

# IESTI01 - TinyML

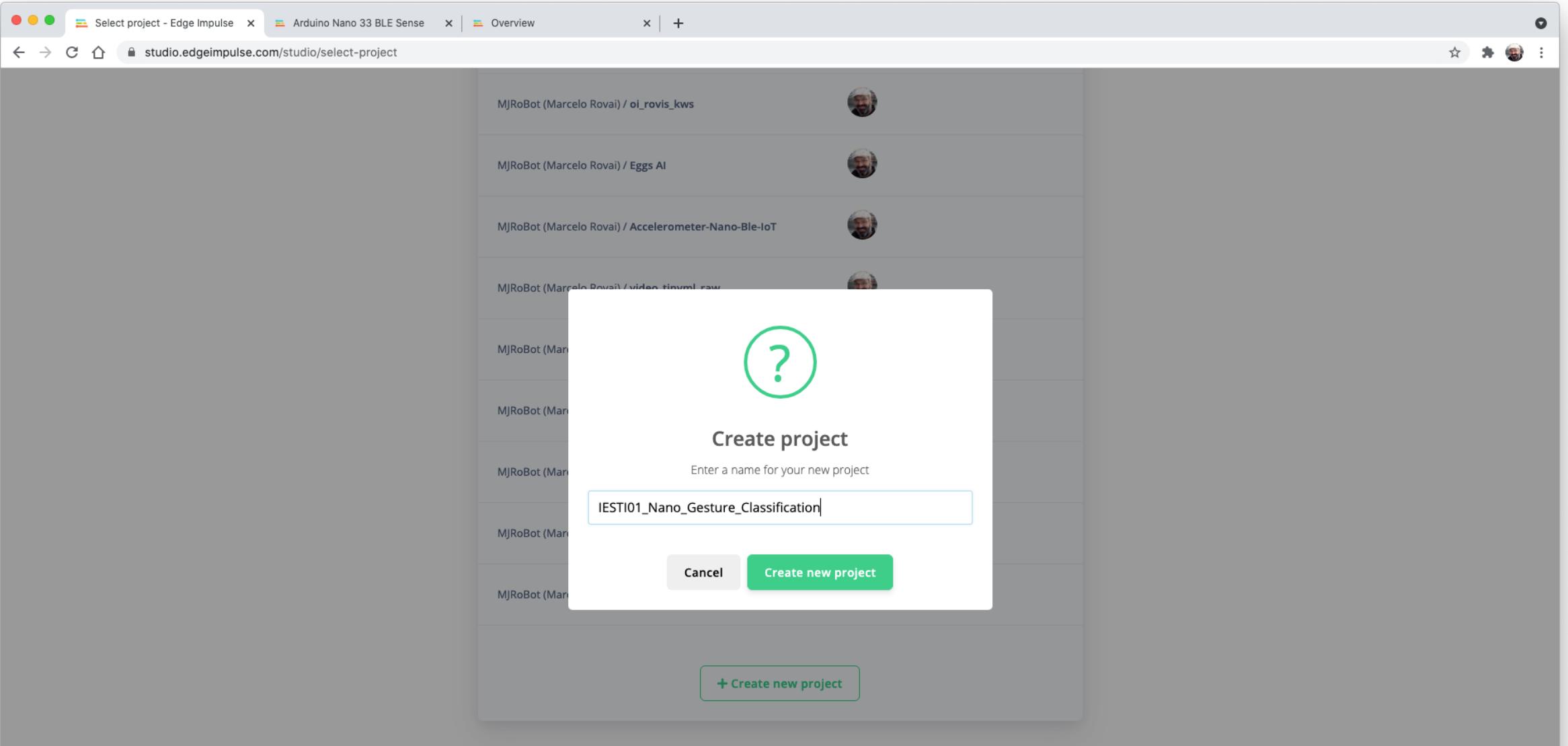
Gesture Classification &  
Anomaly Detection with  
Arduino Nano-33 BLE

Prof. Marcelo Rovai

June 30<sup>rd</sup>, 2021



# Arduino Nano-33 BLE Edge Impulse – Installation



## Your devices

These are devices that are connected

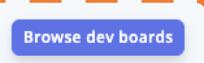
 Collect data

x

You can collect data from development boards, from your own devices, or by uploading an existing dataset.

 Connect a fully supported development board

Get started with real hardware from a wide range of silicon vendors - fully supported by Edge Impulse.



Browse dev boards

3

 Use your mobile phone

Use your mobile phone to capture movement, audio or images, and even run your trained model locally. No app required.

Show QR code

 Use your computer

Capture audio or images from your webcam or microphone, or from an external audio device.

Collect data

 Data from any device with the data forwarder

Capture data from any device or development board over a serial connection, in 10 lines of code.

Show docs

 Upload data

Already have data? You can upload your existing datasets directly in WAV, JPG, PNG, CBOR, CSV or JSON format.

Go to the uploader

 Integrate with your cloud

The enterprise version of Edge Impulse integrates directly with the data stored in your cloud platform.

Contact us

**DOCUMENTATION**

- Getting Started
- API and SDK references
- What is embedded ML, anyway?
- Frequently asked questions

**DEVELOPMENT BOARDS****Overview**

- ST B-L475E-IOT01A
- Arduino Nano 33 BLE Sense
- Eta Compute ECM3532 AI Sensor
- Eta Compute ECM3532 AI Vision
- OpenMV Cam H7 Plus
- Himax WE-I Plus
- Nordic Semi nRF52840 DK
- Nordic Semi nRF5340 DK
- SiLabs Thunderboard Sense 2
- Sony's Spresense
- Arduino Portenta H7 + Vision shield (preview)
- Raspberry Pi 4
- NVIDIA Jetson Nano
- Mobile phone
- Porting guide

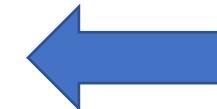
**COMMUNITY BOARDS**

- Seeed Wio Terminal
- Agora Product Development Kit

# Overview

There is a list of development boards that are fully supported by Edge Impulse. These boards come with a special firmware which enables data collection from all their sensors, allows you to build new ready-to-go binaries that include your trained impulse, and come with examples on integrating your impulse with your custom firmware. These boards are the perfect way to start building Machine Learning solutions on real embedded hardware.

- [ST B-L475E-IOT01A \(or Discovery Kit\)](#)
- [Arduino Nano 33 BLE Sense](#)
- [Eta Compute ECM3532 AI Sensor](#)
- [Eta Compute ECM3532 AI Vision](#)
- [OpenMV Cam H7 Plus](#)
- [Himax WE-I Plus](#)
- [Nordic Semiconductor nRF52840 DK](#)
- [Nordic Semiconductor nRF5340 DK](#)
- [Silicon Labs Thunderboard Sense 2](#)
- [Sony's Spresense](#)
- [Arduino Portenta H7 + Vision shield](#) (preview support)
- [Raspberry Pi 4](#)
- [NVIDIA Jetson Nano](#)



Different development board? No problem, you can always collect data using the [Data forwarder](#) or the [Edge Impulse for Linux](#) SDK, and deploy your model back to the device with the [Running your impulse locally](#) tutorials.

Just want to experience Edge Impulse? You can also use your [Mobile phone](#)!

Updated 7 days ago

**EDGE IMPULSE** Home API Reference Log In

Guides > Arduino Nano 33 BLE Sense

DOCUMENTATION

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COMMUNITY BOARDS

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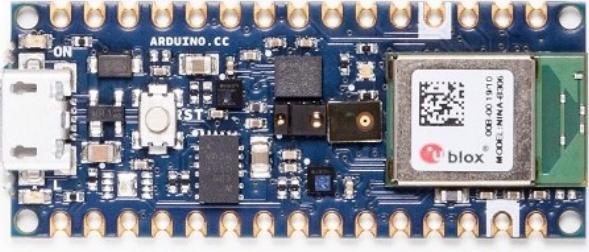
EDGE IMPULSE FOR LINUX

- Edge Impulse for Linux
- Linux Node.js SDK
- Linux Go SDK
- Linux C++ SDK
- Linux Python SDK

## Arduino Nano 33 BLE Sense

The Arduino Nano 33 BLE Sense is a tiny development board with a Cortex-M4 microcontroller, motion sensors, a microphone and BLE - and it's fully supported by Edge Impulse. You'll be able to sample raw data, build models, and deploy trained machine learning models directly from the studio. It's available for around 30 USD from [Arduino](#) and a wide range of distributors.

The Edge Impulse firmware for this development board is open source and hosted on GitHub: [edgeimpulse/firmware-arduino-nano-33-ble-sense](#).



*Arduino Nano 33 BLE Sense*

Installing dependencies

To set this device up in Edge Impulse, you will need to install the following software:

1. [Edge Impulse CLI](#).
2. [Arduino CLI](#).
  - Here's an [instruction video for Windows](#).
  - The [Arduino website](#) has instructions for macOS and Linux.
3. On Linux:
  - GNU Screen: install for example via `sudo apt install screen`.

