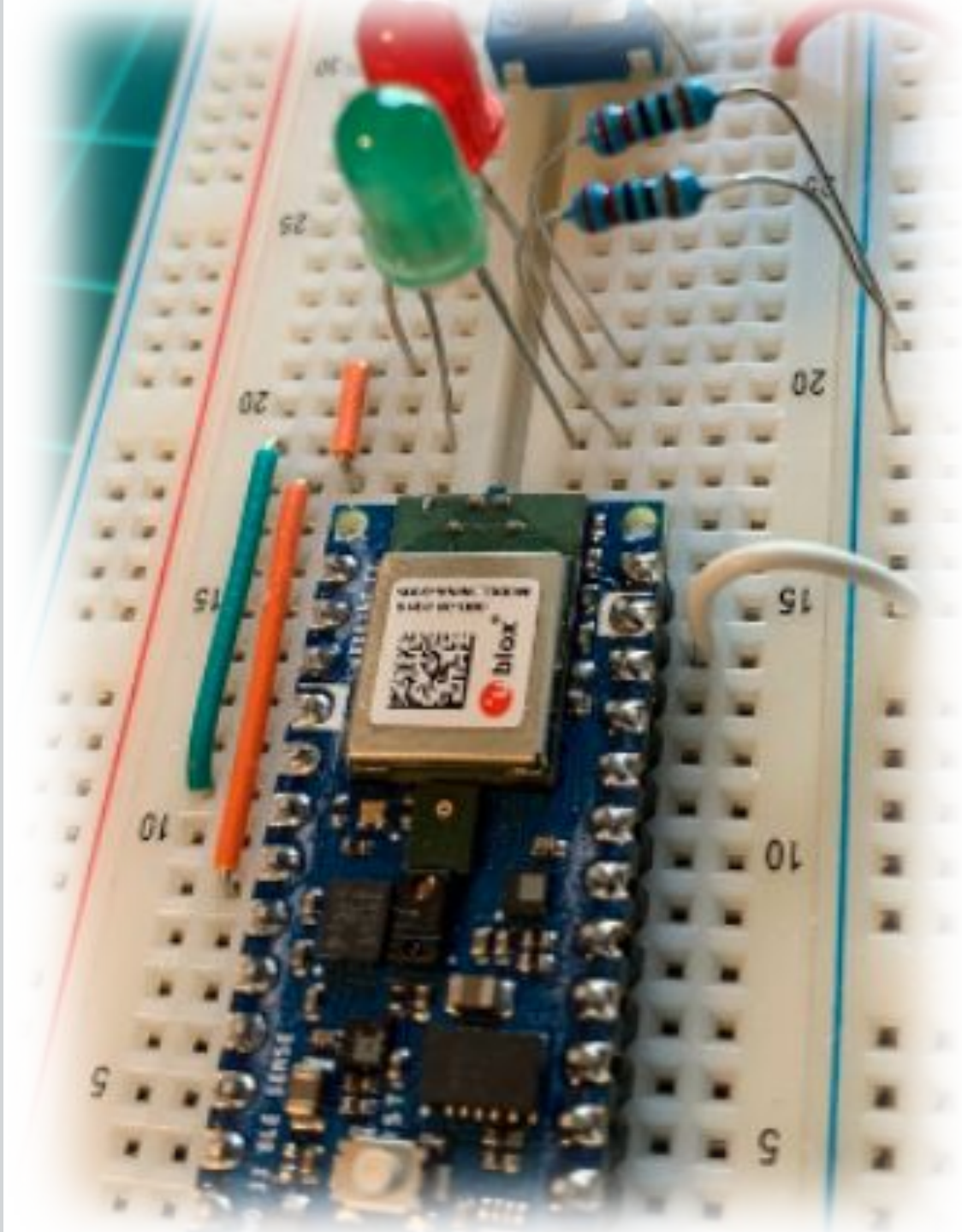
IESTI01 – TinyML

Embedded Machine Learning

19. Motion Classification

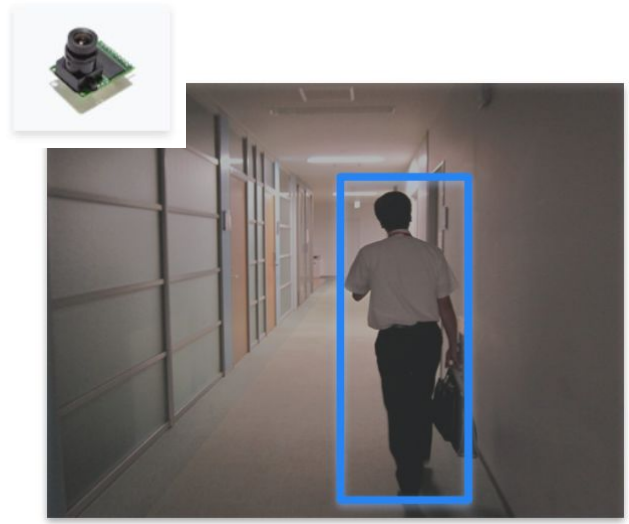


Prof. Marcelo Rovai
UNIFEI

Vibration

Sound

Vision



Vibration

Sound

Vision

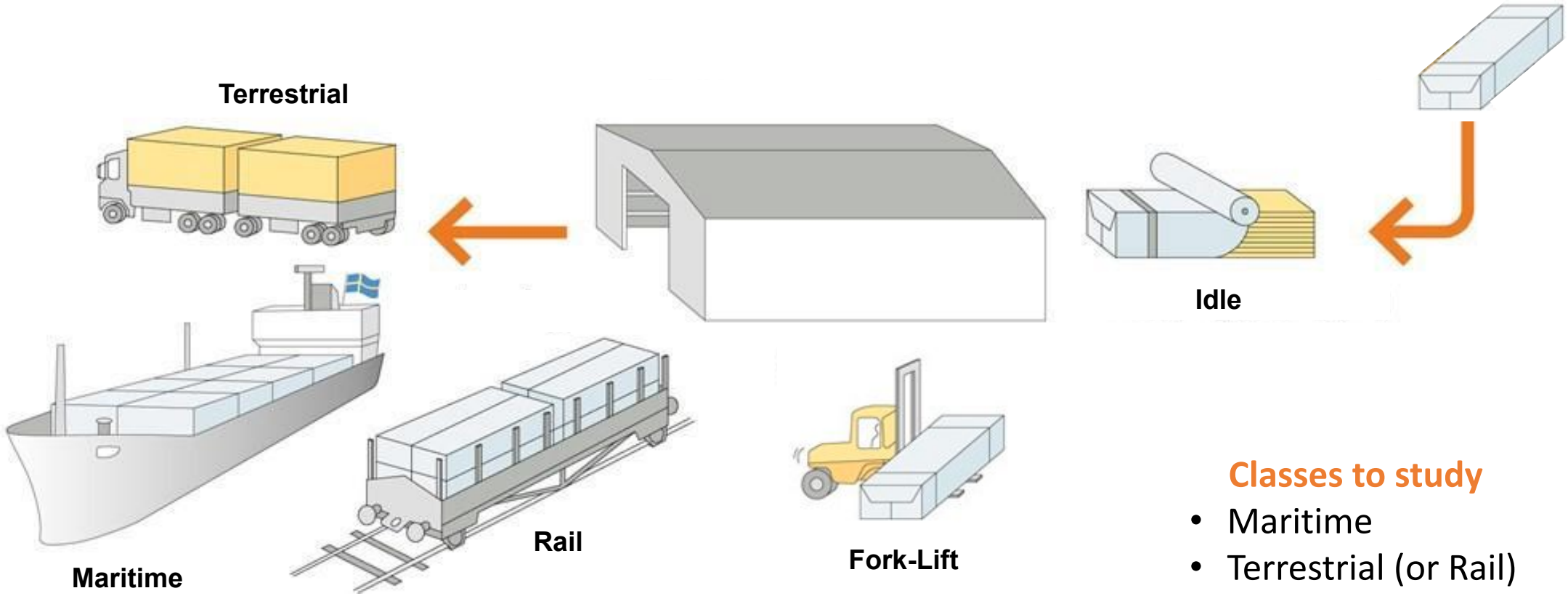
Industrial Embedded Machine Learning Demo

Daniel Situnayake, founding engineer of Edge Impulse

Introduction to Embedded ML course

Motion Classification

Case Study: Mechanical Stresses in Transport

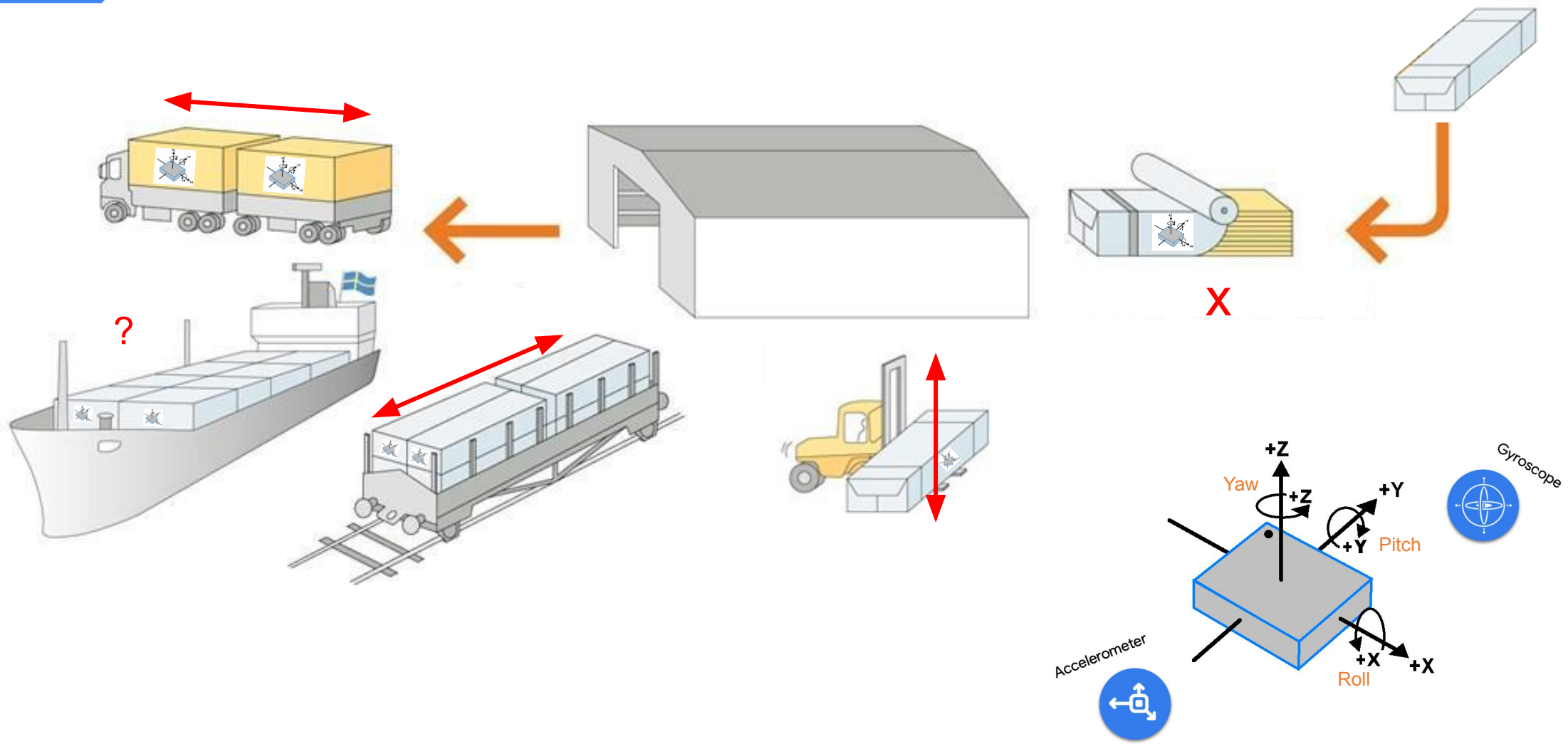


Classes to study

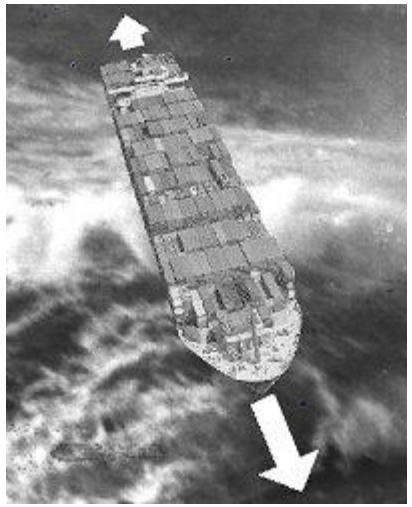
- Maritime
- Terrestrial (or Rail)
- Lift
- Idle

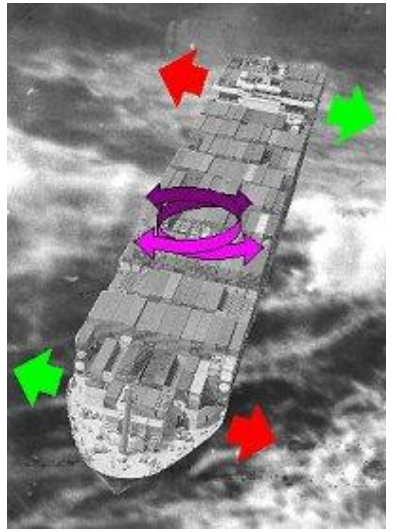
Machine Learning Workflow

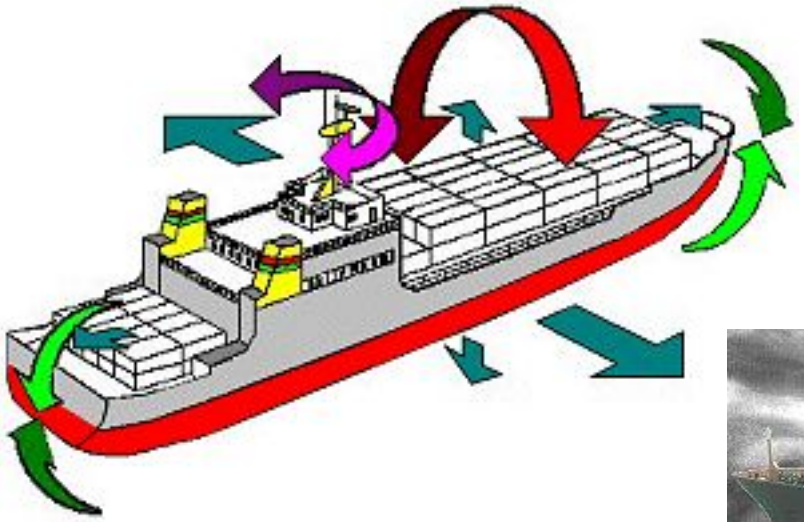
Collect Data

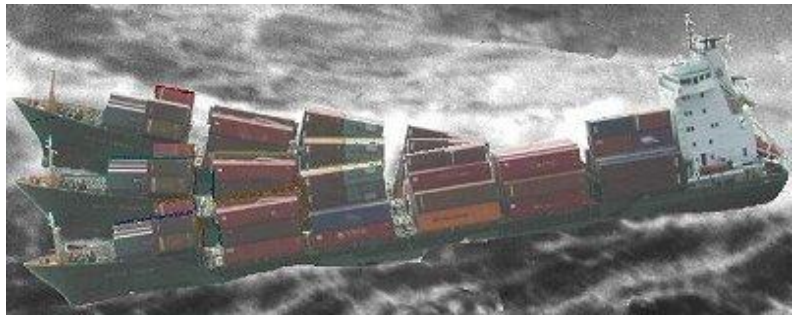


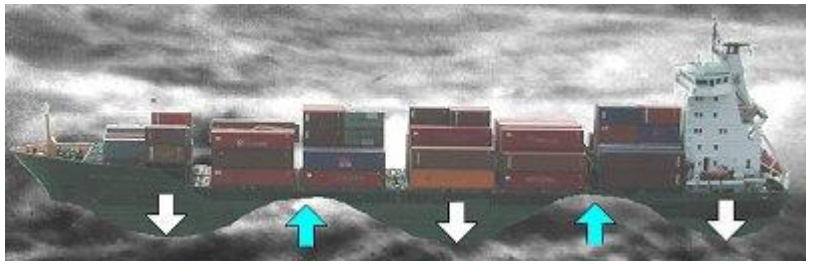
Mechanical Stresses in Maritime Transport





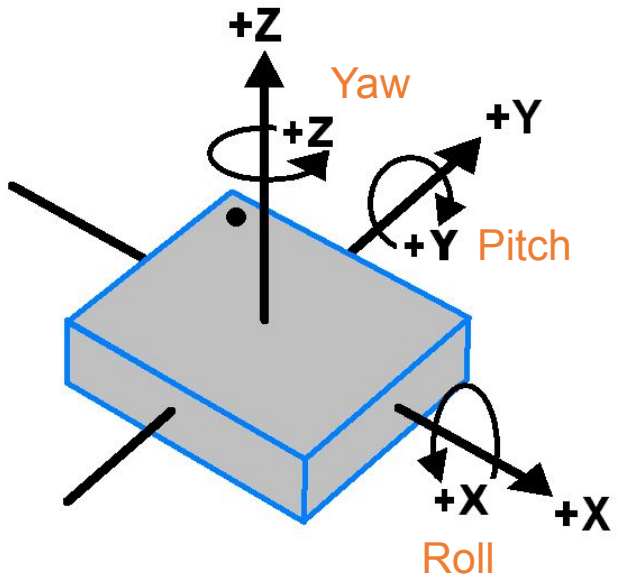


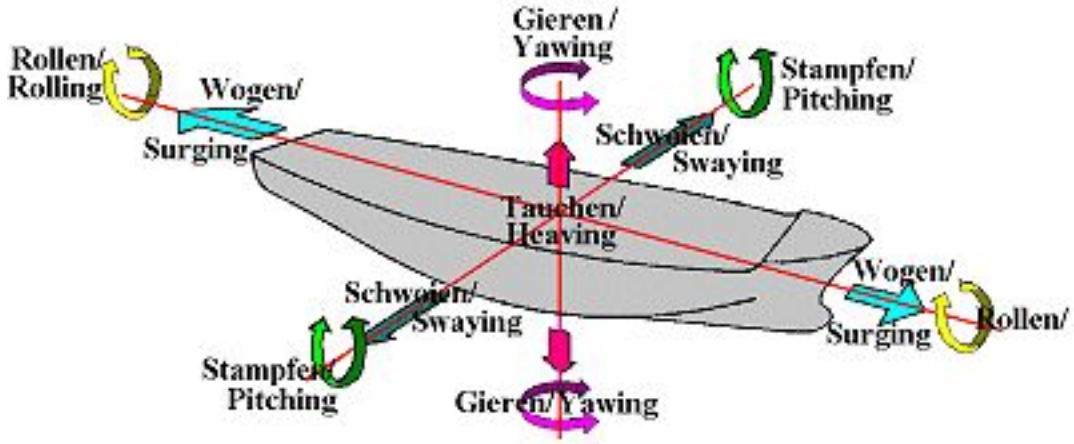




https://www.containerhandbuch.de/chb_e/stra/index.html?/chb_e/stra/stra_02_03_03.html

Mechanical Stresses in Maritime Transport





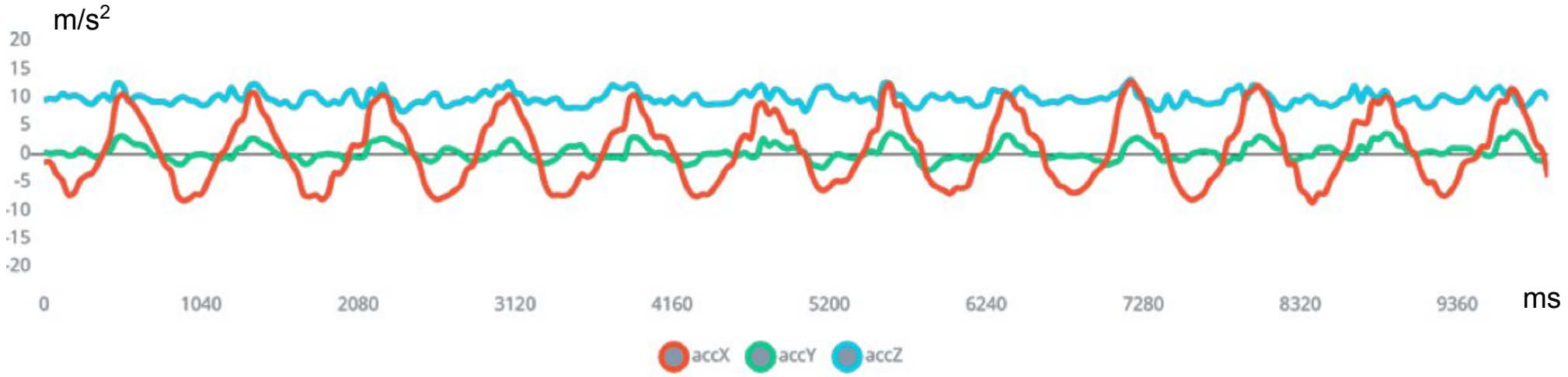
Accelerometer

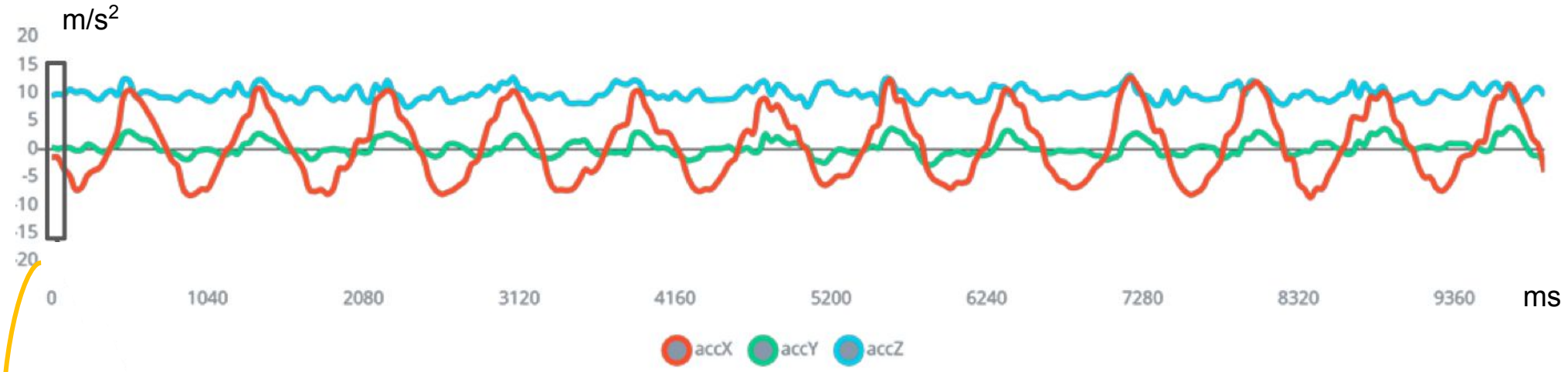
Gyroscope

	Linear motion	Rotational motion	
X	Surging is motion along the longitudinal axis.	Rolling is motion around the longitudinal axis.	Roll
Y	Swaying is motion along the transverse axis.	Pitching is motion around the transverse axis.	Pitch
Z	Heaving is motion along the vertical axis.	Yawing is motion around the vertical axis.	Yaw

Summary of ship movement

Example: 10 seconds of accelerometer data, captured with a sample rate: 62.5 Hz





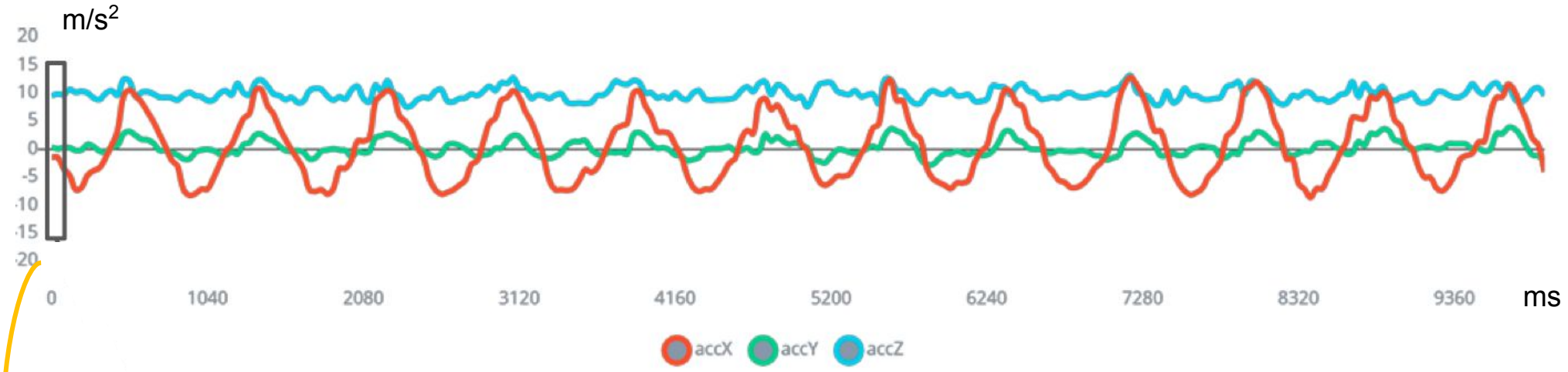
Raw Features

- accX
- accY
- accZ

Model

Classes

- Lift
- Terrestrial
- Maritime
- Iddle



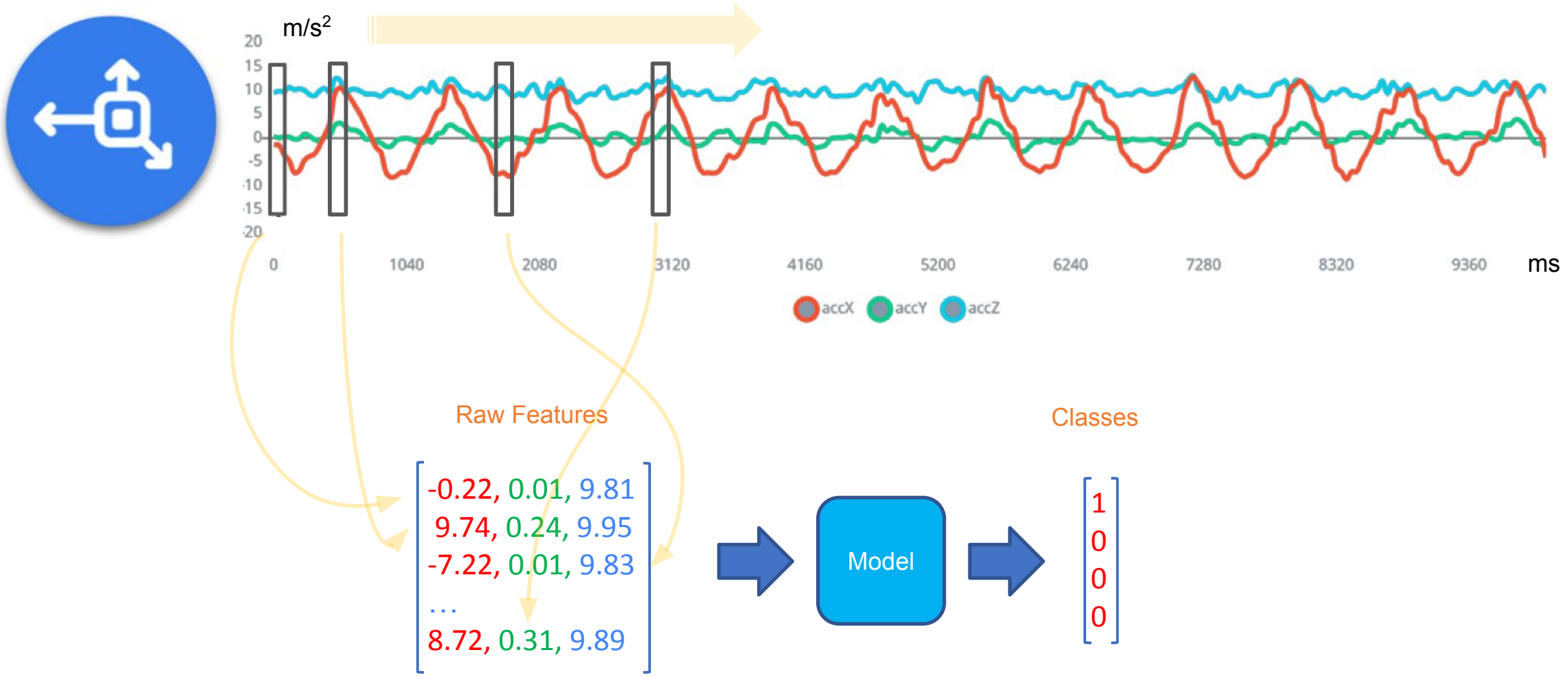
Raw Features

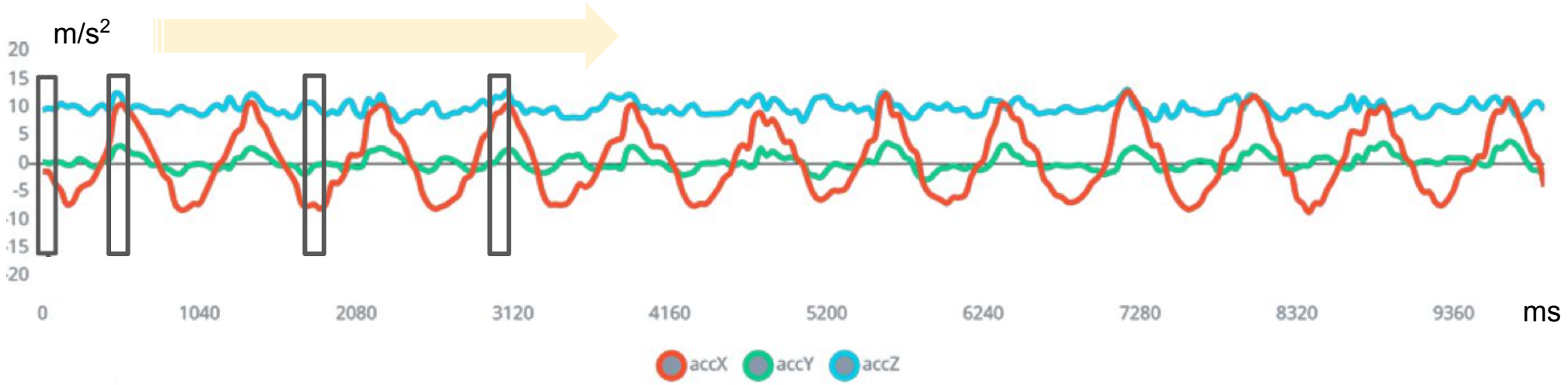
[-0.22, 0.01, 9.81]

Model

Classes

[1 0 0 0]


m/s2
20
15
10
5
0
-5
-10
-15
-20
0
1040
2080
3120
4160
5200
6240
7280
8320
9360
ms
accX
accY
accZ
Raw Features
-0.22, 0.01, 9.81
9.74, 0.24, 9.95
-7.22, 0.01, 9.83
…
8.72, 0.31, 9.89
Model
Classes
1
0
0
0



Raw Features

-0.22, 0.01, 9.81
9.74, 0.24, 9.95
-7.22, 0.01, 9.83
…
8.72, 0.31, 9.89

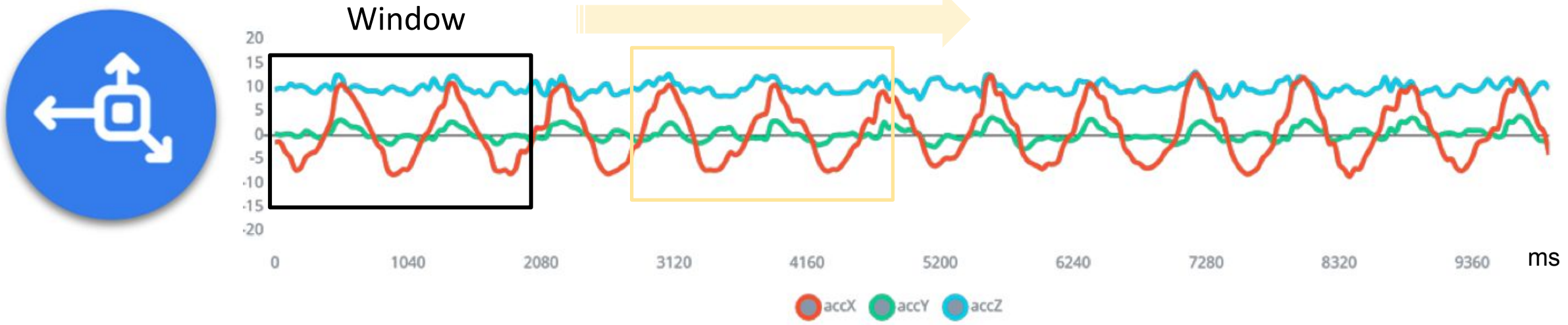
Model

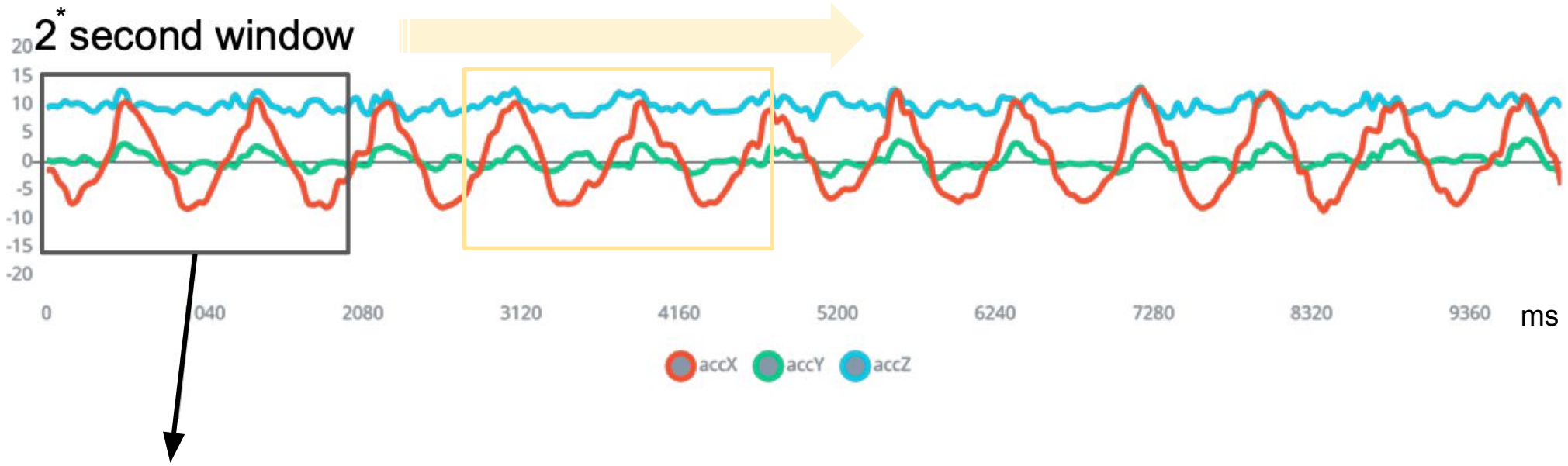
Classes

?
?
?
?

Problem!

✔ Time-Series Data


Window
20
15
10
5
0
-5
-10
-15
-20
0
1040
2080
3120
4160
5200
6240
7280
8320
9360
ms
accX
accY
accZ

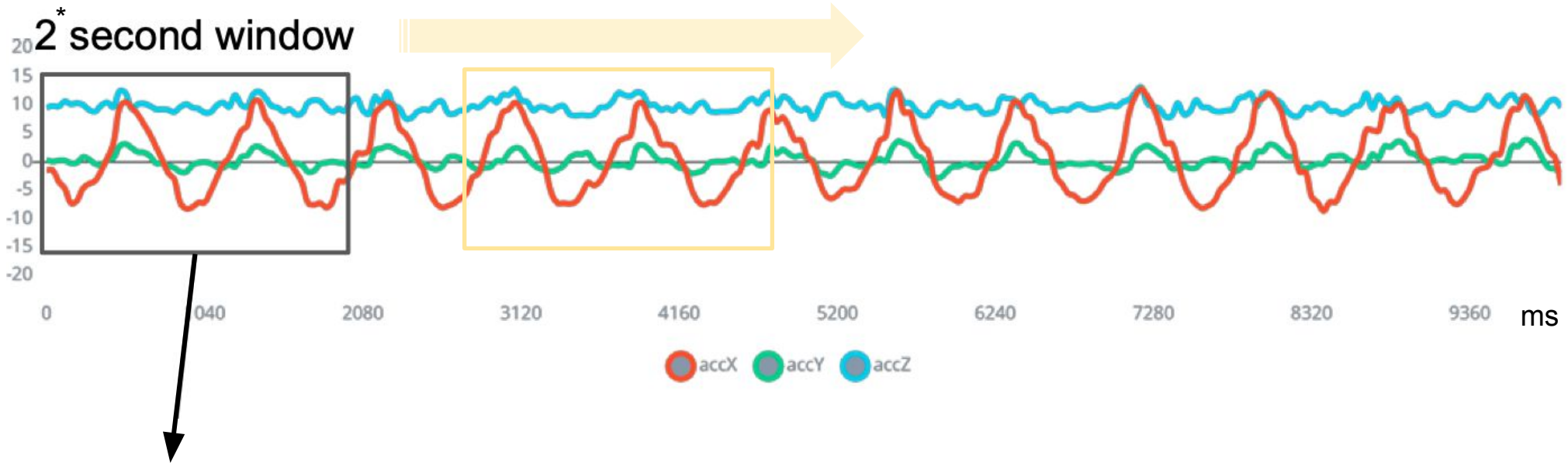


Raw Features as a window

- 125** samples for each axis (62.5Hz x 2s)
- 375 total features (125 x 3 axis)

* 2 seconds is needed to capture 1 or 2 cycles of movement

** 2 seconds at sample rate of 62.5 Hz -> 125 samples



Raw Features as a window

- 125** samples for each axis
- 375 total features

Automatic Feature Extraction using DL

- Computational complexity
- Lots of training data

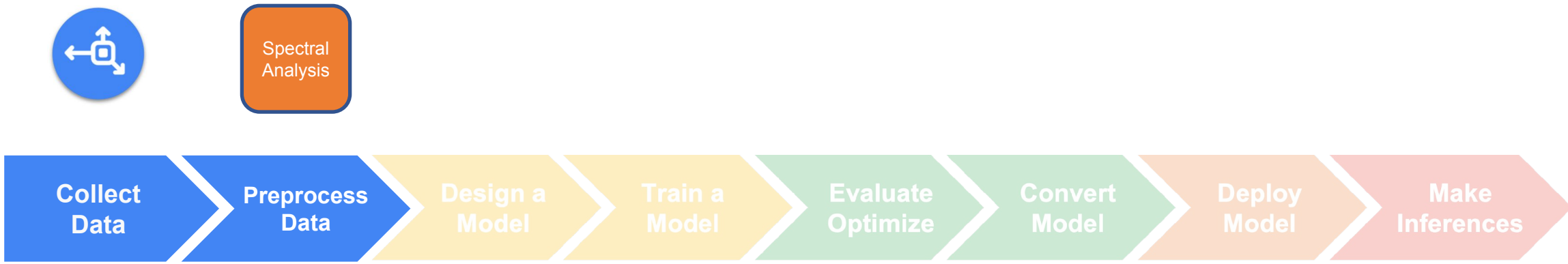
Problem!

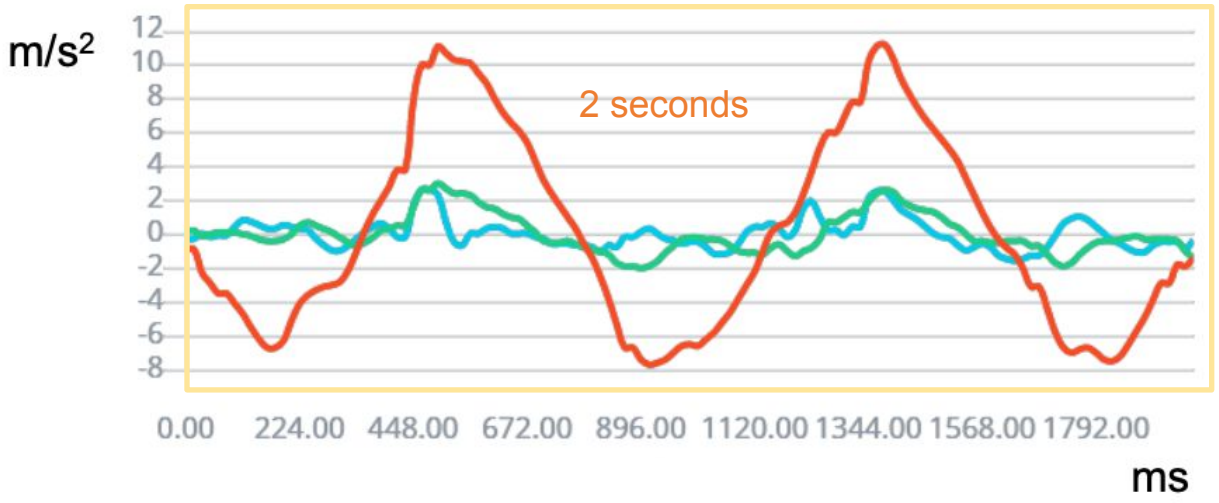
✔ More Memory

* 2 seconds is needed to capture 1 or 2 cycles of movement

** 2 seconds at sample rate of 62.5 Hz -> 125 samples

Data Pre-Processing





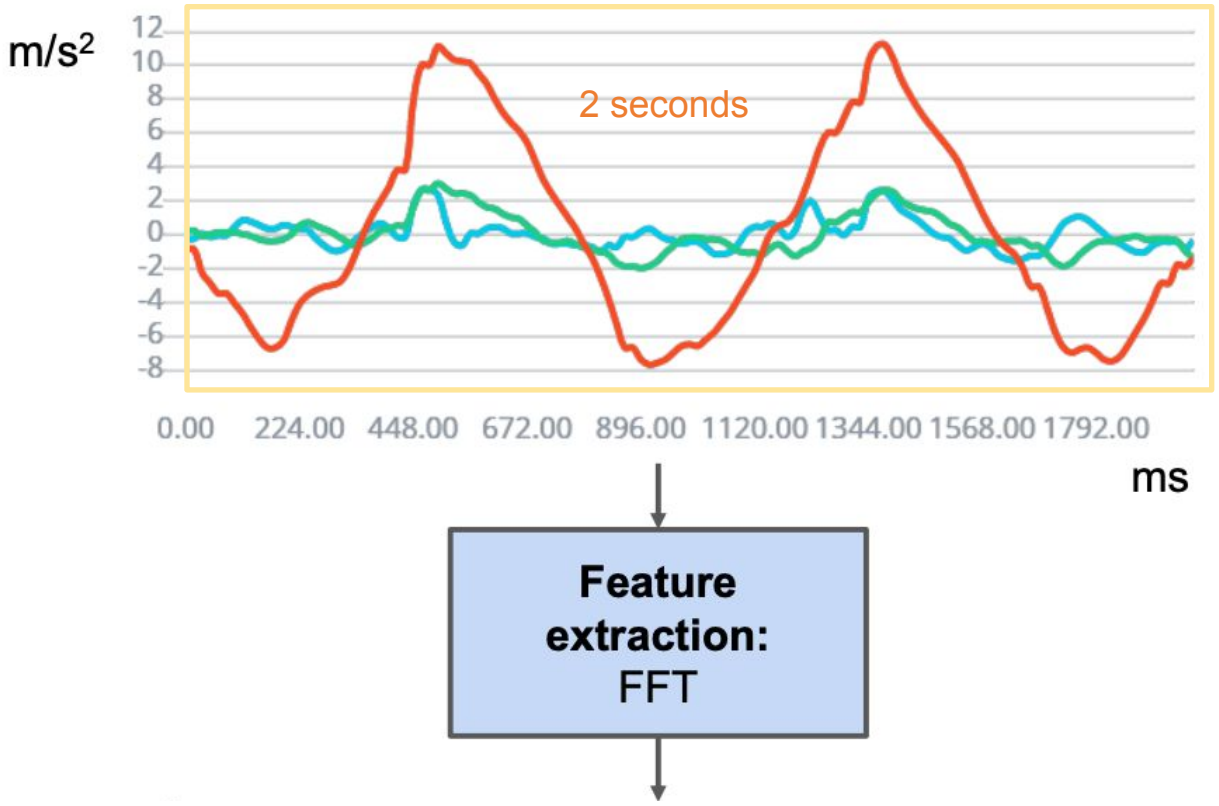
Manual Feature Extraction

3 RMS (Root Mean Square) values

- one for each axis (x, y, z)

$$x_{\mathrm{RMS}} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots + x_n^2\right)}.$$

