

IESTI01 – TinyML

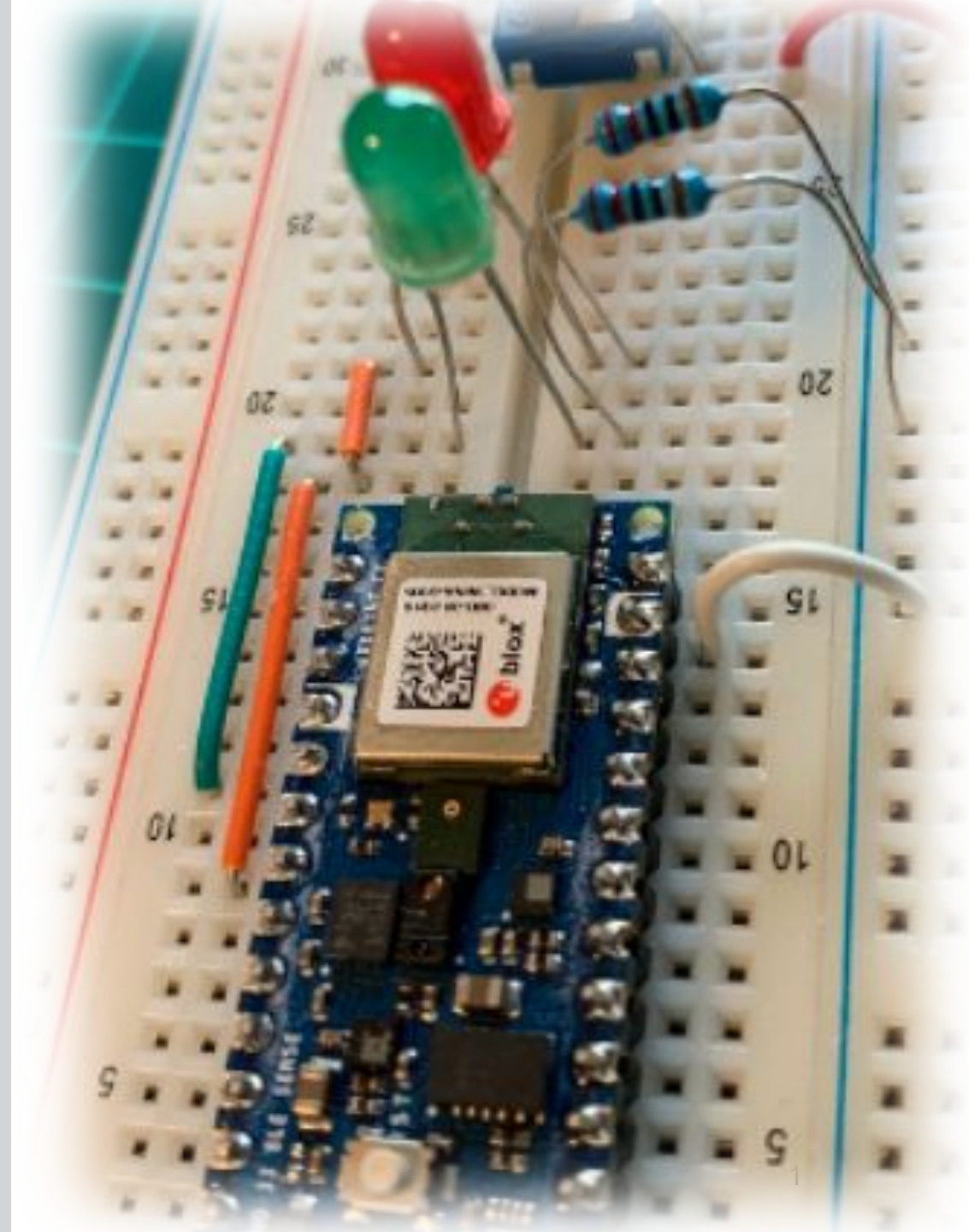
Embedded Machine Learning

- TinyML Kit Overview
- HW and SW installation & Test
- Connection with EI Studio
- Motion Classification



Prof. Marcelo Rovai

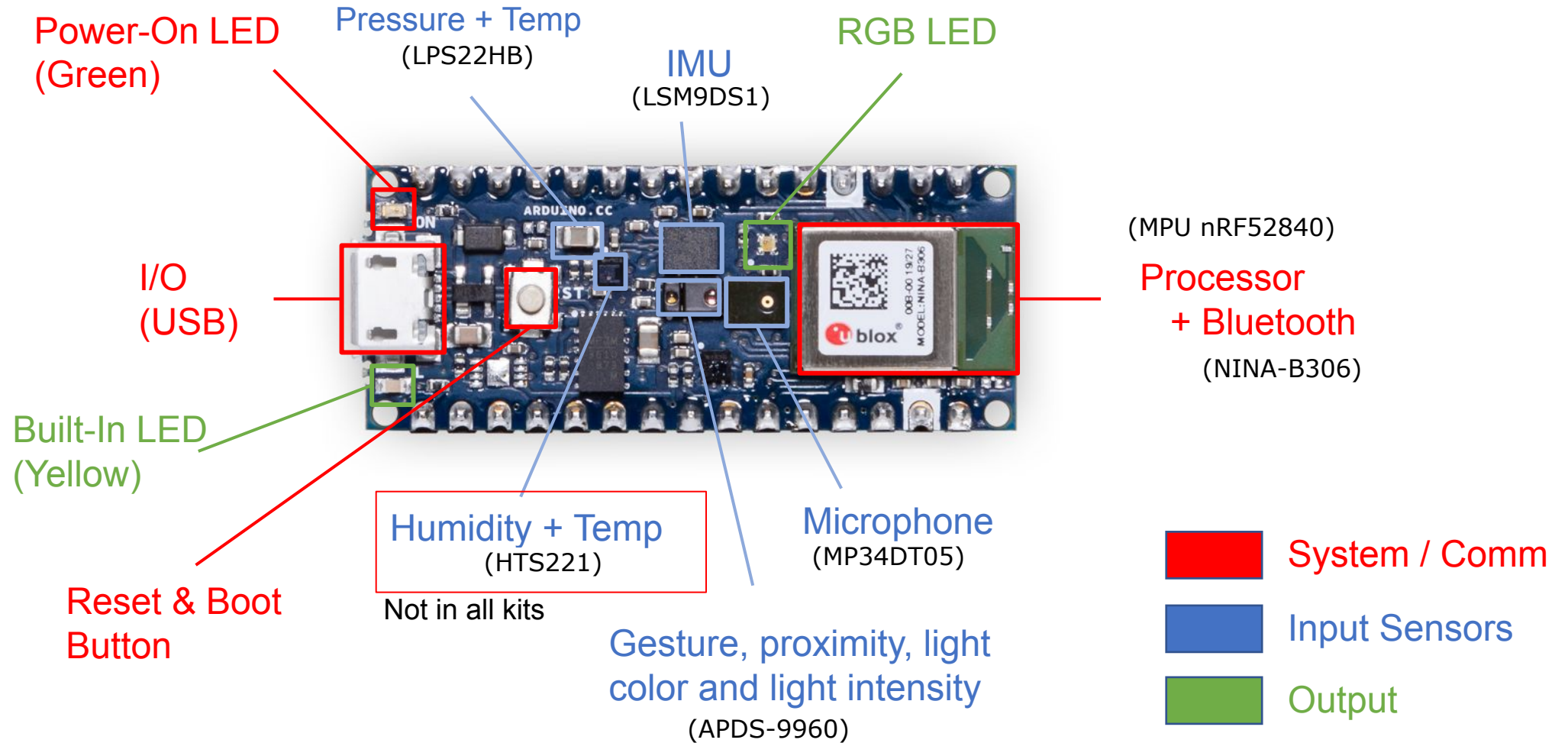
UNIFEI



TinyML Kit Overview



Nano 33 BLE Sense (Development board)

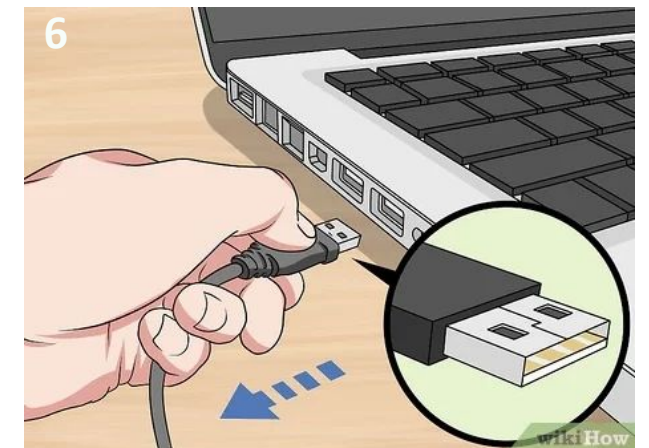
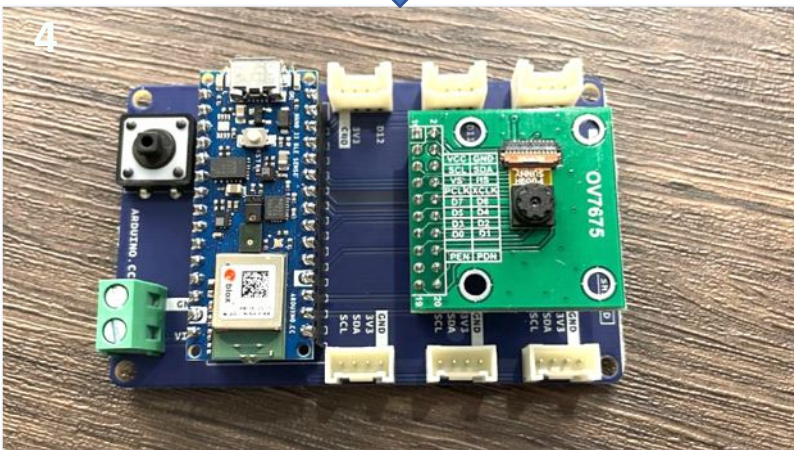
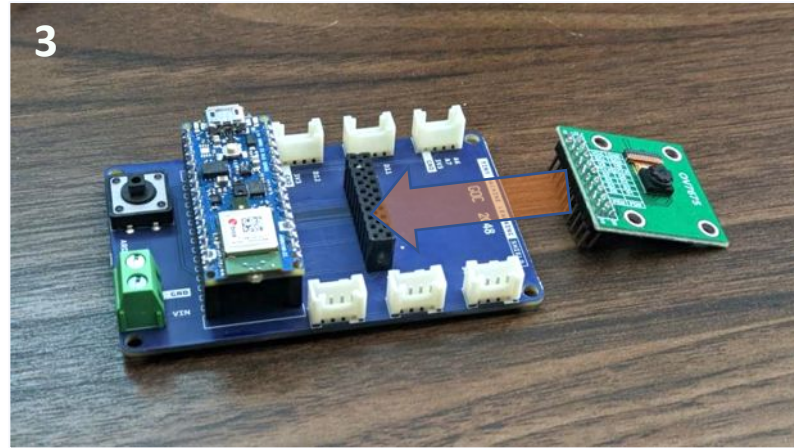
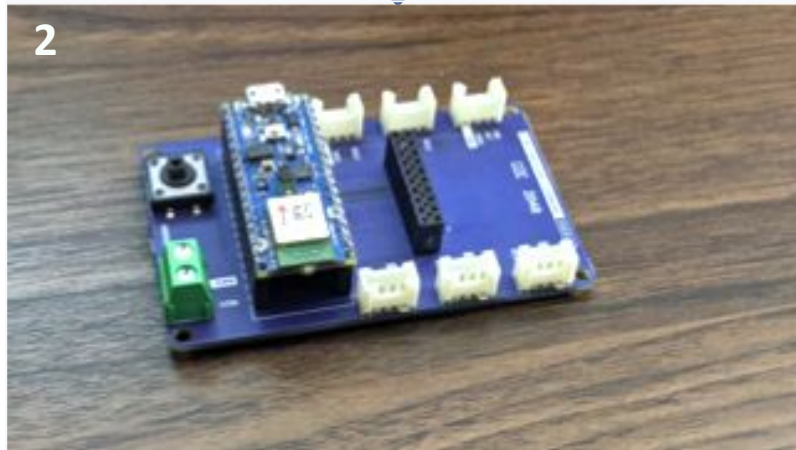
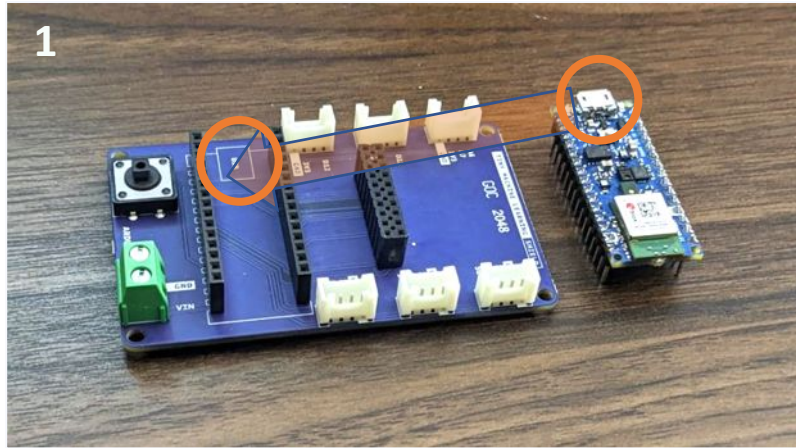