**(Note that the 1. Edge Impulse CLI is not necessary for Arduino Nano-33. We will use WebUSB instead)**

**DOCUMENTATION**

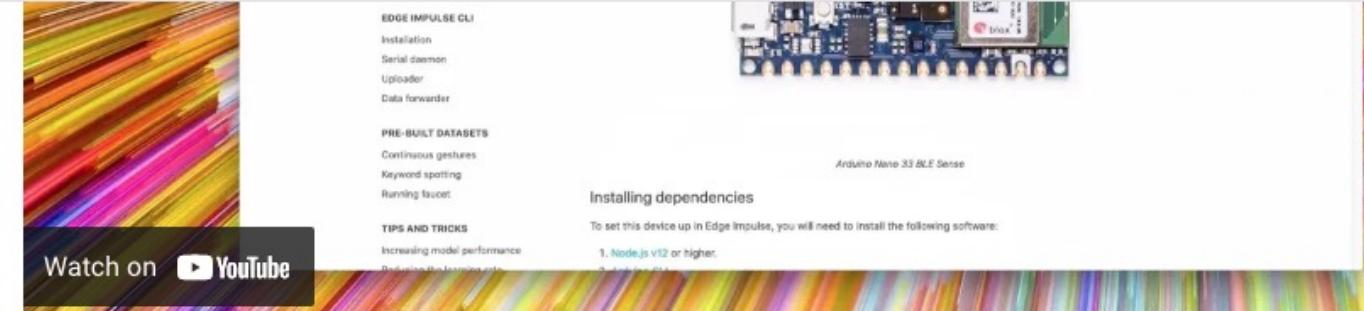
- Getting Started
- API and SDK references
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- Frequently asked questions

**DEVELOPMENT BOARDS**

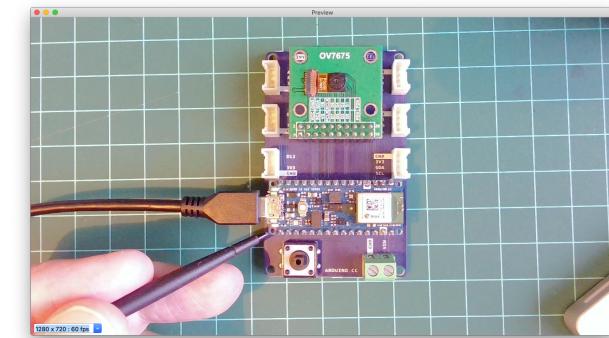
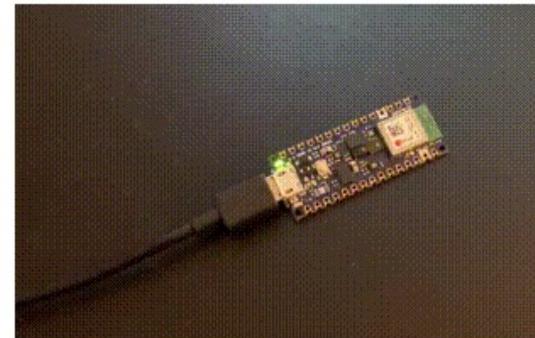
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- ST B-L475E-IOT01A
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**COMMUNITY BOARDS**

- Seeed Wio Terminal
- Agora Product Development Kit

**1. Connect the development board to your computer**

Use a micro-USB cable to connect the development board to your computer. Then press RESET twice to launch into the bootloader. The on-board LED should start pulsating to indicate this.



*Press RESET twice quickly to launch the bootloader on the Arduino Nano 33 BLE Sense.*

**2. Update the firmware**

The development board does not come with the right firmware yet. To update the firmware:

1. [Download the latest Edge Impulse firmware](#), and unzip the file.
2. Open the flash script for your operating system (`flash_windows.bat`, `flash_mac.command` or `flash_linux.sh`) to flash the firmware.
3. Wait until flashing is complete, and press the RESET button once to launch the new firmware.

**3. Setting keys**

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**DEVELOPMENT BOARDS**

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ST B-L475E-IOT01A

**Arduino Nano 33 BLE Sense**

Eta Compute ECM3532 AI Sensor

Eta Compute ECM3532 AI Vision

OpenMV Cam H7 Plus

Himax WE-I Plus

Nordic Semi nRF52840 DK

Nordic Semi nRF5340 DK

SiLabs Thunderboard Sense 2

Sony's SpreSense

Arduino Portenta H7 + Vision shield  
(preview)

Raspberry Pi 4

NVIDIA Jetson Nano

Mobile phone

Porting guide

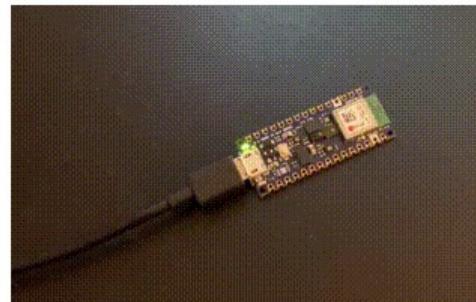
**COMMUNITY BOARDS**

Seeed Wio Terminal

Agora Product Development Kit

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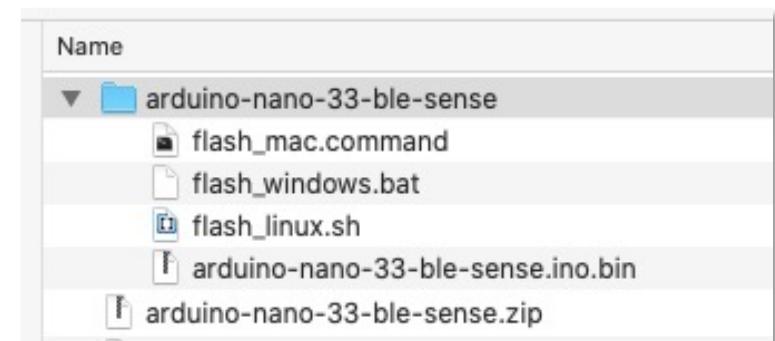
**1**

*Press RESET twice quickly to launch the bootloader on the Arduino Nano 33 BLE Sense.*

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3. Wait until flashing is complete, and press the RESET button once to launch the new firmware.

**3. Setting keys****2**

# MacOS

```
mjrovai — flash_mac.command — 124x43
Last login: Mon Jun 28 08:58:22 on ttys002
You have new mail.
/Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;

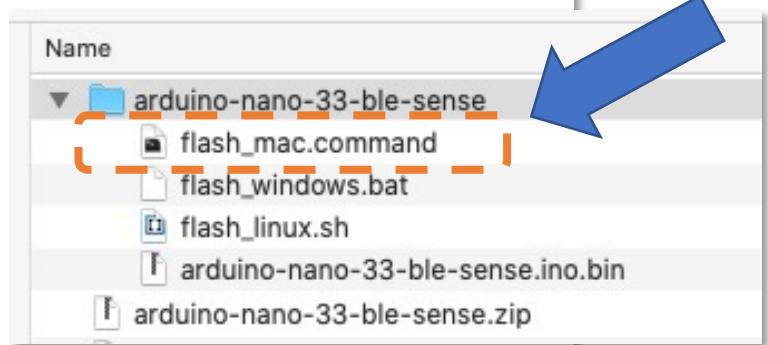
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
(base) MacBook-Pro-de-Marcelo:~ mjrovai$ /Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;
Finding Arduino Mbed core...
Finding Arduino Mbed OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK
Flashing board...
Device      : nRF52840-QIAA
Version     : Arduino Bootloader (SAM-BA extended) 2.0 [Arduino:IKXYZ]
Address     : 0x0
Pages       : 256
Page Size   : 4096 bytes
Total Size  : 1024KB
Planes      : 1
Lock Regions: 0
Locked      : none
Security    : false
Erase flash

Done in 0.001 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 20.533 seconds

Flashed your Arduino Nano 33 BLE development board.
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'
logout
Saving session...
...copying shared history...
...saving history...truncating history files...
...completed.

[Process completed]
```

1. Press Nano-33 Reset button Twice  
2. With Nano-33 LED Flashing:



3.Nano-33 LED Stop Flashing

# Windows 10

```
Prompt de Comando
Microsoft Windows [versão 10.0.19041.1052]
(c) Microsoft Corporation. Todos os direitos reservados.

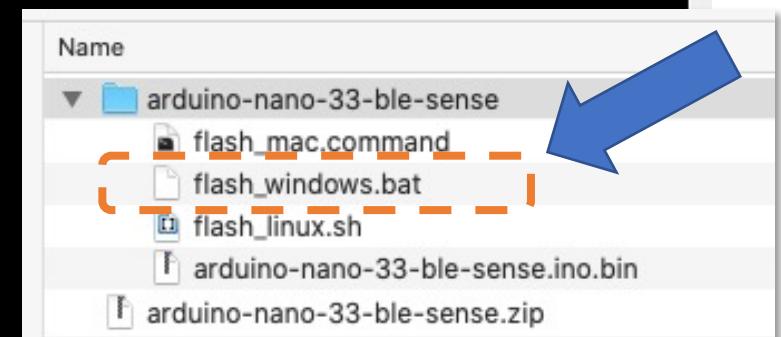
C:\Users\GUILH>arduino-cli
Arduino Command Line Interface (arduino-cli).

Usage:
  arduino-cli [command]

Examples:
  arduino-cli <command> [flags...]

Available Commands:
  board          Arduino board commands.
  burn-bootloader Upload the bootloader.
  cache          Arduino cache commands.
  compile        Compiles Arduino sketches.
  completion    Generates completion scripts
  config         Arduino configuration commands.
  core           Arduino core operations.
  daemon         Run as a daemon on port 50051
  debug          Debug Arduino sketches.
  help           Help about any command
  lib             Arduino commands about libraries.
  outdated       Lists cores and libraries that can be upgraded
  sketch          Arduino CLI sketch commands.
  update         Updates the index of cores and libraries
  upgrade        Upgrades installed cores and libraries.
  upload         Upload Arduino sketches.
  version        Shows version number of Arduino CLI.
```

