

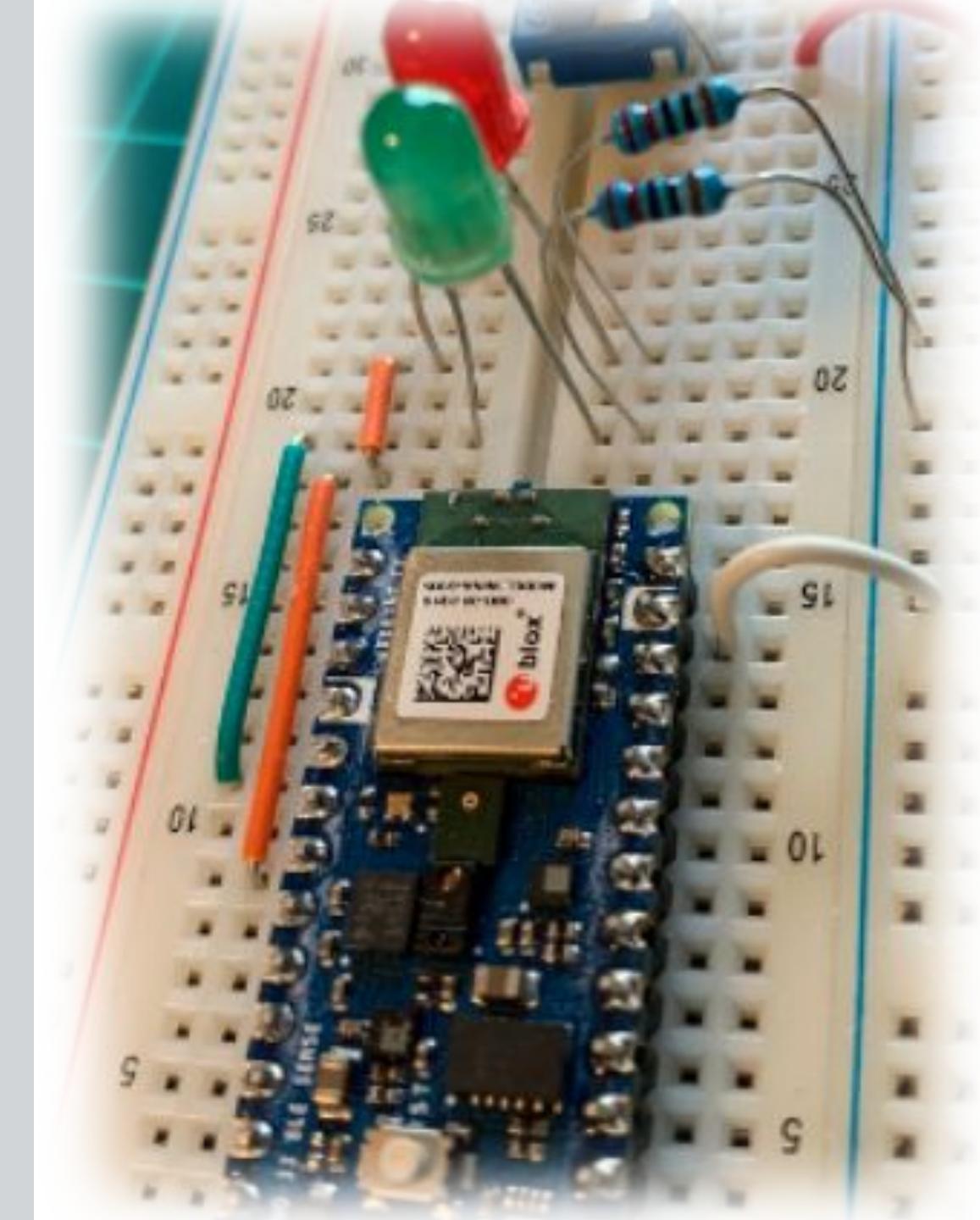
IESTI01 – TinyML

Embedded Machine Learning

19. Motion Classification



Prof. Marcelo Rovai
UNIFEI



Vibration



Sound



Vision



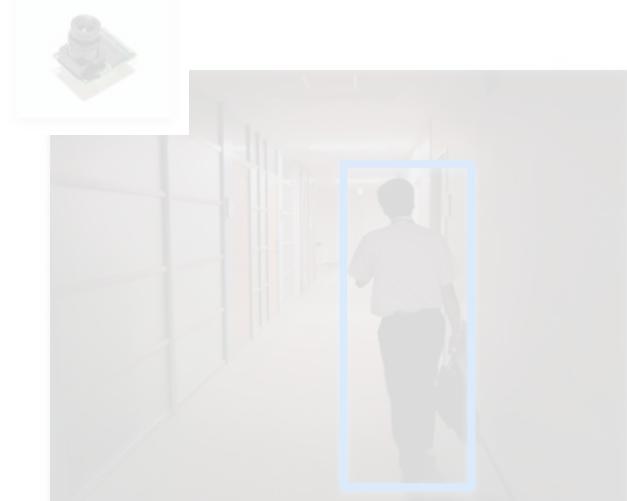
Vibration



Sound



Vision



Industrial Embedded Machine Learning Demo

Daniel Situnayake, founding engineer of Edge Impulse

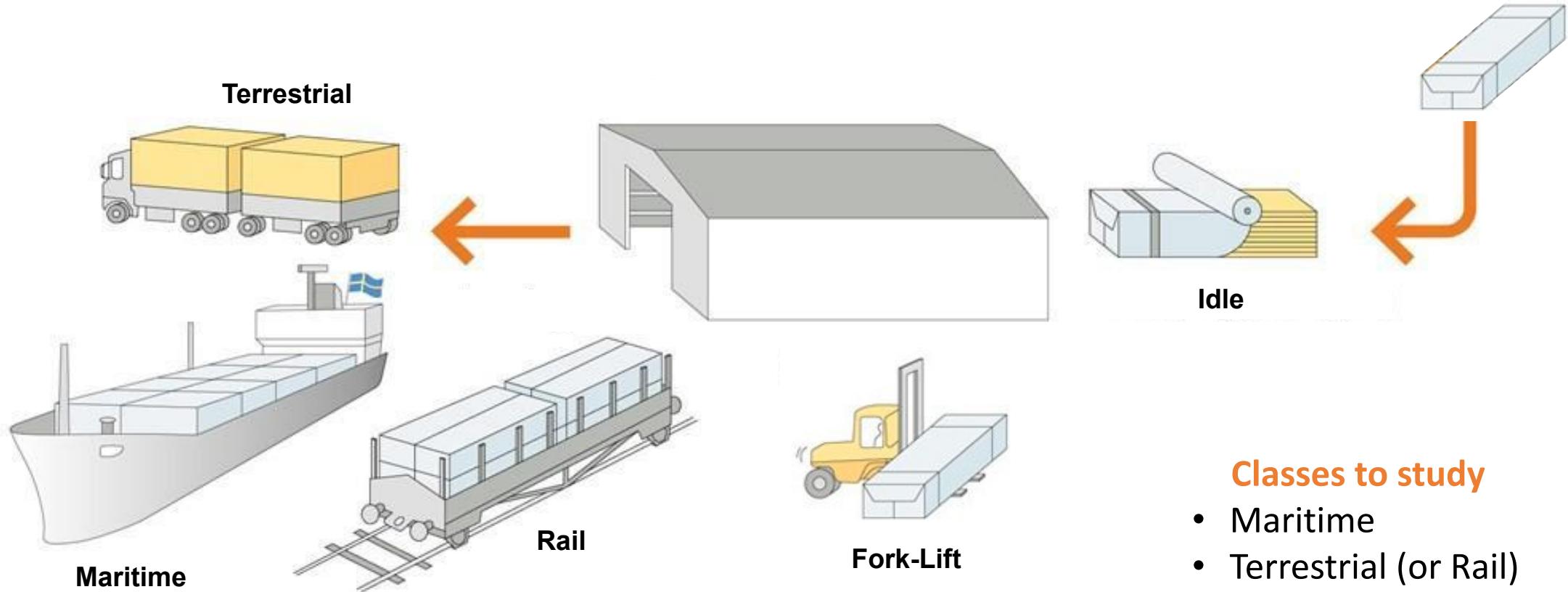
Introduction to Embedded ML course



Motion Classification