125

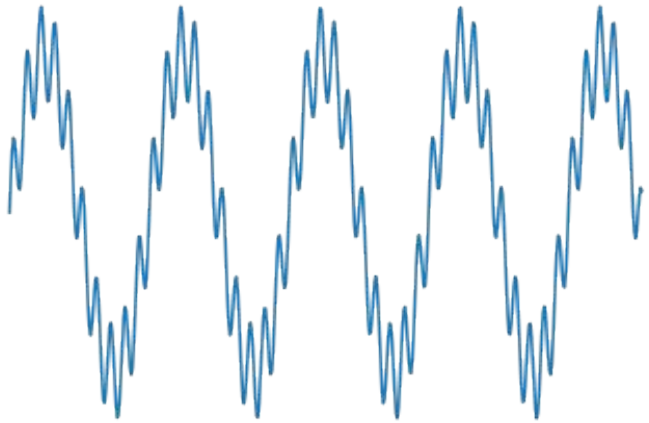


Manual Feature Extraction

3 RMS

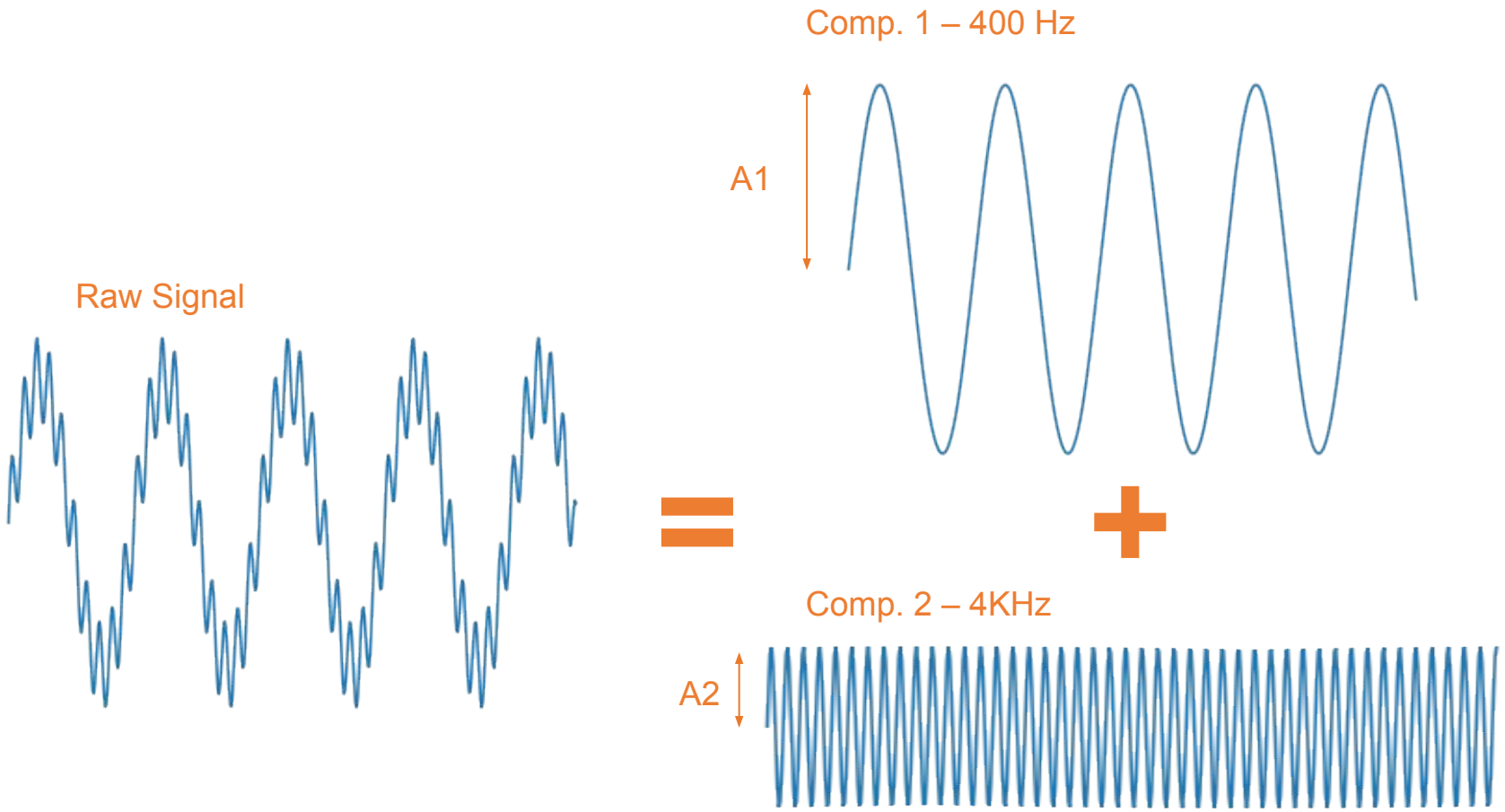
Fast Fourier Transformer (FFT)

Raw Signal

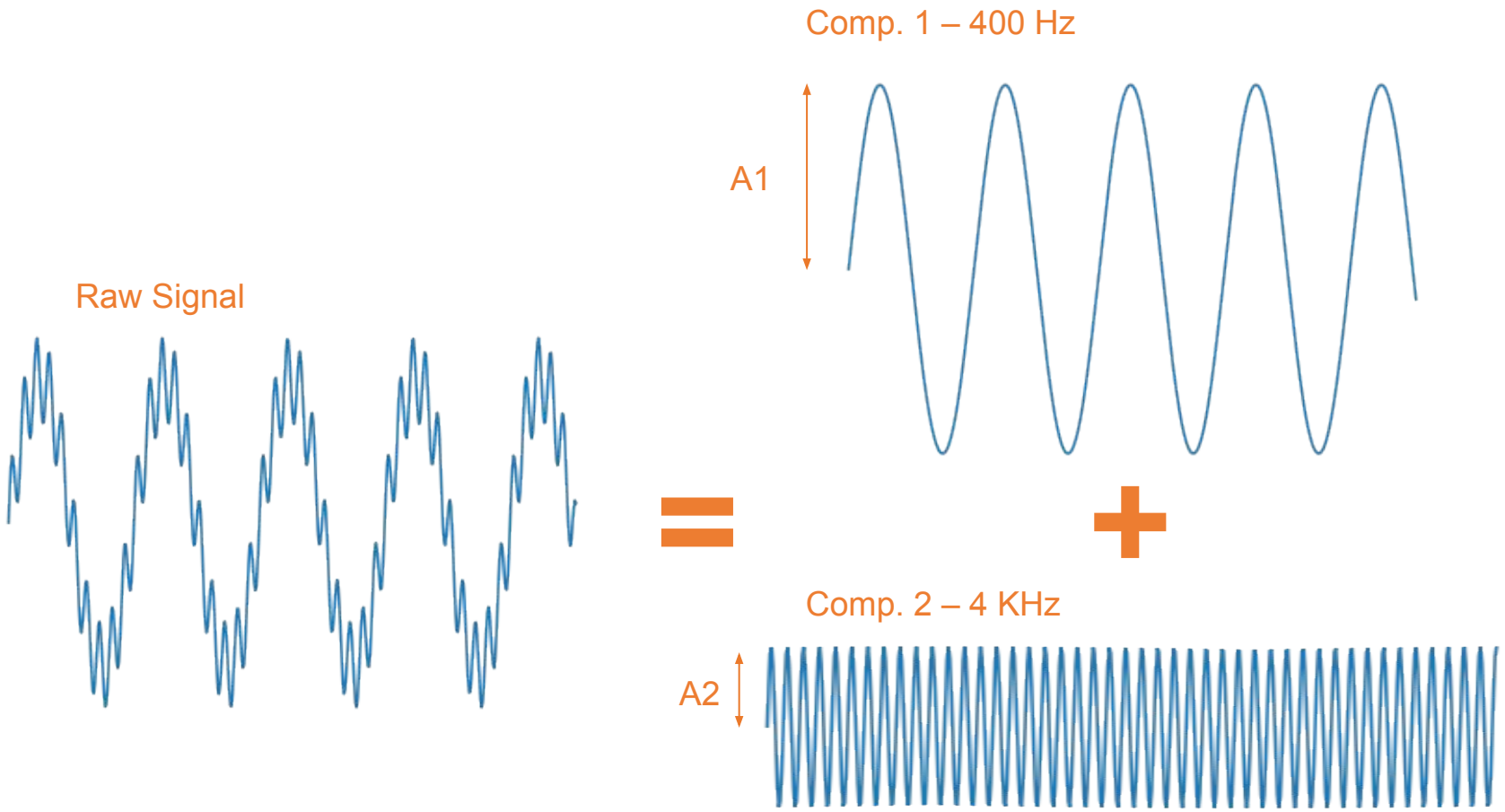


Time Domain

Fast Fourier Transformer (FFT)

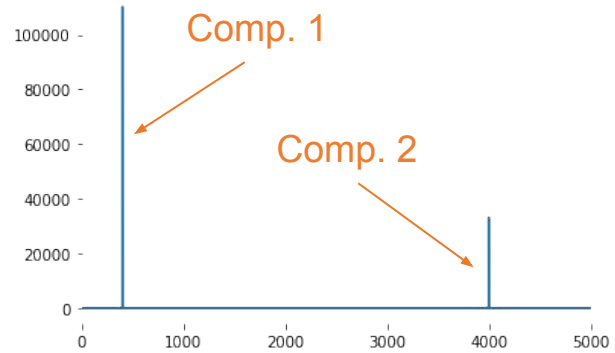


Fast Fourier Transformer (FFT)

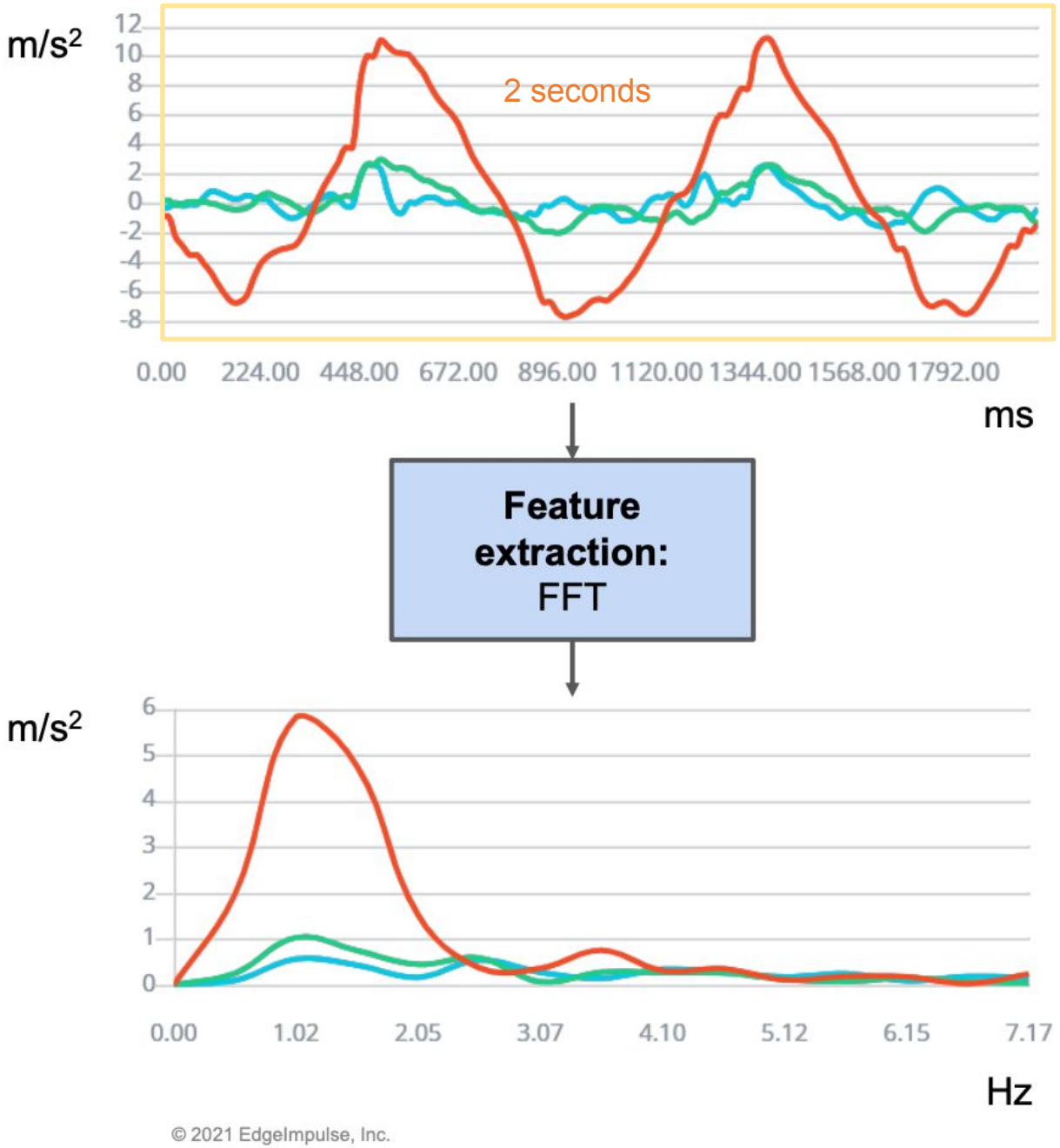


Time Domain

```
from scipy.fft import fft
yf = fft(raw signal)
plt.plot(xf, np.abs(yf));
```



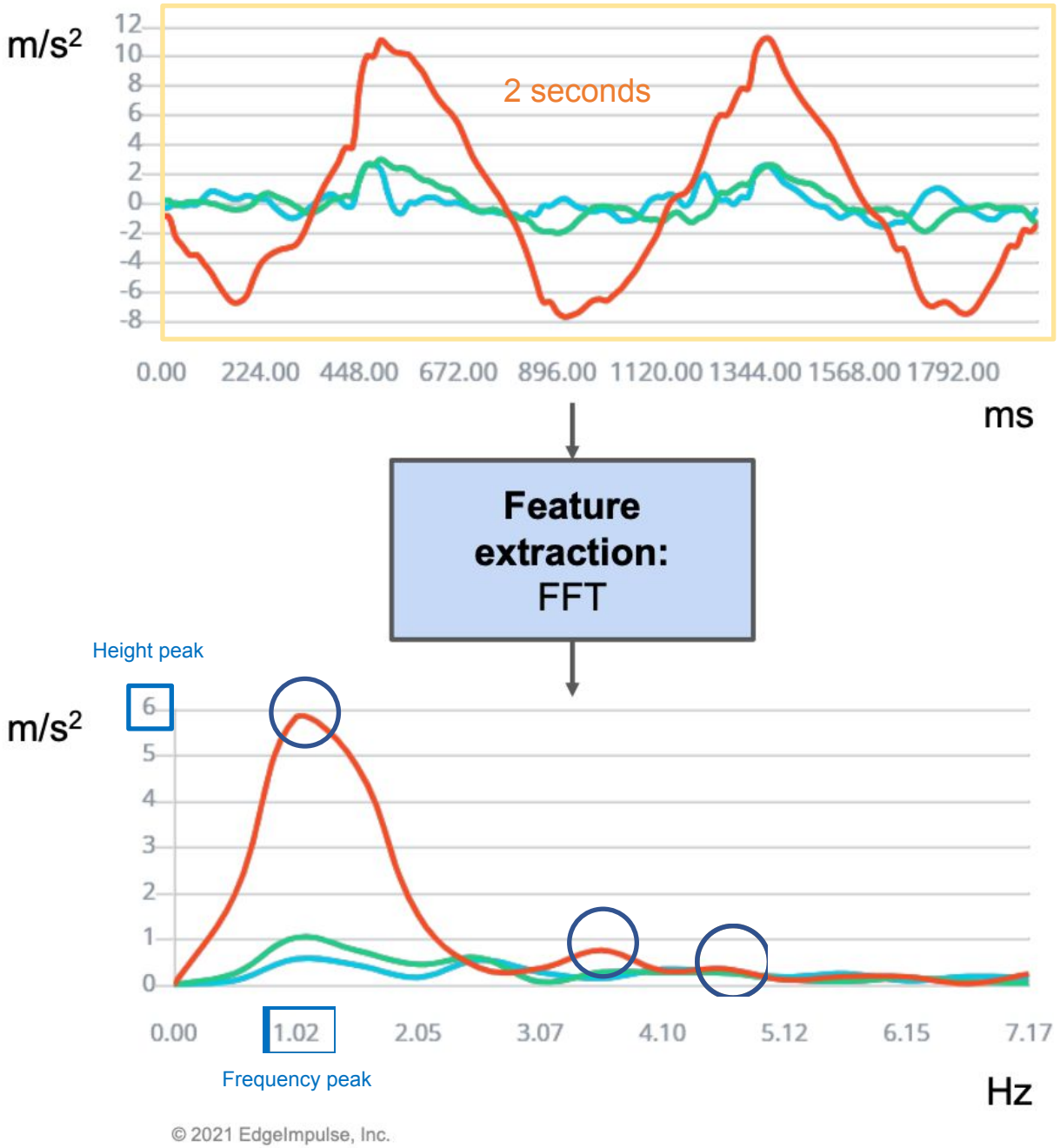
Frequency Domain



Manual Feature Extraction

3 RMS

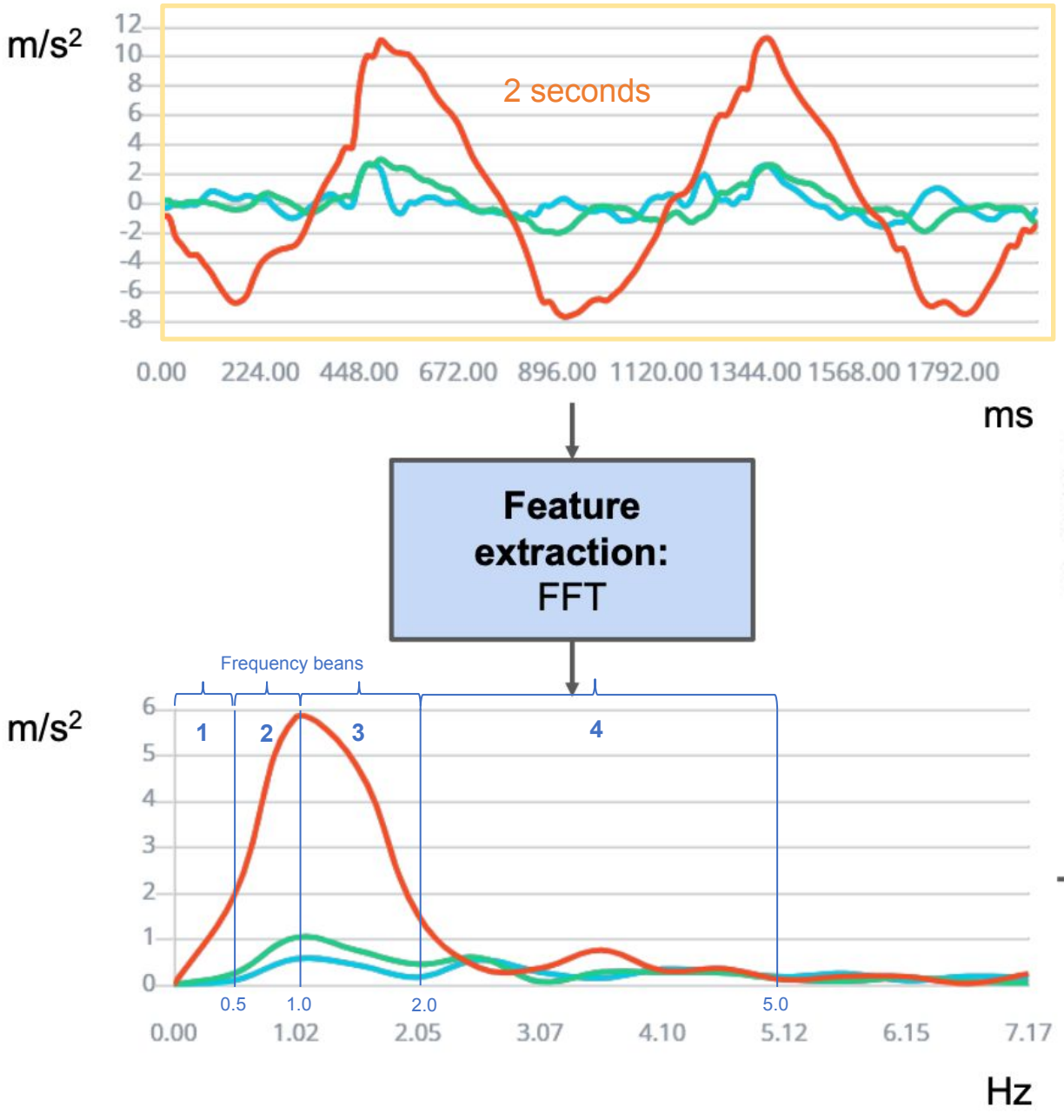
Manual Feature Extraction



3 RMS

9 Height + **9** Freq. peak values

Manual Feature Extraction



3 RMS + **9** HP + **9** FP + **12** PSD values

4 Frequency bins per axix

Feature extraction: PSD

https://blog.endaq.com/why-the-power-spectral-density-psd-is-the-gold-standard-of-vibration-analysis

Sliding Window: 80 ms

375 Raw Features

- Raw Data from sensor

Manual Feature Extraction

Spectral Analysis

11 Features

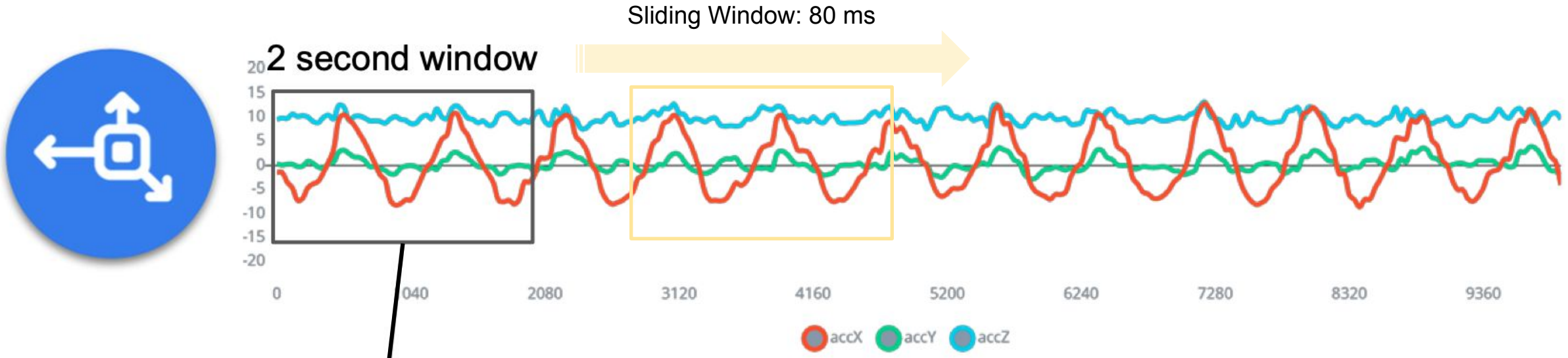
11 Features

11 Features

accX RMS
accX Peak
accX Peak
accX Peak
accX Peak
accX Peak
accX Spec
accX Spec
accX Spec
accX Spec

accY RMS
accY Peak
accY Peak
accY Peak
accY Peak
accY Peak
accY Spec
accY Spec
accY Spec
accY Spec

accZ RMS
accZ Peak 1 Freq
accZ Peak 1 Height
accZ Peak 2 Freq
accZ Peak 2 Height
accZ Peak 3 Freq
accZ Peak 3 Height
accZ Spectral Power 0.1 - 0.5
accZ Spectral Power 0.5 - 1.0
accZ Spectral Power 1.0 - 2.0
accZ Spectral Power 2.0 - 5.0



375 Raw Features

- Raw Data from sensor

Manual Feature Extraction

Spectral Analysis

33 Features

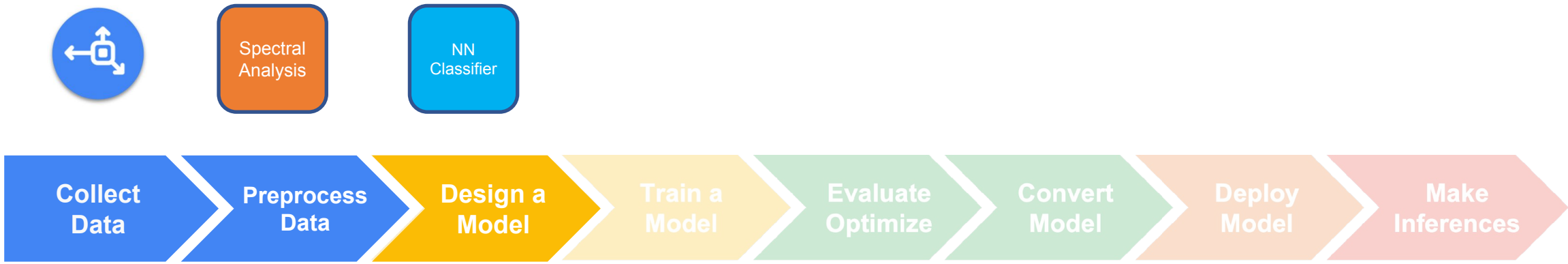
- RMS
- FFT
- PSD

NN Classifier

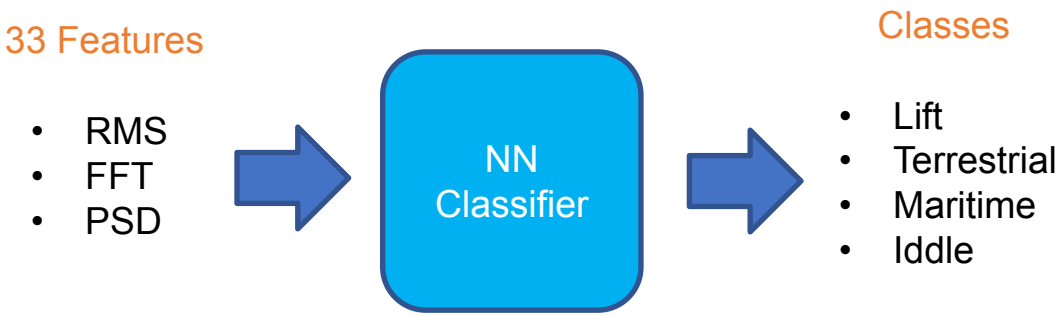
Classes

- Lift
- Terrestrial
- Maritime
- Iddle

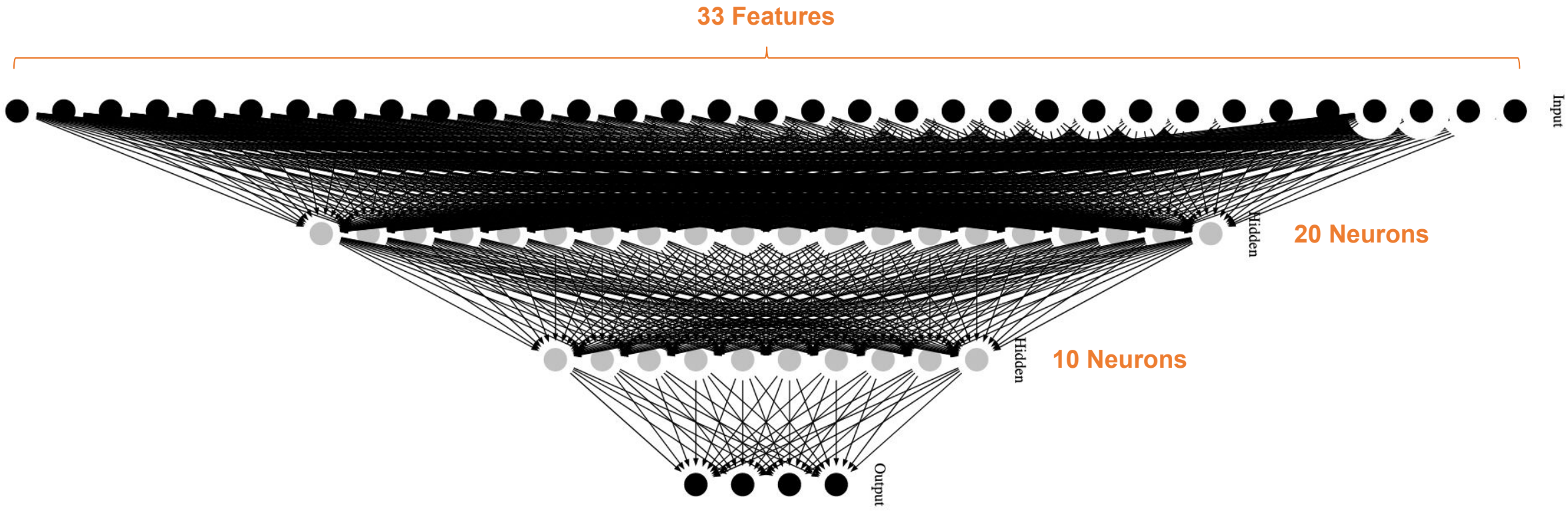
Model Design (NN Classifier)



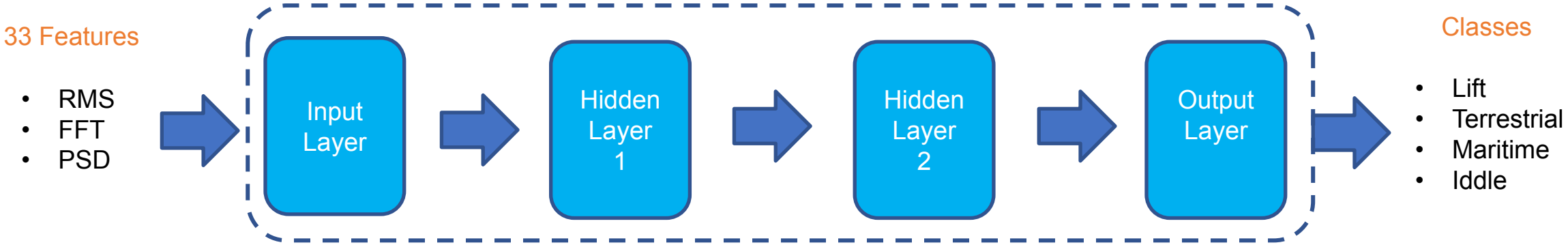
Model Design (NN Classifier)



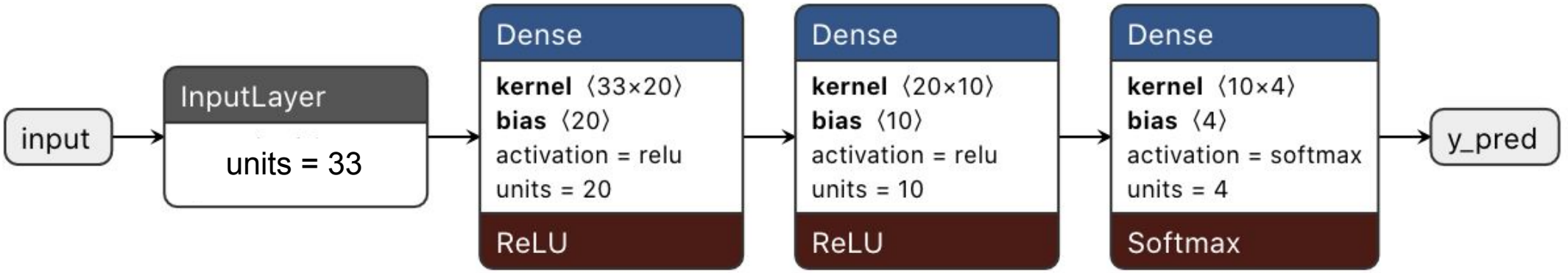
Model Design (DNN Classifier)



Model Design (DNN Classifier)

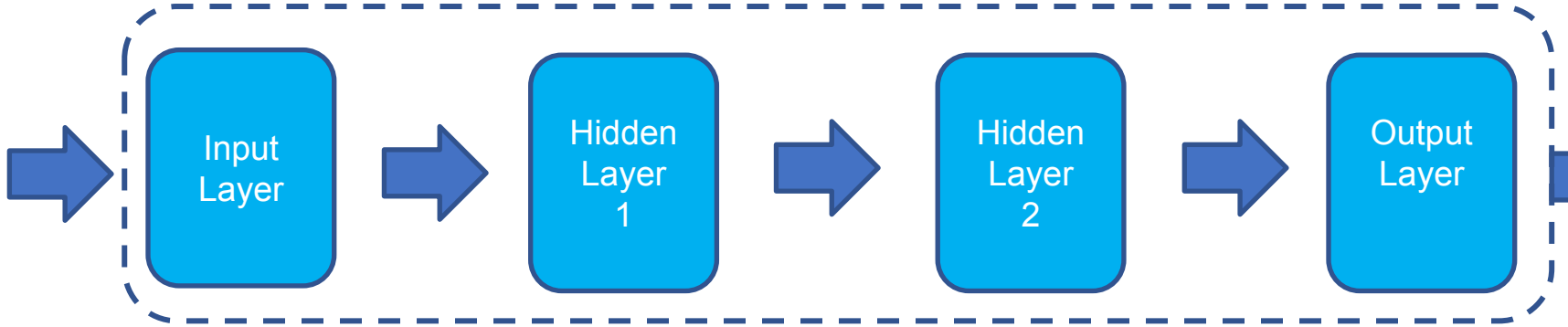


Model Design (DNN Classifier)



33 Features

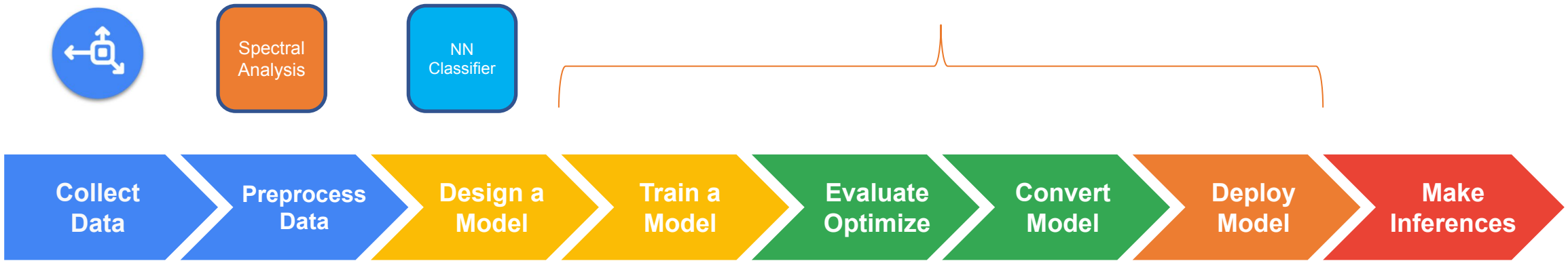
- RMS
- FFT
- PSD



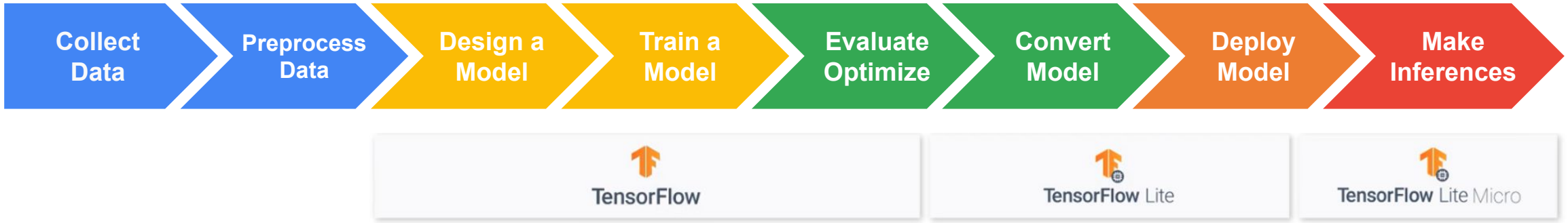
Classes

- Lift
- Terrestrial
- Maritime
- Iddle

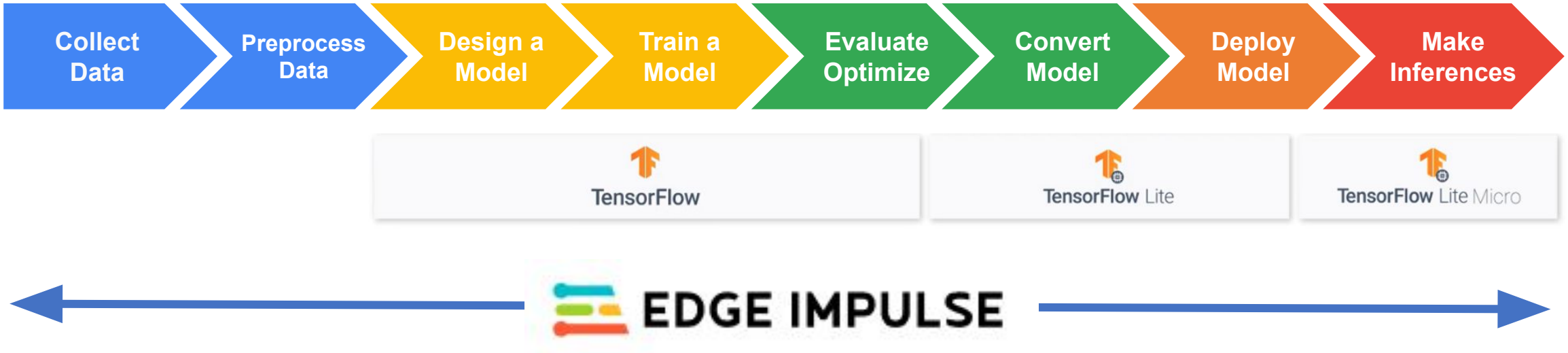
Train, Evaluate, Convert, Deploy the Model



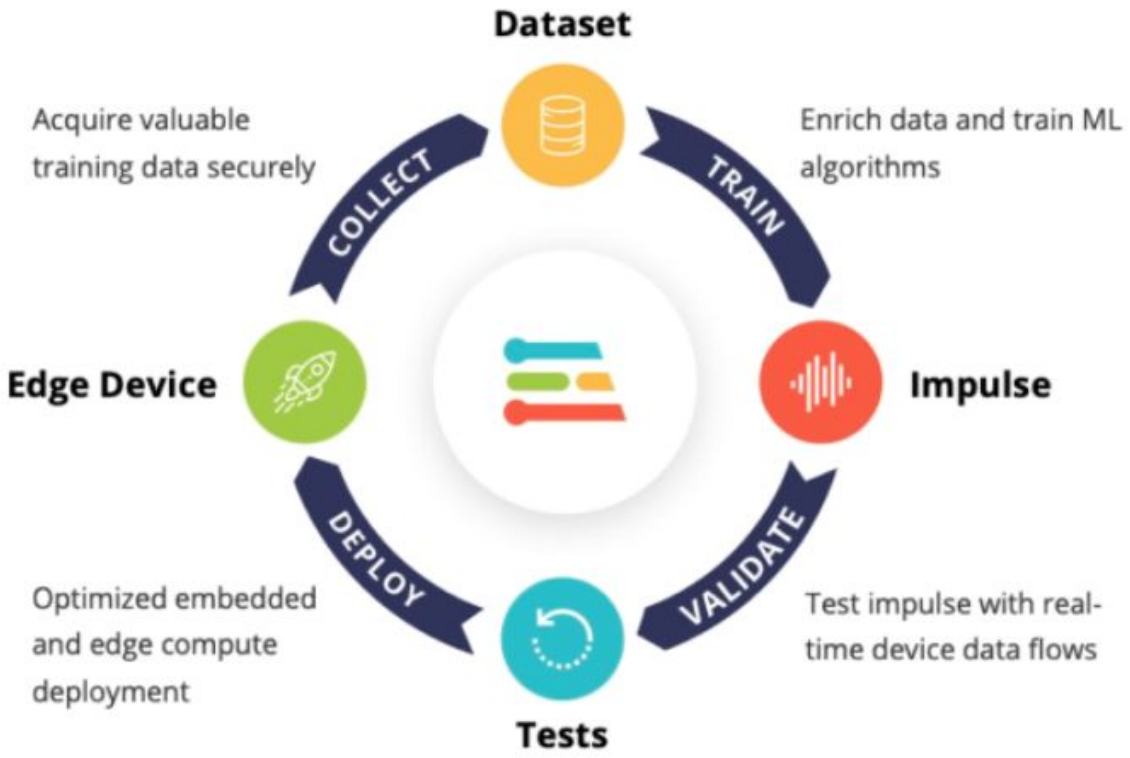
Train, Evaluate, Convert, Deploy the Model