1. Press Nano-33 Reset button Twice
2. With Nano-33 LED Flashing:



# Windows 10

```
cmd C:\WINDOWS\system32\cmd.exe
Finding Arduino Mbed core...
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Finding Arduino Mbed core OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK at COM11
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Device        : nRF52840-QIAA
Version       : Arduino Bootloader (SAM-BA extended) 2.0 [Arduino:IKXYZ]
Address       : 0x0
Pages         : 256
Page Size     : 4096 bytes
Total Size    : 1024KB
Planes        : 1
Lock Regions : 0
Locked        : none
Security      : false
Erase flash

Done in 0.002 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 22.296 seconds
Flashed your Arduino Nano 33 BLE development board
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'
Pressione qualquer tecla para continuar. . .

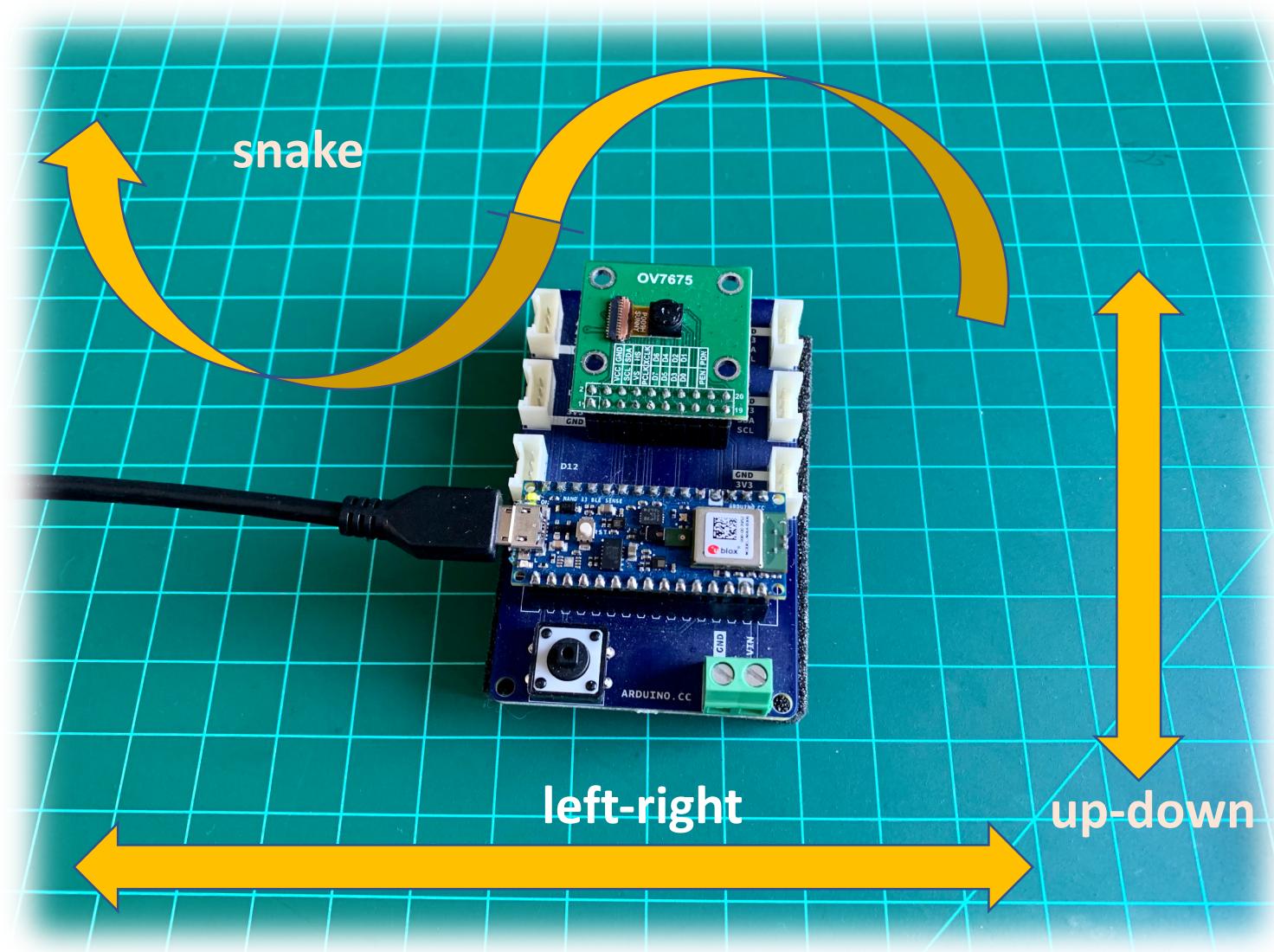
← Nano-33 LED Stop Flashing
```

# Nano-33 BLE Gesture Classification Project

<https://studio.edgeimpulse.com/public/37762/latest>



# Gesture Data Capture (2D Plan)



# Data Acquisition

Dashboard - IESTI01\_Nano\_Ge x Collect Sensor Data Straight Fr x Overview x +

studio.edgeimpulse.com/studio/37762

EDGE IMPULSE

Project info Keys Export

MJRoBot (Marcelo Rovai)

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

**MJRoBot (Marcelo Rovai) / IESTI01\_Nano\_Gesture\_Classification**

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

**Creating your first impulse (0% 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](#)

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

**Summary**

DEVICES CONNECTED 0

DATA COLLECTED -

**Collaborators**

MJRoBot (Marcelo Rovai) OWNER

A blue arrow points to the "Data acquisition" icon in the sidebar.

## EDGE IMPULSE

Dashboard

Devices

Data acquis

Impulse des

Create

Retrain mode

Live classific

Model testing

Versioning

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### GETTING STARTED

Documentation

Forums

studio.edgeimpulse.com wants to connect to a serial port

cu.Bluetooth-Incoming-Port

cu.MALS

cu.RovaisAirPods-Wireless

cu.SOC

Arduino Nano 33 BLE (cu.usbmodem144301)



2

Cancel Connect

No data collected yet

Let's collect some data

### CATEGORIZATION

Get data from any device or development board, or upload your existing datasets - [Show options](#)

LABELS  
0

### Record new data

No devices connected to the remote management API.

1

Connect using WebUSB

### RAW DATA

Click on a sample to load...

Data acquisition - IESTI01... X Arduino Nano 33 BLE Sense X Overview

studio.edgeimpulse.com/studio/37762/acquisition/training?page=1

MJRoBot (Marcelo Rovai)

DATA ACQUISITION (IESTI01\_NANO\_GESTURE\_CLASSIFICATION)

Training data Test data

Did you know? You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

DATA COLLECTOR  LABLES 0

Collected data

No data collected yet

 Let's collect some data

Record new data

Device ② 36:17:55:F9:70:F7

Label left\_right  1

Sample length (ms.) 10000

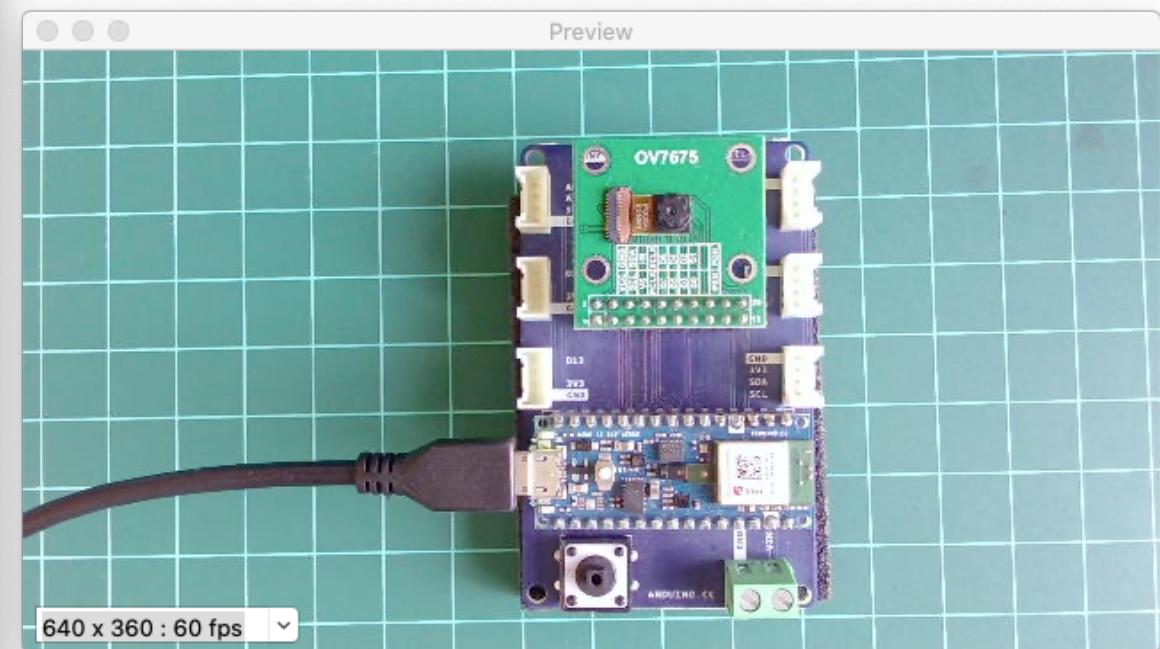
Sensor Built-in accelerometer  2

Frequency 100Hz 

Start sampling

RAW DATA Click on a sample to load... 

arduinonano-33....zip ^ Show All X



If connection broken during data capture, press Nano-33 Reset button once and, start over reconnecting it, via Web-USB

Did you know? You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

**DATA COLLECTOR** 3m 30s

**LABELS** 3

**Collected data**

SAMPLE NAME	LABEL	ADDED	LENGTH
up-down.296...	up-down	Today, 09:...	10s
up-down.296...	up-down	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s
left_right.296...	left_right	Today, 09:...	10s