Case Study: Mechanical Stresses in Transport



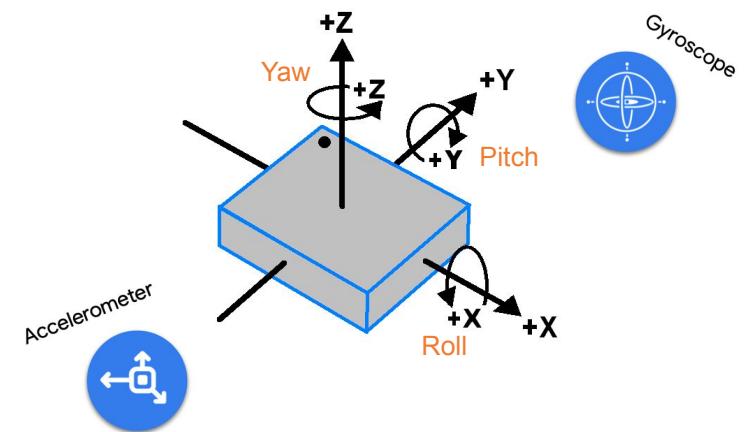
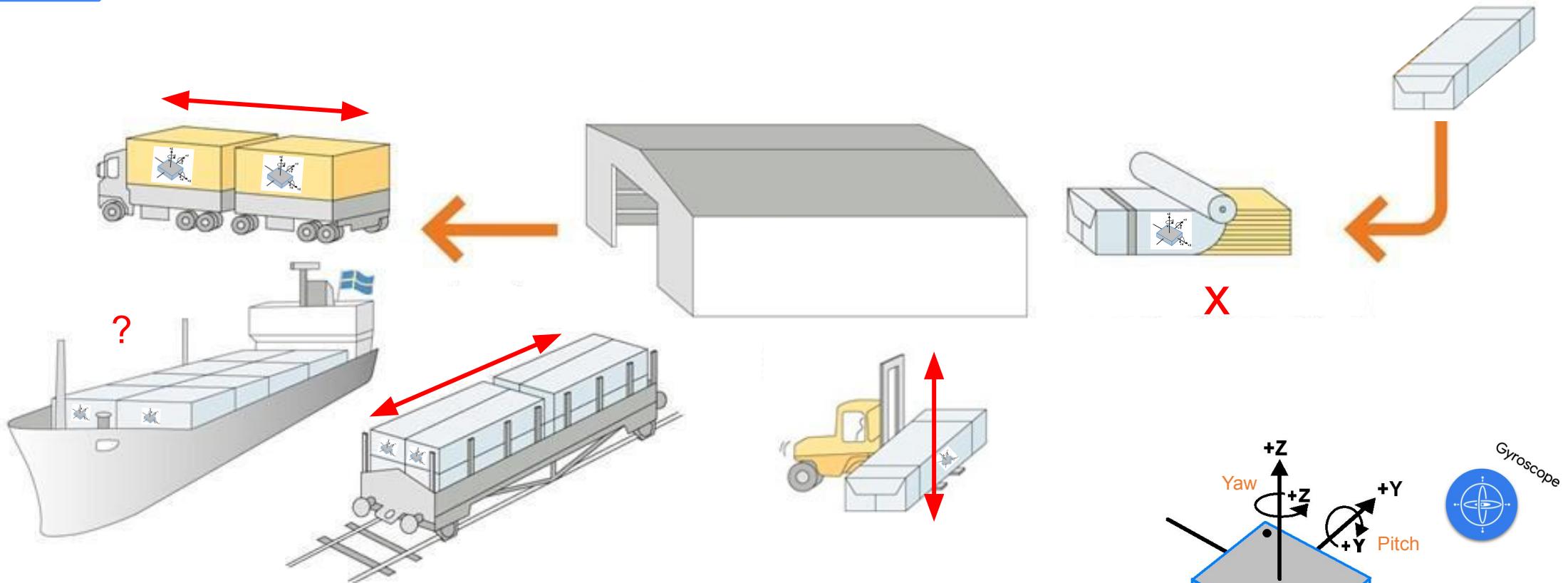
Classes to study

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

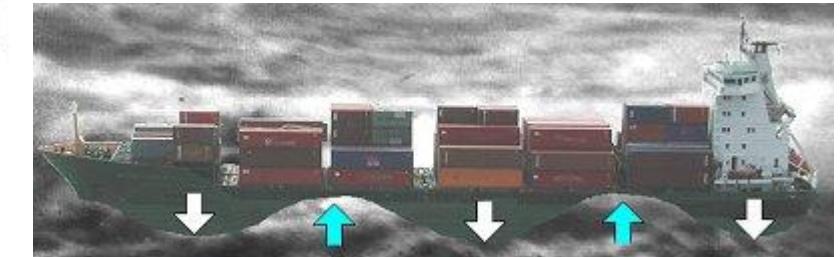
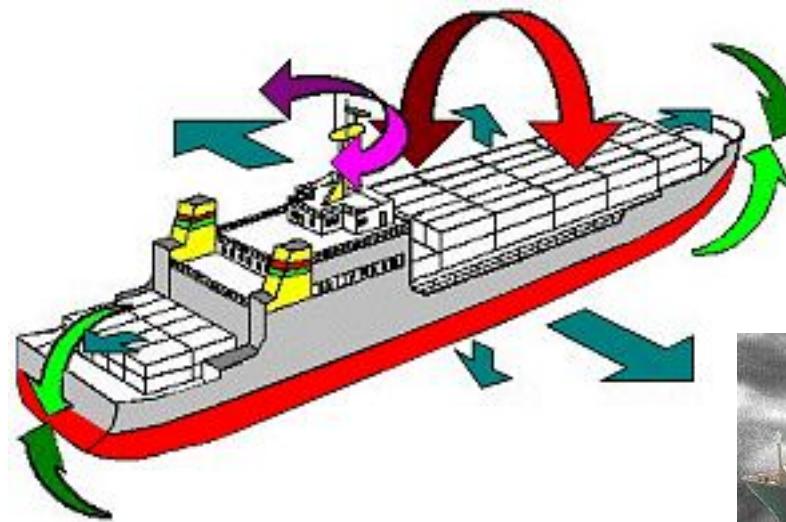
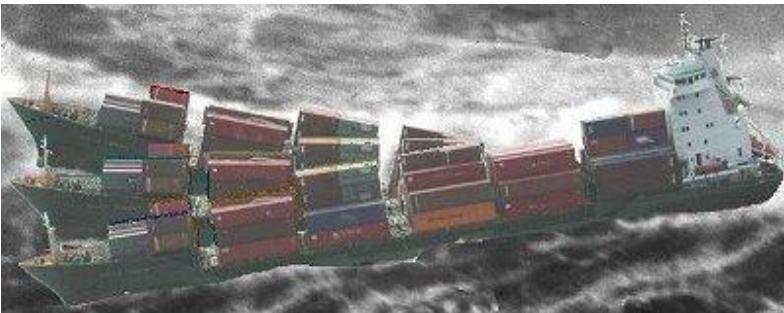
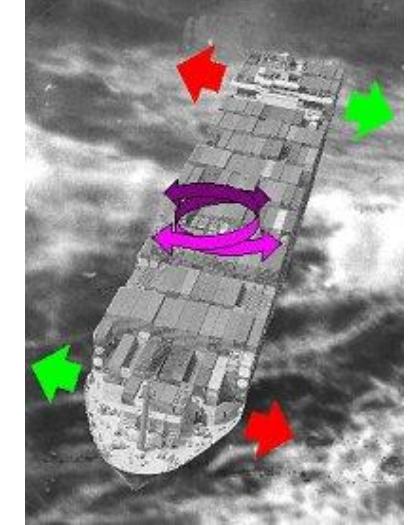
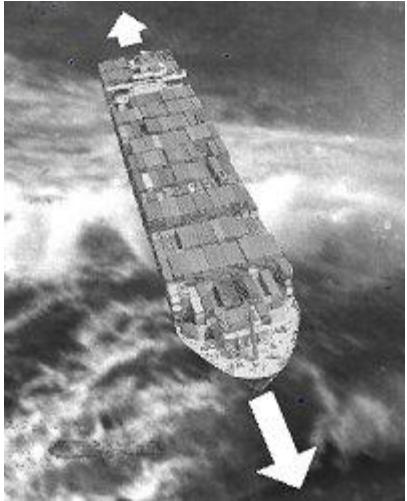
Machine Learning Workflow