TinyML Kit Installation

- Hardware Set-up
- Software Set-up



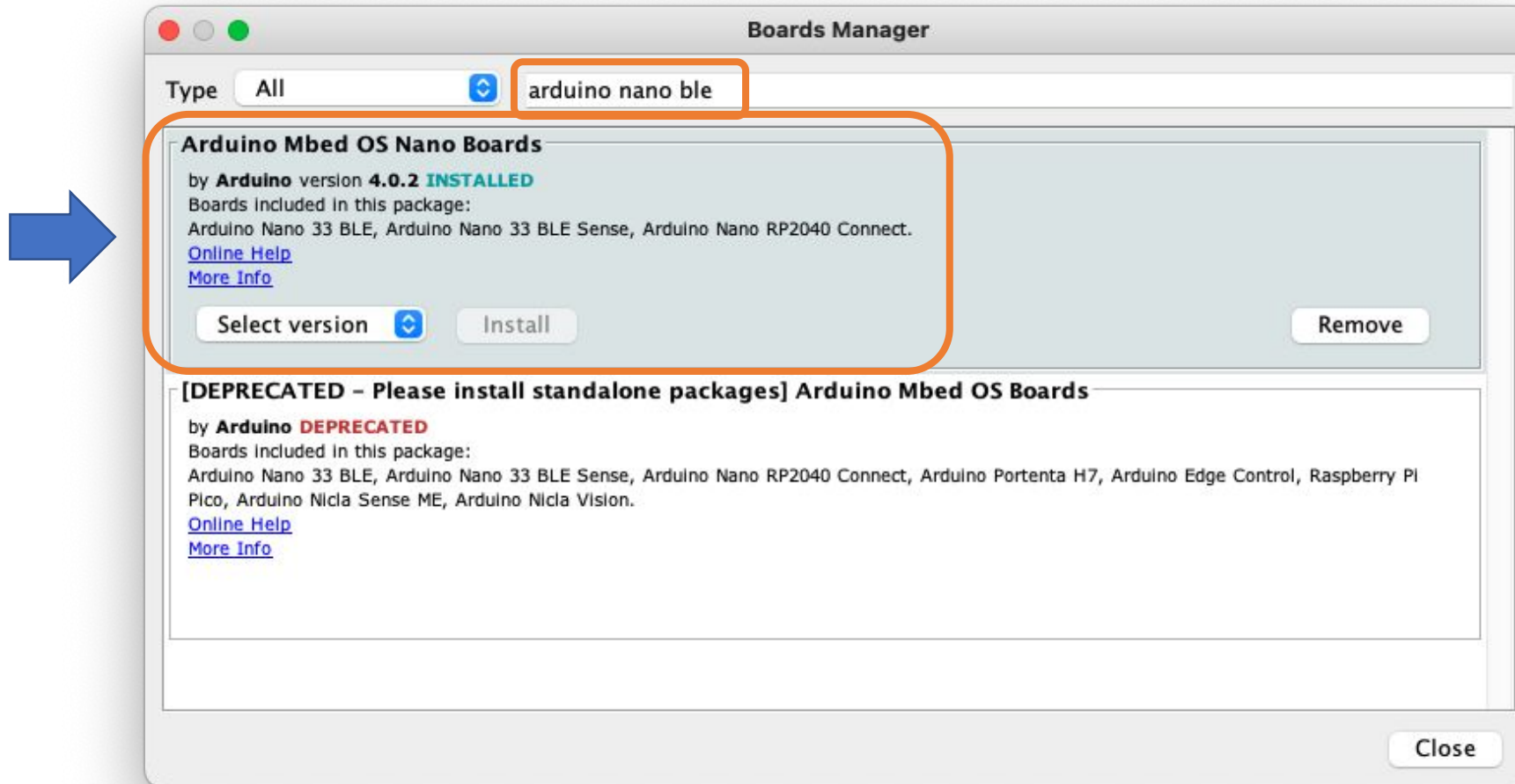
Installing the Hardware



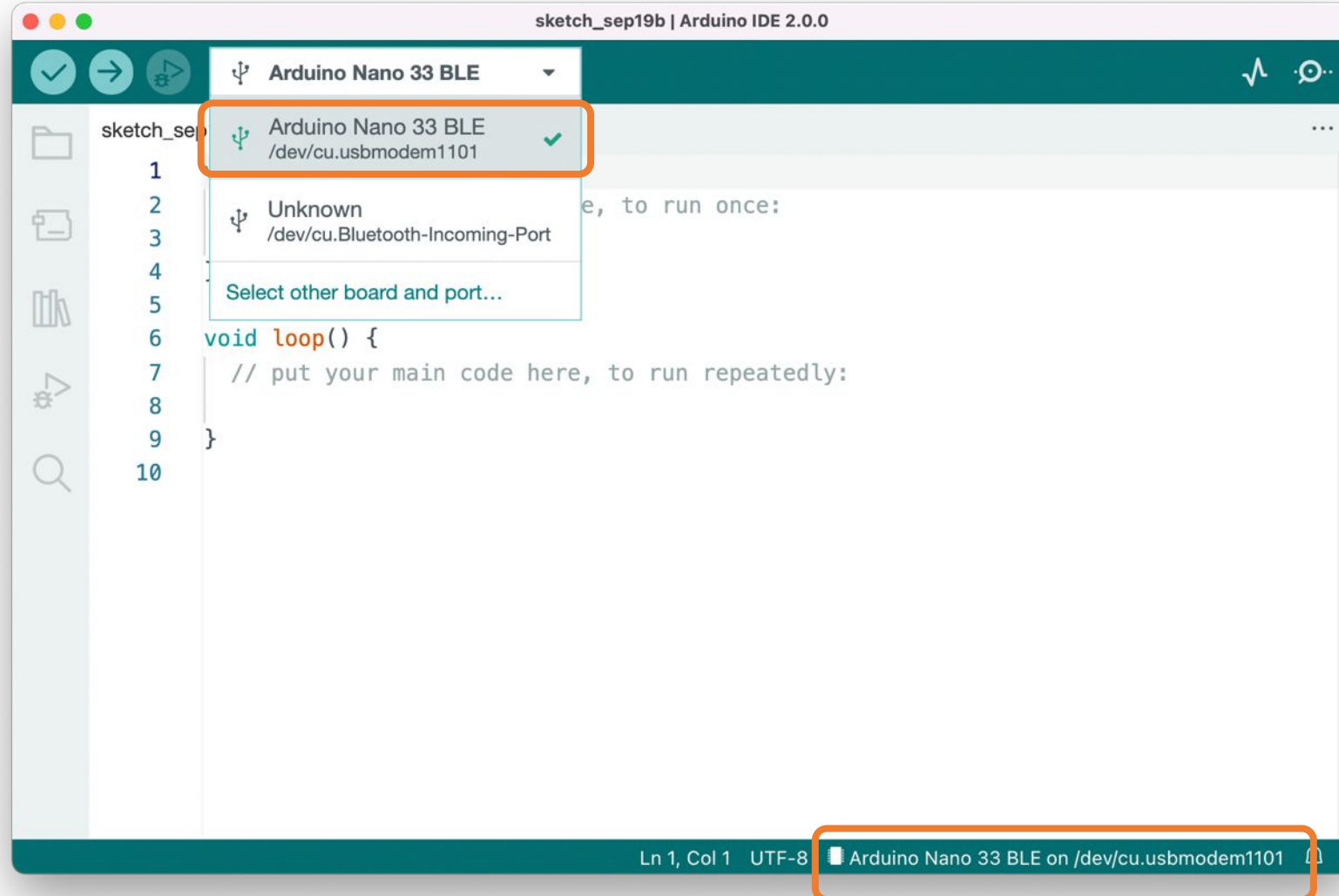
Installing the Board Files



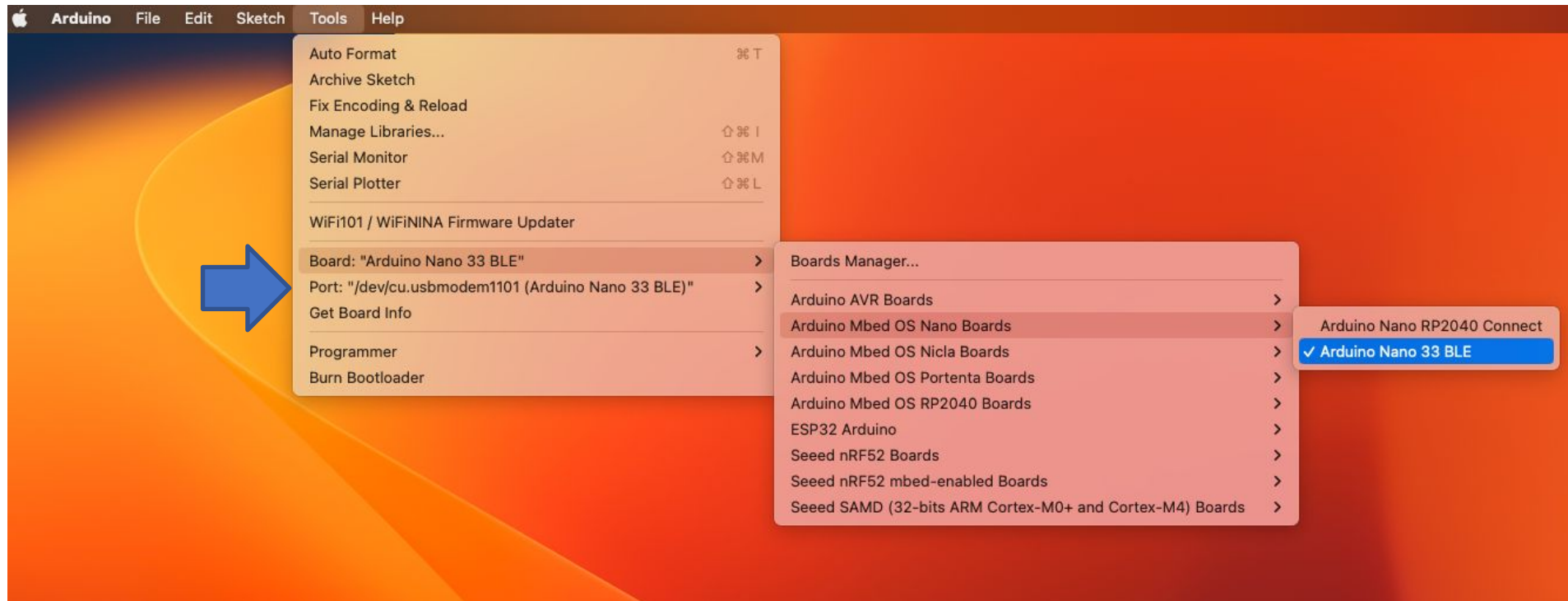
Installing the Board Files (IDE 1.8.19)



Select Board and Port

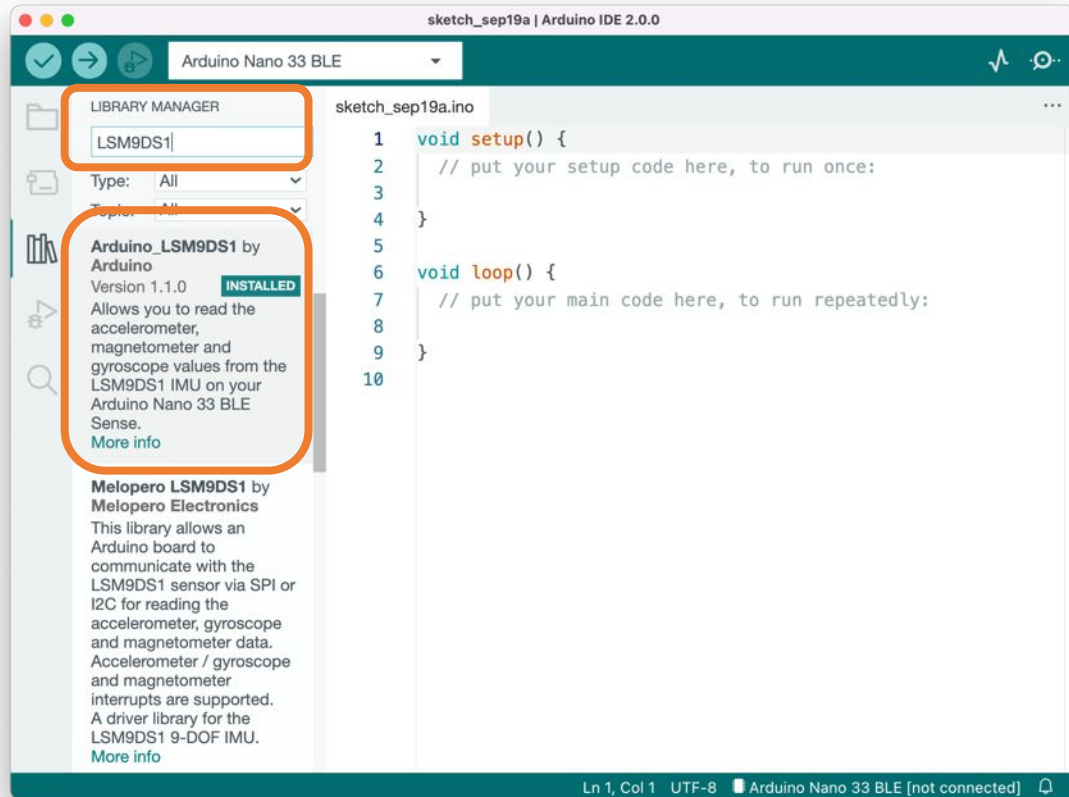


Select Board and Port (IDE 1.8.19)

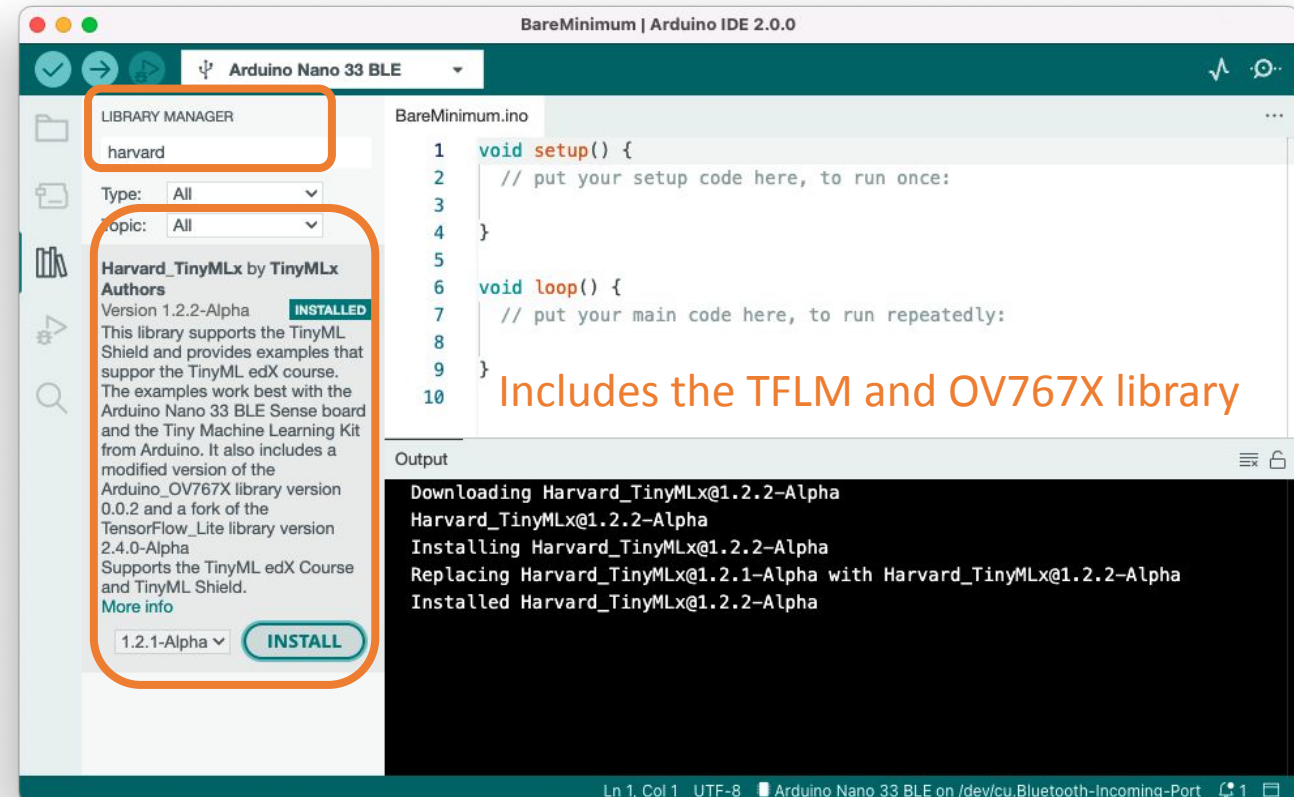


Installing Sensor and Auxiliary Libraries

IMU library

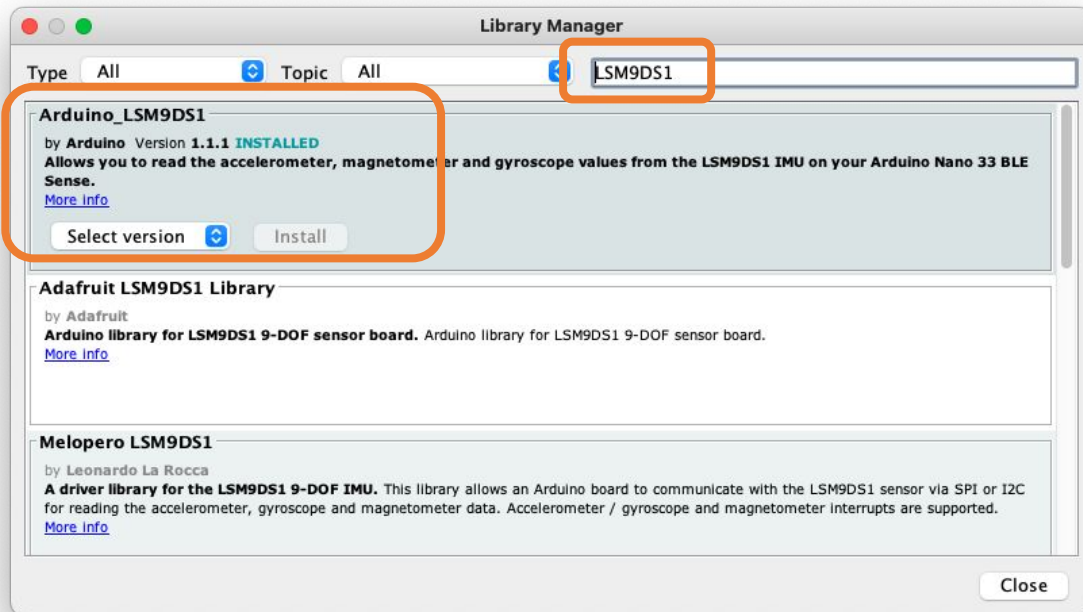


Shield, TFLM and Camera libraries

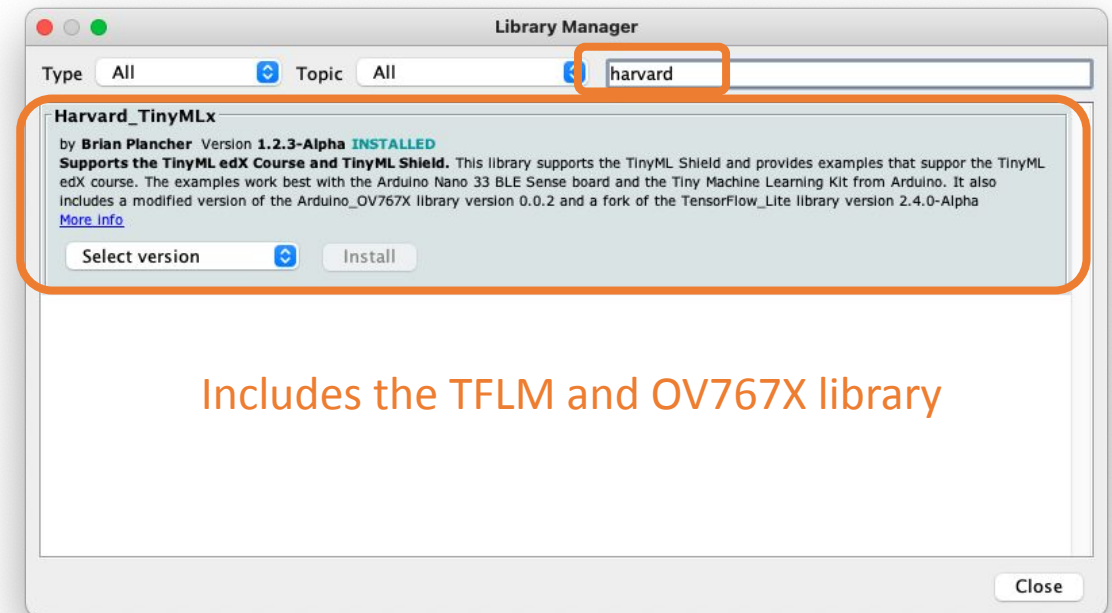


Installing Sensor and Auxiliary Libraries (IDE 1.8.19)