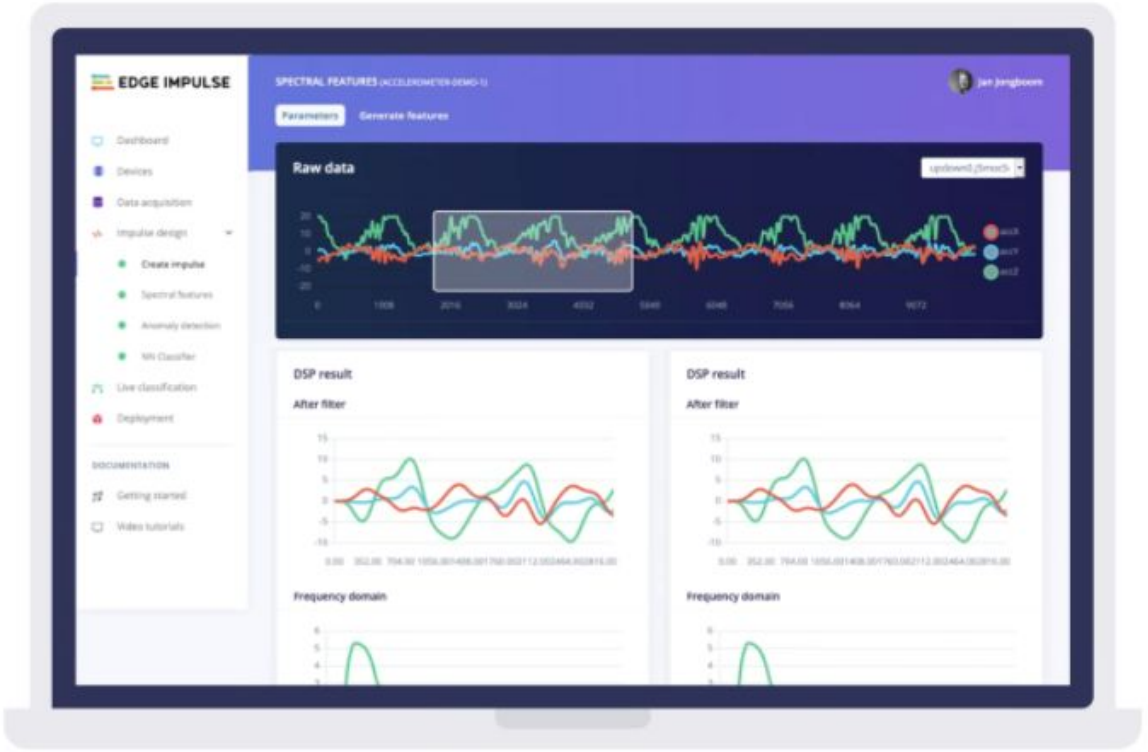


Machine Learning Workflow

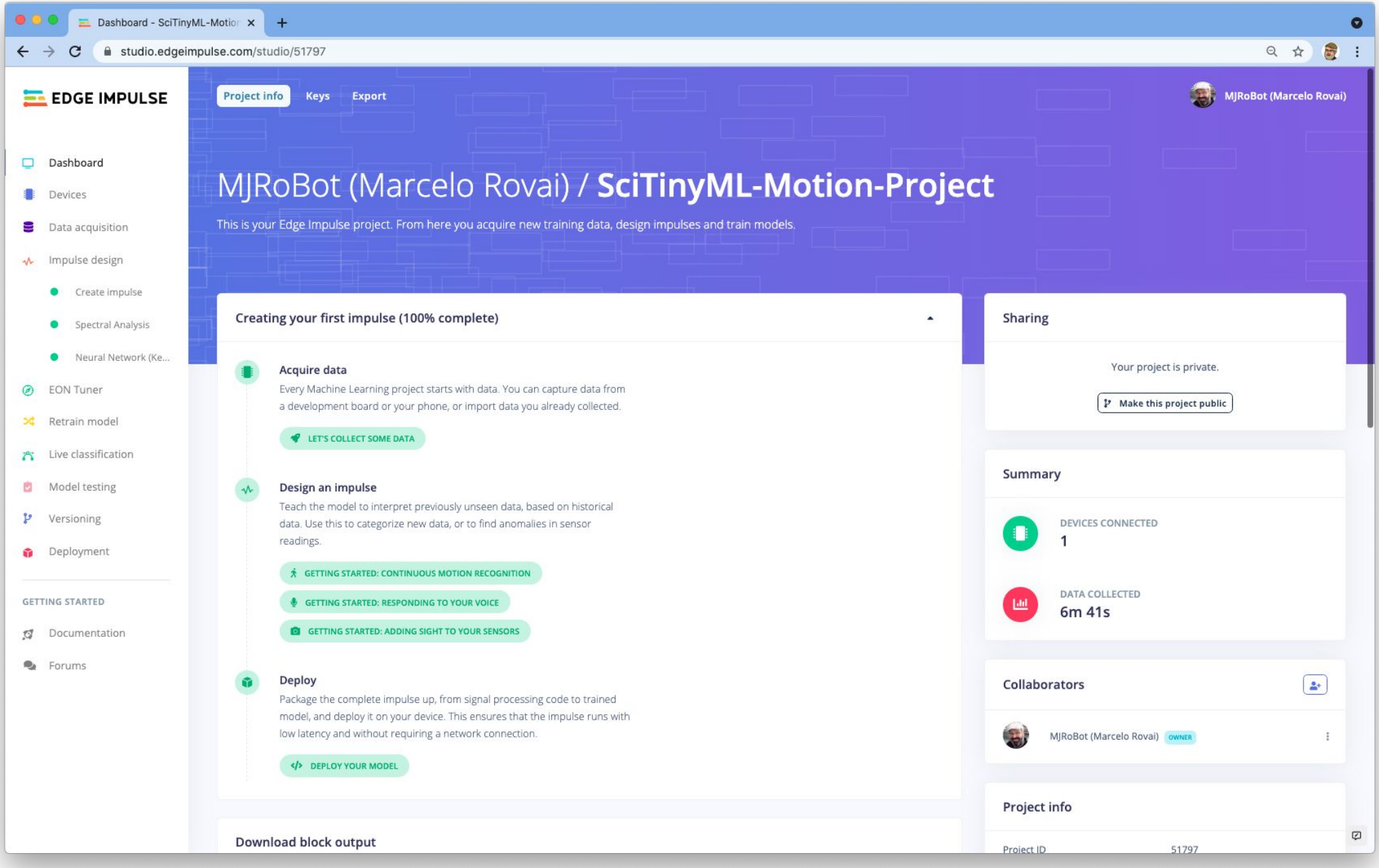


EI Studio - Embedded ML platform

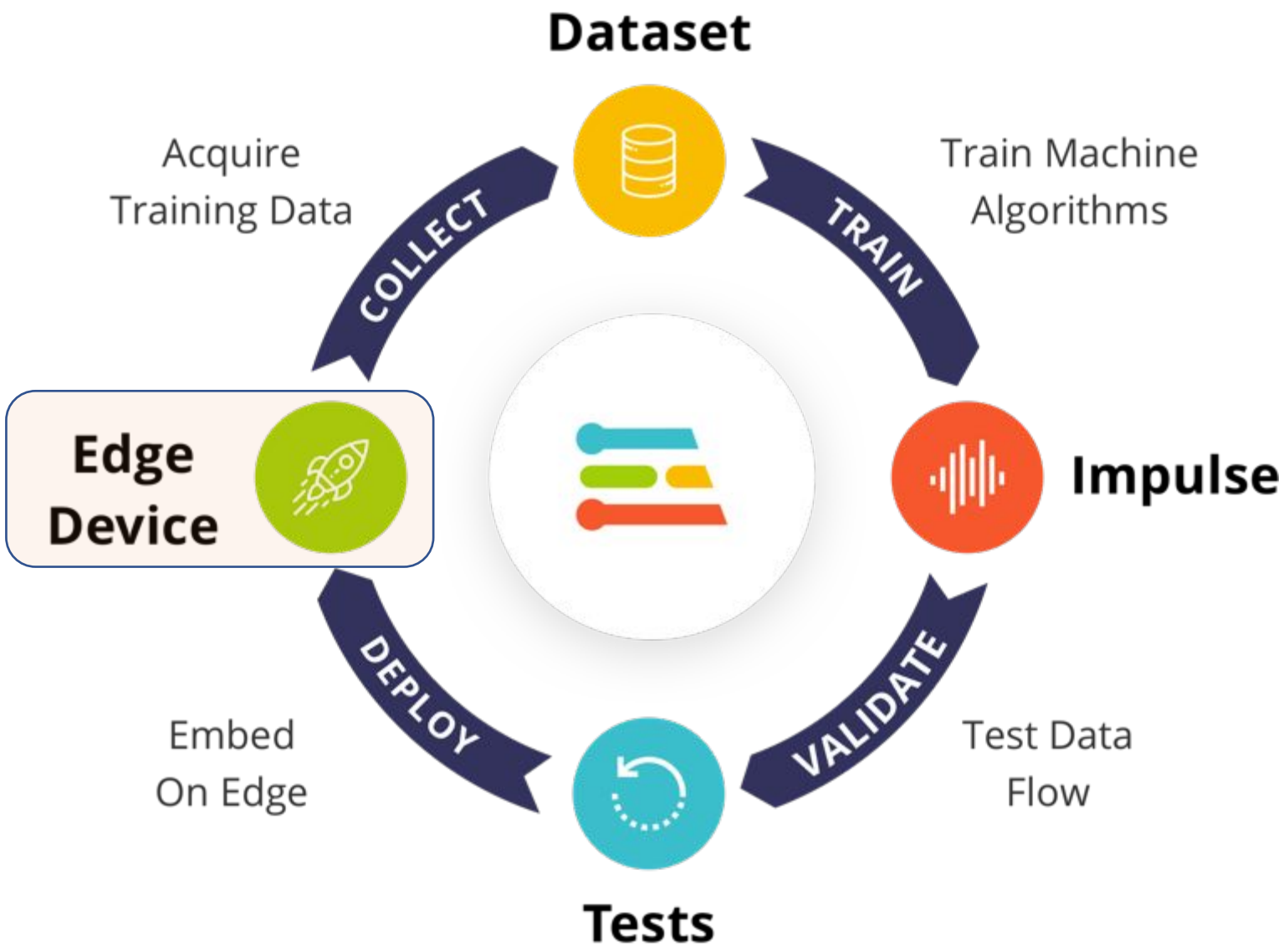




Learn more at http://edgeimpulse.com

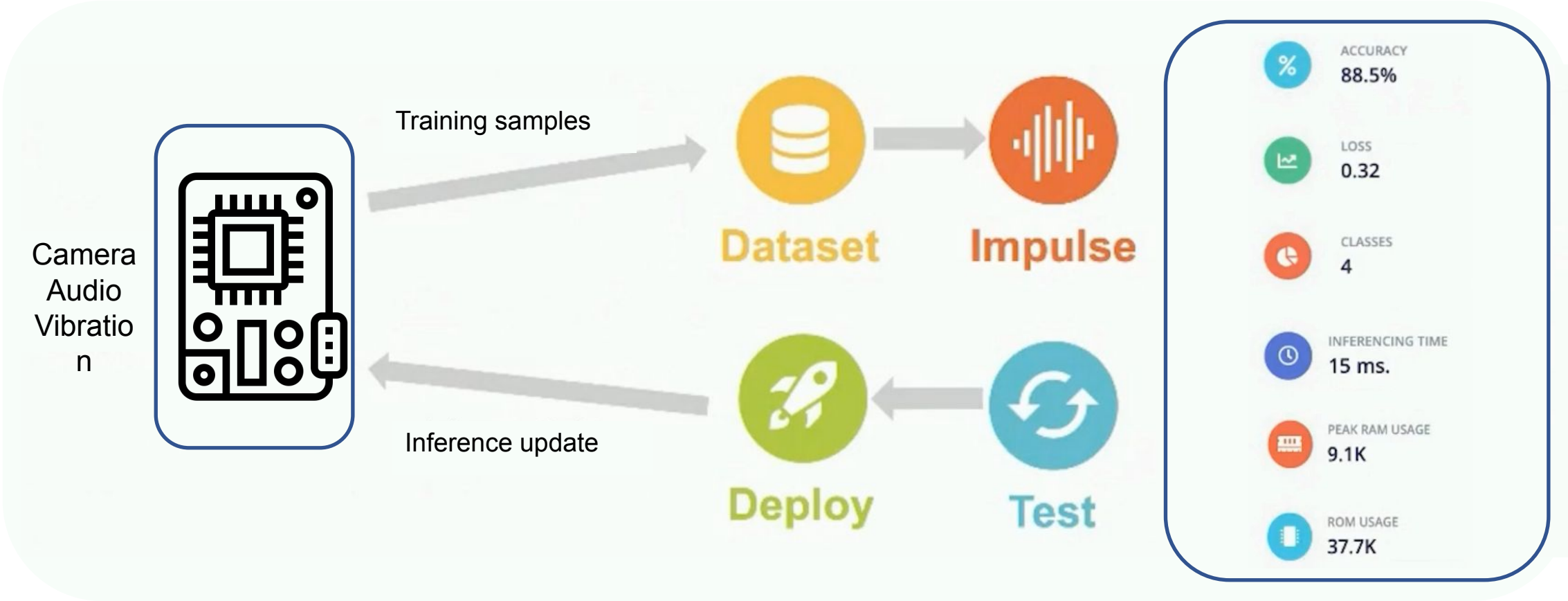


https://studio.edgeimpulse.com/public/51963/latest

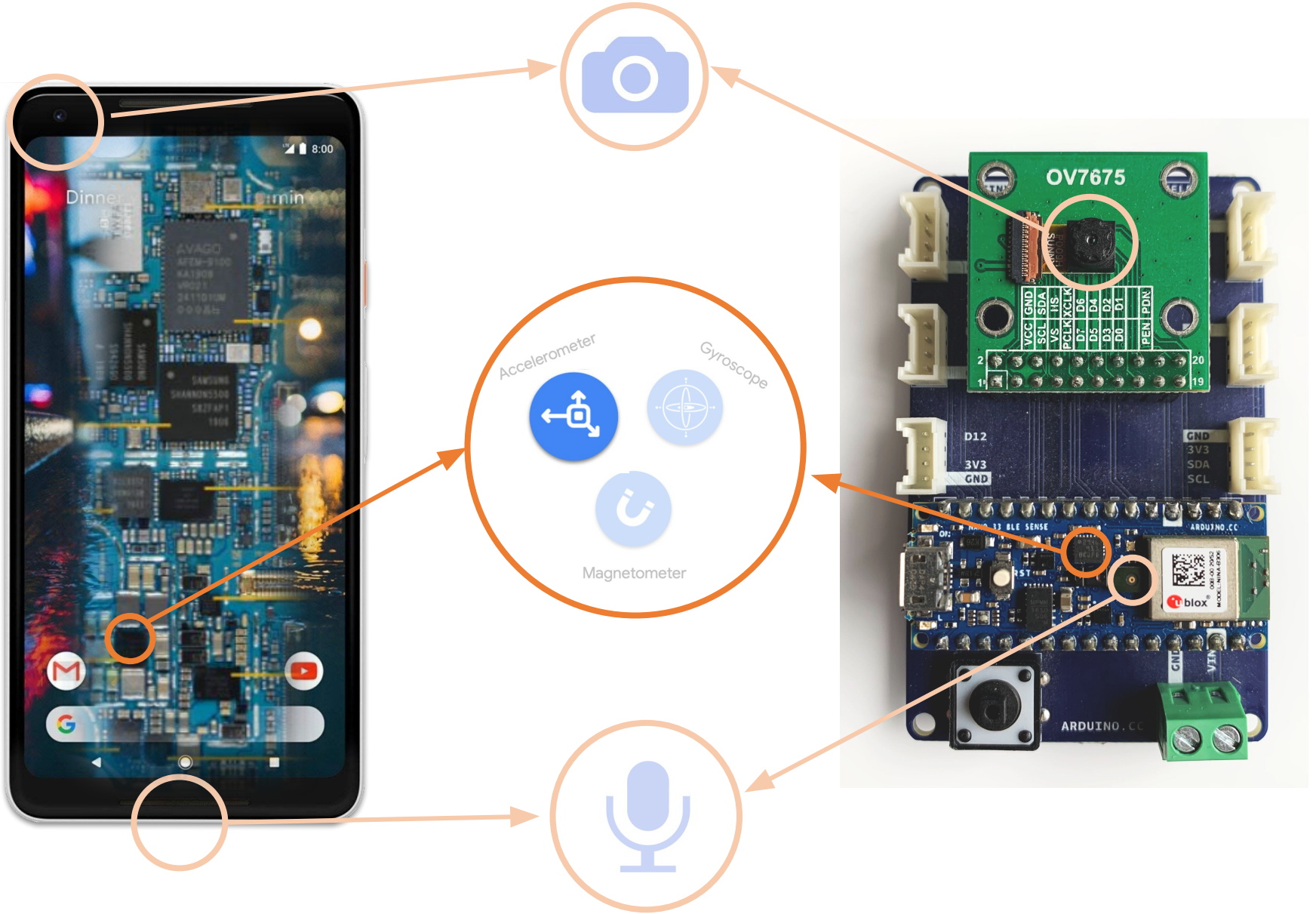


- Pre-Processing Data
- Design a Model
- Train a Model

Data-driven engineering



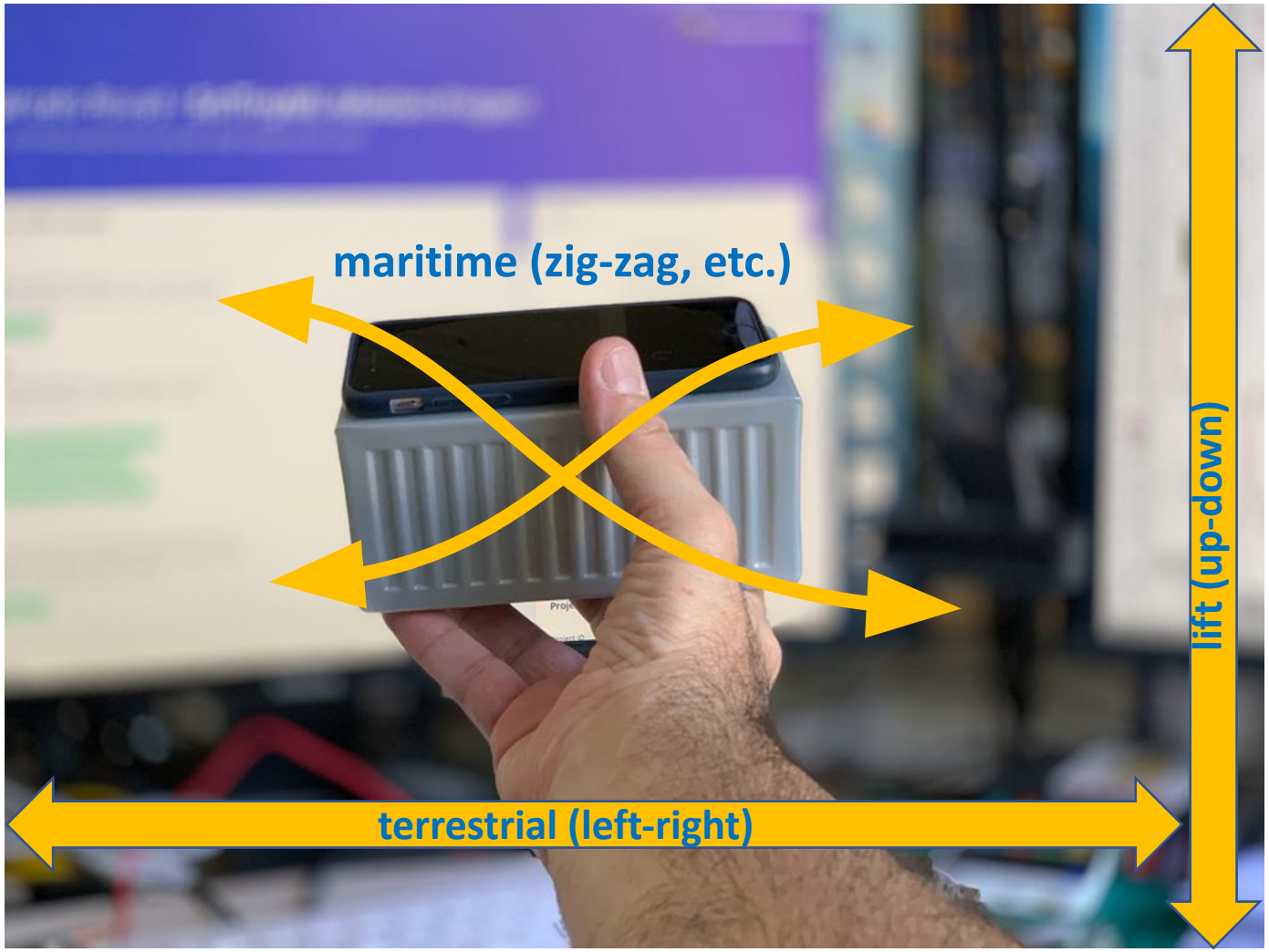
Sensor - IMU (Inertial Measurement Unit)



Motion Classification

Transportation Classes

- **lift** (up-down)
- **terrestrial** (left-right)
- **maritime** (zig-zag, etc.)
- **idle**



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Motion Classification

Transportation Classes

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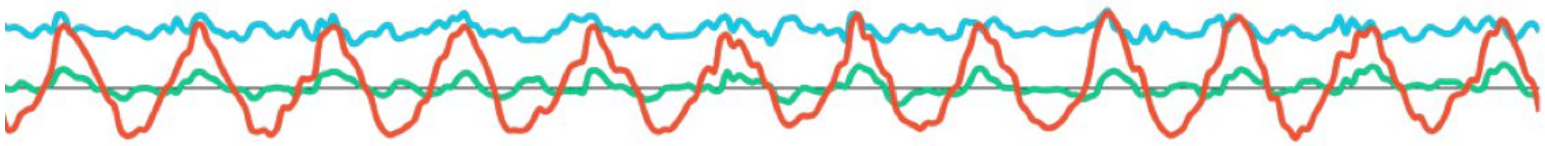
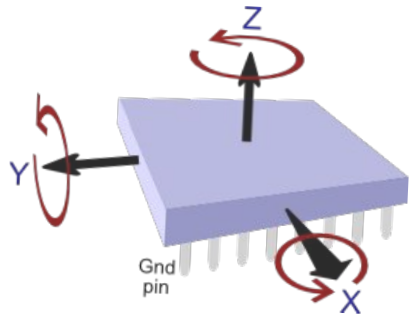
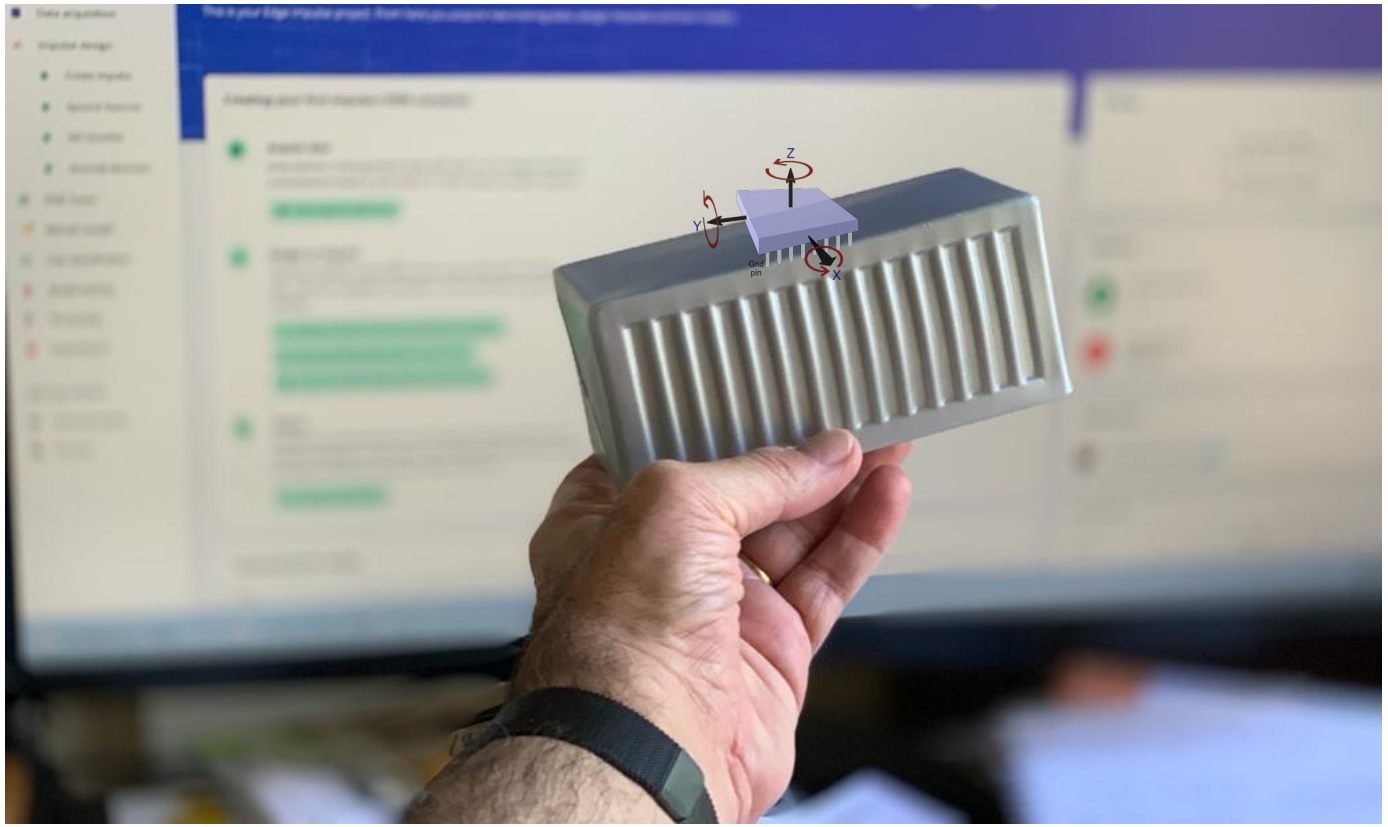


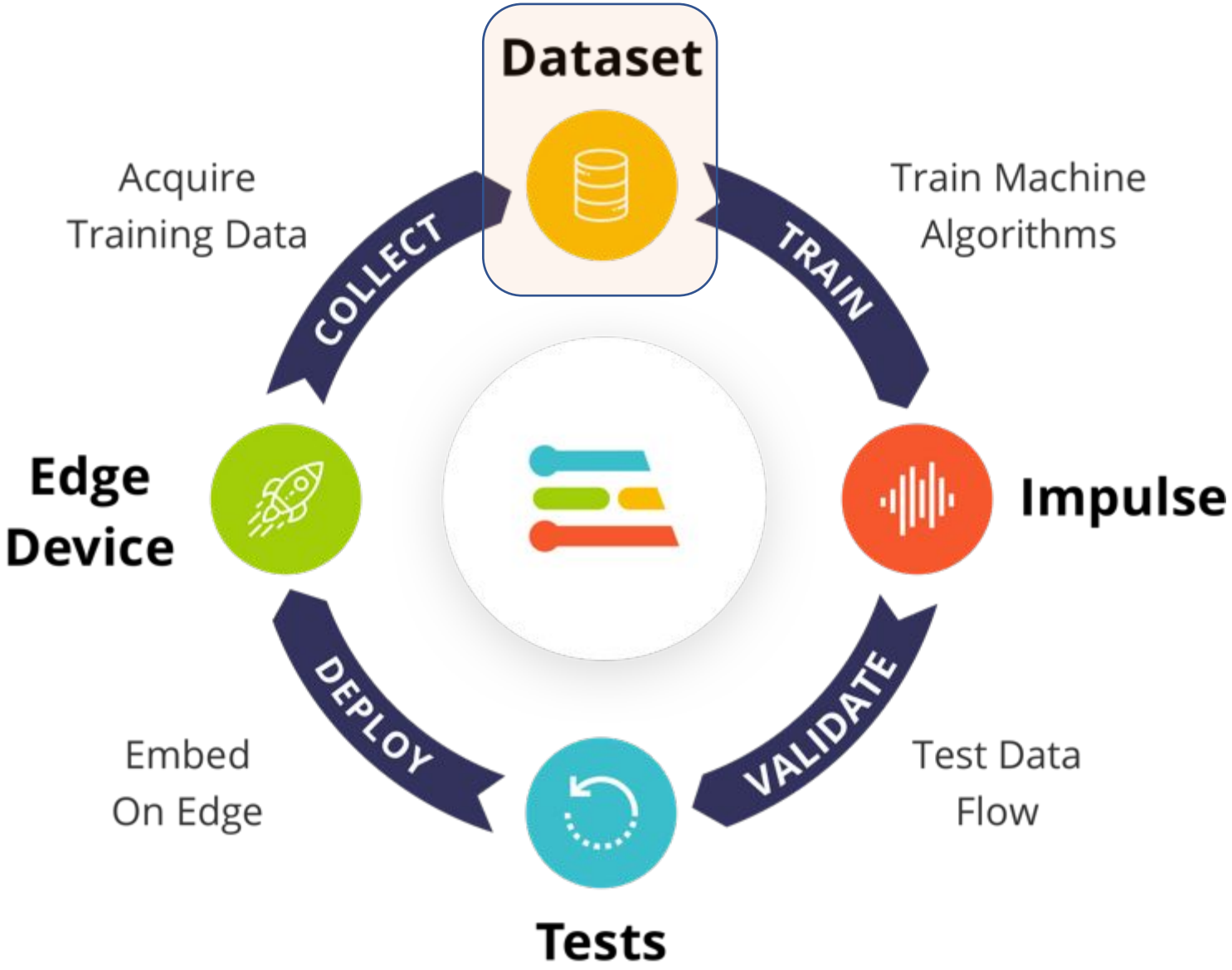




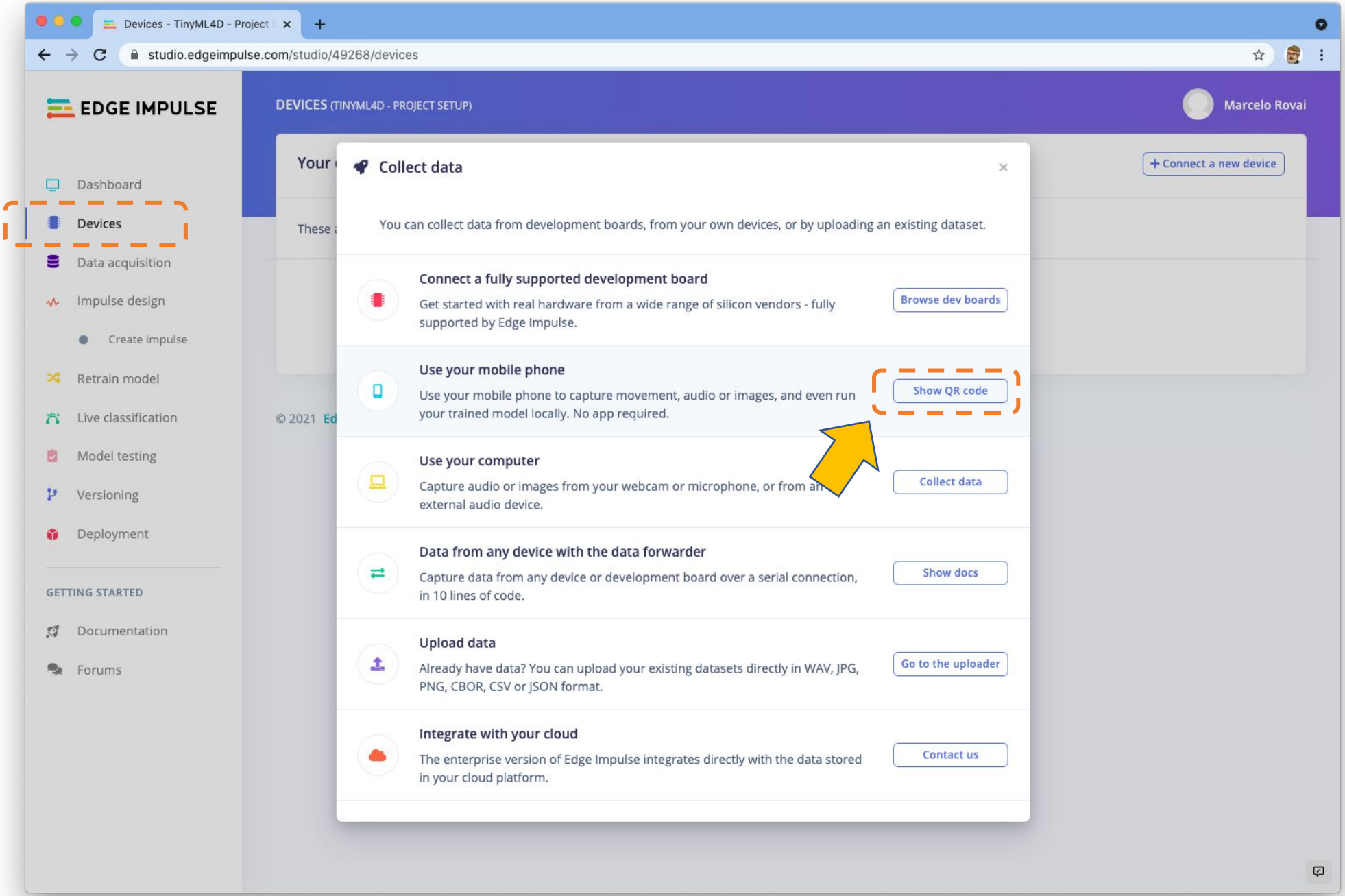
Data: collect & test using accelerometer as sensor

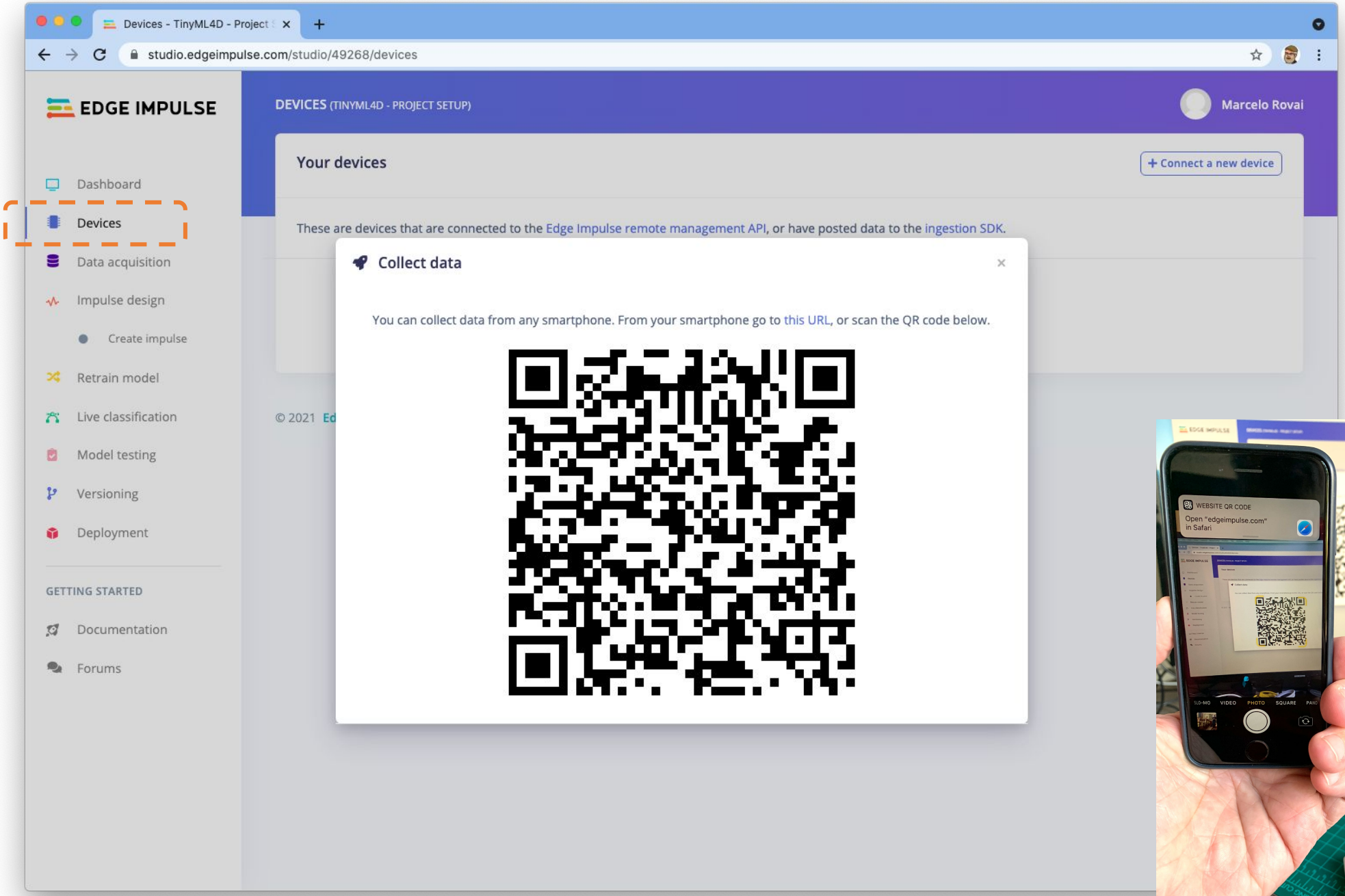
Dataset Collection

Using Smart-Phone



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


Devices - TinyML4D - Project
studio.edgeimpulse.com/studio/49268/devices
EDGE IMPULSE
DEVICES (TINYML4D - PROJECT SETUP)
Marcelo Rovai
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
+ Connect a new device
Collect data
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
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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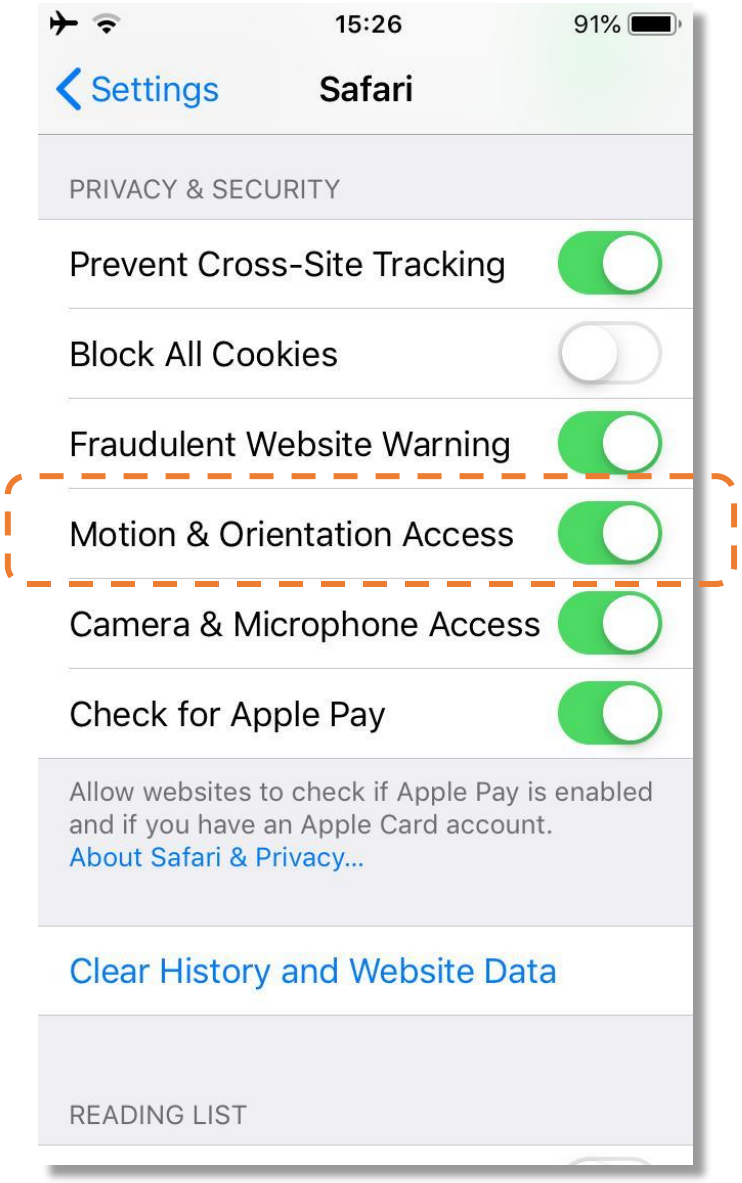
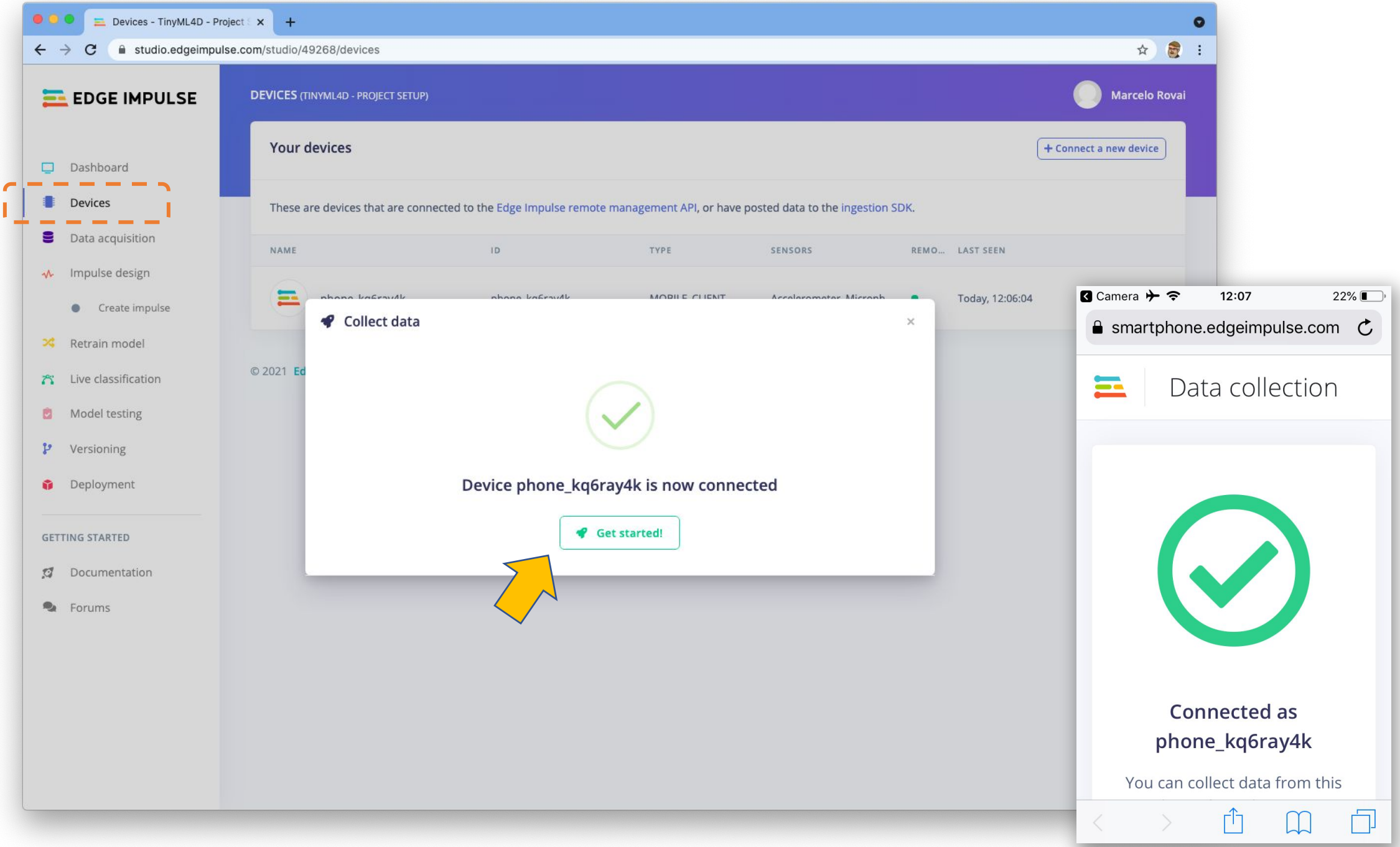
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
Collect data
You can collect data from any smartphone. From your smartphone go to this URL, or scan the QR code below.
© 2021 Ed


WEBSITE QR CODE
Open "edgeimpulse.com" in Safari



Depending on your mobile OS version and/or your Browser, could be necessary to give access to device IMU sensor


Devices - TinyML4D - Project
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DEVICES (TINYML4D - PROJECT SETUP)
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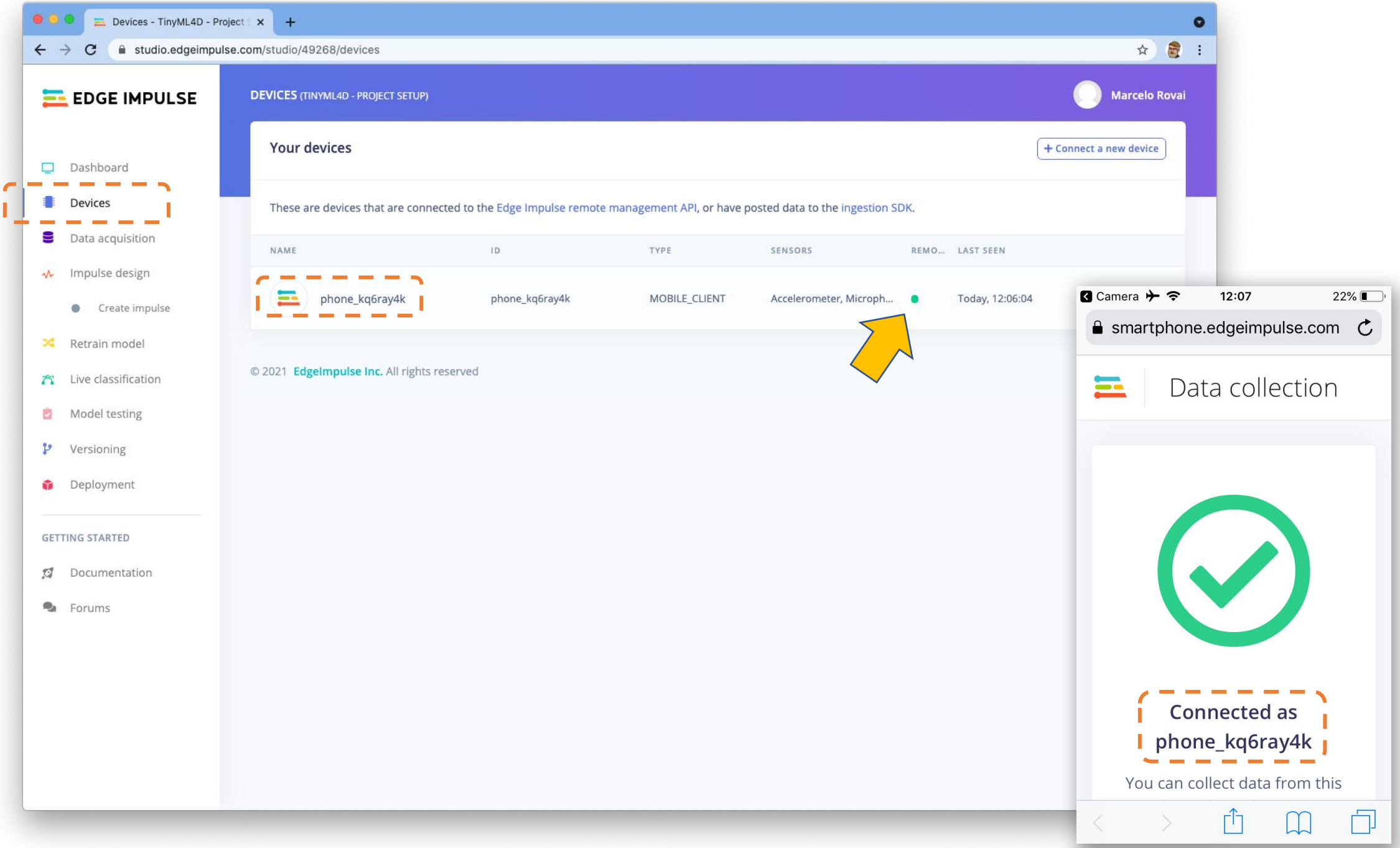
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
NAME
ID
TYPE
SENSORS
REMO...
LAST SEEN
Today, 12:06:04
© 2021
Collect data
Device phone_kq6ray4k is now connected
Get started!
Camera
12:07
22%
smartphone.edgeimpulse.com
Data collection
Connected as
phone_kq6ray4k
You can collect data from this


Devices - TinyML4D - Project
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DEVICES (TINYML4D - PROJECT SETUP)
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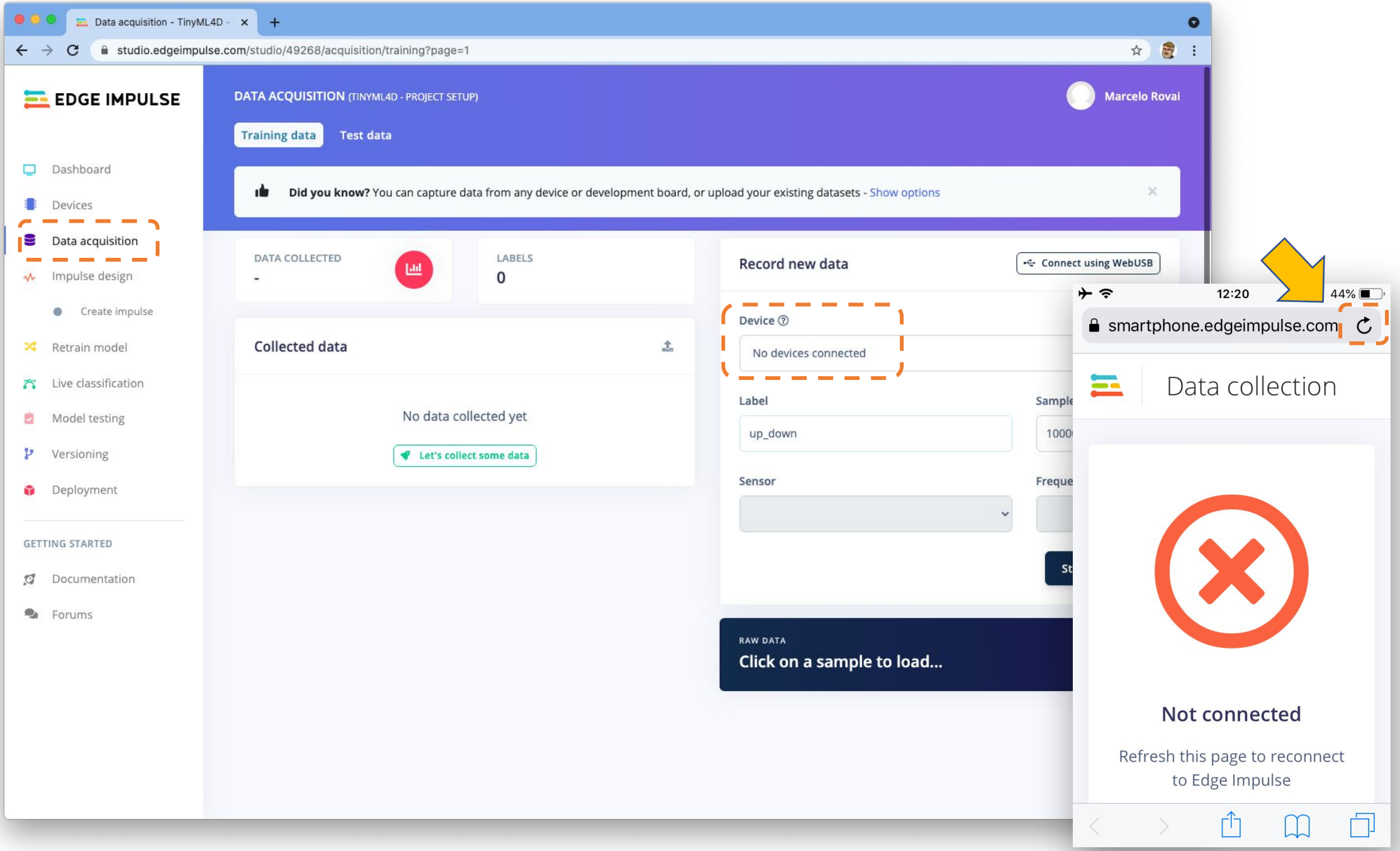
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
NAME
ID
TYPE
SENSORS
REMO...
LAST SEEN
phone_kq6ray4k
phone_kq6ray4k
MOBILE_CLIENT
Accelerometer, Microph...
Today, 12:06:04
© 2021 EdgeImpulse Inc. All rights reserved
Camera
12:07
22%
smartphone.edgeimpulse.com
Data collection
Connected as
phone_kq6ray4k
You can collect data from this


Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/acquisition/training?page=1
EDGE IMPULSE
DATA ACQUISITION (TINYML4D - PROJECT SETUP)
Marcelo Rovai
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
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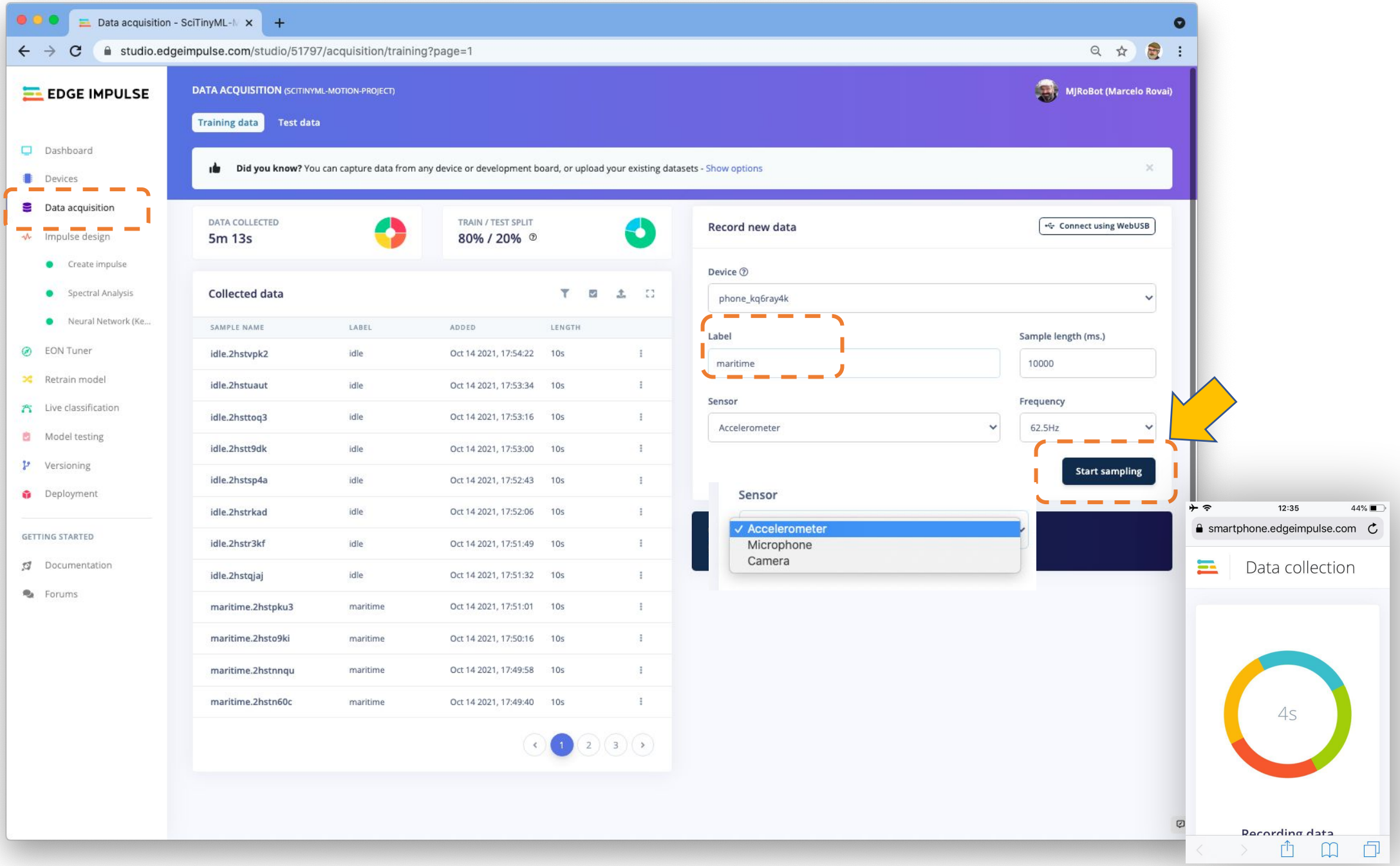
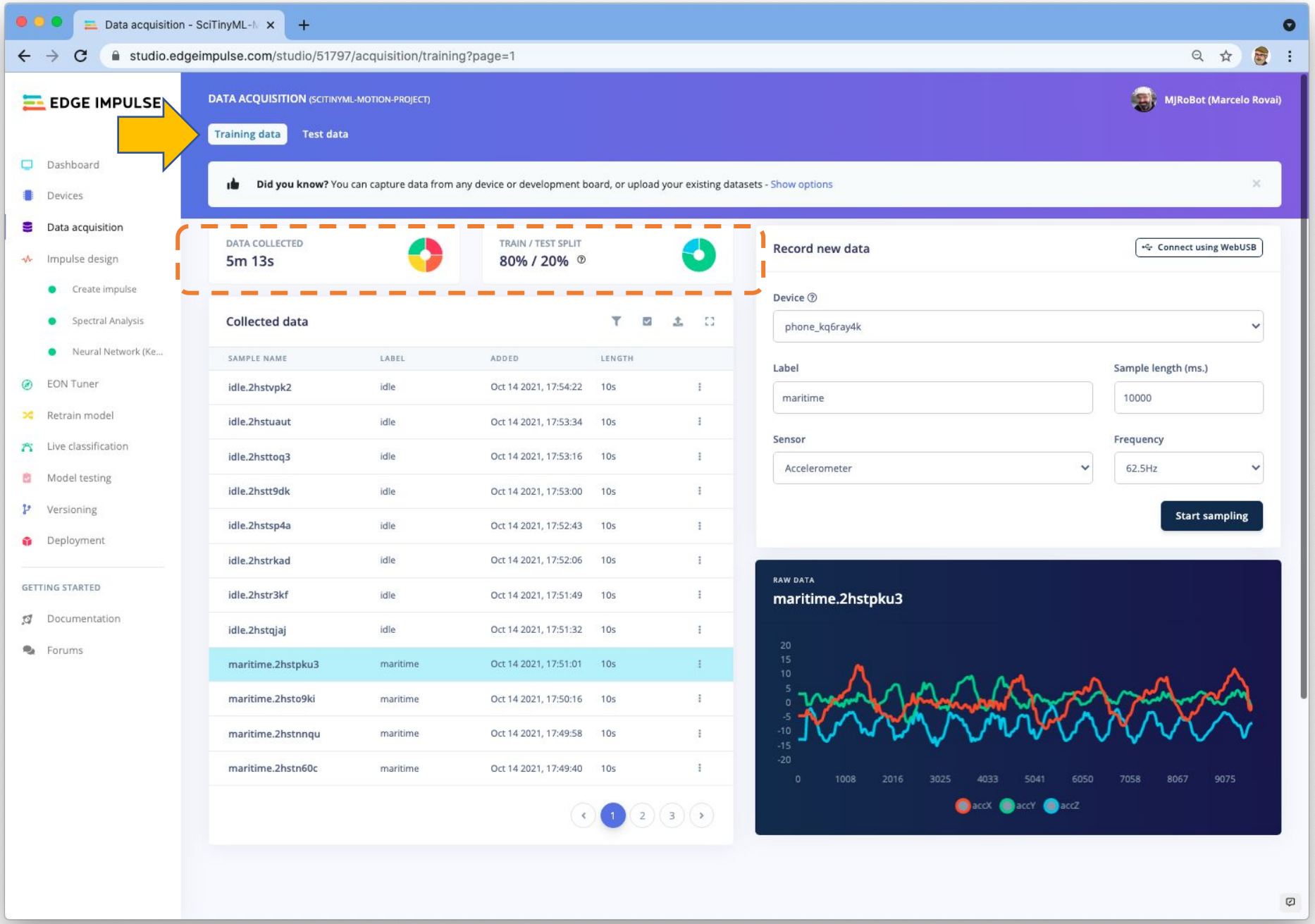
DATA COLLECTED
-
LABELS
0
Collected data
No data collected yet
Let's collect some data
Record new data
Connect using WebUSB
Device
No devices connected
Label
up_down
Sensor
RAW DATA
Click on a sample to load...
12:20
44%
smartphone.edgeimpulse.com
Data collection
Not connected
Refresh this page to reconnect to Edge Impulse

Collect Data



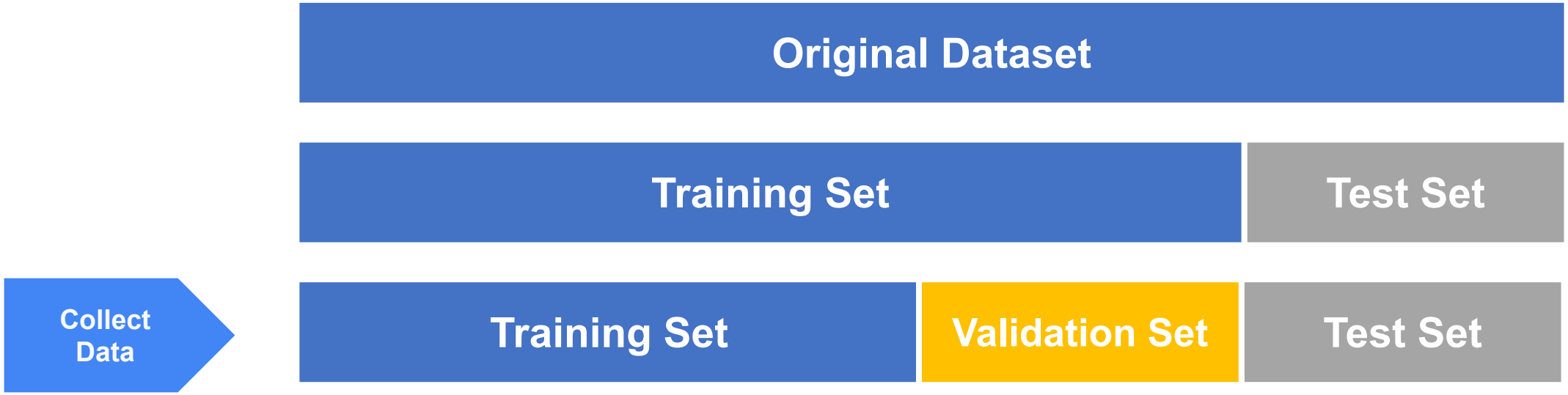
Collect Data

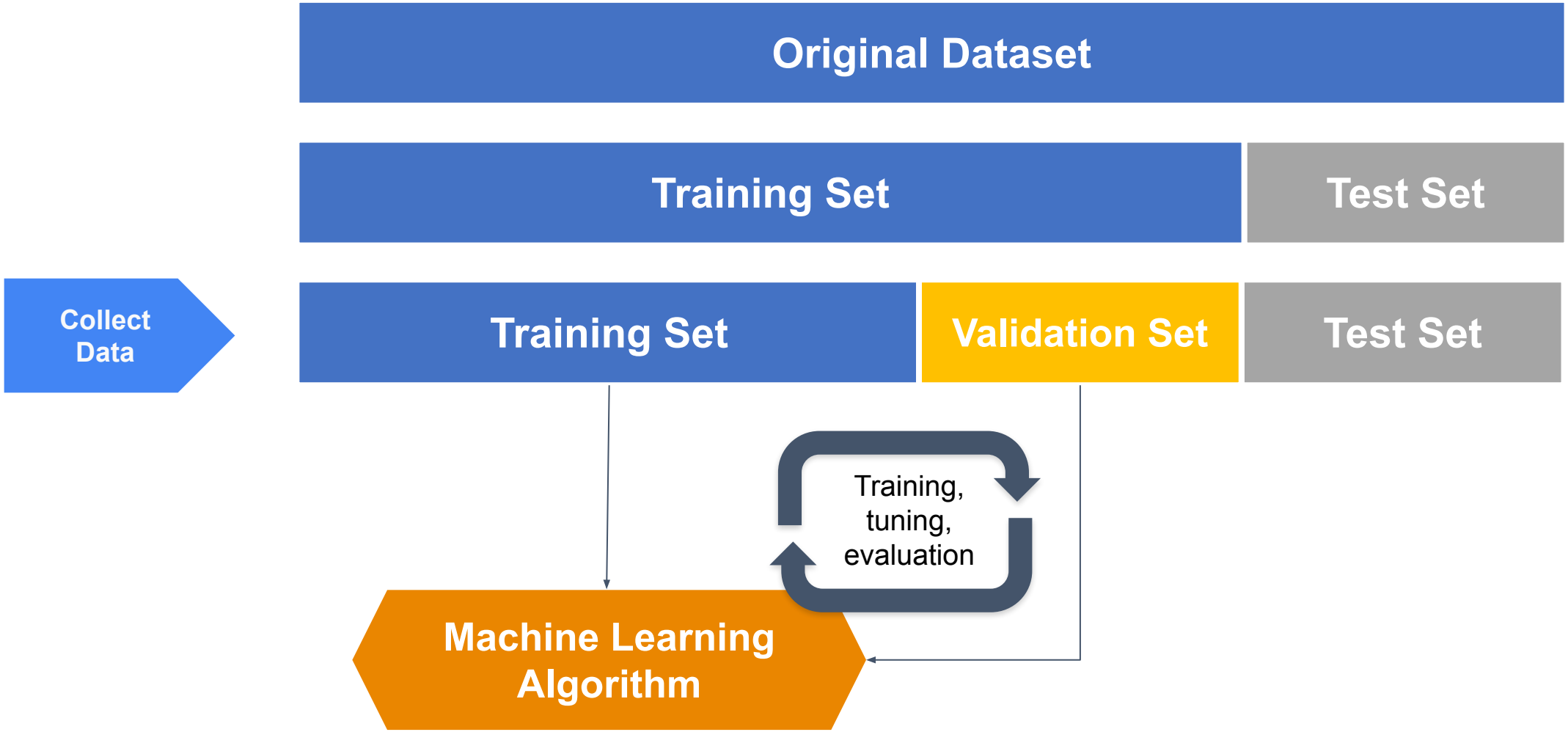


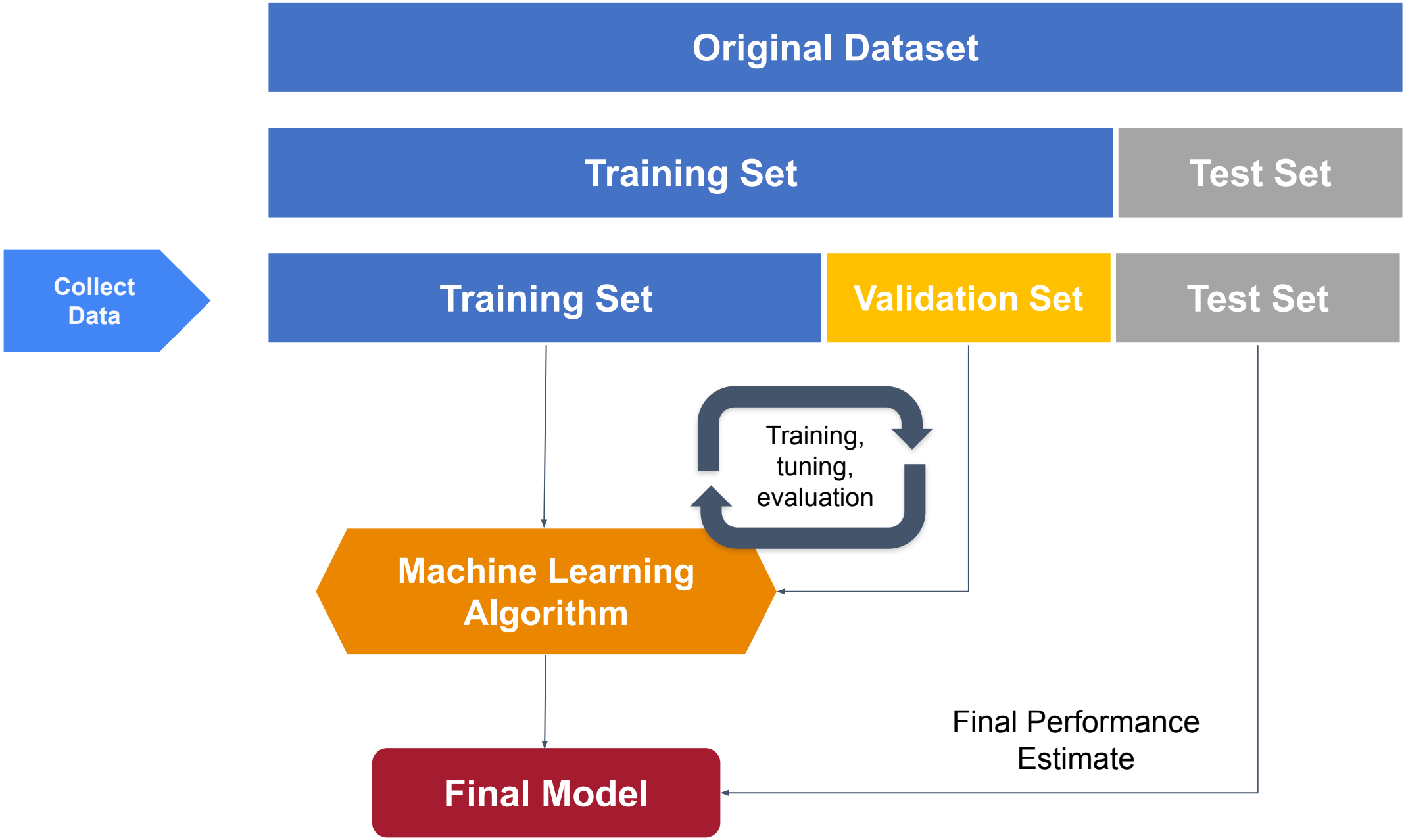
Collect Data

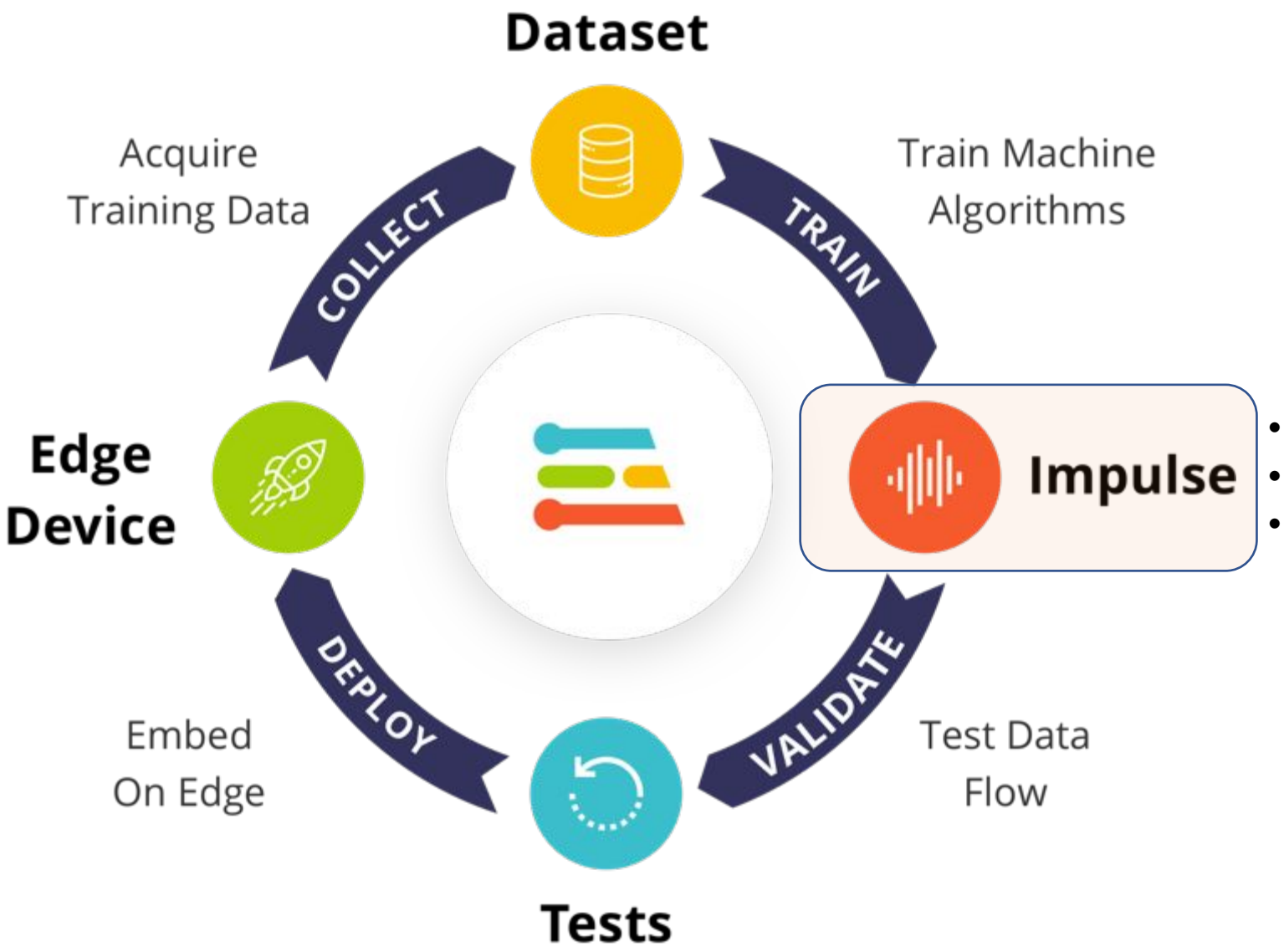
Original Dataset


Original Dataset
Collect Data
Training Set
Test Set

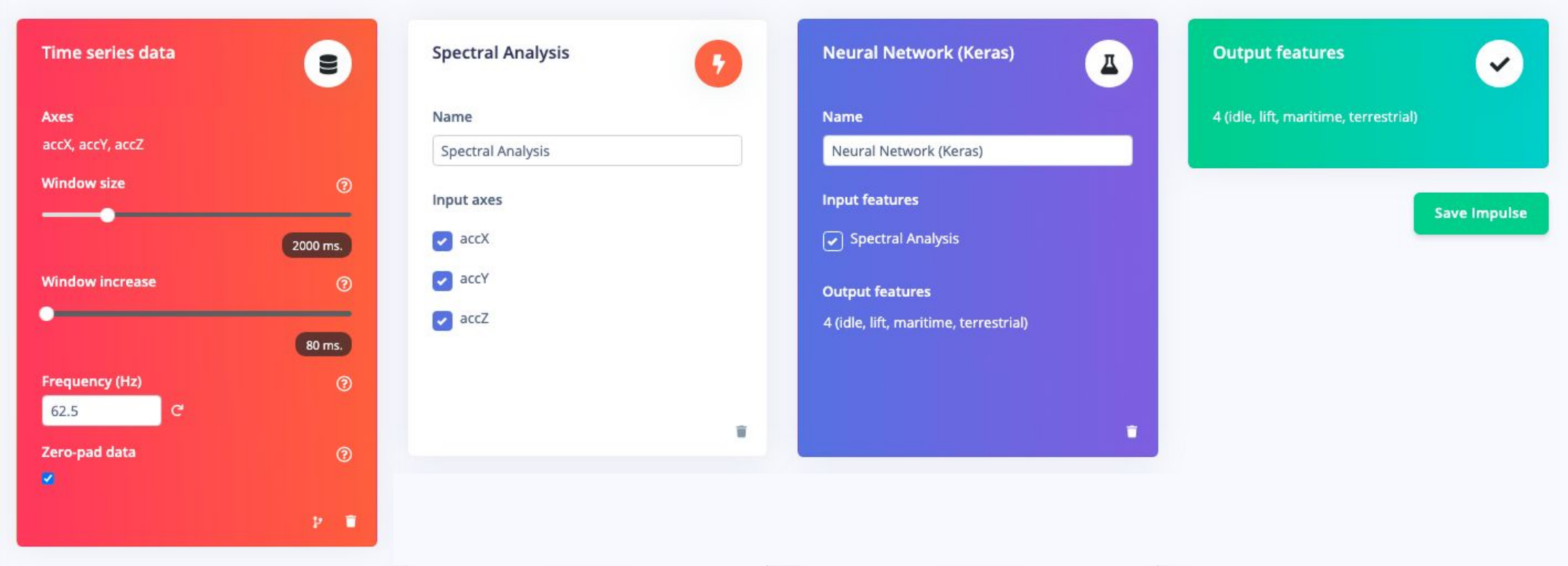

Original Dataset
Training Set
Test Set
Collect Data
Training Set
Validation Set
Test Set

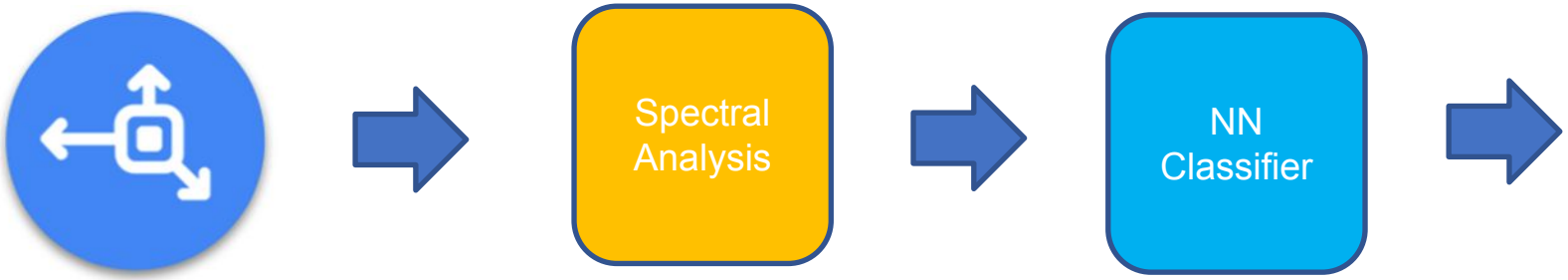

Original Dataset
Training Set
Test Set
Collect Data
Training Set
Validation Set
Test Set
Training, tuning, evaluation
Machine Learning Algorithm


Original Dataset
Training Set
Test Set
Collect Data
Training Set
Validation Set
Test Set
Training, tuning, evaluation
Machine Learning Algorithm
Final Performance Estimate
Final Model



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

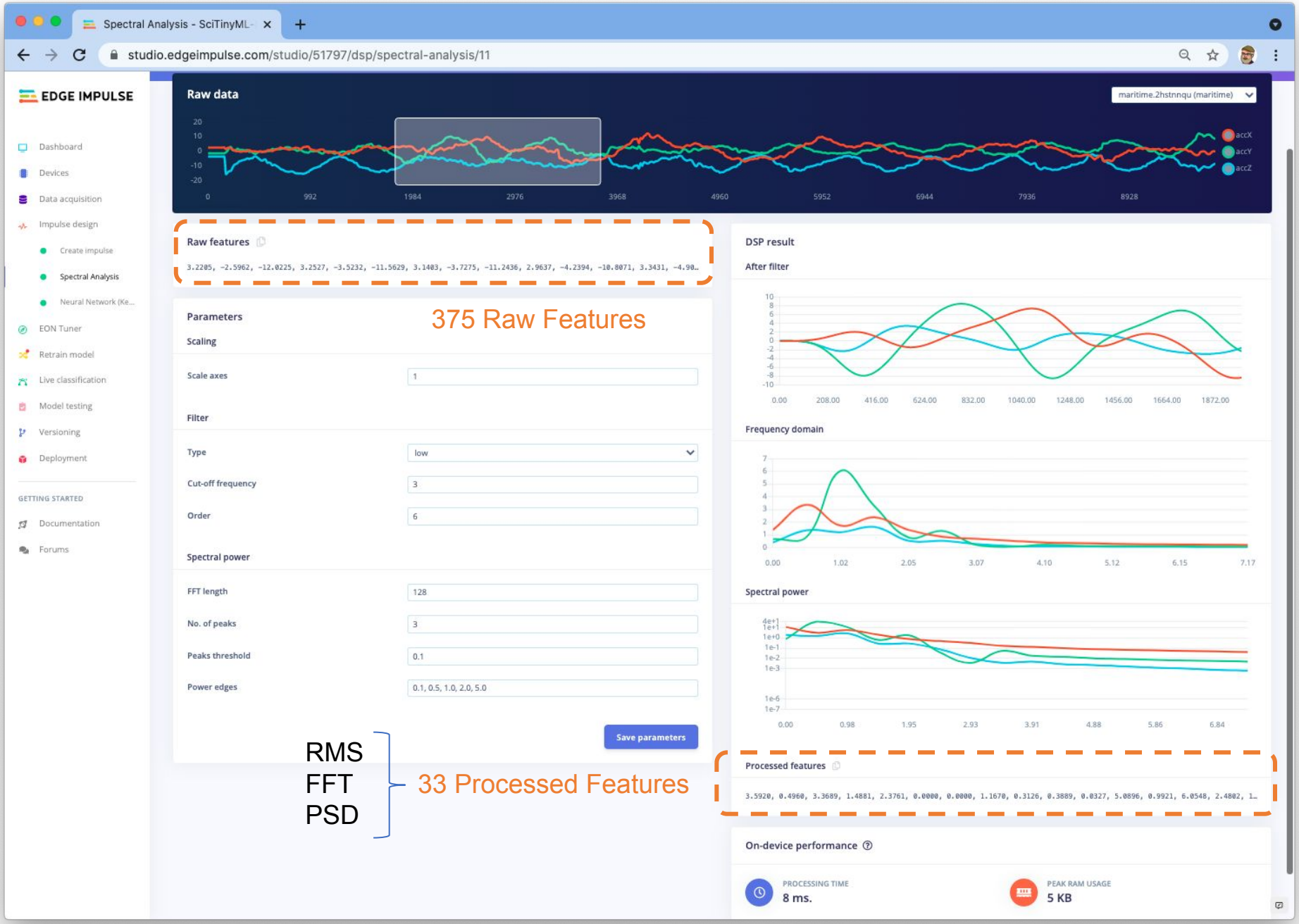




Classes

- Lift
- Terrestrial
- Maritime
- Iddle

Preprocess Data



Preprocess Data

Spectral Analysis - SciTinyML

studio.edgeimpulse.com/studio/51797/dsp/spectral-analysis/11/generate-features

EDGE IMPULSE

- Dashboard
- Devices
- Data acquisition
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  - Create impulse
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  - Neural Network (Ke...
- EON Tuner
- Retrain model
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- Versioning
- Deployment

GETTING STARTED

- Documentation
- Forums

SPECTRAL ANALYSIS (SCITINYML-MOTION-PROJECT)

#1 EON Tuner Primary

Parameters | Generate features

MJRoBot (Marcelo Rovai)

Training set

Data in training set	5m 22s
Classes	4 (idle, lift, maritime, terrestrial)
Window length	2000 ms.
Window increase	80 ms.
Training windows	3,230

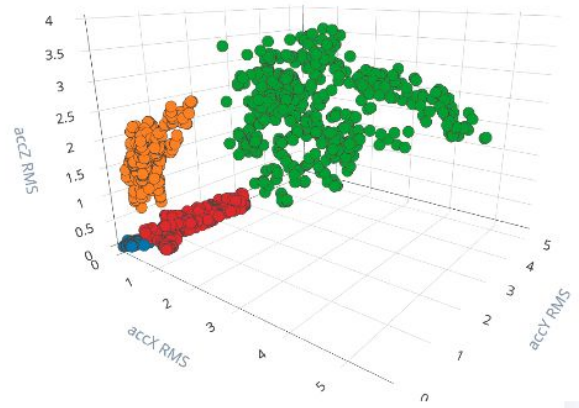
Generate features

- ✓ accX RMS
- accX Peak 1 Freq
- accX Peak 1 Height
- accX Peak 2 Freq
- accX Peak 2 Height
- accX Peak 3 Freq
- accX Peak 3 Height
- accX Spectral Power 0.1 - 0.5
- accX Spectral Power 0.5 - 1.0
- accX Spectral Power 1.0 - 2.0
- accX Spectral Power 2.0 - 5.0
- accY RMS
- accY Peak 1 Freq
- accY Peak 1 Height
- accY Peak 2 Freq
- accY Peak 2 Height
- accY Peak 3 Freq
- accY Peak 3 Height
- accY Spectral Power 0.1 - 0.5
- accY Spectral Power 0.5 - 1.0
- accY Spectral Power 1.0 - 2.0
- accY Spectral Power 2.0 - 5.0
- accZ RMS
- accZ Peak 1 Freq
- accZ Peak 1 Height
- accZ Peak 2 Freq
- accZ Peak 2 Height
- accZ Peak 3 Freq
- accZ Peak 3 Height
- accZ Spectral Power 0.1 - 0.5
- accZ Spectral Power 0.5 - 1.0
- accZ Spectral Power 1.0 - 2.0
- accZ Spectral Power 2.0 - 5.0

Feature explorer (3,132 samples)

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

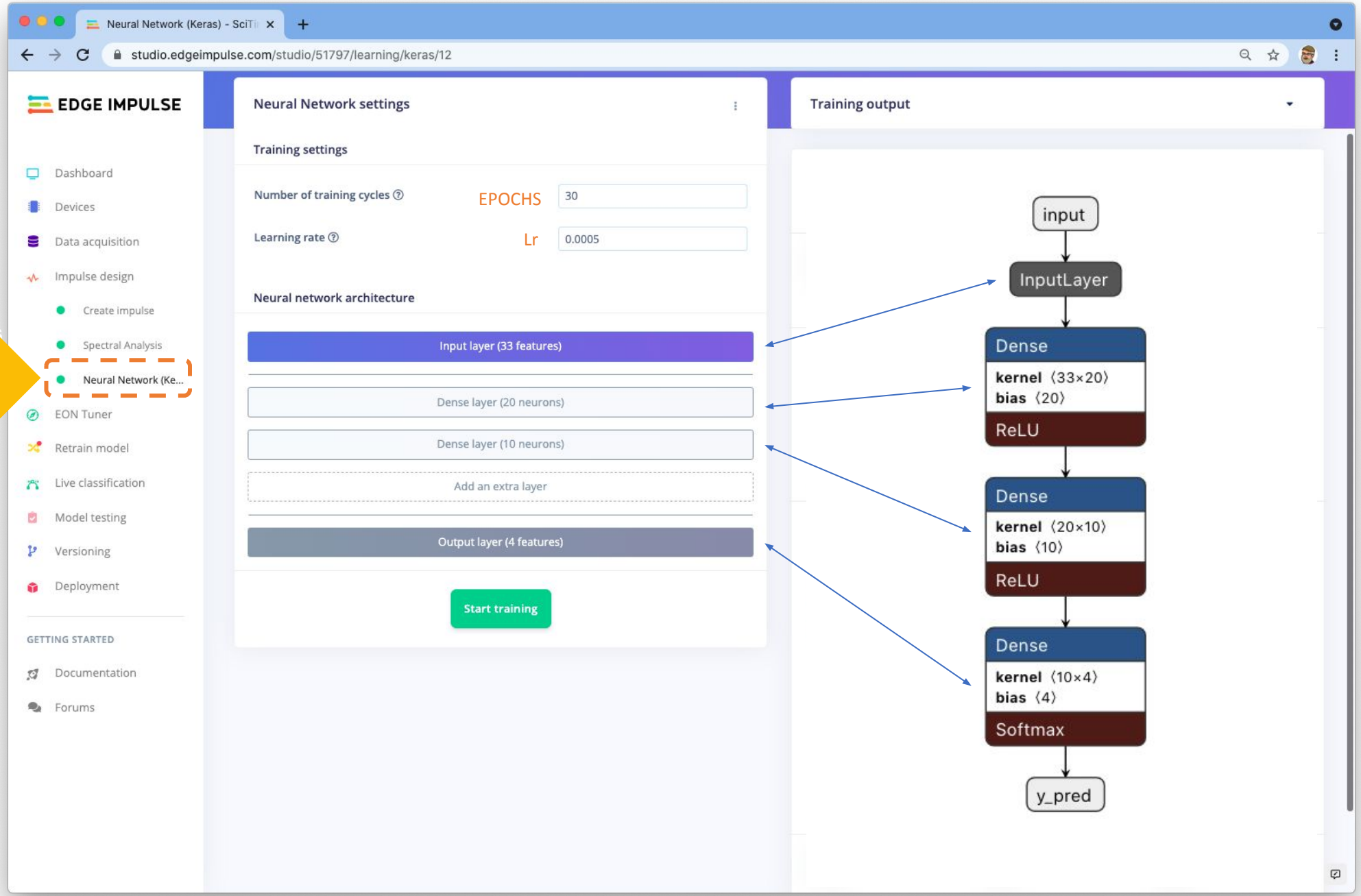
- idle
- lift
- maritime
- terrestrial



On-device performance

PROCESSING TIME
8 ms.

PEAK RAM USAGE
5 KB



Design a Model

Train a Model

Neural Network (Keras) - SciTi

studio.edgeimpulse.com/studio/51797/learning/keras/12

EDGE IMPULSE

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  - Neural Network (Ke...
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GETTING STARTED

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Neural Network settings

Training settings

Number of training cycles — EPOCHS: 30

Learning rate — Lr: 0.0005

Neural network architecture

Input layer (33 features)

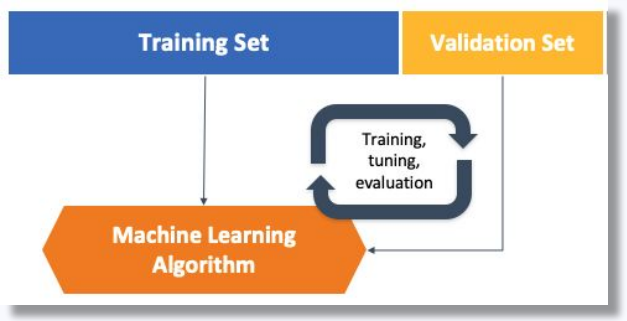
Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (4 features)

Start training



Training output

Model

Model version: Quantized (int8)

Last training performance (validation set)

ACCURACY 99.7%

LOSS 0.01

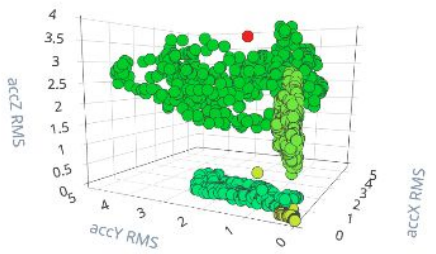
Confusion matrix (validation set)

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	0%	100%	0%	0%
MARITIME	0%	0.6%	99.4%	0%
TERRESTRIAL	0.6%	0%	0%	99.4%
F1 SCORE	1.00	1.00	1.00	1.00

Feature explorer (full training set)

accX RMS | accY RMS | accZ RMS

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



On-device performance

INFERENCING TIME 1 ms.

PEAK RAM USAGE 1.7K

FLASH USAGE 19.0K

Evaluate
Optimize

Neural Network (Keras) - SciTi

studio.edgeimpulse.com/studio/51797/learning/keras/12

EDGE IMPULSE

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Neural Network settings

Training settings

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Neural network architecture

Input layer (33 features)

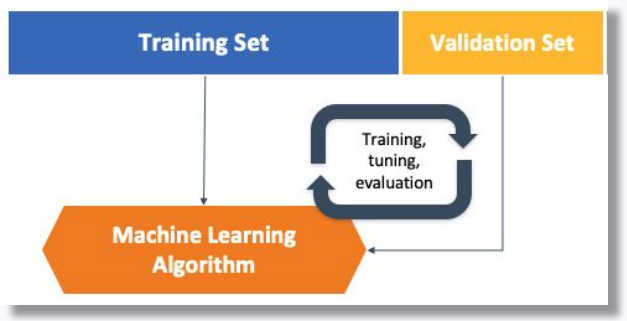
Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (4 features)

Start training



Training output

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Model version: Quantized (int8)

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ACCURACY 99.7%

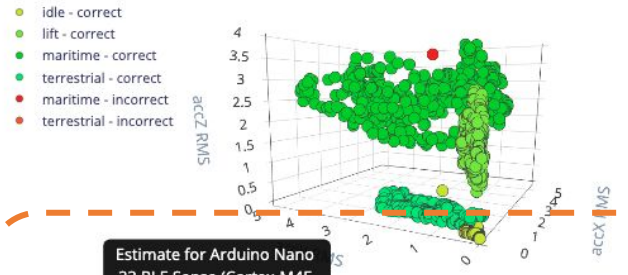
LOSS 0.01

Confusion matrix (validation set)

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	0%	100%	0%	0%
MARITIME	0%	0.6%	99.4%	0%
TERRESTRIAL	0.6%	0%	0%	99.4%
F1 SCORE	1.00	1.00	1.00	1.00

Feature explorer (full training set)

accX RMS | accY RMS | accZ RMS



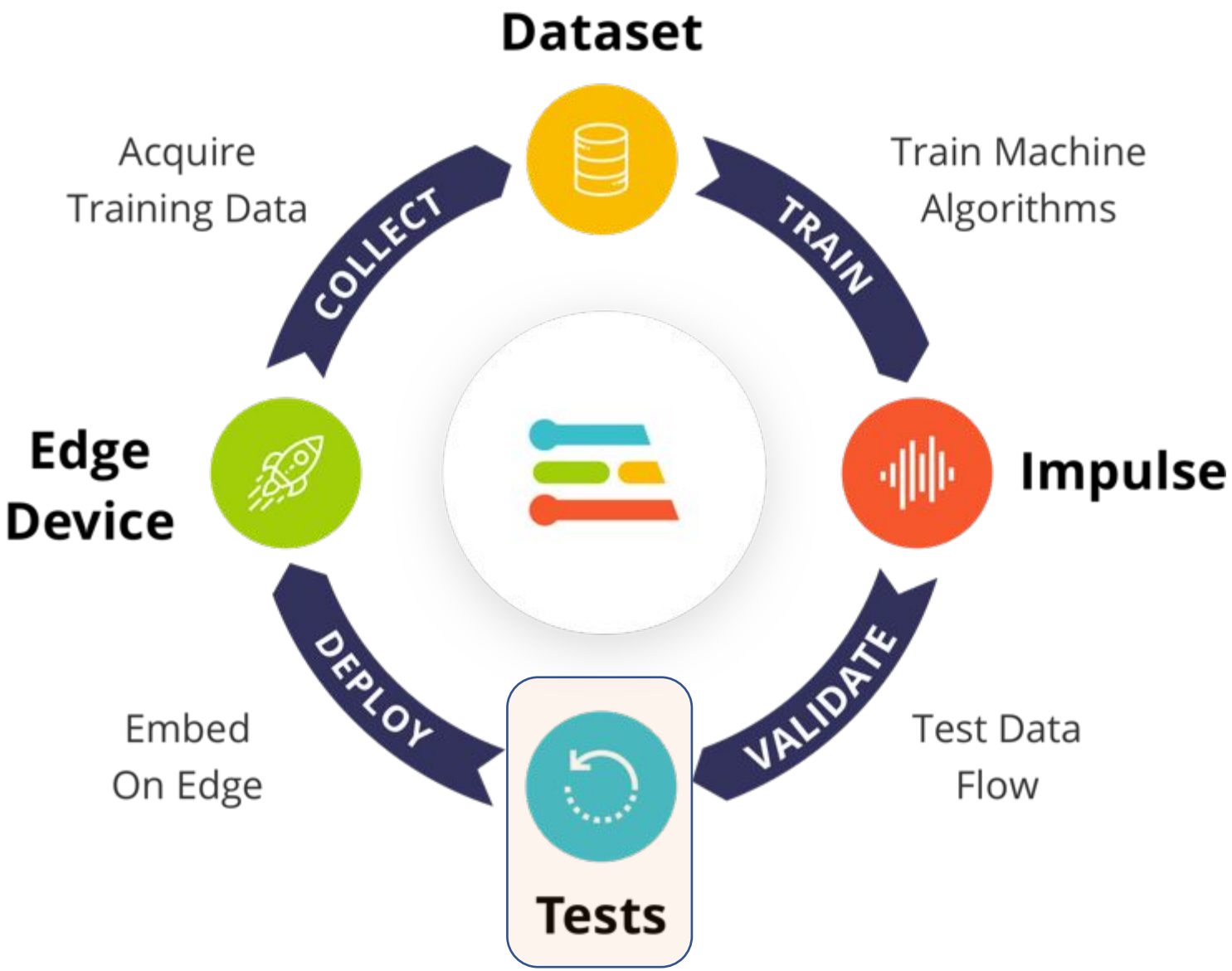
Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz), compiled with Edge Impulse EON™ compiler

On-device performance

INFERENCING TIME 1 ms.

PEAK RAM USAGE 1.7K

FLASH USAGE 19.0K



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

Evaluate
Optimize

Model testing - SciTinyML-Mot

studio.edgeimpulse.com/studio/51797/validation

EDGE IMPULSE

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MODEL TESTING (SCITINYML-MOTION-PROJECT)

MJRoBot (Marcelo Rovai)

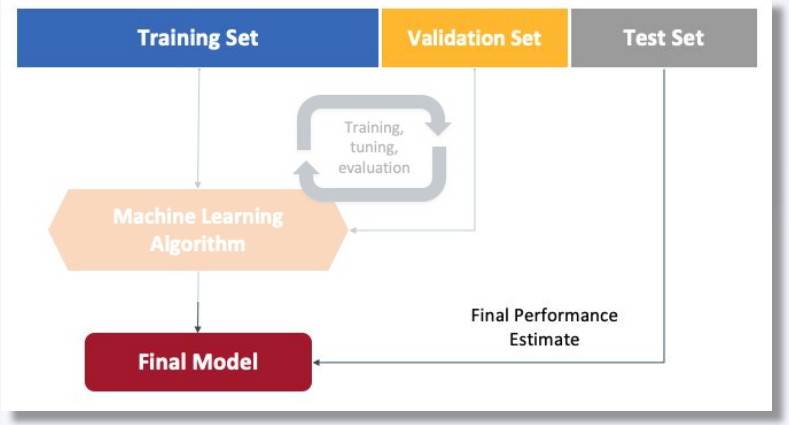
This lists all test data. You can manage this data through Data acquisition.