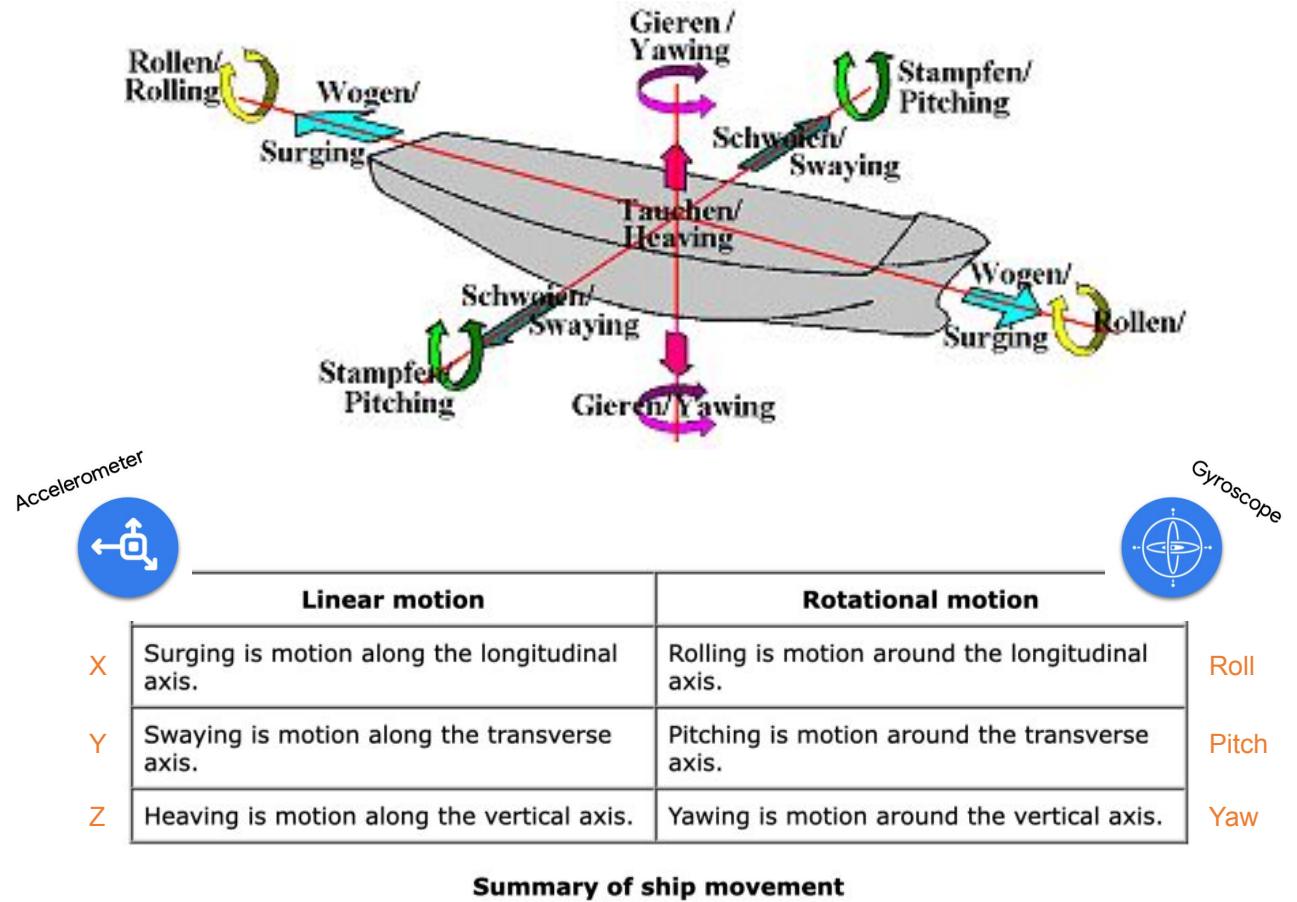
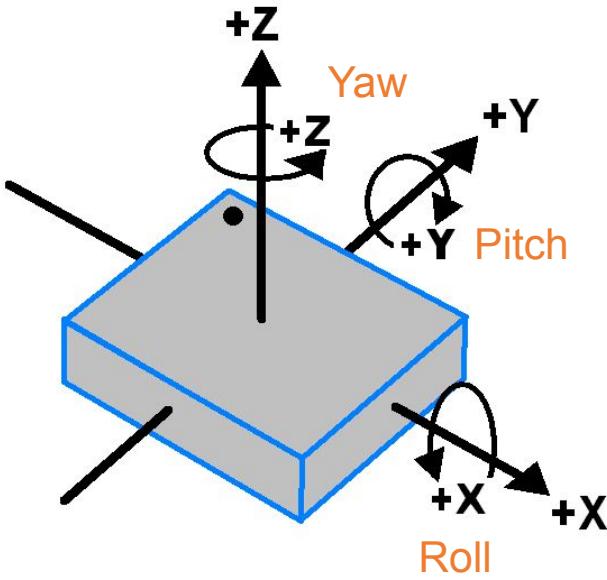
Collect
Data



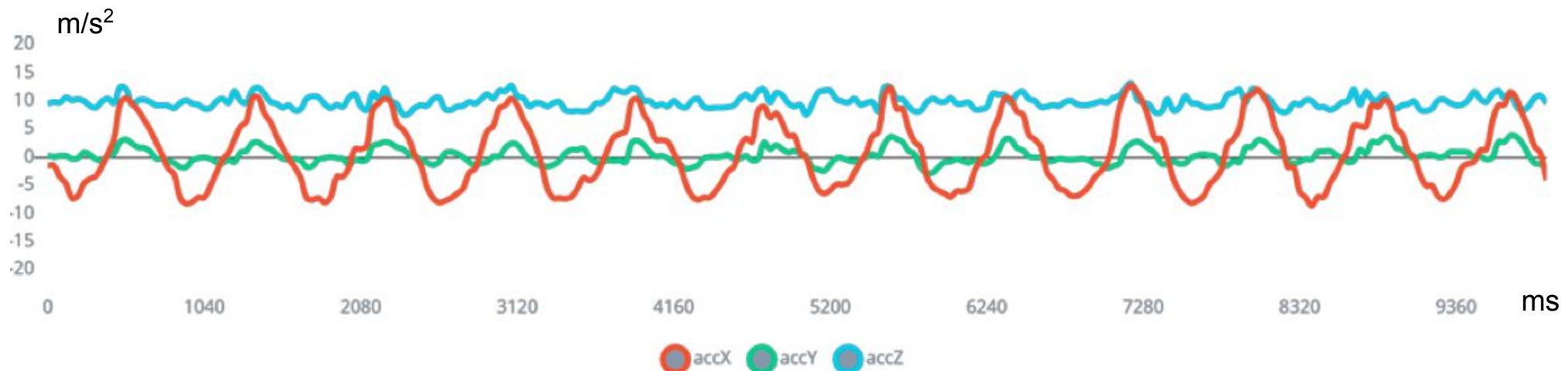
Mechanical Stresses in Maritime Transport