IMU library (LSM9DS1)

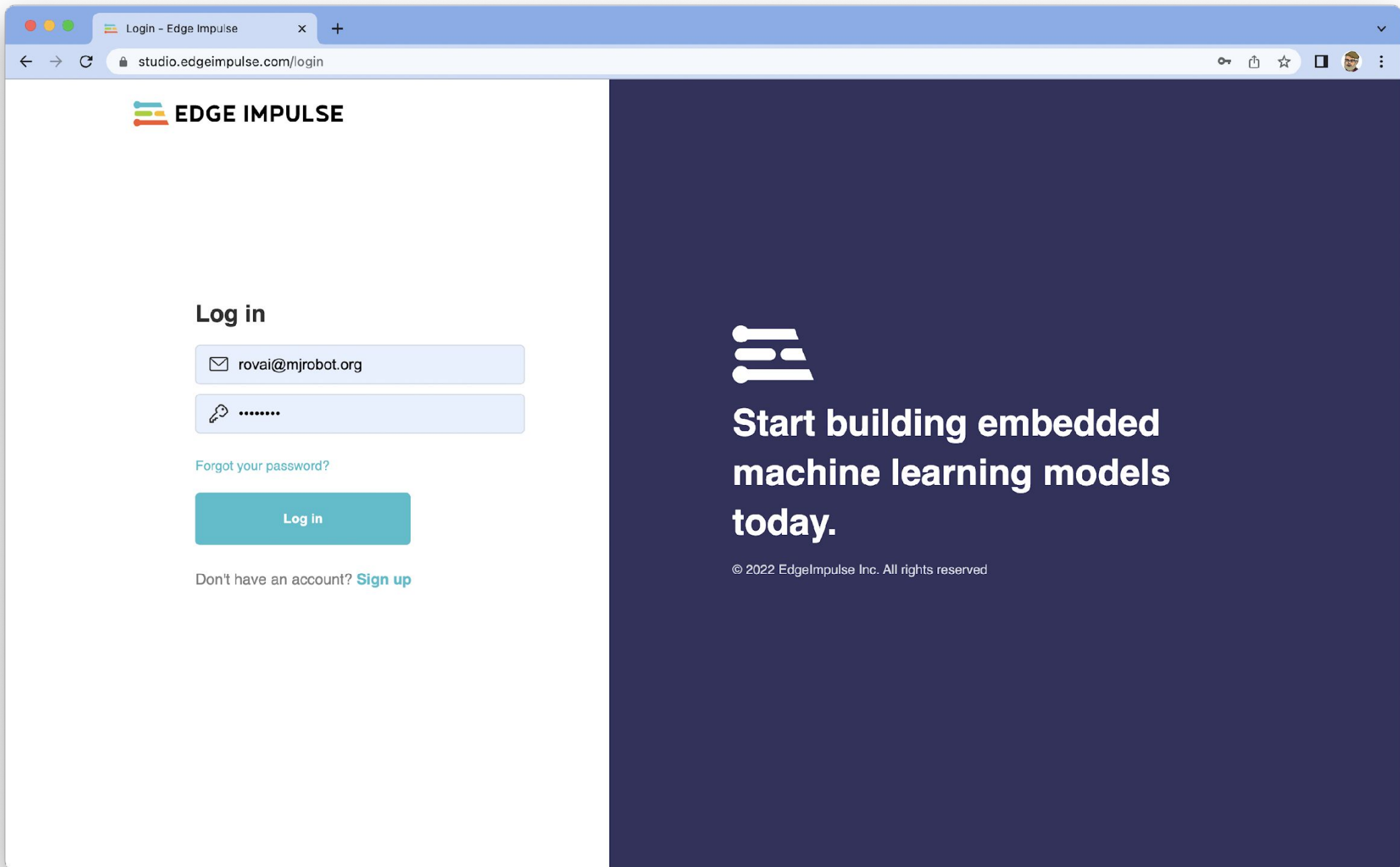


Shield, TFLM, and Camera libraries (Harvard)



Includes the TFLM and OV767X library

Set up connection between **Arduino Nano**
and **Edge Impulse**



Profile - Projects - Edge Impulse

studio.edgeimpulse.com/studio/profile/projects

EDGE IMPULSE

ProjectsCustom ML blocks



Marcelo Rovai

Projects

+ Create new project

Marcelo Rovai / TinyML4D - Project Setup - Gesture Classification

...

...

...

...

...

...

...

...

...

...

...

Marcelo Rovai / Bean Disease Classifier

...

Marcelo Rovai / IESTI01-Motion_Classification-Anomaly_Detection

PUBLIC

...

Marcelo Rovai / IESTI01_Keyword_Spotting_project

...

Marcelo Rovai / IESTI01 - Image Classification

PUBLIC

...

Create a new project

Enter the name for your new project:

IESTI01-2023-1-Motion-Classification-Anomaly-Detection

Choose your project type:

☒ Developer

20 min job limit, 4GB or 4 hours of data, limited collaboration.

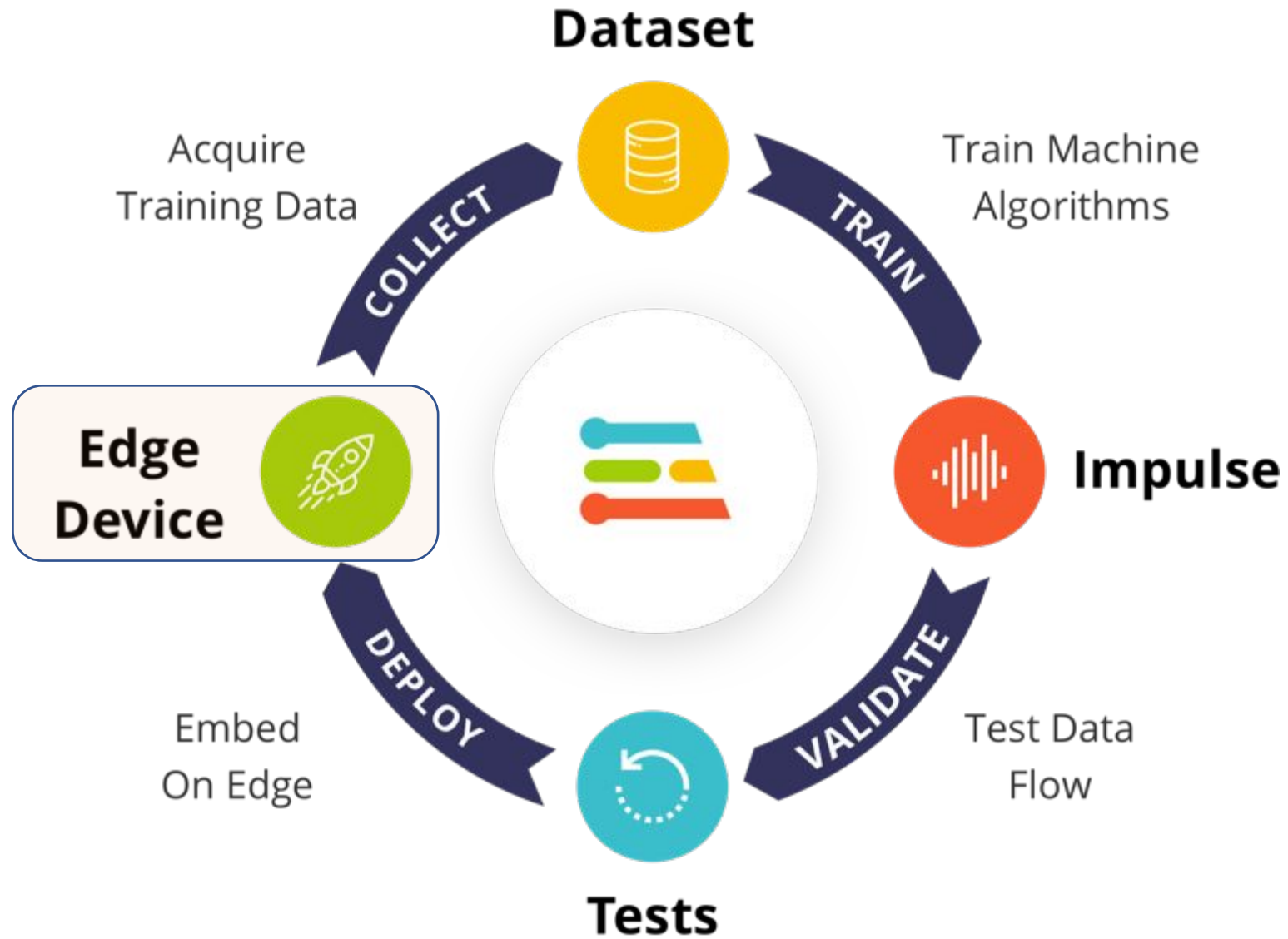
☐ Enterprise

No job or data size limits, higher performance, custom blocks. [Learn more](#)

Create new project

iesti01-motion_cl....zip

Show All



- Pre-Processing Data
- Design a Model
- Train a Model

The screenshot shows the Edge Impulse Studio web interface. On the left sidebar, the 'Devices' menu item is highlighted with an orange box and labeled with a red '1'. A modal dialog titled 'Collect new data' is open in the center, with the 'Connect your device or development board' option highlighted by an orange box and labeled with a red '2'. A large orange arrow points from this option to a second modal dialog titled 'Connect your device or development board'. This second dialog shows a terminal snippet with the command `$ edge-impulse-data-forwarder` and the text 'Or connect a supported device or development board:', which is highlighted by an orange box and labeled with a red '3'. Below this is a search bar for 'Search supported development boards' and a '< Back' button at the bottom left.

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

EON Tuner

Retrain model

Live classification

Model testing

Versioning

Deployment

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Collect new data

Collect data directly from your phone, computer, device, or development board.

Scan QR code to connect to your phone

Connect to your computer

Connect your device or development board

Connect your device or development board

You can connect almost any device over serial using a data forwarder:

```
$ edge-impulse-data-forwarder
```

Or connect a supported device or development board:

Search supported development boards

< Back

IES101-2023-1-Motion-Classi

Overview - Edge Impulse Docu

docs.edgeimpulse.com/docs/development-platforms/fully-supported-development-boards

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API and SDK references

What is embedded ML, anyway?

Frequently asked questions

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Bring your own model (BYOM)

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Learning blocks >

EON Tuner >

Retrain model

Powered By GitBook

Just want to experience Edge Impulse? You can also use your **Mobile phone!**

Officially supported MCU targets

- Alif Ensemble E7
- Arduino Nano 33 BLE Sense
- Arduino Nicla Sense ME
- Arduino Nicla Vision
- Arduino Nicla Voice
- Arduino Portenta H7 + Vision Shield
- Espressif ESP32
- Himax WE-I Plus
- Infineon CY8CKIT-062-BLE Pioneer Kit
- Infineon PSoC 62S2 Wi-Fi BT Pioneer Kit
- Nordic Semi nRF52840 DK
- Nordic Semi nRF5340 DK
- Nordic Semi nRF9160 DK
- Nordic Semi Thingy:53
- Nordic Semi Thingy:91
- OpenMV Cam H7 Plus
- Renesas CK-RA6M5 Cloud Kit
- Seeed Grove Vision AI Module

https://docs.edgeimpulse.com/docs/development-platforms/officially-supported-mcu-targets/arduino-nano-33-ble-sense

El/Arduino CLI



Devices - SciTinyML-Motion-A X Arduino Nano 33 BLE Sense - X Arduino Nano 33 BLE Sense - X

docs.edgeimpulse.com/docs/development-boards/arduino-nano-33-ble-sense

EDGE IMPULSE Guides API Reference Forum Search...

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
Arduino Portenta H7 + Vision Shield
Open MV Cam H7 Plus
Himax WE-I Plus
Nordic Semi nRF52840 DK
Nordic Semi nRF5340 DK
Nordic Semi nRF9160 DK
Nordic Semi Thingy:91
SiLabs Thunderboard Sense 2
Sony's Spresense
Syntiant Tiny ML Board
TI CC1352P Launchpad
Raspberry Pi 4
Raspberry Pi RP2040
NVIDIA Jetson Nano
Intel Based Macs
Linux x86_64
Mobile Phone

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.

You can also use the [Arduino Tiny Machine Learning Kit](#) to run image classification models on the edge with the Arduino Nano and attached OV7675 camera module (or [connect the hardware together via jumper wire and a breadboard](#) if purchased separately).

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

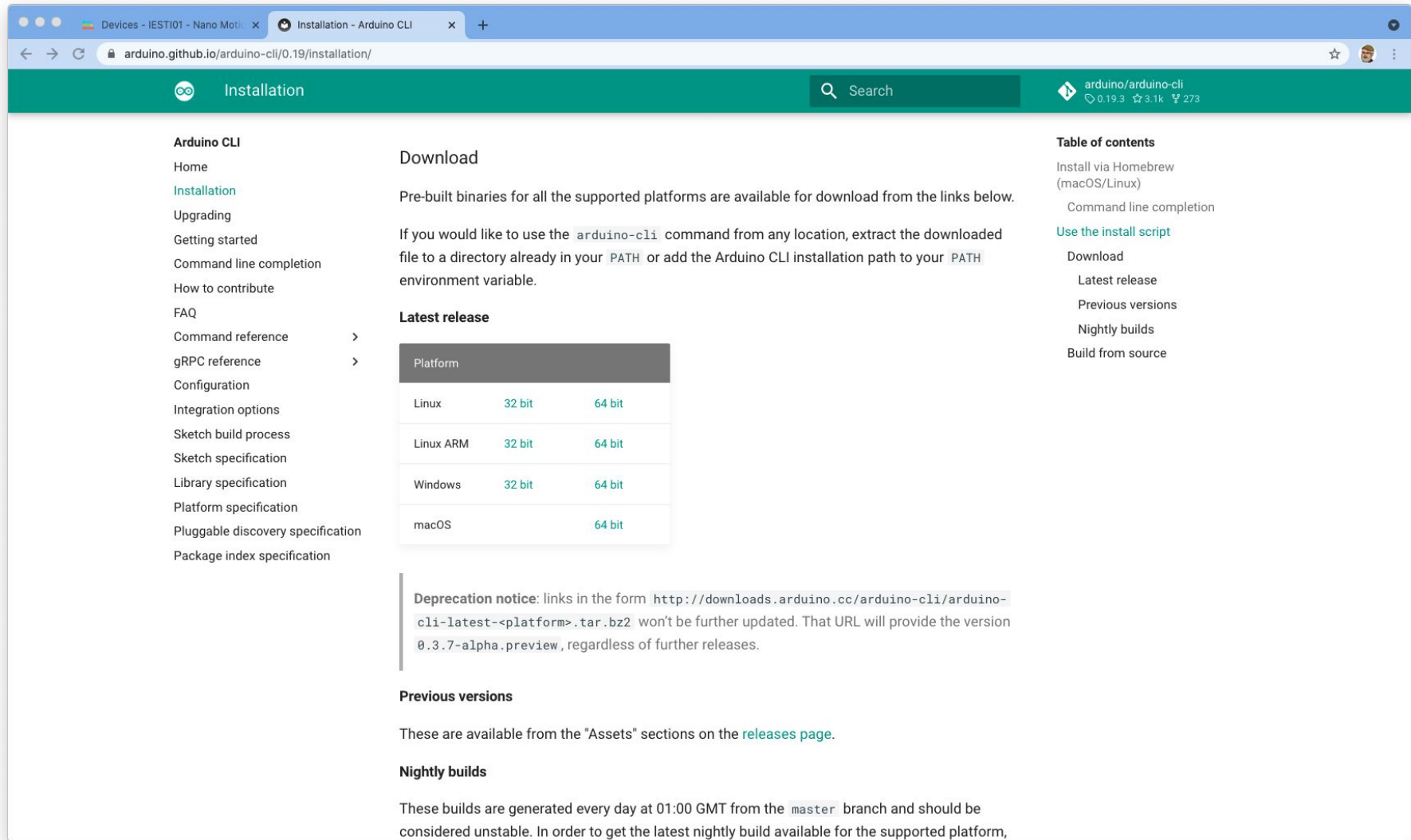
To set this device up in Edge Impulse, you will need to install the following software:

1. [Edge Impulse CLI](#).
2. [Arduino CLI](#).
 - Here's an [instruction video for Windows](#).
 - The [Arduino website](#) has instructions for macOS and Linux.

