

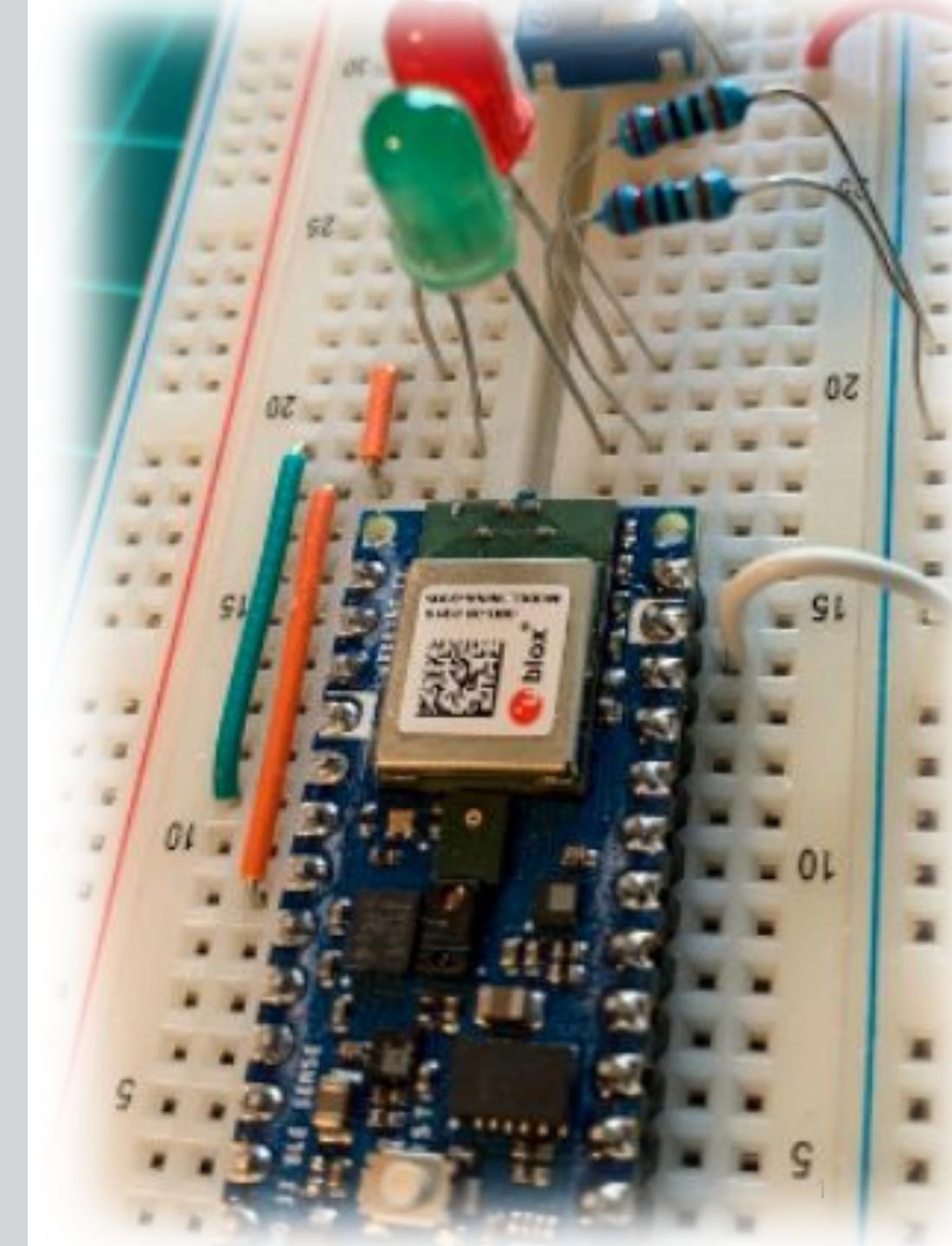
IESTI01 – TinyML

Embedded Machine Learning

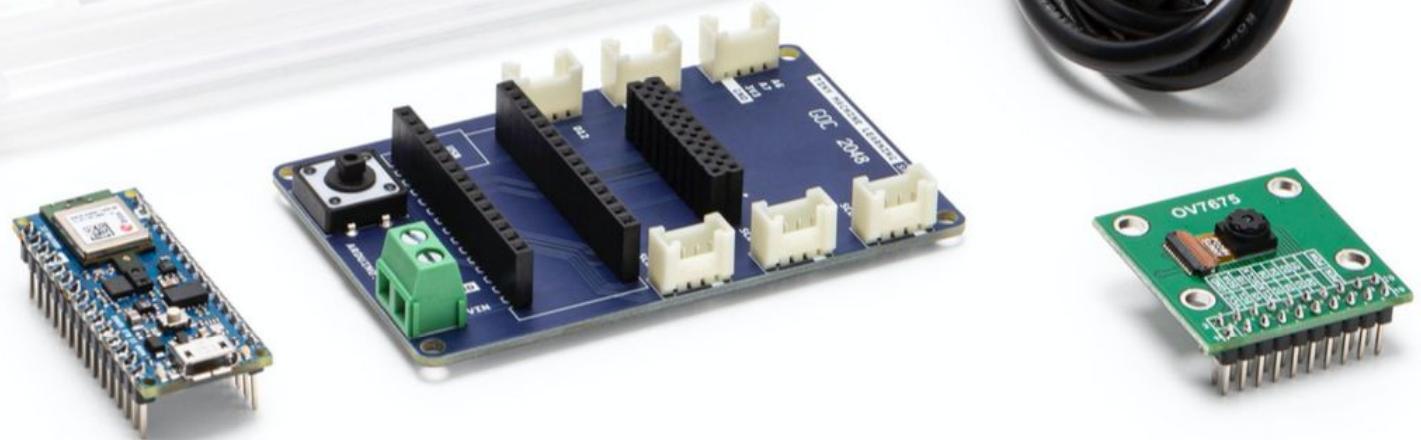
- TinyML Kit Overview
- HW and SW installation & Test
- Connection with EI Studio
- Motion Classification



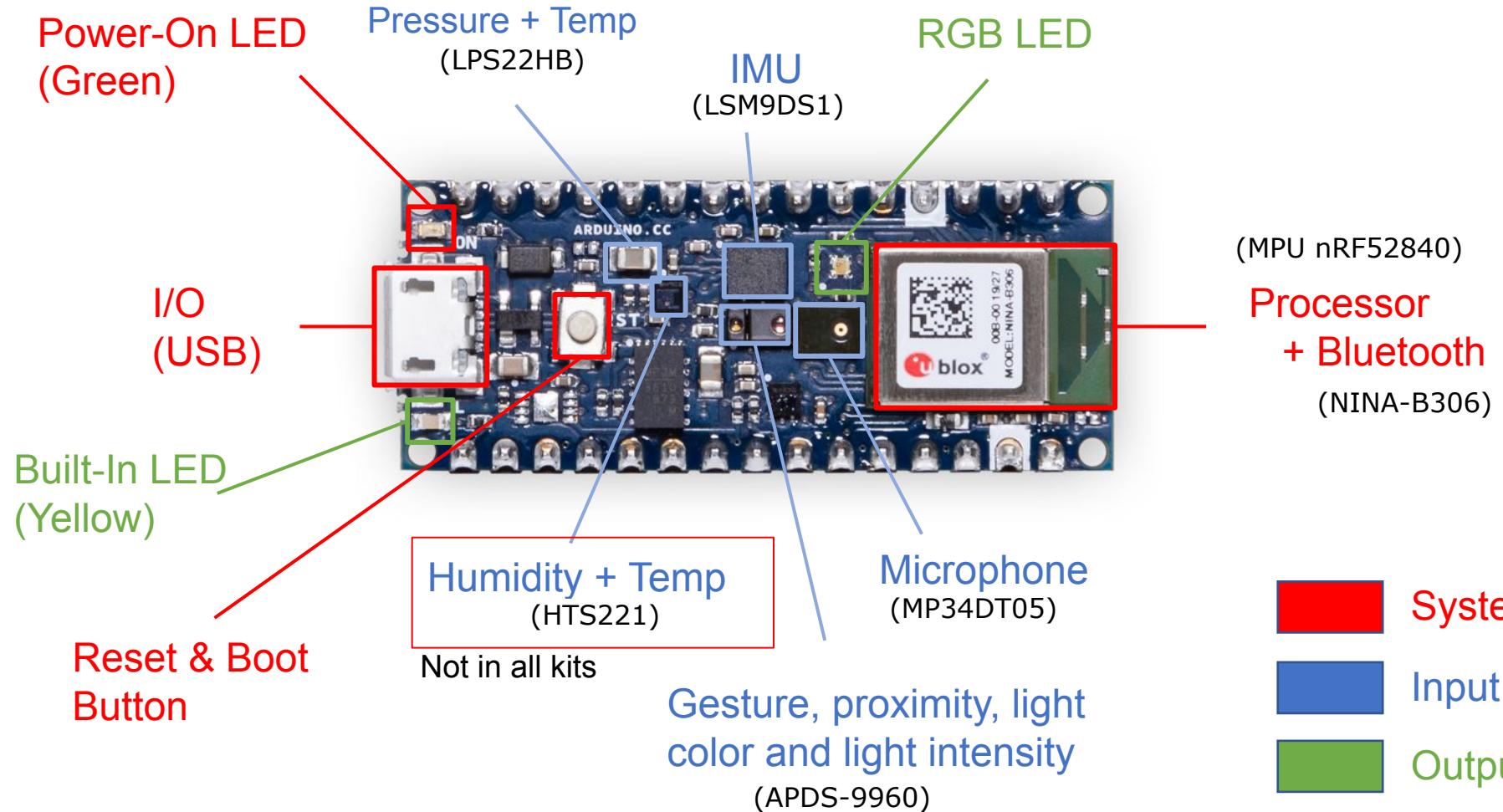
Prof. Marcelo Rovai
UNIFEI



TinyML Kit Overview



Nano 33 BLE Sense (Development board)

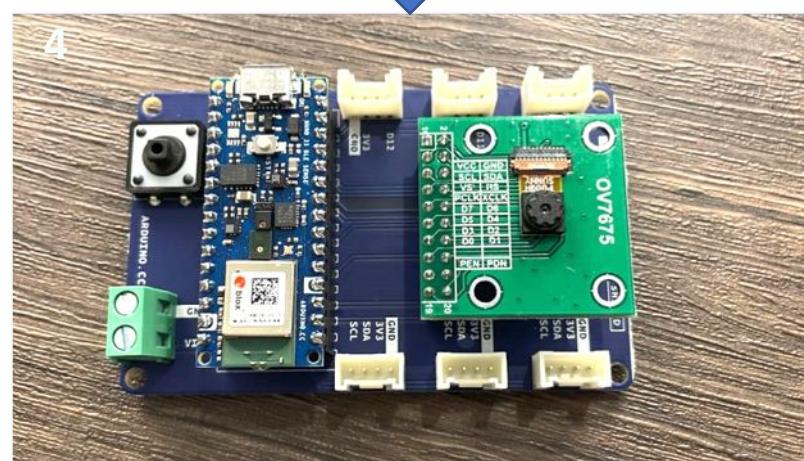
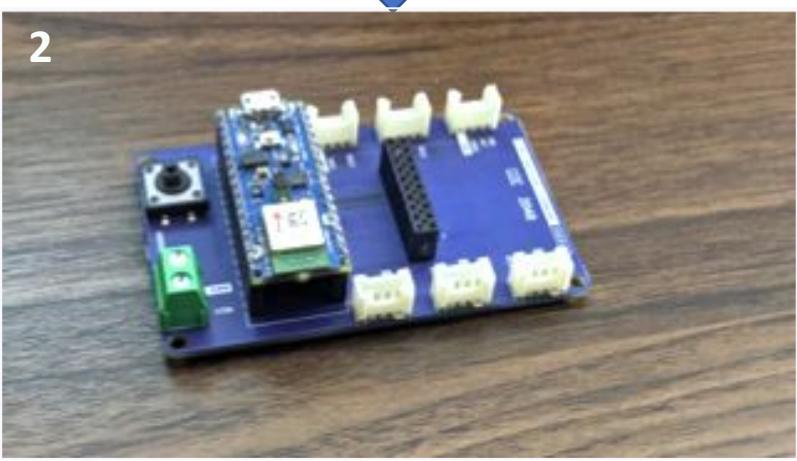
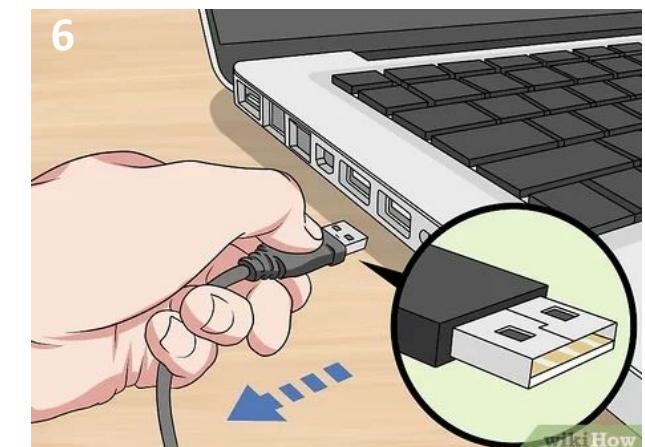
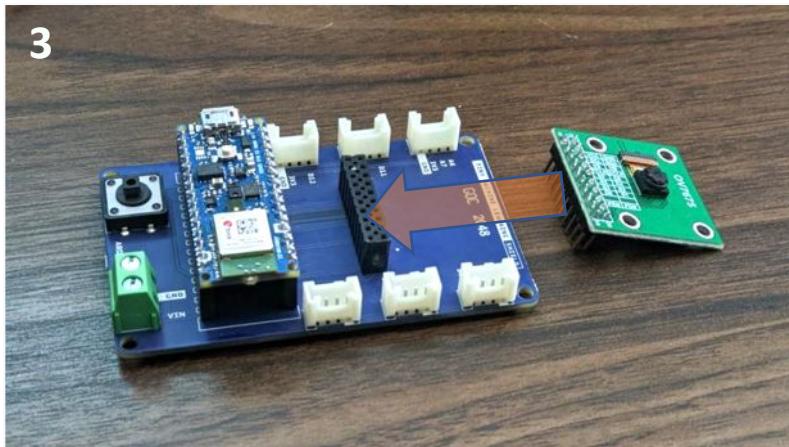
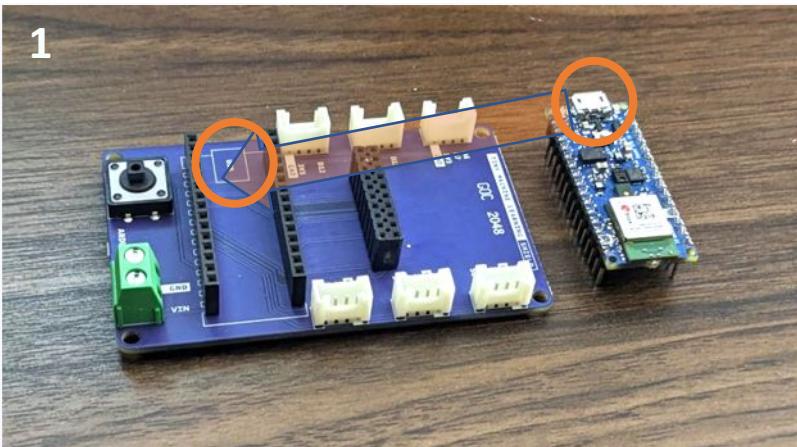