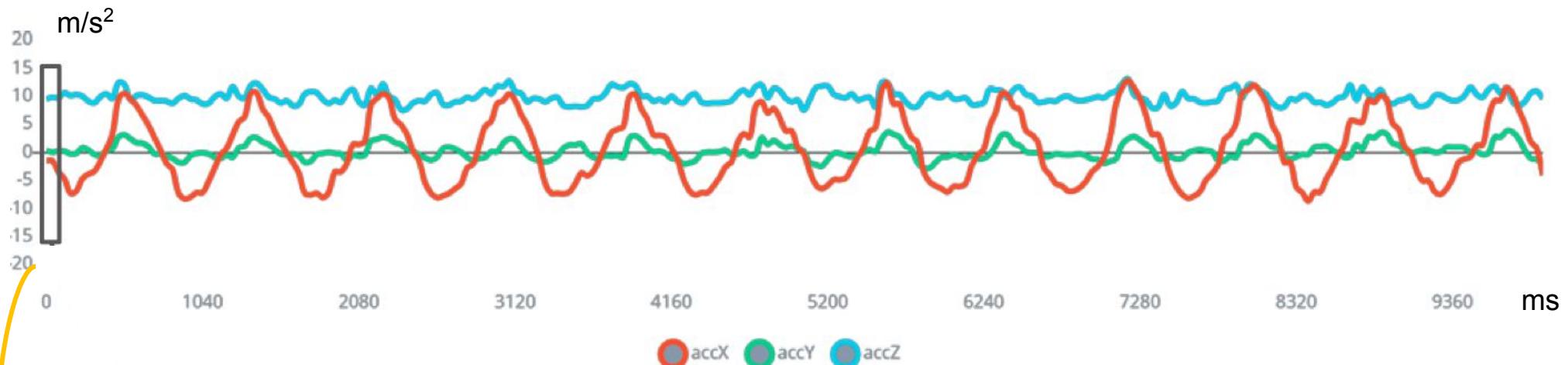
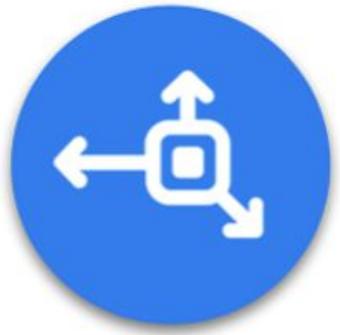


Mechanical Stresses in Maritime Transport



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





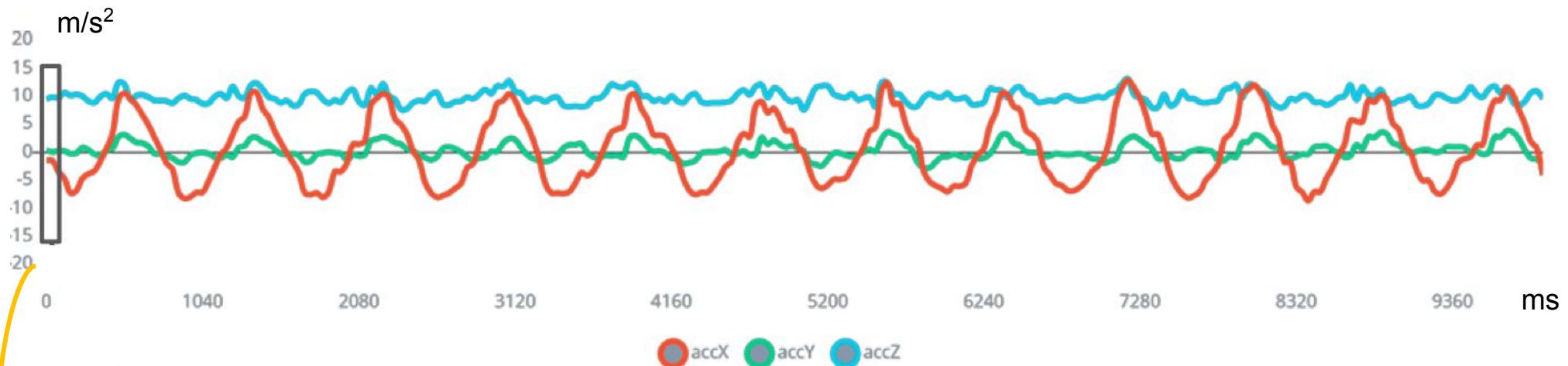
Raw Features

- accX
- accY
- accZ



Classes

- Lift
- Terrestrial
- Maritime
- Idle



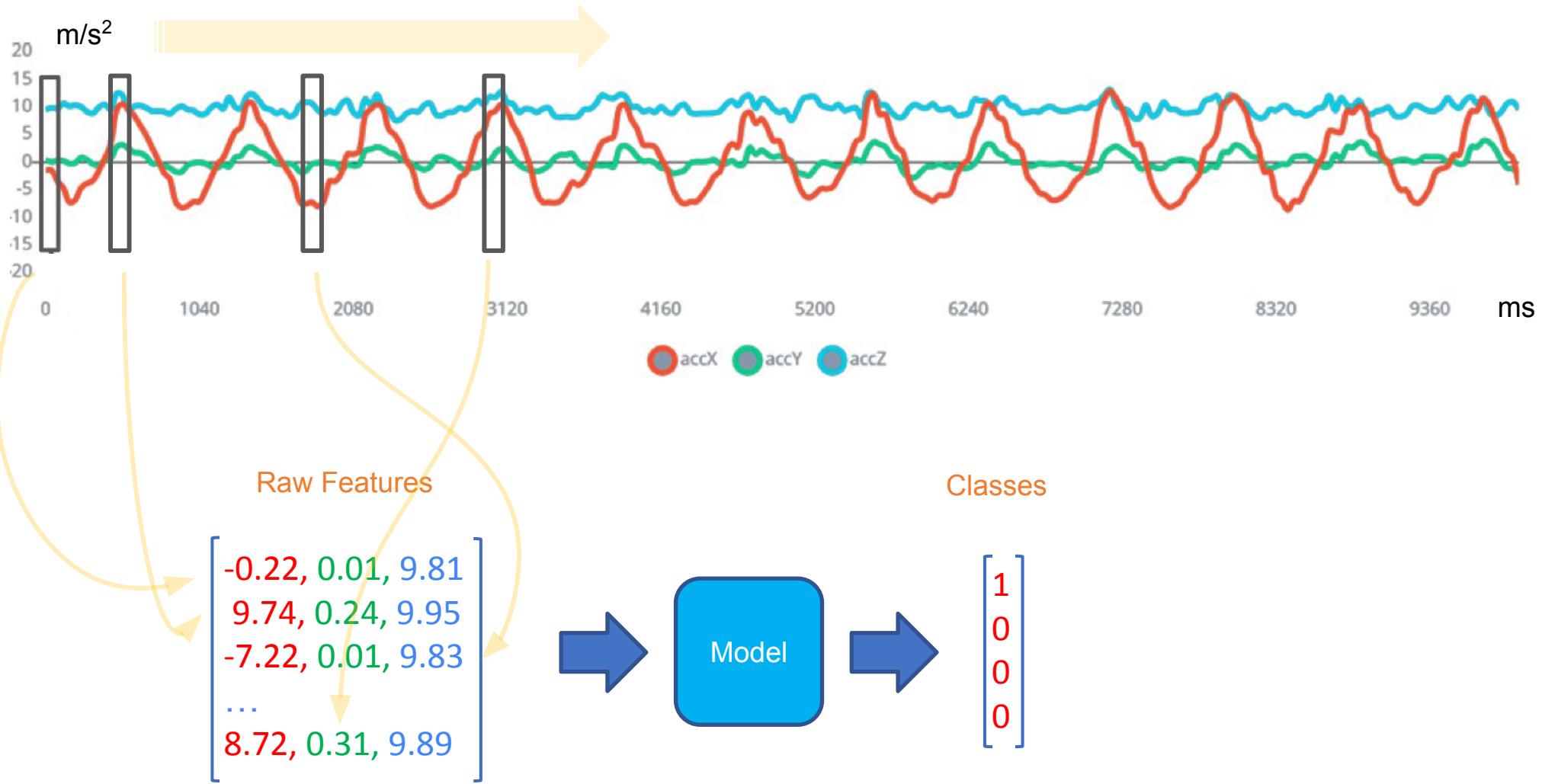
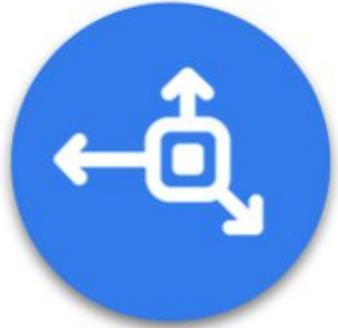
Raw Features