**RAW DATA** left\_right.2961b6lf

accX accY accZ

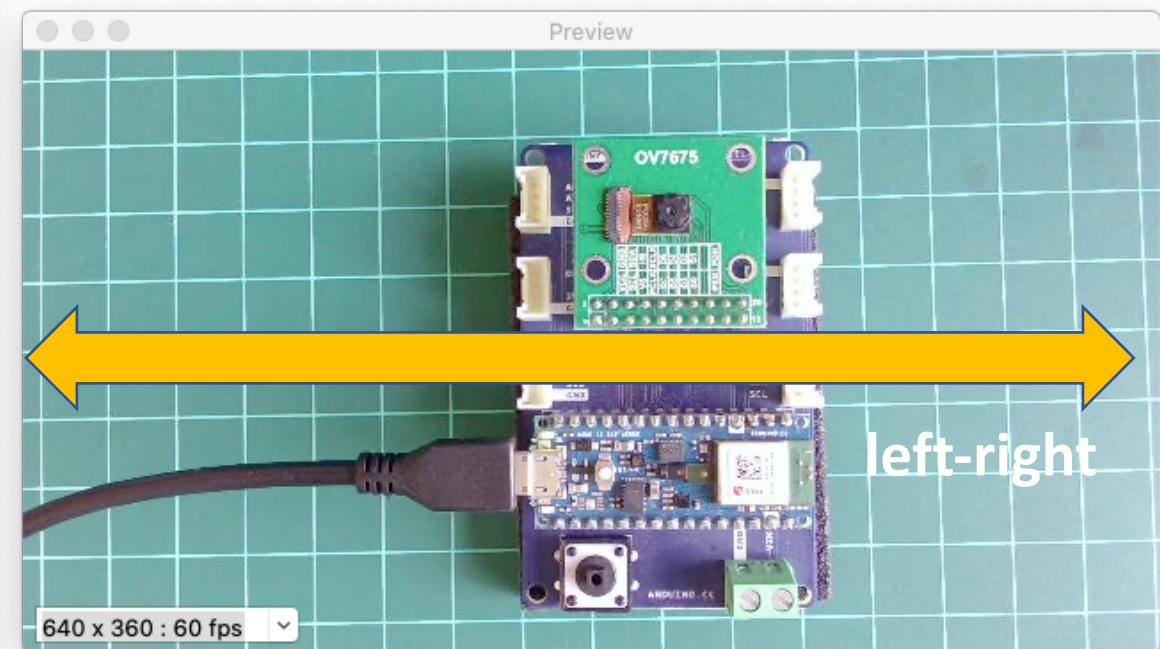
**Record new data**

**Device** 36:17:55:F9:70:F7

**Label** left-right **Sample length (ms.)** 10000

**Sensor** Built-in accelerometer **Frequency** 100Hz

**Start sampling**



DATA COLLEC... 2m 10s

LABELS 2

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
left_right.296...	left_right	Today, 09...	10s
left_right.296...	left_right	Today, 09...	10s
left_right.296...	left_right	Today, 09...	10s
left_right.296...	left_right	Today, 09...	10s
left_right.296...	left_right	Today, 09...	10s
left_right.296...	left_right	Today, 09...	10s

RAW DATA  
up-down.2961m7fm

Device ②  
36:17:55:F9:70:F7

Label  
up-down

Sample length (ms.)  
10000

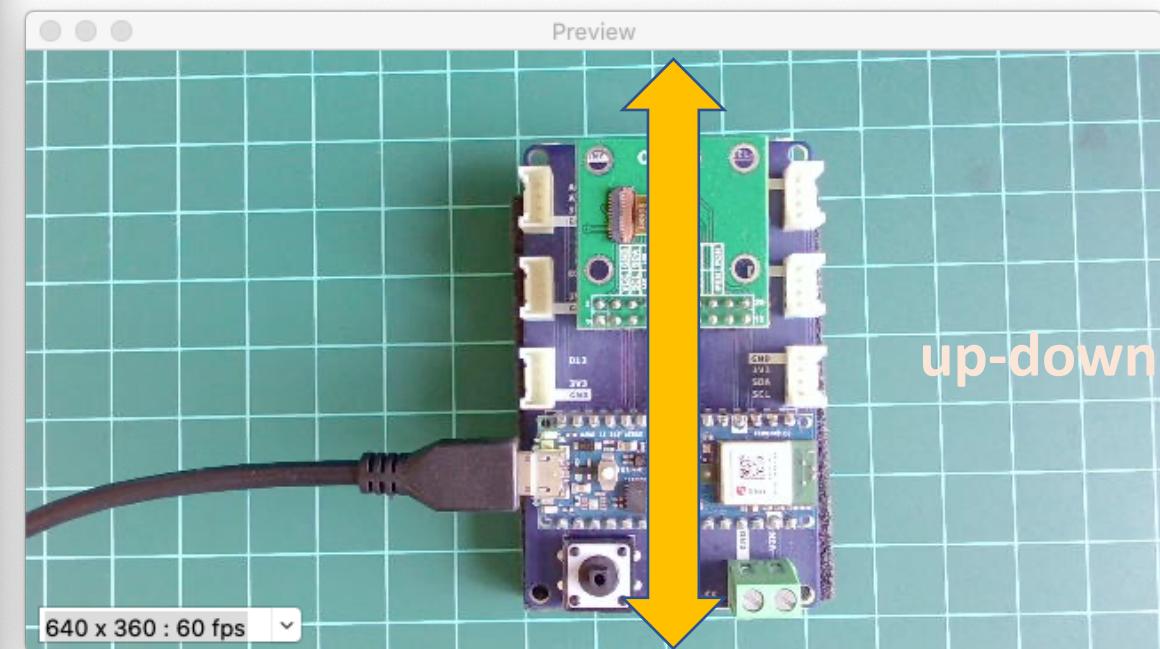
Sensor  
Built-in accelerometer

Frequency  
100Hz

Start sampling

https://studio.edgeimpulse.com/studio/37762/acquisition/training?page=1#!

Show All



DATA COLLEC...  3m 30s

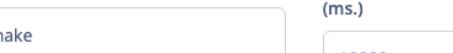
LABELS  3

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
snake.29620uej	snake	Today, 09...	10s
snake.296208...	snake	Today, 09...	10s
snake.2961ug...	snake	Today, 09...	10s
snake.2961to...	snake	Today, 09...	10s
snake.2961rsv1	snake	Today, 09...	10s
snake.2961ptnt	snake	Today, 09...	10s
snake.2961p9...	snake	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s
up-down.296...	up-down	Today, 09...	10s

Record new data

Device  36:17:55:F9:70:F7

Label  snake

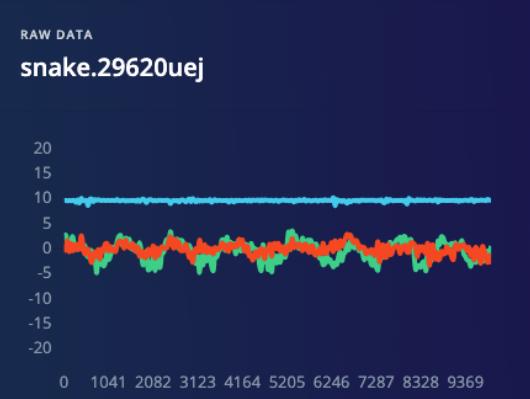
Sample length (ms.)  10000

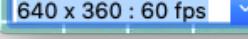
Sensor  Built-in accelerometer

Frequency  100Hz

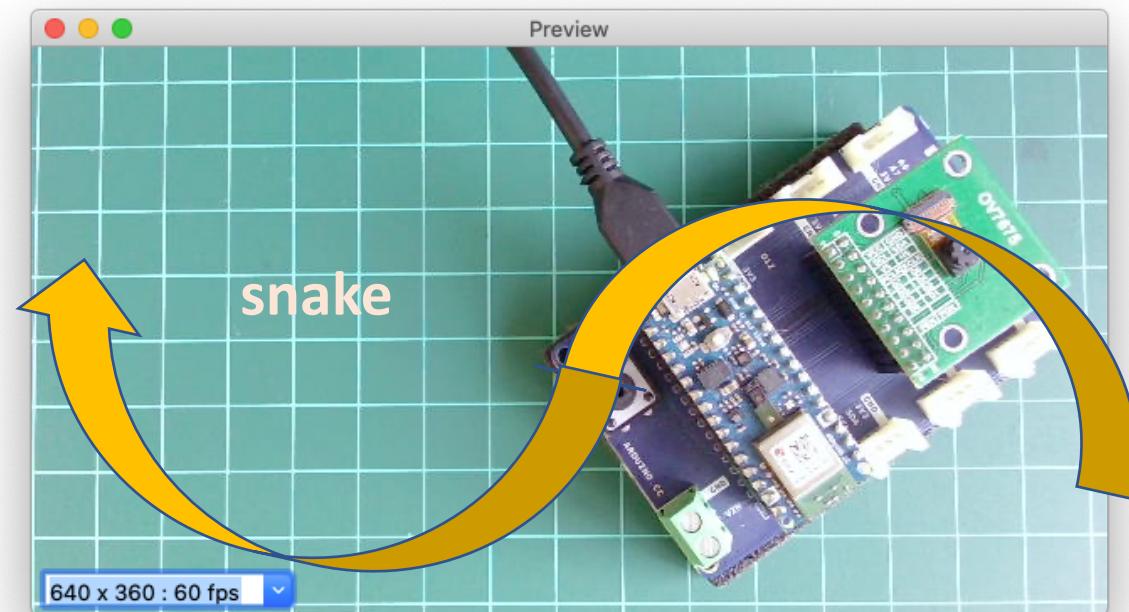
**Start sampling**

RAW DATA  
snake.29620uej



640 x 360 : 60 fps 

accX accY accZ



Did you know? You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

**DATA COLLECTED** 4m 40s

**LABELS** 4

**Collected data**

SAMPLE NAME	LABEL	ADDED	LENGTH	...
idle.296391i5	idle	Today, 09:...	10s	...
idle.29638777	idle	Today, 09:...	10s	...
idle.29636mpq	idle	Today, 09:...	10s	...
idle.296365s6	idle	Today, 09:...	10s	...
idle.29635k0p	idle	Today, 09:...	10s	...
idle.296351me	idle	Today, 09:...	10s	...
idle.29634d9b	idle	Today, 09:...	10s	...
snake.29620uej	snake	Today, 09:...	10s	...
snake.296208...	snake	Today, 09:...	10s	...
snake.2961ug...	snake	Today, 09:...	10s	...
snake.2961to...	snake	Today, 09:...	10s	...
snake.2961rsv1	snake	Today, 09:...	10s	...