Test data

Classify all

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

SAMPLE NAME	EXPECTED OUTCO...	LENGTH	ACCURACY	RESULT
testing.2hvf...	testing	10s		
terrestrial.2...	terrestrial	10s	100%	98 terrestrial
terrestrial.2...	terrestrial	10s	100%	98 terrestrial
lift .2hssi1t6	lift	10s	100%	98 lift
lift .2hst8tvj	lift	10s	100%	98 lift



Model testing output

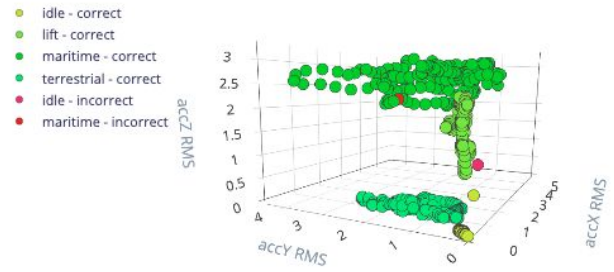
Model testing results

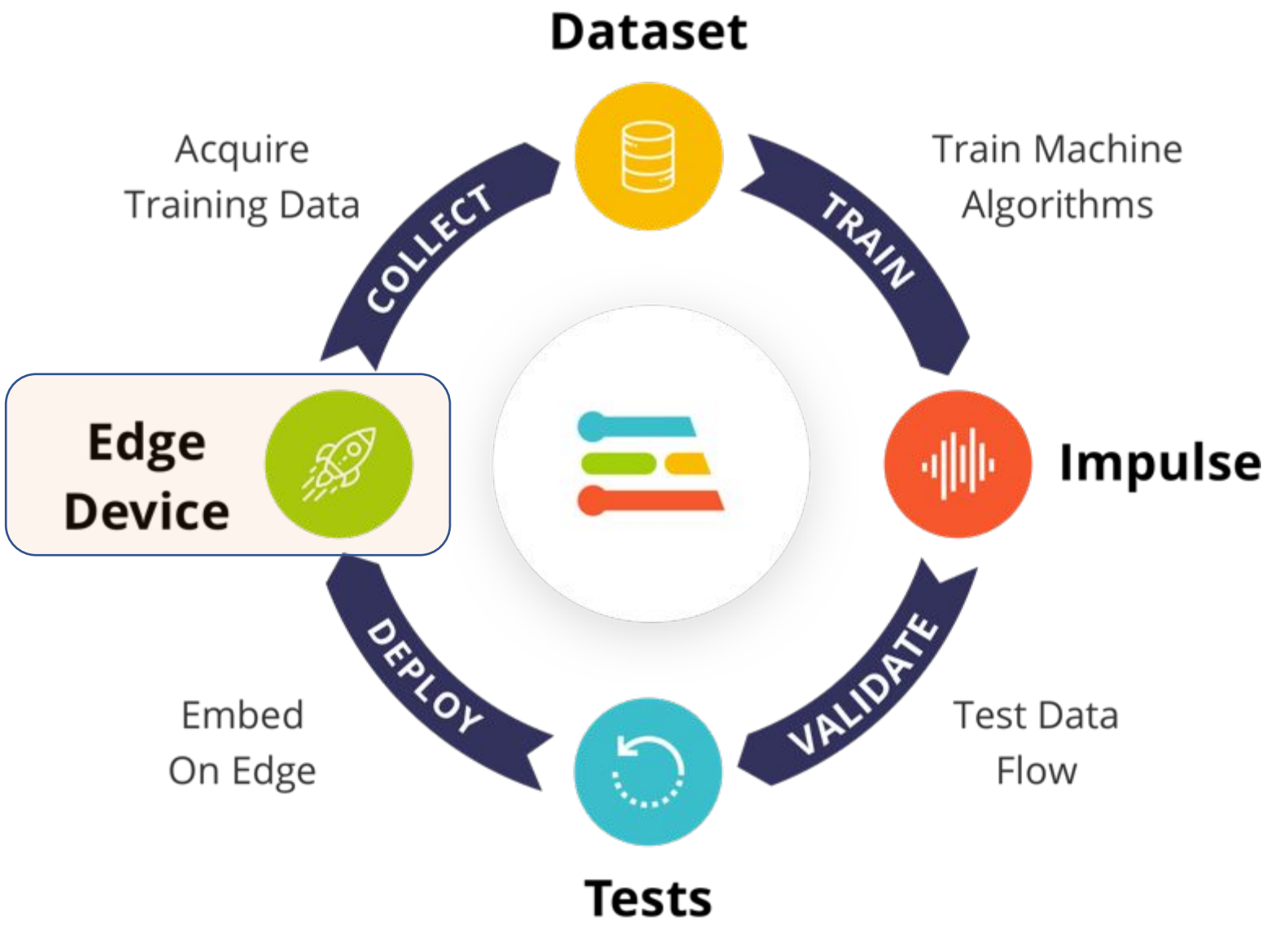
ACCURACY
99.74%

	IDLE	LIFT	MARITIME	TERRESTRIAL	UNCERTAIN
IDLE	99.5%	0.5%	0%	0%	0%
LIFT	0%	100%	0%	0%	0%
MARITIME	0%	0%	99.5%	0%	0.5%
TERRESTRIAL	0%	0%	0%	100%	0%
F1 SCORE	1.00	1.00	1.00	1.00	

Feature explorer

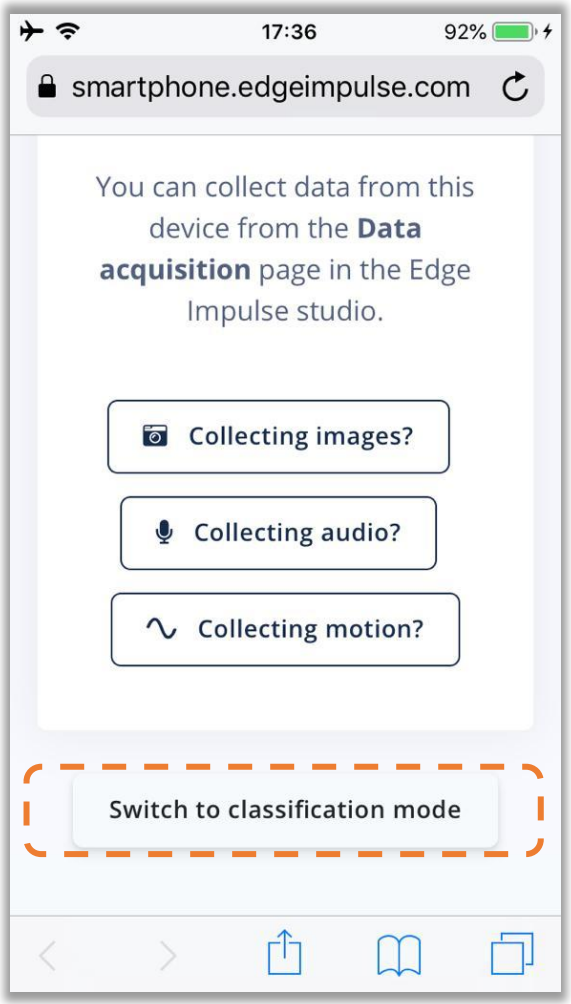
accX RMS | accY RMS | accZ RMS

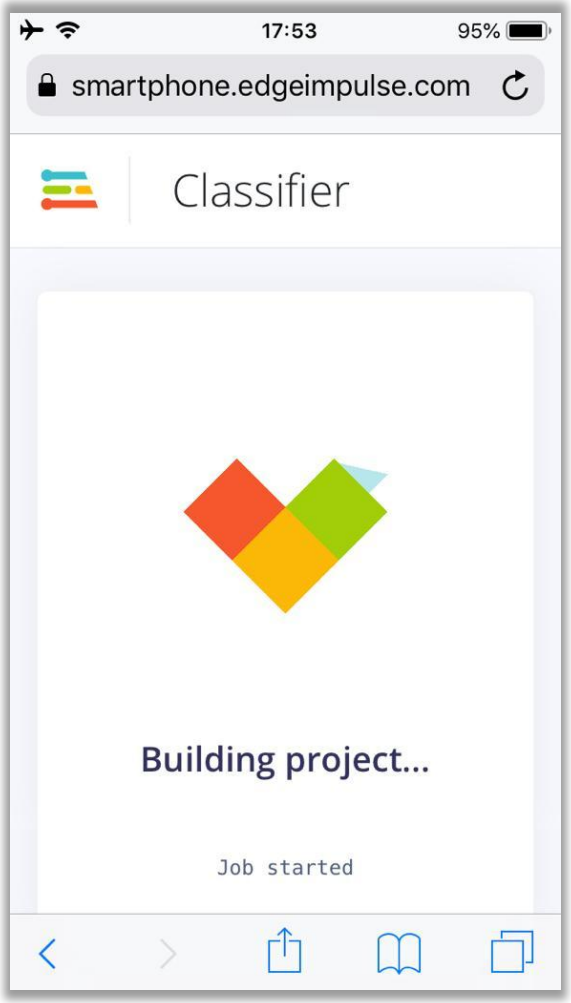




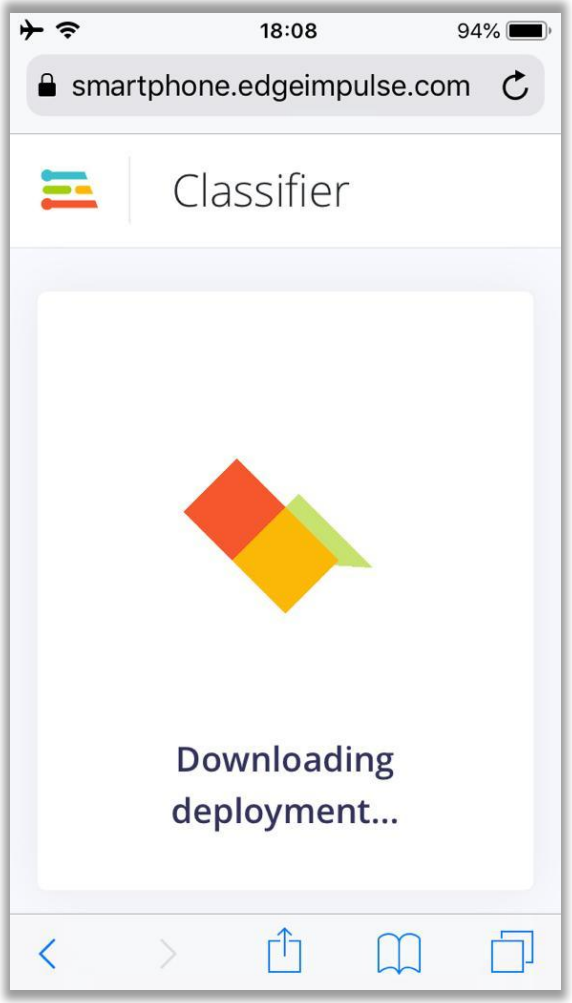
- Pre-Processing Data
- Design a Model
- Train a Model

Convert Model

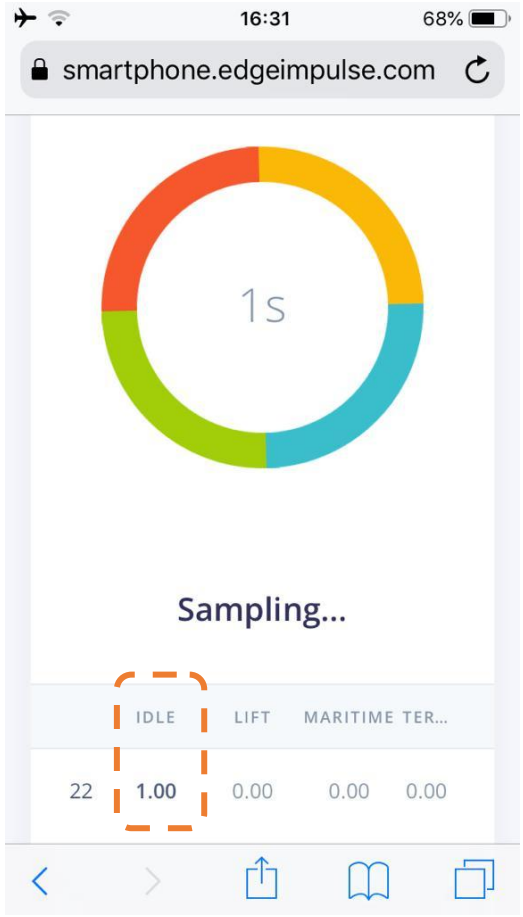


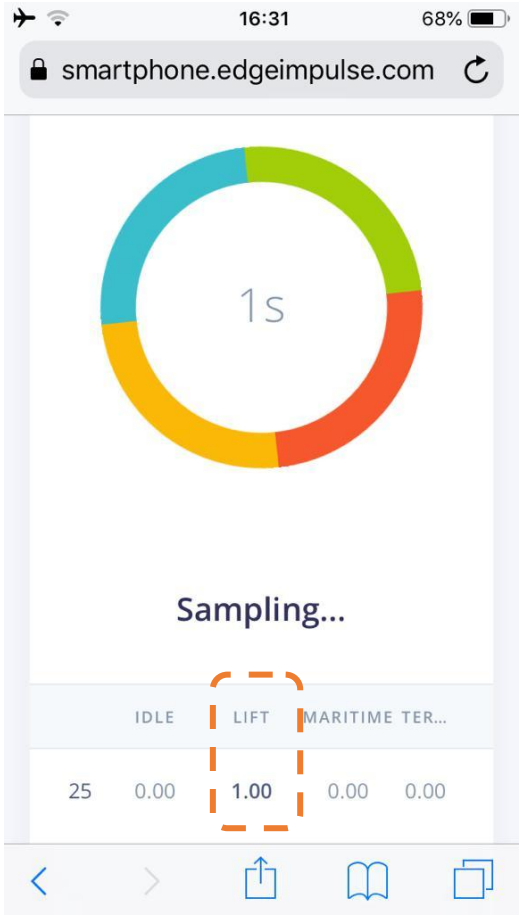


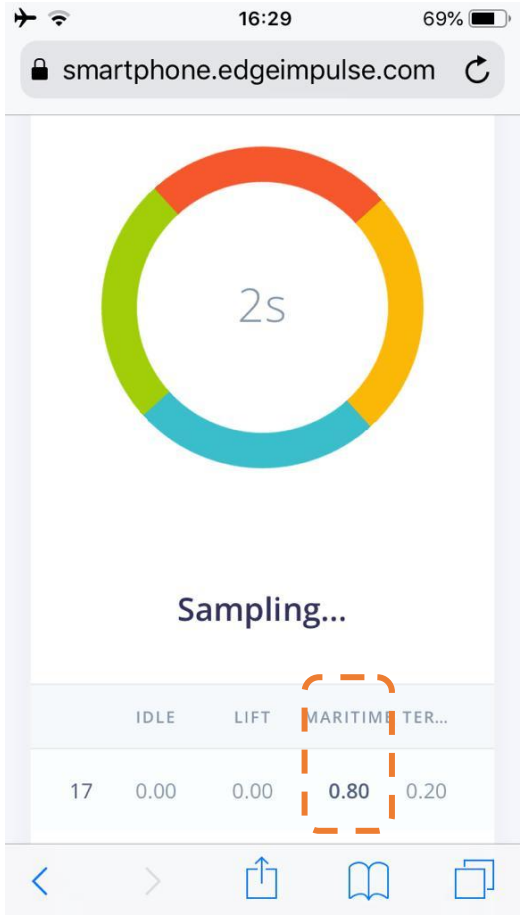
Deploy Model

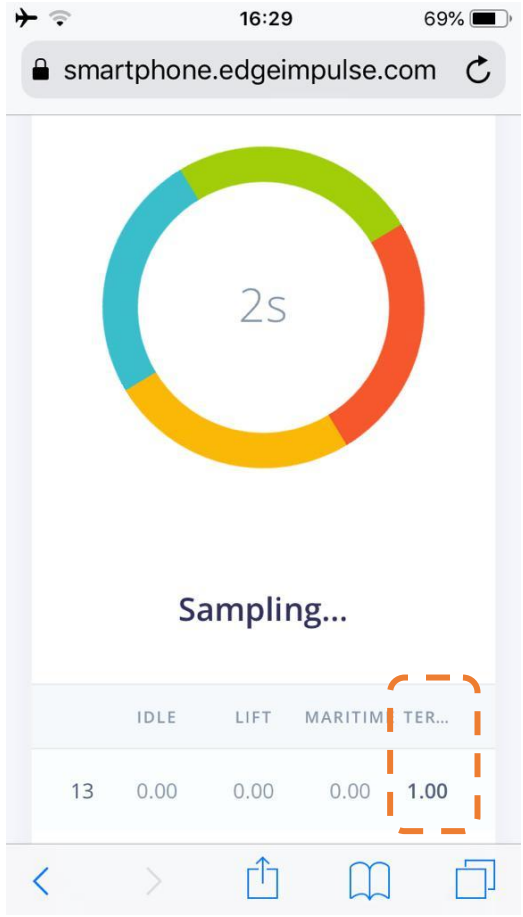


Make Inferences



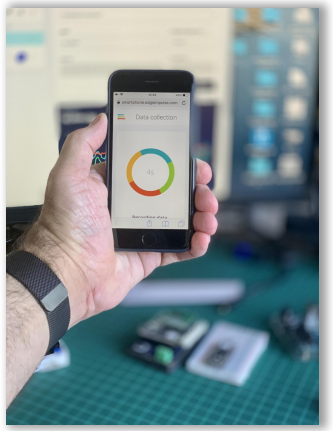


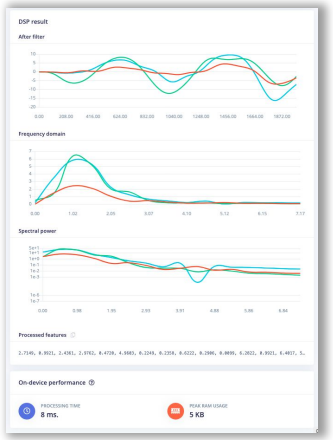


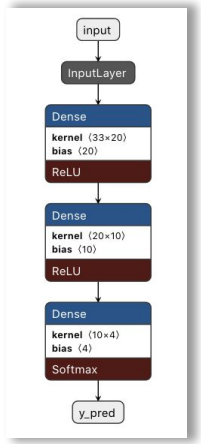


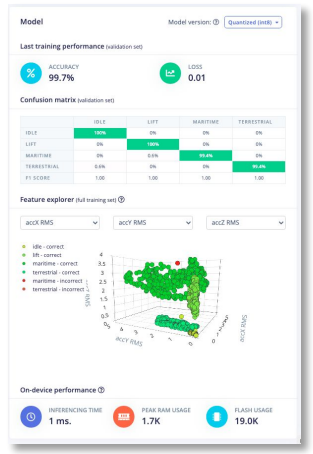
Motion Classification - Summary

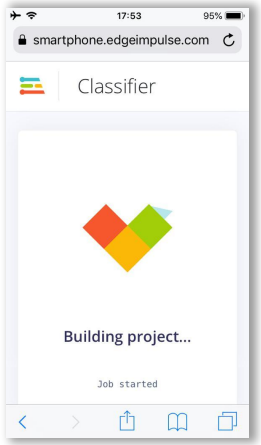
Collect Data → Preprocess Data → Design a Model → Train a Model → Evaluate Optimize → Convert Model → Deploy Model → Make Inferences

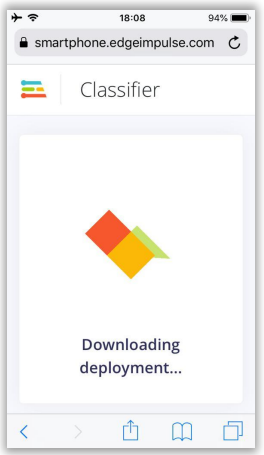


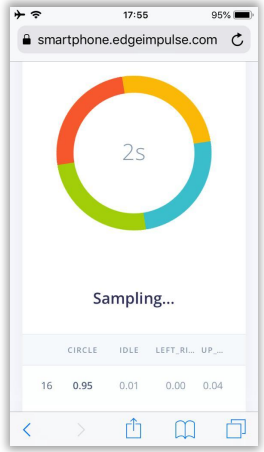






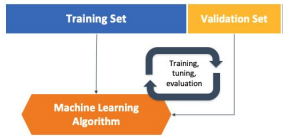


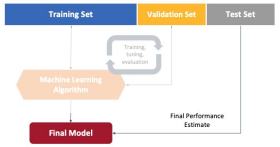




Spectral Analysis

NN Classifier



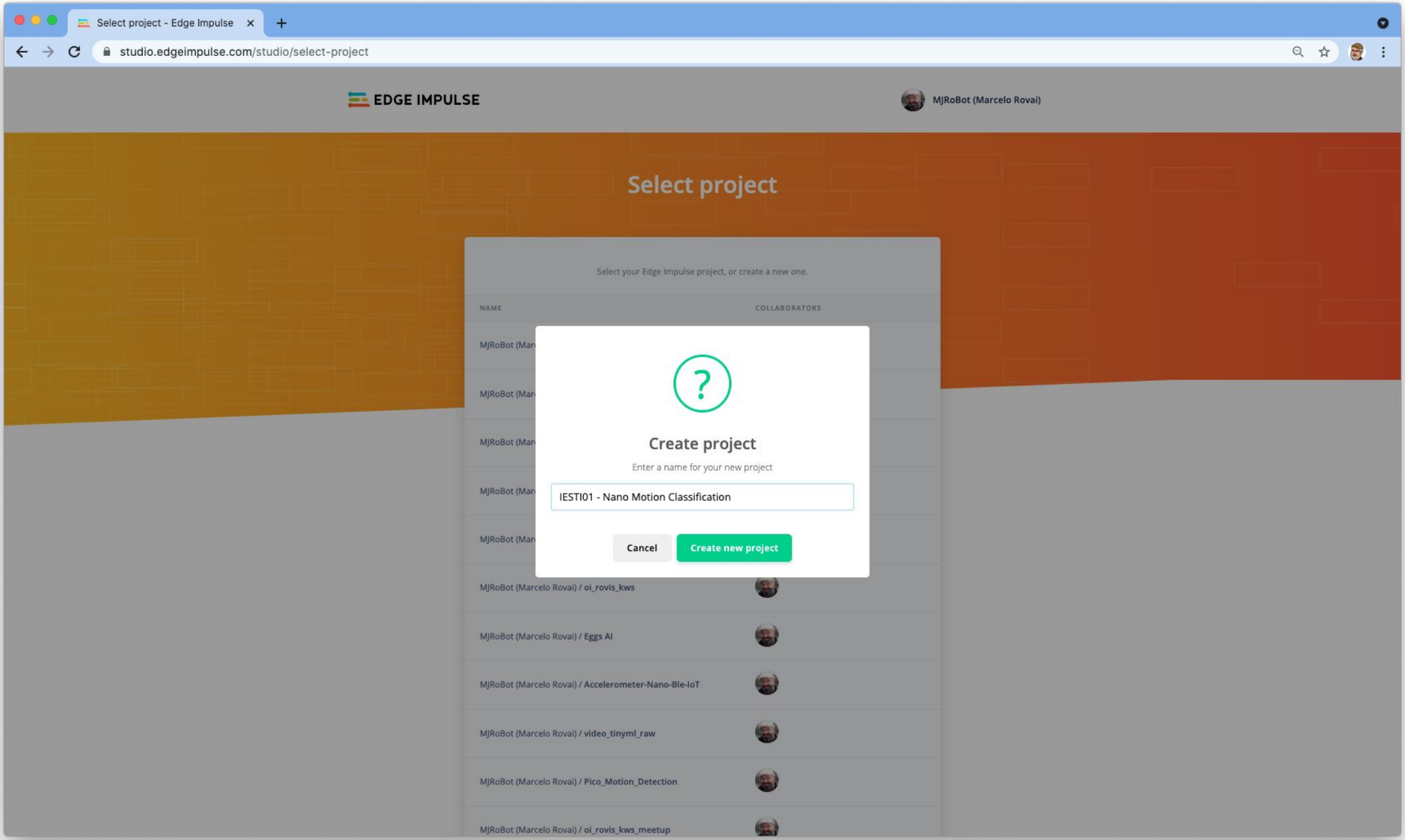


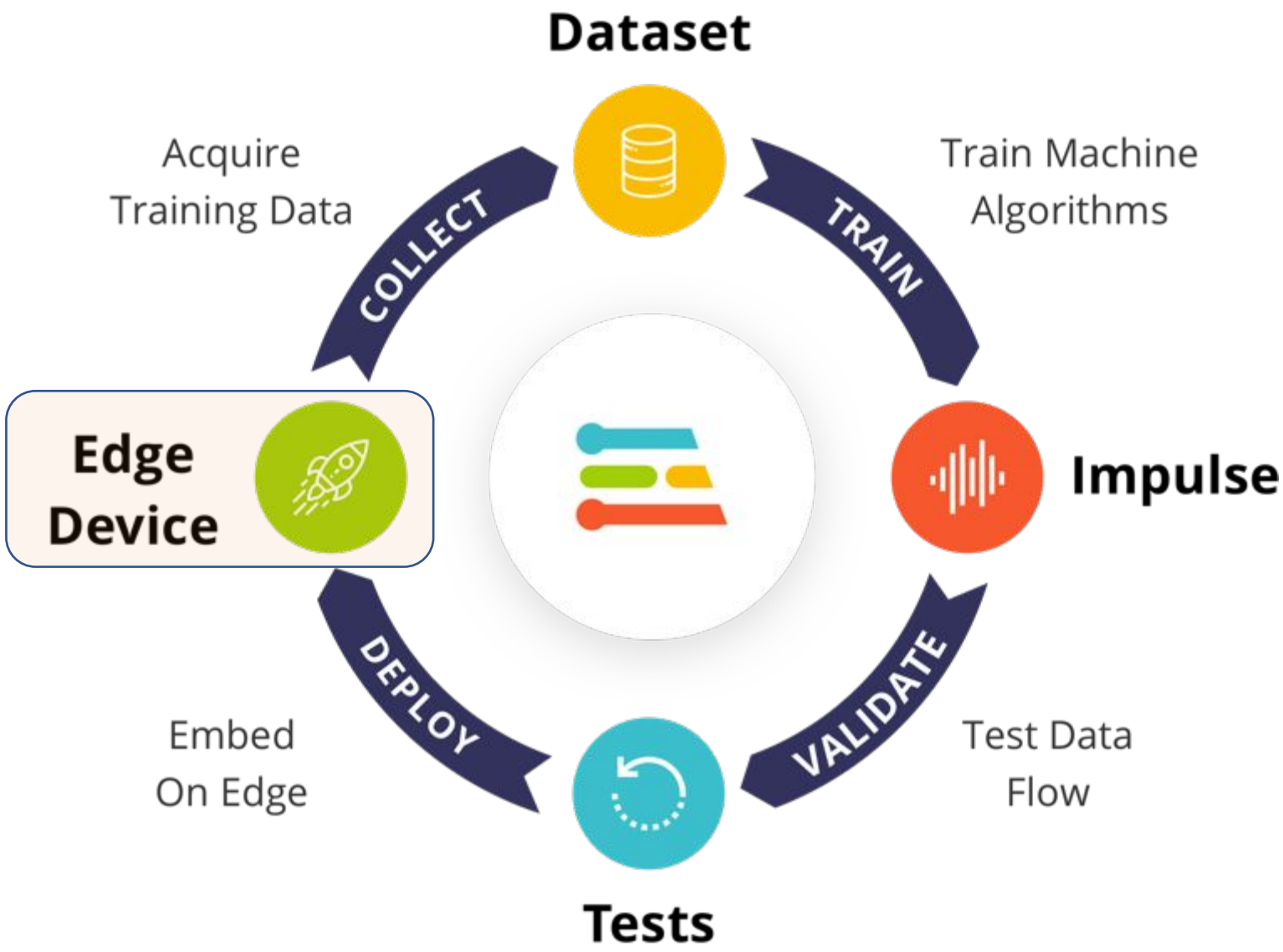
Dataset Collection

Using MCUs

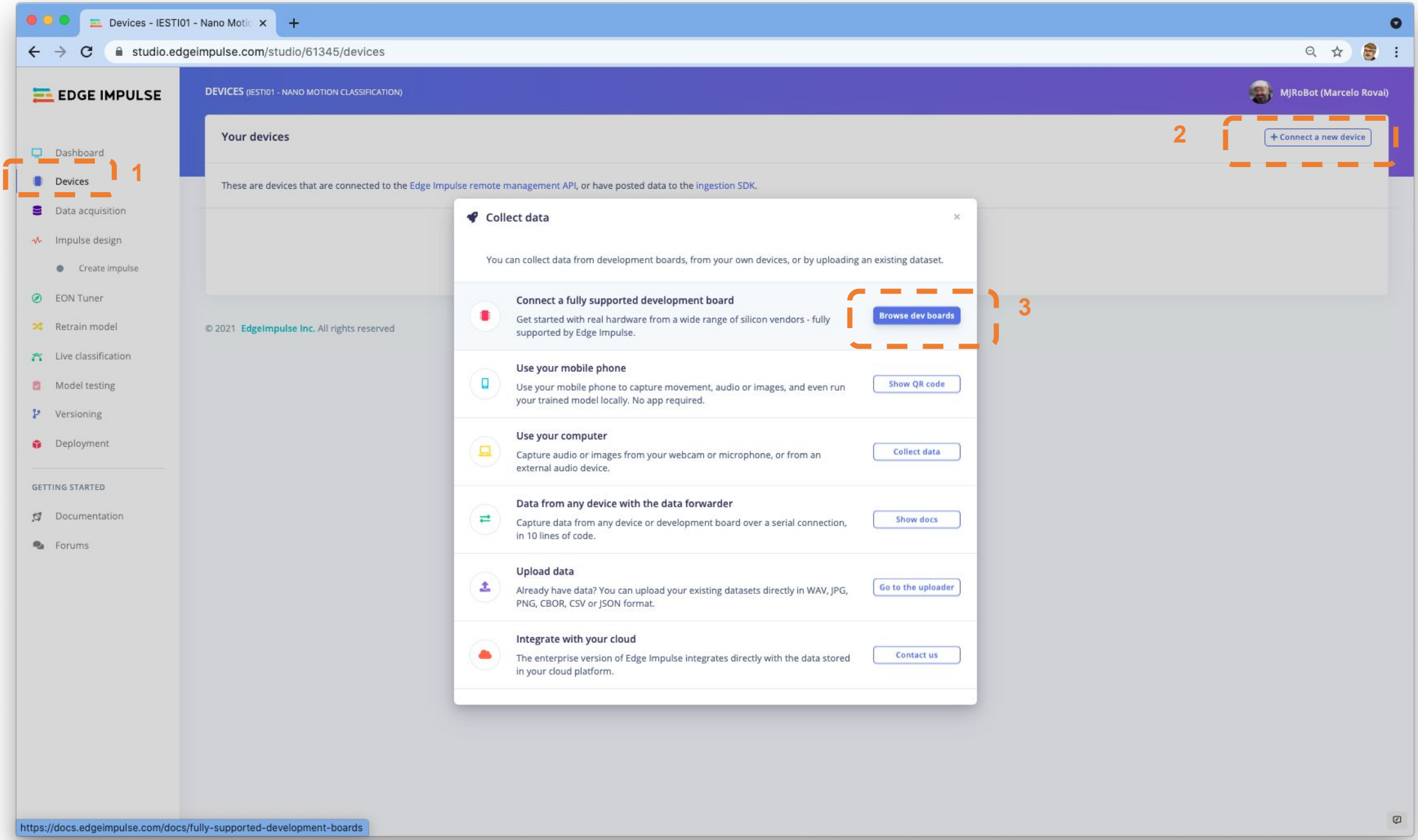
Arduino Nano-33 BLE

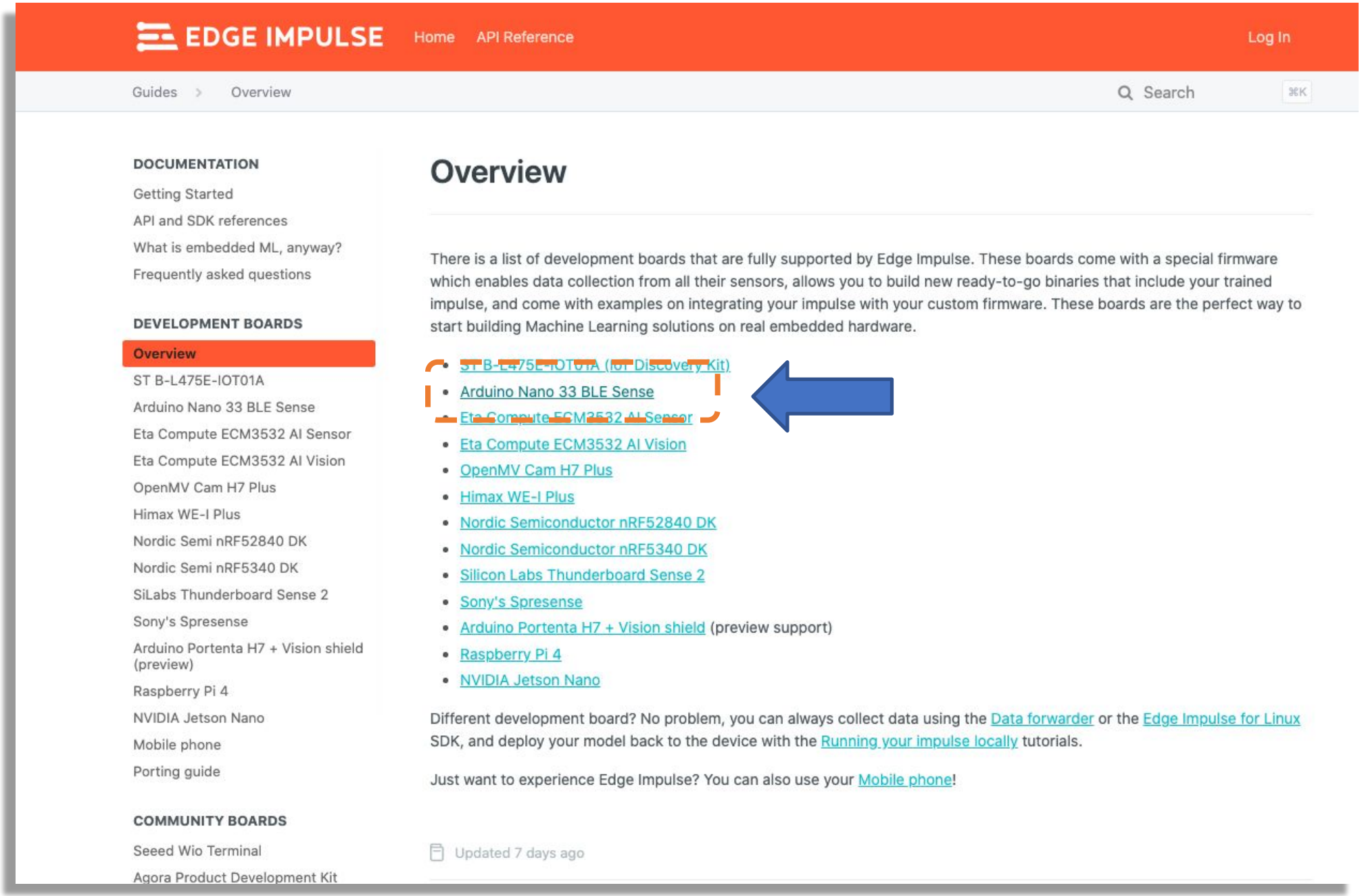
Edge Impulse – Installation


Select project - Edge Impulse
studio.edgeimpulse.com/studio/select-project
EDGE IMPULSE
MJRoBot (Marcelo Rovai)
Select project
Select your Edge Impulse project, or create a new one.
NAME
COLLABORATORS
Create project
Enter a name for your new project
IESTI01 - Nano Motion Classification
Cancel
Create new project
MJRoBot (Marcelo Rovai) / oi_rovis_kws
MJRoBot (Marcelo Rovai) / Eggs AI
MJRoBot (Marcelo Rovai) / Accelerometer-Nano-Ble-IoT
MJRoBot (Marcelo Rovai) / video_tinyml_raw
MJRoBot (Marcelo Rovai) / Pico_Motion_Detection
MJRoBot (Marcelo Rovai) / oi_rovis_kws_meetup



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


Devices - IESTI01 - Nano Motic
studio.edgeimpulse.com/studio/61345/devices
EDGE IMPULSE
DEVICES (IESTI01 - NANO MOTION CLASSIFICATION)
MJRoBot (Marcelo Rovai)
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
1
Your devices
2
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
© 2021 EdgeImpulse Inc. All rights reserved
Collect data
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
https://docs.edgeimpulse.com/docs/fully-supported-development-boards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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 (IoT 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

EI CLI

EDGE IMPULSE Home API Reference Log In

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

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- Agora Product Development Kit

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** insteady)

Installation

Edge Impulse CLI optional Installation

This Edge Impulse CLI is used to control local devices, act as a proxy to synchronise data for devices that don't have an internet connection, and to upload and convert local files. The CLI consists of seven tools:

- edge-impulse-daemon - configures devices over serial, and acts as a proxy for devices that do not have an IP connection.
- edge-impulse-uploader - allows uploading and signing local files.
- edge-impulse-data-forwarder - a very easy way to collect data from any device over a serial connection, and forward the data to Edge Impulse.
- edge-impulse-run-impulse - show the impulse running on your device.
- edge-impulse-blocks - create organizational transformation blocks.
- eta-flash-tool - to flash the Eta Compute ECM3532 AI Sensor.
- himax-flash-tool - to flash the Himax WE-I Plus.

Connect to devices without the CLI? Recent versions of Google Chrome and Microsoft Edge can connect directly to fully-supported development boards, without the CLI. See this blog post for more information.

Installation - macOS and Windows

1. Install Python 3 on your host computer.
2. Install Node.js v14 or higher on your host computer.
    - For Windows users, install the **Additional Node.js tools** when prompted. You may skip this setup if you have Visual Studio 2015 or more.
3. Install the CLI tools via:

```
npm install -g edge-impulse-cli --force
```

You should now have the tools available in your PATH.

Installation - Linux/Ubuntu and Raspbian OS

Installation

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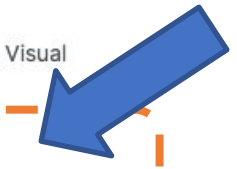

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Installation - Linux/Ubuntu and Raspbian OS

Arduino CLI

EDGE IMPULSE Home API Reference Log In

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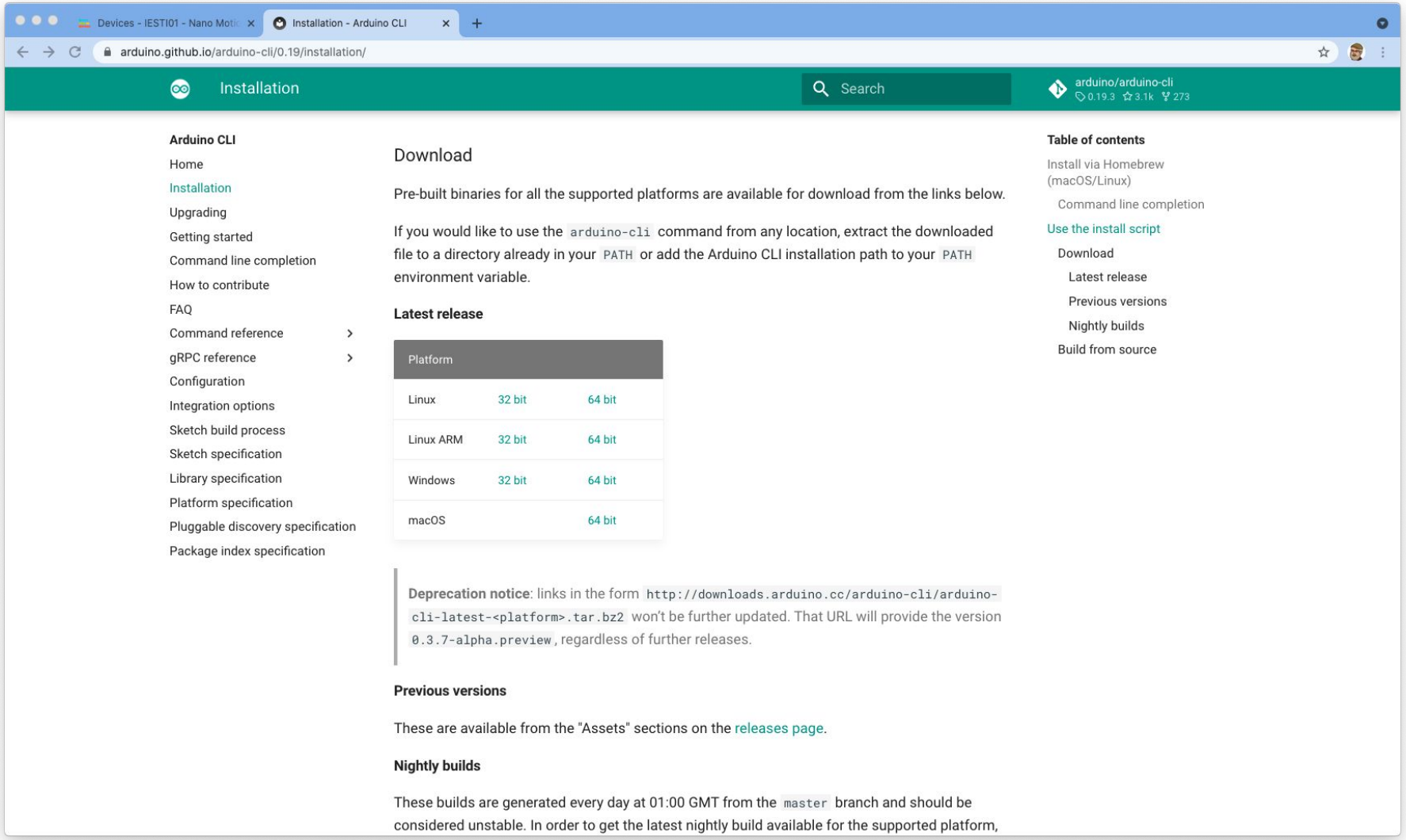
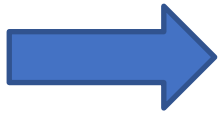
Arduino CLI

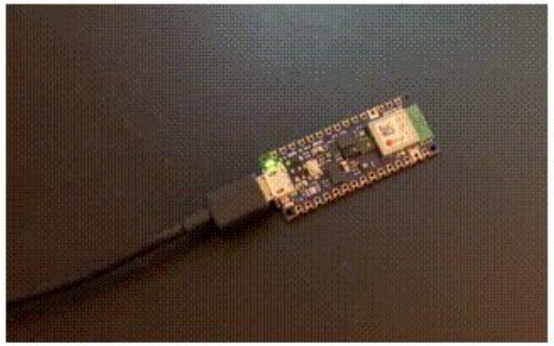


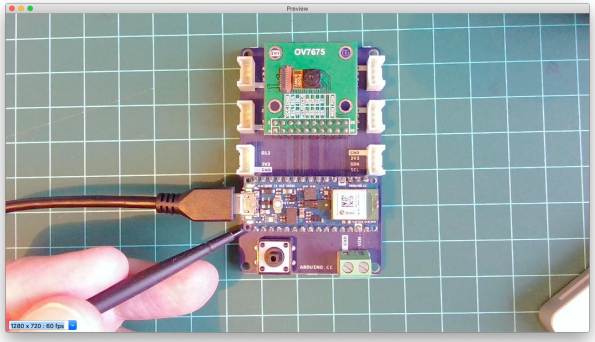


See this video for Windows installation: https://www.youtube.com/watch?v=1jMWsFER-Bc

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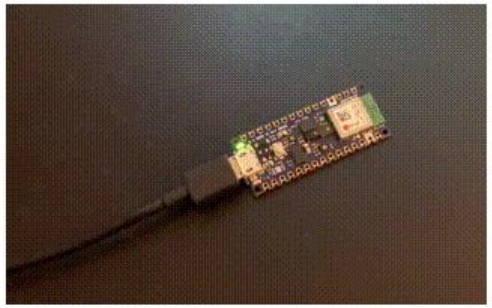
Use a micro-USB cable to connect the development board to your computer. Then press RESET twice to launch into the bootloader. The on-board LED should start pulsating to indicate this.



