

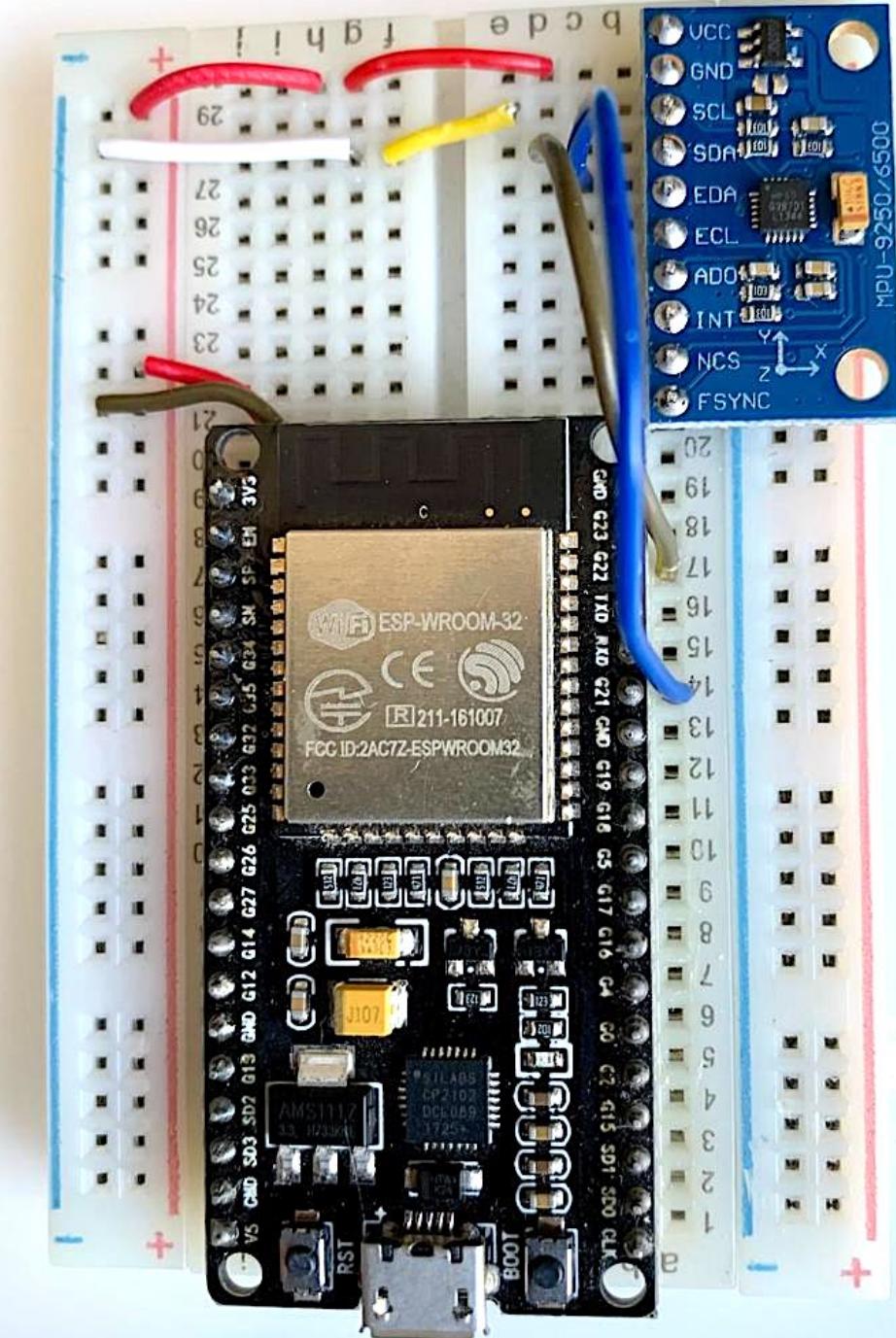
IESTI01 – TinyML

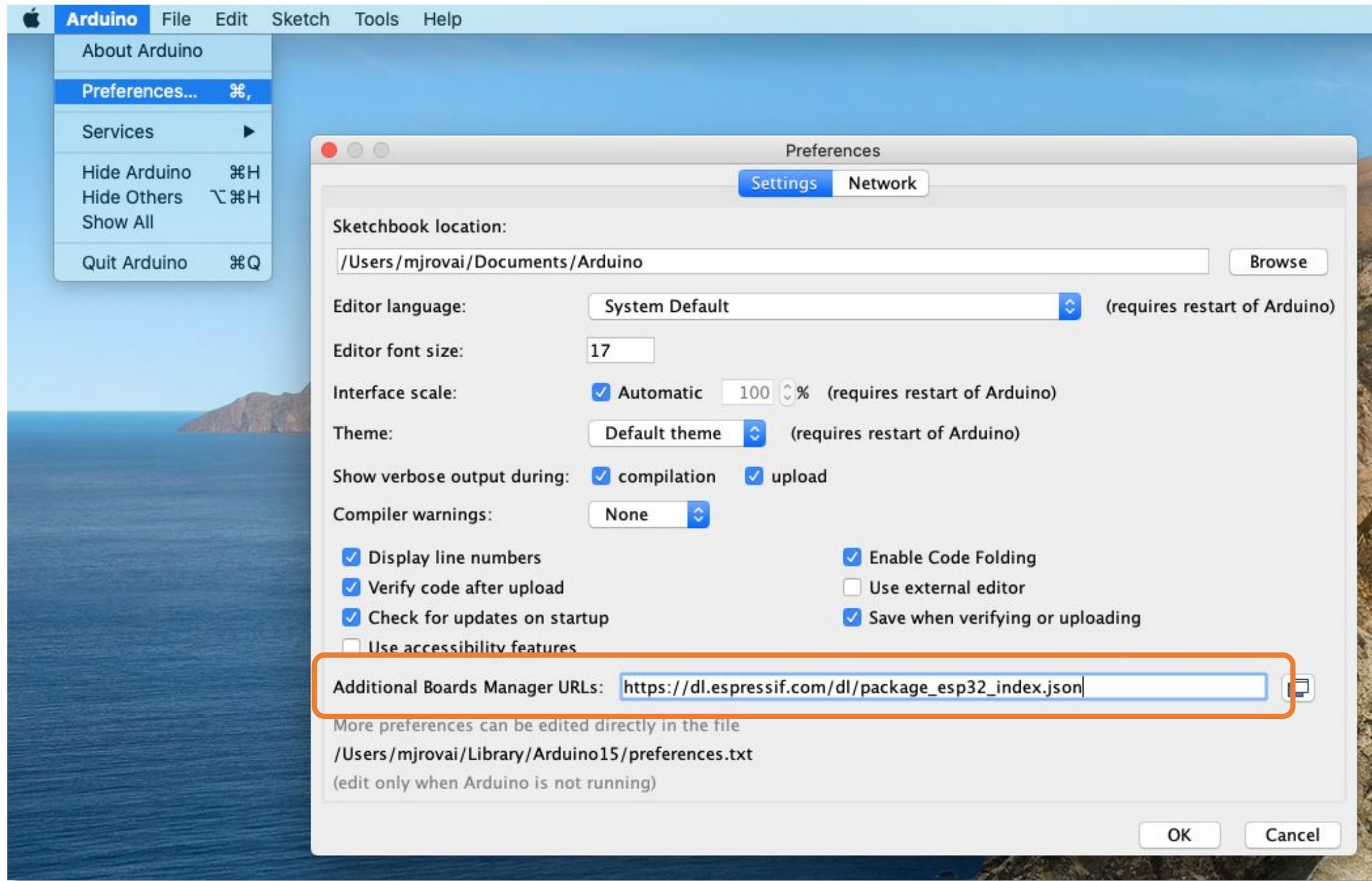
Embedded Machine Learning

20a. Motion Classification - ESP32