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

Go to 2. Arduino CLI

Arduino CLI



The screenshot shows the Arduino CLI installation page on GitHub. The page has a green header with the Arduino logo and the text "Installation". Below the header, there is a sidebar on the left with a list of links: Home, Installation (highlighted), Upgrading, Getting started, Command line completion, How to contribute, FAQ, Command reference, gRPC reference, Configuration, Integration options, Sketch build process, Sketch specification, Library specification, Platform specification, Pluggable discovery specification, and Package index specification. The main content area is titled "Download" and contains the following text: "Pre-built binaries for all the supported platforms are available for download from the links below. If you would like to use the `arduino-cli` command from any location, extract the downloaded file to a directory already in your `PATH` or add the Arduino CLI installation path to your `PATH` environment variable." Below this text is a table titled "Latest release" with the following data:

Platform	32 bit	64 bit
Linux	32 bit	64 bit
Linux ARM	32 bit	64 bit
Windows	32 bit	64 bit
macOS		64 bit

Below the table is a "Deprecation notice" stating: "links in the form `http://downloads.arduino.cc/arduino-cli/latest-<platform>.tar.bz2` won't be further updated. That URL will provide the version `0.3.7-alpha.preview`, regardless of further releases." Below the notice is a "Previous versions" section with the text: "These are available from the 'Assets' sections on the [releases page](#)." Below that is a "Nightly builds" section with the text: "These builds are generated every day at 01:00 GMT from the `master` branch and should be considered unstable. In order to get the latest nightly build available for the supported platform,"

On the right side of the page, there is a "Table of contents" section with the following links: "Install via Homebrew (macOS/Linux)", "Command line completion", "Use the install script", "Download", "Latest release", "Previous versions", "Nightly builds", and "Build from source".



See this video for Windows installation: <https://www.youtube.com/watch?v=1jMWsFER-Bc>

Arduino CLI Installation Summary

If you're on Windows:

- Unzip the .zip file to C:\Program Files\arduino-cli
- Open System Properties > Advanced > Environment Variables
- Path under "user variables" > Edit
- Add C:\Program Files\arduino-cli

If you're on macOS:

- I recommend using the curl method or homebrew shown on the installation page:
<https://arduino.github.io/arduino-cli/0.21/installation/>
- if you use the curl method, it likely installs arduino-cli to ~/bin. That might not be on your path. So, you might need to run: `export PATH=$PATH:~/bin`

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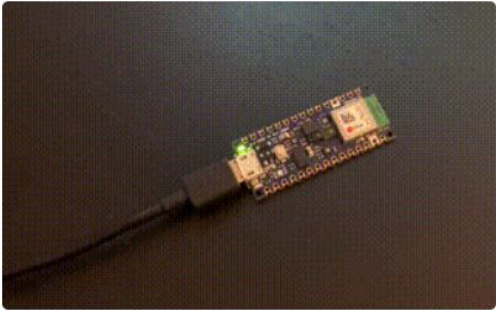
EON Tuner

Powered By GitBook

1

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

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.

arduino-nano-33....zip

Show All

```
marcelo_rovai — flash_mac.command — 138x42

Last login: Tue May 23 15:47:55 on console
/Users/marcelo_rovai/Downloads/arduino-nano-33-ble-sense\ \({18}\)/flash_mac.command ; exit;
(base) marcelo_rovai@Marcelos-MacBook-Pro ~ % /Users/marcelo_rovai/Downloads/arduino-nano-33-ble-sense\ \({18}\)/flash_mac.command ; exit;
You're using an untested version of Arduino CLI, this might cause issues (found: 0.31.0, expected: 0.18.x)
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 352560 bytes to flash (87 pages)
[=====] 100% (87/87 pages)
Done in 13.971 seconds

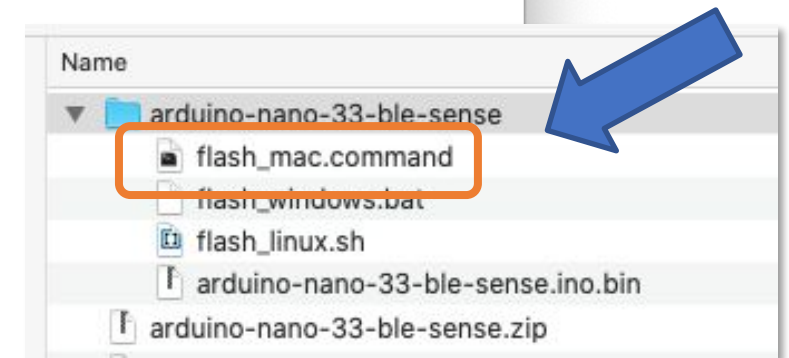
A new release of Arduino CLI is available: 0.31.0 → 0.32.2
https://arduino.github.io/arduino-cli/latest/installation/#latest-packages

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'

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

```

C:\> Prompt de Comando

Microsoft Windows [versão 10.0.19041.1052]
(c) Microsoft Corporation. Todos os direitos reservados.

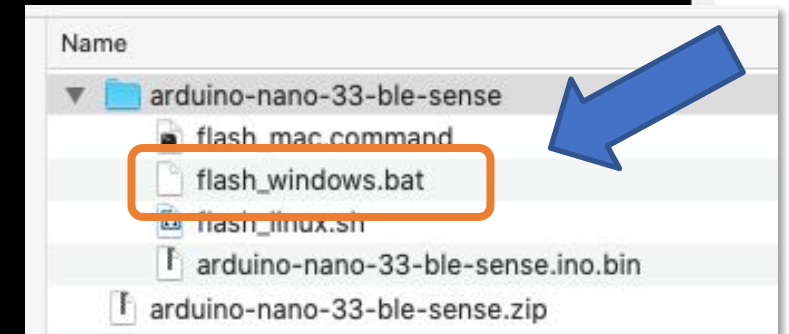
C:\Users\GUILH>arduino-cli
Arduino Command Line Interface (arduino-cli).

Usage:
  arduino-cli [command]

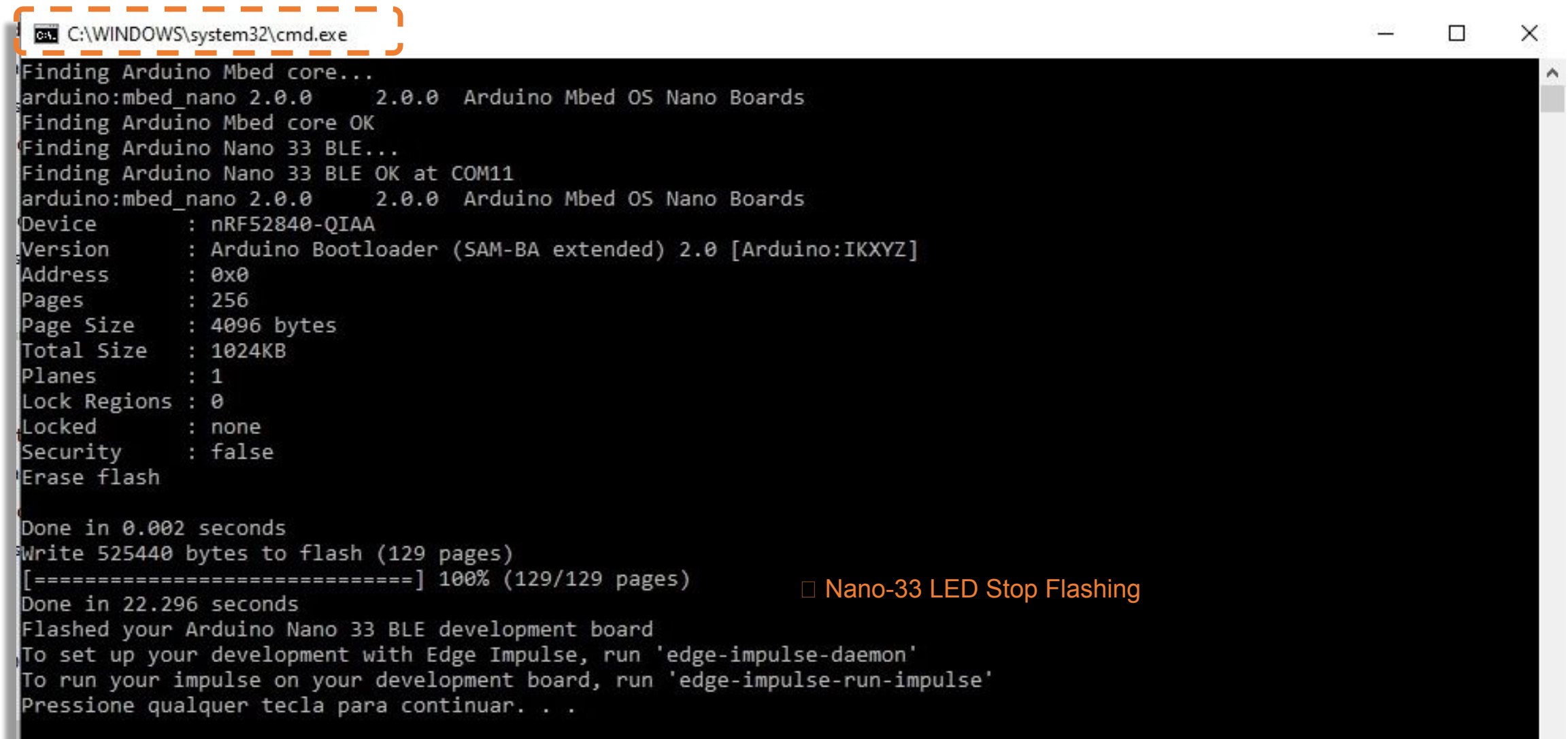
Examples:
  arduino-cli <command> [flags...]