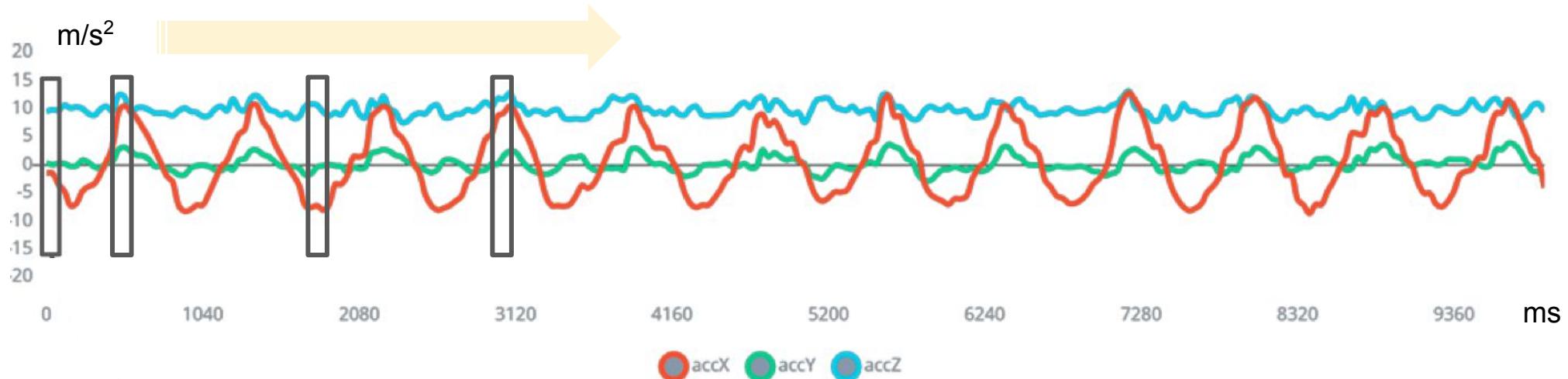
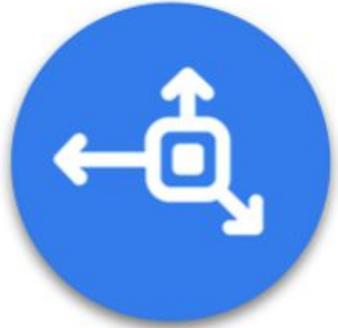
$$[-0.22, 0.01, 9.81]$$

Model

Classes

$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$





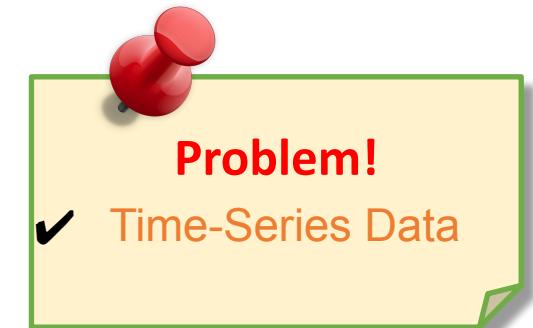
Raw Features

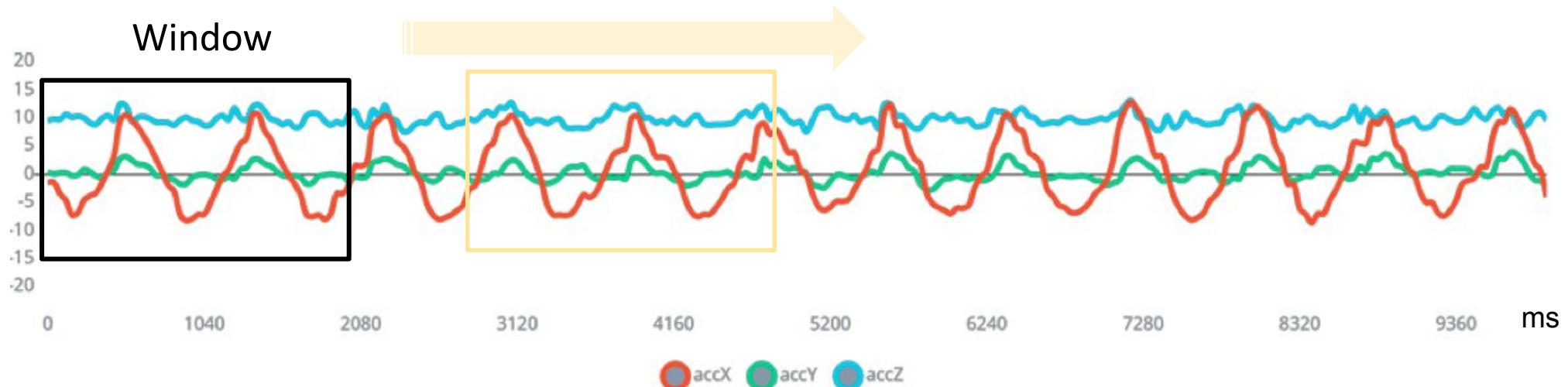
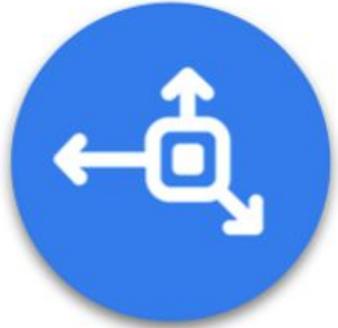
$$\begin{bmatrix} -0.22, 0.01, 9.81 \\ 9.74, 0.24, 9.95 \\ -7.22, 0.01, 9.83 \\ \dots \\ 8.72, 0.31, 9.89 \end{bmatrix}$$