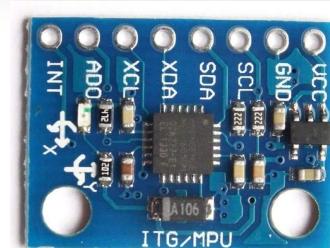
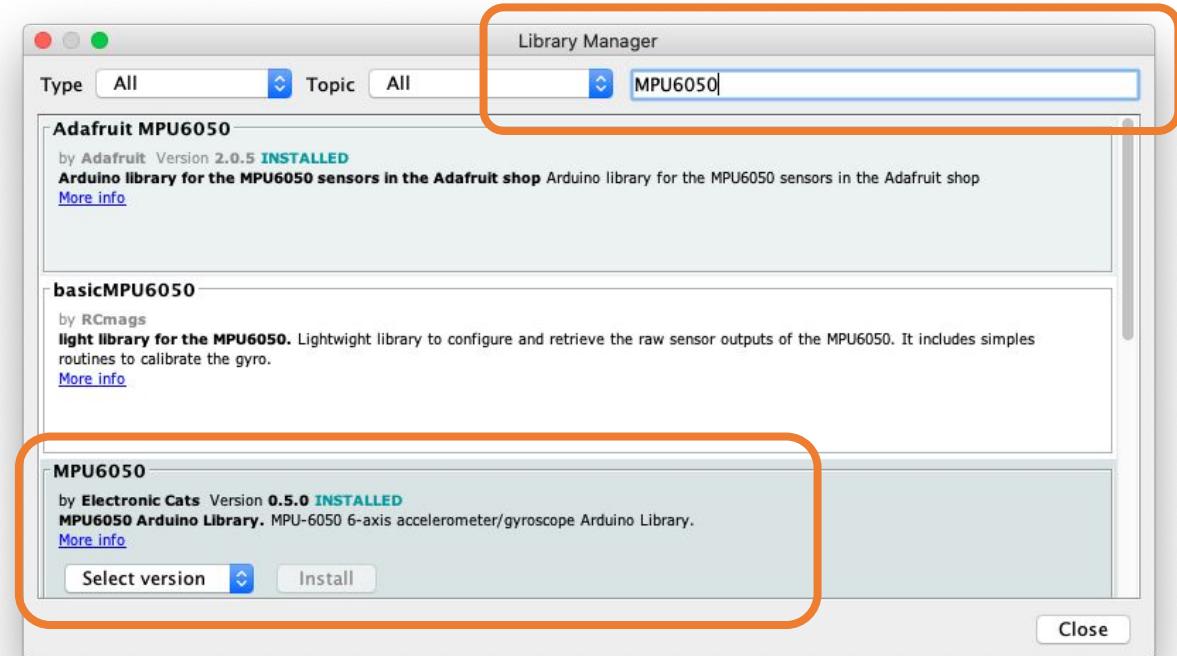
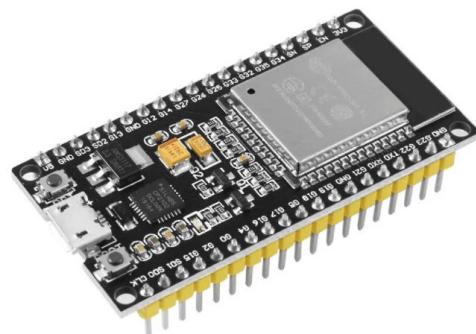
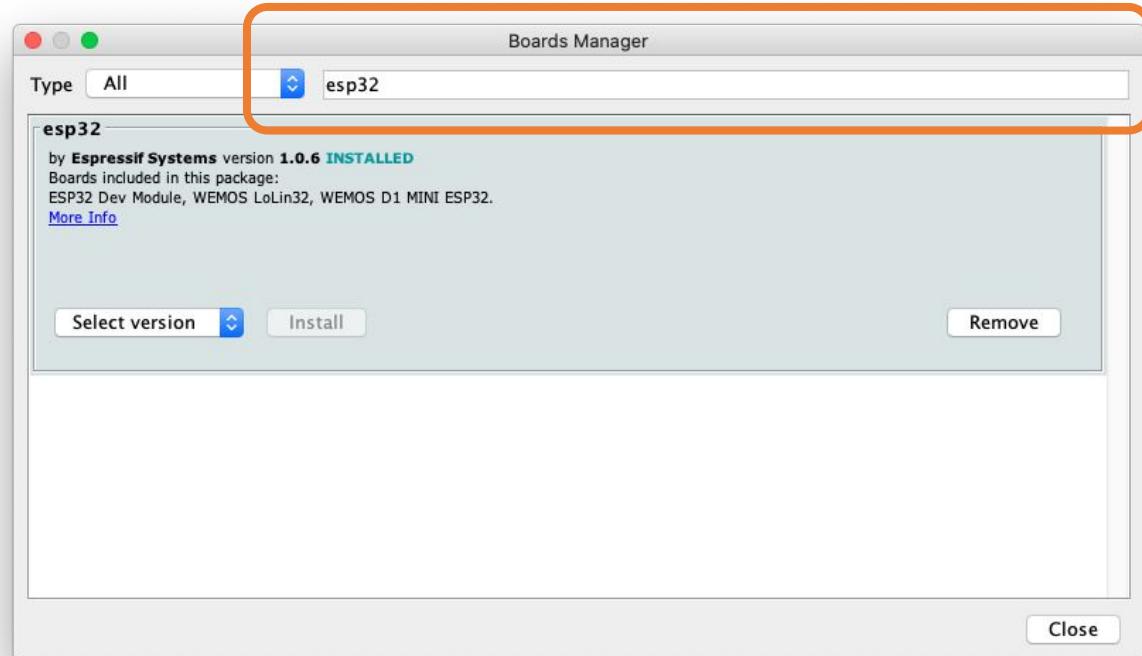


