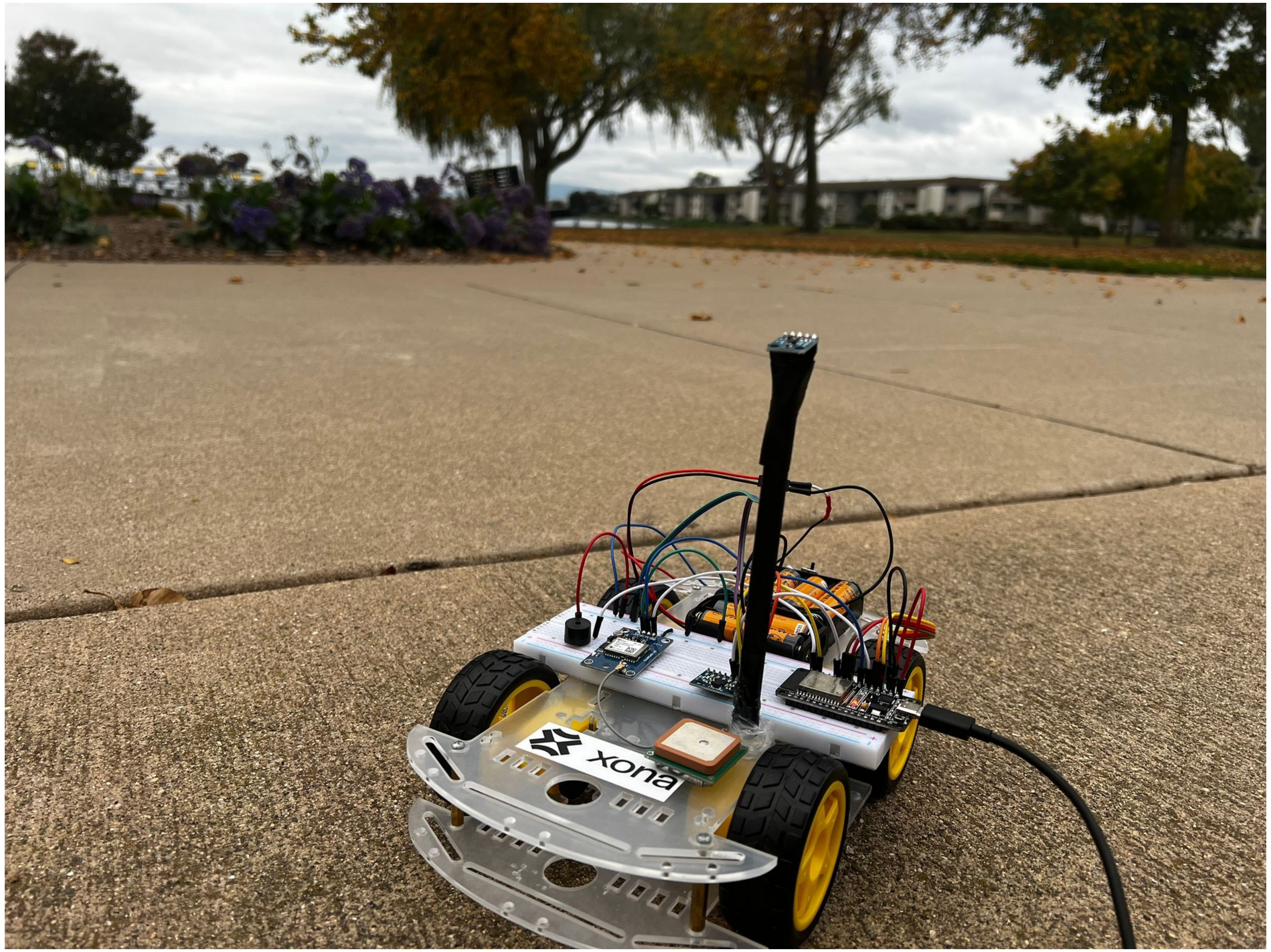


SCATCAR

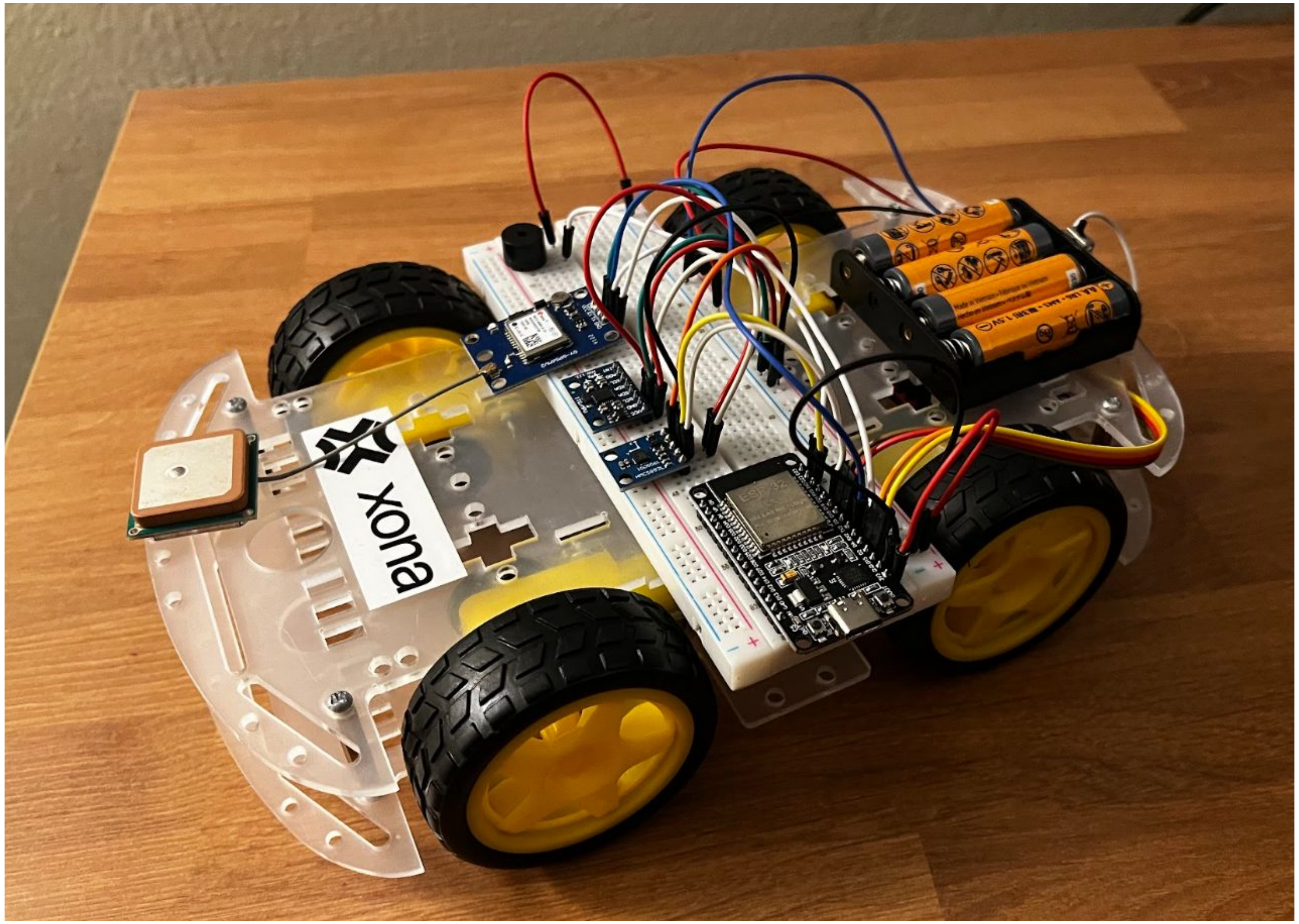
- A Personal Project -

Atahan Çaldır

Content

- Introduction
- Development environment
- Project details
  - Hardware
  - Software
- Challenges
- Outdoor test video
- Future improvements