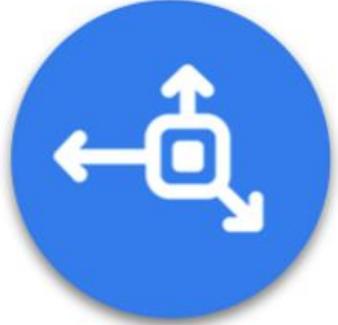
Model

Classes

$$\begin{bmatrix} ? \\ ? \\ ? \\ ? \end{bmatrix}$$





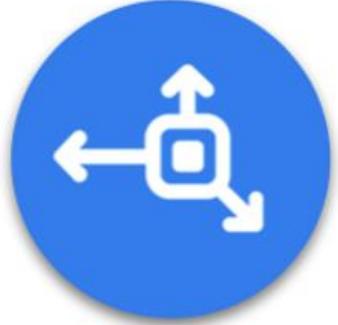


Raw Features as a window

- 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



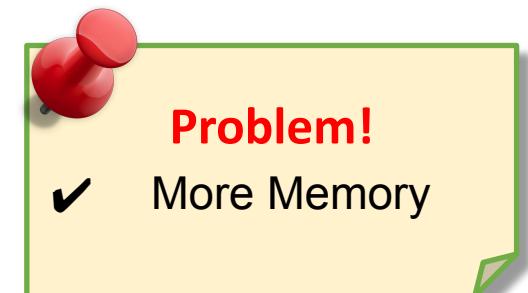
Raw Features as a window

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



Automatic Feature Extraction using DL

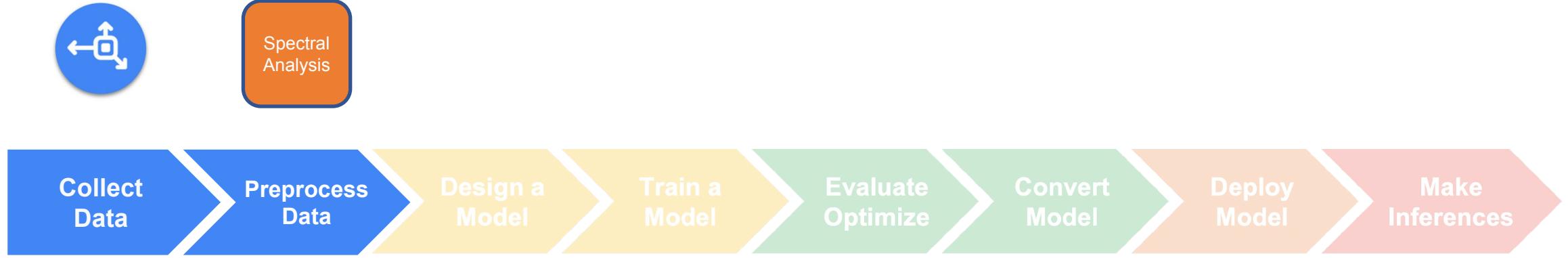
- Computational complexity
- Lots of training data

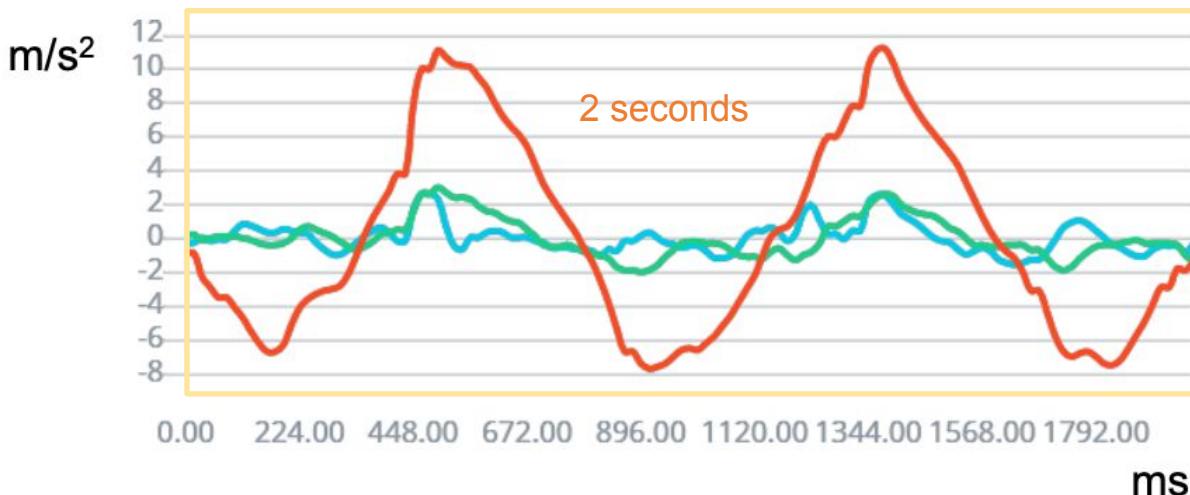


* 2 seconds is needed to capture 1 or 2 cycles of movement

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

Data Pre-Processing



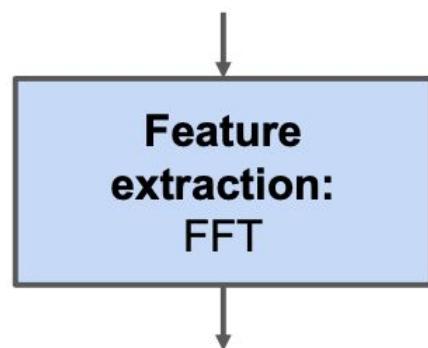
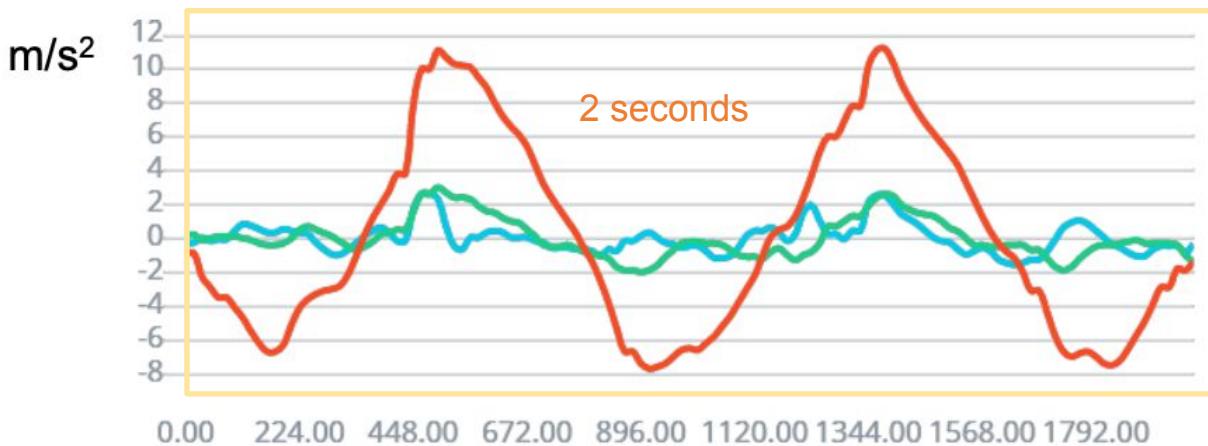