Prof. Marcelo Rovai
UNIFEI



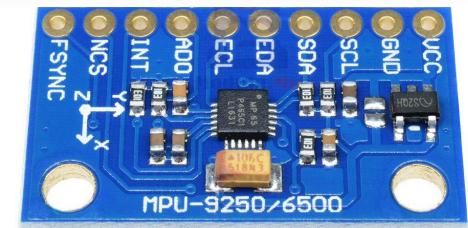


Install HW Libraries

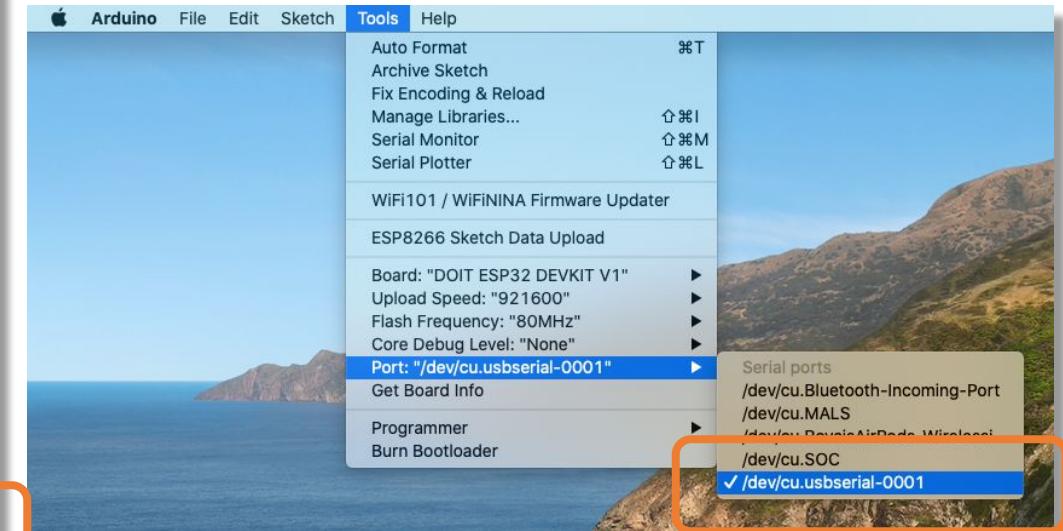
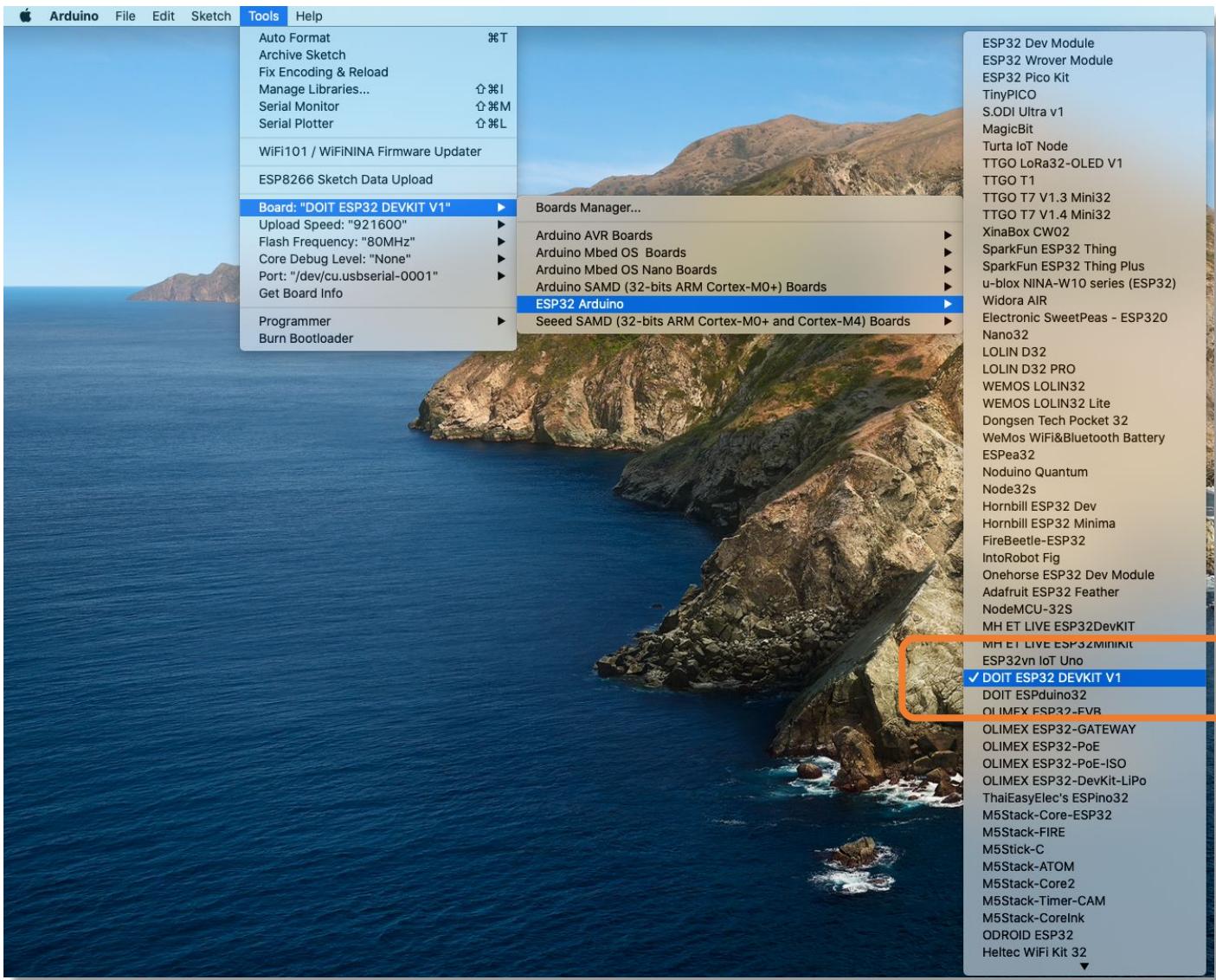


MPU6050

I2C - Accelerometer & Gyroscope - I2C/SPI



MPU6500



Select Board and Port

GetChipID | Arduino 1.8.16

```
/* The true ESP32 chip ID is essentially its MAC address.
2 This sketch provides an alternate chip ID that matches
3 the output of the ESP.getChipId() function on ESP8266
4 (i.e. a 32-bit integer matching the last 3 bytes of
5 the MAC address. This is less unique than the
6 MAC address chip ID, but is helpful when you need
7 an identifier that can be no more than a 32-bit integer
8 (like for switch...case).
9
10 created 2020-06-07 by cweinhofer
11 with help from Cicicok */
12
13 uint32_t chipId = 0;
14
15 void setup() {
16   Serial.begin(115200);
17 }
18
19 void loop() {
20   for(int i=0; i<17; i=i+8) {
21     chipId |= ((ESP.getEfuseMac() >> (40 - i)) & 0xff) << i;
22   }
23
24   Serial.printf("ESP32 Chip model = %s Rev %d\n", ESP.getChipModel(), ESP.getChipRev());
25   Serial.printf("This chip has %d cores\n", ESP.getChipCores());
26   Serial.print("Chip ID: "); Serial.println(chipId);
27
28   delay(3000);
29 }
30 }
```

Done uploading.

Compressed 3072 bytes to 128...
Writing at 0x00008000... (100 %)
Wrote 3072 bytes (128 compressed) at 0x00008000 in 0.0 seconds (effective 2623.9 kbi
Hash of data verified.

Leaving...
Hard resetting via RTS pin...