**Record new data**

**Device** 36:17:55:F9:70:F7

**Label** idle **Sample length (ms.)** 10000

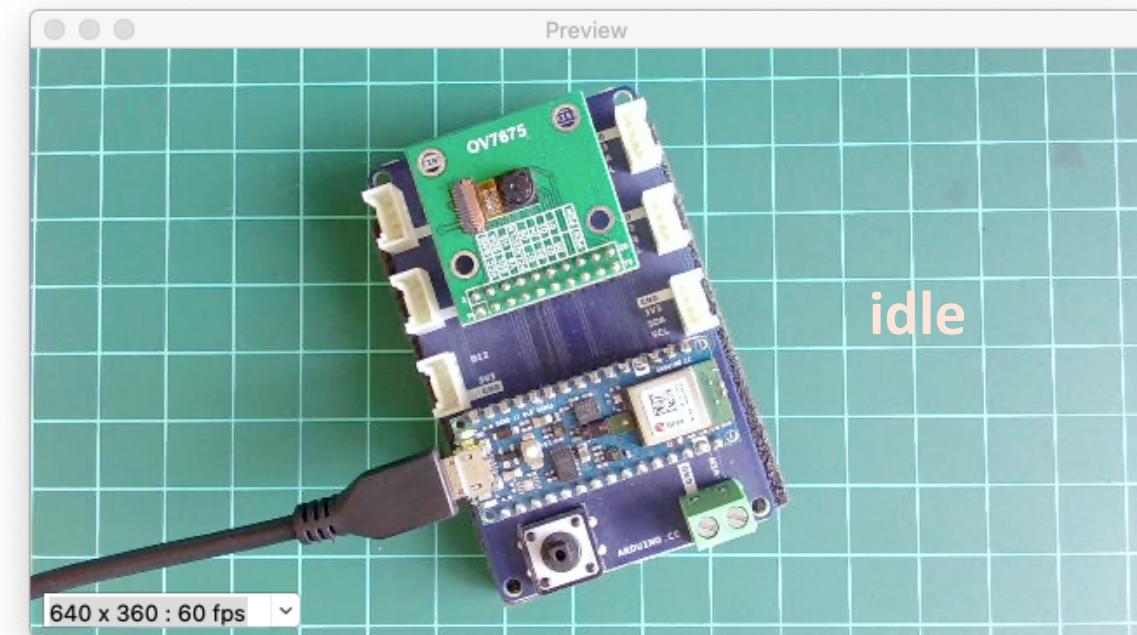
**Sensor** Built-in accelerometer **Frequency** 100Hz

**Start sampling**

**RAW DATA** idle.296391i5

accX accY accZ

640 x 360 : 60 fps



# Feature Engineering and Model training

CREATE IMPULSE (IESTI01\_NANO\_GESTURE\_CLASSIFICATION)

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

**1**

**Time series data**

Axes: accX, accY, accZ

Window size: 2000 ms.

Window increase: 80 ms.

Zero-pad data:

**Spectral Analysis**

Name: Spectral features

Input axes: accX, accY, accZ

**Neural Network (Keras)**

Name: NN Classifier

Input features: Spectral features, accX, accY, accZ

Output features: 4 (idle, left\_right, snake, up-down)

**K-means Anomaly Detection**

Name: Anomaly detection

Input features: Spectral features

Output features: 1 (Anomaly score)

**Output features**

5 (idle, left\_right, snake, up-down, Anomaly score)

**2**

**Save Impulse**

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Impulse design

Create impulse

Retrain model

Live classification

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Forums

MJRoBot (Marcelo Rovai)

Spectral features - IESTI01\_Nano | Arduino Nano 33 BLE Sense | Overview | +

studio.edgeimpulse.com/studio/37762/dsp/spectral-analysis/3

**EDGE IMPULSE**

**Raw data**

up-down.2961o2dp (up-down)

accX (red), accY (green), accZ (blue)

**Raw features**

0.6345, -3.9899, 9.7456, 0.6632, -3.9325, 9.7444, 0.7470, -3.2549, 9.7576, 0.7985, -2.5235, 9.7863, 0.8045, -1.3312, 9.8055, 0.624...

**Parameters**

1

Scale axes

Filter

Type: low

Cut-off frequency: 3

Order: 6

Spectral power

FFT length: 128

No. of peaks: 3

Peaks threshold: 0.1

Power edges: 0.1, 0.5, 1.0, 2.0, 5.0

**DSP result**

**After filter**

Frequency domain

Spectral power

Processed features

**Save parameters**

The screenshot shows the Edge Impulse DSP spectral analysis interface. On the left, a sidebar lists various project management and documentation links. The main area is divided into sections: 'Raw data' (displaying three sensor signals over time), 'Raw features' (listing numerical feature values), 'Parameters' (containing configuration for a low-pass filter and spectral power analysis), and 'DSP result' (showing the signal after filtering and its frequency spectrum). A large blue arrow points from the 'Parameters' section to the 'Save parameters' button at the bottom right.

Spectral features - IESTI01\_Nano

Arduino Nano 33 BLE Sense

Overview

studio.edgeimpulse.com/studio/37762/dsp/spectral-analysis/3/generate-features

**EDGE IMPULSE**

**SPECTRAL FEATURES (IESTI01\_NANO\_GESTURE\_CLASSIFICATION)**

Parameters **Generate features**

**Training set**

1

Data in training set 4m 40s

Classes 4 (idle, left\_right, snake, up-down)

Window length 2000 ms.

Window increase 80 ms.

Training windows 2,828

2

**Feature generation output**

Scheduling job in cluster...  
Job started  
Creating windows from 28 files...  
[ 1/28] Creating windows from files...  
[28/28] Creating windows from files...  
Created 2828 windows: idle: 707, left\_right: 707, snake: 707, up-down: 707

Creating features  
[ 1/2828] Creating features...  
[1053/2828] Creating features...  
[2110/2828] Creating features...  
[2828/2828] Creating features...  
Created features

Job completed

MJRoBot (Marcelo Rovai)

**Feature explorer (2,828 samples)**

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

idle (blue), left\_right (orange), snake (green), up-down (red)

**left\_right.29619fp9**

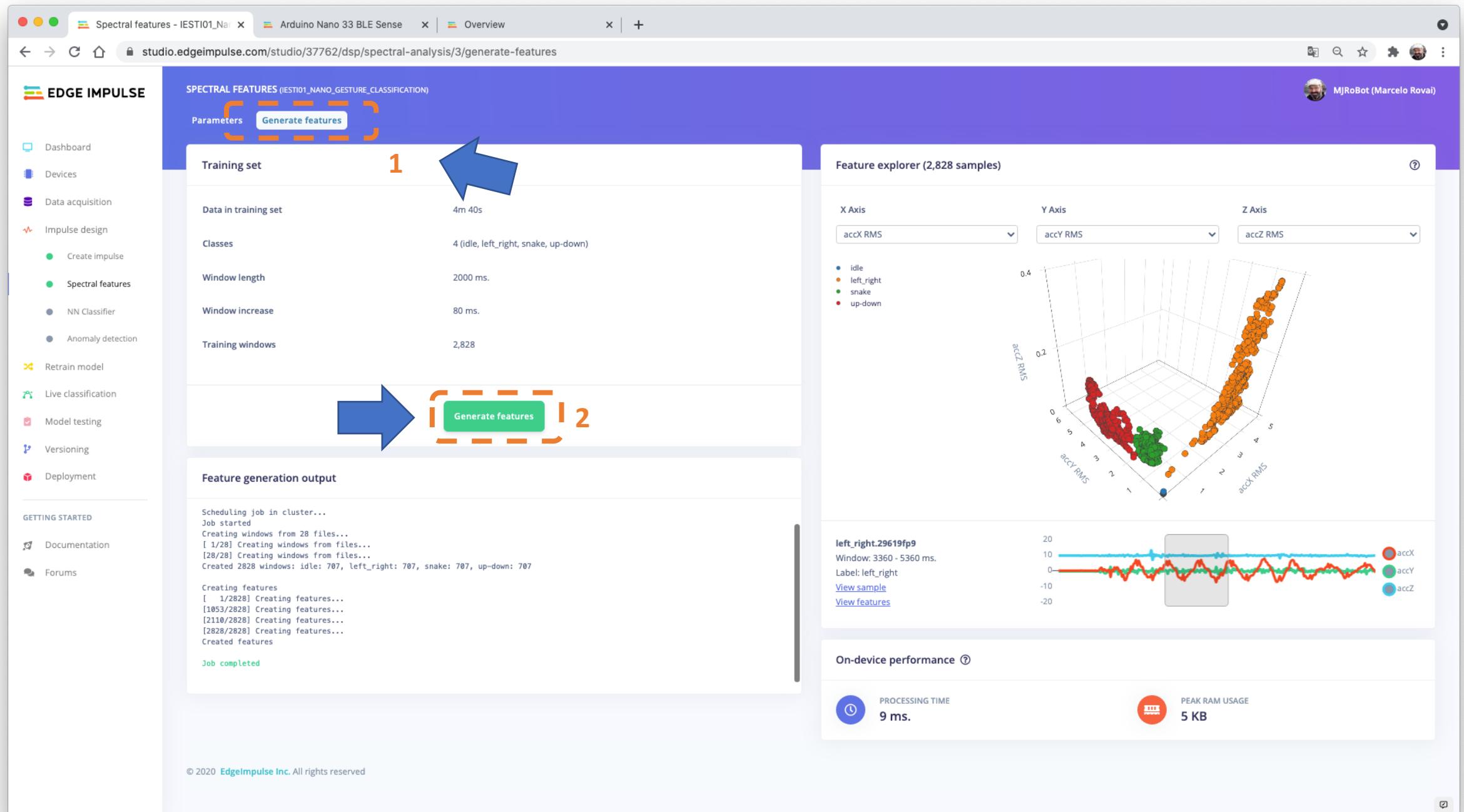
Window: 3360 - 5360 ms.  
Label: left\_right  
[View sample](#) [View features](#)

**On-device performance**

PROCESSING TIME 9 ms.