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

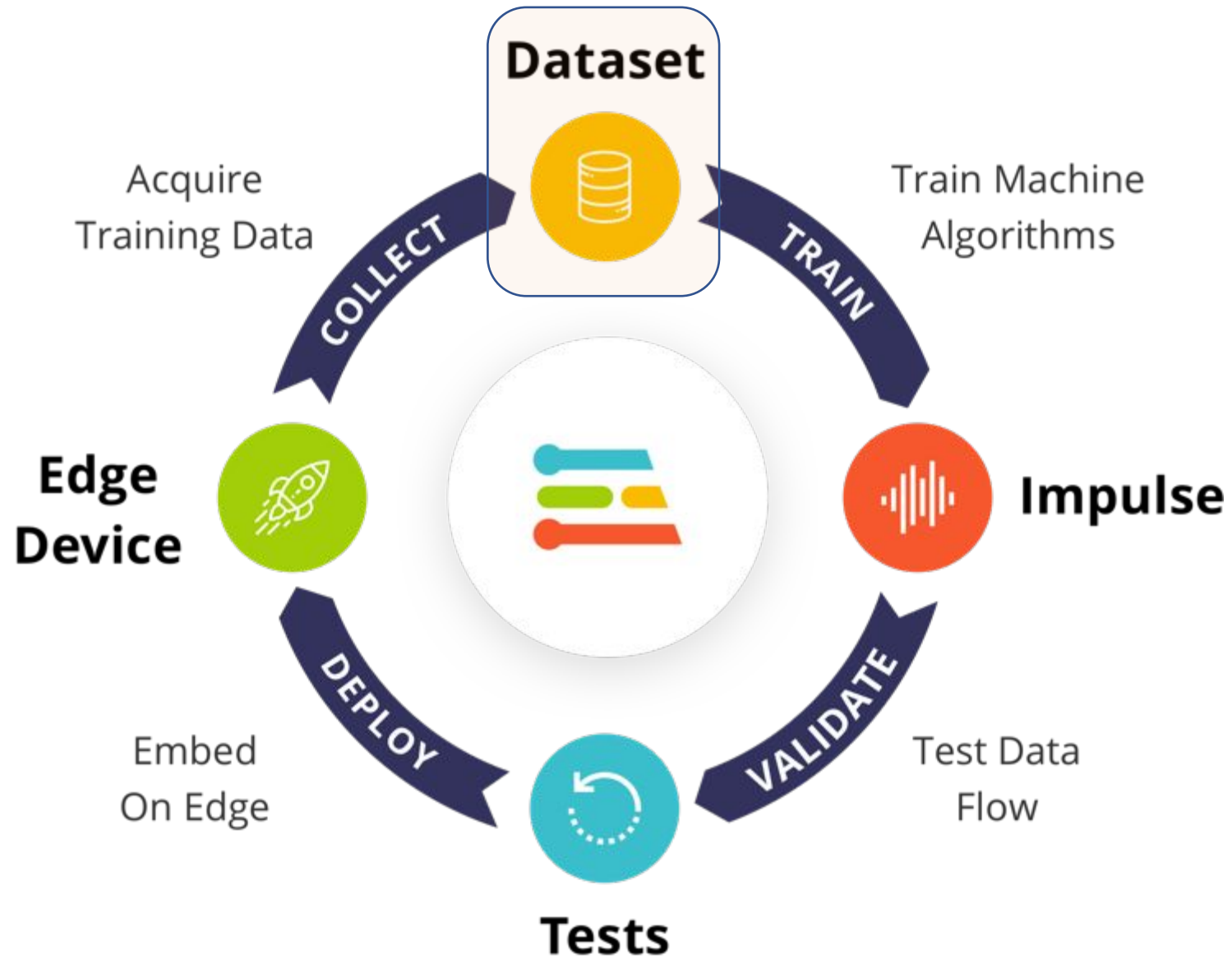


```
C:\WINDOWS\system32\cmd.exe
Finding Arduino Mbed core...
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Finding Arduino Mbed core OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK at COM11
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Device       : 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

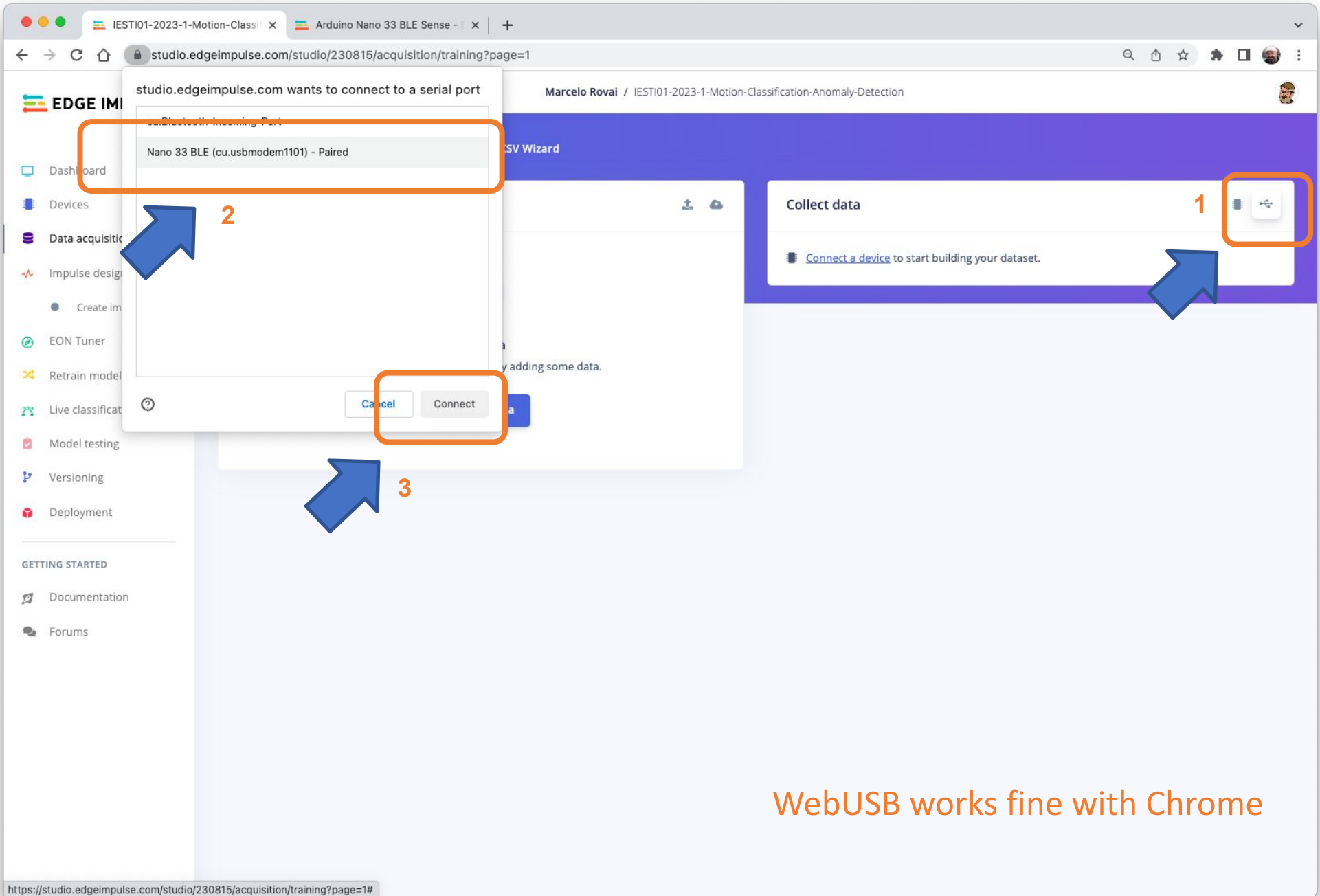
Done in 0.002 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 22.296 seconds
Flashed your Arduino Nano 33 BLE development board
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'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

□ Nano-33 LED Stop Flashing

Sensor's Test



- Pre-Processing Data
- Design a Model
- Train a Model



WebUSB works fine with Chrome

Select the **sensor** that you want to capture data from. For example, to capture accelerometer data, select **Inertial**. Then, enter with a **label**, for example, **lift**, and the **sample length**, for example, 10s (10,000 ms). And **Start Sampling**. The sampling frequency is automatically captured from the MCU" code.

The screenshot shows the Edge Impulse Studio web interface. The browser address bar displays 'studio.edgeimpulse.com/studio/204591/acquisition/training?page=1'. The user is logged in as 'Marcelo Rovai / IESTI01 - Sensor Test'. The interface has a sidebar on the left with navigation links: Dashboard, Devices, Data sources, Data acquisition, Impulse design, EON Tuner, Retrain model, Live classification, Model testing, Versioning, and Deployment. The main content area has tabs for 'Training data', 'Test data', 'Data explorer', 'Upload data', 'CSV Wizard', and 'Export data'. A notification bar says 'Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options'. The 'Collected data' section shows 'No data collected yet' with a 'Let's collect some data' button. The 'Record new data' section contains a 'Device' dropdown (36:17:55:F9:70:F7), a 'Label' input (lift), a 'Sample length (ms.)' input (10000), a 'Sensor' dropdown (Built-in microphone), and a 'Frequency' dropdown (100Hz). The 'Sensor' dropdown is open, showing a list of options: Inertial (selected), Environmental, Interactional, Inertial + Environmental, Inertial + Interactional, Environmental + Interactional, Inertial + Environmental + Interactional, Camera (160x120), and Camera (128x96). A blue arrow points from the 'Inertial' option to the 'Start sampling' button.

IMU sensor (Inertial)



EDGE IMPULSE

Marcelo Roval / IESTI01-2023-1-Motion-Classification-Anomaly-Detection

Dataset | Data explorer | Data sources | CSV Wizard

DATA COLLECTED: 10s

TRAIN / TEST SPLIT: 100% / 0%

Collect data

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

Label: lift

Sample length (ms.): 10000

Sensor: Inertial

Frequency: 100Hz

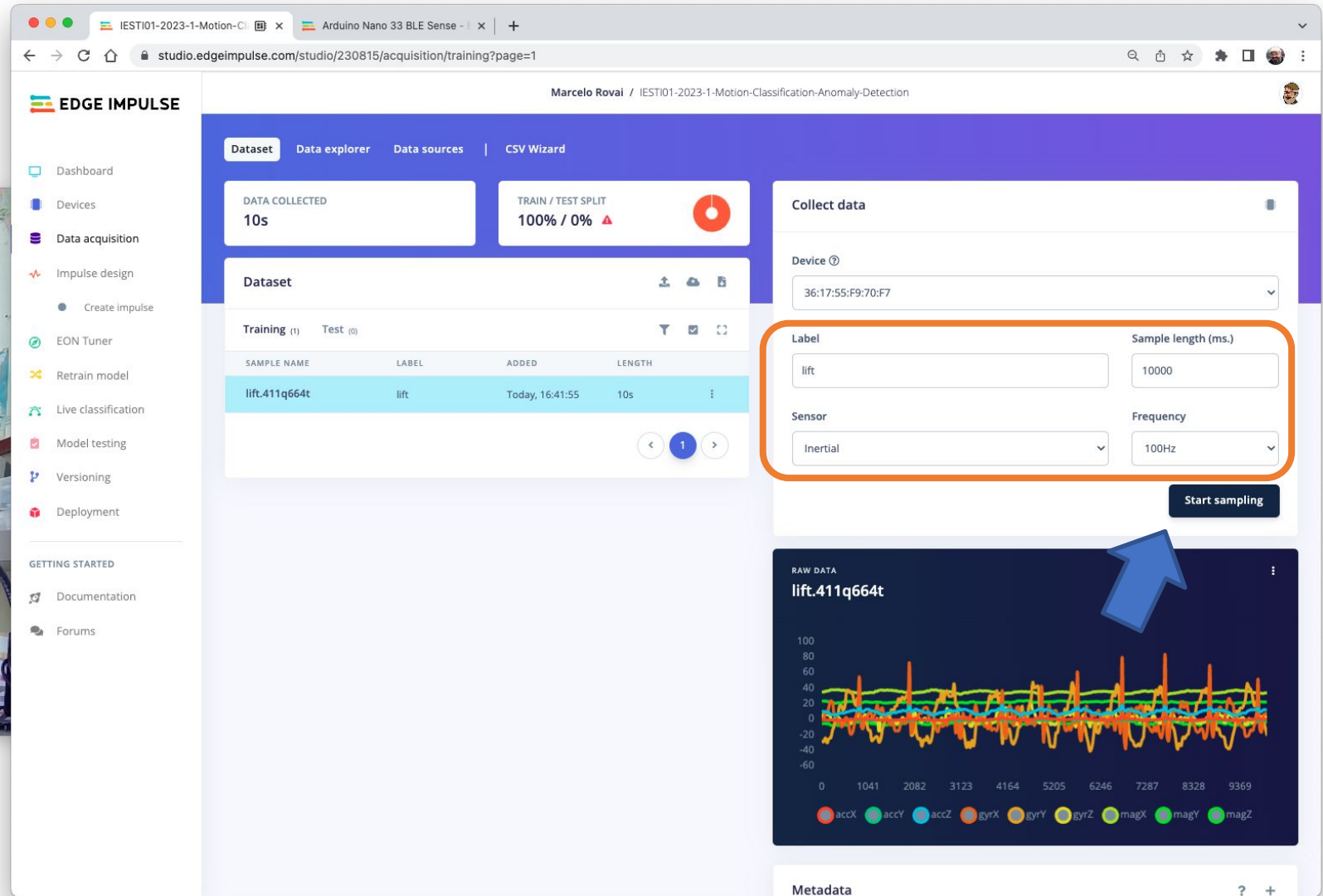
Start sampling

RAW DATA: lift.411q664t

accX accY accZ gyrX gyrY gyrZ magX magY magZ

Metadata

SAMPLE NAME	LABEL	ADDED	LENGTH
lift.411q664t	lift	Today, 16:41:55	10s



Accelerometer

Note that on capturing data from the IMU (Inertial Measurement Unit) sensor, now with the Studio, all nine axes will be captured simultaneously (from the accelerometer, gyroscope, and magnetron). Therefore, if you need only the accelerometer data, select it in the **Create Impulse** section.

The screenshot displays the Edge Impulse Studio web interface for a project named 'IESTI01 - Motion Classification'. The left sidebar shows the project structure with 'Create impulse' selected. The main workspace contains several configuration blocks:

- Time series data** (red block):
 - Input axes (9): accX, accY, accZ, gyrX, gyrY, gyrZ, magX, magY, magZ
 - Window size: 2000 ms
 - Window increase: 80 ms
 - Frequency (Hz): 62.5
 - Zero-pad data: ☒
- Spectral Analysis** (light blue block):
 - Name: Spectral Analysis
 - Input axes (3): ☒ accX, ☒ accY, ☒ accZ (this section is highlighted with an orange box)
 - Other axes (gyrX, gyrY, gyrZ, magX, magY, magZ) are unchecked.
- Classification** (purple block):
 - Name: Classifier
 - Input features: ☒ Spectral Analysis
 - Output features: 4 (idle, lift, maritime, terrestrial)
- Output features** (teal block):
 - 4 (idle, lift, maritime, terrestrial)
 - Save Impulse button
- Anomaly Detection (K-means)** (purple block):
 - Name: Anomaly detection
 - Input features: ☒ Spectral Analysis
 - Output features: 1 (Anomaly score)

A dashed box at the bottom indicates where to 'Add a processing block'.

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DATA COLLECTED

10s

LABELS

1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
unifei.29js37tq	unifei	Today, 18:22:34	10s

Record new data

Device ?

36:17:55:F9:70:F7

Label

unifei

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

unifei.29js37tq

10000

8000

6000

4000

2000

0

-2000

-4000

-6000

-8000

-10000

0

1051

2103

3154

4206

5258

6309

7361

8413

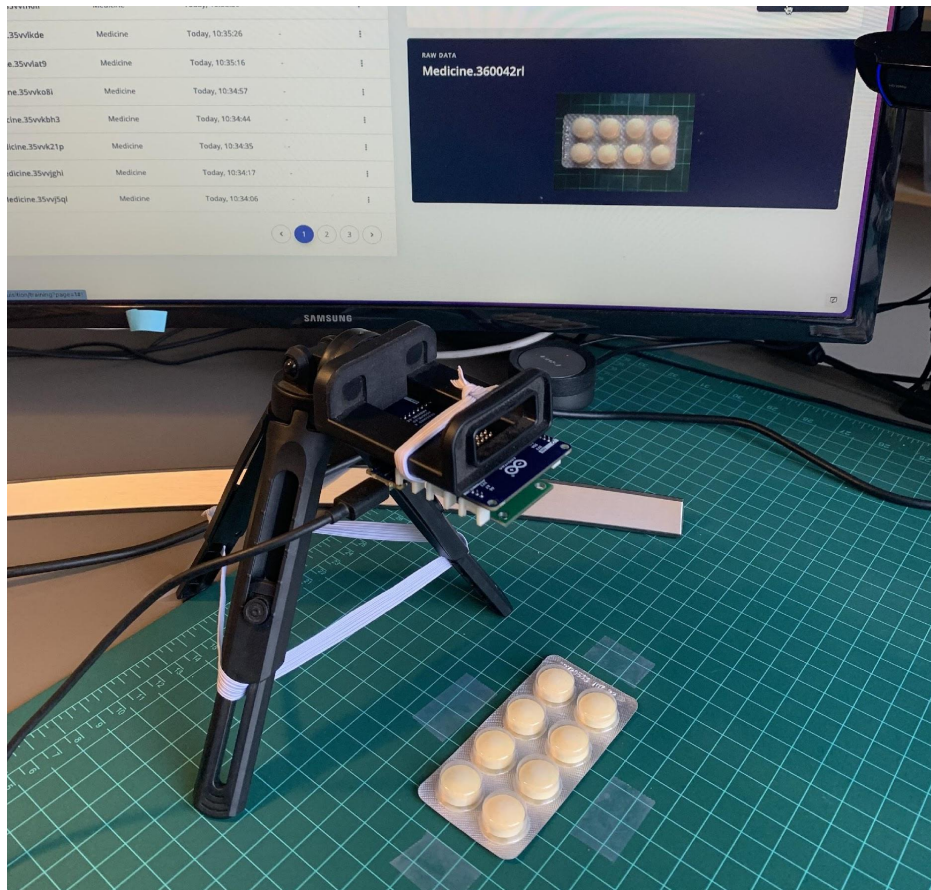
9464

audio

0:10 / 0:10



Camera



Data acquisition - IESTI01 x +

studio.edgeimpulse.com/studio/114253/acquisition/training?page=1

Record new data

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

Label
medicine

Sensor
Camera (128x96)

Camera feed



Start sampling

RAW DATA
Click on a sample to load...

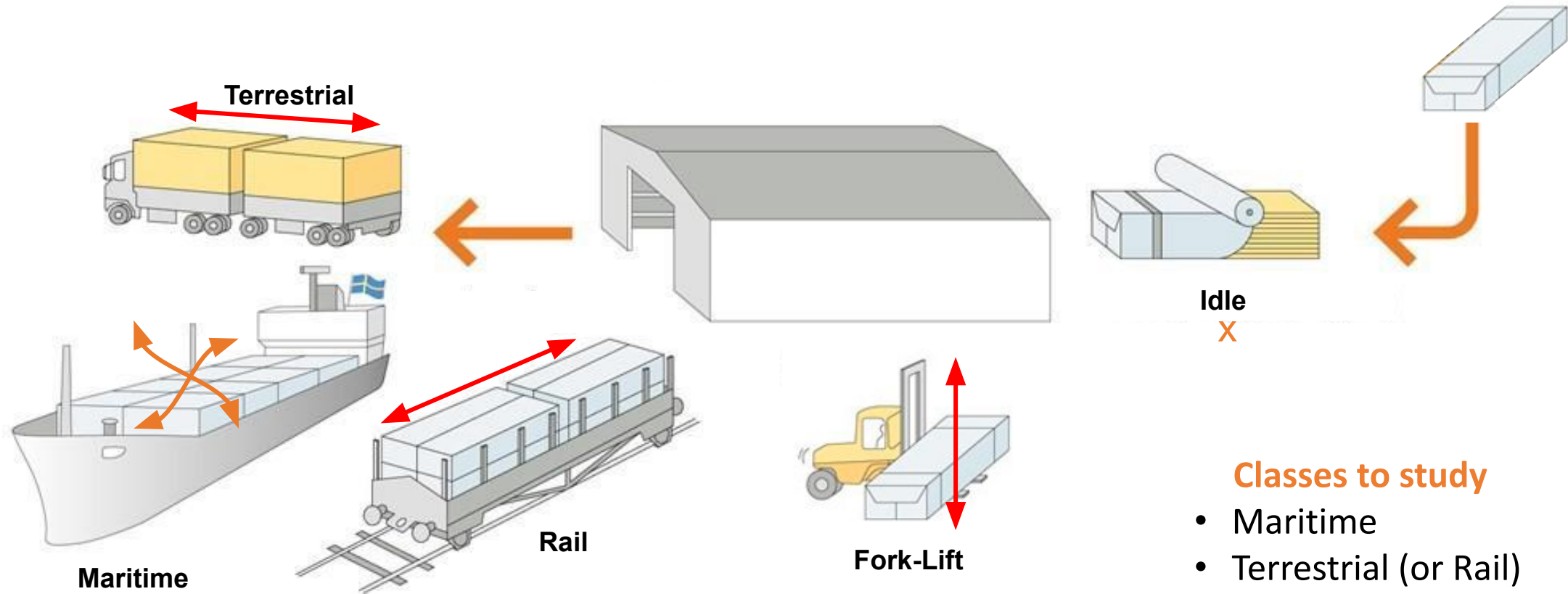
© 2022 EdgeImpulse Inc. All rights reserved

Motion Classification

<https://studio.edgeimpulse.com/public/230815/latest>

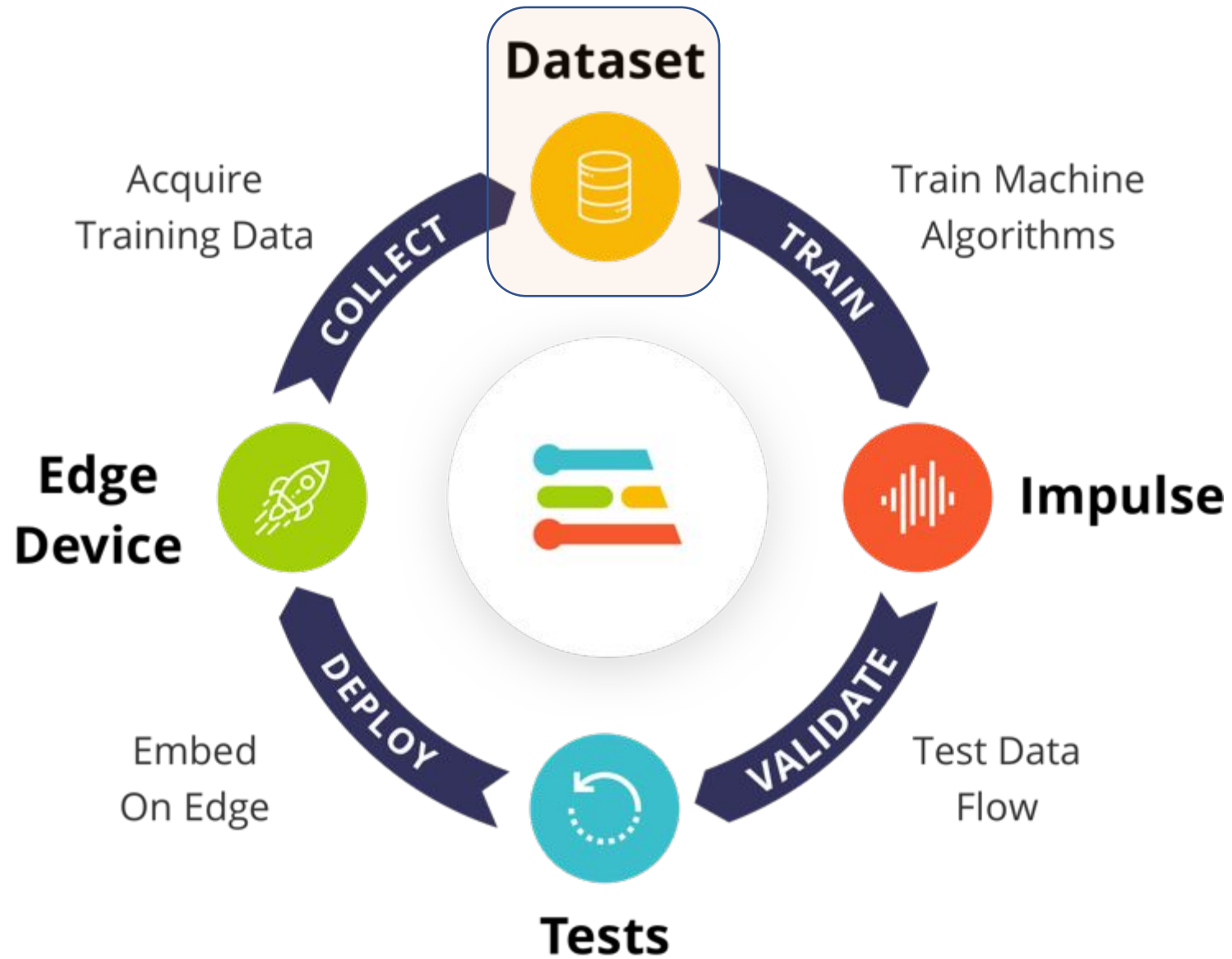


Case Study: Mechanical Stresses in Transport

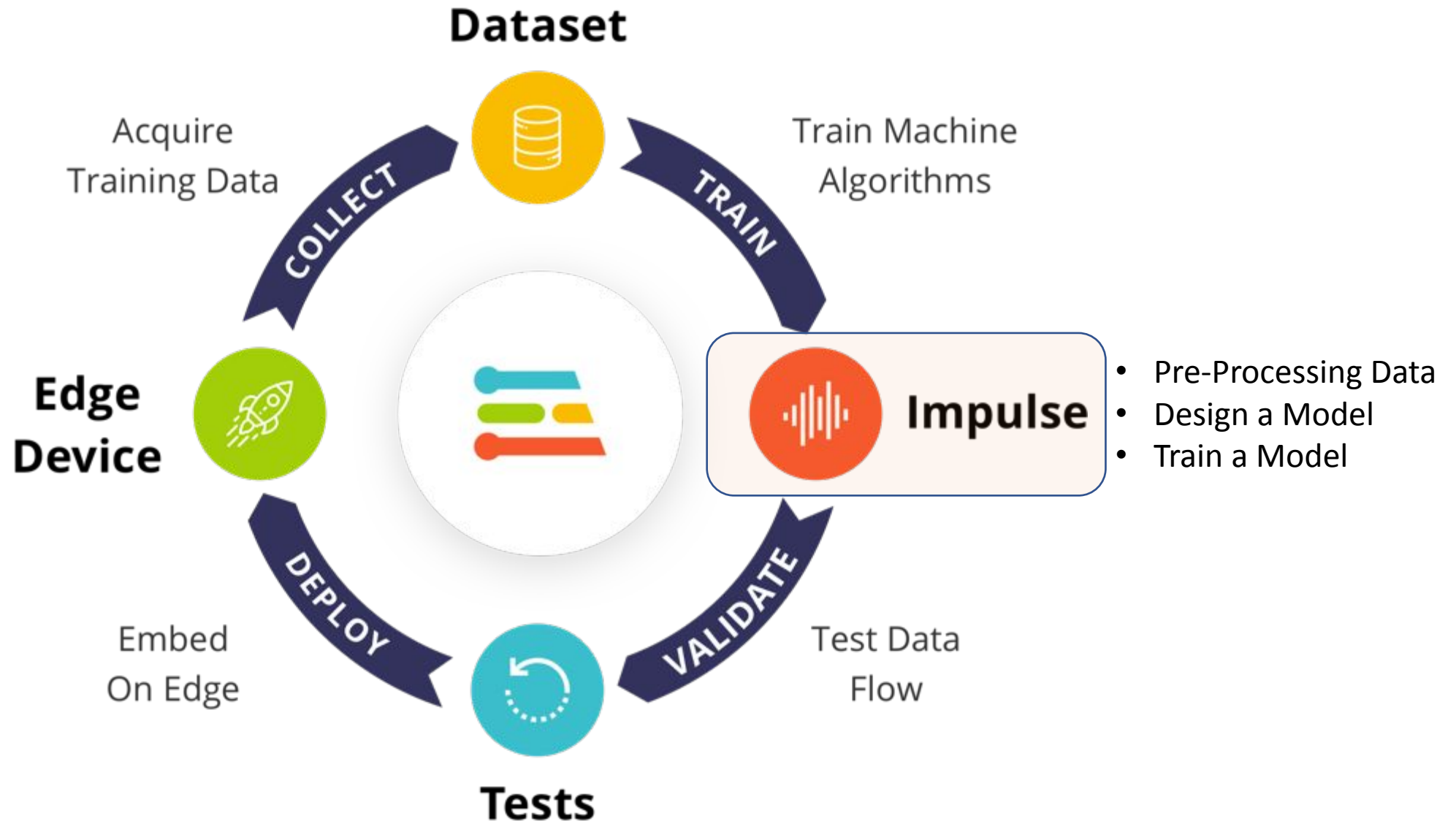


Classes to study

- Maritime
- Terrestrial (or Rail)
- Lift
- Idle



- Pre-Processing Data
- Design a Model
- Train a Model



EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral features
- Classifier

EON Tuner

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Marcelo Rovai / IESTI01-2023-1-Motion-Classification-Anomaly-Detection

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

Time series data

Input axes (3)
accX, accY, accZ

Window size
2000 ms.

Window increase
200 ms.

Frequency (Hz)
62,5

Zero-pad data

Spectral Analysis

Name
Spectral features

Input axes (3)

- accX
- accY
- accZ

Classification

Name
Classifier

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 Analysis

- [Spectral Analysis under the hood](#)
- [Edge Impulse - Spectral Analysis Block](#) - Open in CoLab



Parameters

Autotune parameters

Filter

Scale axes ?

0.0509920331756334

Input decimation ratio ?

1

Type ?

low

Cut-off frequency ?

15.625

Order ?

6

Analysis

Type ?

FFT

FFT length ?

32

Take log of spectrum? ?



Overlap FFT frames? ?



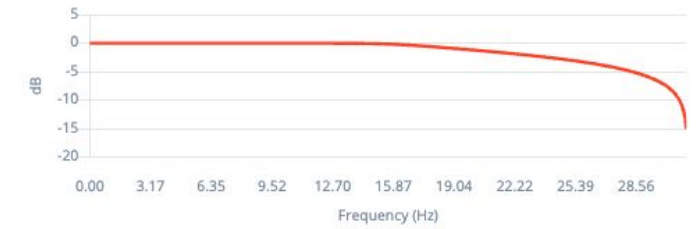
Improve low frequency resolution? ?



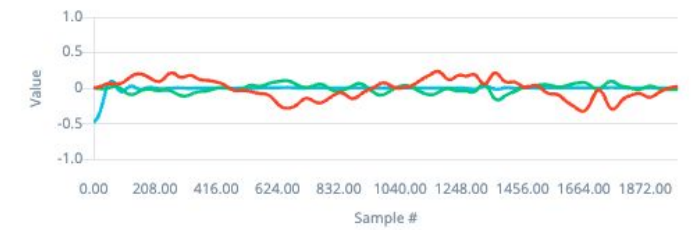
Save parameters

DSP result

Filter response



After filter



Spectral power (log)



Processed features

0.1410, -0.3215, -0.7833, 3.4014, 10.2211, -0.9719, -1.7806, -2.0805, -1.5185, -1.93...

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#1 Click to set a description for this version

Parameters

Generate features

Training set

Data in training set

5m 30s

Classes

4 (idle, lift, maritime, terrestrial)

Training windows

1,386

Calculate feature importance

☒

Generate features

Feature generation output

Reducing dimensions for visualizations OK

Scheduling job in cluster...
Container image pulled!
Job started
Determining feature importance...
[1/5] Determining feature importance for all classes...
[2/5] Determining feature importance for idle...
[3/5] Determining feature importance for lift...
[4/5] Determining feature importance for maritime...
[5/5] Determining feature importance for terrestrial...
Determining feature importance OK

Job completed

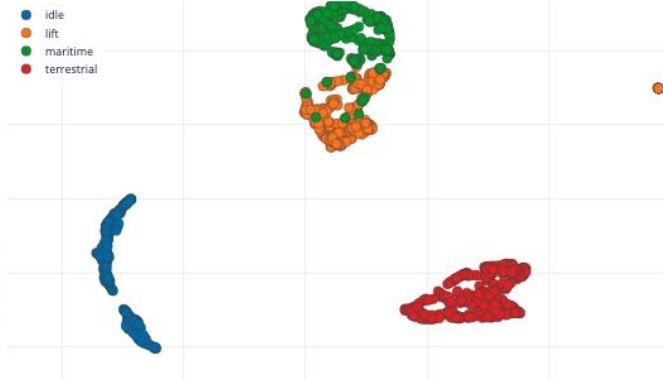
Feature explorer

idle

lift

maritime

terrestrial



Feature importance ?

All data

accZ RMS

accX Spectral Power 0.98 - 2.93 Hz

accZ Skewness

accY Spectral Power 2.93 - 4.88 Hz

accX Spectral Power 6.84 - 8.79 Hz

Show more

On-device performance ?

PROCESSING TIME

5 ms.

PEAK RAM USAGE

2 KB

EDGE IMPULSE

Marcelo Roval / IESTI01-2023-1-Motion-Classification-Anomaly-Detection

#1 Click to set a description for this version

Target: Cortex-M4F 80MHz

Neural Network settings

Training settings

Number of training cycles 30

Learning rate 0.0005

Advanced training settings

Validation set size 20 %

Split train/validation set on metadata key

Auto-balance dataset

Profile int8 model

Neural network architecture

Training output