25 DOIT ESP32 DEVKIT V1, 80MHz, 921600, None on /dev/cu.usbserial-0001

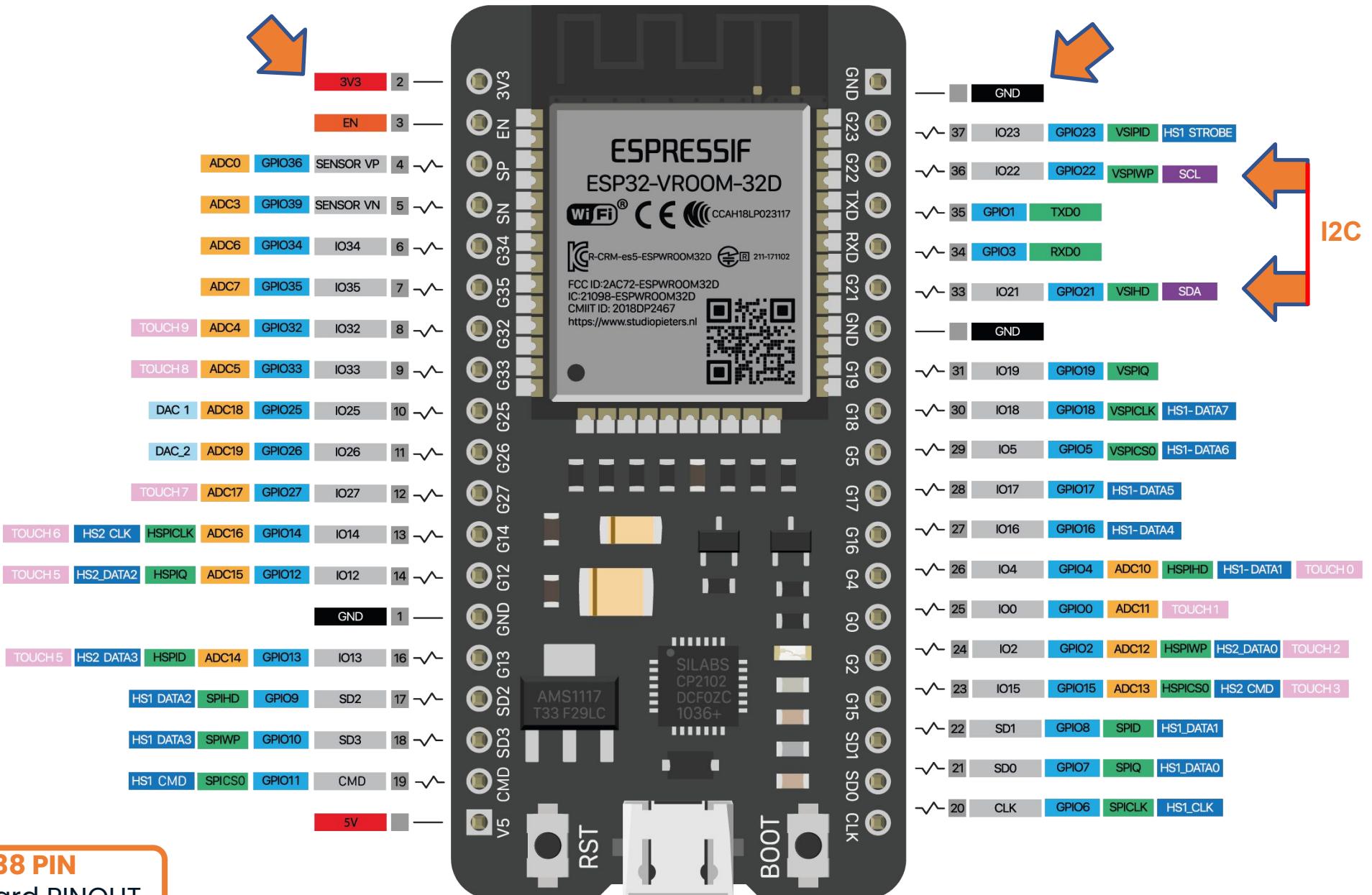
Test ESP32 Installation

/dev/cu.usbserial-0001

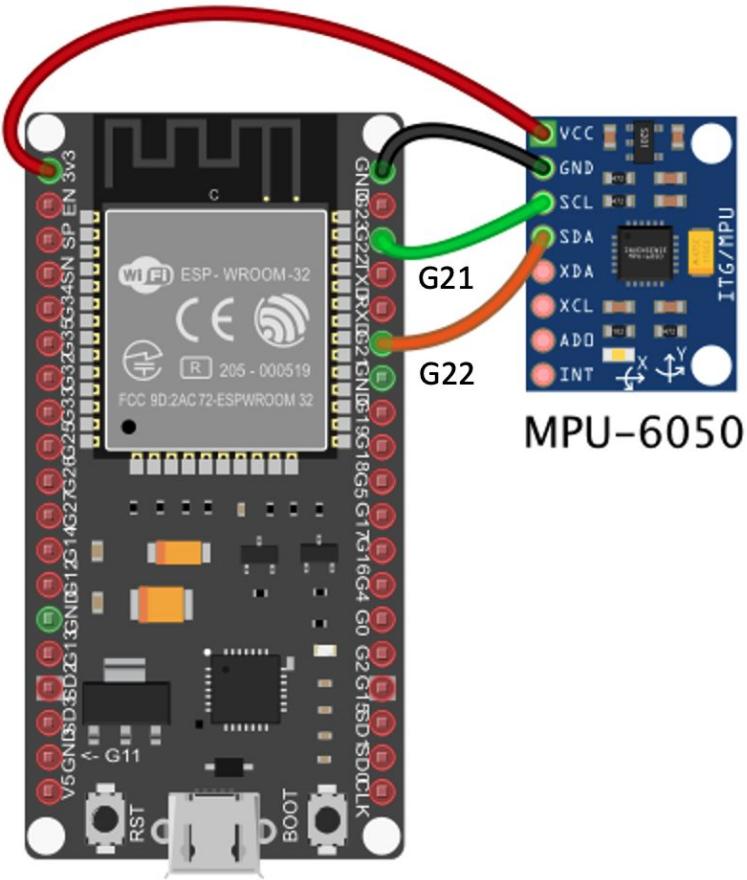
```
ESP32 Chip model = ESP32-D0WDQ6 Rev 1
This chip has 2 cores
Chip ID: 4487988
ESP32 Chip model = ESP32-D0WDQ6 Rev 1
This chip has 2 cores
Chip ID: 4487988
ESP32 Chip model = ESP32-D0WDQ6 Rev 1
This chip has 2 cores
Chip ID: 4487988
ESP32 Chip model = ESP32-D0WDQ6 Rev 1
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Chip ID: 4487988
ESP32 Chip model = ESP32-D0WDQ6 Rev 1
This chip has 2 cores
Chip ID: 4487988
ESP32 Chip model = ESP32-D0WDQ6 Rev 1
This chip has 2 cores
Chip ID: 4487988
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

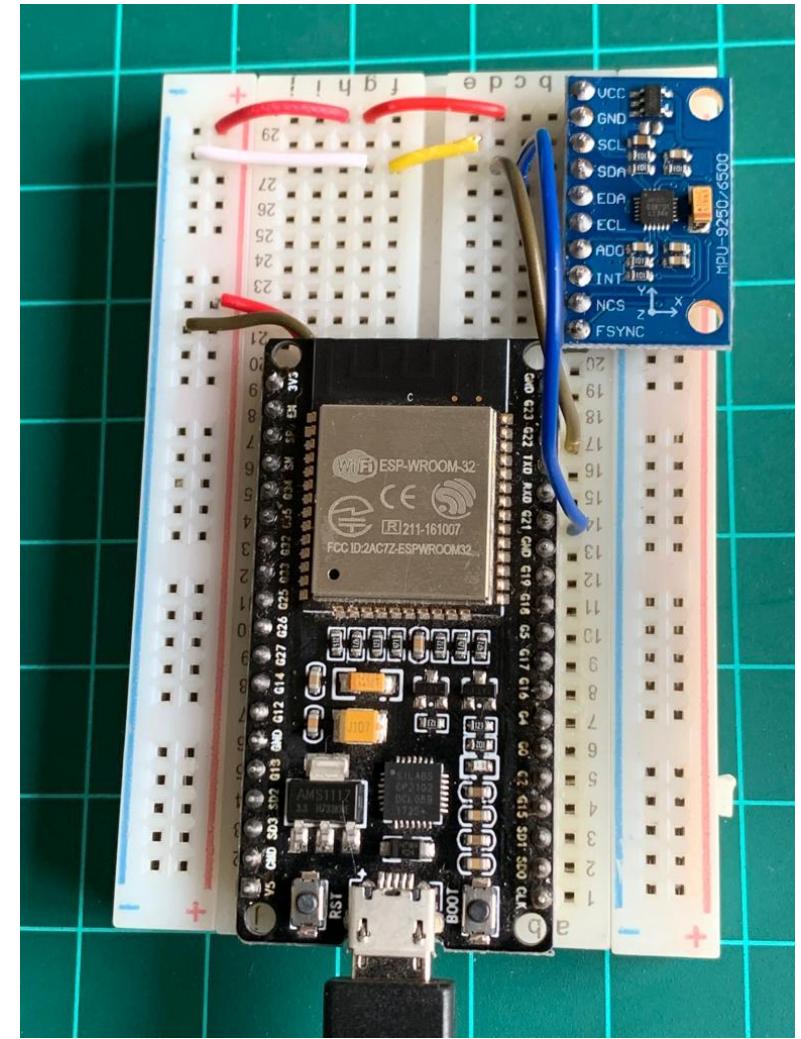
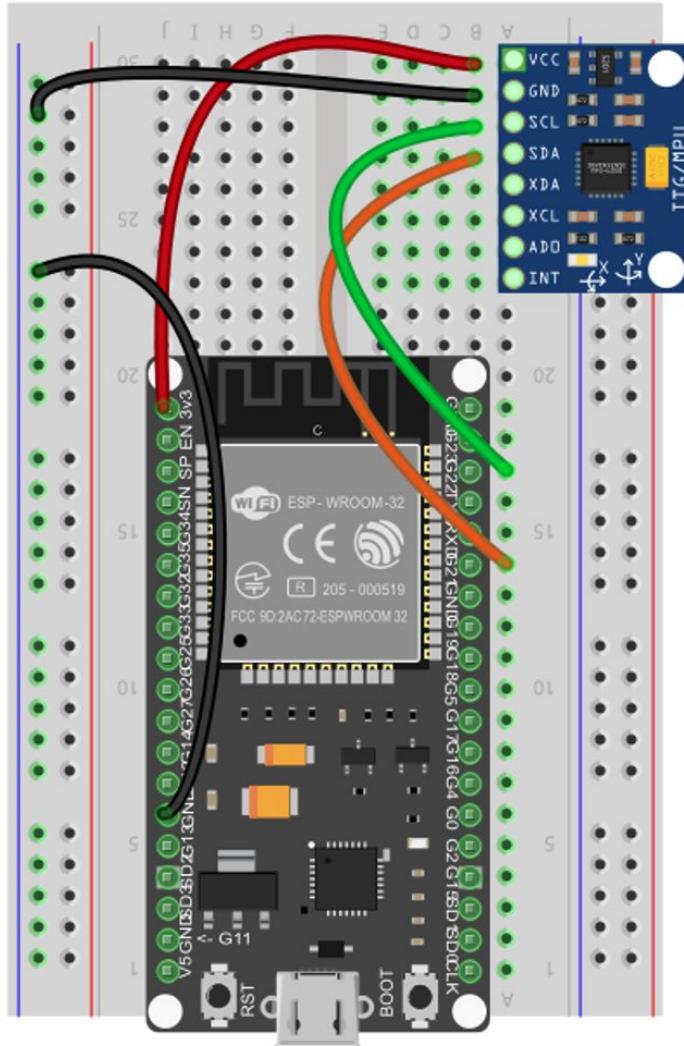
PWM
 PIN NUMBER
 NAME
 GROUND
 POWER
 CONTROL
 I/O
 ADC
 COMM. INTERFACE
 DAC
 I2C
 HS
 TOUCH



Connect HW



ESP32-38PinWide



MPU6050_Acc_Data_Acquisition | Arduino 1.8.16

```

MPU6050_Acc_Data_Acquisition

/*
 * Based on I2C device class (I2Cdev) Arduino sketch for MPU6050 class by Jeff Rowberg <jeff@rowberg.net>