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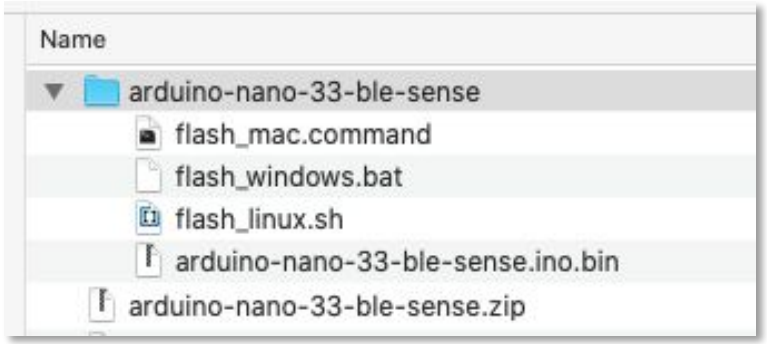


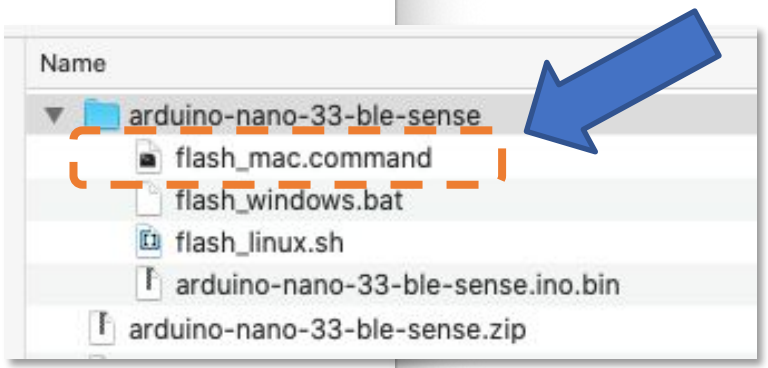
2

MacOS

```
mjrovai — flash_mac.command — 126×44
Last login: Tue Nov  9 12:15:56 on ttys002
You have new mail.
/Users/mjrovai/Downloads/arduino-nano-33-ble-sense\ \(2\)/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\ \(2\)/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 280848 bytes to flash (69 pages)
[==============================] 100% (69/69 pages)
Done in 10.984 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]
```

3.Nano-33 LED Stop Flashing

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

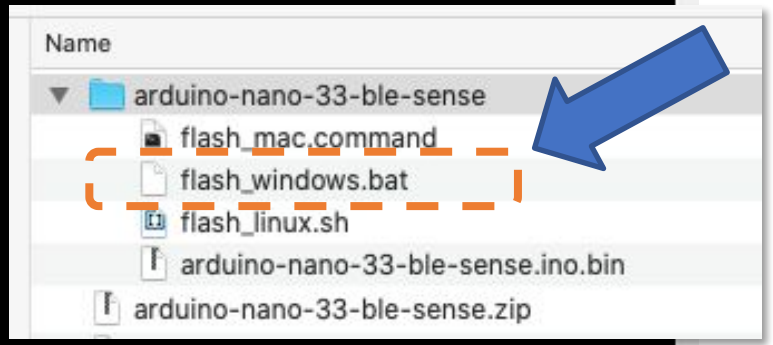


Windows 10

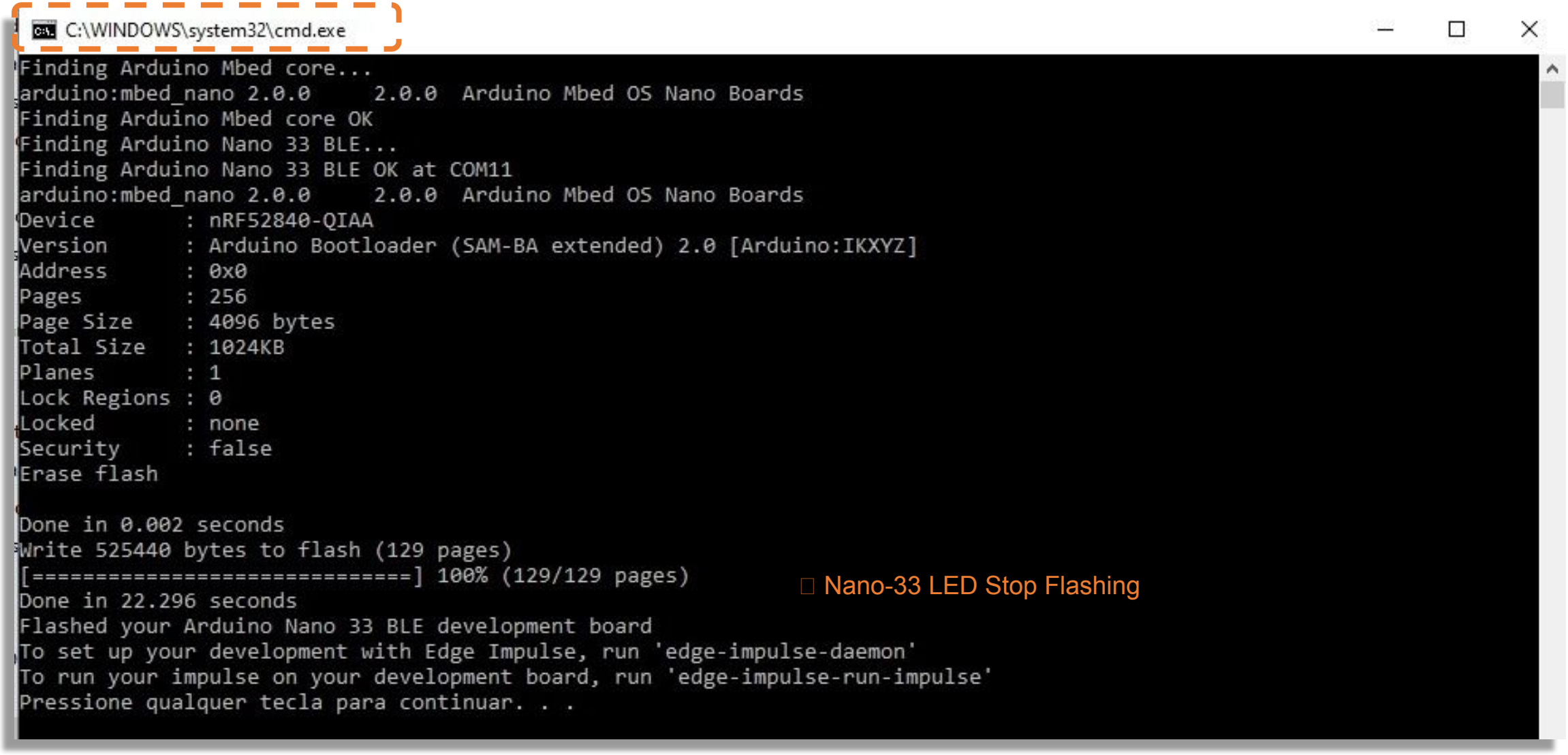
Prompt de Comando

```
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.
```

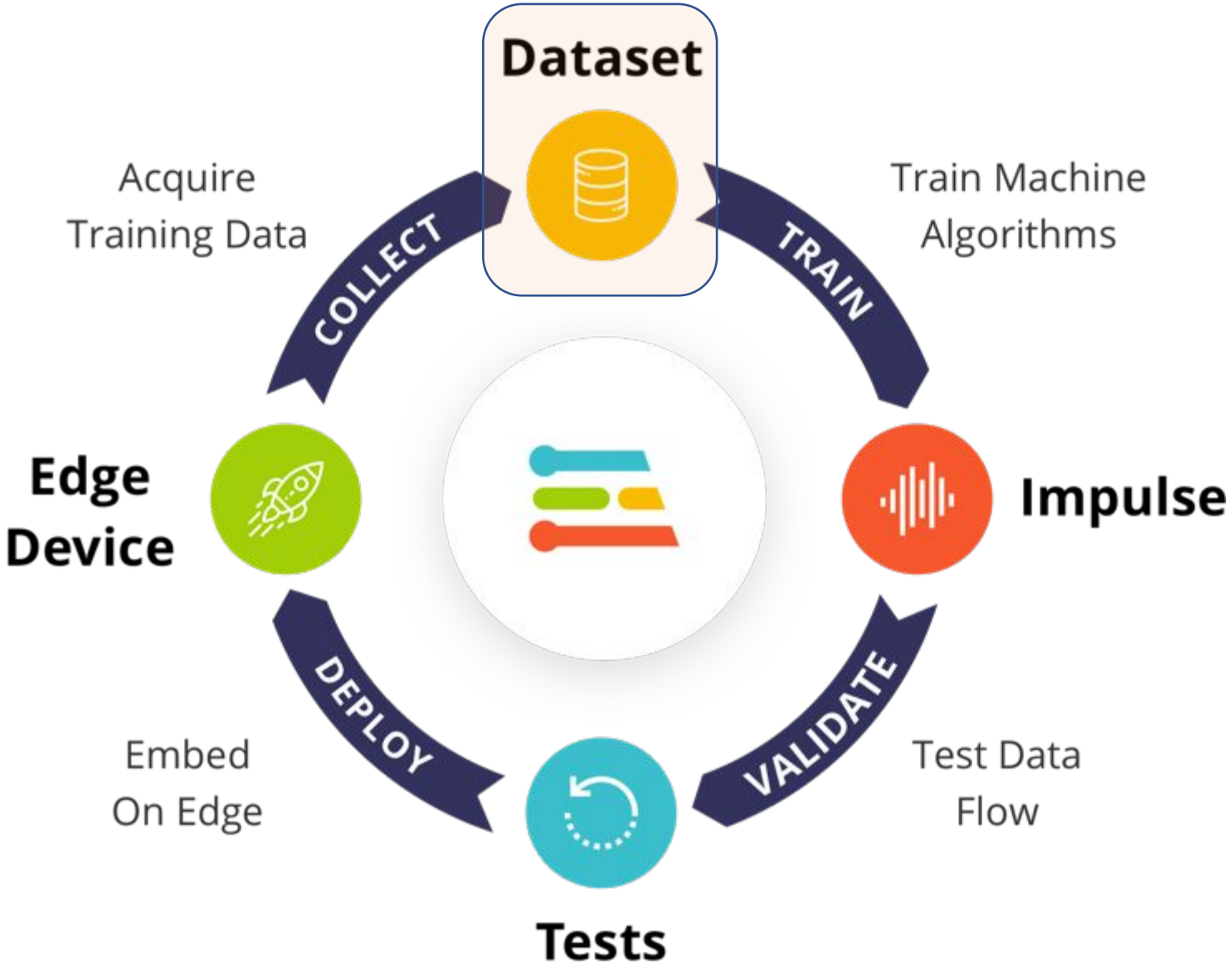
1. Press Nano-33 Reset button Twice
2. With Nano-33 LED Flashing:



Windows 10



 Nano-33 LED Stop Flashing



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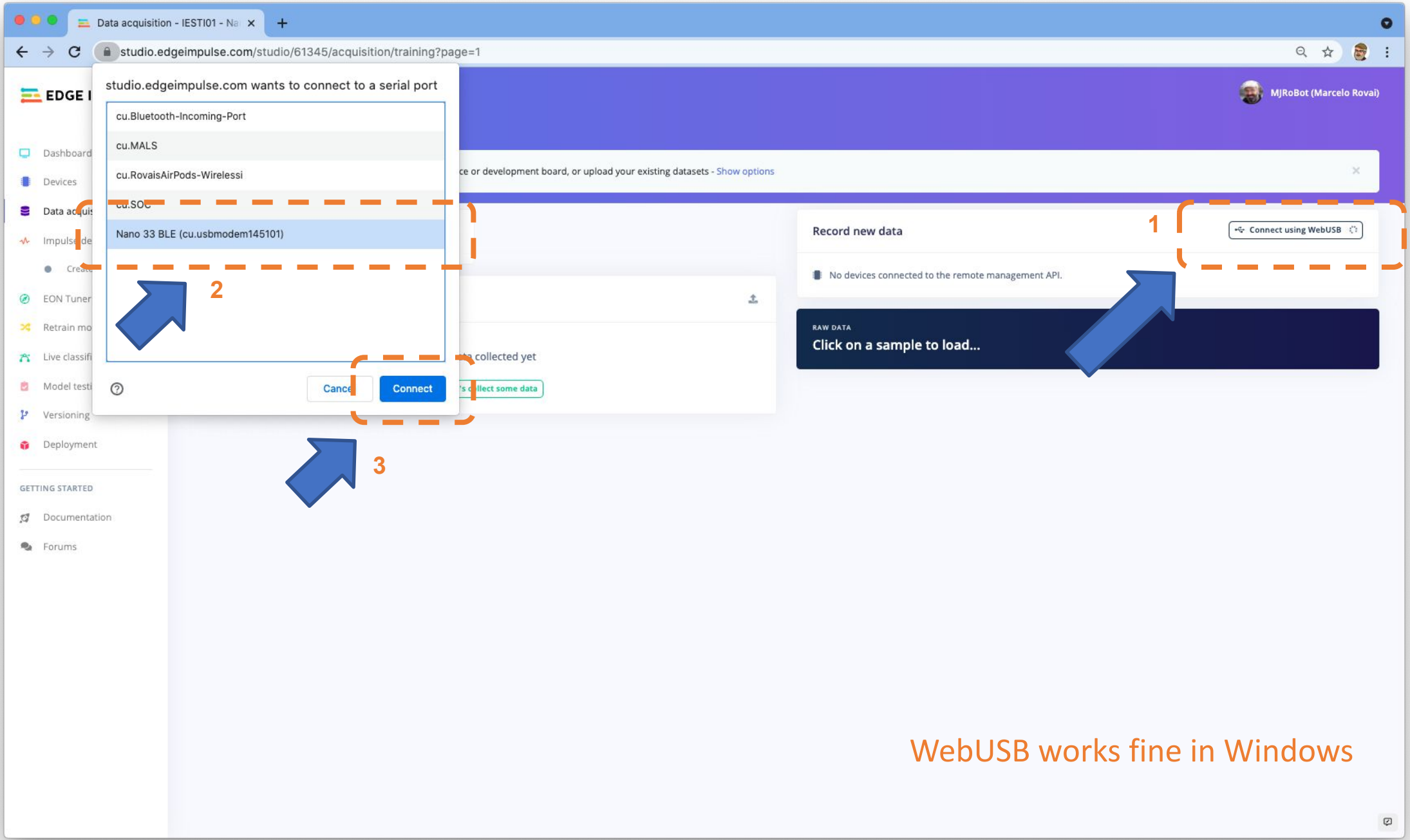
- Design a Model
- Train a Model


Data acquisition - IESTI01 - Na
studio.edgeimpulse.com/studio/61345/acquisition/training?page=1
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.usbmodem145101)
Cancel
Connect
1
2
3
MJRoBot (Marcelo Rovai)
Dashboard
Devices
Data acquis
Impulse de
EON Tuner
Retrain mo
Live classifi
Model testi
Versioning
Deployment
GETTING STARTED
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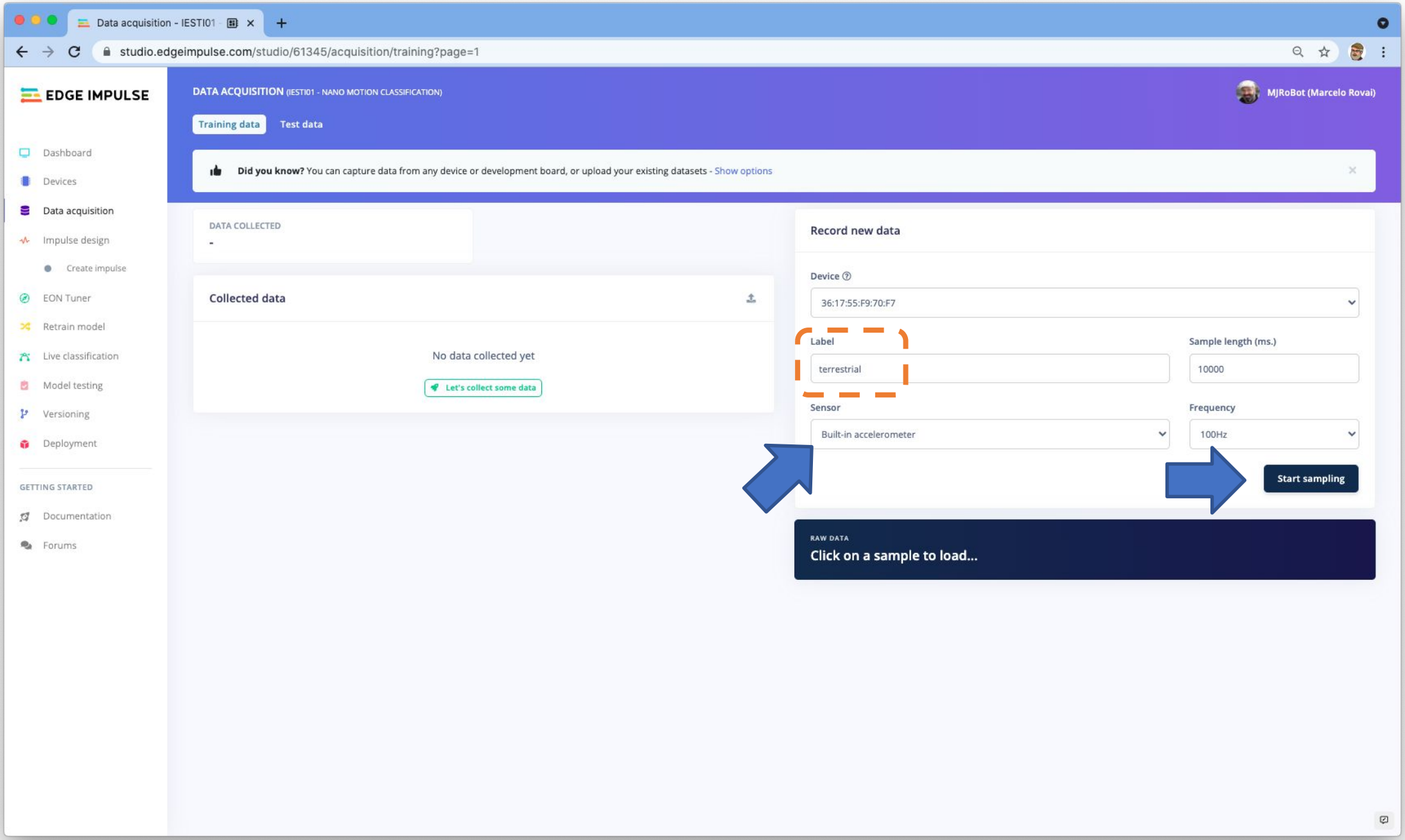
ce or development board, or upload your existing datasets - Show options
Record new data
Connect using WebUSB
No devices connected to the remote management API.
RAW DATA
Click on a sample to load...
collected yet
WebUSB works fine in Windows


Data acquisition - IESTI01
studio.edgeimpulse.com/studio/61345/acquisition/training?page=1
EDGE IMPULSE
DATA ACQUISITION (IESTI01 - NANO MOTION CLASSIFICATION)
MJRoBot (Marcelo Rovai)
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
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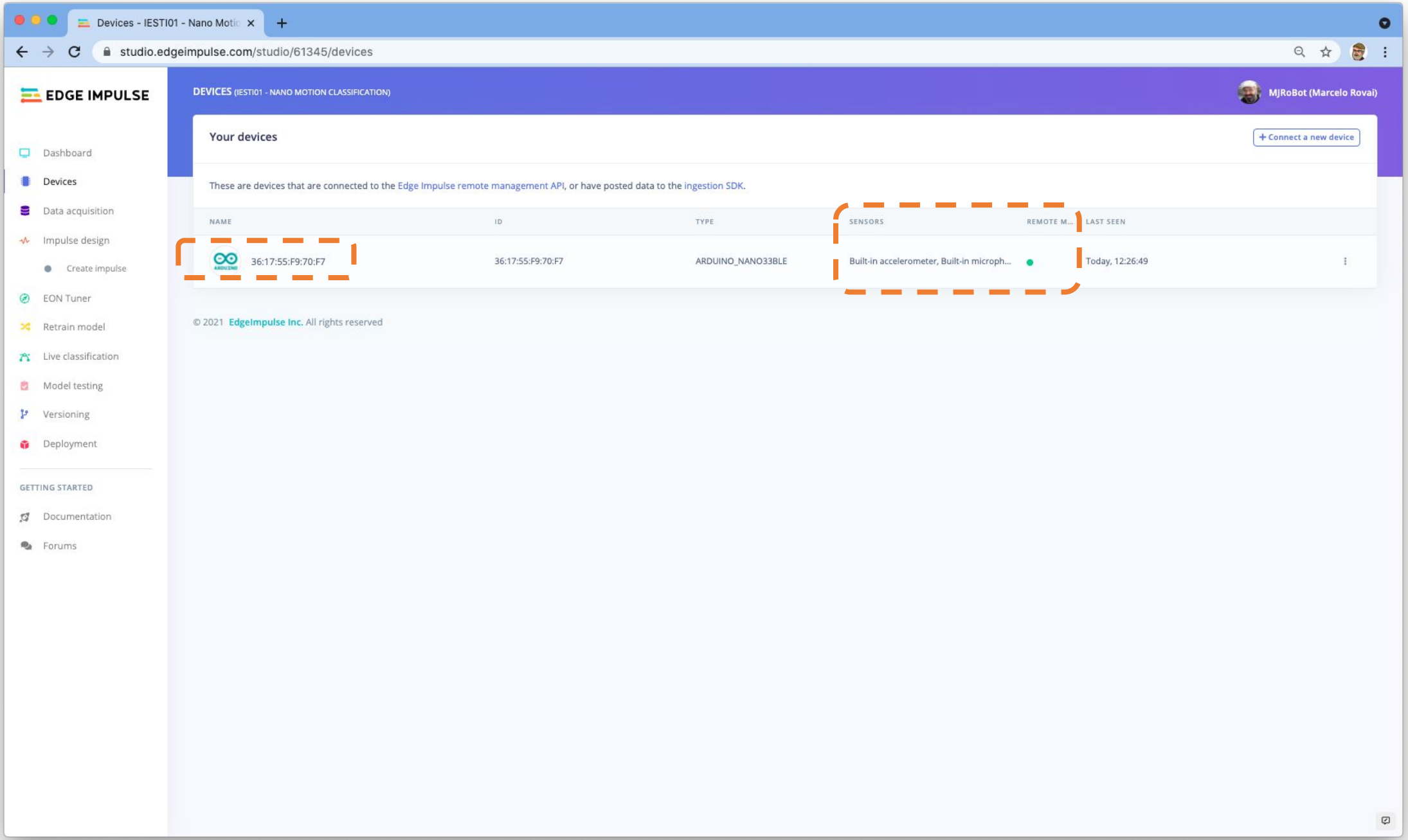
DATA COLLECTED
-
Collected data
No data collected yet
Let's collect some data
Record new data
Device
36:17:55:F9:70:F7
Label
terrestrial
Sample length (ms.)
10000
Sensor
Built-in accelerometer
Frequency
100Hz
Start sampling
RAW DATA
Click on a sample to load...


Devices - IESTI01 - Nano Motic
studio.edgeimpulse.com/studio/61345/devices
EDGE IMPULSE
DEVICES (IESTI01 - NANO MOTION CLASSIFICATION)
MJRoBot (Marcelo Rovai)
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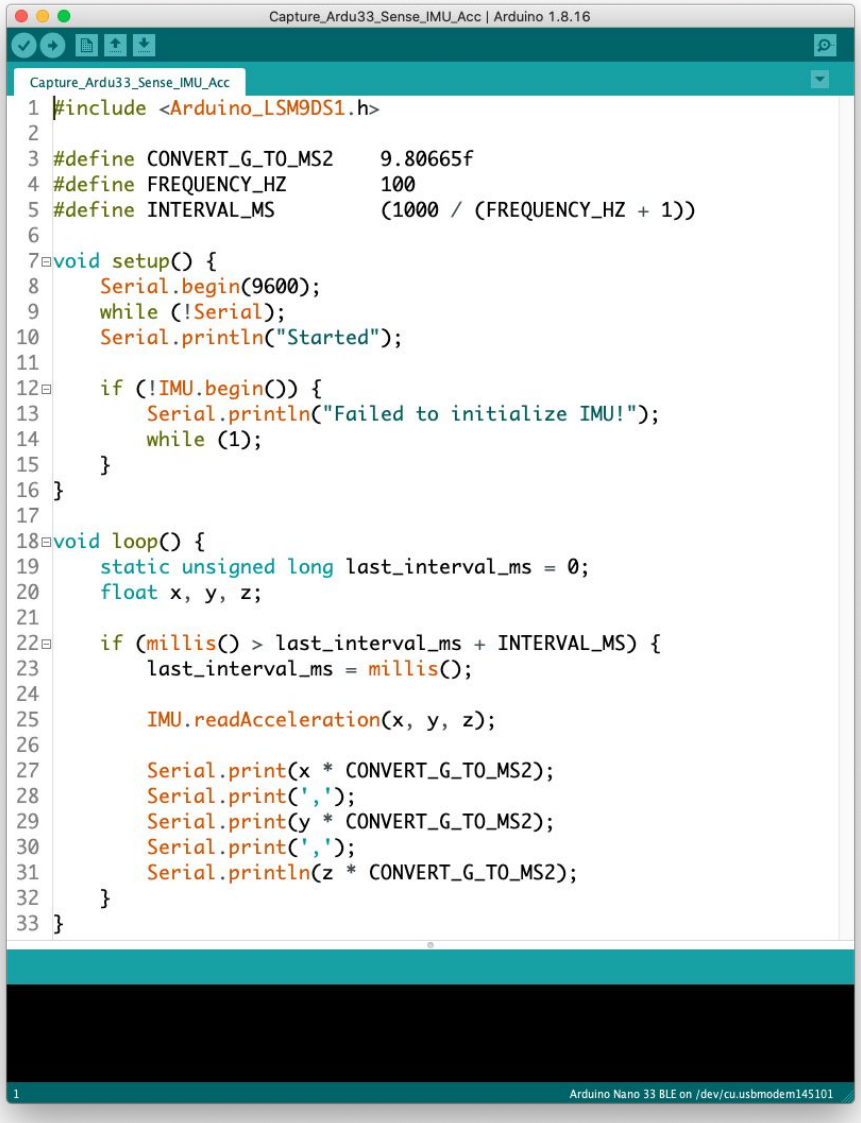
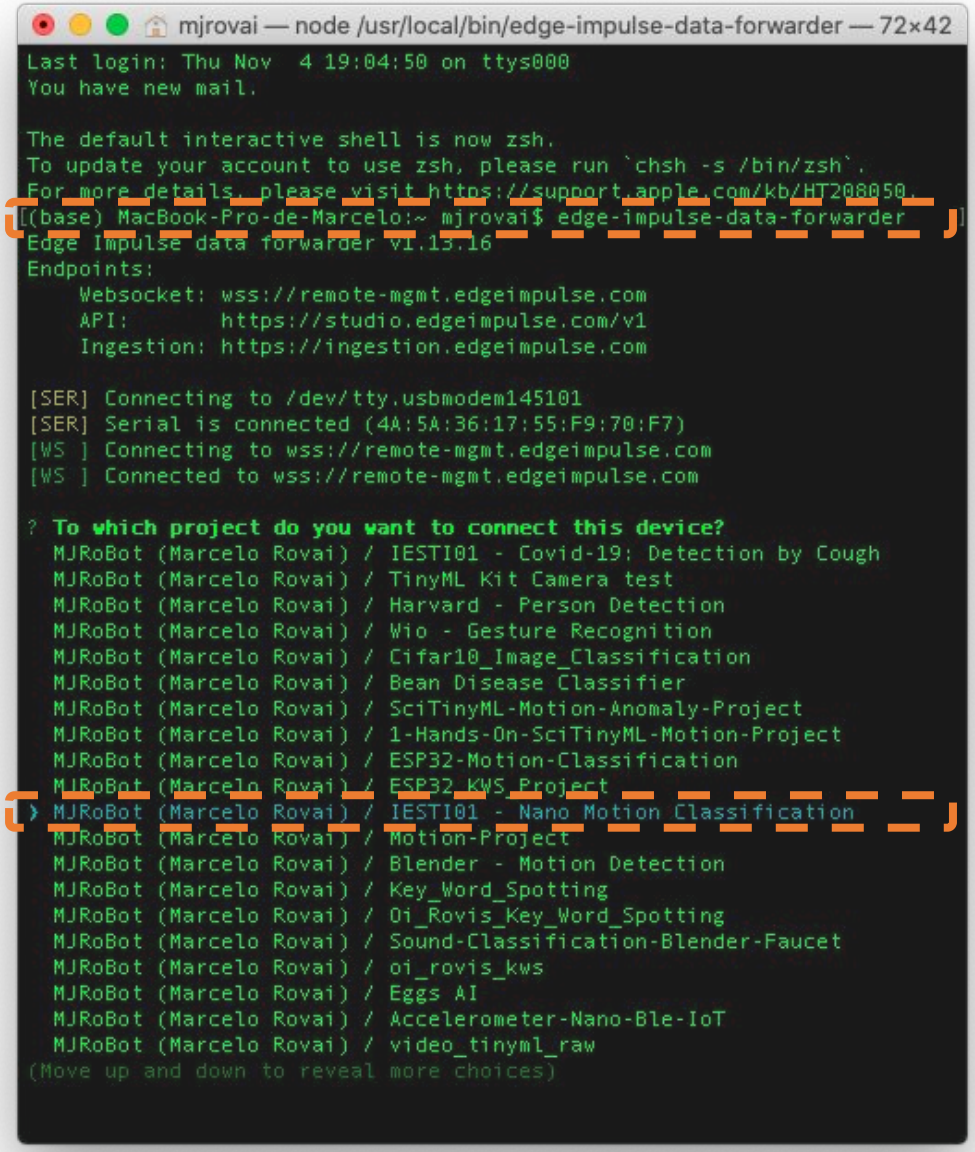
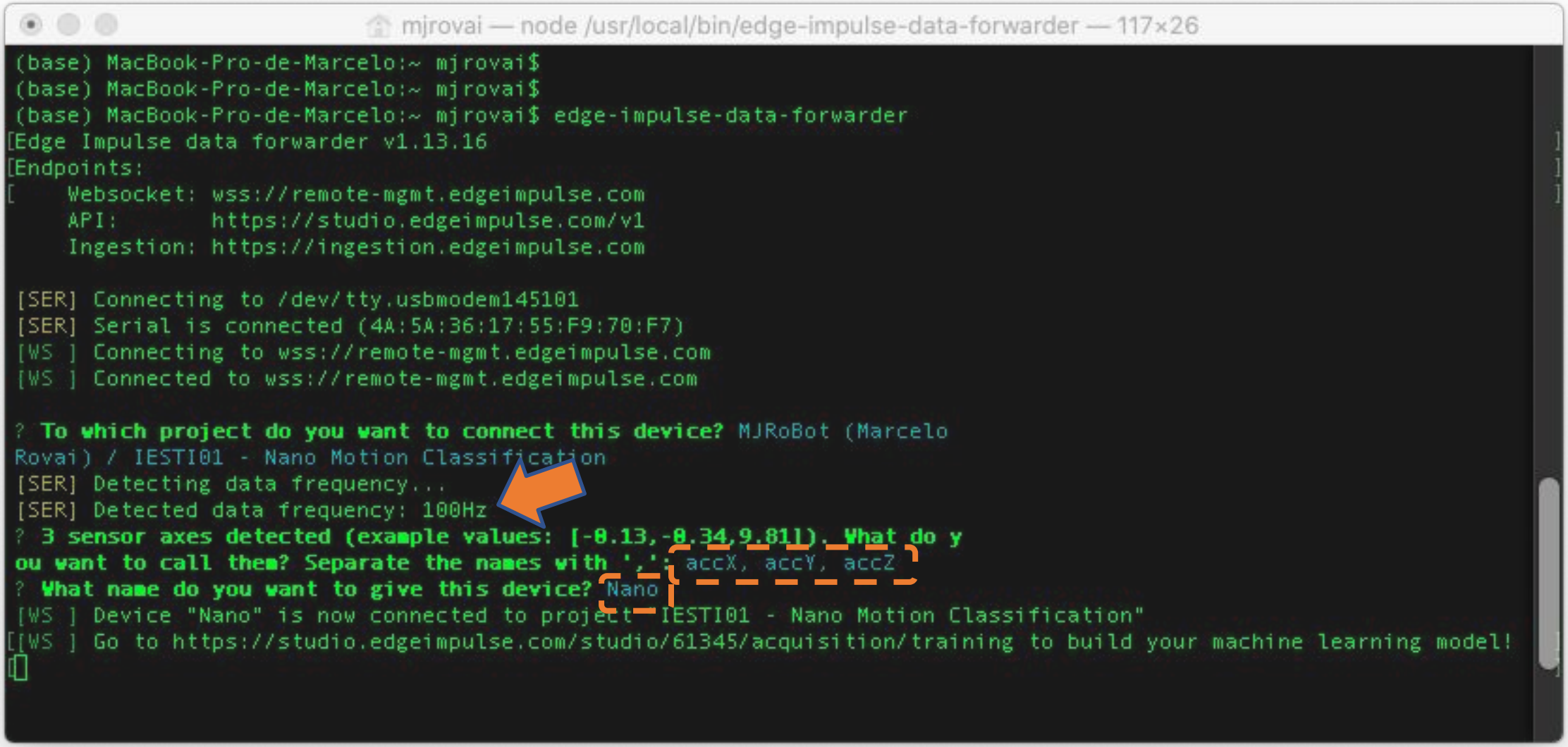
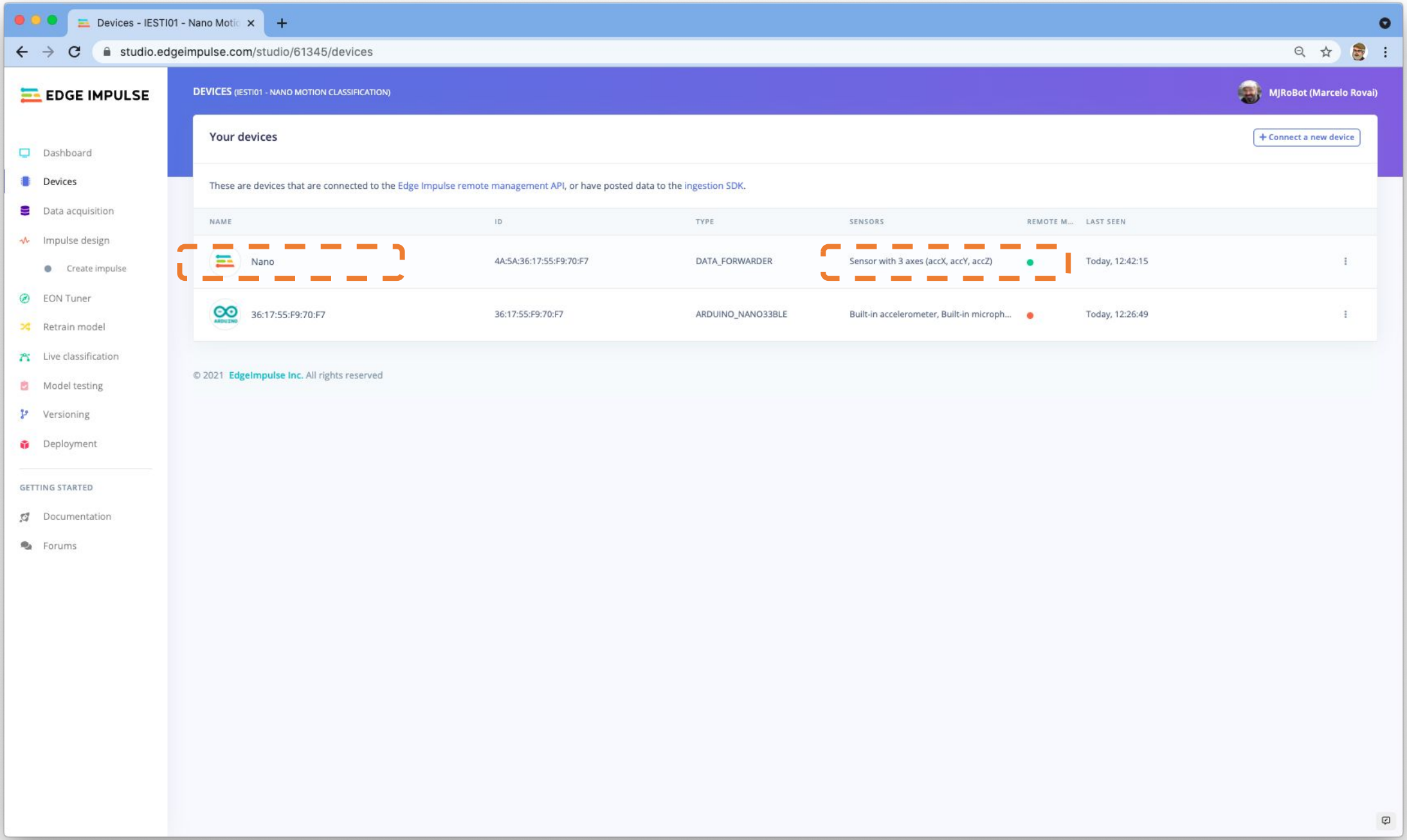
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
NAME
ID
TYPE
SENSORS
REMOTE M...
LAST SEEN
36:17:55:F9:70:F7
36:17:55:F9:70:F7
ARDUINO_NANO33BLE
Built-in accelerometer, Built-in microph...
Today, 12:26:49
© 2021 EdgeImpulse Inc. All rights reserved

Alternative Data Capture using EI CLI: $ edge-impulse-data-forwarder






mjrovai — node /usr/local/bin/edge-impulse-data-forwarder — 117×26
(base) MacBook-Pro-de-Marcelo:~ mjrovai$
(base) MacBook-Pro-de-Marcelo:~ mjrovai$
(base) MacBook-Pro-de-Marcelo:~ mjrovai$ edge-impulse-data-forwarder
[Edge Impulse data forwarder v1.13.16
[Endpoints:
[Websocket: wss://remote-mgmt.edgeimpulse.com
API: https://studio.edgeimpulse.com/v1
Ingestion: https://ingestion.edgeimpulse.com
[SER] Connecting to /dev/tty.usbmodem145101
[SER] Serial is connected (4A:5A:36:17:55:F9:70:F7)
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS] Connected to wss://remote-mgmt.edgeimpulse.com
? To which project do you want to connect this device? MJRoBot (Marcelo
Rovai) / IESTI01 - Nano Motion Classification
[SER] Detecting data frequency...
[SER] Detected data frequency: 100Hz
? 3 sensor axes detected (example values: [-0.13,-0.34,9.81]). What do y
ou want to call them? Separate the names with ',': accX, accY, accZ
? What name do you want to give this device? Nano
[WS] Device "Nano" is now connected to project "IESTI01 - Nano Motion Classification"
[[WS] Go to https://studio.edgeimpulse.com/studio/61345/acquisition/training to build your machine learning model!


Devices - IESTI01 - Nano Motic
studio.edgeimpulse.com/studio/61345/devices
EDGE IMPULSE
DEVICES (IESTI01 - NANO MOTION CLASSIFICATION)
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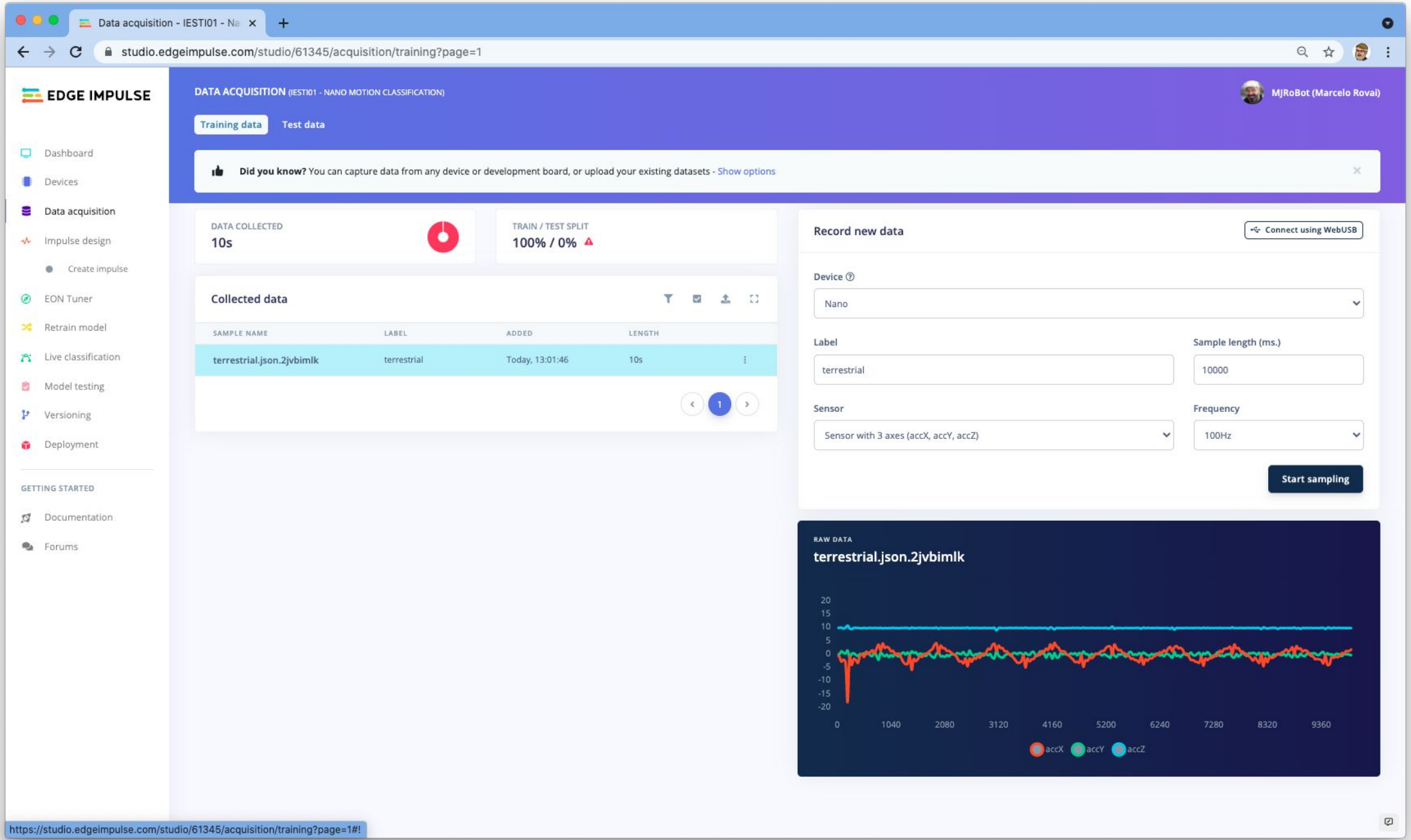
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
NAME
ID
TYPE
SENSORS
REMOTE M...
LAST SEEN
Nano
4A:5A:36:17:55:F9:70:F7
DATA_FORWARDER
Sensor with 3 axes (accX, accY, accZ)
Today, 12:42:15
36:17:55:F9:70:F7
36:17:55:F9:70:F7
ARDUINO_NANO33BLE
Built-in accelerometer, Built-in microph...
Today, 12:26:49
© 2021 EdgeImpulse Inc. All rights reserved


Data acquisition - IESTI01 - Na
studio.edgeimpulse.com/studio/61345/acquisition/training?page=1
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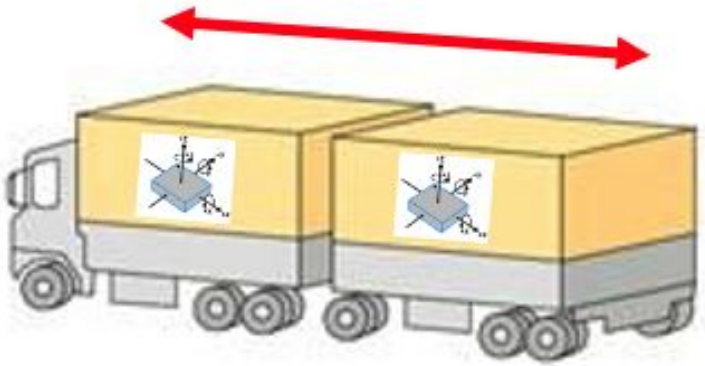
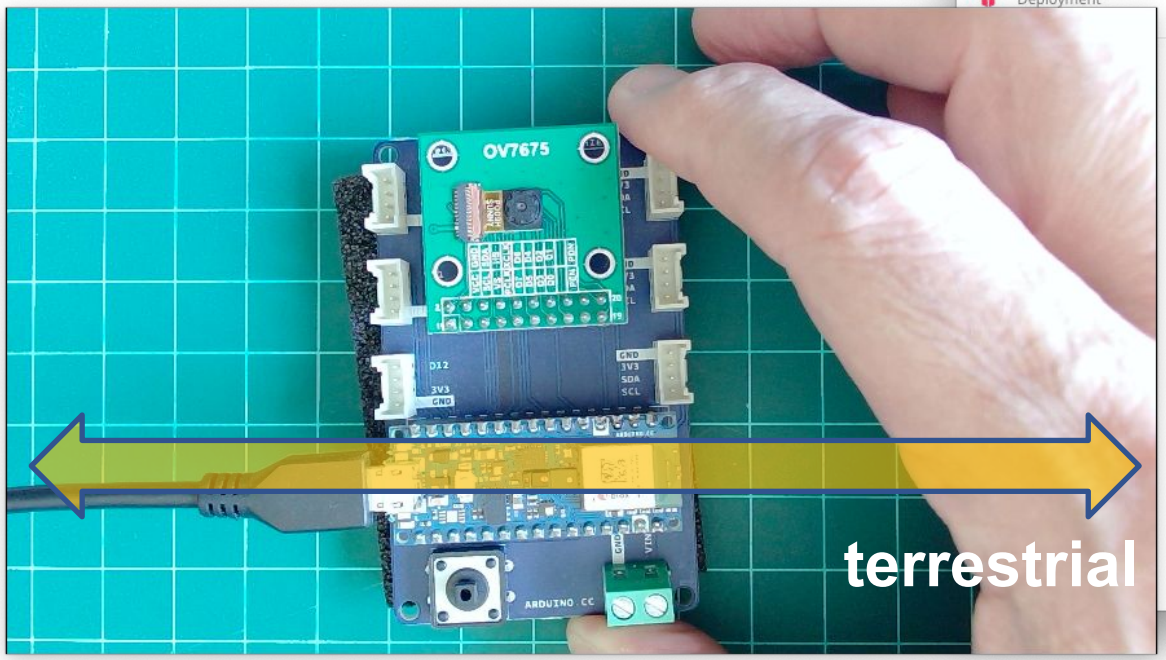
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
DATA COLLECTED
10s
TRAIN / TEST SPLIT
100% / 0%
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
terrestrial.json.2jvbimlk
terrestrial
Today, 13:01:46
10s
Record new data
Connect using WebUSB
Device
Nano
Label
terrestrial
Sample length (ms.)
10000
Sensor
Sensor with 3 axes (accX, accY, accZ)
Frequency
100Hz
Start sampling
RAW DATA
terrestrial.json.2jvbimlk
20
15
10
5
0
-5
-10
-15
-20
0
1040
2080
3120
4160
5200
6240
7280
8320
9360
accX
accY
accZ
https://studio.edgeimpulse.com/studio/61345/acquisition/training?page=1#!