```
Calculating inferencing time OK
Profiling float32 model...
Profiling float32 model (TensorFlow Lite Micro)...
Profiling float32 model (EON)...
Attached to job 9259830...
Attached to job 9259830...
Profiling int8 model...
Profiling int8 model (TensorFlow Lite Micro)...
Profiling int8 model (EON)...
Attached to job 9259830...
Attached to job 9259830...

Model training complete
Job completed
```

Model version: Quantized (int8)

LOSS 0.02

IDLE	LIFT	MARITIME	TERRESTRIAL
100%	0%	0%	0%
0%	100%	0%	0%
0%	0%	100%	0%
0%	0%	0%	100%
1.00	1.00	1.00	1.00

Target device

Configure your target device for model performance calculations, and to enable target specific optimizations.

- Alif HE (Cortex-M55 160MHz + U55-128MACC)
- Alif HP (Cortex-M55 400MHz + U55-256MACC)
- ✓ Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz)
- Arduino Nicla Vision (Cortex-M7 480MHz)
- Arduino Portenta H7 (Cortex-M7 480MHz)
- BrainChip AKD1000 MINI PCIe Board
- Cortex-M4F 80MHz
- Cortex-M7 216MHz
- Espressif ESP-EYE (ESP32 240MHz)
- Himax WE-I (ARC DSP 400MHz)
- Infineon PSoC6 CY8C624 (Cortex-M4F 150 MHz)
- Infineon PSoC6 CY8C6347 (Cortex-M4F 150 MHz)
- Jetson Nano
- MacBook Pro 16" 2020 (Intel Core i9 2.4GHz)
- Nordic nRF52840 DK (Cortex-M4F 64MHz)
- Nordic nRF5340 DK (Cortex-M33 128MHz)
- Nordic nRF9160 DK (Cortex-M33 64MHz)
- Raspberry Pi 4
- Raspberry Pi RP2040 (Cortex-M0+ 133MHz)
- Renesas RA6M5 (Cortex-M33 200MHz)
- Renesas RZ/V2L (CPU)
- Renesas RZ/V2L (with DRP-AI accelerator)
- ST IoT Discovery Kit (Cortex-M4F 80MHz)
- Seed SenseCAP A1101 (HX6537-A ARC DSP 400MHz)
- Seed Studio Wio Terminal (Cortex-M4F 120MHz)
- Seed Vision AI Module (HX6537-A ARC DSP 400MHz)

Neural Network settings

Training settings

Number of training cycles ?

Learning rate ?

Advanced training settings

Validation set size ?

%

Split train/validation set on metadata key ?

Auto-balance dataset ?

☐

Profile int8 model ?

☒

Neural network architecture

Input layer (39 features)

Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (4 classes)

Start training

Model

Model version: ?

Quantized (int8) ▾

Last training performance (validation set)

ACCURACY
100.0%

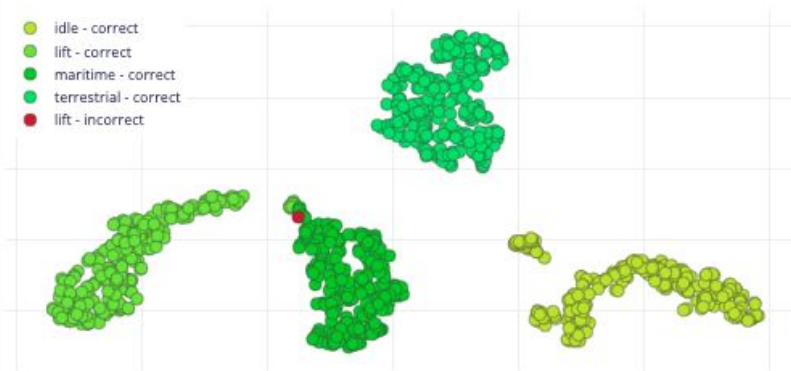
LOSS
0.02

Confusion matrix (validation set)

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	0%	100%	0%	0%
MARITIME	0%	0%	100%	0%
TERRESTRIAL	0%	0%	0%	100%
F1 SCORE	1.00	1.00	1.00	1.00

Data explorer (full training set) ?

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

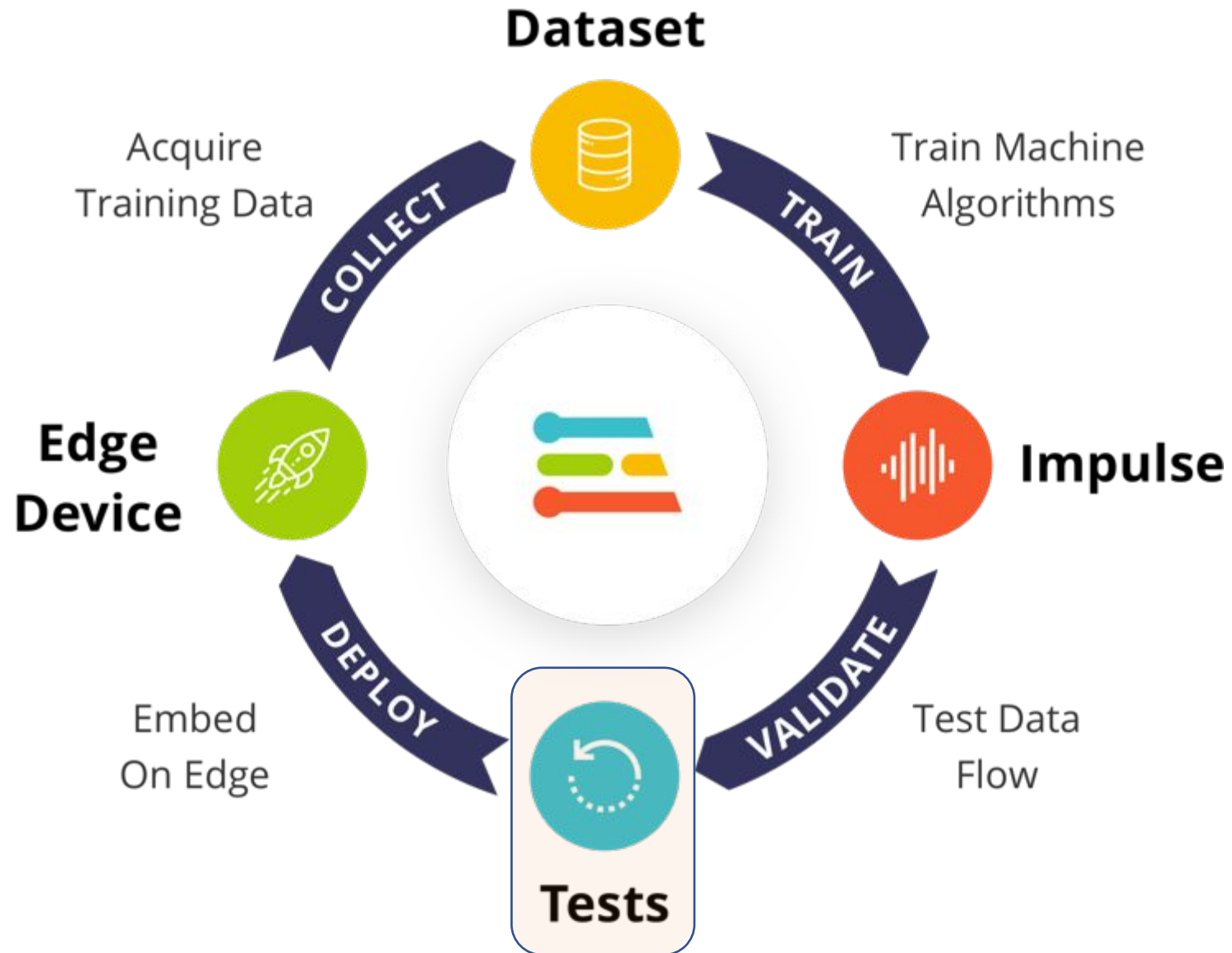


On-device performance ?

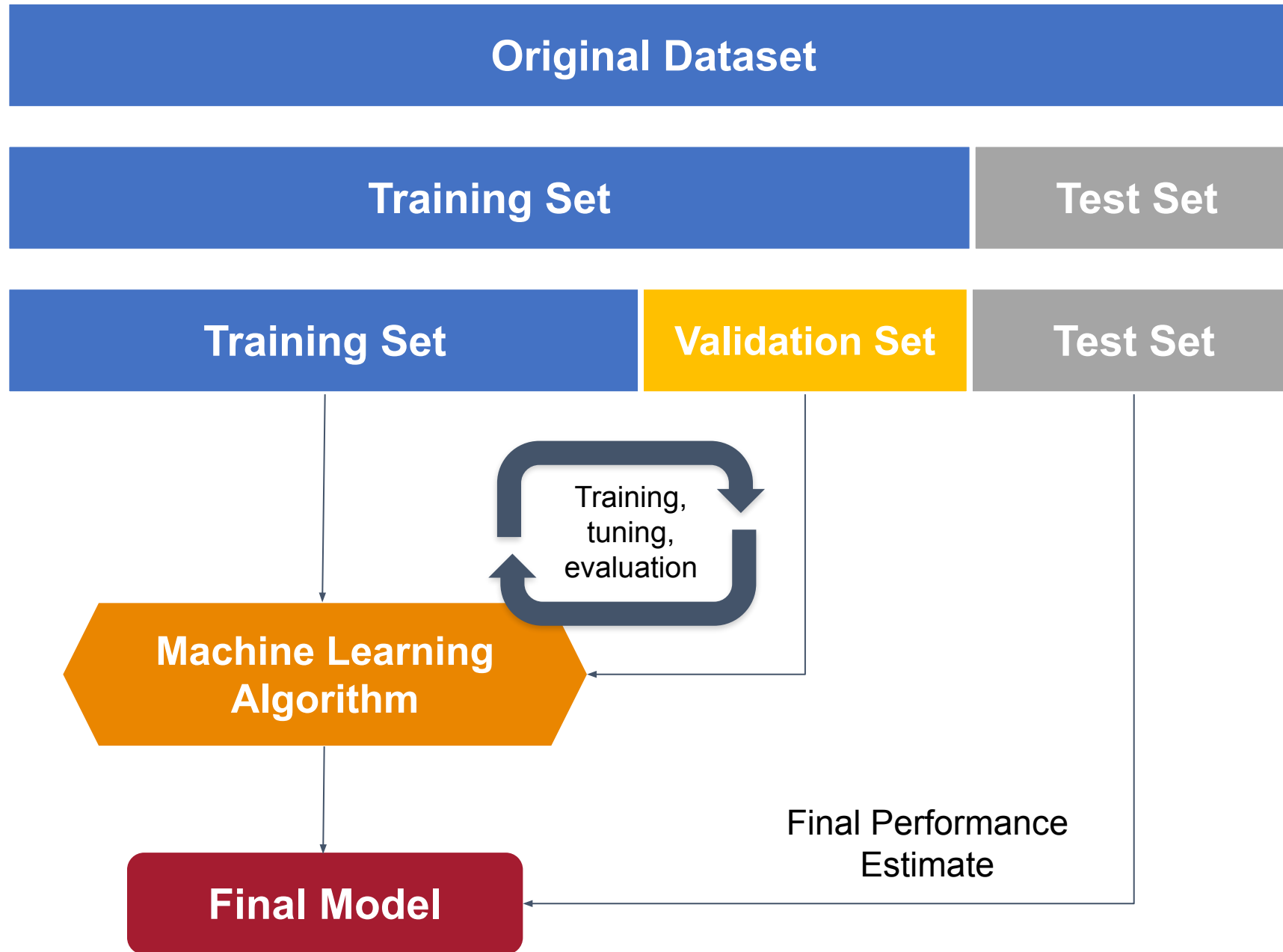
INFERRING TIME
1 ms.

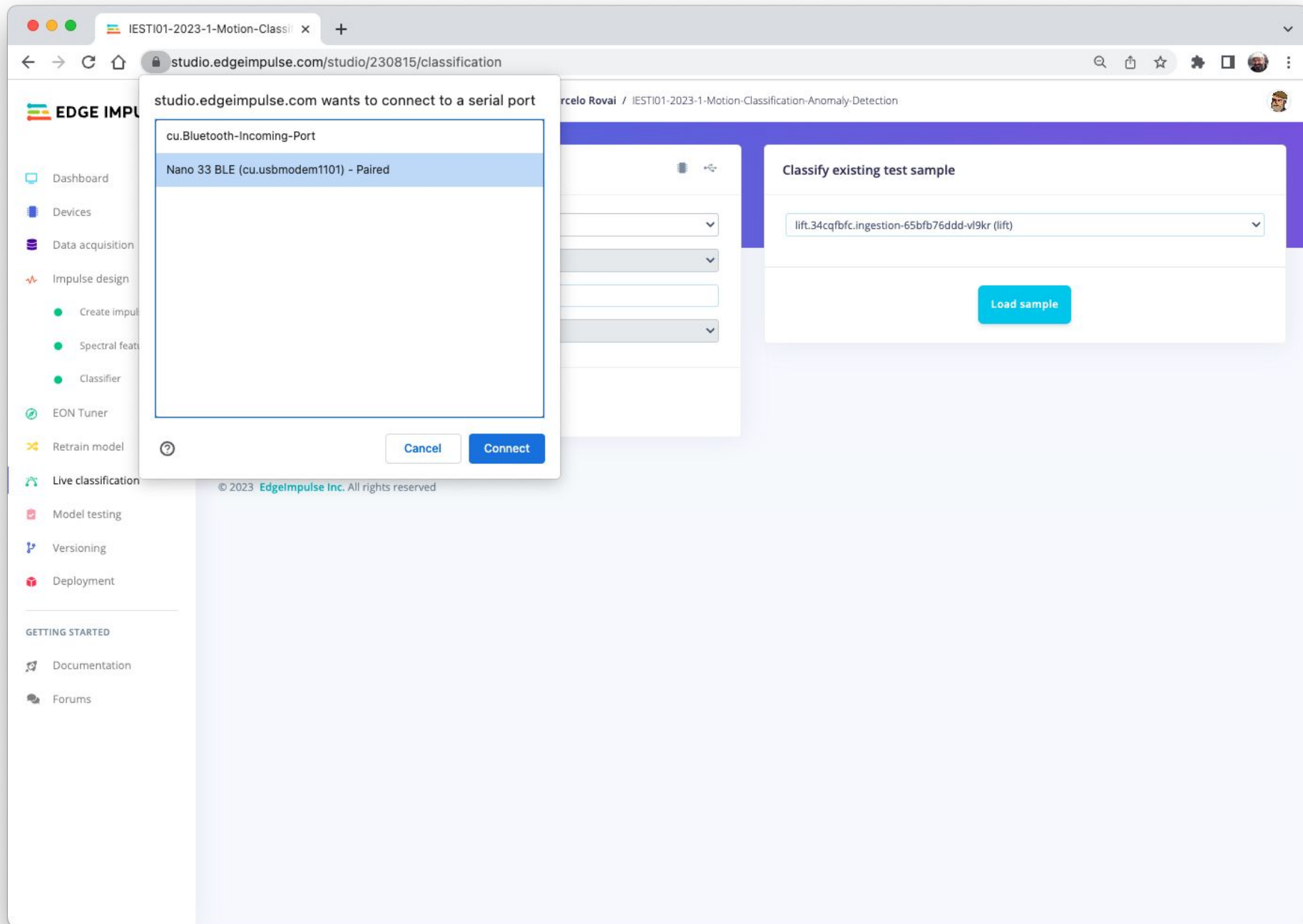
PEAK RAM USAGE
1.3K

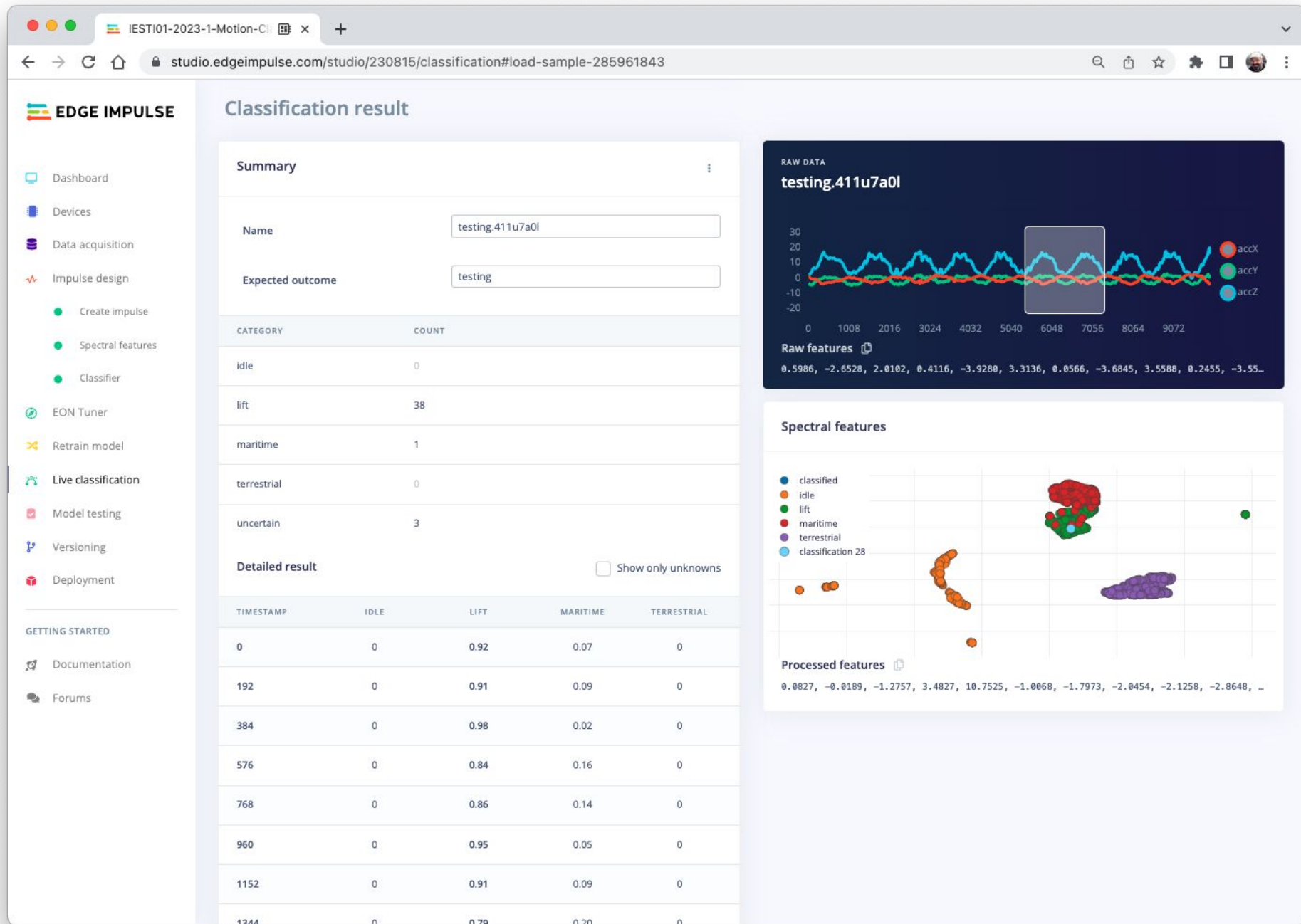
FLASH USAGE
14.8K

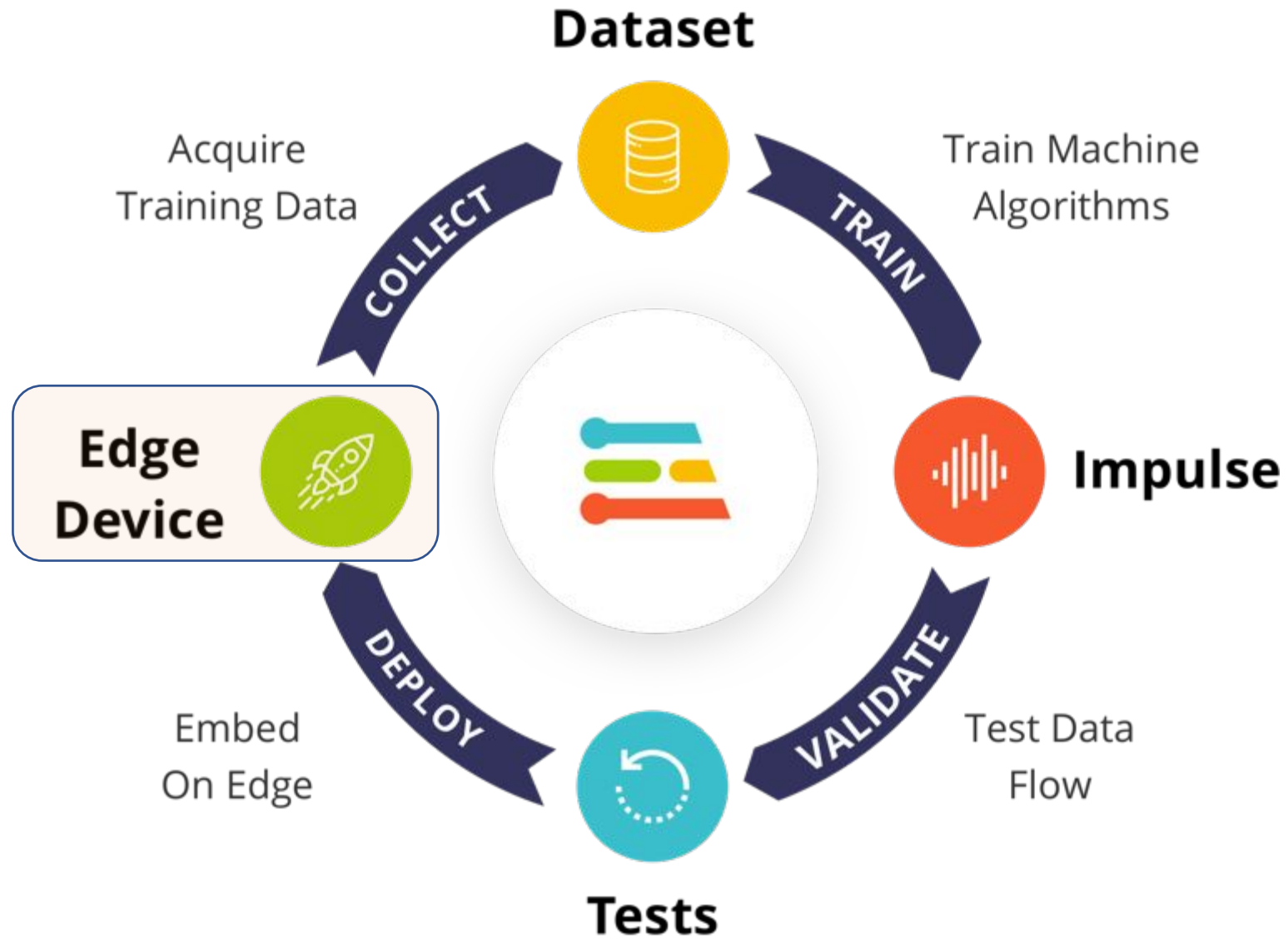


- Pre-Processing Data
- Design a Model
- Train a Model









- Pre-Processing Data
- Design a Model
- Train a Model

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Configure your deployment