 * and Edge Impulse Data Forwarder Example (Arduino) - https://docs.edgeimpulse.com/docs/cli-data-forwarder
 *
 * Developed by M.Rovai for IESTI01 TinyML Course
 */

#include "I2Cdev.h"
#include "MPU6050.h"
#include "Wire.h"

#define FREQUENCY_HZ 50
#define INTERVAL_MS (1000 / (FREQUENCY_HZ + 1))
static unsigned long last_interval_ms = 0;

#define OUTPUT_READABLE_ACCELGYRO
MPU6050 accelgyro;
int16_t ax, ay, az;

void setup() {
    Wire.begin();
    Serial.begin(115200);

    // initialize device
    Serial.println("Initializing I2C devices...");
    accelgyro.initialize();

    // verify connection
    Serial.println("Testing device connections...");
    Serial.println(accelgyro.testConnection() ? "MPU6050 connection successful" : "MPU6050 connection failed");
}

void loop() {
    if (millis() > last_interval_ms + INTERVAL_MS) {
        last_interval_ms = millis();

        // read raw accel/gyro measurements from device
        accelgyro.getAcceleration(&ax, &ay, &az);

        Serial.print(ax); Serial.print("\t");
        Serial.print(ay); Serial.print("\t");
        Serial.println(az);
    }
}

Done Saving.