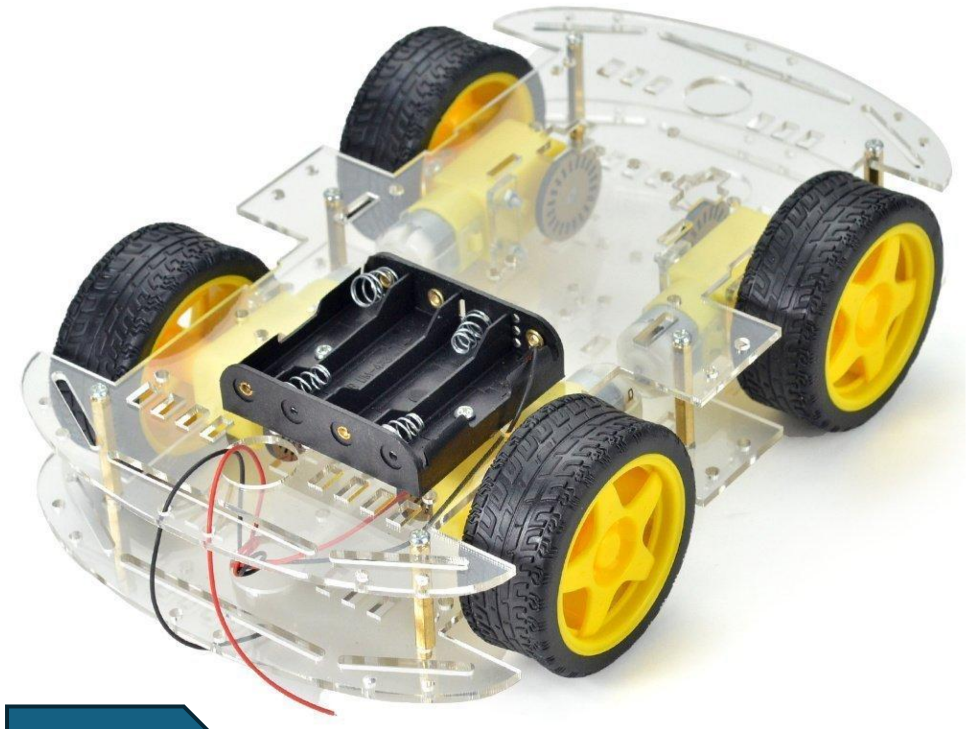
Introduction



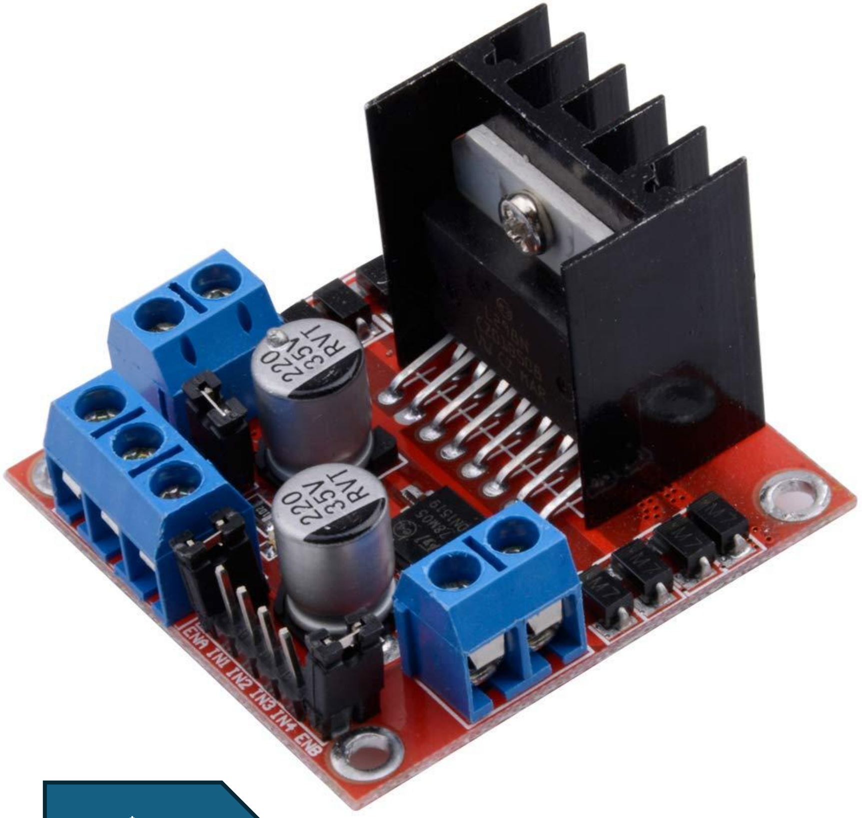
- GNSS guided robotic car
- Manual controls
- Web based interface
- Plays ScatMan
- $35-$40 production cost

Development Environment

Hardware – Chassis, motors and motor driver (L298N)