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.](#)

Search deployment options

C++ library

A portable C++ library with no external dependencies, which can be compiled with any modern C++ compiler.

Arduino library

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

Cube.MX CMSIS-PACK

A STM32Cube.MX CMSIS-PACK, for fast inferencing on many ST MCUs.

Ethos-U library

A C++ library with inferencing for devices with an Ethos-U NPU.

MemryX Dataflow Program

Generate machine learning models in DEP format to use with MemryX Accelerator

Unoptimized (float32)

Select

	SPECTRAL FEATUR...	CLASSIFIER	TOTAL
LATENCY	8 ms.	18 ms.	26 ms.
RAM	1.9K	1.3K	1.9K
FLASH	-	13.6K	-
ACCURACY			

To compare model accuracy, run model testing.

Run model testing

Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz) - [Change target](#)

Build

Run this model

Scan QR code or launch in browser to test your prototype



Launch in browser

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Arduino library

SELECTED DEPLOYMENT

Arduino library

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

MODEL OPTIMIZATIONS

Model optimizations can increase on-device performance but may reduce accuracy.

Enable EON™ Compiler

Quantized (int8)

Selected ✓

	SPECTRAL FEATUR...	CLASSIFIER	TOTAL
LATENCY	8 ms.	1 ms.	9 ms.
RAM	1.9K	1.3K	1.9K
FLASH	-	14.8K	-
ACCURACY			-

Unoptimized (float32)

Select

	SPECTRAL FEATUR...	CLASSIFIER	TOTAL
LATENCY	8 ms.	18 ms.	26 ms.
RAM	1.9K	1.3K	1.9K
FLASH	-	13.6K	-
ACCURACY			-

To compare model accuracy, run model testing.

Run model testing

Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz) - [Change target](#)

Build

Run this model

Scan QR code or launch in browser to test your prototype



Launch in browser

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Configure your deployment

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.](#)

Arduino library

SELECTED DEPLOYMENT

Arduino library

MODEL OPT

Model opti

En

Quantized

Selected

Unoptimized (float32)

Select

	SPECTRAL FEATUR...	CLASSIFIER	TOTAL
LATENCY	8 ms.	18 ms.	26 ms.
RAM	1.9K	1.3K	1.9K
FLASH	-	13.6K	-
ACCURACY			-

To compare model accuracy, run model testing.

Run model testing

Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz) - [Change target](#)

Build

Latest build

Arduino v1 (Arduino library)

Today, 18:01:09

View docs

Build output

Container image pulled!

Job started

Writing templates...

OK

cluster...

ulled!

Use SDK...

Use SDK OK

el...

el OK

and updating headers...

and updating headers OK

...

OK

Built Arduino library

Add this library through the Arduino IDE via:

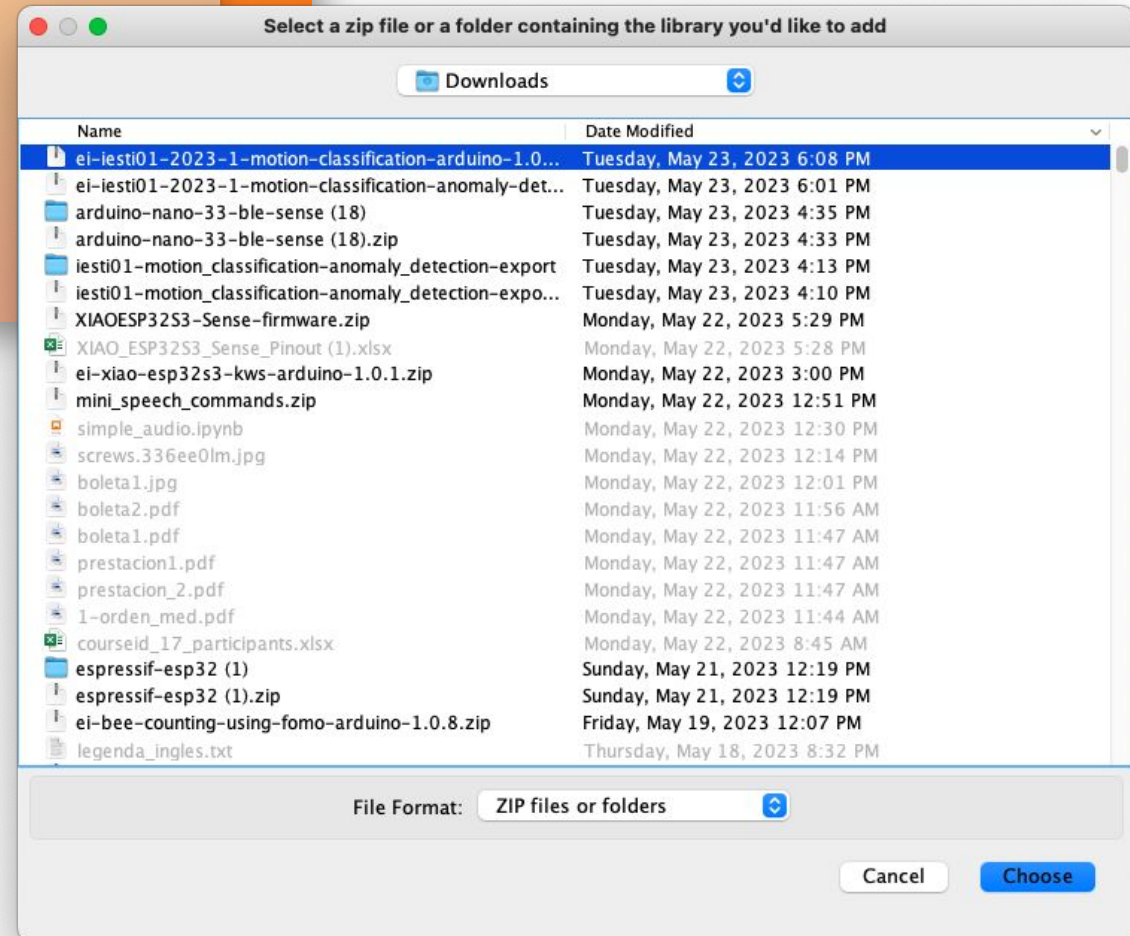
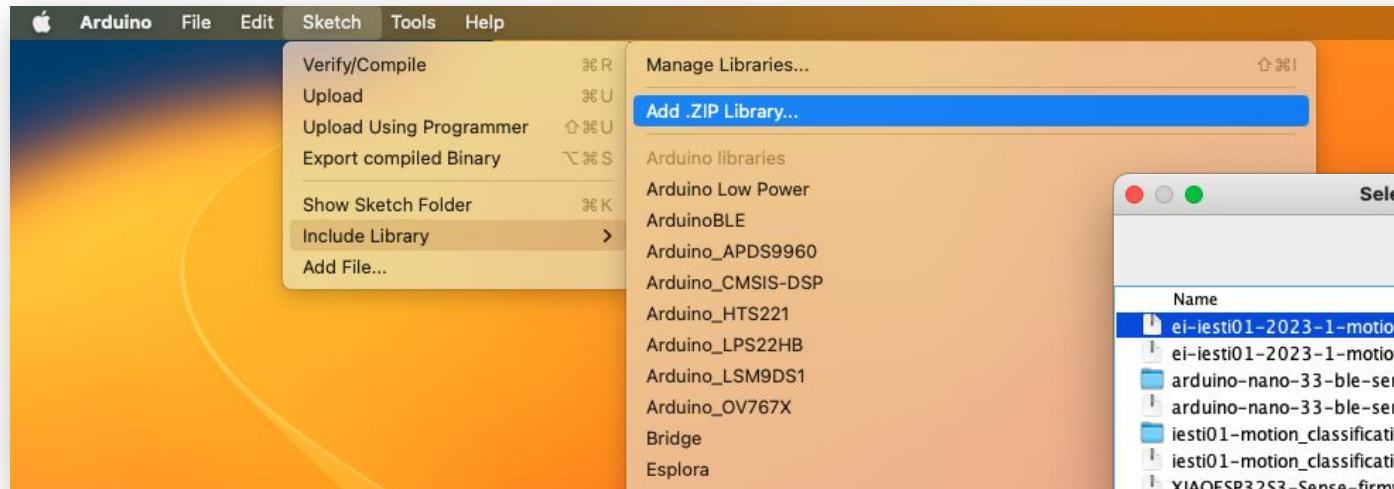
Sketch > Include Library > Add .ZIP Library...

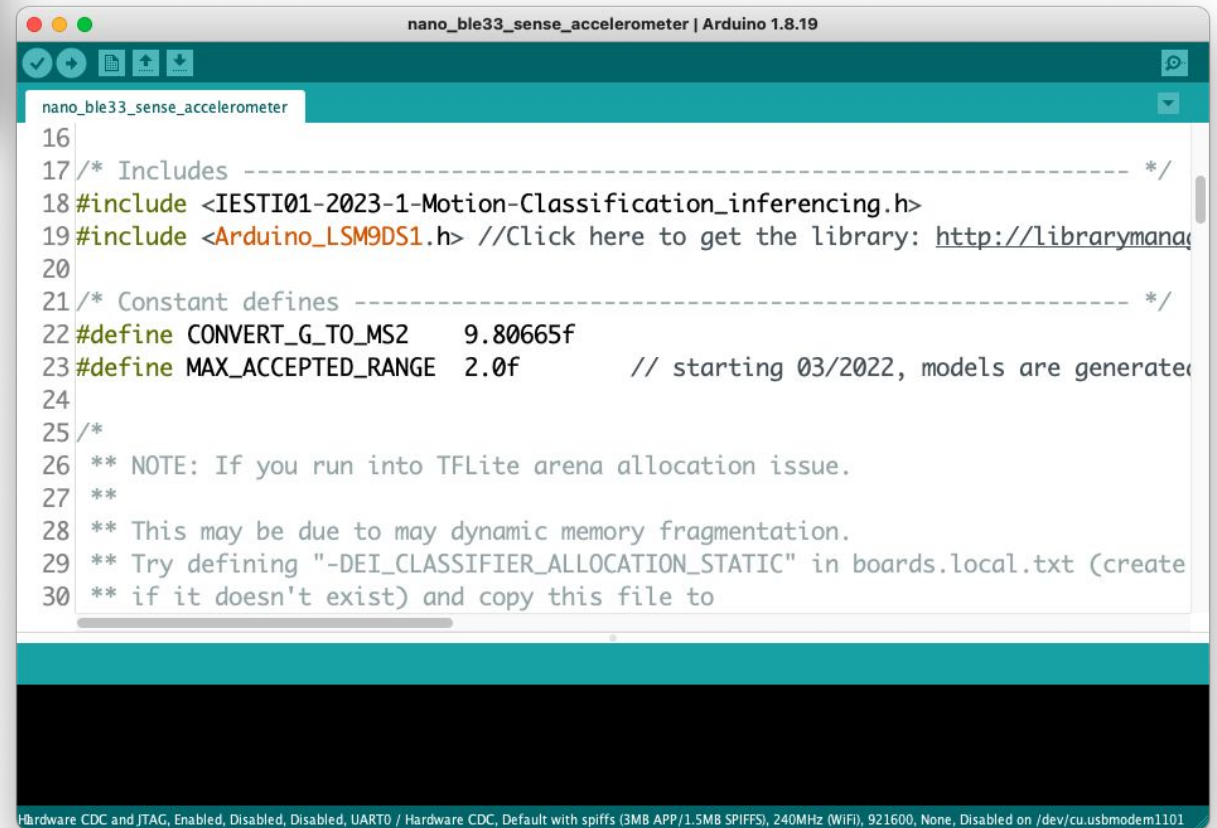
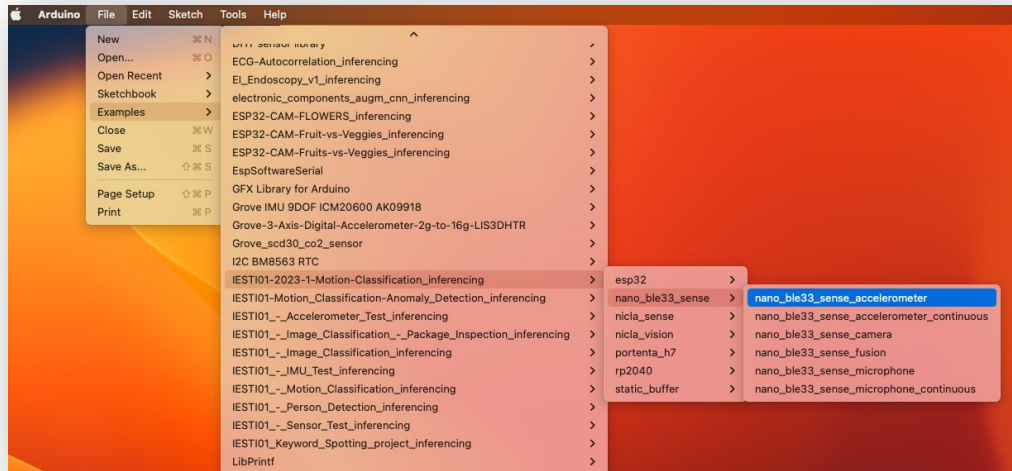
Examples can then be found under:

File > Examples > IESTI01-2023-1-Motion-Classification-Anomaly-Detection_inferencing

ei-iesti01-2023-1....zip

Show All





Model Inference