TinyML Kit Installation

- Hardware Set-up
- Software Set-up



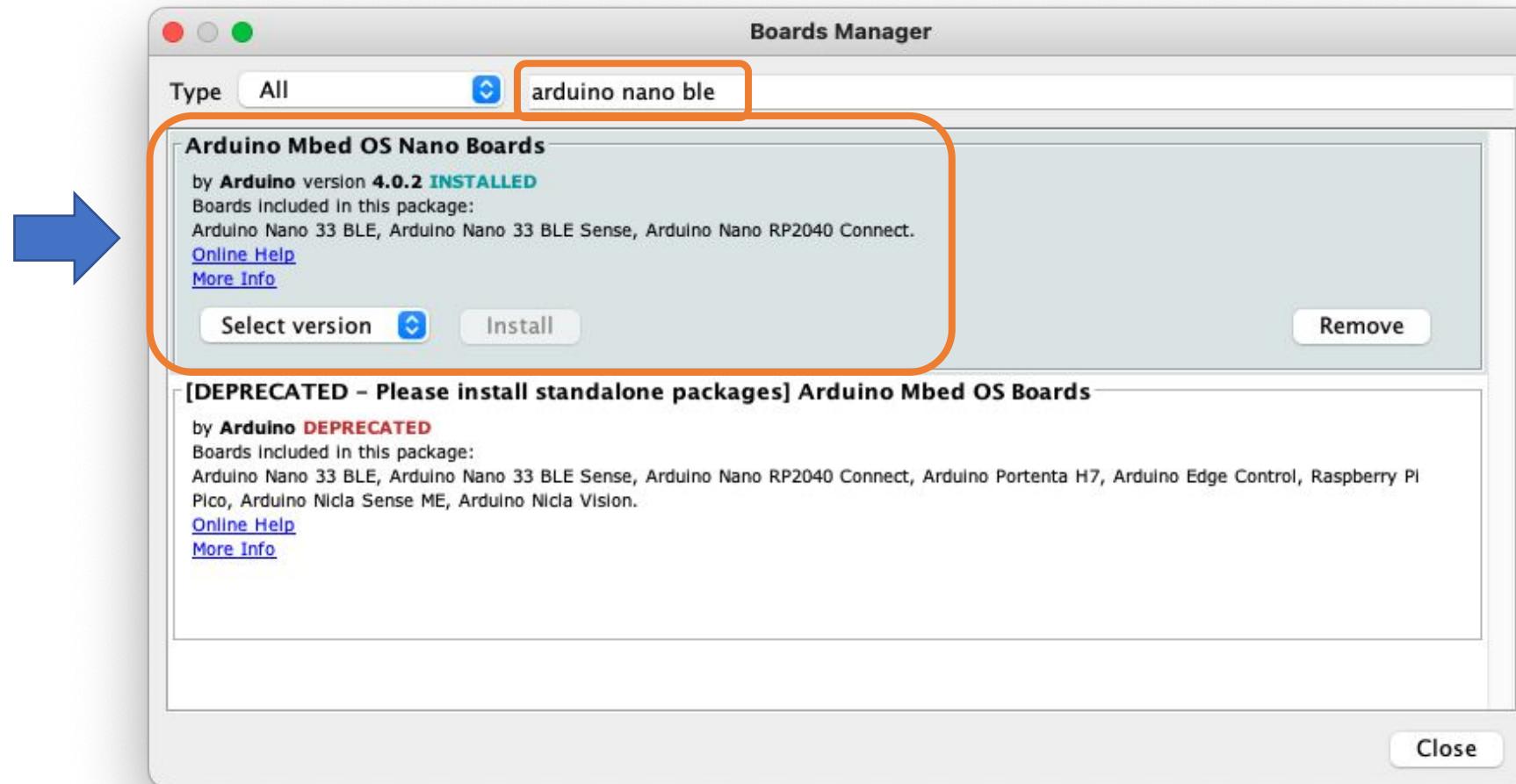
Installing the Hardware



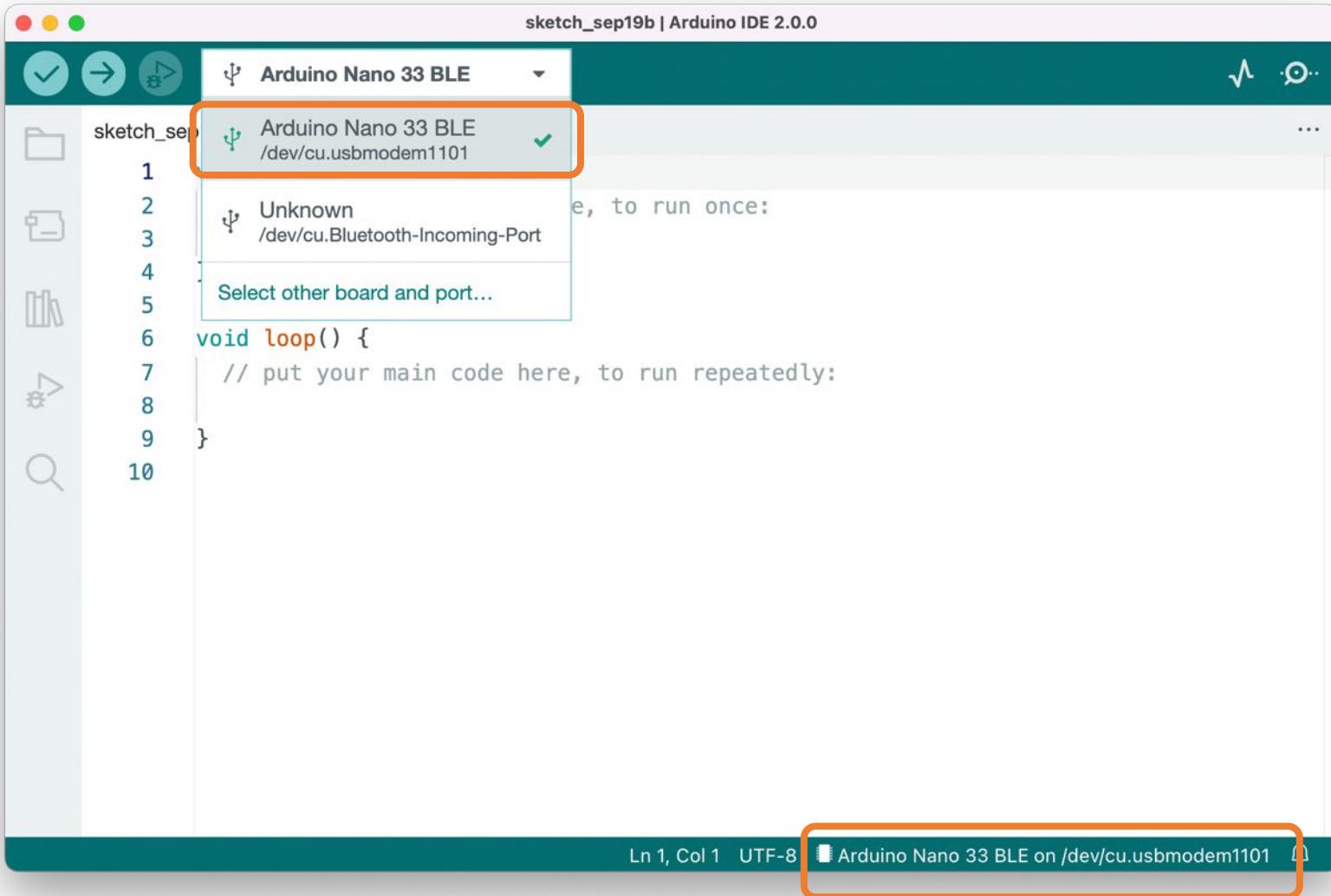
Installing the Board Files



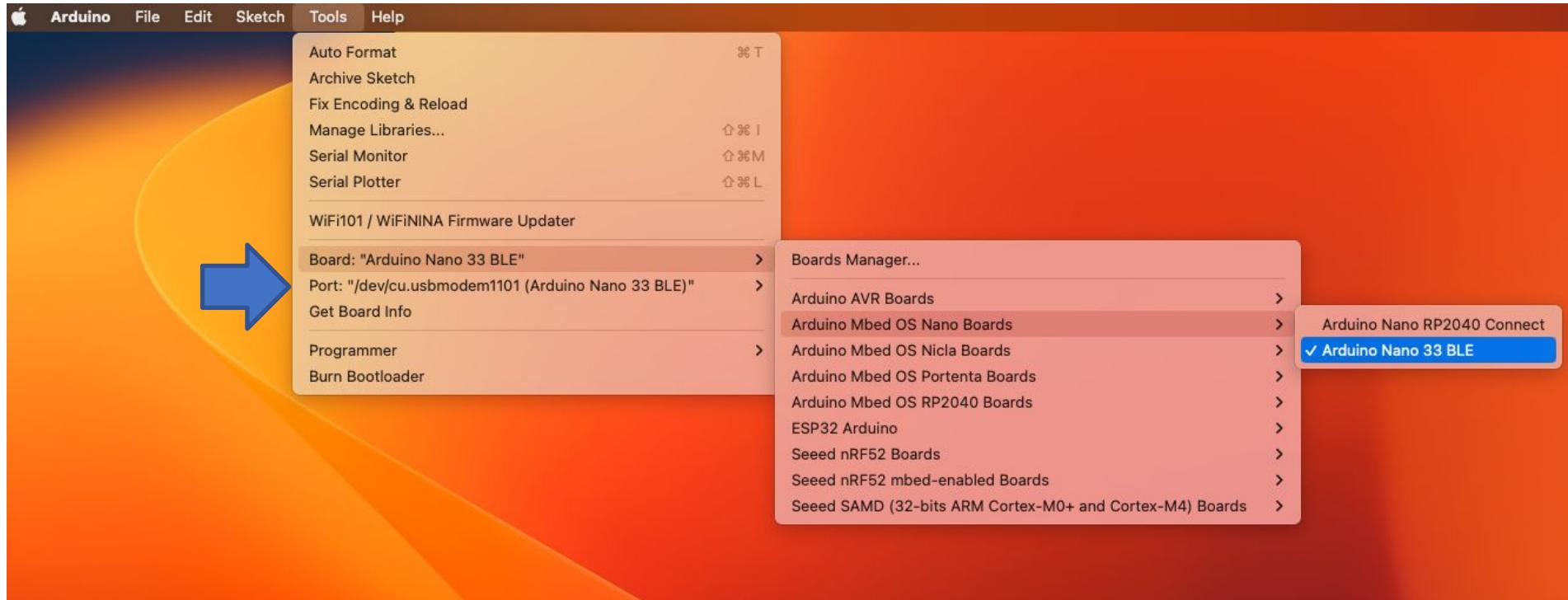
Installing the Board Files (IDE 1.8.19)



Select Board and Port

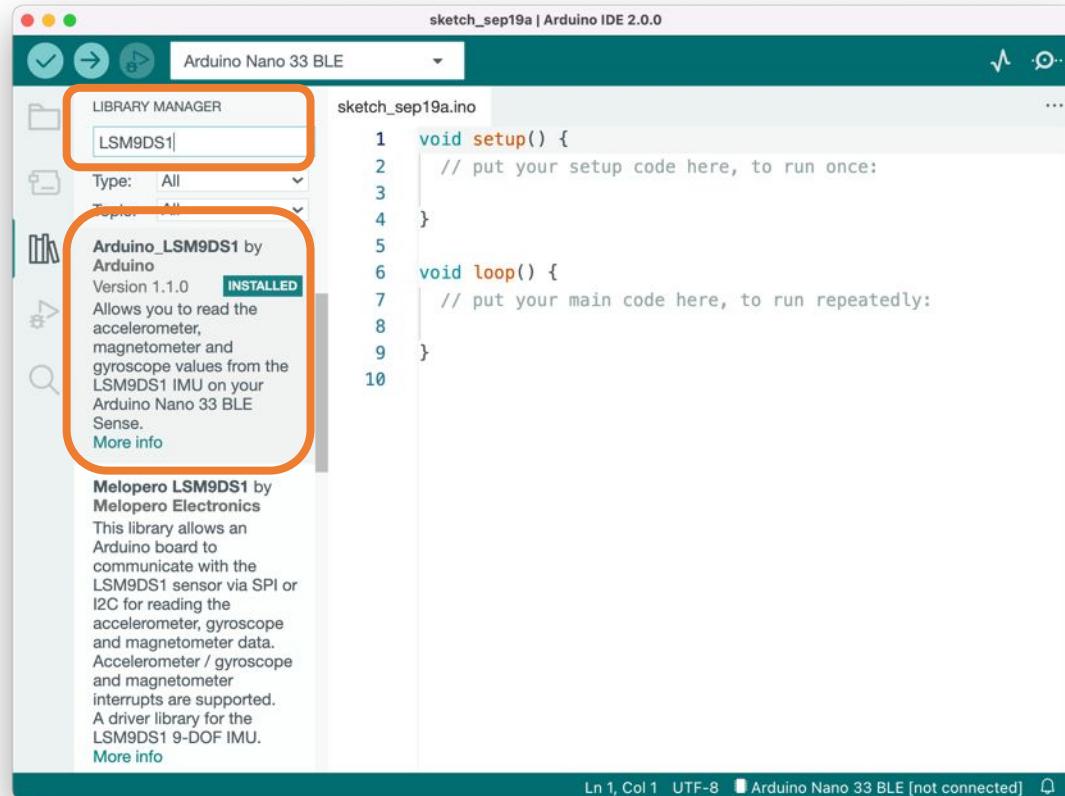


Select Board and Port (IDE 1.8.19)