Leaving...
Hard resetting via RTS pin...

```

18

DOIT ESP32 DEVKIT V1, 80MHz, 921600, None on /dev/cu.usbserial-0001

Test Sensor

/dev/cu.usbserial-0001

-1240	444	17136	
-1276	428	17180	
-1296	412	17212	
-1296	432	17164	
-1272	472	17180	
-1284	432	17188	
-1312	436	17260	
-1280	504	17160	
-1288	484	17224	
-1192	468	17276	
-1316	428	17224	
-1252	460	17108	
-1248	440	17200	
-1388	420	17308	
-1156	448	17184	
-1328	400	17236	

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output



Dashboard - ESP32-Motion-CI

studio.edgeimpulse.com/studio/54781

EDGE IMPULSE

Project info Keys Export

MJRoBot (Marcelo Rovai)

MJRoBot (Marcelo Rovai) / ESP32-Motion-Classification

This is your Edge Impulse project. From here you acquire new training data, design impulses and train models.

Creating your first impulse (100% complete)

Acquire data
Every Machine Learning project starts with data. You can capture data from a development board or your phone, or import data you already collected.
[LET'S COLLECT SOME DATA](#)

Design an impulse
Teach the model to interpret previously unseen data, based on historical data. Use this to categorize new data, or to find anomalies in sensor readings.
[GETTING STARTED: CONTINUOUS MOTION RECOGNITION](#)
[GETTING STARTED: RESPONDING TO YOUR VOICE](#)
[GETTING STARTED: ADDING SIGHT TO YOUR SENSORS](#)

Deploy
Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.
[DEPLOY YOUR MODEL](#)

Download block output

TITLE	TYPE	SIZE
Spectral features training data	NPY file	2414 windows

Sharing
Your project is private.
[Make this project public](#)

Summary

DEVICES CONNECTED
1

DATA COLLECTED
5m 59s

Collaborators

MJRoBot (Marcelo Rovai) OWNER

Project info

Project ID
54781

Labeling method
One label per data item

Latency calculations
Cortex-M4F 80MHz

Connect ESP32 to EDGE IMPULSE CLI (Via USB)

The screenshot shows a terminal window titled "mjrovai — node /usr/local/bin/edge-impulse-data-forwarder — 139x34". The window displays the "edge-impulse-data-forwarder" command being run, which is version v1.13.16. It lists endpoints for Websocket (wss://remote-mgmt.edgeimpulse.com), API (https://studio.edgeimpulse.com/v1), and Ingestion (https://ingestion.edgeimpulse.com). The process then connects to a serial port (/dev/tty.usbserial-0001) and establishes a websocket connection to the management server. The user is prompted to select a project for the device. The selected project is "MJRoBot (Marcelo Rovai) / ESP32-Motion-Classification". The user also specifies three sensor axes: accX, accY, and accZ. Finally, the device is named "ESP32", and it is connected to the project. A message encourages the user to go to the Edge Impulse studio to build a machine learning model.

```
mjrovai — node /usr/local/bin/edge-impulse-data-forwarder — 139x34
(base) MacBook-Pro-de-Marcelo:~ mjrovai$ edge-impulse-data-forwarder
Edge Impulse data forwarder v1.13.16
Endpoints:
  Websocket: wss://remote-mgmt.edgeimpulse.com
  API:      https://studio.edgeimpulse.com/v1
  Ingestion: https://ingestion.edgeimpulse.com

[SER] Connecting to /dev/tty.usbserial-0001
[SER] Serial is connected (00:01)
[WS ] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS ] Connected to wss://remote-mgmt.edgeimpulse.com

? To which project do you want to connect this device? MJRoBot (Marcelo Rovai) / ESP32-Motion-Classification
[SER] Detecting data frequency...
[SER] Detected data frequency: 51Hz
? 3 sensor axes detected (example values: [-1084, 436, 17144]). What do you want to call them? Separate the names with ',': accX, accY, accZ
? What name do you want to give this device? ESP32
[WS ] Device "ESP32" is now connected to project "ESP32-Motion-Classification"
[WS ] Go to https://studio.edgeimpulse.com/studio/54781/acquisition/training to build your machine learning model!
```

```
mjrovai — node /usr/local/bin/edge-impulse-data-forwarder — 139x34
[(base) MacBook-Pro-de-Marcelo:~ mjrovai$ edge-impulse-data-forwarder
Edge Impulse data forwarder v1.13.16
Endpoints:
  Websocket: wss://remote-mgmt.edgeimpulse.com
  API:      https://studio.edgeimpulse.com/v1
  Ingestion: https://ingestion.edgeimpulse.com

[SER] Connecting to /dev/tty.usbserial-0001
[SER] Serial is connected (00:01)
[WS ] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS ] Connected to wss://remote-mgmt.edgeimpulse.com

? To which project do you want to connect this device? MJRobot (Marcelo Rovai) / ESP32-Motion-Classification
[SER] Detecting data frequency...
[SER] Detected data frequency: 51Hz
? 3 sensor axes detected (example values: [-1084,436,17144]). What do you want to call them? Separate the names with ',': accX, accY, accZ
? What name do you want to give this device? ESP32
[WS ] Device "ESP32" is now connected to project "ESP32-Motion-Classification"
[WS ] Go to https://studio.edgeimpulse.com/studio/54781/acquisition/training to build your machine learning model!
[WS ] Incoming sampling request {
  path: '/api/testing/data',
  label: 'idle',
  length: 10000,
  interval: 19.607843137254903,
  hmacKey: 'a81704600713d60c2f2ab34721143d08',
  sensor: 'Sensor with 3 axes (accX, accY, accZ)'
}
[SER] Waiting 2 seconds...
[SER] Reading data from device...
[SER] Reading data from device OK (504 samples at 51Hz)
[SER] Uploading sample to https://ingestion.edgeimpulse.com/api/testing/data...
[SER] Sampling finished
```

Devices - ESP32-Motion-Class X +

studio.edgeimpulse.com/studio/54781/devices

EDGE IMPULSE MJRoBot (Marcelo Rovai)

Deleted device (" ESP32 ")

Your devices

+ Connect a new device

These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.

NAME	ID	TYPE	SENSORS	REMO...	LAST SEEN
00:01	00:01	DATA_FORWARDER	Sensor with 3 axes (accX, a...	●	Today, 16:30:34

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Dashboard Devices Data acquisition Impulse design Create impulse Spectral features NN Classifier EON Tuner Retrain model Live classification Model testing Versioning Deployment

GETTING STARTED Documentation Forums

The screenshot shows the Edge Impulse studio interface. On the left is a sidebar with various project management and documentation links. The main area is titled 'DEVICES (ESP32-MOTION-CLASSIFICATION)' and displays a green banner indicating a 'Deleted device (" ESP32 ")'. Below this is a section titled 'Your devices' with a table listing a single device: '00:01' (ID: 00:01), which is a 'DATA_FORWARDER' type sensor with 3 axes. This row is highlighted with an orange rectangle. A message at the bottom states 'These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.' The footer includes a copyright notice for Edgimpulse Inc. and links for documentation and forums.

CREATE IMPULSE (ESP32-MOTION-CLASSIFICATION)

An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

Time series data

Axes: accX, accY, accZ

Window size: 2000 ms.

Window increase: 80 ms.

Frequency (Hz): 50

Zero-pad data:

Spectral Analysis

Name: Spectral features

Classification (Keras)

Name: NN Classifier

Input axes: accX, accY, accZ

Input features: Spectral features

Output features: 4 (idle, lift, maritime, terrestrial)

Output features

4 (idle, lift, maritime, terrestrial)

Save Impulse

Add a processing block

Add a learning block

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Spectral features - ESP32-Motion-classification

studio.edgeimpulse.com/studio/54781/dsp/spectral-analysis/3/generate-features

EDGE IMPULSE

SPECTRAL FEATURES (ESP32-MOTION-CLASSIFICATION)

#1 ▾ Click to set a description for this version

Parameters **Generate features**

Training set

- Data in training set 3m 59s
- Classes 4 (idle, lift, maritime, terrestrial)
- Window length 2000 ms.
- Window increase 80 ms.
- Training windows 2,414

Feature explorer (2,414 samples)

X Axis accX RMS Y Axis accY RMS Z Axis accZ RMS

Legend:

- idle (blue)
- lift (orange)
- maritime (green)
- terrestrial (red)

Feature generation output