~ $20.00
Amazon

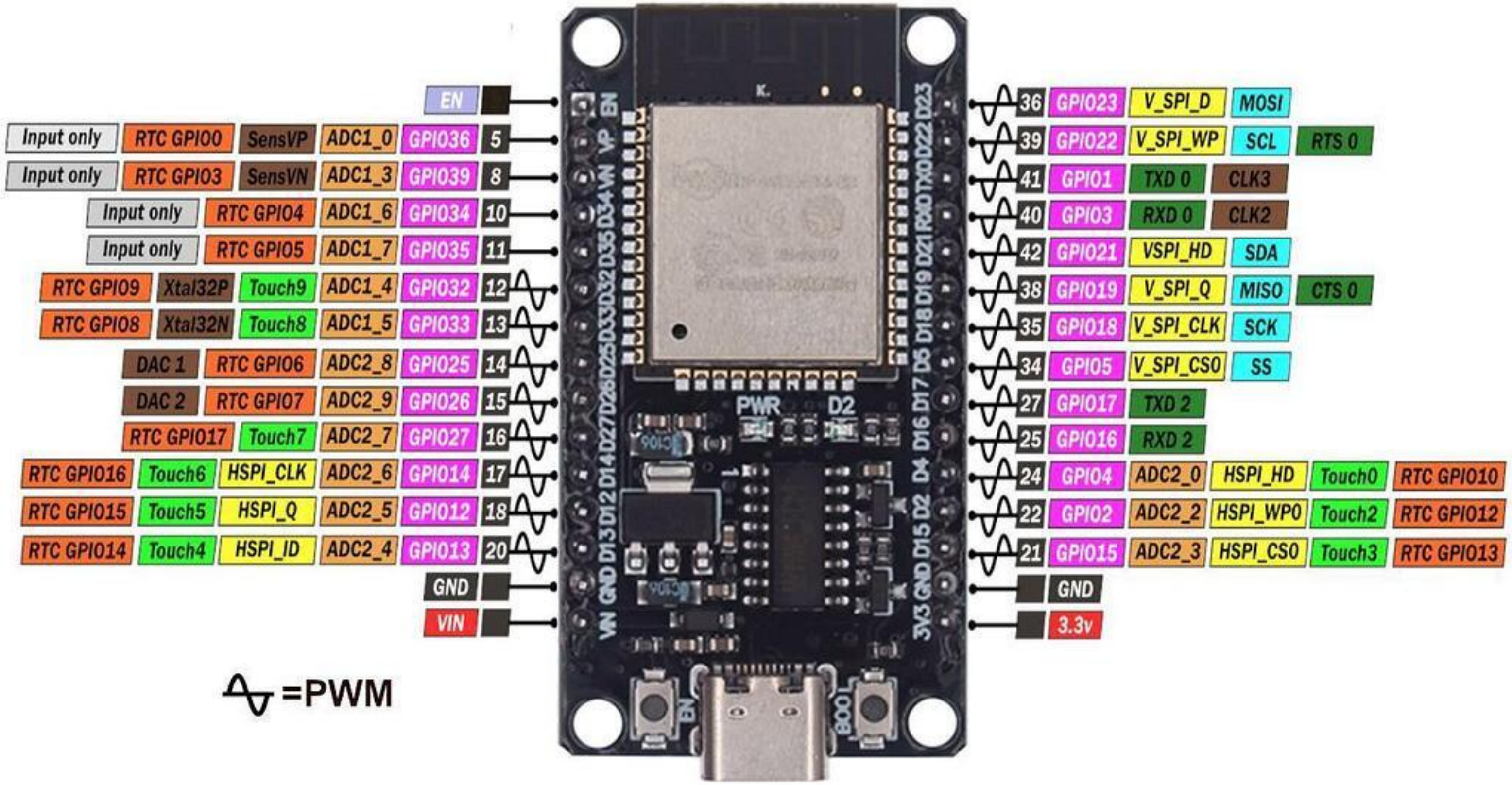


~ $2.50
AliExpress

- Four DC motors controlled by a single motor driver
  - Each side runs two motors

Hardware – Microcontroller (ESP32)

- Built-in Bluetooth and WiFi
- Dual-core



~ $3.00
AliExpress

🧠 Core and Processing

- **Dual-core** or **single-core** Tensilica Xtensa LX6 processor (up to **240 MHz**)
- **32-bit architecture**
- **Up to 600 DMIPS** performance
- Integrated **floating-point unit (FPU)** and **DSP instructions**

📶 Wireless Connectivity

- **Wi-Fi 802.11 b/g/n** (2.4 GHz)
- **Bluetooth v4.2 BR/EDR** and **Bluetooth Low Energy (BLE)**
- Supports **SoftAP**, **Station**, and **Promiscuous** modes

💾 Memory and Storage

- **520 KB SRAM** (on-chip)
- **448 KB ROM** (for bootloader, Wi-Fi, and BT stacks)
- External **SPI Flash** support (up to 16 MB typical)
- Optional **PSRAM** (up to 8 MB, depending on module)

⚡ Power Management

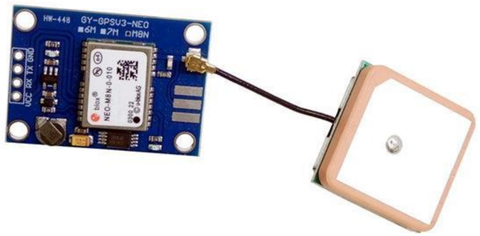
- **Wide supply voltage**: 2.3 V – 3.6 V
- **Ultra-low-power co-processor (ULP)** for deep sleep and sensor monitoring
- Multiple **sleep modes** (Active, Modem-sleep, Light-sleep, Deep-sleep)
- Typical **deep-sleep current <10 µA**

🔌 I/O and Peripherals

- Up to **34 GPIO pins** (depending on module)
- **ADC**: 12-bit, up to 18 channels
- **DAC**: 2 channels (8-bit)
- **Touch sensors**: up to 10 channels
- **Temperature sensor**
- **Hall-effect sensor**
- **SPI, I²C, I²S, UART, CAN, PWM, RMT, SD/MMC, Ethernet MAC**

Hardware – GNSS Receiver (Ublox NEO M8N)