Label: terrestrial





Data acquisition - IESTI01 - Na

studio.edgeimpulse.com/studio/61345/acquisition/training?page=1

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- Devices
- Data acquisition
- Impulse design
- Create impulse
- EON Tuner
- Retrain model
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DATA ACQUISITION (IESTI01 - NANO MOTION CLASSIFICATION)

MJRoBot (Marcelo Rovai)

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 COLLECTED
1m 40s

TRAIN / TEST SPLIT
100% / 0%

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
terrestrial.json.2jv...	terrestrial	Today, 14:26:56	10s
terrestrial.json.2jv...	terrestrial	Today, 14:26:29	10s
terrestrial.json.2jv...	terrestrial	Today, 14:26:06	10s
terrestrial.json.2jv...	terrestrial	Today, 14:25:48	10s
terrestrial.json.2jv...	terrestrial	Today, 14:25:29	10s
terrestrial.json.2jv...	terrestrial	Today, 14:25:04	10s
terrestrial.json.2jv...	terrestrial	Today, 14:24:45	10s
terrestrial.json.2jv...	terrestrial	Today, 14:24:21	10s
terrestrial.json.2jvf...	terrestrial	Today, 14:17:45	10s
terrestrial.json.2jv...	terrestrial	Today, 13:01:46	10s

1

Record new data — Connect using WebUSB

Device: Nano

Label: terrestrial

Sample length (ms.): 10000

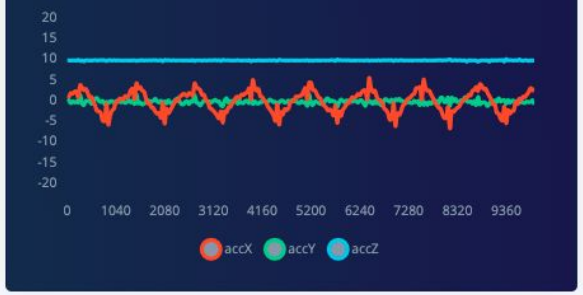
Sensor: Sensor with 3 axes (accX, accY, accZ)

Frequency: 100Hz

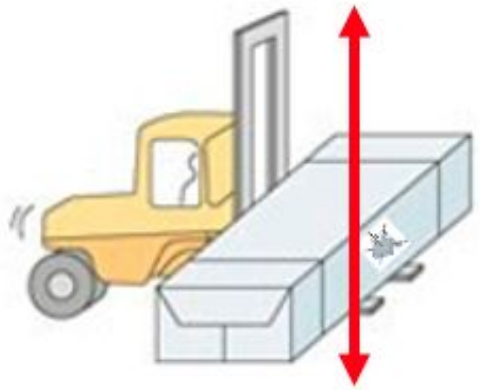
Start sampling

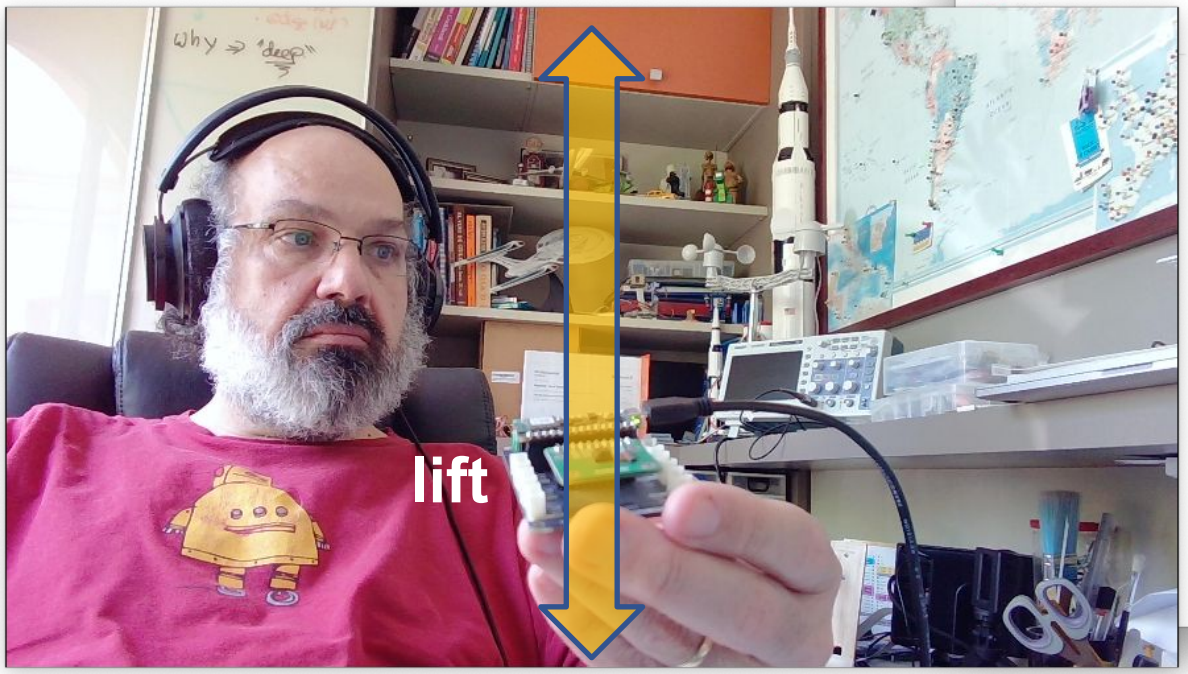
RAW DATA

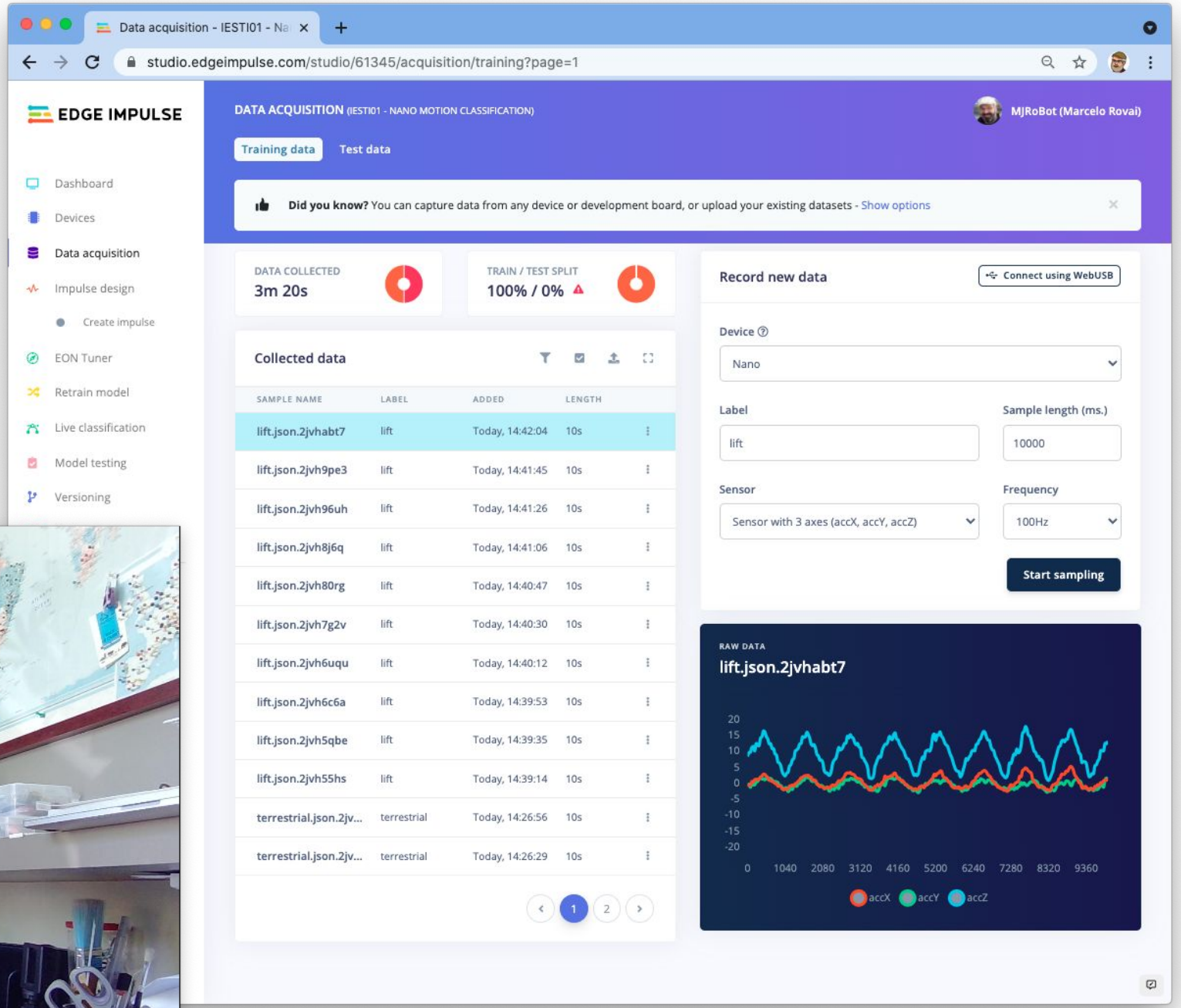
terrestrial.json.2jvgelce



Label: LIFT




lift


Data acquisition - IESTI01 - Na
studio.edgeimpulse.com/studio/61345/acquisition/training?page=1
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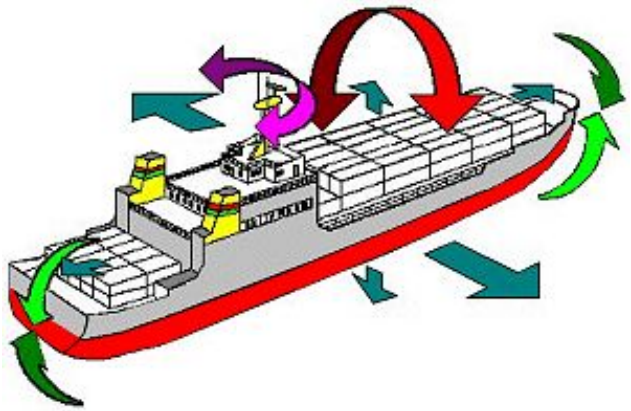
MJRoBot (Marcelo Rovai)
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
DATA COLLECTED
3m 20s
TRAIN / TEST SPLIT
100% / 0%
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
lift.json.2jvhabt7 lift Today, 14:42:04 10s
lift.json.2jvh9pe3 lift Today, 14:41:45 10s
lift.json.2jvh96uh lift Today, 14:41:26 10s
lift.json.2jvh8j6q lift Today, 14:41:06 10s
lift.json.2jvh80rg lift Today, 14:40:47 10s
lift.json.2jvh7g2v lift Today, 14:40:30 10s
lift.json.2jvh6uqu lift Today, 14:40:12 10s
lift.json.2jvh6c6a lift Today, 14:39:53 10s
lift.json.2jvh5qbe lift Today, 14:39:35 10s
lift.json.2jvh55hs lift Today, 14:39:14 10s
terrestrial.json.2jv... terrestrial Today, 14:26:56 10s
terrestrial.json.2jv... terrestrial Today, 14:26:29 10s
Record new data
Connect using WebUSB
Device
Nano
Label
lift
Sample length (ms.)
10000
Sensor
Sensor with 3 axes (accX, accY, accZ)
Frequency
100Hz
Start sampling
RAW DATA
lift.json.2jvhabt7
accX
accY
accZ

Label: maritime



Data acquisition - IESTI01 - Na

studio.edgeimpulse.com/studio/61345/acquisition/training?page=1

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DATA ACQUISITION (IESTI01 - NANO MOTION CLASSIFICATION)

MJRoBot (Marcelo Rovai)

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 COLLECTED
5m 0s

TRAIN / TEST SPLIT
100% / 0%

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
maritime.json.2jvi6...	maritime	Today, 14:57:35	10s
maritime.json.2jvi6...	maritime	Today, 14:57:13	10s
maritime.json.2jvi5...	maritime	Today, 14:56:48	10s
maritime.json.2jvi4...	maritime	Today, 14:56:31	10s
maritime.json.2jvi4...	maritime	Today, 14:56:13	10s
maritime.json.2jvi3...	maritime	Today, 14:55:55	10s
maritime.json.2jvi3...	maritime	Today, 14:55:36	10s
maritime.json.2jvi2...	maritime	Today, 14:55:19	10s
maritime.json.2jvi2...	maritime	Today, 14:55:00	10s
maritime.json.2jvi1...	maritime	Today, 14:54:42	10s
lift.json.2jvhabt7	lift	Today, 14:42:04	10s
lift.json.2jvh9pe3	lift	Today, 14:41:45	10s

1 2 3

Record new data

Connect using WebUSB

Device
Nano

Label
maritime

Sample length (ms.)
10000

Sensor
Sensor with 3 axes (accX, accY, accZ)

Frequency
100Hz

Start sampling

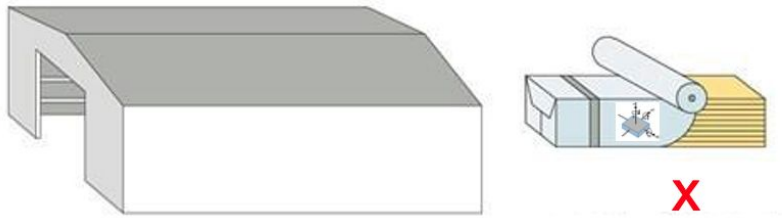
RAW DATA
maritime.json.2jvi6p3r

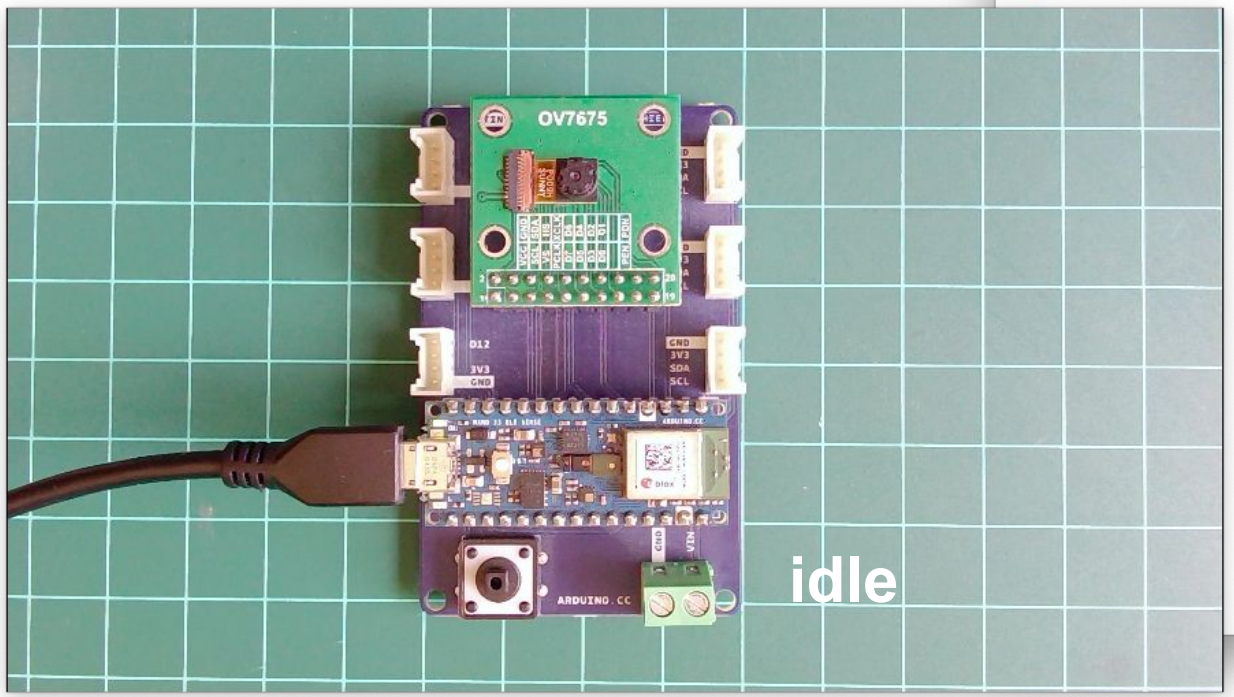
25 20 15 10 5 0 -5 -10 -15 -20

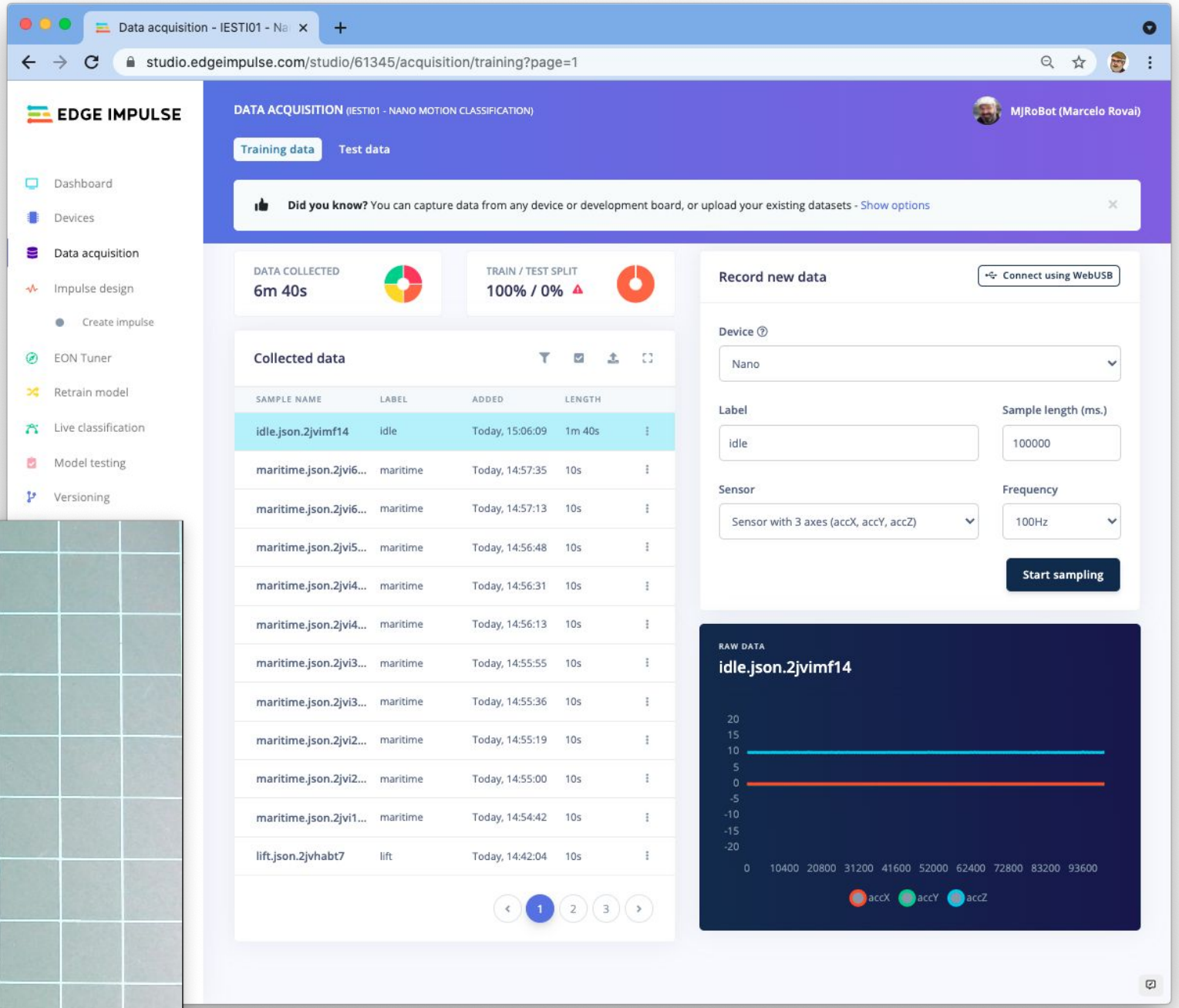
0 1040 2080 3120 4160 5200 6240 7280 8320 9360

accX accY accZ

Label: idle


X


OV7675
idle


Data acquisition - IESTI01 - Na
studio.edgeimpulse.com/studio/61345/acquisition/training?page=1
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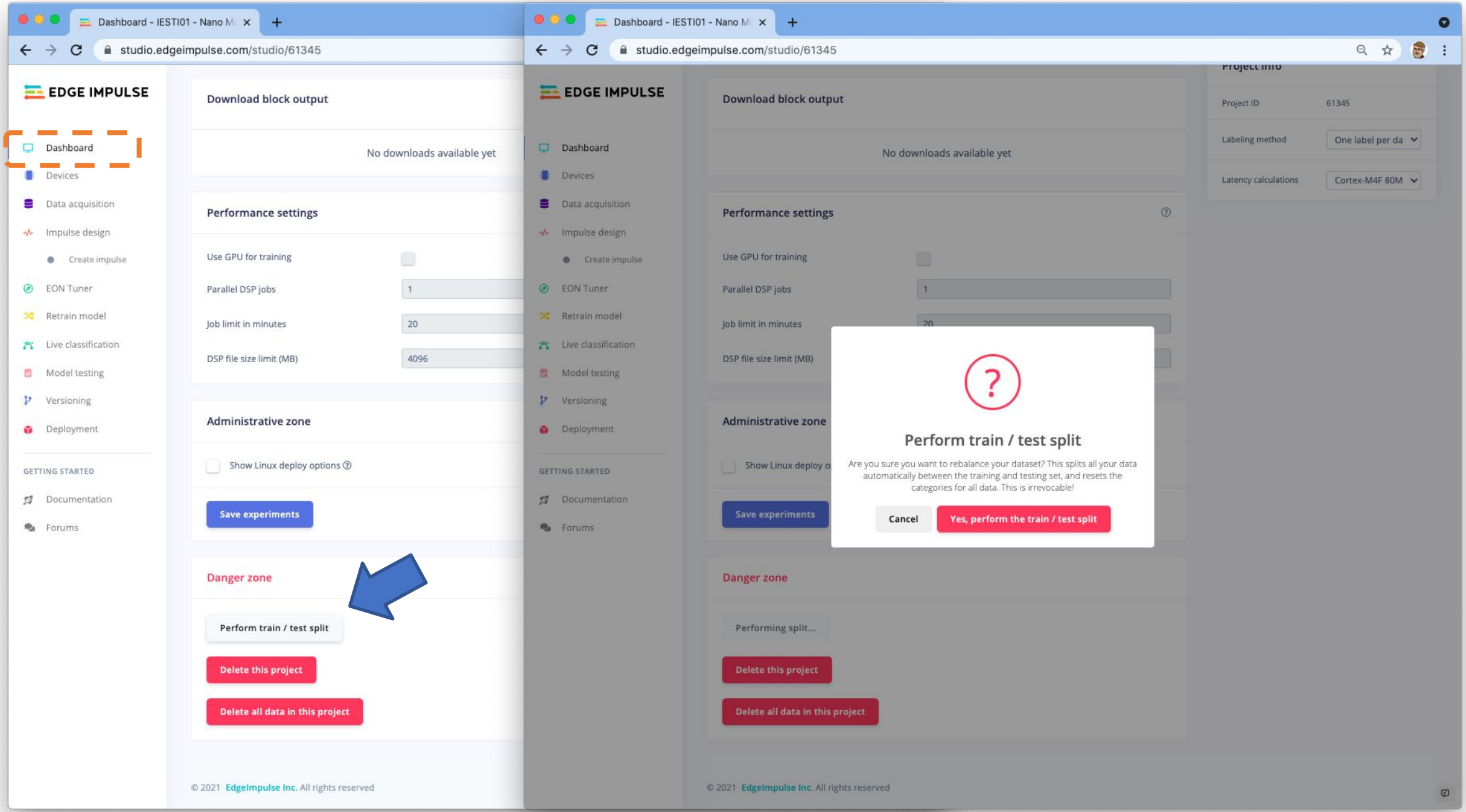
Versioning
DATA ACQUISITION (IESTI01 - NANO MOTION CLASSIFICATION)
MJRoBot (Marcelo Rovai)
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
DATA COLLECTED
6m 40s
TRAIN / TEST SPLIT
100% / 0%
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
idle.json.2jvimf14 idle Today, 15:06:09 1m 40s
maritime.json.2jvi6... maritime Today, 14:57:35 10s
maritime.json.2jvi6... maritime Today, 14:57:13 10s
maritime.json.2jvi5... maritime Today, 14:56:48 10s
maritime.json.2jvi4... maritime Today, 14:56:31 10s
maritime.json.2jvi4... maritime Today, 14:56:13 10s
maritime.json.2jvi3... maritime Today, 14:55:55 10s
maritime.json.2jvi3... maritime Today, 14:55:36 10s
maritime.json.2jvi2... maritime Today, 14:55:19 10s
maritime.json.2jvi2... maritime Today, 14:55:00 10s
maritime.json.2jvi1... maritime Today, 14:54:42 10s
lift.json.2jvhabt7 lift Today, 14:42:04 10s
Record new data
Connect using WebUSB
Device
Nano
Label
idle
Sample length (ms.)
100000
Sensor
Sensor with 3 axes (accX, accY, accZ)
Frequency
100Hz
Start sampling
RAW DATA
idle.json.2jvimf14
20
15
10
5
0
-5
-10
-15
-20
0
10400
20800
31200
41600
52000
62400
72800
83200
93600
accX
accY
accZ


Dashboard - IESTI01 - Nano M
studio.edgeimpulse.com/studio/61345
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Deployment
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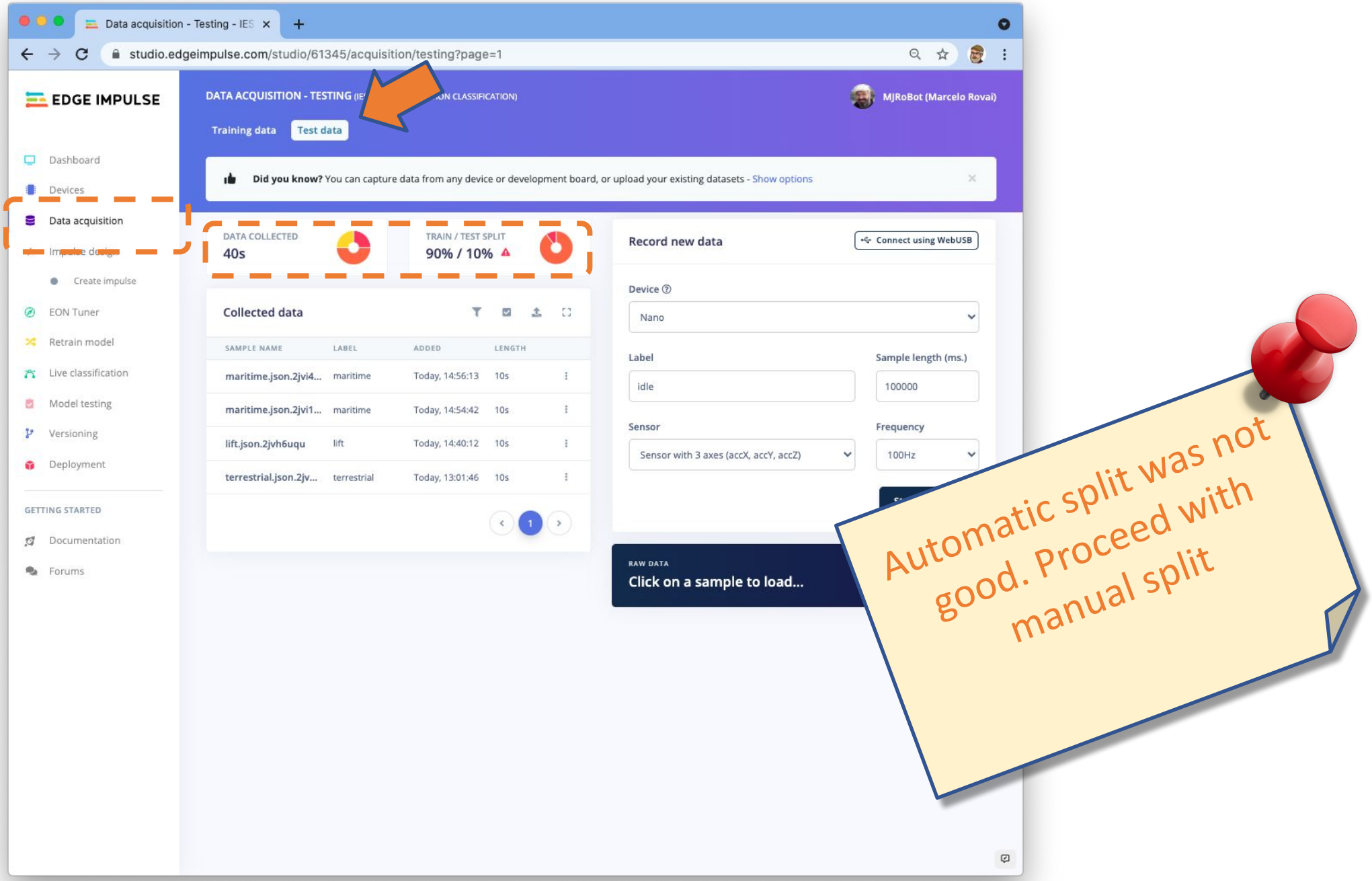
Download block output
No downloads available yet
Performance settings
Use GPU for training
Parallel DSP jobs
1
Job limit in minutes
20
DSP file size limit (MB)
4096
Administrative zone
Show Linux deploy options
Save experiments
Danger zone
Perform train / test split
Delete this project
Delete all data in this project
© 2021 EdgeImpulse Inc. All rights reserved
Project info
Project ID
61345
Labeling method
One label per da
Latency calculations
Cortex-M4F 80M
Perform train / test split
Are you sure you want to rebalance your dataset? This splits all your data automatically between the training and testing set, and resets the categories for all data. This is irrevocable!
Cancel
Yes, perform the train / test split
Performing split...


Data acquisition - Testing - IES
studio.edgeimpulse.com/studio/61345/acquisition/testing?page=1
EDGE IMPULSE
DATA ACQUISITION - TESTING
MJRoBot (Marcelo Rovai)
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Test data
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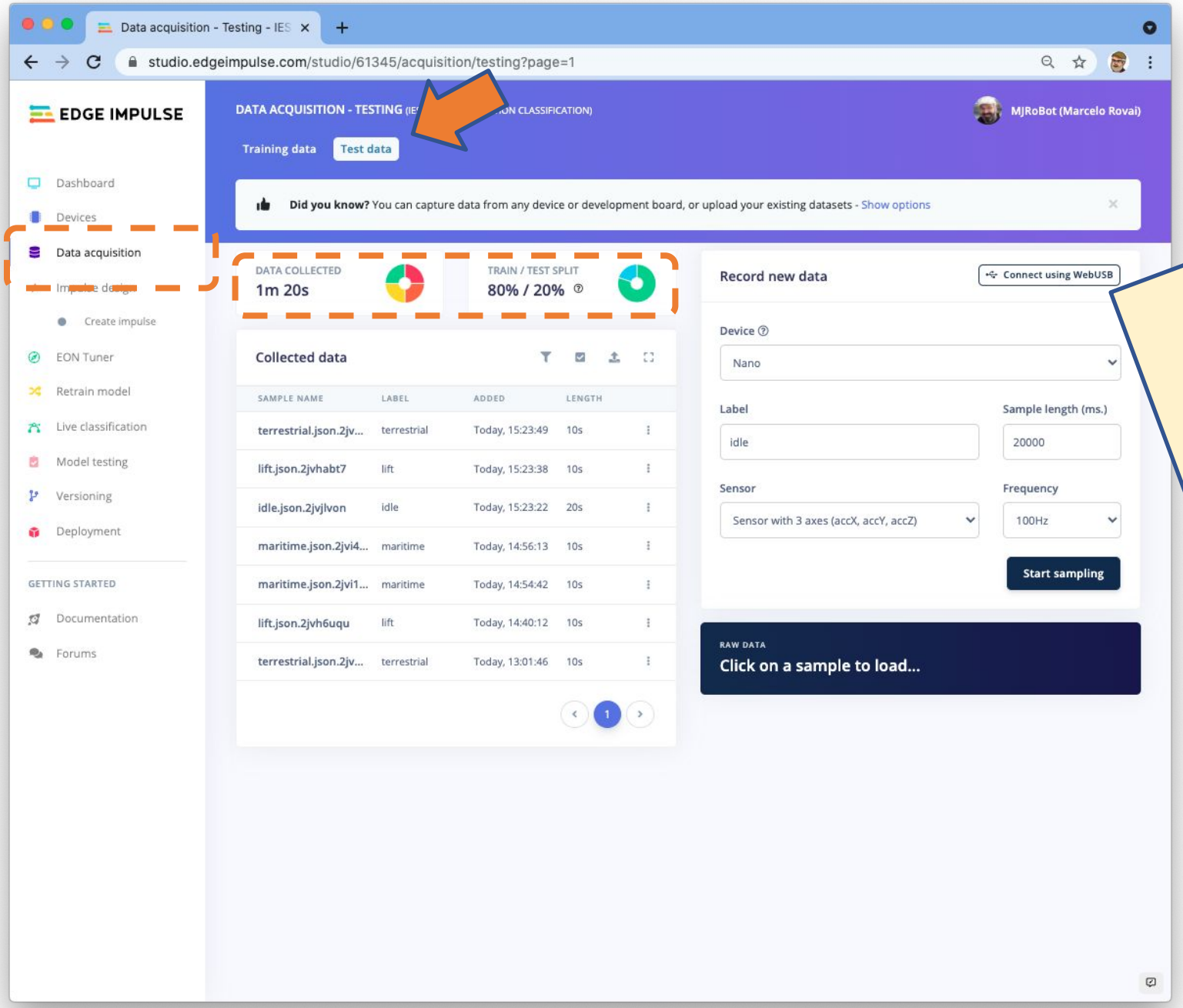
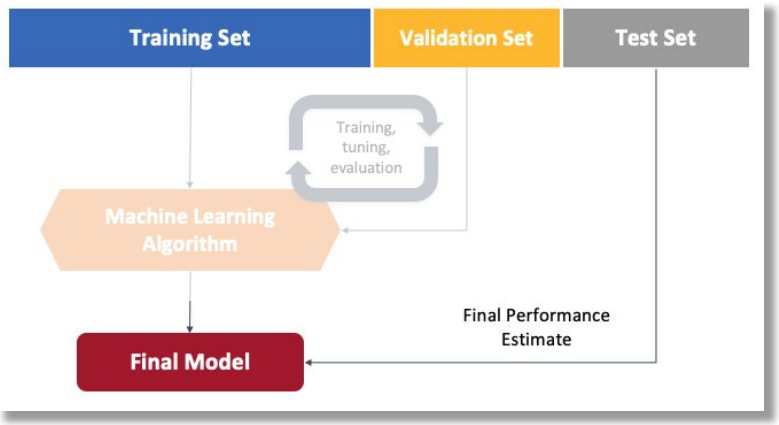
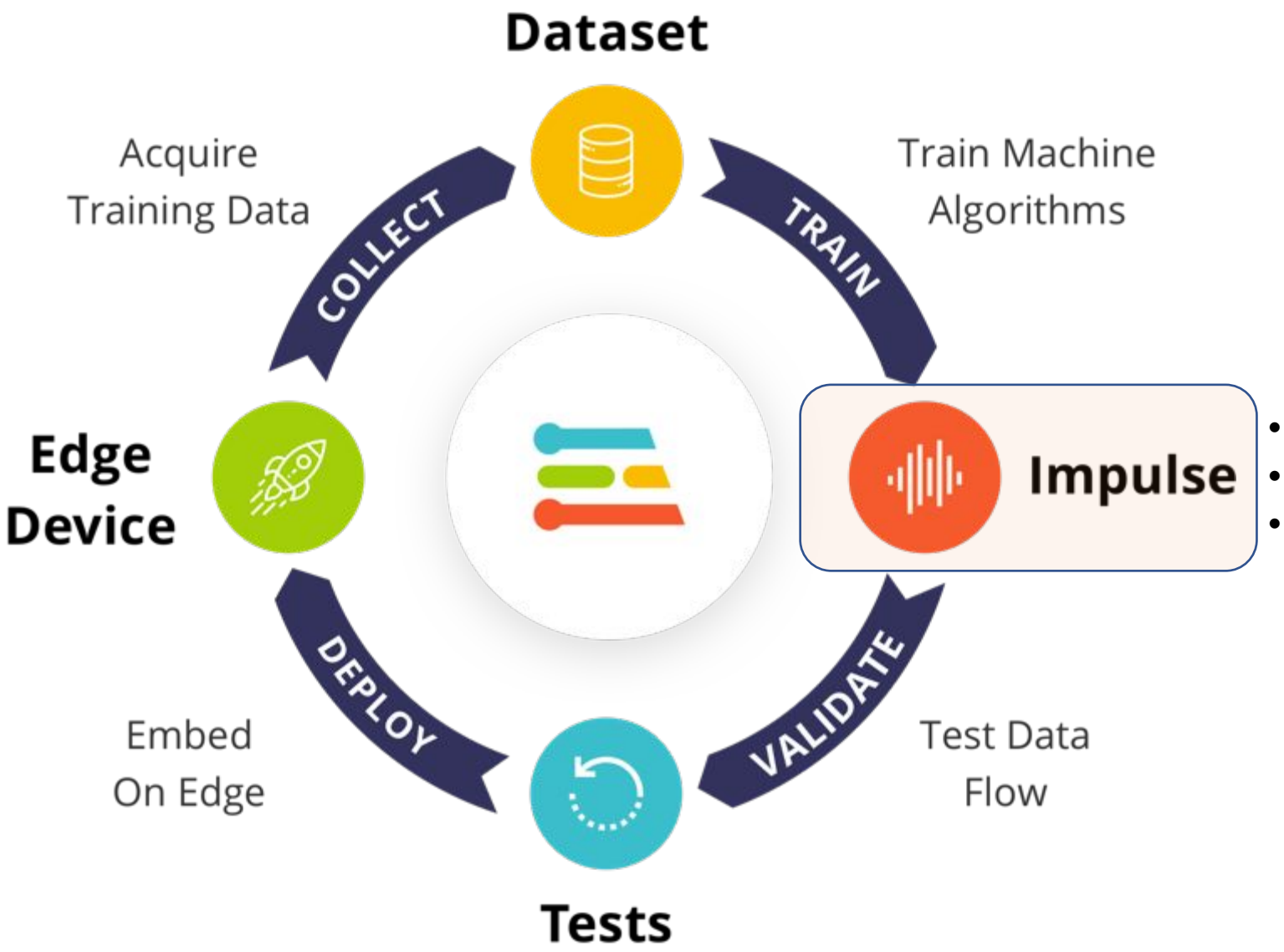
DATA COLLECTED
40s
TRAIN / TEST SPLIT
90% / 10%
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
maritime.json.2jvi4...
maritime
Today, 14:56:13
10s
maritime.json.2jvi1...
maritime
Today, 14:54:42
10s
lift.json.2jvh6uqu
lift
Today, 14:40:12
10s
terrestrial.json.2jv...
terrestrial
Today, 13:01:46
10s
Record new data
Connect using WebUSB
Device
Nano
Label
idle
Sample length (ms.)
100000
Sensor
Sensor with 3 axes (accX, accY, accZ)
Frequency
100Hz
RAW DATA
Click on a sample to load...
Automatic split was not good. Proceed with manual split

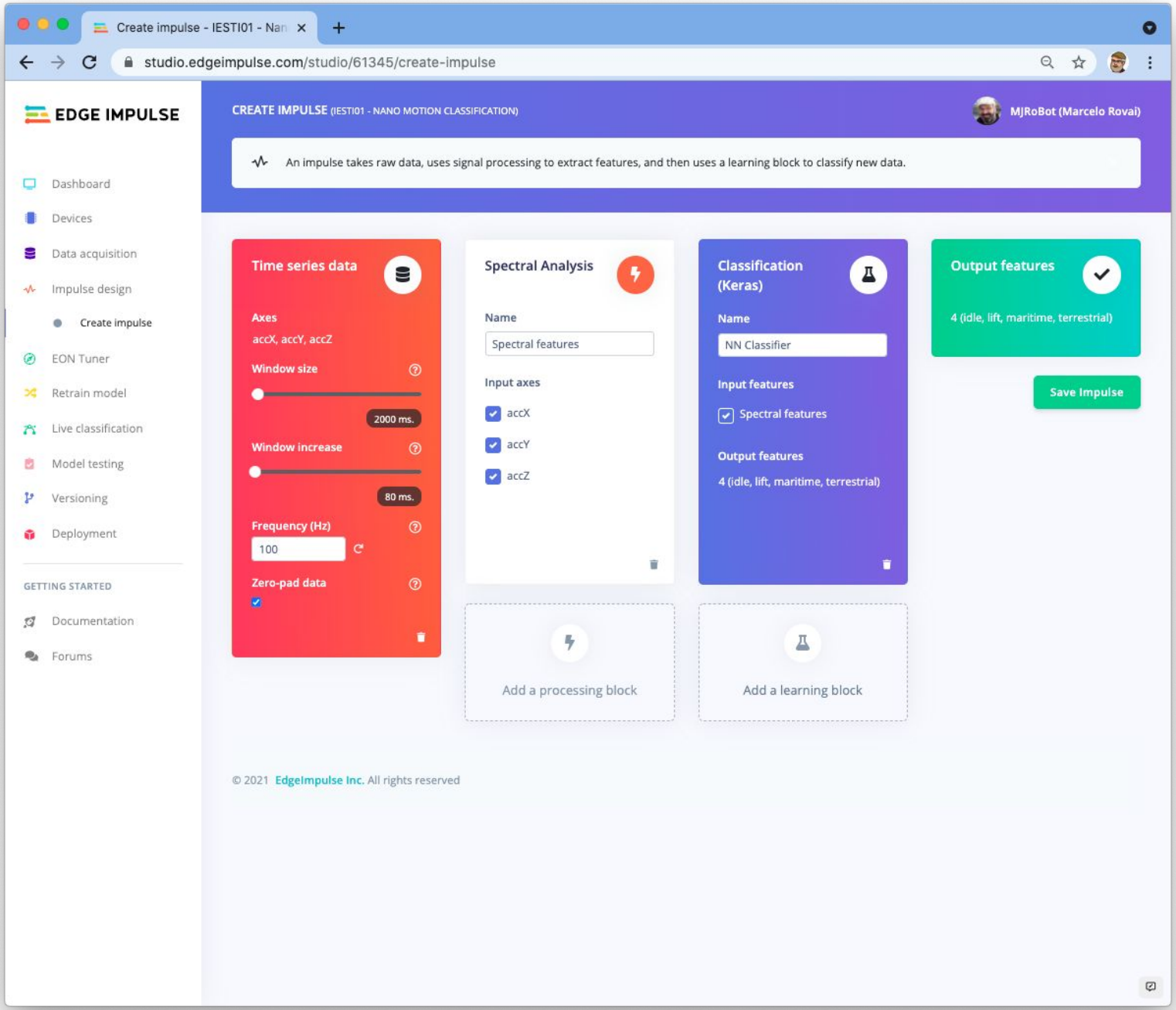


Dataset is balanced (have representative samples from all classes) and split 80%/20%





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


Create impulse - IESTI01 - Nan
studio.edgeimpulse.com/studio/61345/create-impulse
EDGE IMPULSE
Dashboard
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CREATE IMPULSE (IESTI01 - NANO MOTION CLASSIFICATION)
MJRoBot (Marcelo Rovai)
An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.
Time series data
Axes
accX, accY, accZ
Window size
2000 ms.
Window increase
80 ms.
Frequency (Hz)
100
Zero-pad data
Spectral Analysis
Name
Spectral features
Input axes
accX
accY
accZ
Classification (Keras)
Name
NN 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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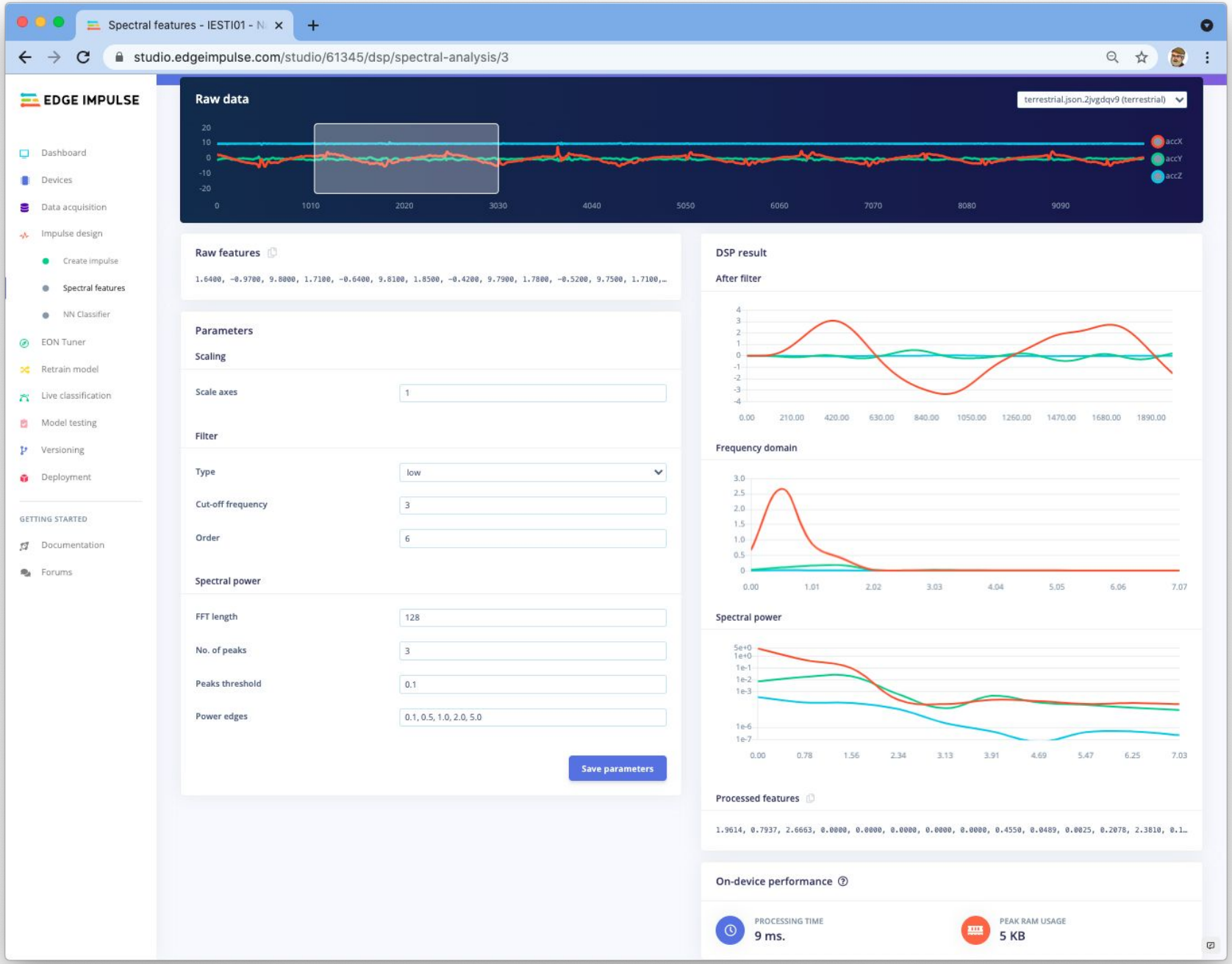
Spectral features - IESTI01 - N
studio.edgeimpulse.com/studio/61345/dsp/spectral-analysis/3
EDGE IMPULSE
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Forums
Raw data
terrestrial.json.2jvgdqv9 (terrestrial)
accX
accY
accZ
Raw features
1.6400, -0.9700, 9.8000, 1.7100, -0.6400, 9.8100, 1.8500, -0.4200, 9.7900, 1.7800, -0.5200, 9.7500, 1.7100,...
Parameters
Scaling
Scale axes
1
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
Save parameters
DSP result
After filter
Frequency domain
Spectral power
Processed features
1.9614, 0.7937, 2.6663, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.4550, 0.0489, 0.0025, 0.2078, 2.3810, 0.1...
On-device performance
PROCESSING TIME
9 ms.
PEAK RAM USAGE
5 KB

Spectral features - IESTI01 - N

studio.edgeimpulse.com/studio/61345/dsp/spectral-analysis/3/generate-features

EDGE IMPULSE

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SPECTRAL FEATURES (IESTI01 - NANO MOTION CLASSIFICATION)

MJRoBot (Marcelo Rovai)

#1 Click to set a description for this version

Parameters | Generate features

Training set

Data in training set	5m 20s
Classes	4 (idle, lift, maritime, terrestrial)
Window length	2000 ms.
Window increase	80 ms.
Training windows	3,400

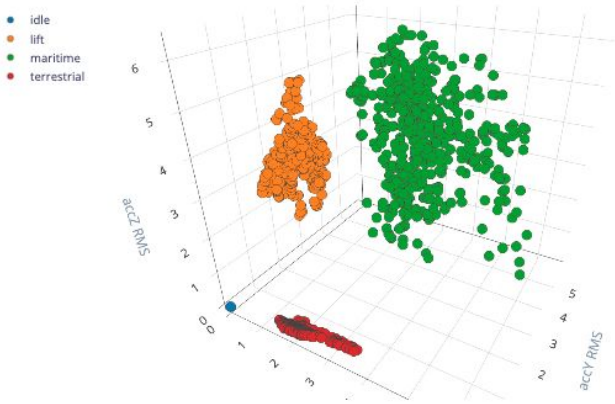
Generate features

Feature generation output

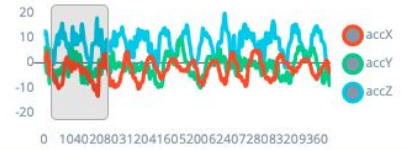
```
Job started
Creating windows from 25 files...
[ 0/25] Creating windows from files...
[ 1/25] Creating windows from files...
[25/25] Creating windows from files...
Created 3400 windows: idle: 976, lift: 808, maritime: 808, terrestrial: 808

Creating features
[   1/3400] Creating features...
[ 898/3400] Creating features...
[1798/3400] Creating features...
[2704/3400] Creating features...
[3400/3400] Creating features...
Created features

Job completed
```

Feature explorer (3,400 samples)

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



maritime.json.2jvi4q7j
Window: 240 - 2240 ms.
Label: maritime
View sample
View features



On-device performance

PROCESSING TIME	PEAK RAM USAGE
9 ms.	5 KB

Neural Network settings

Training settings

Number of training cycles: 30

Learning rate: 0.0005

Neural network architecture

Input layer (33 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
99.9%

LOSS
0.01

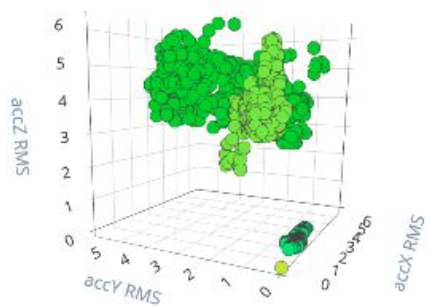
Confusion matrix (validation set)

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	0%	99.4%	0.6%	0%
MARITIME	0%	0%	100%	0%
TERRESTRIAL	0%	0%	0%	100%
F1 SCORE	1.00	1.00	1.00	1.00

Feature explorer (full training set)

accX RMS | accY RMS | accZ RMS

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

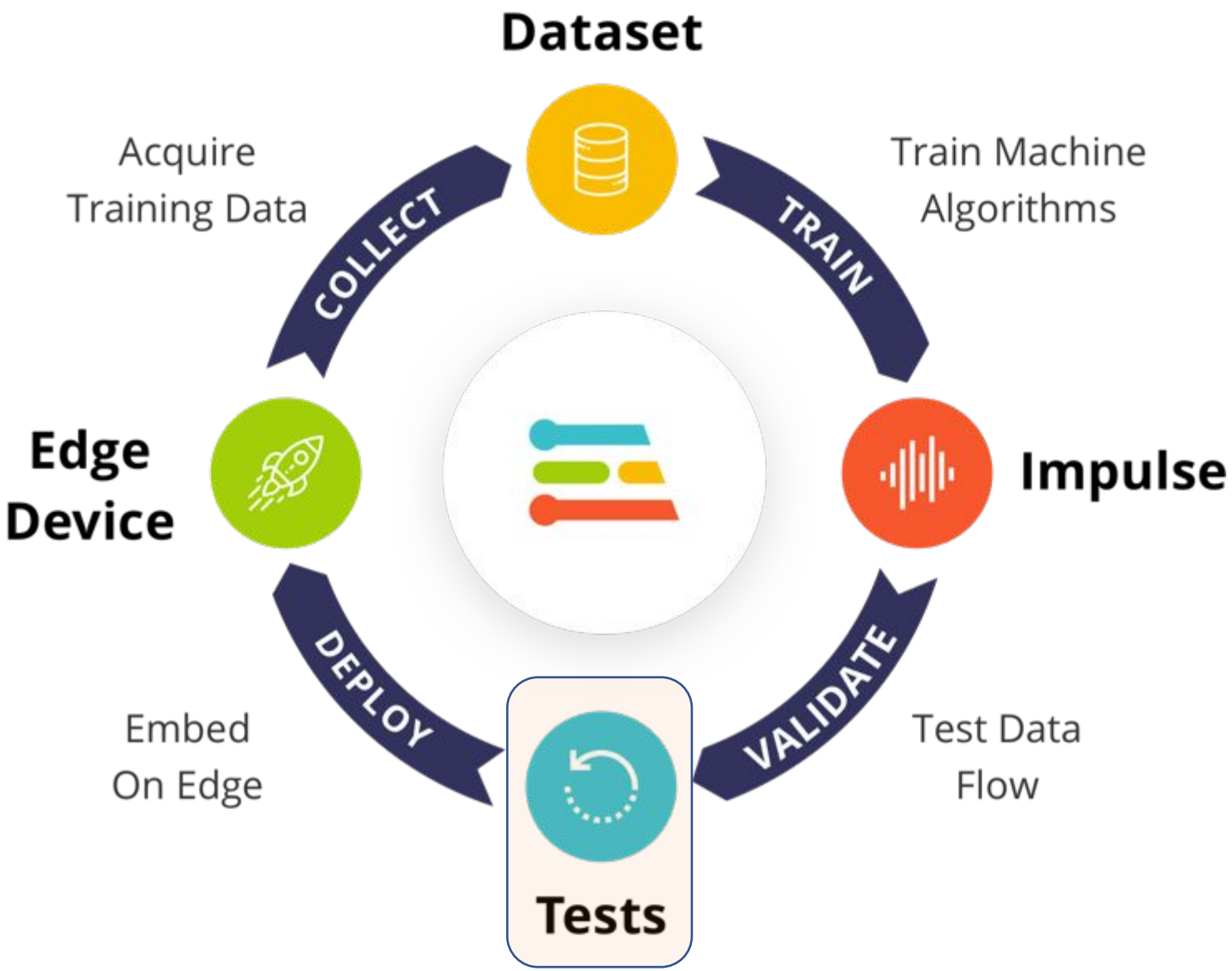


On-device performance

INFERENCING TIME
1 ms.