Manual Feature Extraction

- 3 RMS (Root Mean Square) values
- one for each axis (x, y, z)

$$x_{\text{RMS}} = \sqrt{\frac{1}{n} (x_1^2 + x_2^2 + \dots + x_n^2)}.$$

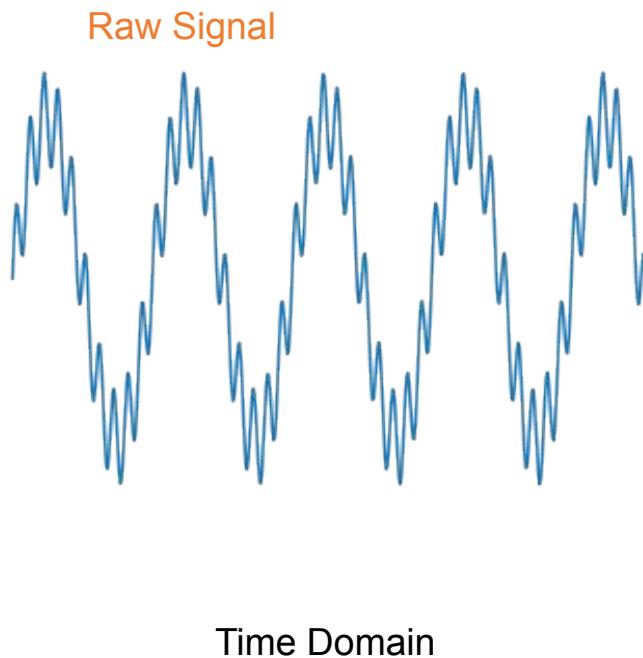
→ 125



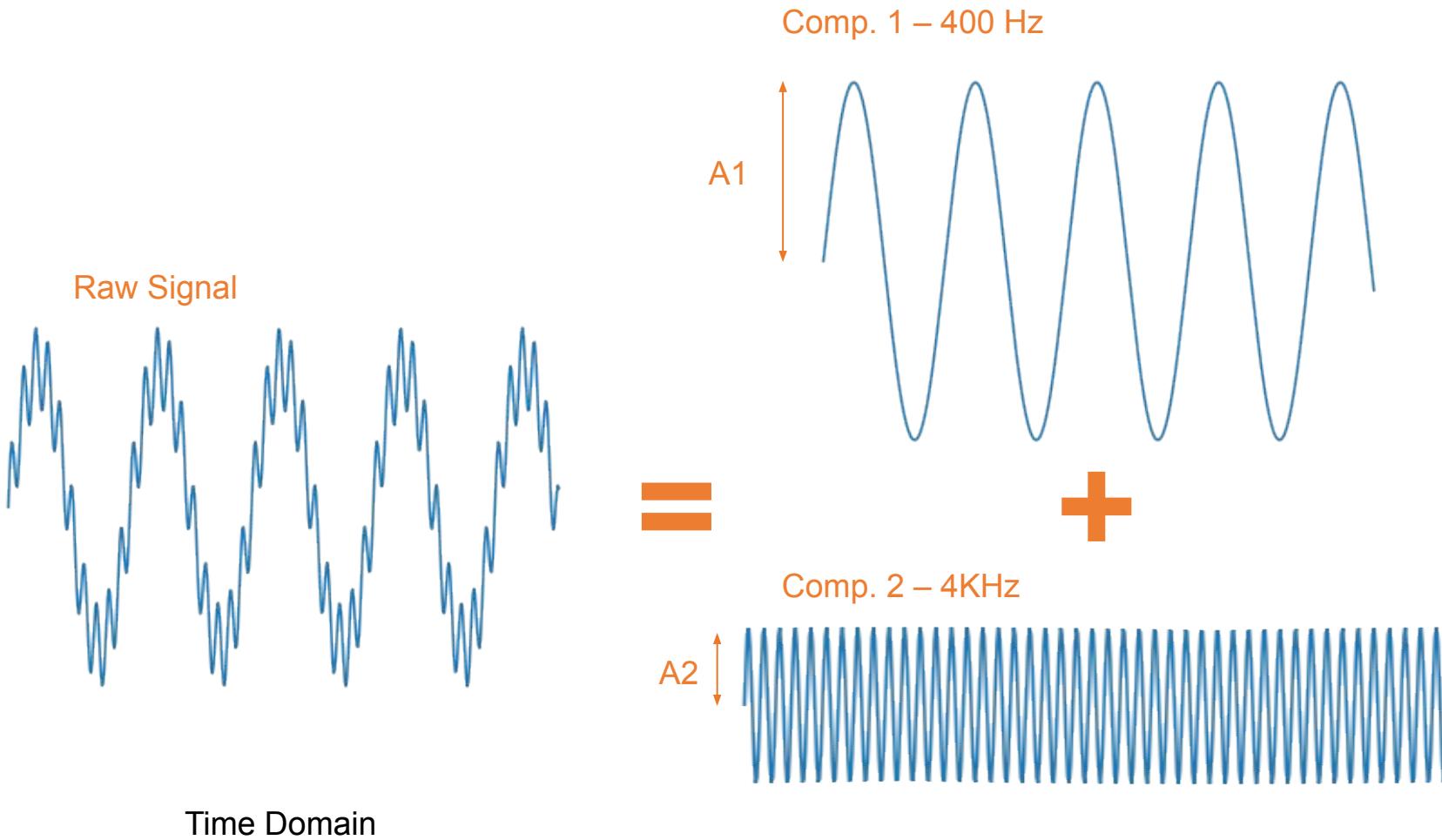
Manual Feature Extraction

3 RMS

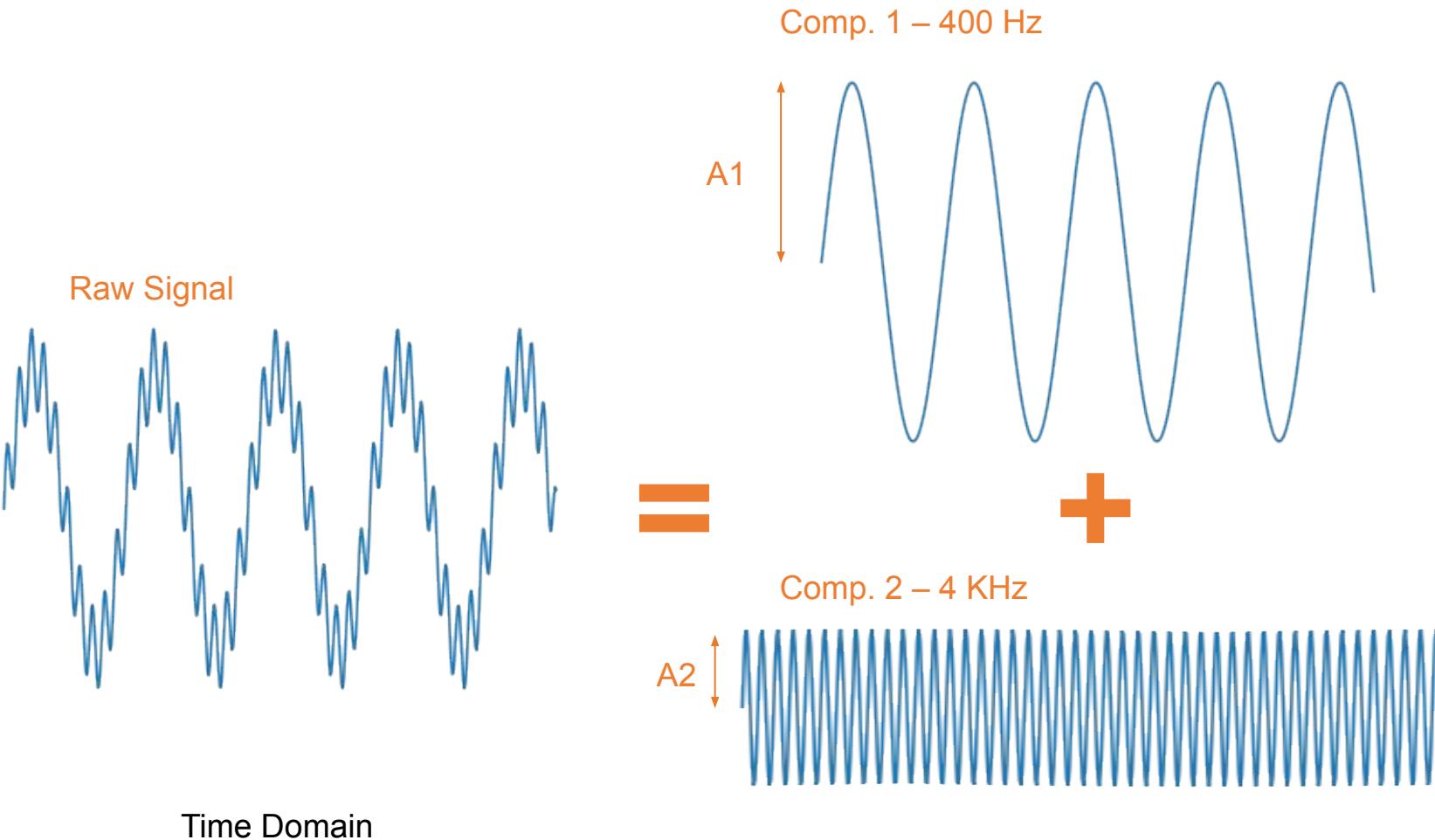
Fast Fourier Transformer (FFT)