```
/dev/cu.usbmodem1101
18:20:34.827 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:20:34.827 ->   idle: 0.98438
18:20:34.827 ->   lift: 0.01172
18:20:34.827 ->   maritime: 0.00391
18:20:34.827 ->   terrestrial: 0.00000
18:20:34.827 -> Starting inferencing in 2 seconds...
18:20:36.846 -> Sampling...
18:20:38.879 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:20:38.879 ->   idle: 0.97266
18:20:38.879 ->   lift: 0.01953
18:20:38.879 ->   maritime: 0.00781
18:20:38.879 ->   terrestrial: 0.00000
18:20:38.879 -> Starting inferencing in 2 seconds...
18:20:40.868 -> Sampling...
```

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

```
/dev/cu.usbmodem1101
18:24:38.439 -> Sampling...
18:24:40.470 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:24:40.470 ->   idle: 0.00000
18:24:40.470 ->   lift: 0.94531
18:24:40.470 ->   maritime: 0.05469
18:24:40.470 ->   terrestrial: 0.00000
18:24:40.470 -> Starting inferencing in 2 seconds...
18:24:42.466 -> Sampling...
18:24:44.495 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:24:44.495 ->   idle: 0.00000
18:24:44.495 ->   lift: 0.97656
18:24:44.495 ->   maritime: 0.02344
18:24:44.495 ->   terrestrial: 0.00000
18:24:44.495 -> Starting inferencing in 2 seconds...
```

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

```
/dev/cu.usbmodem1101
18:23:34.004 -> Sampling...
18:23:36.040 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:23:36.040 ->   idle: 0.00000
18:23:36.040 ->   lift: 0.00781
18:23:36.040 ->   maritime: 0.00000
18:23:36.040 ->   terrestrial: 0.99219
18:23:36.040 -> Starting inferencing in 2 seconds...
18:23:38.024 -> Sampling...
18:23:40.062 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:23:40.062 ->   idle: 0.00000
18:23:40.062 ->   lift: 0.00391
18:23:40.062 ->   maritime: 0.00000
18:23:40.062 ->   terrestrial: 0.99609
18:23:40.062 -> Starting inferencing in 2 seconds...
```

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

```
/dev/cu.usbmodem1101
18:25:28.777 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:25:28.777 ->   idle: 0.00000
18:25:28.777 ->   lift: 0.46875
18:25:28.777 ->   maritime: 0.53125
18:25:28.777 ->   terrestrial: 0.00000
18:25:28.777 -> Starting inferencing in 2 seconds...
18:25:30.790 -> Sampling...
18:25:32.812 -> Predictions (DSP: 12 ms., Classification: 0 ms., Anomaly: 0 ms.):
18:25:32.812 ->   idle: 0.00000
18:25:32.812 ->   lift: 0.03906
18:25:32.812 ->   maritime: 0.96094
18:25:32.812 ->   terrestrial: 0.00000
18:25:32.812 -> Starting inferencing in 2 seconds...
18:25:34.817 -> Sampling...
```

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

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/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](#)

I want to thank **Shawn Hymel** and Edge Impulse, **Pete Warden** and **Laurence Moroney** from Google, Professor **Vijay Janapa Reddi** and **Brian Plancher** from Harvard, and the rest of the **TinyMLedu** team 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



UNIFEI