PEAK RAM USAGE 5 KB

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studio.edgeimpulse.com/studio/37762/learning/keras/7

**EDGE IMPULSE**

NN CLASSIFIER (IESTI01\_NANO\_GESTURE\_CLASSIFICATION)  
#1 Click to set a description for this version

**Neural Network settings**

**Training settings**

- Number of training cycles: 30
- Learning rate: 0.0005
- Minimum confidence rating: 0.60

**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)]
    
```

**Training output**

Open source  
71/71 - 1s - loss: 0.0180 - accuracy: 0.9973 - val\_loss: 0.0197 - val\_accuracy: 0.9947  
Finished training

Saving best performing model...  
Converting Tensorflow Lite float32 model...  
Converting Tensorflow Lite int8 quantized model with float32 input and output...  
Converting Tensorflow Lite int8 quantized model with int8 input and output...  
Calculating performance metrics...  
Profiling float32 model...  
Profiling float32 model (tflite)...  
Profiling float32 model (EON)...  
Profiling int8 model...  
Profiling int8 model (tflite)...  
Profiling int8 model (EON)...  
Model training complete

**Model**  
Model version: Quantized (int8)

**Last training performance (validation set)**

	ACCURACY %	LOSS
	99.5%	0.02

**Confusion matrix (validation set)**

	IDLE	LEFT_RIGHT	SNAKE	UP_DOWN
IDLE	100%	0%	0%	0%
LEFT_RIGHT	1.4%	98.6%	0%	0%
SNAKE	0%	0%	99.3%	0.7%
UP_DOWN	0%	0%	0%	100%
F1 SCORE	0.99	0.99	1.00	1.00

**Feature explorer (full training set)**

accX RMS, accY RMS, accZ RMS

idle - correct, left\_right - correct, snake - correct, up\_down - correct, left\_right - incorrect, snake - incorrect, up\_down - incorrect

SNR ZDR

**On-device performance**

INFERRING TIME: 1 ms., PEAK RAM USAGE: 1.5K, ROM USAGE: 15.4K



# Model testing

Live classification - IESTI01\_Nano 33 BLE Sense | Arduino Nano 33 BLE Sense | Overview

studio.edgeimpulse.com/studio/37762/classification

EDGE IMPULSE

LIVE CLASSIFICATION (IESTI01\_NANO\_GESTURE\_CLASSIFICATION)

Did you know? Capture data from any device or development board into the *testing* category to live classify data - [Show options](#)

Classify new data

Device ⓘ No devices connected

Sensor

Sample length (ms.) 10000

Frequency

Start sampling

Connect using WebUSB

Classify existing test sample

testing.2965pa2d (left-right)

Load sample

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

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Live classification - IESTI01\_Ne | Arduino Nano 33 BLE Sense | Overview

studio.edgeimpulse.com/studio/37762/classification

studio.edgeimpulse.com wants to connect to a serial port

- cu.Bluetooth-Incoming-Port
- cu.MALS
- cu.RovaisAirPods-Wirelessi
- cu.SOC
- Nano 33 BLE (cu.usbmodem144301) - Paired

Connect using WebUSB

devices connected

Start sampling

Classify existing test sample

testing.2965pa2d (left-right)

Load sample

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral features
- NN Classifier
- Anomaly detection

Retrain model

Live classification

Model testing

Versioning

Deployment

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A large blue arrow points from the "NANO 33 BLE (cu.usbmodem144301) - Paired" item in the list to the "Connect" button. The "Connect" button is highlighted with a dashed orange border.

Live classification - IESTIO X Arduino Nano 33 BLE Sense X Overview

studio.edgeimpulse.com/studio/37762/classification#load-sample-34924205

## Classification result

**Summary**

Name: testing.2966pdie  
Expected outcome: testing

CATEGORY	COUNT
idle	0
left_right	99
snake	0
up-down	0
uncertain	2
anomaly	0

**Detailed result**

TIMESTAMP	IDLE	LEFT_RIGHT	SNAKE	UP-DOWN	ANOMALY
0	0	0.99	0.01	0	-0.31
80	0	0.98	0.02	0	-0.32
160	0	0.98	0.02	0	-0.31
240	0	0.99	0	0	-0.27
320	0	0.97	0.03	0	-0.22
400	0	0.93	0.07	0	-0.21
480	0	0.96	0.04	0	-0.22
560	0	0.93	0.07	0	-0.26
640	0	0.95	0.05	0	-0.31

**Raw data**  
testing.2966pdie

**Raw features**

```
-0.8856, 0.2179, 9.7971, -0.7266, 0.1712, 9.8090, -0.7051, -0.0790, 9.8138, -0.8212, -0.3041, 9.8234, -0.8452, -0.3005, 9.8114, -0...
```

**Spectral features (2,929 samples)**

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

**Processed features**

```
1.7157, 0.7937, 2.3502, 2.3810, 0.6182, 0.0000, 0.0000, 0.0000, 0.3535, 0.0034, 0.0079, 0.2118, 0.7937, 0.1547, 2.3810, 0.1420, 0.0...
```

**Anomaly explorer (2,929 samples)**

X Axis: accX RMS, Y Axis: accY RMS

Live classification - IESTIO X Arduino Nano 33 BLE Sense X Overview

studio.edgeimpulse.com/studio/37762/classification#load-sample-34924191

## Classification result

**Summary**

Name	testing.2966l26d
Expected outcome	testing
CATEGORY	COUNT
idle	0
left_right	0
snake	7
up-down	87
uncertain	7
anomaly	0

**Detailed result**

TIMESTAMP	IDLE	LEFT_RIGHT	SNAKE	UP-DOWN	ANOMALY
400	0.06	0.06	0.63	0.25	-0.08
480	0.04	0.06	0.58	0.31	-0.09
560	0	0.02	0.95	0.03	-0.09
640	0	0.02	0.92	0.06	-0.10
720	0	0.01	0.83	0.16	-0.08
800	0	0.01	0.49	0.49	-0.05
880	0	0	0.85	0.14	-0.02
960	0	0	0.58	0.42	-0.04
1040	0	0	0.31	0.69	-0.05

Show only unknowns

**RAW DATA**  
testing.2966l26d

accX  
accY  
accZ

**Raw features**

```
0.5519, -1.0738, 9.8102, 0.6273, -1.1217, 9.8246, 0.4956, -1.1205, 9.7923, 0.5004, -1.4533, 9.7959, 1.0391, -2.1308, 9.7851, 0.8021...
```

**Spectral features (2,929 samples)**

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

classified  
idle  
left\_right  
snake  
up-down  
classification 29

**Processed features**

```
0.3685, 0.7937, 0.4497, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0129, 0.0052, 0.0003, 2.3360, 0.7937, 2.5732, 3.1746, 0.3635, 0.0...
```

**Anomaly explorer (2,929 samples)**

X Axis: accX RMS  
Y Axis: accY RMS

trained  
classified  
classification 29





Live classification - IESTIO X | Arduino Nano 33 BLE Sense X | Overview X | +

studio.edgeimpulse.com/studio/37762/classification#load-sample-34929936

**EDGE IMPULSE**

**Summary**

Name: testing.2967slu4  
Expected outcome: testing

CATEGORY	COUNT
idle	0
left_right	0
snake	0
up-down	0

**Detailed result**

TIMESTAMP	IDLE	LEFT_RIGHT	SNAKE	UP-DOWN	ANOMALY
80	0	0.92	0	0.08	45.07
160	0	1.00	0	0	45.56
240	0	1.00	0	0	45.82
320	0	0.95	0	0.05	46.00
400	0	1.00	0	0	45.93
480	0	0.30	0	0.70	44.65
560	0	0.95	0	0.05	43.52
640	0	1.00	0	0	42.88
720	0	1.00	0	0	43.07
800	0	1.00	0	0	43.12
880	0	1.00	0	0	42.75

Show only unknowns

**RAW DATA**  
**testing.2967slu4**

accX, accY, accZ

**Raw features**

```
0.8775, -2.2851, 6.7576, 0.6907, -1.9201, 7.0210, 0.7599, -1.8567, 7.2377, 0.5507, -1.8675, 7.6555, 0.3316, -2.2817, 8.1918, 0.2023, -2.1069, 8.2744, 0.1532, -1.642...
```

**Spectral features (2,929 samples)**

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

classified, idle, left\_right, snake, up-down, classification 0

**Processed features**