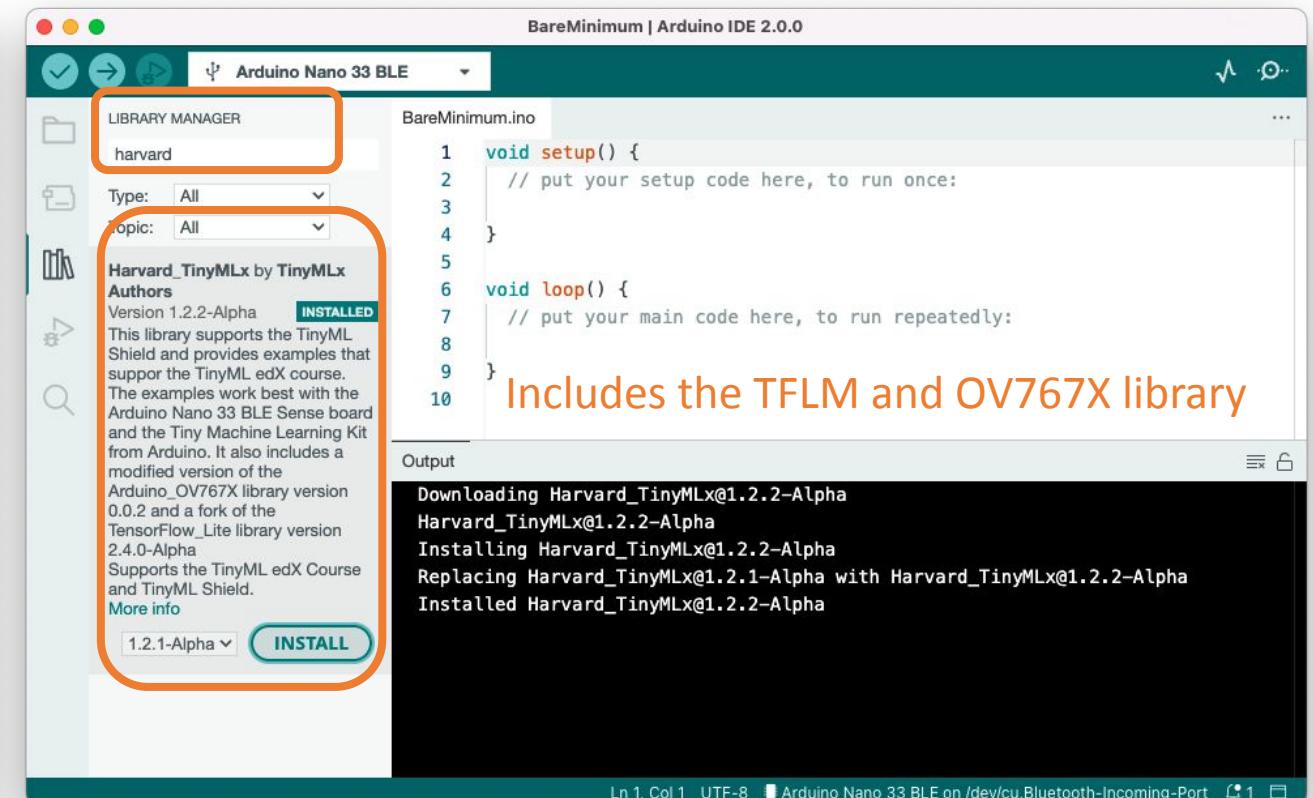


Installing Sensor and Auxiliary Libraries

IMU library

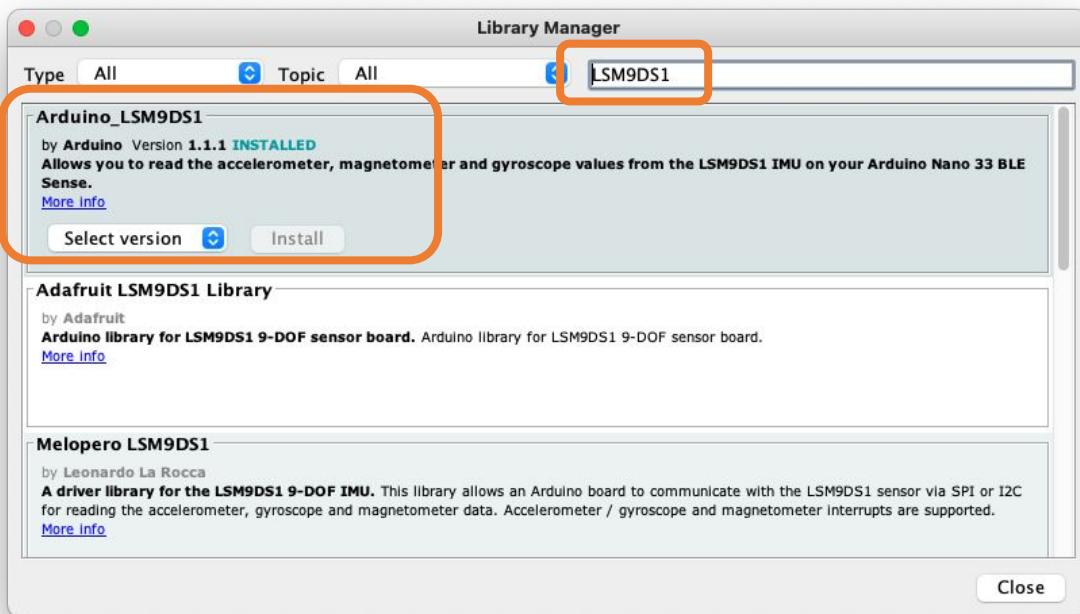


Shield, TFLM and Camera libraries

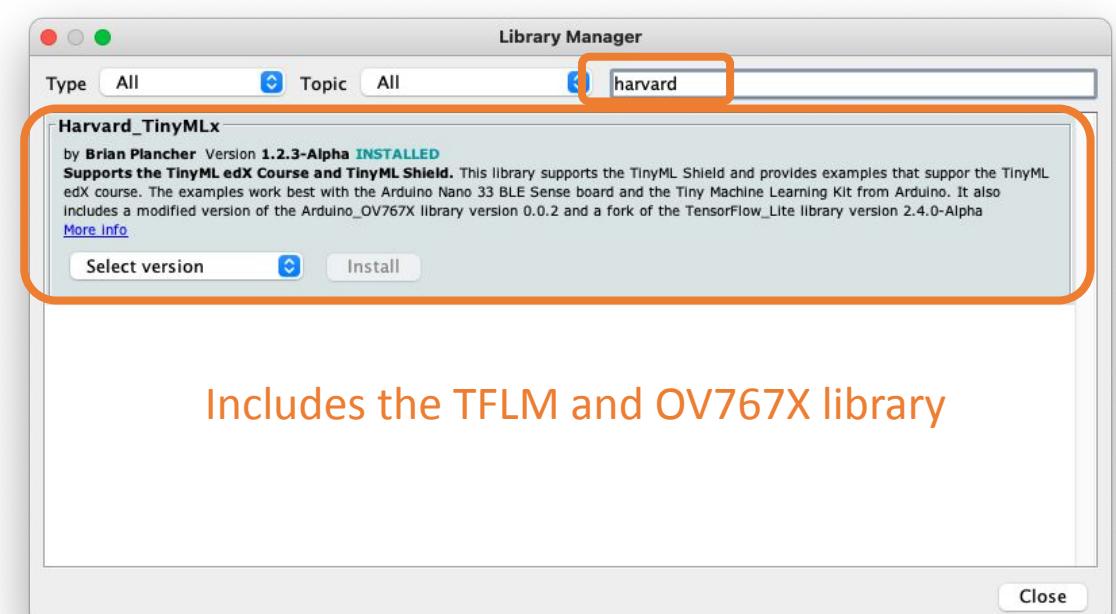


Installing Sensor and Auxiliary Libraries (IDE 1.8.19)

IMU library (LSM9DS1)



Shield, TFLM, and Camera libraries (Harvard)



Includes the TFLM and OV767X library

Set up connection between Arduino Nano
and Edge Impulse

Login - Edge Impulse

studio.edgeimpulse.com/login

EDGE IMPULSE

Log in

rovai@mjrobot.org

.....

[Forgot your password?](#)

[Log in](#)

Don't have an account? [Sign up](#)



Start building embedded machine learning models today.

© 2022 EdgeImpulse Inc. All rights reserved

Profile - Projects - Edge Impulse

studio.edgeimpulse.com/studio/profile/projects

EDGE IMPULSE

Projects Custom ML blocks

Marcelo Rovai

Projects

+ Create new project

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

Marcelo Rovai / TinyML4D - Project Setup - Gesture Classification

Marcelo Rovai / Bean Disease Classifier

Marcelo Rovai / IESTI01-Motion_Classification-Anomaly_Detection PUBLIC

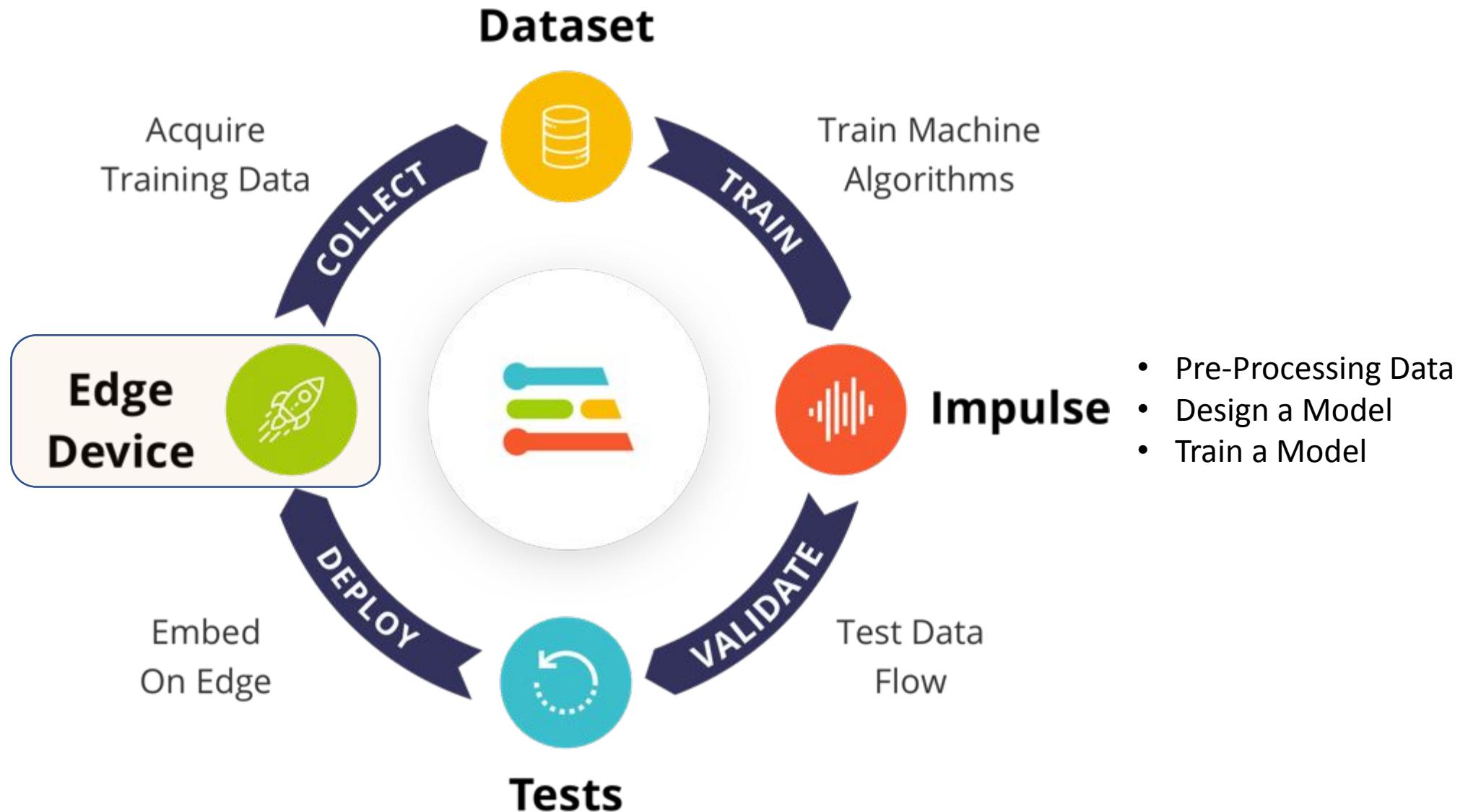
Marcelo Rovai / IESTI01_Keyword_Spotting_project