```

Scheduling job in cluster...
Job started
Creating windows from 24 files...
[ 0/24] Creating windows from files...
[ 1/24] Creating windows from files...
[24/24] Creating windows from files...
Created 2414 windows: idle: 596, lift: 606, maritime: 606, terrestrial : 606

Creating features
[ 1/2414] Creating features...
[1046/2414] Creating features...
[2076/2414] Creating features...
[2414/2414] Creating features...
Created features

Job completed
  
```

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NN CLASSIFIER (ESP32-MOTION-CLASSIFICATION)
#1 ▾ Click to set a description for this version

Neural Network settings

Training settings

Number of training cycles ② 30

Learning rate ② 0.0005

Neural network architecture

```

graph TD
    Input[Input layer (33 features)] --- Dense1[Dense layer (20 neurons)]
    Dense1 --- Dense2[Dense layer (10 neurons)]
    Dense2 --- Output[Output layer (4 features)]
    
```

Add an extra layer

Start training

Model

Last training performance (validation set)

ACCURACY
96.9%LOSS
0.95

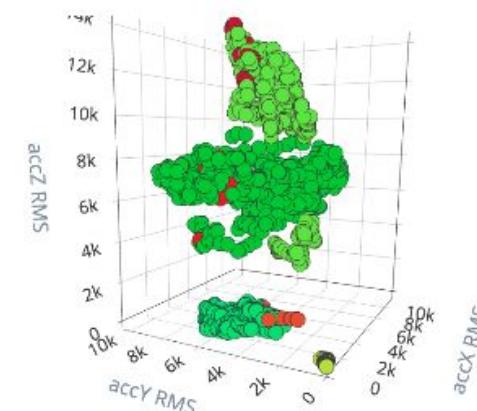
Confusion matrix (validation set)

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	3.3%	96.7%	0%	0%
MARITIME	1.7%	2.6%	95.7%	0%
TERRESTRIAL	0.8%	4.1%	0%	95.0%
F1 SCORE	0.97	0.95	0.98	0.97

Feature explorer (full training set) ②

accX RMS ▾ accY RMS ▾ accZ RMS ▾

- idle - correct
- lift - correct
- maritime - correct
- terrestrial - correct
- lift - incorrect
- maritime - incorrect
- terrestrial - incorrect



On-device performance ②

INFERENCING TIME
1 ms.PEAK RAM USAGE
1.7KFLASH USAGE
19.0K

Model testing - ESP32-Motion X + studio.edgeimpulse.com/studio/54781/validation

Test data

Set the 'expected outcome' for each sample to the desired outcome to automatically score the impulse.

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
idle.json.2jb4ipqd	idle	10s	89%	90 idle, 6 lift, 4 uncertain, 1 maritime
testing.json.2jb2djgq	maritime	10s	98%	99 maritime, 2 idle
testing.json.2jb2cdi2	terrestrial	10s		101 terrestrial
testing.json.2jb29lqg	lift	10s	70%	71 lift, 30 maritime
idle.json.2jb1mdjv	idle	10s	18%	76 maritime, 19 idle, 4 lift, 2 uncertain
idle.json.2jb1j3th	idle	10s	100%	101 idle
lift.json.2jb1hmvt	lift	10s	85%	86 lift, 15 maritime
terrestrial.json.2jb1gu...	terrestrial	10s		101 terrestrial
maritime.json.2jb1e80t	maritime	10s	100%	101 maritime
maritime.json.2jb1c79k	maritime	10s	100%	101 maritime
terrestrial.json.2jb18...	terrestrial	10s		101 terrestrial
lift.json.2jb130ml	lift	10s	94%	95 lift, 6 maritime

Model testing output

Classifying data for NN Classifier...
 Copying features from processing blocks...
 Copying features from DSP block...
 Copying features from DSP block OK
 Copying features from processing blocks OK

Classifying data for float32 model...
 Scheduling job in cluster...
 Job started
 Classifying data for NN Classifier OK

Job completed

Model testing results

ACCURACY 83.94%

	IDLE	LIFT	MARITIME	TERRESTRIAL	UNCERTAIN
IDLE	69.3%	3.3%	25.4%	0%	2.0%
LIFT	0%	83.2%	16.8%	0%	0%
MARITIME	0.7%	0%	99.3%	0%	0%
TERRESTRIAL	-	-	-	-	-
F1 SCORE	0.82	0.89	0.82	0.00	

Feature explorer

accX RMS accY RMS accZ RMS

Legend:

- idle - correct
- lift - correct
- maritime - correct
- idle - incorrect
- lift - incorrect
- maritime - incorrect
- terrestrial

Model testing - ESP32-Motion X + studio.edgeimpulse.com/studio/54781/validation

Test data

Set the 'expected outcome' for each sample to the desired outcome to automatically score the impulse.

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
idle.json.2jb4ipqd	idle	10s	89%	90 idle, 6 lift, 4 uncertain, 1 maritime
testing.json.2jb2djgq	maritime	10s	98%	99 maritime, 2 idle
testing.json.2jb2cdi2	terrestrial	10s		101 terrestrial
testing.json.2jb29lqg	lift	10s	70%	71 lift, 30 maritime
idle.json.2jb1mdjv	idle	10s		
idle.json.2jb1j3th	idle	10s		
lift.json.2jb1hmvt	lift	10s		
terrestrial.json.2jb1gu...	terrestrial	10s		
maritime.json.2jb1e80t	maritime	10s		
maritime.json.2jb1c79k	maritime	10s		
terrestrial.json.2jb18...	terrestrial	10s		
lift.json.2jb130ml	lift	10s	94%	95 lift, 6 maritime

Model testing output

Classifying data for NN Classifier...
 Copying features from processing blocks...
 Copying features from DSP block...
 Copying features from DSP block OK
 Copying features from processing blocks OK

Classifying data for float32 model...
 Scheduling job in cluster...
 Job started
 Classifying data for NN Classifier OK

Job completed

Set confidence thresholds

Every learning block has a threshold. This can be the minimum confidence that a neural network needs to have, or the maximum anomaly score before a sample is tagged as an anomaly. You can configure these thresholds to tweak the sensitivity of these learning blocks. This affects both live classification and model testing.

NN Classifier

Minimum confidence rating

Set confidence thresholds

IDLE	LIFT	MARITIME	TERRESTRIAL	UNCERTAIN
69.3%	3.3%	25.4%	0%	2.0%
0%	83.2%	16.8%	0%	0%
0.7%	0%	99.3%	0%	0%
-	-	-	-	-
0.82	0.89	0.82	0.00	

Feature explorer

accX RMS accY RMS accZ RMS

Legend:

- idle - correct
- lift - correct
- maritime - correct
- idle - incorrect
- lift - incorrect
- maritime - incorrect
- terrestrial

DEPLOYMENT (ESP32-MOTION-CLASSIFICATION)

Deploy your impulse

You can deploy your impulse to any device. This makes the model run without an internet connection, minimizes latency, and runs with minimal power consumption. [Read more.](#)

Create library

Turn your impulse into optimized source code that you can run on any device.

 C++ library	 Arduino library	 Cube.MX CMSIS-PACK
 WA	 NVIDIA.	

Select optimizations (optional)

Model optimizations can increase on-device performance but may reduce accuracy. Click below to analyze optimizations and see the recommended choices for your target. Or, just click Build to use the currently selected options.

Enable EON™ Compiler

Same accuracy, up to 50% less memory. Open source.

Available optimizations for NN Classifier

Optimization Type	RAM USAGE	LATENCY	CONFUSION MATRIX																				
Quantized (int8) ★	1.7K	1 ms	<table border="1"> <tr><td>0</td><td>0</td><td>0</td><td>0</td><td>100</td></tr> <tr><td>0</td><td>80.9</td><td>15.2</td><td>0</td><td>4.0</td></tr> <tr><td>0.7</td><td>0</td><td>98.7</td><td>0</td><td>0.7</td></tr> <tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr> </table>	0	0	0	0	100	0	80.9	15.2	0	4.0	0.7	0	98.7	0	0.7	-	-	-	-	-
0	0	0	0	100																			
0	80.9	15.2	0	4.0																			
0.7	0	98.7	0	0.7																			
-	-	-	-	-																			
Unoptimized (float32)	1.8K	1 ms	<table border="1"> <tr><td>69.3</td><td>3.3</td><td>25.4</td><td>0</td><td>2.0</td></tr> <tr><td>0</td><td>83.2</td><td>16.8</td><td>0</td><td>0</td></tr> <tr><td>0.7</td><td>0</td><td>99.3</td><td>0</td><td>0</td></tr> <tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr> </table>	69.3	3.3	25.4	0	2.0	0	83.2	16.8	0	0	0.7	0	99.3	0	0	-	-	-	-	-
69.3	3.3	25.4	0	2.0																			
0	83.2	16.8	0	0																			
0.7	0	99.3	0	0																			
-	-	-	-	-																			

Estimate for Cortex-M4F 80MHz

Build

esp32_sense_accelerometer | Arduino 1.8.16

