
The onDataReceived() and onDataSent() are two call-back functions that get evoked on each corresponding event.

```
// 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);
    }
}
```

Schematic



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.

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.

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.

TRANSMITTER

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;
```

Reading Joystick x- and y- Axis Values

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));

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

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();

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

RECEIVER

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;
};
```

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;

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

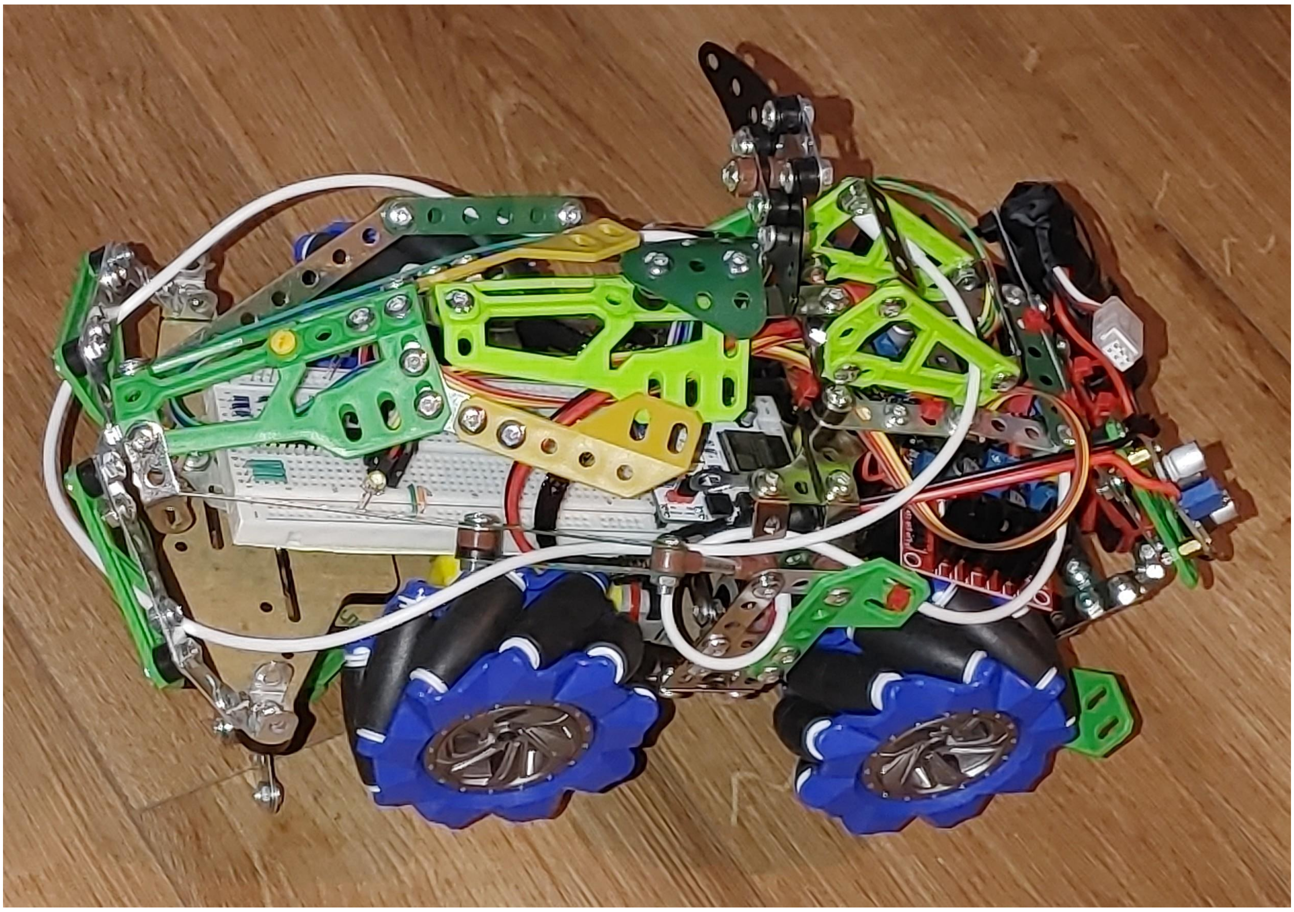
Main Function

```
#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();

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

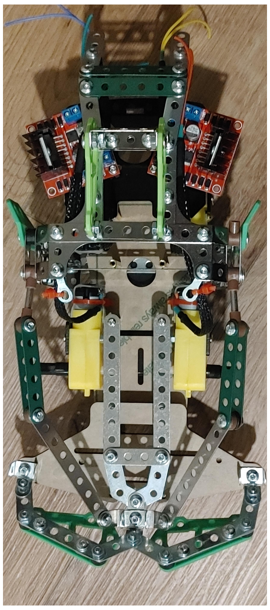
```
    ... ... ...
}
```

WORK-IN-PROGRESS WALK THROUGH

Finished Work

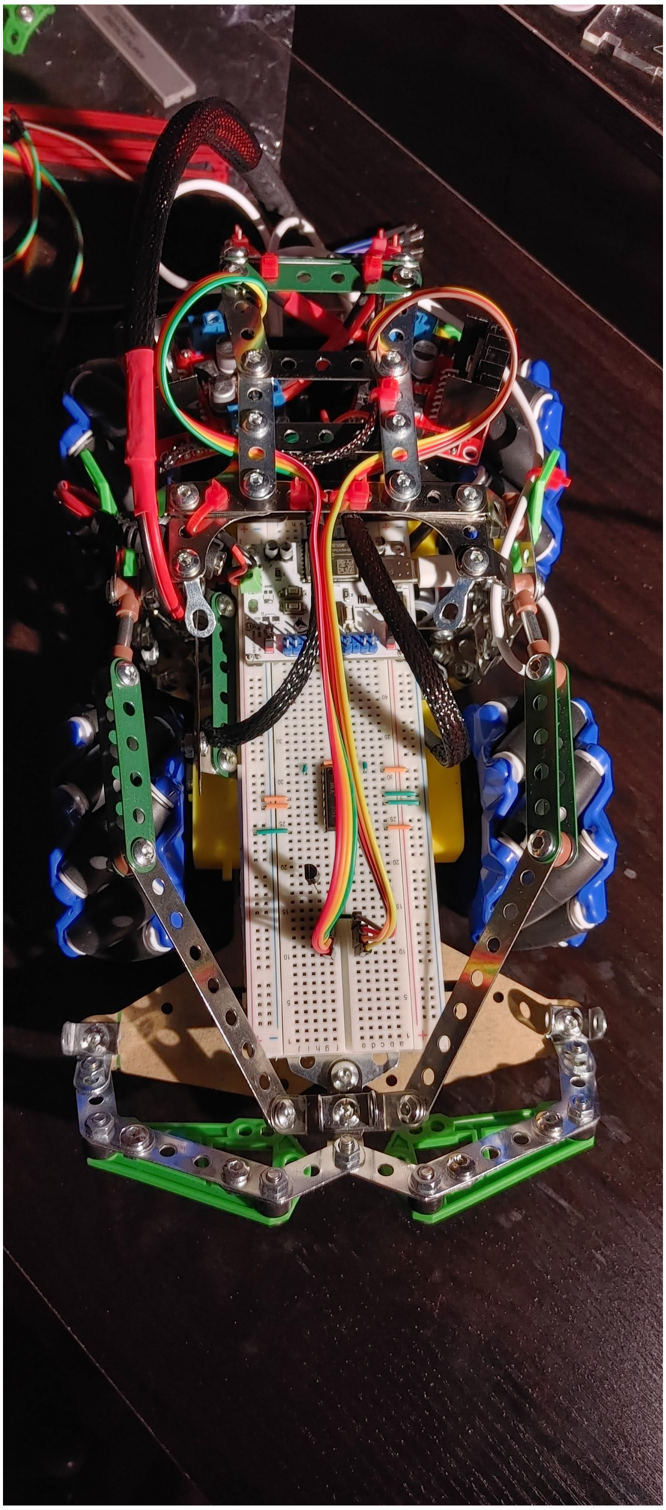


Chassis



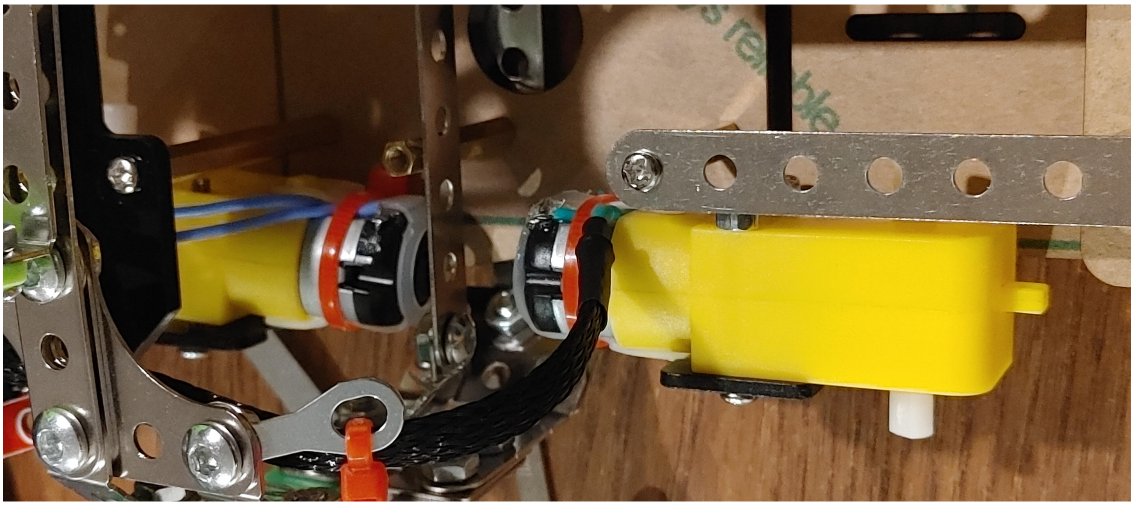
Completed chassis with only DC motor controllers installed.

Wiring



Completed wiring.

Motor Wires Harness



DC Motors wires secured inside harnes.

REFERENCES

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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