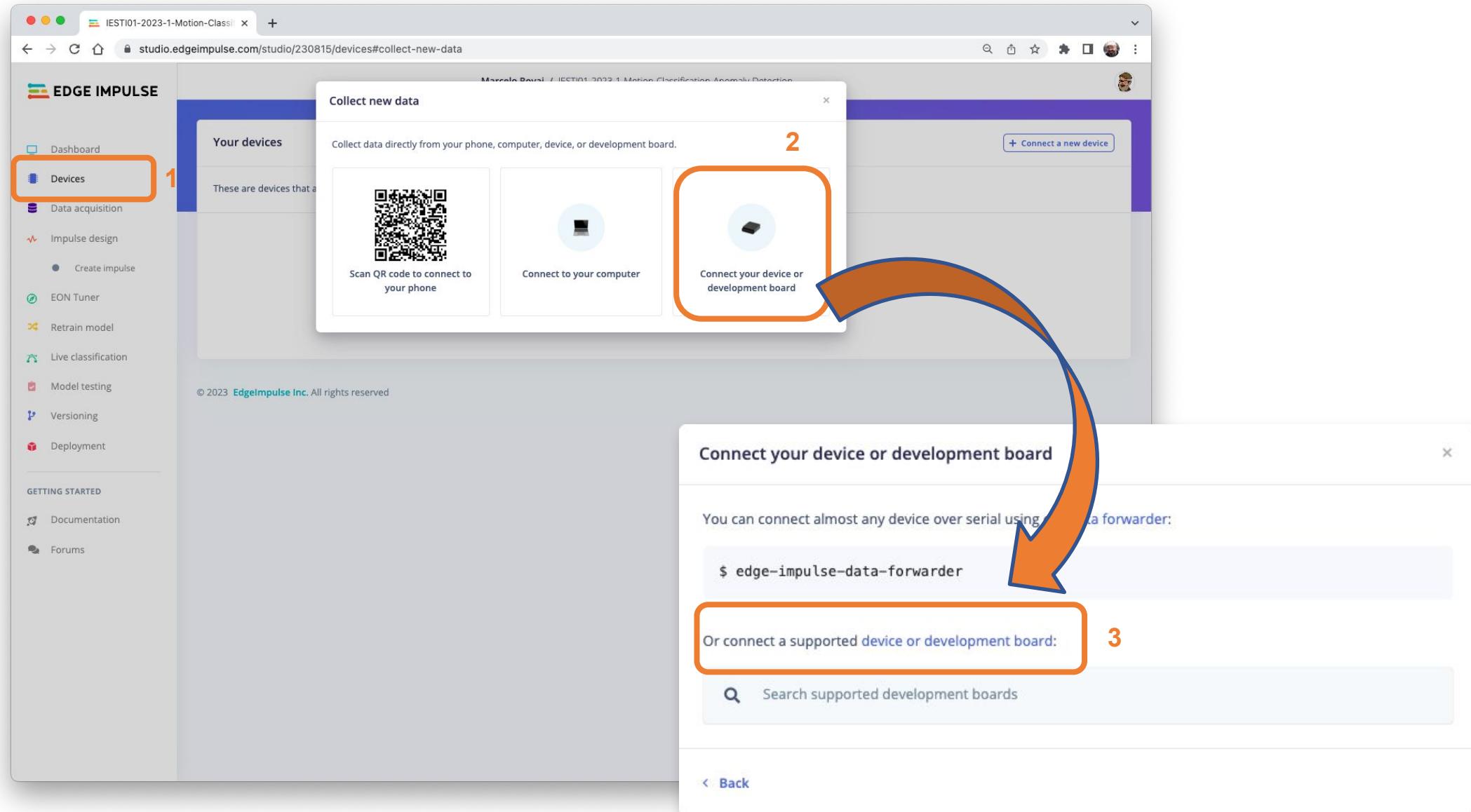
Marcelo Rovai / IESTI01 - Image Classification PUBLIC

iesti01-motion_cl....zip

Show All X

The screenshot shows the Edge Impulse studio interface. At the top, there's a navigation bar with tabs for 'Profile' and 'Projects'. Below that is a search bar and a user profile icon. The main area has a blue header with the 'EDGE IMPULSE' logo and two tabs: 'Projects' (which is selected) and 'Custom ML blocks'. On the left, there's a sidebar with a user profile picture and the name 'Marcelo Rovai'. The main content area displays a list of projects under the 'Projects' tab. One project is highlighted: 'Marcelo Rovai / TinyML4D - Project Setup - Gesture Classification'. Below this, a modal window titled 'Create a new project' is open. It asks for a project name ('IESTI01-2023-1-Motion-Classification-Anomaly-Detection') and allows selecting a project type ('Developer' is selected). At the bottom of the modal is a green 'Create new project' button. The background shows other projects: 'Bean Disease Classifier', 'IESTI01-Motion_Classification-Anomaly_Detection' (marked as 'PUBLIC'), 'IESTI01_Keyword_Spotting_project', and 'IESTI01 - Image Classification' (also marked as 'PUBLIC'). A file download progress bar for 'iesti01-motion_cl....zip' is visible at the bottom left, and a 'Show All' button with a close icon is at the bottom right.





IESTI01-2023-1-Motion-Classif Overview - Edge Impulse Doc

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

EDGE IMPULSE

Home Guides Projects Forum

Search

Getting Started

Getting Started: Next Steps

API and SDK references

What is embedded ML, anyway?

Frequently asked questions

EDGE IMPULSE STUDIO

Dashboard

Devices

Data sources

Data acquisition >

Data explorer

Impulse design

Bring your own model (BYOM)

Processing blocks >

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-bie-sense>

EI/Arduino CLI

The screenshot shows a web browser displaying the Edge Impulse documentation for the Arduino Nano 33 BLE Sense. The page title is "Arduino Nano 33 BLE Sense". The left sidebar lists various development boards, with "Arduino Nano 33 BLE Sense" highlighted. The main content area describes the board and its features, including its Cortex-M4 microcontroller, motion sensors, microphone, and BLE support. It also mentions the availability from Arduino and its use with the Arduino Tiny Machine Learning Kit. A blue arrow points from the text "Go to 2. Arduino CLI" to the "Installing dependencies" section at the bottom of the page.

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

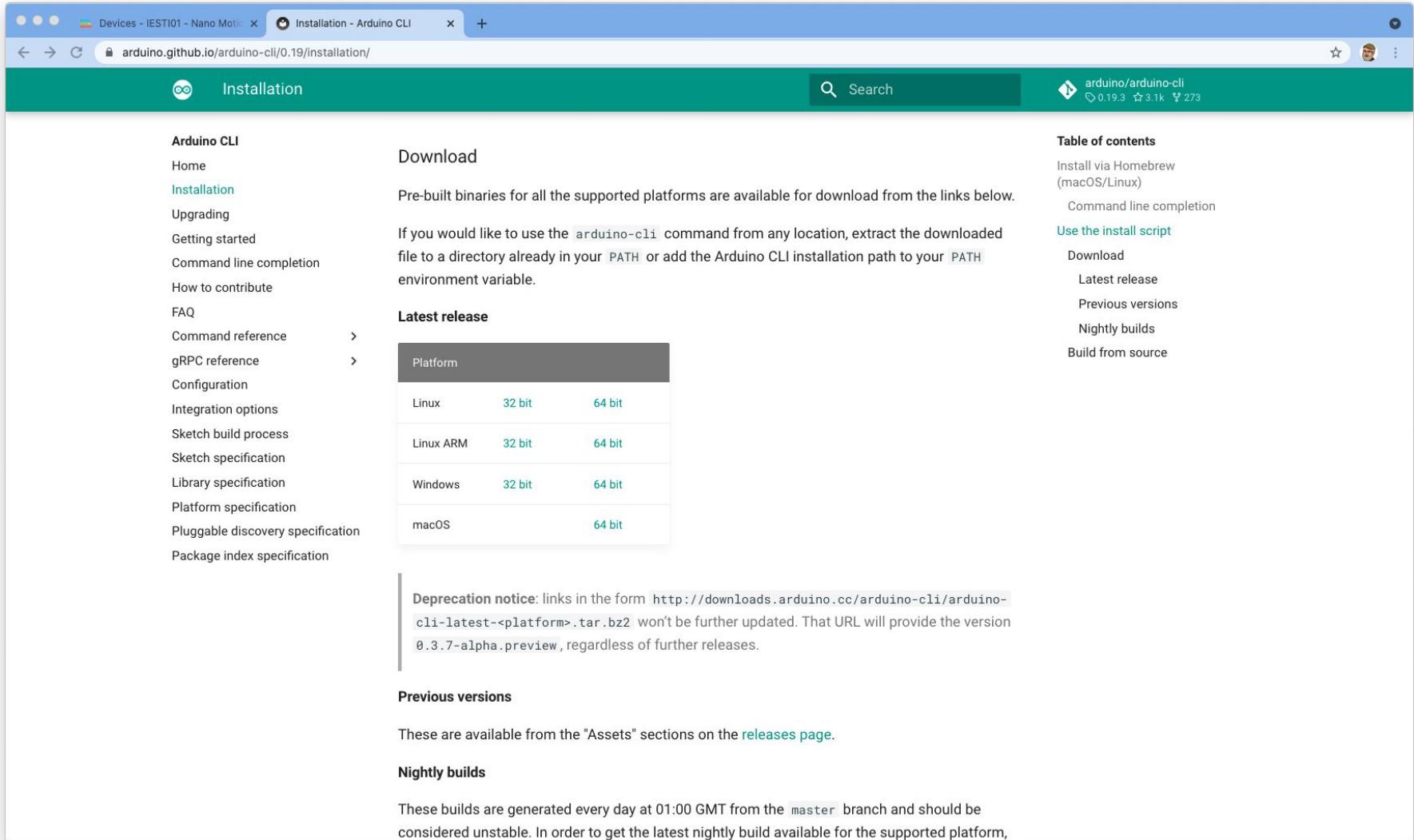
Go to 2. Arduino CLI

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.

Arduino CLI



The screenshot shows the "Installation" page for the Arduino CLI on GitHub. The URL in the address bar is arduino.github.io/arduino-cli/0.19/installation/. The page has a green header with the title "Installation". On the left, there's a sidebar with links like Home, Installation (which is active), 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 starts with a "Download" section, which says "Pre-built binaries for all the supported platforms are available for download from the links below." It then provides instructions for using the command line and a "Latest release" table. The table lists platforms and bit sizes:

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, there's a "Deprecation notice" about old URLs. Further down are sections for "Previous versions" and "Nightly builds". A "Table of contents" sidebar on the right lists various installation and usage topics.



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`

IESTI01-2023-1-Motion-Classi x Arduino Nano 33 BLE Sense - +
docs.edgeimpulse.com/docs/development-platforms/officially-supported-mcu-targets/arduino-nano-33-ble-sense

EDGE IMPULSE Home Guides Projects Forum Q Search 8K

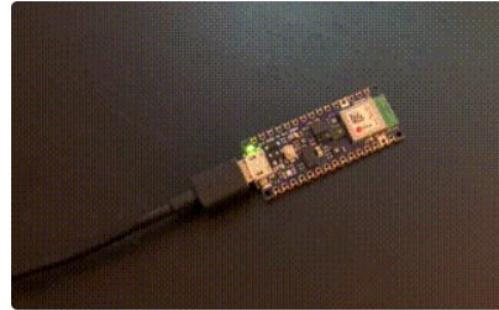
Getting Started
Getting Started: Next Steps
API and SDK references
What is embedded ML, anyway?
Frequently asked questions

EDGE IMPULSE STUDIO
Dashboard
Devices
Data sources
Data acquisition >
Data explorer
Impulse design
Bring your own model (BYOM)
Processing blocks >
Learning blocks >
EON Timer >

1 2 3

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.

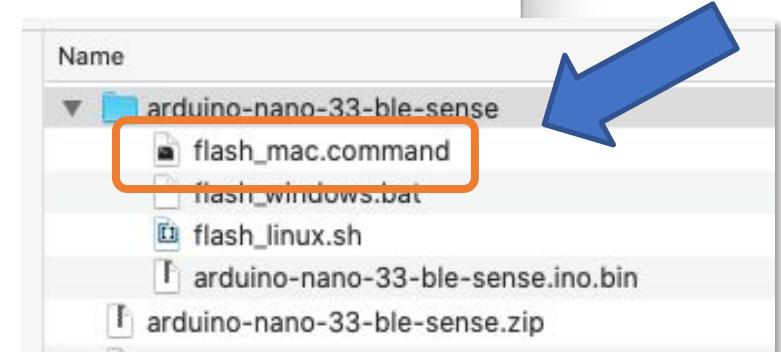
arduino-nano-33....zip Show All X

MacOS

```
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]
```

3.Nano-33 LED Stop Flashing

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



Windows 10

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

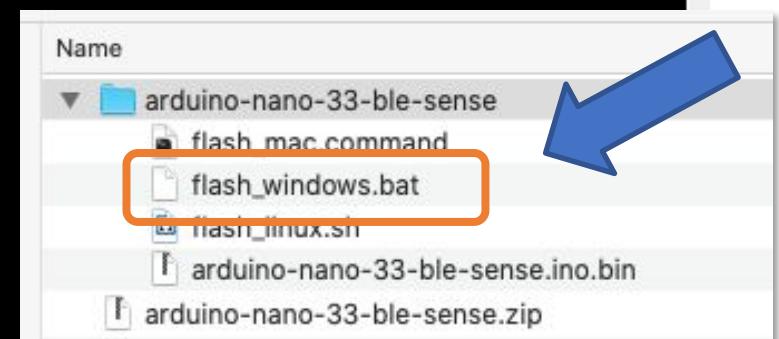
C:\Users\GUILH>arduino-cli
Arduino Command Line Interface (arduino-cli).

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:



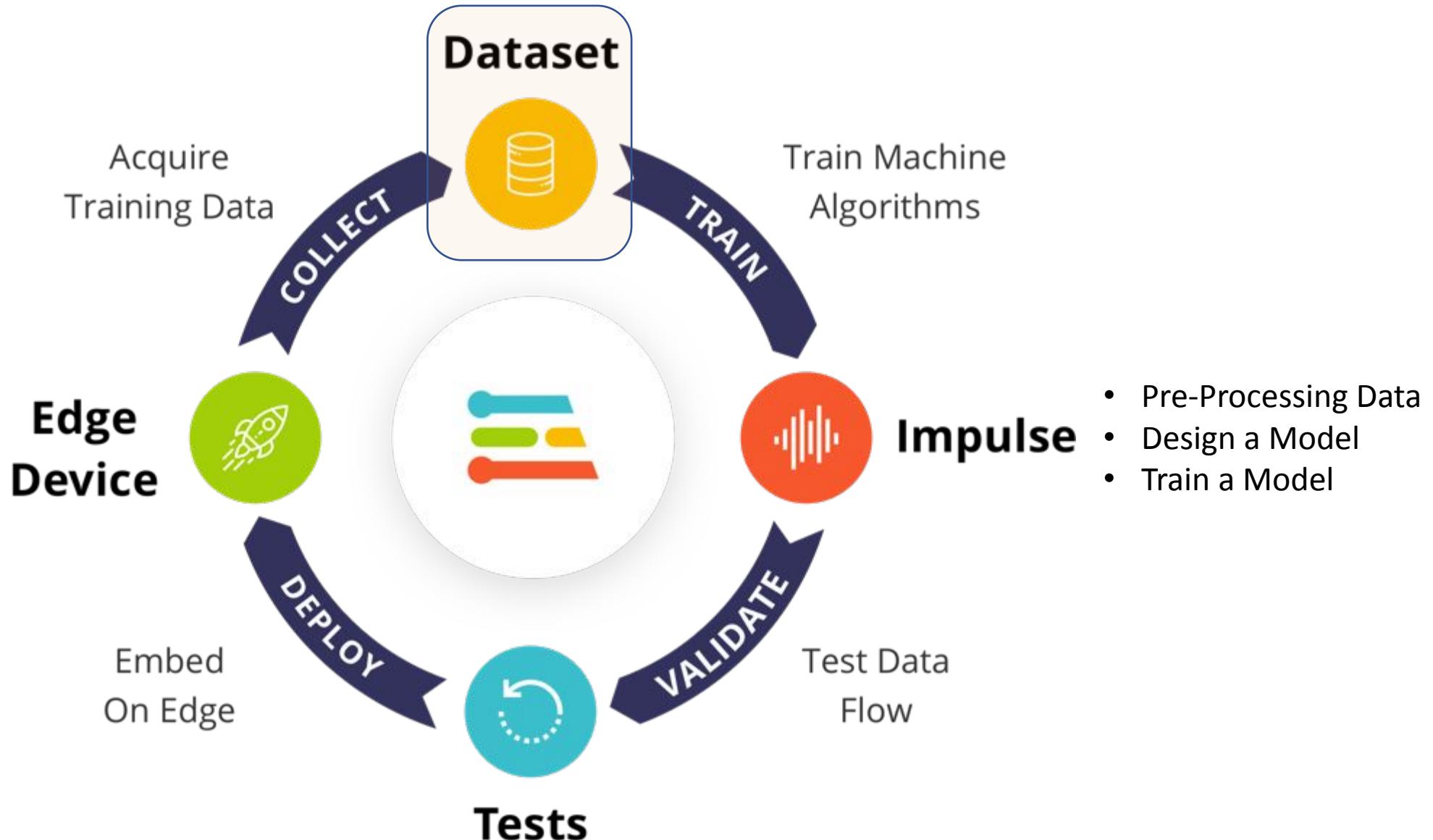
Windows 10

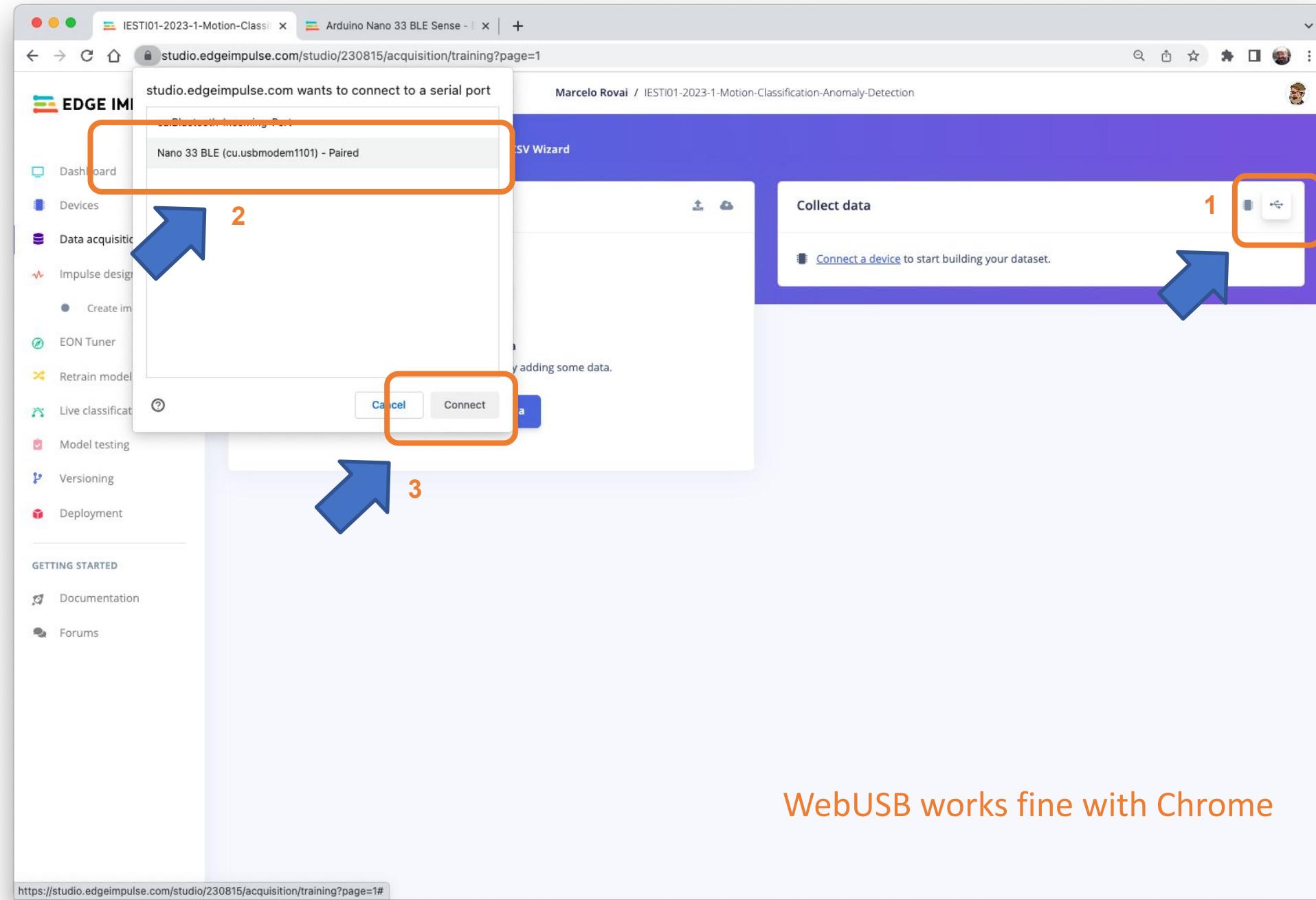
```
cmd C:\WINDOWS\system32\cmd.exe
Finding Arduino Mbed core...
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Finding Arduino Mbed core OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK at COM11
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Device 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

Sensor's Test





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 interface for a project titled "IESTI01 - Sensor Test". The left sidebar contains navigation links like Dashboard, Devices, Data sources, Data acquisition, Impulse design, EON Tuner, Retrain model, Live classification, Model testing, Versioning, Deployment, Documentation, and Forums. The main area has tabs for Training data, Test data, Data explorer, Upload data, CSV Wizard, and Export data. A blue banner at the top 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 includes fields for Device (set to 36:17:55:F9:70:F7), Label (set to lift), Sample length (ms) (set to 10000), Sensor (set to Built-in microphone, Inertial checked), and Frequency (set to 100Hz). A "Start sampling" button is present. Two blue arrows point to the "Inertial" option in the Sensor dropdown menu and the "Start sampling" button.

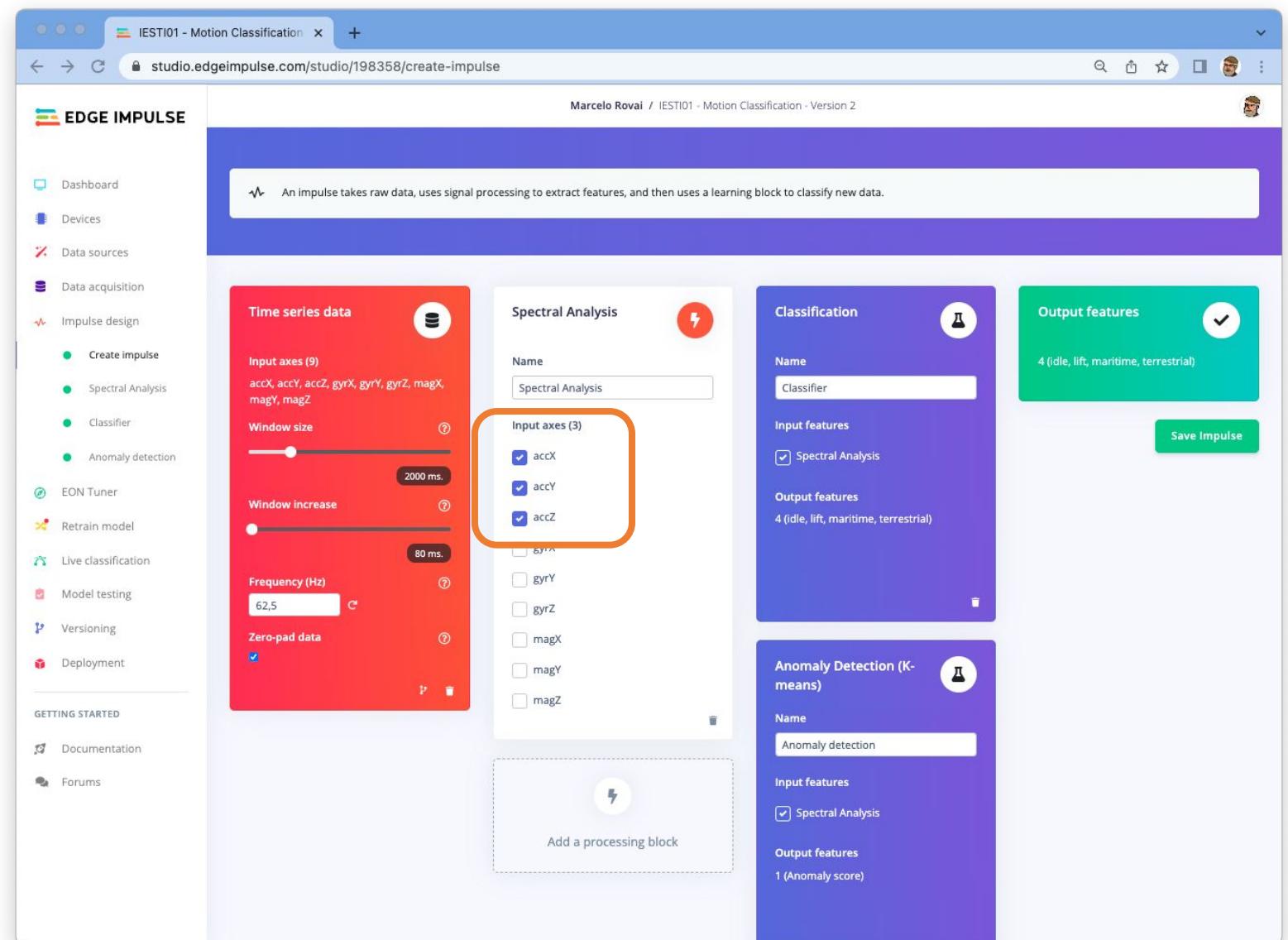
IMU sensor (Inertial)



The screenshot shows the Edge Impulse studio interface. On the left, a sidebar lists various features: Dashboard, Devices, Data acquisition, Impulse design, Create impulse, EON Tuner, Retrain model, Live classification, Model testing, Versioning, Deployment, Documentation, and Forums. The main area is titled "Dataset" and shows "DATA COLLECTED 10s" and "TRAIN / TEST SPLIT 100% / 0%". A dataset table lists a single entry: "lift.411q664t" with "label: lift", "added: Today, 16:41:55", and "length: 10s". To the right, a "Collect data" section is shown with a "Device" dropdown set to "36:17:55:F9:70:F7". The "Label" field is set to "lift" and the "Sample length (ms)" is set to "10000". The "Sensor" field is set to "Inertial" and the "Frequency" is set to "100Hz". A "Start sampling" button is present. Below this is a "RAW DATA" plot titled "lift.411q664t" showing multiple colored time-series signals (accX, accY, accZ, gyrX, gyrY, gyrZ, magX, magY, magZ) over time. A blue arrow points from the "Inertial" label in the "Collect data" section to the "mag" signals in the raw data plot.

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.



Data acquisition - IESTI01

studio.edgeimpulse.com/studio/38744/acquisition/training?page=1

EDGE IMPULSE

DATA COLLECTED
10s

LABELS
1

Collected data

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

Device ②
36:17:55:F9:70:F7

Label
unifei

Sample length (ms.)
10000

Sensor
Built-in microphone

Frequency
16000Hz

Start sampling

RAW DATA
unifei.29js37tq



0 1051 2103 3154 4206 5258 6309 7361 8413 9464

audio

▶ 0:10 / 0:10

⋮

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

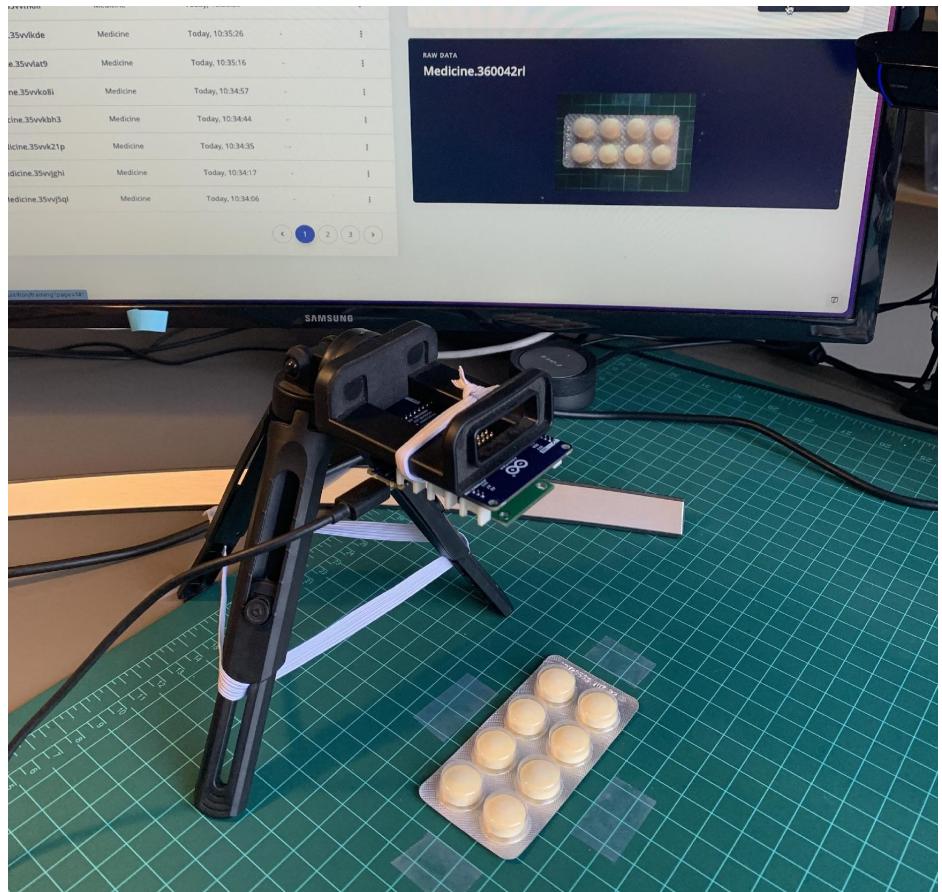
GETTING STARTED

Documentation

Forums

Record new data

Camera



Data acquisition - IESTI01

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

Record new data

Device ②

36:17:55:F9:70:F7

Label

medicine

Camera feed

Sensor

Camera (128x96)

Start sampling

RAW DATA