```
1.1784, 0.7937, 1.3914, 4.7619, 0.1173, 0.0000, 0.0000, 0.0000, 0.1239, 0.0162, 0.0049, 1.9500, 0.7937, 2.2978, 3.9683, 0.1699, 0.0000, 0.0000, 0.3377, 0.05...
```

**Anomaly explorer (2,929 samples)**

X Axis: accY RMS, Y Axis: accX RMS

trained, classified

Distance from closest cluster  
accX RMS: 2.2272, accY RMS: 1.0098, accZ RMS: 45.4578

Model testing - IESTI01\_Nano\_ | Arduino Nano 33 BLE Sense | Overview

studio.edgeimpulse.com/studio/37762/validation

### EDGE IMPULSE

This lists all test data. You can manage this data through Data acquisition.

#### 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
testing.2968kh59	idle	10s	100%	101 idle
testing.2967slu4	testing	10s		101 anomaly
testing.29675kbr	snake	10s	64%	65 snake, 22 idle, 14 uncertain
testing.2966pdie	left_right	10s	98%	99 left_right, 2 uncertain
testing.2966l26d	up-down	10s	86%	87 up-down, 7 snake, 7 uncertain
testing.2965pa2d	left-right	10s		100 left_right, 1 uncertain

**Classify all**

#### Model testing output

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

Classifying data for Anomaly detection...  
Copying features from DSP block...  
Copying features from DSP block OK  
Classifying data...  
Scheduling job in cluster...  
Classifying data for Anomaly detection OK

**Job completed**

#### Model testing results

ACCURACY 87.13%

	IDLE	LEFT_RIGHT	SNAKE	UP-DOWN	ANOMALY	UNCERTAIN
IDLE	100%	0%	0%	0%	0%	0%
LEFT_RIGHT	0%	98.0%	0%	0%	0%	2.0%
SNAKE	21.8%	0%	64.4%	0%	0%	13.9%
UP-DOWN	0%	0%	6.9%	86.1%	0%	6.9%
ANOMALY	-	-	-	-	-	-

#### Feature explorer

accX RMS accY RMS accZ RMS

- idle - correct
- left\_right - correct
- snake - correct
- up-down - correct
- left\_right - incorrect
- snake - incorrect
- up-down - incorrect
- left-right
- testing

# Model Deployment

Deployment - IESTI01\_Nano\_G... | Arduino Nano 33 BLE Sense | Overview

studio.edgeimpulse.com/studio/37762/deployment

EDGE IMPULSE

DEPLOYMENT (IESTI01\_NANO\_GESTURE\_CLASSIFICATION)

MJRoBot (Marcelo Roval)

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.

An Arduino library with examples that runs on most Arm-based Arduino development boards.

C++ library

ARDUINO

Cube.MX CMSIS-PACK

WebAssembly

NVIDIA

TensorRT library

Build firmware

Or get a ready-to-go binary for your development board that includes your impulse.


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 FON™ Compiler

This screenshot shows the Edge Impulse deployment interface for a gesture classification model named 'IESTI01\_NANO\_GESTURE\_CLASSIFICATION'. The main area is titled 'DEPLOYMENT' and displays five deployment paths: 'Create library' (selected), 'C++ library', 'ARDUINO' (highlighted with a blue border), 'Cube.MX CMSIS-PACK', 'WebAssembly', and 'TensorRT library'. Below this, a section titled 'Build firmware' lists nine supported development boards: ST IoT Discovery Kit, Arduino Nano 33 BLE Sense, Eta Compute ECM3532 AI Sensor, SiLabs Thunderboard Sense 2, Himax WE-I Plus, Nordic nRF52840 DK + IKS02A1, Nordic nRF5340 DK + IKS02A1, Sony's Spresense, and Linux boards. At the bottom, there's an optional 'Select optimizations' section with a note about performance vs. accuracy and a 'Enable FON™ Compiler' button.

Deployment - IESTI01\_Nano\_G | Arduino Nano 33 BLE Sense | Overview

studio.edgeimpulse.com/studio/37762/deployment

## EDGE IMPULSE

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

### GETTING STARTED

- Documentation
- Forums

Nordic nRF5340 DK + IKS02A1

Sony's Spresense

Linux boards

#### 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

Quantized (int8)	RAM USAGE 1.5K	LATENCY 1 ms	ACCURACY
<b>Currently selected</b>	ROM USAGE 15.4K	-	<b>Analyze optimizations</b>
Unoptimized (float32)	RAM USAGE 1.5K	LATENCY 1 ms	ACCURACY
<b>Click to select</b>	ROM USAGE 17.8K	-	

Estimate for Cortex-M4F 80MHz (ST IoT Discovery Kit)

**Build**

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Deployment - IESTI01\_Nano\_G | Arduino Nano 33 BLE Sense | Overview

stUDIO.edgeimpulse.com/studio/37762/deployment

## EDGE IMPULSE

- Dashboard
- Devices
- Data acquisition
- Impulse design**
  - Create impulse
  - Spectral features
  - NN Classifier
  - Anomaly detection
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment**

---

### GETTING STARTED

- Documentation
- Forums

SiLabs Thunderboard Sense 2

Himax WE-I Plus

Nordic nRF52840 DK + IKS02A1

Sony's Spresense

Linux boards

**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**

Quantized (int8) ★	RAM USAGE <b>1.5K</b>	LATENCY <b>1 ms</b>	CONFUSION MATRIX
Currently selected	ROM USAGE <b>15.4K</b>	ACCURACY <b>87.87%</b>	
This optimization is recommended for best performance.			

Unoptimized (float32)	RAM USAGE <b>1.5K</b>	LATENCY <b>1 ms</b>	CONFUSION MATRIX
Click to select	ROM USAGE <b>17.8K</b>	ACCURACY <b>87.13%</b>	

Estimate for Cortex-M4F 64MHz (Arduino Nano 33 BLE Sense)

Build

Deployment - IESTI01\_Nano\_G... X | Arduino Nano 33 BLE Sense X | Overview X | +

stUDIO.edgeimpulse.com/studio/37762/deployment

**EDGE IMPULSE**

- Dashboard
- Devices
- Data acquisition
- Impulse design
  - Create impulse
  - Spectral features
  - NN Classifier
  - Anomaly detection
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment**

**GETTING STARTED**

- Documentation
- Forums

SiLabs Thunderboard Sense 2 | Himax WE-I Plus | Nordic nRF52840 DK + IKS02A1

Nordic nRF5340 DK + IKS02A1 | Sony's Spresense | Linux boards

**Select optimizations (optional)**

Model optimizations can increase computation speed. Select the recommended choices for your application.

**Enable EON™ Compilation**  
Same accuracy, up to 5x faster

**Available optimizations for NN**

Quantized (int8) ★	Currently selected
This optimization is recommended for best performance.	

Unoptimized (float32)	Click to select
1.5K ROM USAGE	1 ms ACCURACY
17.8K	87.13%

Estimate for Cortex-M4F 64MHz (Arduino Nano 33 BLE Sense)

**Built Arduino library**

Add this library through the Arduino IDE via:  
**Sketch > Include Library > Add .ZIP Library...**

Examples can then be found under:  
**File > Examples > IESTI01\_Nano\_Gesture\_Classification\_inferencing**

**Build**

**Build output**

- Creating job... OK (ID: 1029729)
- Writing templates...
- Writing templates OK
- Copying Edge Impulse SDK...
- Copying Edge Impulse SDK OK

model...

model OK

er and updating headers...

er and updating headers OK

ave...

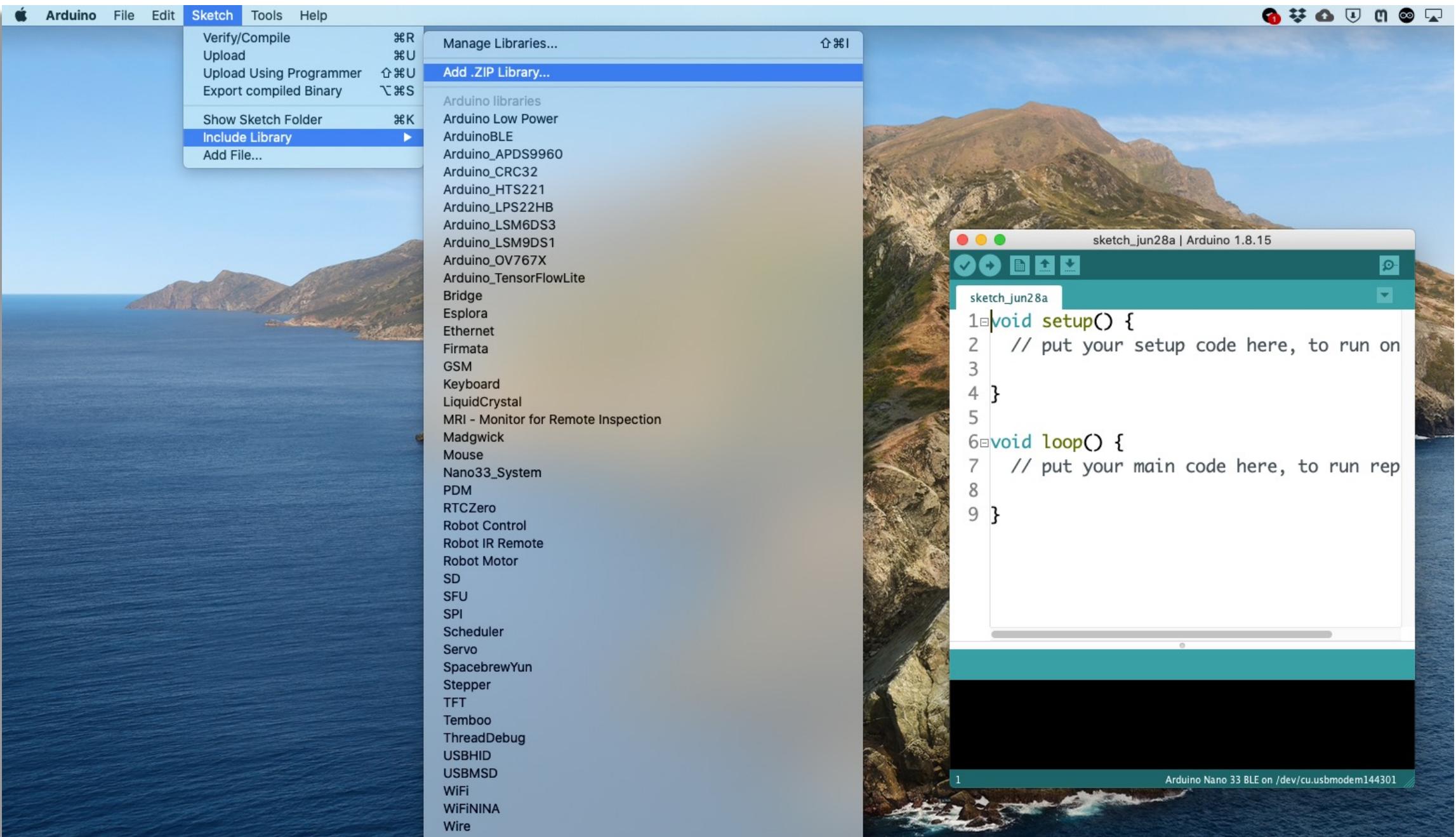
ave OK

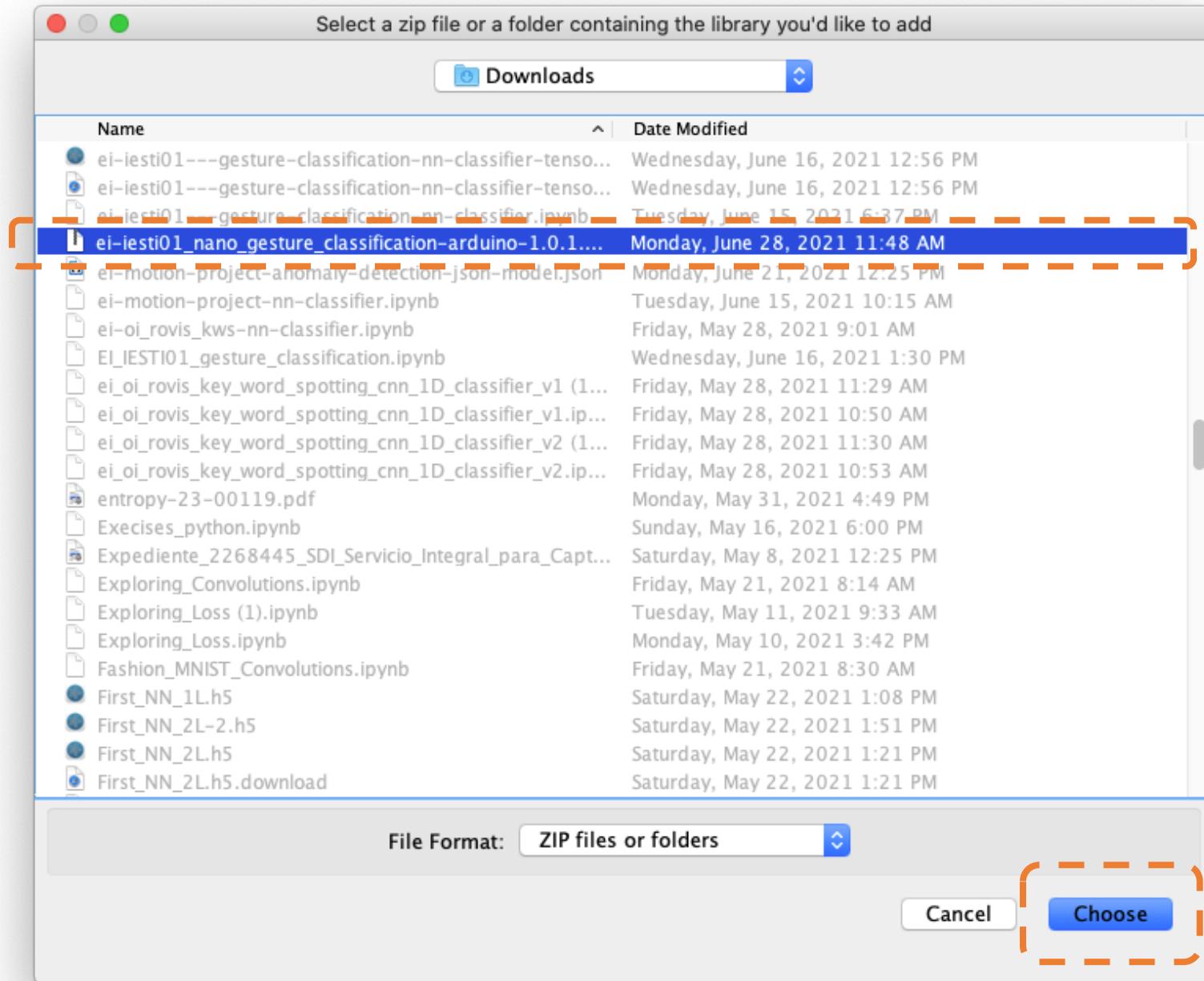
ei-iesti01\_nano\_g....zip

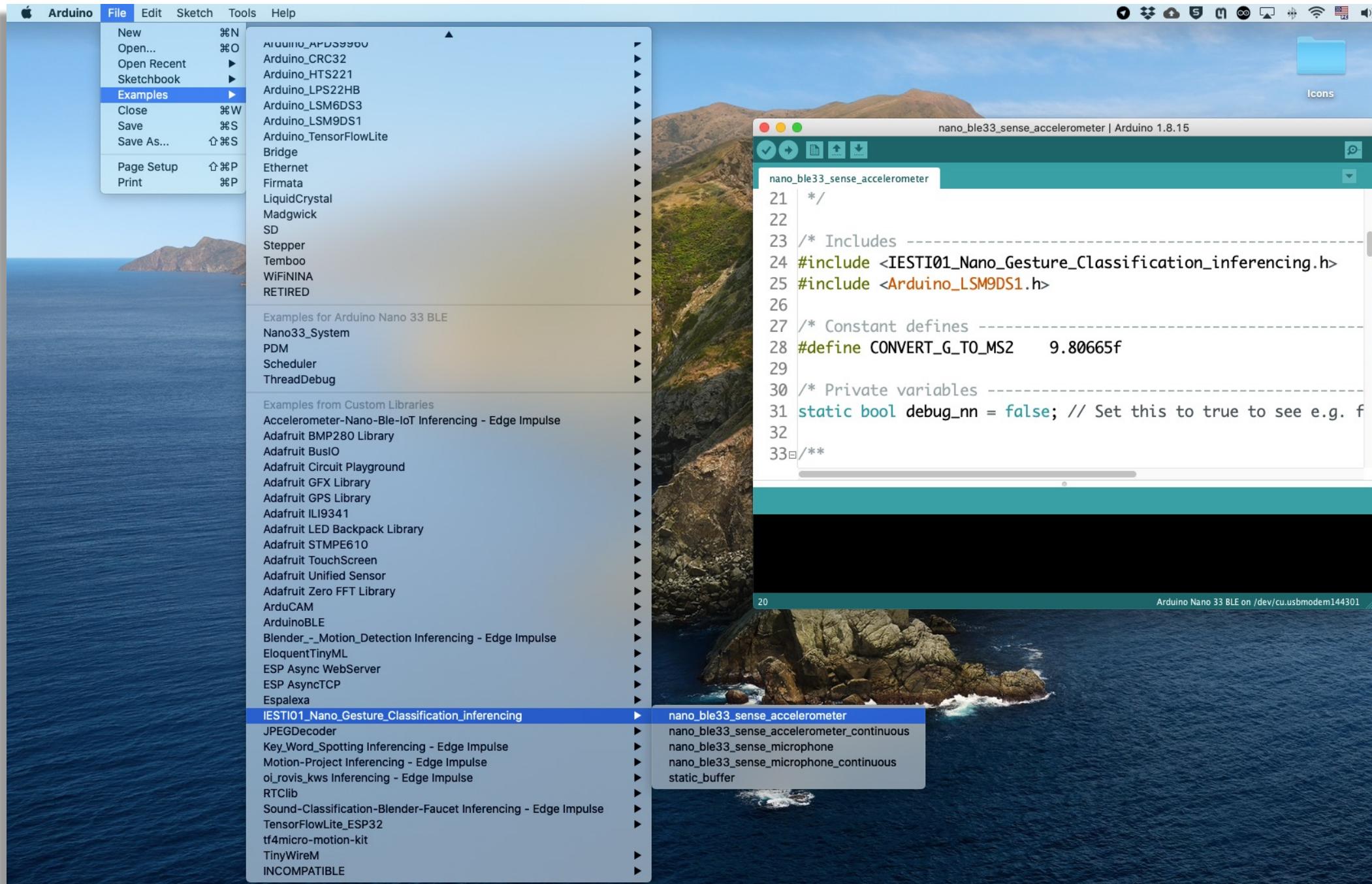
Show All X

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# Model Inference







Arduino

/dev/cu.usbmodem144301

Sampling...

Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):