~ $1.35
AliExpress



Parameter	Specification					
Receiver type	72-channel u-blox M8 engine GPS L1C/A, SBAS L1C/A, QZSS L1C/A, QZSS L1 SAIF, GLONASS L1OF, BeiDou B1I, Galileo E1B/C					
Accuracy of time pulse signal	RMS 99%	30 ns 60 ns				
Frequency of time pulse signal		0.25 Hz...10 MHz (configurable)				
Operational limits [1]	Dynamics	≤ 4 g				
	Altitude	50,000 m				
	Velocity	500 m/s				
Velocity accuracy [2]		0.05 m/s				
Heading accuracy [2]		0.3 degrees				
GNSS		**GPS & GLONASS**	**GPS**	**GLONASS**	**BeiDou**	**Galileo**
Horizontal position accuracy [3]		2.5 m	2.5 m	4 m	3 m	3 m
	With SBAS	2.0 m	2.0 m	-	-	-
NEO-M8N/Q						
Max navigation update rate	NEO-M8N	5 Hz	10 Hz	10 Hz	10 Hz	10 Hz
	NEO-M8Q	10 Hz	18 Hz	18 Hz	18 Hz	18 Hz
Time-To-First-Fix [4]	Cold start	26 s	29 s	30 s	34 s	45 s
	Hot start	1 s	1 s	1 s	1 s	1 s
	Aided starts [5]	2 s	2 s	2 s	3 s	7 s
Sensitivity[6]	Tracking & Navigation	–167 dBm	–166 dBm	-166 dBm	-160 dBm	-159 dBm
	Reacquisition	–160 dBm	–160 dBm	-156 dBm	-157 dBm	-153 dBm
	Cold start	–148 dBm	–148 dBm	-145 dBm	-143 dBm	-138 dBm
	Hot start	–157 dBm	–157 dBm	-156 dBm	-155 dBm	-151 dBm

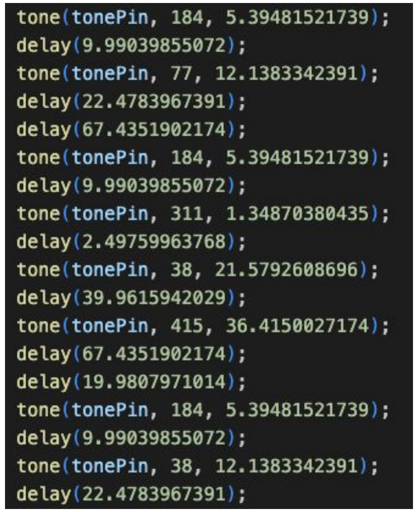
- Concurrent reception of up to 3 GNSS (GPS, Galileo, GLONASS, BeiDo). Constellations are configurable.
- Important features:
  - Geofencing
  - Spoofing detection: Checks inconsistencies and suspicious patterns on messages
  - Internal flash for firmware updates
  - AssistNow service: Online GNSS broadcast parameters (ephemeris, almanac plus time, rough position and time) to reduce first fix time, offline data (up to 35 days), autonomous data (up to 6 days)
  - Multiple power modes
  - **UART**, USB, SPI

Hardware – Passive buzzer

~ $0.000001?
AliExpress

- It is a **piezoelectric speaker**, it doesn’t have any internal oscillator or circuitry. It only produces sound when it is driven with an oscillating voltage (AC signal) at an audio frequency.
- tone(pin, frequency) function provides square wave at the specified **frequency**
  - Different then analogWrite(pin, value) as that produces PWM signal with a certain duty cycle
- Any music can be converted to a set of **tones** and **delays**, and be played by buzzer

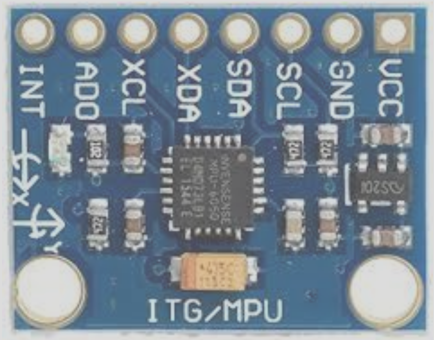
Mp3 to tone converter



```
tone(tonePin, 184, 5.39481521739);
delay(9.99039855072);
tone(tonePin, 77, 12.1383342391);
delay(22.4783967391);
delay(67.4351902174);
tone(tonePin, 184, 5.39481521739);
delay(9.99039855072);
tone(tonePin, 311, 1.34870380435);
delay(2.49759963768);
tone(tonePin, 38, 21.5792608696);
delay(39.9615942029);
tone(tonePin, 415, 36.4150027174);
delay(67.4351902174);
delay(19.9807971014);
tone(tonePin, 184, 5.39481521739);
delay(9.99039855072);
tone(tonePin, 38, 12.1383342391);
delay(22.4783967391);
```