Click on a sample to load...

© 2022 Edgimpulse Inc. All rights reserved

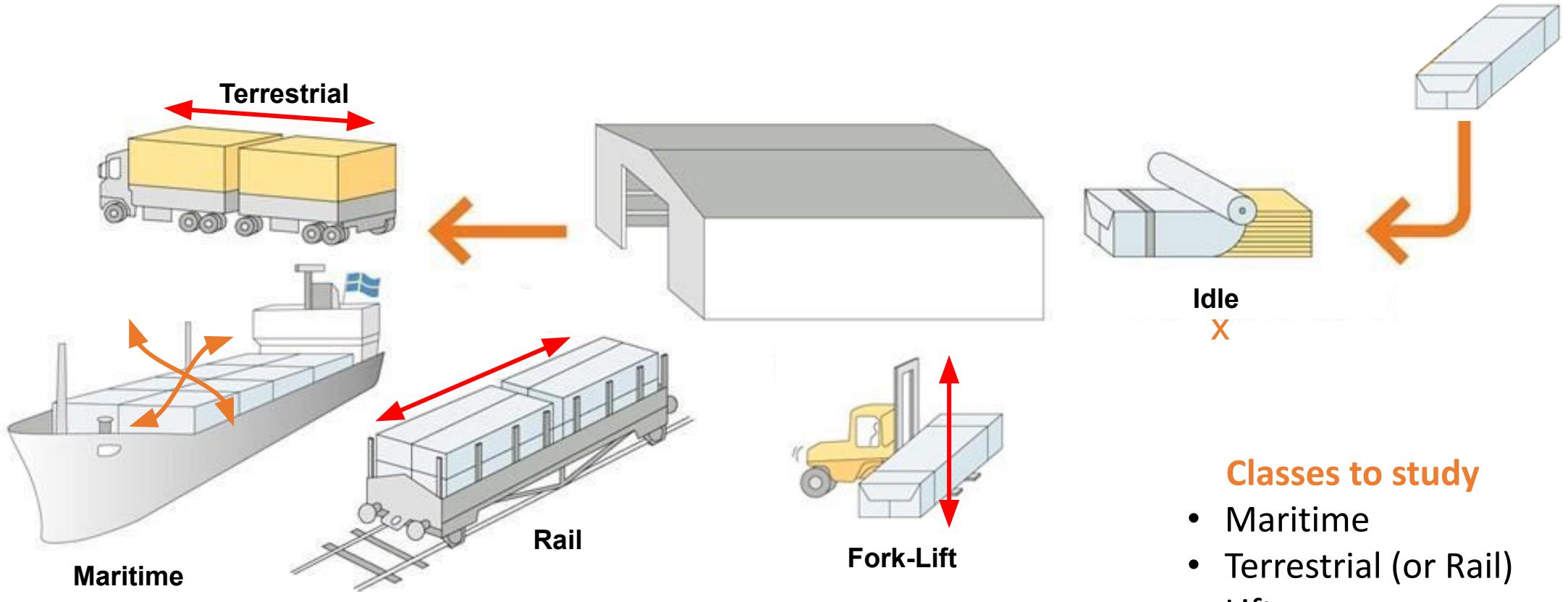
This screenshot shows the Edge Impulse Studio interface for data acquisition. The main title bar reads "Data acquisition - IESTI01". The URL in the address bar is "studio.edgeimpulse.com/studio/114253/acquisition/training?page=1". The main content area is titled "Record new data". It includes fields for "Device" (set to "36:17:55:F9:70:F7"), "Label" (set to "medicine"), and "Sensor" (set to "Camera (128x96)", which is highlighted with an orange rectangle). To the right, there is a "Camera feed" window showing a live image of a blister pack of medicine. Below the feed is a "Start sampling" button. At the bottom, there is a "RAW DATA" section with the instruction "Click on a sample to load...".

Motion Classification

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

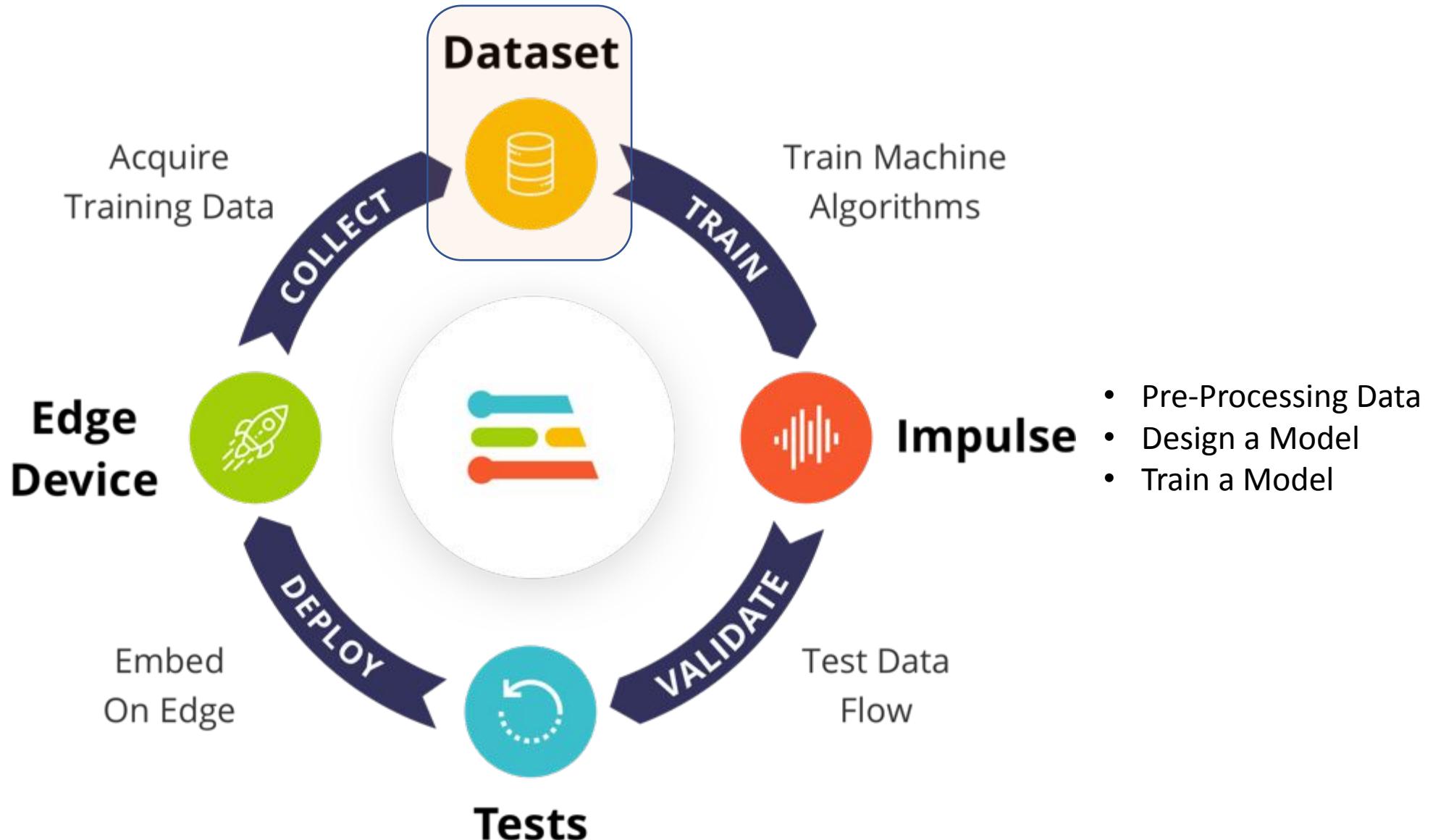


Case Study: Mechanical Stresses in Transport



Classes to study

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



IESTI01-2023-1-Motion-Classifi X +

studio.edgeimpulse.com/studio/230815/acquisition/training?page=1

EDGE IMPULSE

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

Dataset Data explorer Data sources | CSV Wizard

DATA COLLECTED 6m 50s TRAIN / TEST SPLIT 80% / 20%

Dataset

Training (33) Test (8)

SAMPLE NAME	LABEL	ADDED	LENGTH
testing.34upcqid.ingestio...	terrestrial	Today, 16:55:43	10s
maritime.34cqj20d.inges...	maritime	Today, 16:52:37	10s
maritime.34cqmnb.inge...	maritime	Today, 16:52:37	10s
lift.34cqimov.ingestion-6...	lift	Today, 16:52:36	10s
terrestrial.34cqci2.inges...	terrestrial	Today, 16:52:36	10s
idle.34cq5b5.ingestion-6...	idle	Today, 16:52:36	10s
lift.34cqj52p.ingestion-65...	lift	Today, 16:52:35	10s
idle.34cqvupv.ingestion-...	idle	Today, 16:52:35	10s
lift.34cqhit7.ingestion-65...	lift	Today, 16:52:35	10s
lift.34cqh2c8.ingestion-6...	lift	Today, 16:52:34	10s
maritime.34cqom0d.inge...	maritime	Today, 16:52:34	10s
terrestrial.34cq9pib.inge...	terrestrial	Today, 16:52:34	10s

Collect data

Connect a device to start building your dataset.

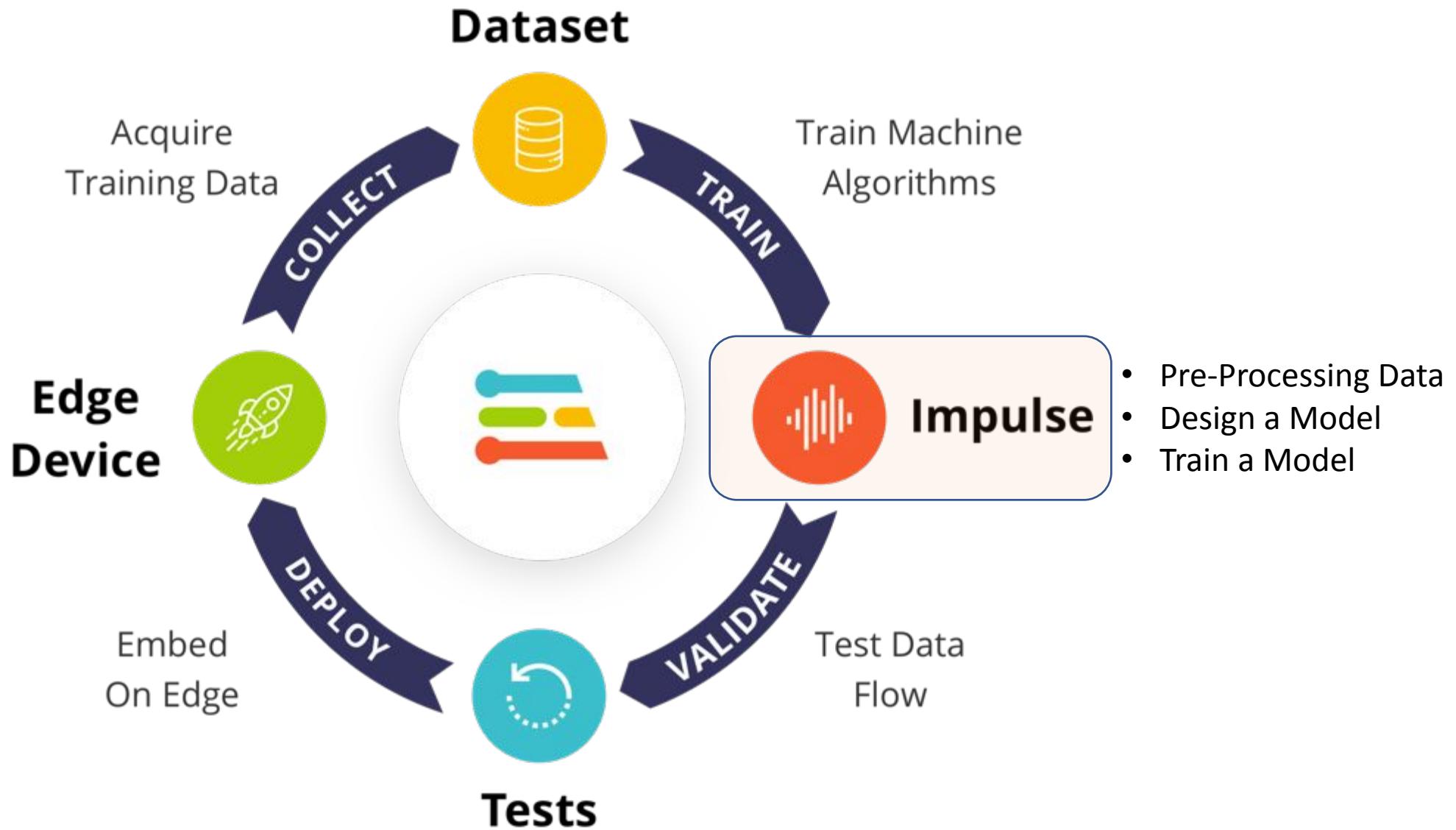
RAW DATA

testing.34upcqid.ingestion-68b7b864c-j5g9x

accX accY accZ

Metadata

No metadata.



The screenshot shows the Edge Impulse Studio interface for creating a motion classification impulse. The top navigation bar includes the Edge Impulse logo, the project name "IESTI01-2023-1-Motion-Classif", and the URL "studio.edgeimpulse.com/studio/230815/create-impulse". The top right corner features user information for "Marcelo Rovai / IESTI01-2023-1-Motion-Classification-Anomaly-Detection" and a profile picture.

The left sidebar contains a navigation menu with the following items:

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

Below this is a "GETTING STARTED" section with links to Documentation and Forums.

The main workspace is divided into four main sections:

- Time series data** (Orange box):
 - Input axes (3)**: accX, accY, accZ
 - Window size**: Sliders for Window size (2000 ms) and Window increase (200 ms).
 - Frequency (Hz)**: Input field set to 62,5 Hz.
 - Zero-pad data**: Checkmark selected.
- Spectral Analysis** (Light Blue box):
 - Name**: Spectral features
 - Input axes (3)**: accX, accY, accZ
- Classification** (Dark Blue box):