PEAK RAM USAGE
1.7K

FLASH USAGE
19.0K



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

Model testing - IESTI01 - Nano

studio.edgeimpulse.com/studio/61345/validation

EDGE IMPULSE

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Test data

Classify all

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

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
terrestrial.json.2...	terrestrial	10s	100%	101 terrestrial
lift.json.2jvhabt7	lift	10s	100%	101 lift
idle.json.2jvjlvon	idle	20s	100%	226 idle
maritime.json.2j...	maritime	10s	100%	101 maritime
maritime.json.2j...	maritime	10s	100%	101 maritime
lift.json.2jvh6uqu	lift	10s	100%	101 lift
terrestrial.json.2...	terrestrial	10s	100%	101 terrestrial

Model testing output

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

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


Job completed
```

Model testing results

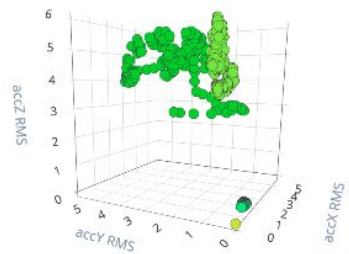
ACCURACY
100.00%

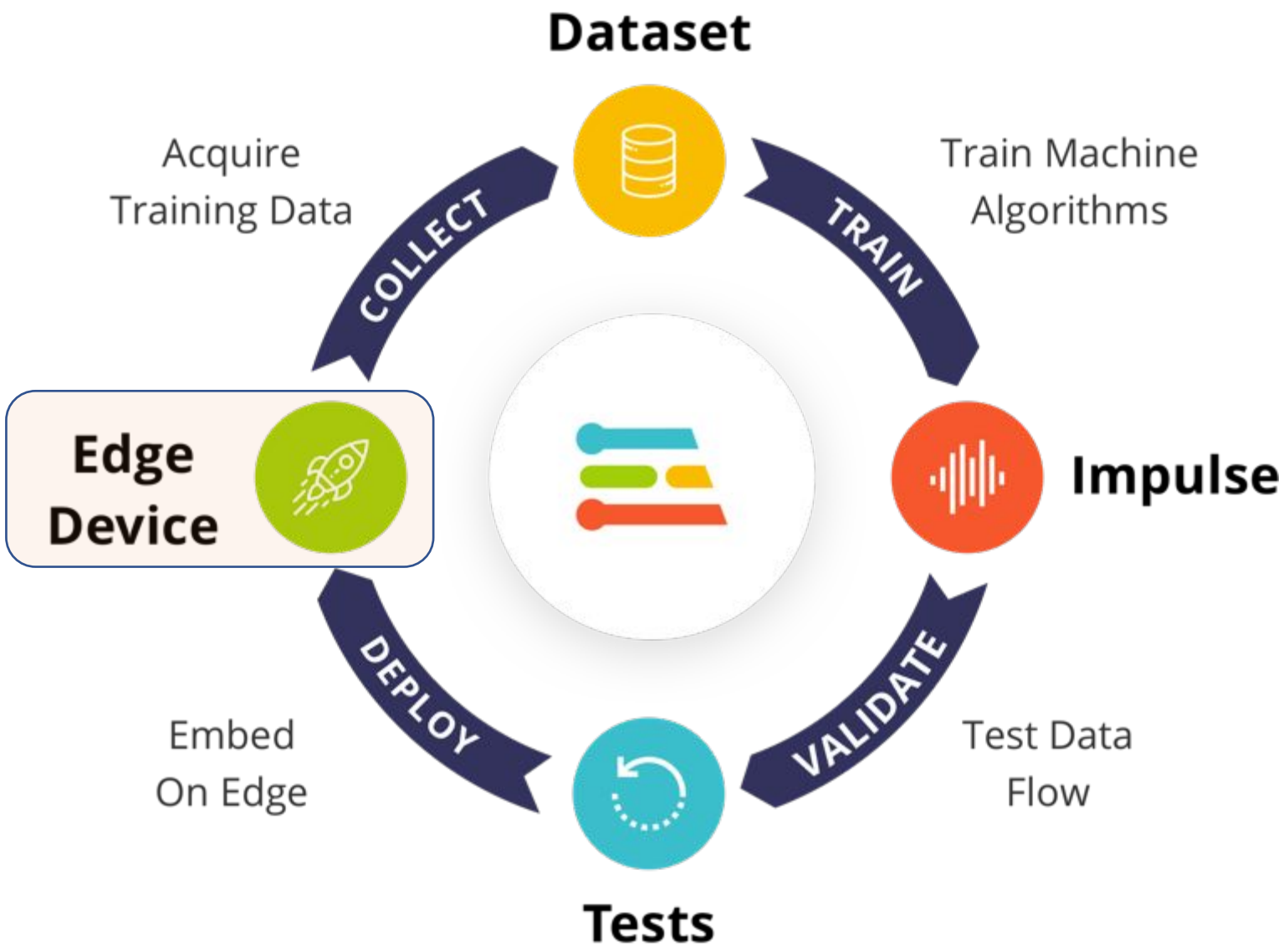
	IDLE	LIFT	MARITIME	TERRESTRIAL	UNCERTAIN
IDLE	100%	0%	0%	0%	0%
LIFT	0%	100%	0%	0%	0%
MARITIME	0%	0%	100%	0%	0%
TERRESTRIAL	0%	0%	0%	100%	0%
F1 SCORE	1.00	1.00	1.00	1.00	

Feature explorer

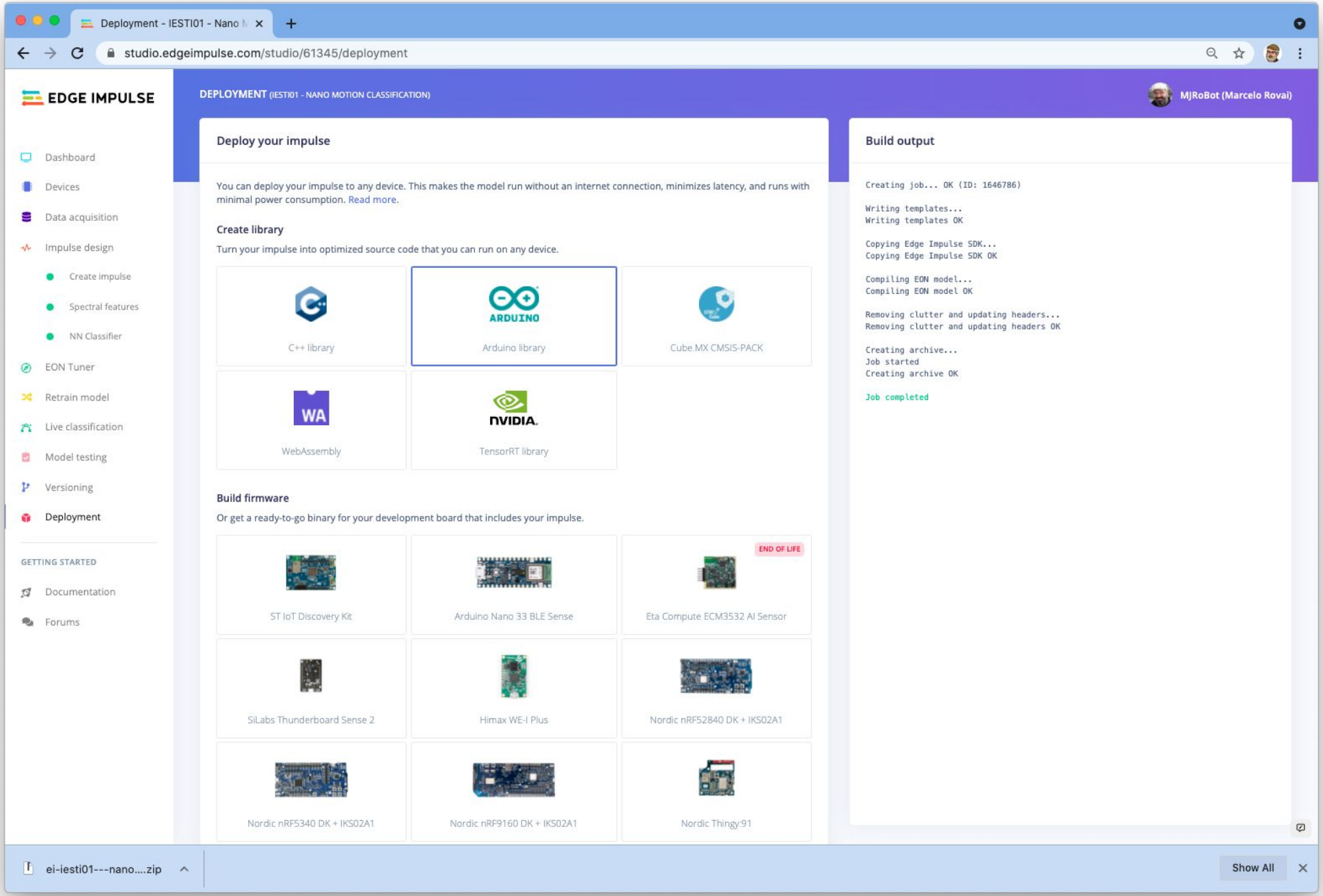
accX RMS | accY RMS | accZ RMS

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





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


Deployment - IESTI01 - Nano
studio.edgeimpulse.com/studio/61345/deployment
EDGE IMPULSE
DEPLOYMENT (IESTI01 - NANO MOTION CLASSIFICATION)
MJRoBot (Marcelo Rovai)
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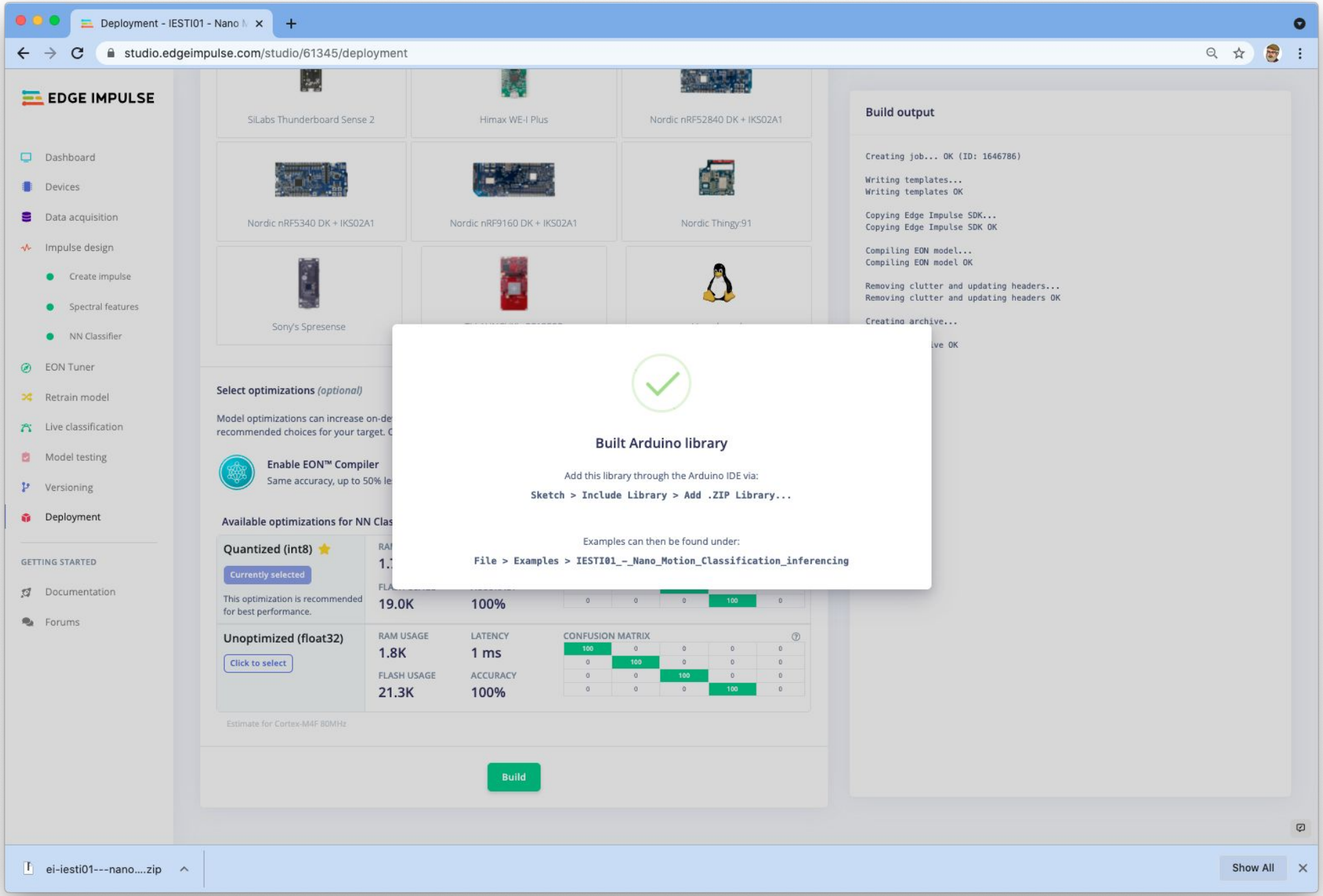
Deploy your impulse
You can deploy your impulse to any device. This makes the model run without an internet connection, minimizes latency, and runs with minimal power consumption. Read more.
Create library
Turn your impulse into optimized source code that you can run on any device.
C++ library
Arduino library
Cube.MX CMSIS-PACK
WebAssembly
TensorRT library
Build firmware
Or get a ready-to-go binary for your development board that includes your impulse.
ST IoT Discovery Kit
Arduino Nano 33 BLE Sense
END OF LIFE
Eta Compute ECM3532 AI Sensor
SiLabs Thunderboard Sense 2
Himax WE-I Plus
Nordic nRF52840 DK + IKS02A1
Nordic nRF5340 DK + IKS02A1
Nordic nRF9160 DK + IKS02A1
Nordic Thingy:91
Build output
Creating job... OK (ID: 1646786)
Writing templates...
Writing templates OK
Copying Edge Impulse SDK...
Copying Edge Impulse SDK OK
Compiling EON model...
Compiling EON model OK
Removing clutter and updating headers...
Removing clutter and updating headers OK
Creating archive...
Job started
Creating archive OK
Job completed
ei-iesti01---nano....zip
Show All


Deployment - IESTI01 - Nano
studio.edgeimpulse.com/studio/61345/deployment
EDGE IMPULSE
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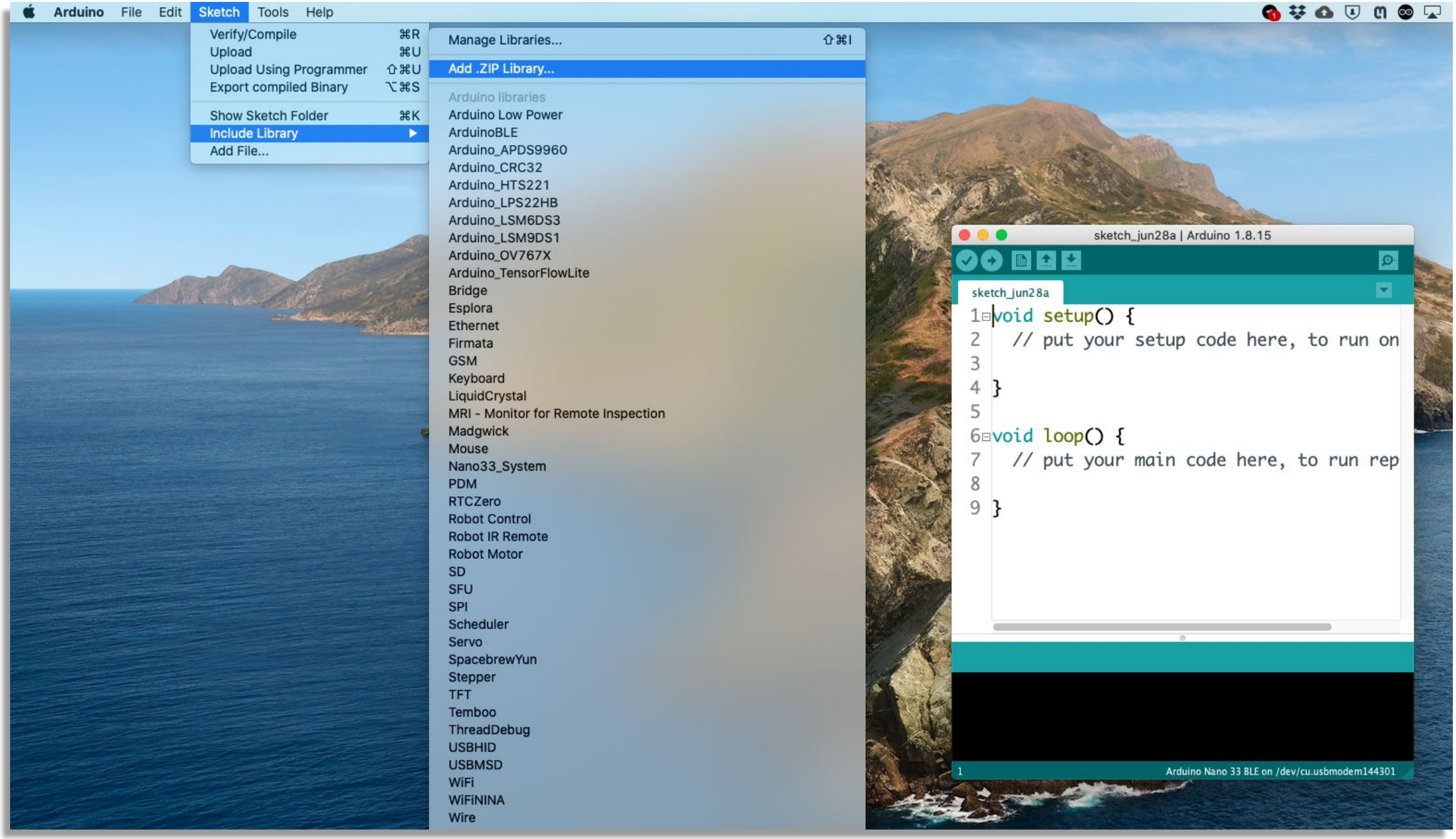
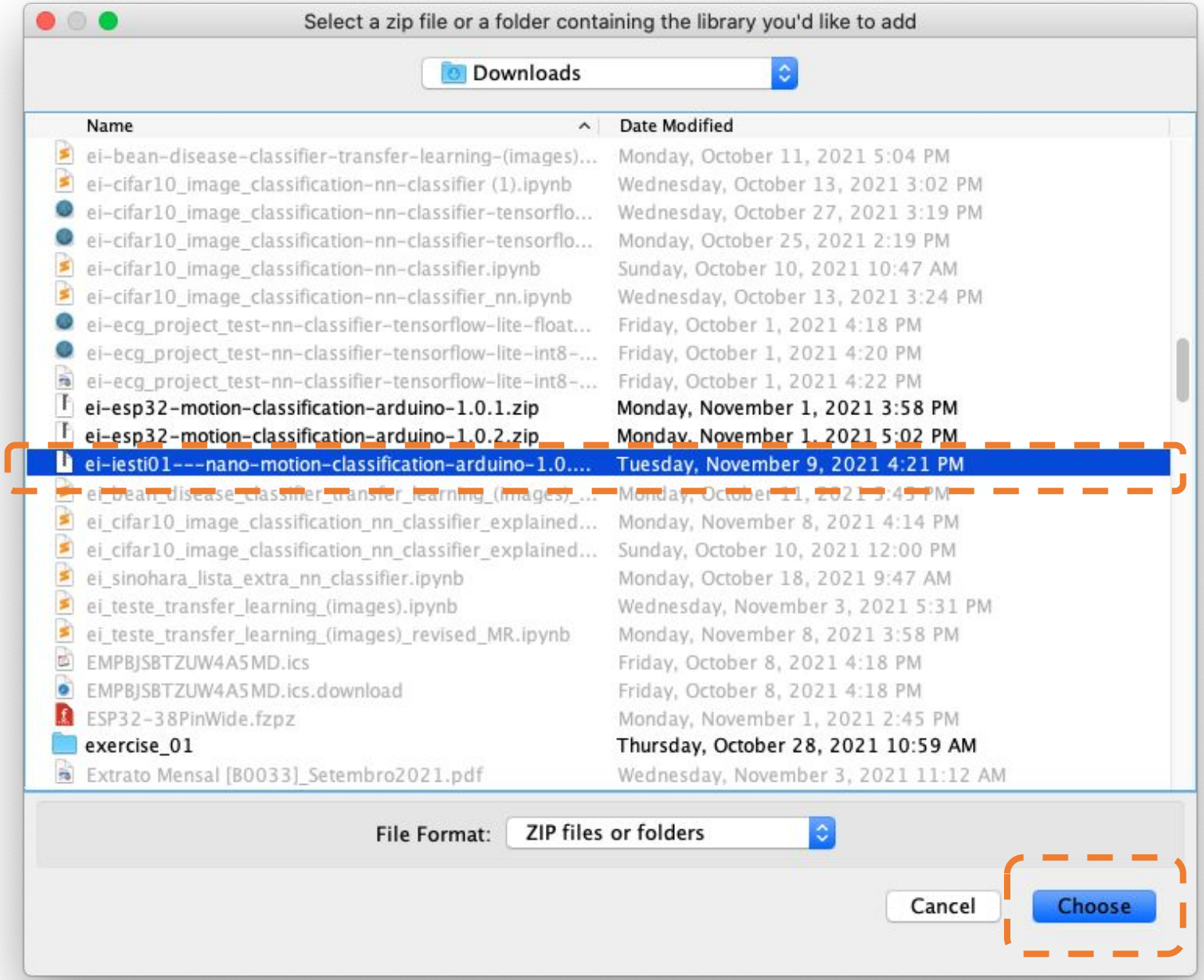
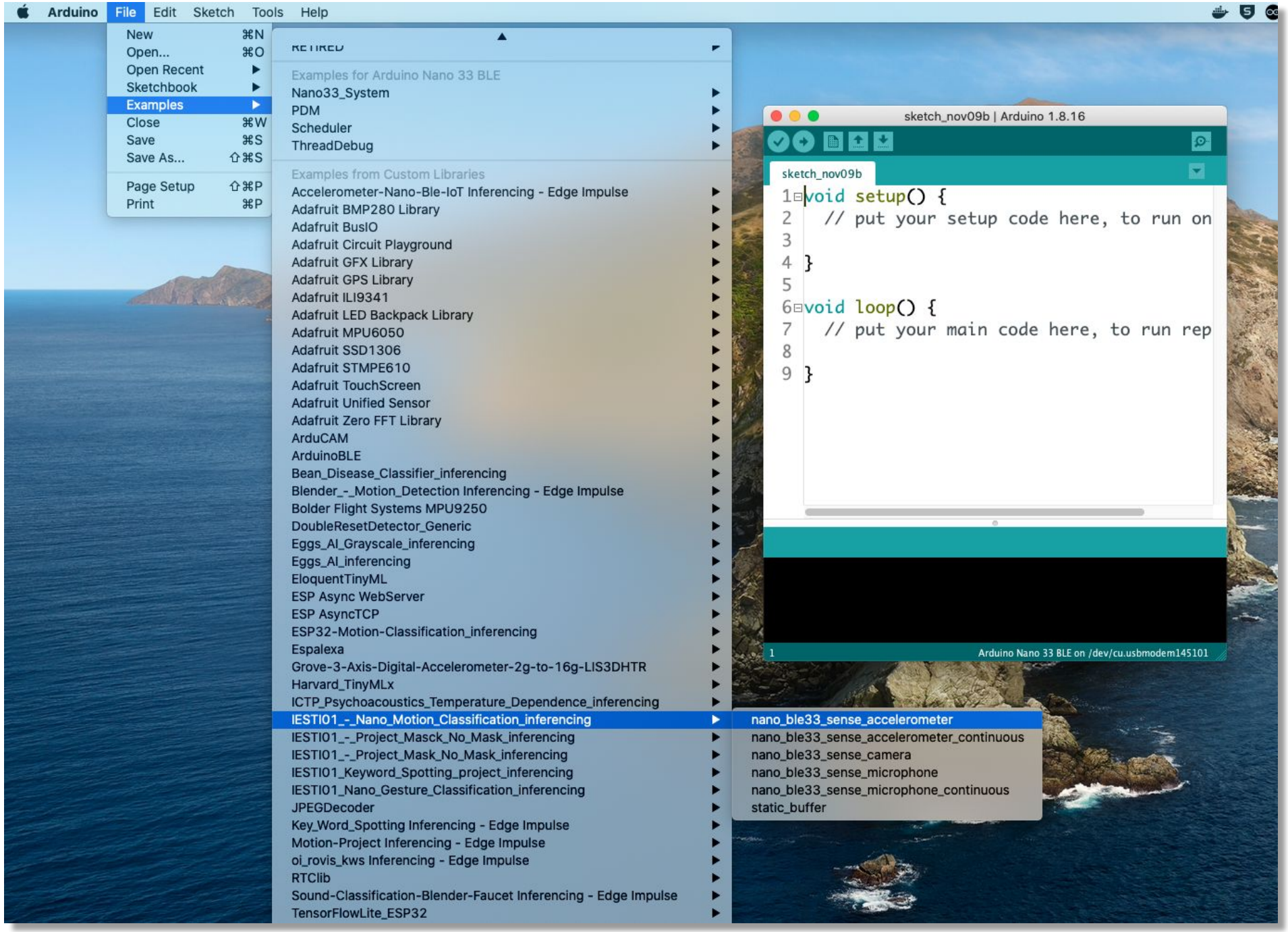
SiLabs Thunderboard Sense 2
Himax WE-I Plus
Nordic nRF52840 DK + IKS02A1
Nordic nRF5340 DK + IKS02A1
Nordic nRF9160 DK + IKS02A1
Nordic Thingy:91
Sony's Spresense
Select optimizations (optional)
Enable EON™ Compiler
Available optimizations for NN Clas
Quantized (int8)
Currently selected
This optimization is recommended for best performance.
RAM USAGE
1.7
FLASH USAGE
19.0K
ACCURACY
100%
CONFUSION MATRIX
Unoptimized (float32)
Click to select
RAM USAGE
1.8K
LATENCY
1 ms
FLASH USAGE
21.3K
ACCURACY
100%
Estimate for Cortex-M4F 80MHz
Build
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_Motion_Classification_inferencing
Build output
Creating job... OK (ID: 1646786)
Writing templates...
Writing templates OK
Copying Edge Impulse SDK...
Copying Edge Impulse SDK OK
Compiling EON model...
Compiling EON model OK
Removing clutter and updating headers...
Removing clutter and updating headers OK
Creating archive...
ei-iesti01---nano....zip
Show All


Arduino File Edit Sketch Tools Help
Verify/Compile ⌘R
Upload ⌘U
Upload Using Programmer ⇧⌘U
Export compiled Binary ⌥⌘S
Show Sketch Folder ⌘K
Include Library
Add File...
Manage Libraries... ⇧⌘I
Add .ZIP Library...
Arduino libraries
Arduino Low Power
ArduinoBLE
Arduino_APDS9960
Arduino_CRC32
Arduino_HTS221
Arduino_LPS22HB
Arduino_LSM6DS3
Arduino_LSM9DS1
Arduino_OV767X
Arduino_TensorFlowLite
Bridge
Esplora
Ethernet
Firmata
GSM
Keyboard
LiquidCrystal
MRI - Monitor for Remote Inspection
Madgwick
Mouse
Nano33_System
PDM
RTCZero
Robot Control
Robot IR Remote
Robot Motor
SD
SFU
SPI
Scheduler
Servo
SpacebrewYun
Stepper
TFT
Temboo
ThreadDebug
USBHID
USBMSD
WiFi
WiFiNINA
Wire
sketch_jun28a | Arduino 1.8.15
sketch_jun28a
1 void setup() {
2 // put your setup code here, to run on
3
4 }
5
6 void loop() {
7 // put your main code here, to run rep
8
9 }
1
Arduino Nano 33 BLE on /dev/cu.usbmodem144301


Select a zip file or a folder containing the library you'd like to add
Downloads
Name
Date Modified
ei-bean-disease-classifier-transfer-learning-(images)... Monday, October 11, 2021 5:04 PM
ei-cifar10_image_classification-nn-classifier (1).ipynb Wednesday, October 13, 2021 3:02 PM
ei-cifar10_image_classification-nn-classifier-tensorflo... Wednesday, October 27, 2021 3:19 PM
ei-cifar10_image_classification-nn-classifier-tensorflo... Monday, October 25, 2021 2:19 PM
ei-cifar10_image_classification-nn-classifier.ipynb Sunday, October 10, 2021 10:47 AM
ei-cifar10_image_classification-nn-classifier_nn.ipynb Wednesday, October 13, 2021 3:24 PM
ei-ecg_project_test-nn-classifier-tensorflow-lite-float... Friday, October 1, 2021 4:18 PM
ei-ecg_project_test-nn-classifier-tensorflow-lite-int8-... Friday, October 1, 2021 4:20 PM
ei-ecg_project_test-nn-classifier-tensorflow-lite-int8-... Friday, October 1, 2021 4:22 PM
ei-esp32-motion-classification-arduino-1.0.1.zip Monday, November 1, 2021 3:58 PM
ei-esp32-motion-classification-arduino-1.0.2.zip Monday, November 1, 2021 5:02 PM
ei-iesti01---nano-motion-classification-arduino-1.0.... Tuesday, November 9, 2021 4:21 PM
ei_bean_disease_classifier_transfer_learning_(images)_... Monday, October 11, 2021 5:45 PM
ei_cifar10_image_classification_nn_classifier_explained... Monday, November 8, 2021 4:14 PM
ei_cifar10_image_classification_nn_classifier_explained... Sunday, October 10, 2021 12:00 PM
ei_sinohara_lista_extra_nn_classifier.ipynb Monday, October 18, 2021 9:47 AM
ei_teste_transfer_learning_(images).ipynb Wednesday, November 3, 2021 5:31 PM
ei_teste_transfer_learning_(images)_revised_MR.ipynb Monday, November 8, 2021 3:58 PM
EMPBJSBTZUW4A5MD.ics Friday, October 8, 2021 4:18 PM
EMPBJSBTZUW4A5MD.ics.download Friday, October 8, 2021 4:18 PM
ESP32-38PinWide.fzpz Monday, November 1, 2021 2:45 PM
exercise_01 Thursday, October 28, 2021 10:59 AM
Extrato Mensal [B0033]_Setembro2021.pdf Wednesday, November 3, 2021 11:12 AM
File Format:
ZIP files or folders
Cancel
Choose


Arduino
File
Edit
Sketch
Tools
Help
New ⌘N
Open... ⌘O
Open Recent
Sketchbook
Examples
Close ⌘W
Save ⌘S
Save As... ⇧⌘S
Page Setup ⇧⌘P
Print ⌘P
RETIRED
Examples for Arduino Nano 33 BLE
Nano33_System
PDM
Scheduler
ThreadDebug
Examples from Custom Libraries
Accelerometer-Nano-Ble-IoT Inferencing - Edge Impulse
Adafruit BMP280 Library
Adafruit BusIO
Adafruit Circuit Playground
Adafruit GFX Library
Adafruit GPS Library
Adafruit ILI9341
Adafruit LED Backpack Library
Adafruit MPU6050
Adafruit SSD1306
Adafruit STMPE610
Adafruit TouchScreen
Adafruit Unified Sensor
Adafruit Zero FFT Library
ArduCAM
ArduinoBLE
Bean_Disease_Classifier_inferencing
Blender_-_Motion_Detection Inferencing - Edge Impulse
Bolder Flight Systems MPU9250
DoubleResetDetector_Generic
Eggs_AI_Grayscale_inferencing
Eggs_AI_inferencing
EloquentTinyML
ESP Async WebServer
ESP AsyncTCP
ESP32-Motion-Classification_inferencing
Espalexa
Grove-3-Axis-Digital-Accelerometer-2g-to-16g-LIS3DHTR
Harvard_TinyMLx
ICTP_Psychoacoustics_Temperature_Dependence_inferencing
IESTI01_-_Nano_Motion_Classification_inferencing
IESTI01_-_Project_Masck_No_Mask_inferencing
IESTI01_-_Project_Mask_No_Mask_inferencing
IESTI01_Keyword_Spotting_project_inferencing
IESTI01_Nano_Gesture_Classification_inferencing
JPEGDecoder
Key_Word_Spotting Inferencing - Edge Impulse
Motion-Project Inferencing - Edge Impulse
oi_rovis_kws Inferencing - Edge Impulse
RTClib
Sound-Classification-Blender-Faucet Inferencing - Edge Impulse
TensorFlowLite_ESP32
nano_ble33_sense_accelerometer
nano_ble33_sense_accelerometer_continuous
nano_ble33_sense_camera
nano_ble33_sense_microphone
nano_ble33_sense_microphone_continuous
static_buffer
sketch_nov09b | Arduino 1.8.16
sketch_nov09b
1 void setup() {
2 // put your setup code here, to run on
3
4 }
5
6 void loop() {
7 // put your main code here, to run rep
8
9 }
1
Arduino Nano 33 BLE on /dev/cu.usbmodem145101

Model Inference

Arduino File Edit Sketch Tools Help

/dev/cu.usbmodem145101

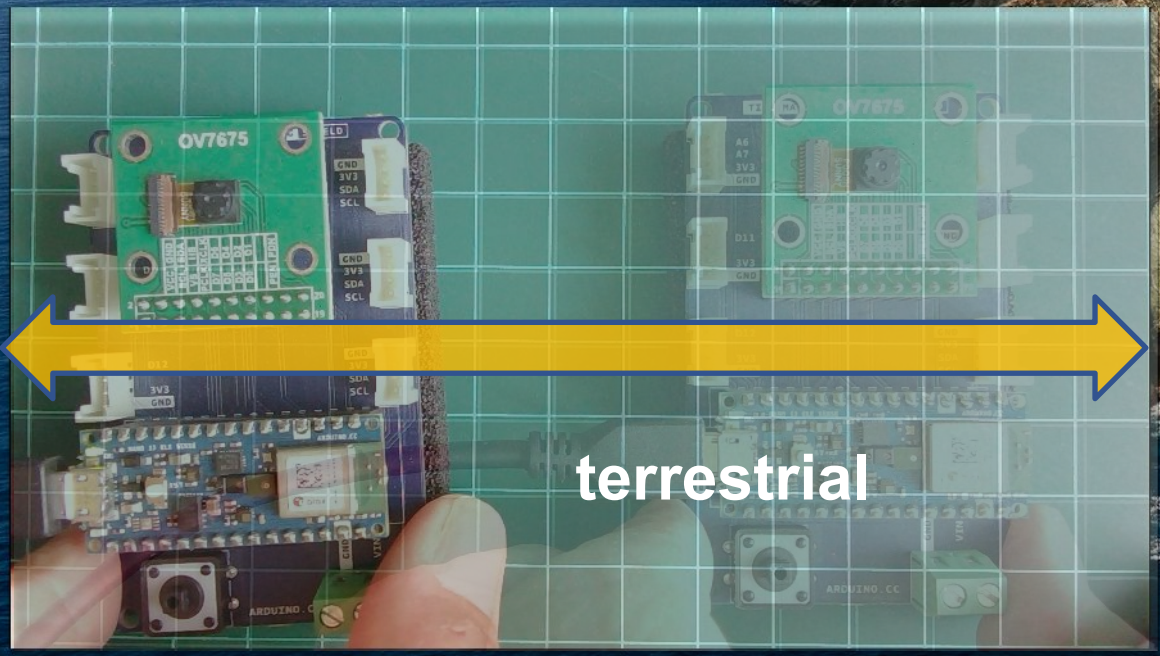
Send

```
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 0 ms.):
    idle: 0.00000
    lift: 0.00000
    maritime: 0.00000
    terrestrial: 0.99609

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 0 ms.):
    idle: 0.00000
    lift: 0.00000
    maritime: 0.00000
    terrestrial: 0.99609

Starting inferencing in 2 seconds...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output



nano_ble33_sense_accelerometer | Arduino 1.8.16

nano_ble33_sense_accelerometer

```
/* Edge Impulse Arduino examples
 * Copyright (c) 2021 EdgeImpulse Inc.
 *
 * Permission is hereby granted, free of charge, to any person obtaining a cop
 * of this software and associated documentation files (the "Software"), to de
 * in the Software without restriction, including without limitation the right
 * to use, copy, modify, merge, publish, distribute, sublicense, and/or sell
 * copies of the Software, and to permit persons to whom the Software is
 * furnished to do so, subject to the following conditions:
 *
 * The above copyright notice and this permission notice shall be included in
 * all copies or substantial portions of the Software.
 *
 * THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR
 * IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY,
 * FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE
 * AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER
 * LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FRO
 * OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN T
 * SOFTWARE.
 */

/* Includes ---------------------------------------------------------------- *
#include <IESTI01_-_Nano_Motion_Classification_inferencing.h>
#include <Arduino_LSM9DS1.h>

/* Constant defines -------------------------------------------------------- *
#define CONVERT_G_TO_MS2    9.80665f

/* Private variables ------------------------------------------------------- *
static bool debug_nn = false; // Set this to true to see e.g. features generat
```

```
Done in 6.027 seconds
reset()
```

15 Arduino Nano 33 BLE on /dev/cu.usbmodem145101

Quick Camera Camera Edit Window Help

/dev/cu.usbmodem145101

Send

```
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
Predictions (DSP: 27 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
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Predictions (DSP: 29 ms., Classification: 0 ms., Anomaly: 0 ms.): terrestrial  [ 0, 0, 0, 10, 0, 0,
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

nano_ble33_sense_accelerometer_continuous | Arduino 1.8.16

nano_ble33_sense_accelerometer_continuous

```
/* Includes ---------------------------------------------------------------
#include <IESTI01_-_Nano_Motion_Classification_inferencing.h>
#include <Arduino_LSM9DS1.h>

/* Constant defines -------------------------------------------------------
#define CONVERT_G_TO_MS2    9.80665f

/* Private variables ------------------------------------------------------
static bool debug_nn = false; // Set this to true to see e.g. features
static uint32_t run_inference_every_ms = 200;
static rtos::Thread inference_thread(osPriorityLow);
static float buffer[EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE] = { 0 };
static float inference_buffer[EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE];

/* Forward declaration */
void run_inference_background();

/**
* @brief      Arduino setup function
*/
void setup()
{
    // put your setup code here, to run once:
    Serial.begin(115200);
    Serial.println("Edge Impulse Inferencing Demo");

    if (!IMU.begin()) {
        ei_printf("Failed to initialize IMU!\r\n");
    }
    else {
        ei_printf("IMU initialized\r\n");
    }
```

Done uploading.

```
Done in 6.034 seconds
reset()
```

40 Arduino Nano 33 BLE on /dev/cu.usbmodem145101

TinyML motion classification uses on Real Life

Cow Monitoring

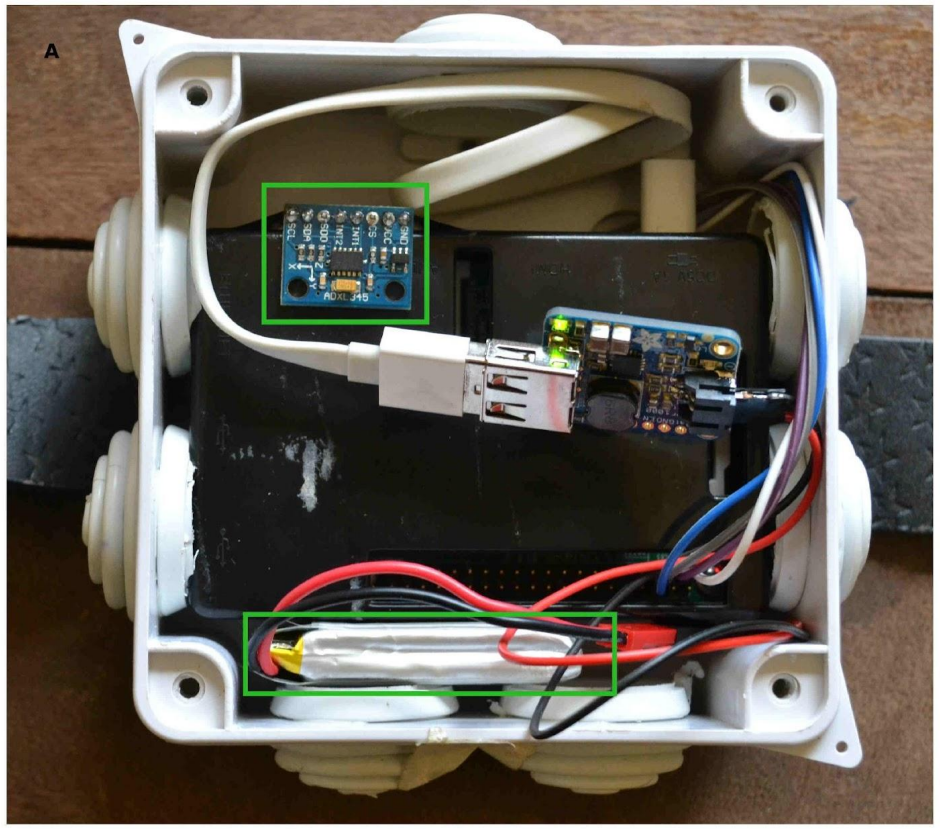
Using the Internet of Things for Agricultural Monitoring

"We aim to deploy a variety of sensors for agricultural monitoring. One of the projects involves using accelerometer sensors to monitor activity levels in dairy cows with a view to determining when the cows are on heat or when they are sick."

Ciira wa Maina, Ph.D.

Senior Lecturer
Department of Electrical and Electronic Engineering
Dedan Kimathi University of Technology
Nyeri Kenya
Email: ciira.maina@dkut.ac.ke

Kenia



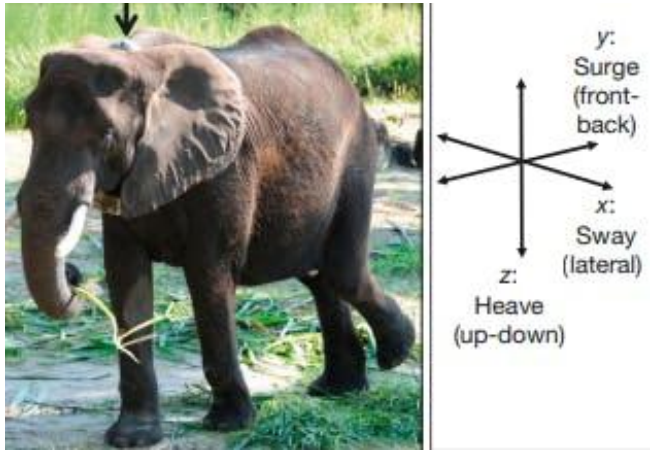
https://sites.google.com/site/cwamainadekut/research

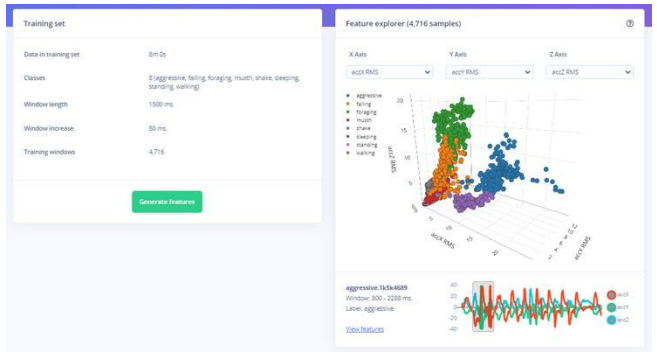
Predict and classify common Elephant behavior

Aggressive

Standing

Sleeping





https://www.hackster.io/dhruvsheth_/eletect-tinyml-and-iot-based-smart-wildlife-tracker-c03e5a#toc-accelerometer-data-models-4

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, Pete Warden and Laurence Moroney from Google, and especially 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!

UNIFEI