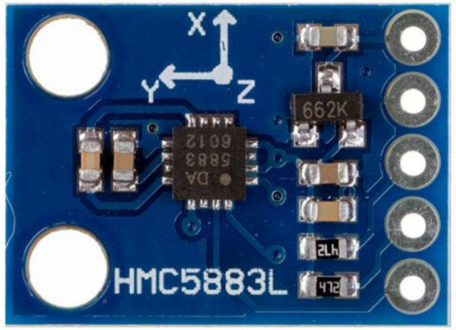
Hardware – IMU (MPU6050) & Magnetometer (HMC5883)

~ $5.00
AliExpress

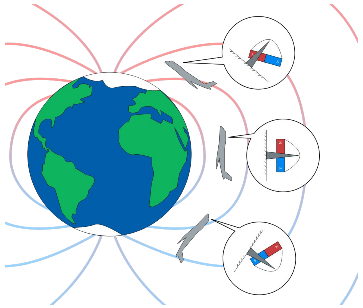


- IMU = Inertia measurement unit
- 3 axis gyroscope + accelerometer

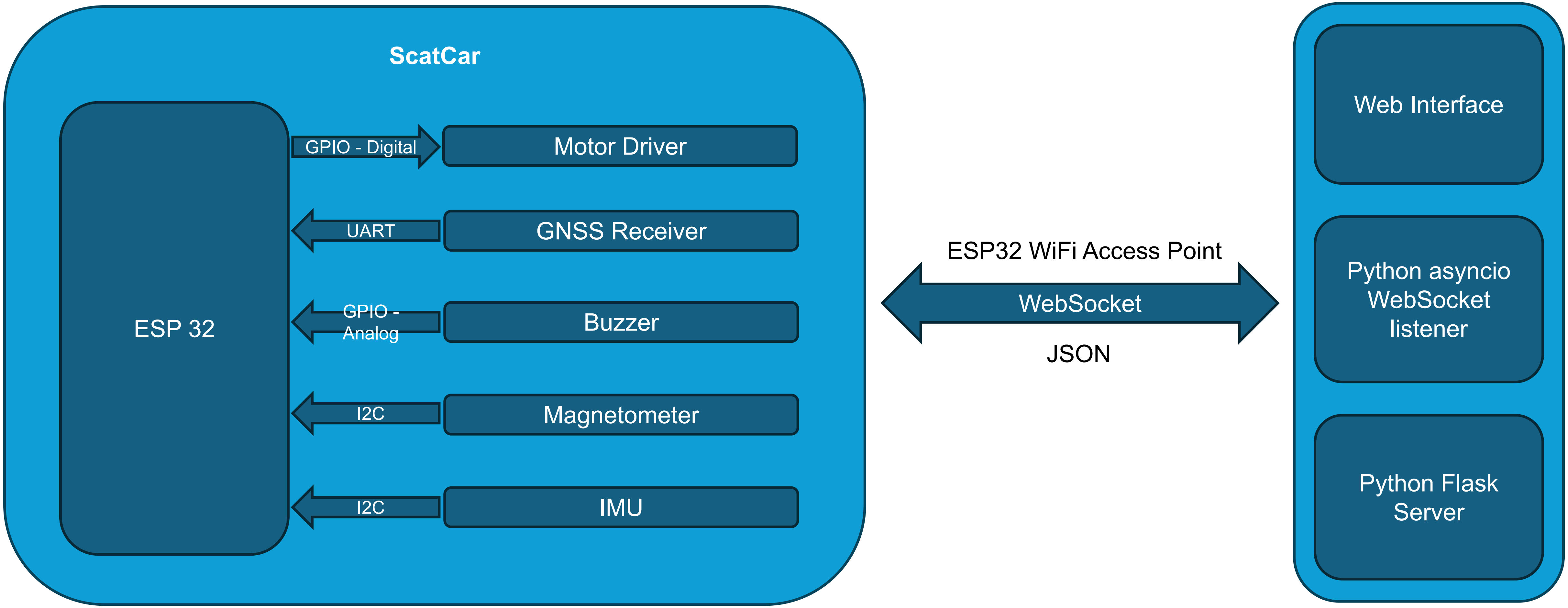
~ $2.00
AliExpress



- Magnetometer that works as compass to calculate the heading
- Calibration needed
  - X/Y/Z offsets and scales
  - Azimuth offset (Compared with iPhone compass)
  - **Magnetic inclination/dip** based on location: The angle between Earth's magnetic field lines and the horizontal plane