 - Name**: Classifier
 - Input features**: Spectral features
 - Output features**: 4 (idle, lift, maritime, terrestrial)
- Output features** (Green box):
 - 4 (idle, lift, maritime, terrestrial)

At the bottom center are two dashed boxes with buttons: "Add a processing block" and "Add a learning block". A green "Save Impulse" button is located on the right side of the workspace.

The footer of the page includes the copyright notice "© 2023 EdgeImpulse Inc. All rights reserved".

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? ?

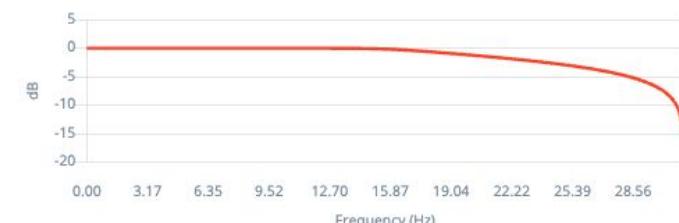
Overlap FFT frames? ?

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...

IESTI01-2023-1-Motion-Classif

studio.edgeimpulse.com/studio/230815/dsp/spectral-analysis/3/generate-features

#1 Click to set a description for this version

EDGE IMPULSE

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 (0)

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

Feature importance

Feature	Importance
accZ RMS	High
accX Spectral Power 0.98 - 2.93 Hz	Medium
accZ Skewness	Medium
accY Spectral Power 2.93 - 4.88 Hz	Low
accX Spectral Power 6.84 - 8.79 Hz	Low

Show more

On-device performance

PROCESSING TIME 5 ms.

PEAK RAM USAGE 2 KB

IESTI01-2023-1-Motion-Classif X +

studio.edgeimpulse.com/studio/230815/learning/keras/7

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

#1 Click to set a description for this version

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral features
- Classifier

EON Tuner

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Neural Network settings

Training settings

Number of training cycles ② 30

Learning rate ② 0.0005

Advanced training settings

Validation set size ② 20 %

Split train/validation set on metadata key ②

Auto-balance dataset ②

Profile int8 model ②

Neural network architecture

Target device

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

Model version: ② Quantized (int8)

Alif HE (Cortex-M55 160MHz + U55-128MACC)
Alif HP (Cortex-M55 400MHz + U55-256MACC)
Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz)
Arduino Nidia 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)
Seeed SenseCAP A1101 (HX6537-A ARC DSP 400MHz)
Seeed Studio Wio Terminal (Cortex-M4F 120MHz)
Seeed Vision AI Module (HX6537-A ARC DSP 400MHz)

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

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

Scatter plot showing data points clustered by category.

Target: Cortex-M4F 80MHz

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)

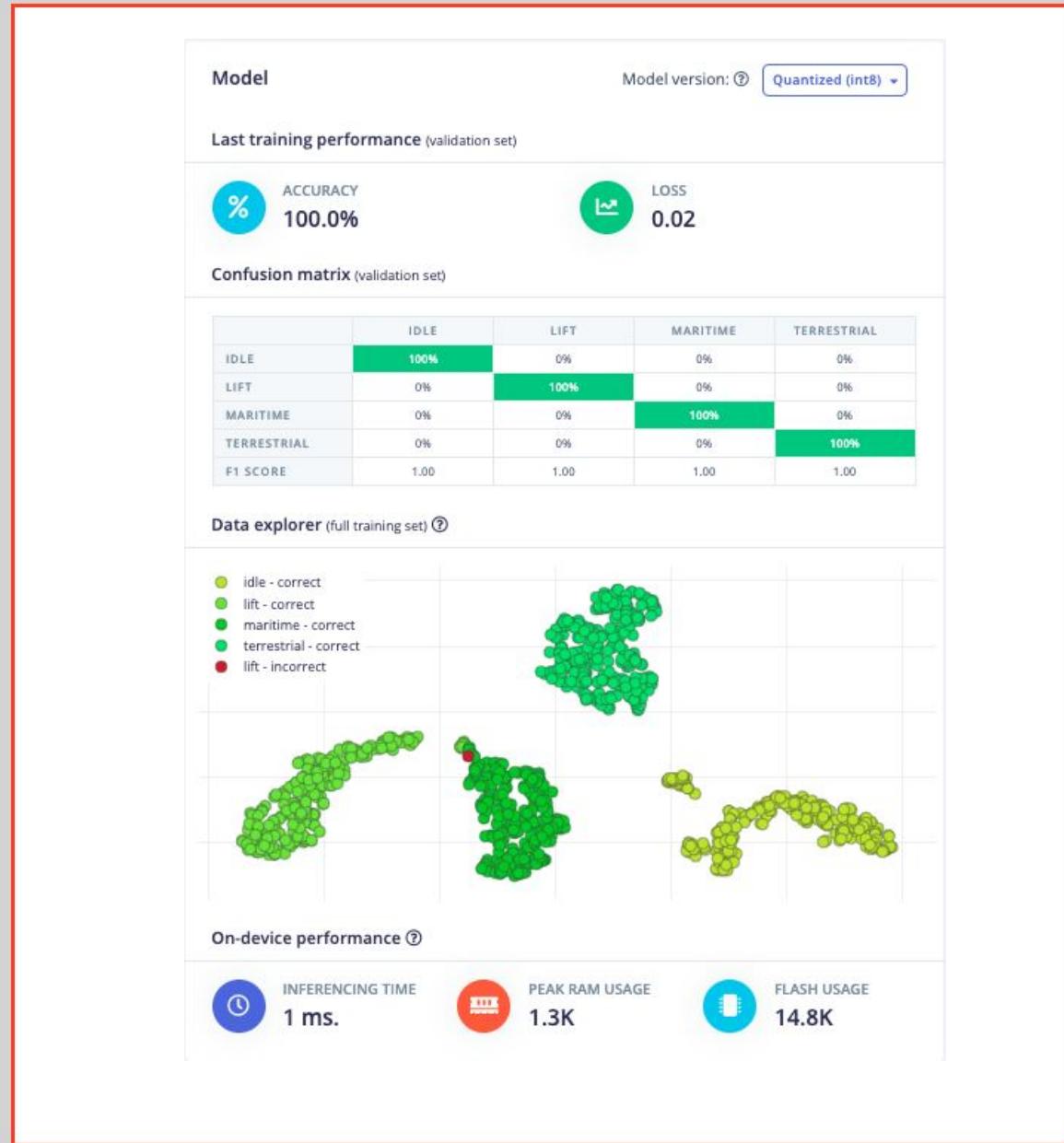
Dense layer (20 neurons)

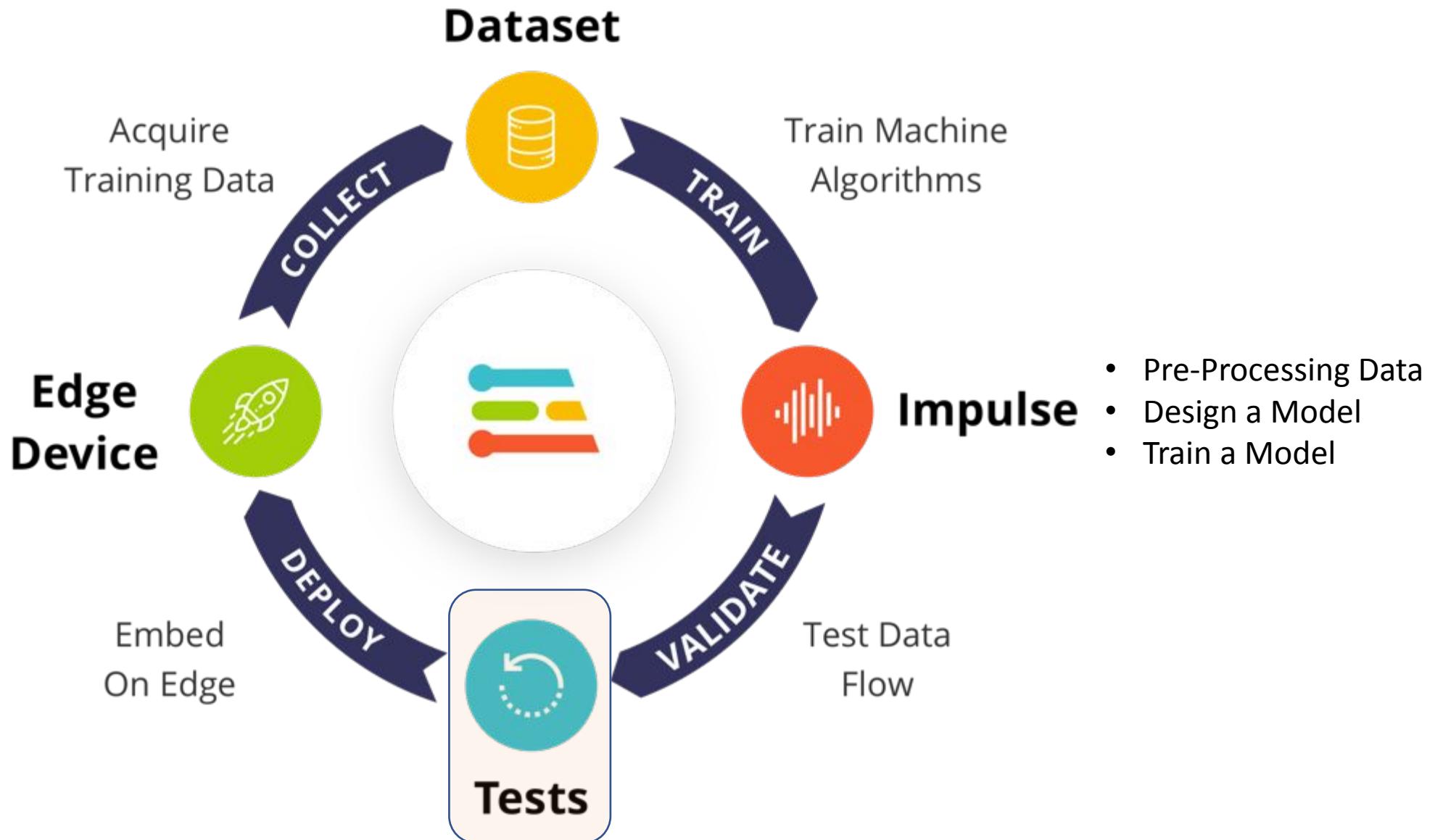
Dense layer (10 neurons)

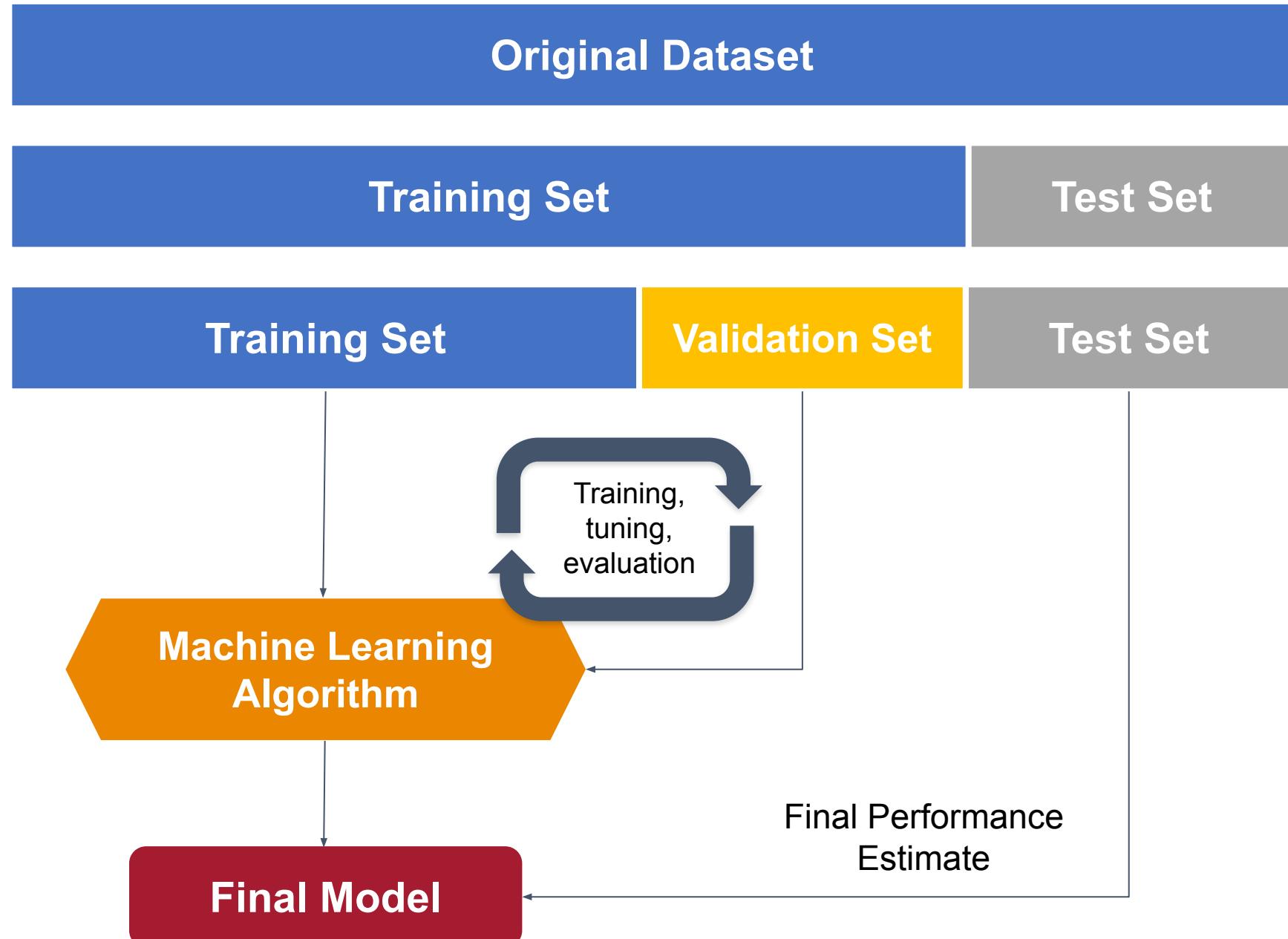
Add an extra layer

Output layer (4 classes)

Start training







ESTI01-2023-1-Motion-Classif

studio.edgeimpulse.com/studio/230815/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	
lift.34cqfbfc.in...	lift	10s	100%	42 lift	⋮
terrestrial.34c...	terrestrial	10s	100%	42 terrestrial	⋮
maritime.34cq...	maritime	10s	97%	41 maritime, 1 uncertain	⋮
idle.34cr0hvr.i...	idle	10s	100%	42 idle	⋮
terrestrial.34c...	terrestrial	10s	100%	42 terrestrial	⋮
idle.34cqskr1.i...	idle	10s	100%	42 idle	⋮
maritime.34cq...	maritime	10s	100%	42 maritime	⋮
lift.34cqjaad.in...	lift	10s	100%	42 lift	⋮

Model testing output