```

idle: 0.0000
left_right: 0.93359 ←
snake: 0.06250
up-down: 0.00000
anomaly score: -0.261

```

Starting inferencing in 2 seconds...

Sampling...

Predictions (DSP: 21 ms., Classification: 0 ms., Anomaly: 1 ms.):

```

idle: 0.00391
left_right: 0.94141 ←
snake: 0.05469
up-down: 0.00000
anomaly score: -0.277

```

Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output

Preview

640 x 480 : 60 fps

nano\_ble33\_sense\_accelerometer | Arduino 1.8.15

```

113     err = run_classifier(&signal, &result, debug_nn);
114     if (err != EI_IMPULSE_OK) {
115         ei_printf("ERR: Failed to run classifier (%d)\n", err);
116         return;
117     }
118
119     // print the predictions
120     ei_printf("Predictions ");
121     ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
122             result.timing.dsp, result.timing.classification, result.timing.anomaly);
123     ei_printf(": \n");
124     for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
125         ei_printf("    %s: %.5f\n", result.classification[ix].label, result.classification[ix].score);
126     }
127 #if EI_CLASSIFIER_HAS_ANOMALY == 1
128     ei_printf("    anomaly score: %.3f\n", result.anomaly);
129 #endif
130

```

```

[=====] 97% (65/67 pages)write(addr=0x34, size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x41000, size=0x1000)
[=====] 98% (66/67 pages)write(addr=0x34, size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x42000, size=0x1000)
[=====] 100% (67/67 pages)
Done in 10.641 seconds
reset()

```

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Arduino Nano 33 BLE on /dev/cu.usbmodem144301 MAZINHO Developer

# Reading Material

# 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 \(Coursera\)](#)
- [Text Book: "TinyML" by Pete Warden, Daniel Situnayake](#)

I want to thank [Shawn Hymel](#) and [Edge Impulse](#), [Laurence Moroney from Google](#), [Harvard professor Vijay Janapa Reddi](#), [Ph.D. student Brian Plancher](#) and their staff for preparing the excellent material on TinyML that is the basis of this course at UNIFEI.

The IESTI01 course is part of the [TinyML4D](#), an initiative to make TinyML education available to everyone globally.

**Thanks**  
And stay safe!