Software/Hardware Interface



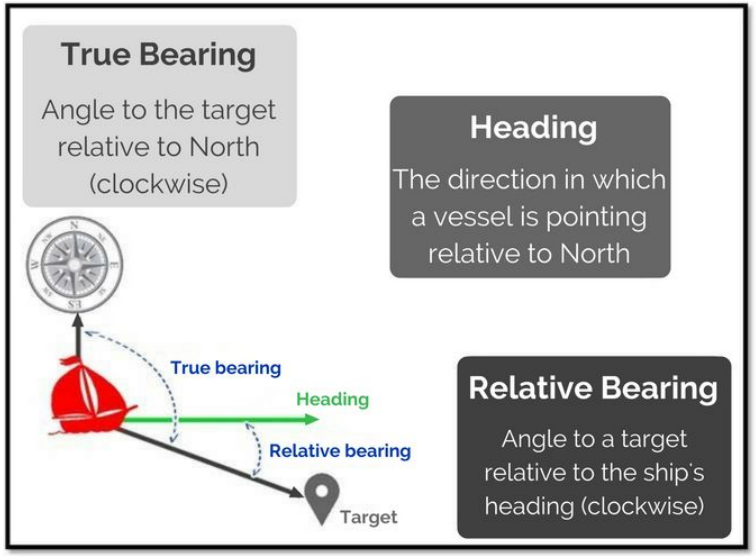
Software – Web Interface

Software – Python Server

- asyncio
  - Connection to ESP32 WiFi access point
  - Bidirectional communication with ESP32
- Flask REST API
  - Asyncio <-> web interface communication
  - User’s interaction with the web interface triggers an HTTP request to Flask server, which sends a relevant command to ESP32 through async function
  - Incoming telemetry data is handled by async function, and collected by web interface through Flask server

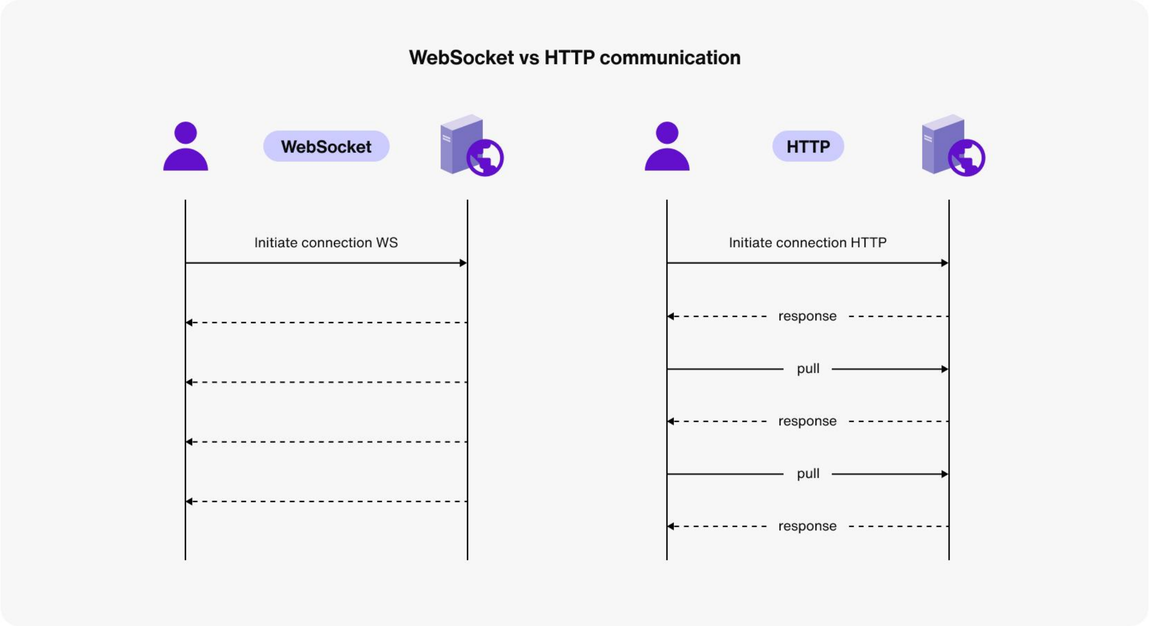
Software – Navigation

- Assuming a perfect world without any obstacles 🤗
- TinyGPS+ library
  - NEO M8N output formatting
  - Bearing calculation
  - Distance calculation
- Navigation algorithm
  - Loop - 5Hz
    1. Get distance between current and target locations
    2. If distance is less than threshold, **stop**
    3. Get relative bearing (angle) between current and target locations
    4. Check if the heading angle matches bearing
       1. If so, start going forward
       2. Otherwise, start rotating the car from heading direction to bearing direction



Software – WebSocket

- WebSocket is a computer communications protocol that provides a full-duplex, bidirectional communication channel over a single, persistent TCP connection
  - Establishment: A WebSocket connection is initiated through a standard HTTP request-response handshake. After the handshake is complete, the connection is "upgraded" to a persistent WebSocket connection.
  - Communication: Once the connection is established, it remains open, and both the client and server can send data to each other at any time without having to re-establish a new connection for each message.