```
CLASSIFYING DATA FOR 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...
Container image pulled!
Job started
Classifying data for Classifier OK

Job completed
```

Model testing results

ACCURACY
99.70%

	IDLE	LIFT	MARITIME	TERRESTRIAL	UNCERTAIN
IDLE	100%	0%	0%	0%	0%
LIFT	0%	100%	0%	0%	0%
MARITIME	0%	0%	98.8%	0%	1.2%
TERRESTRIAL	0%	0%	0%	100%	0%
F1 SCORE	1.00	1.00	0.99	1.00	

Feature explorer

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

The screenshot shows the Edge Impulse Studio interface on a web browser. The main window displays a project titled "IESTI01-2023-1-Motion-Classification-Anomaly-Detection". A modal window titled "studio.edgeimpulse.com wants to connect to a serial port" is open in the foreground. The modal lists available ports: "cu.Bluetooth-Incoming-Port" and "Nano 33 BLE (cu.usbmodem1101) - Paired". The "Nano 33 BLE" port is highlighted with a blue background. At the bottom of the modal are two buttons: "Cancel" and "Connect".

studio.edgeimpulse.com/studio/230815/classification

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

cu.Bluetooth-Incoming-Port

Nano 33 BLE (cu.usbmodem1101) - Paired

Cancel Connect

© 2023 EdgeImpulse Inc. All rights reserved

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

Classify existing test sample

lift.34cqfbfc.ingestion-65bfb76ddd-vl9kr (lift)

Load sample

ESTI01-2023-1-Motion-CI

studio.edgeimpulse.com/studio/230815/classification#load-sample-285961843

Classification result

Summary

Name	testing.411u7a0l
Expected outcome	testing
CATEGORY	COUNT
idle	0
lift	38
maritime	1
terrestrial	0
uncertain	3

Detailed result

TIMESTAMP	IDLE	LIFT	MARITIME	TERRESTRIAL
0	0	0.92	0.07	0
192	0	0.91	0.09	0
384	0	0.98	0.02	0
576	0	0.84	0.16	0
768	0	0.86	0.14	0
960	0	0.95	0.05	0
1152	0	0.91	0.09	0
1344	0	0.79	0.20	0

Raw data

testing.411u7a0l

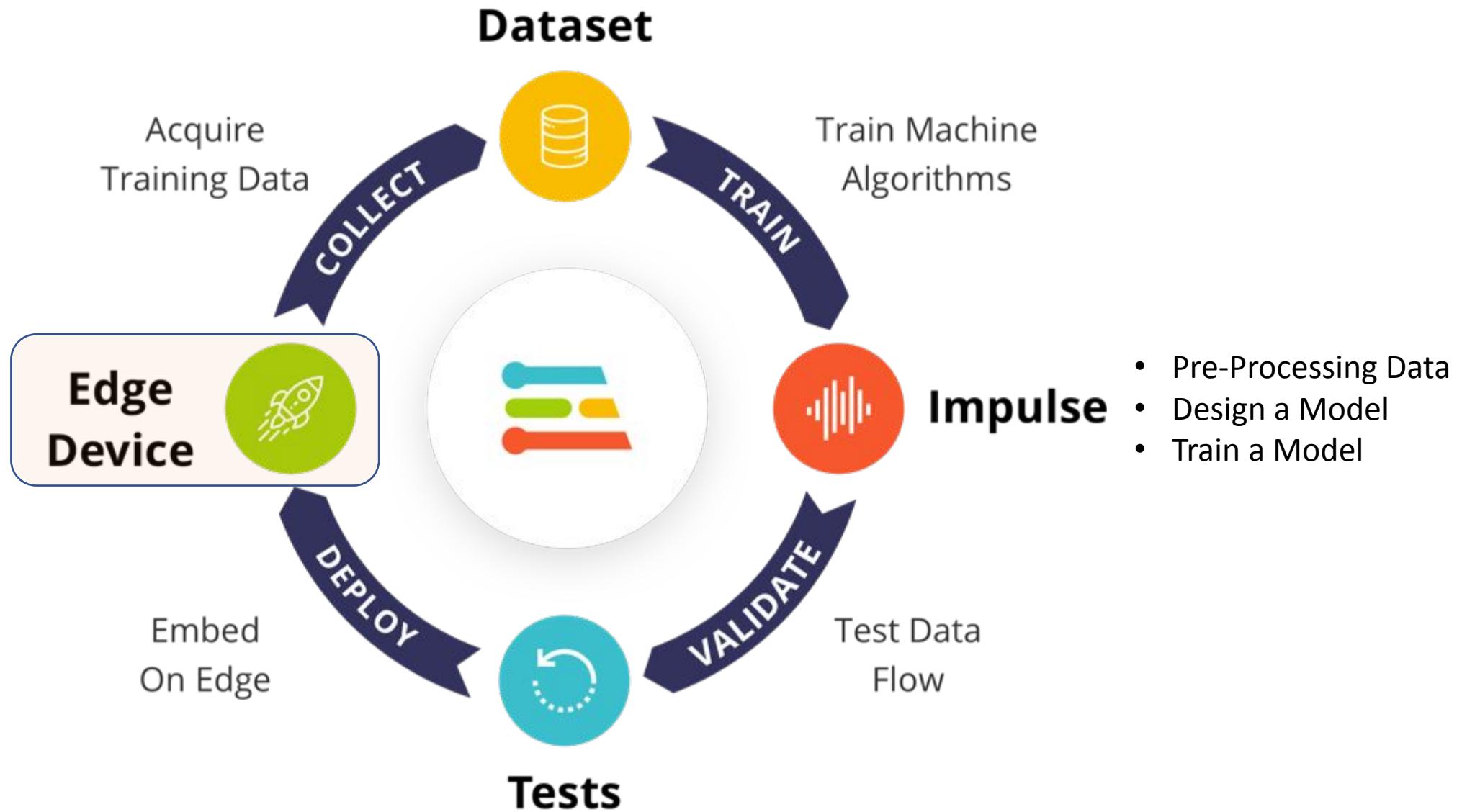
Raw features

```
0.5986, -2.6528, 2.0102, 0.4116, -3.9280, 3.3136, 0.0566, -3.6845, 3.5588, 0.2455, -3.55
```

Spectral features

Processed features

```
0.0827, -0.0189, -1.2757, 3.4827, 10.7525, -1.0068, -1.7973, -2.0454, -2.1258, -2.8648, -
```



The screenshot shows the Edge Impulse studio interface with a blue arrow pointing from the left sidebar to the 'Arduino library' section in the main content area.

EDGE IMPULSE

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

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

	RAM	1.9K	1.3K	1.9K
FLASH	-	14.8K	-	-
ACCURACY				-

Unoptimized (float32)

	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

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**
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 Same accuracy, up to 50% less memory. [Learn more](#)

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)

	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.

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



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 OPTIMIZATION

Model optimization

Quantized (float16)

Selected

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

Unoptimized (float32)

	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

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

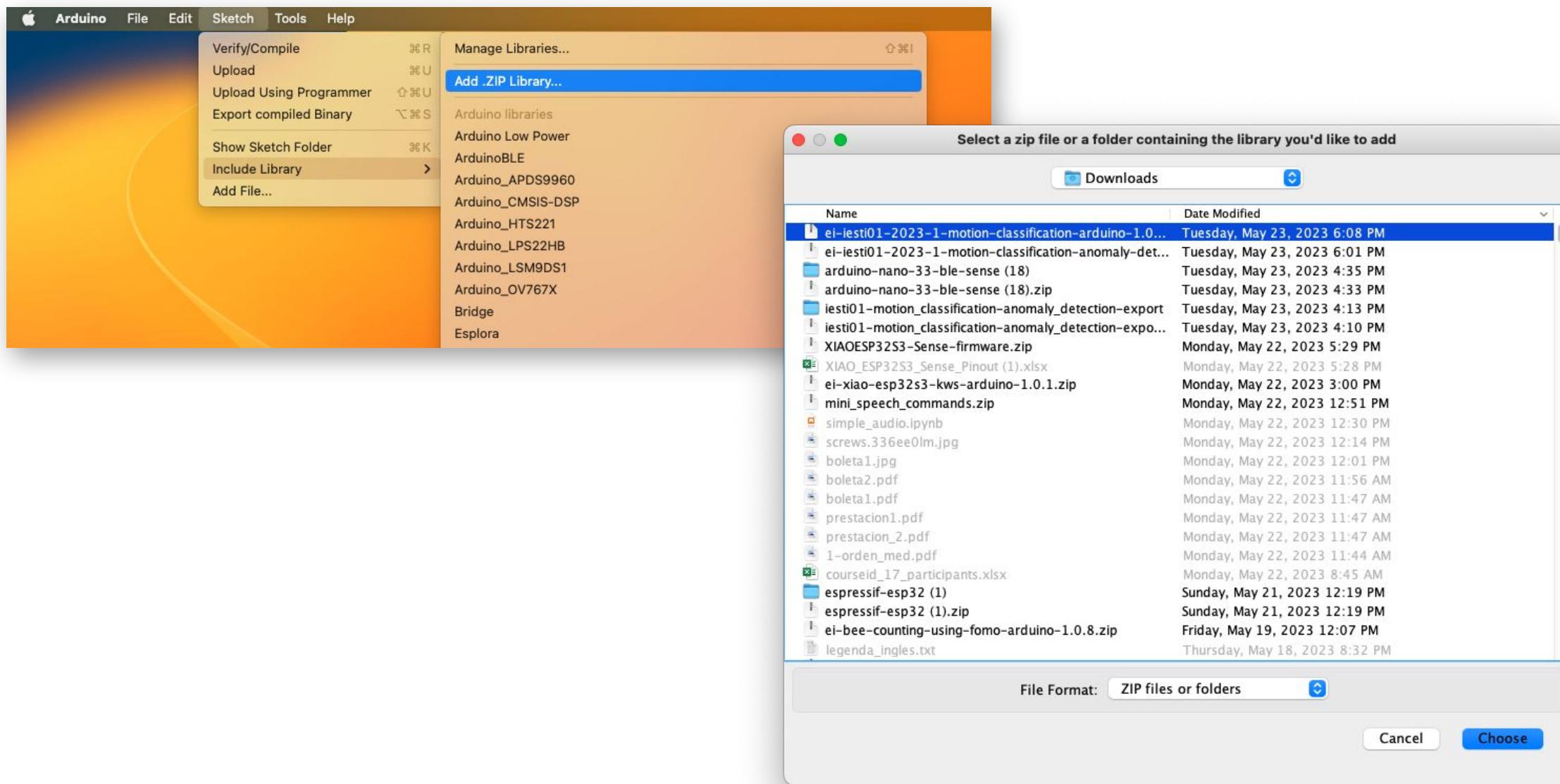
Show All

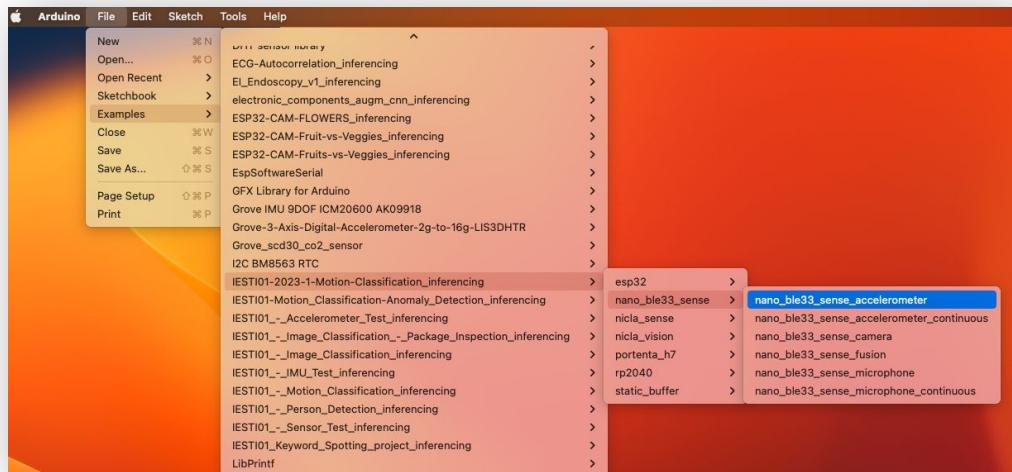
Latest build

v1 (Arduino library)
Today, 18:01:09

View docs

Container image pulled!
Job started
Writing templates...
OK
cluster...
uled!
lse SDK...
lse SDK OK
el...
el OK
and updating headers...
and updating headers OK
OK





The screenshot shows the Arduino IDE code editor with the sketch "nano_ble33_sense_accelerometer" open. The code is written in C++ and includes comments explaining the setup and usage of the IESTI library. The code editor has a dark theme with syntax highlighting for keywords and comments.

```
16
17 /* Includes -----
18 #include <IESTI01-2023-1-Motion-Classification_inferencing.h>
19 #include <Arduino_LSM9DS1.h> //Click here to get the library: http://librarymanager.arduino.cc
20
21 /* Constant defines -----
22 #define CONVERT_G_TO_MS2 9.80665f
23 #define MAX_ACCEPTED_RANGE 2.0f           // starting 03/2022, models are generated
24
25 /*
26 ** NOTE: If you run into TFLite arena allocation issue.
27 **
28 ** This may be due to memory fragmentation.
29 ** Try defining "-DEI_CLASSIFIER_ALLOCATION_STATIC" in boards.local.txt (create
30 ** if it doesn't exist) and copy this file to
```

Hardware CDC and JTAG, Enabled, Disabled, UART0 / Hardware CDC, Default with spiffs (3MB APP/1.5MB SPIFFS), 240MHz (WiFi), 921600, None, Disabled on /dev/cu.usbmodem1101

Model Inference

```
Sampling...
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 ->
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 ->
18:20:38.879 -> Starting inferencing in 2 seconds...
18:20:40.868 -> Sampling...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

```
Sampling...
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 ->
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 ->
18:23:40.062 -> Starting inferencing in 2 seconds...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

```
Sampling...
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 ->
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 ->
18:24:44.495 -> Starting inferencing in 2 seconds...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

```
Sampling...
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 ->
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 ->
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