```

22
23 /* Includes ----- */
24 #include <ESP32-Motion-Classification_inferencing.h>
25 #include "I2Cdev.h"
26 #include "MPU6050.h"
27 #include "Wire.h"
28
29 /* Constant defines ----- */
30 #define CONVERT_G_TO_MS2 1.0f
31 #define OUTPUT_READABLE_ACCELGYRO
32 MPU6050 accelgyro;
33 int16_t ax, ay, az;
34
35 /* Private variables ----- */
36 static bool debug_nn = false; // Set this to true to see e.g. features generated from the raw signal
37
38 /**
39 * @brief      Arduino setup function
40 */
41 void setup()
42{
43     // put your setup code here, to run once:
44     Serial.begin(115200);
45     Serial.println("Edge Impulse Inferencing - ESP32-Motion Classification");
46
47     Wire.begin();
48
49     // initialize device
50     Serial.println("Initializing I2C devices...");
51     accelgyro.initialize();
52
53     // verify connection
54     Serial.println("Testing device connections...");
55     Serial.println(accelgyro.testConnection() ? "MPU6050 connection successful" : "MPU6050 connection failed");
56
57 if (EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME != 3) {
58     ei_printf("ERR: EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME should be equal to 3 (the 3 sensor axes)\n");
59     return;
60 }
61 }
```

Writing at 0x00008000... (100 %)
Wrote 3072 bytes (128 compressed) at 0x00008000 in 0.0 seconds (effective 2165.5 kbit/s)...
Hash of data verified.

Leaving...
Hard resetting via RTS pin...

22 DOIT ESP32 DEVKIT V1, 80MHz, 921600, None on /dev/cu.usbserial-0001

esp32_sense_accelerometer | Arduino 1.8.16

```

86
87 void loop() {
88     ei_printf("\nStarting inferencing in 2 seconds...\n");
89     delay(2000);
90     ei_printf("Sampling...\n");
91
92     // Allocate a buffer here for the values we'll read from the IMU
93     float buffer[EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE] = { 0 };
94
95     for (size_t ix = 0; ix < EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE; ix += 3) {
96         // Determine the next tick (and then sleep later)
97         uint64_t next_tick = micros() + (EI_CLASSIFIER_INTERVAL_MS * 1000);
98
99         accelgyro.getAcceleration(&ax, &ay, &az);
100        buffer[ix + 0] = ax*CONVERT_G_TO_MS2;
101        buffer[ix + 1] = ay*CONVERT_G_TO_MS2;
102        buffer[ix + 2] = az*CONVERT_G_TO_MS2;
103
104        delayMicroseconds(next_tick - micros());
105
106        // Turn the raw buffer in a signal which we can then classify
107        signal_t signal;
108        int err = numpy::signal_from_buffer(buffer, EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE, &signal);
109        if (err != 0) {
110            ei_printf("Failed to create signal from buffer (%d)\n", err);
111            return;
112        }
113
114        // Run the classifier
115        ei_impulse_result_t result = { 0 };
116
117        err = run_classifier(&signal, &result, debug_nn);
118        if (err != EI_IMPULSE_OK) {
119            ei_printf("ERR: Failed to run classifier (%d)\n", err);
120            return;
121        }
122
123        // Print the predictions
124        ei_printf("Predictions ");
125        ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
126                  result.timing.dsp, result.timing.classification, result.timing.anomaly);
127        ei_printf("\n");
128        for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
129            ei_printf("    %s: %.5f\n", result.classification[ix].label, result.classification[ix].value);
130        }
131        #if EI_CLASSIFIER_HAS_ANOMALY == 1
132            ei_printf("    anomaly score: %.3f\n", result.anomaly);
133        #endif
134
135    #if !defined(EI_CLASSIFIER_SENSOR) || EI_CLASSIFIER_SENSOR != EI_CLASSIFIER_SENSOR_ACCELEROMETER
136        #error "Invalid model for current sensor"
137    #endif
138 }
```

104 DOIT ESP32 DEVKIT V1, 80MHz, 921600, None on /dev/cu.usbserial-0001

```
/dev/cu.usbserial-0001
Send

lift: 0.02348
maritime: 0.14678
terrestrial : 0.00562

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 19 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.88469
lift: 0.05896
maritime: 0.03198
terrestrial : 0.02436

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 19 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.86179
lift: 0.03734
maritime: 0.08310
terrestrial : 0.01776

Starting inferencing in 2 seconds...

 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output
```

```
maritime: 0.18839
terrestrial : 0.00147

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 19 ms., Classification: 0 ms., Anomaly: 0 ms.):
    idle: 0.00000
    lift: 1.00000
    maritime: 0.00000
    terrestrial : 0.00000

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 19 ms., Classification: 0 ms., Anomaly: 0 ms.):
    idle: 0.00000
    lift: 0.00000
    maritime: 1.00000
    terrestrial : 0.00000

Starting inferencing in 2 seconds...
Sampling...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

Main references

- [Harvard School of Engineering and Applied Sciences - CS249r: Tiny Machine Learning](#)
- [Professional Certificate in Tiny Machine Learning \(TinyML\) – edX/Harvard](#)
- [Introduction to Embedded Machine Learning - Coursera/Edge Impulse](#)
- [Computer Vision with Embedded Machine Learning - Coursera/Edge Impulse](#)
- Fundamentals textbook: “[Deep Learning with Python](#)” by François Chollet
- Applications & Deploy textbook: “[TinyML](#)” by Pete Warden, Daniel Situnayake
- Deploy textbook “[TinyML Cookbook](#)” by Gian Marco Iodice

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Thanks



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