Software FreeRTOS

Open-source real-time operating system for **running multiple tasks concurrently**, each with its own **priority** and **execution schedule**. For inter-task communication, **queues** and **semaphores** are provided.

- **Task:** Independent functions running concurrently, each with its **own stack and priority**.
- **Scheduler:** Preemptive scheduler to ensure tasks are executed on time regarding their priorities. Lower priority tasks might be blocked in favor of higher priority ones to accomplish real-time behavior.
- **Priorities:** Higer numbers indicate higher priority (e.g., 1 = low, 5 = high).

```
// Sensor reading task - High priority, runs on Core 0
void sensorTask(void *parameter)
{
  TickType_t xLastWakeTime = xTaskGetTickCount();
  const TickType_t xFrequency = pdMS_TO_TICKS(100); // 10Hz update rate

  for (;;)
  {
    // Read all sensors
    TinyGPSPlus localGnssData = gnss->getData();
    MagnetometerMeasurement localMagMeasurement = magnetometer->getMeasurement();
    MpuMeasurement localMpuMeasurement = imu->getMeasurement();

    // Update shared data with mutex protection
    if (xSemaphoreTake(sensorDataMutex, portMAX_DELAY) == pdTRUE)
    {
      sharedSensorData.gnssData = localGnssData;
      sharedSensorData.magMeasurement = localMagMeasurement;
      sharedSensorData.mpuMeasurement = localMpuMeasurement;
      sharedSensorData.lastUpdate = millis();
      xSemaphoreGive(sensorDataMutex);
    }

    vTaskDelayUntil(&xLastWakeTime, xFrequency);
  }
}
```

```
xTaskCreatePinnedToCore(
    sensorTask,          // Task function
    "SensorTask",        // Task name
    8192,                // Stack size (bytes)
    NULL,                // Parameter
    3,                   // Priority (high)
    &sensorTaskHandle,   // Task handle
    0                    // Core 0
);
```

Software freeRTOS

Sensor data collector task

10 Hz

Priority: 3

Core: 0

Navigation task

5 Hz

Priority: 2

Core: 0

Command processing task

100 Hz

Priority: 2

Core: 1

Telemetry broadcast task

2 Hz

Priority: 1

Core: 1

- WebSocket event handler passes incoming messages/commands to **queue**, which is polled by "**command processing task**" regularly.

Challenges

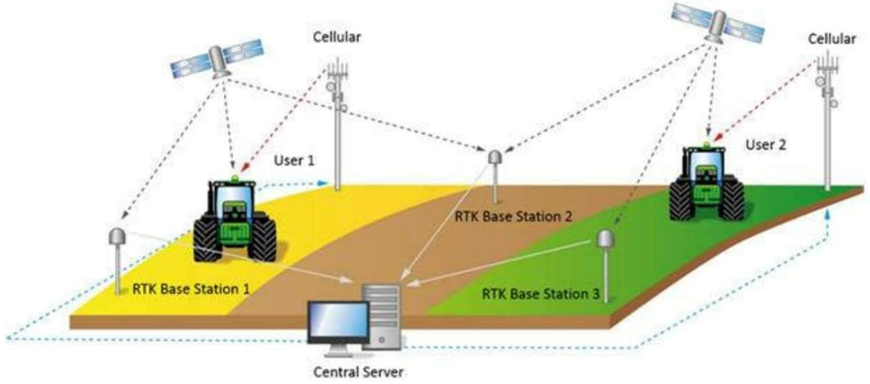
- Burned two ESP-32 due to short circuits caused by bad soldering
- Electromagnetic interference (EMI) issue of magnetometer
  - Needs to be isolated from other electronic components
- GNSS receiver might take a while to initialize and optimize its location
- Power management
  - 6 AA batteries are not enough to handle WiFi access point

⚡ **Power Consumption Overview**

Mode / State	ESP32 (typical)
Active (CPU running, Wi-Fi off)	~80–150 mA
Wi-Fi transmitting	180–260 mA
Modem-sleep (Wi-Fi connected, idle)	3–20 mA
Light-sleep	0.8–2 mA
Deep-sleep	5–10 µA

Outdoor Tests

Future Improvements



- Increasing accuracy
  - AssistNow service for GNSS receiver
  - Encoders
  - RTK station
  - IMU integration + Kalman filter
    - Kalman filter is a **dynamic estimator**. It’s an algorithm that updates its estimates of a system’s state as new (possibly noisy) measurements come in. It can be used for noise reduction and sensor fusion in real-time systems.
- Custom PCB Design: Using breadboards reduces power and sensor reading stability dramatically compared to soldered PCBs.
- Path planning and collision avoidance
- LiPo battery
- Long distance control