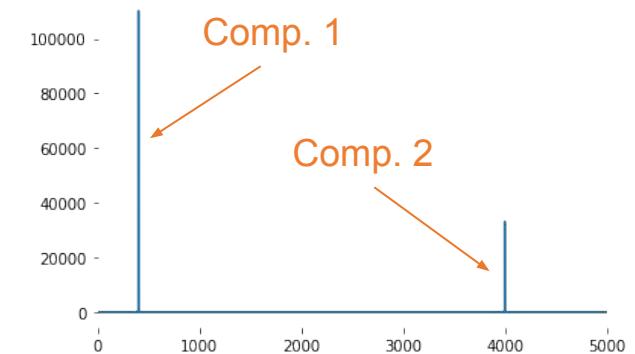
Fast Fourier Transformer (FFT)



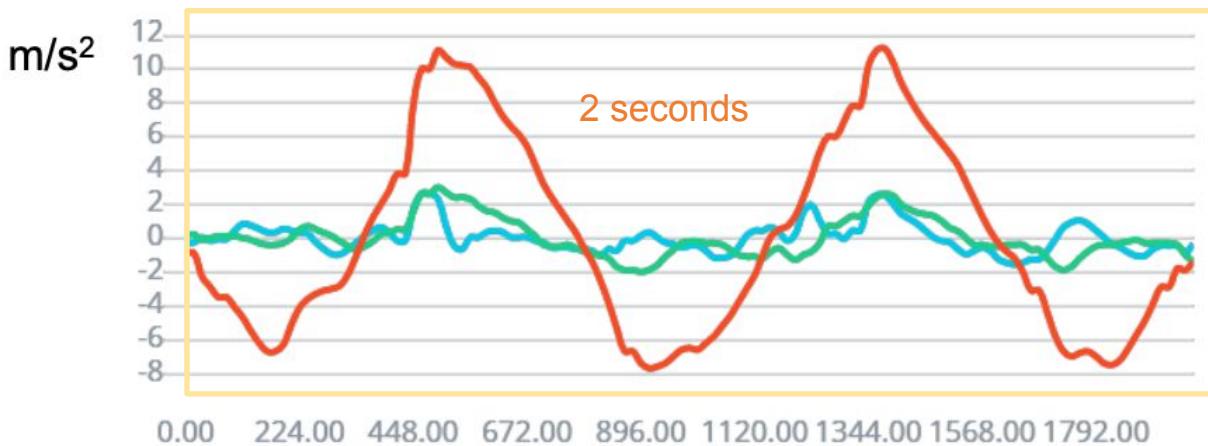
Fast Fourier Transformer (FFT)



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

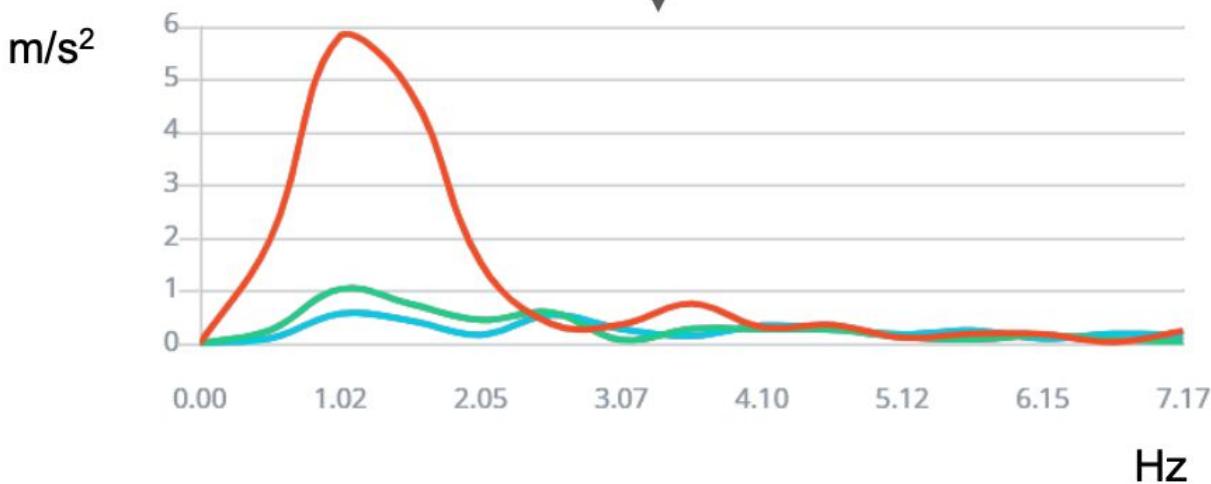
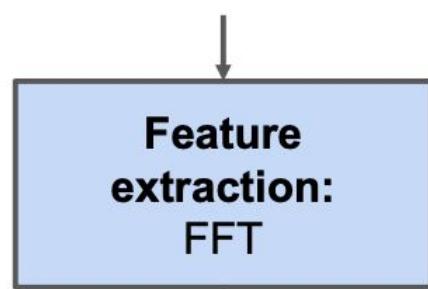


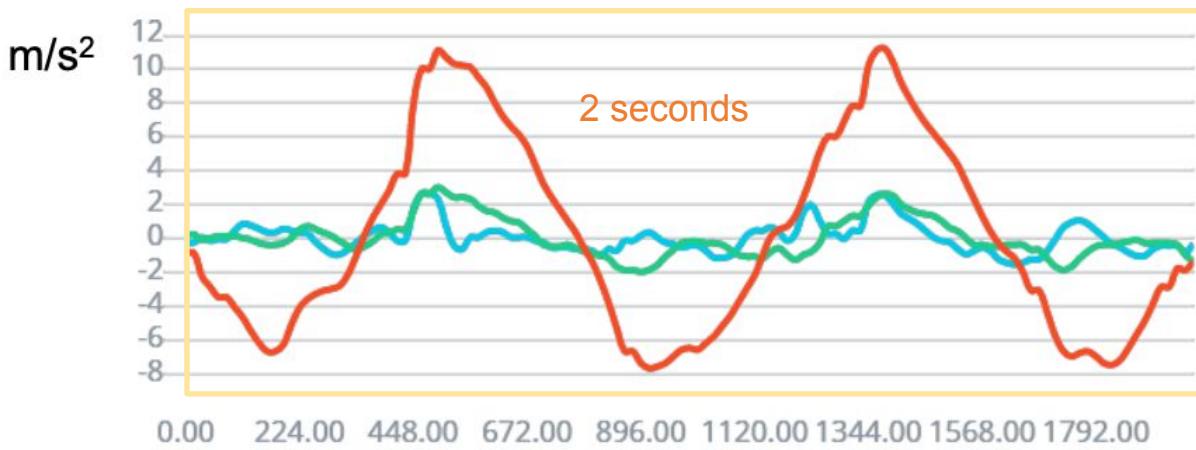
Frequency Domain



Manual Feature Extraction

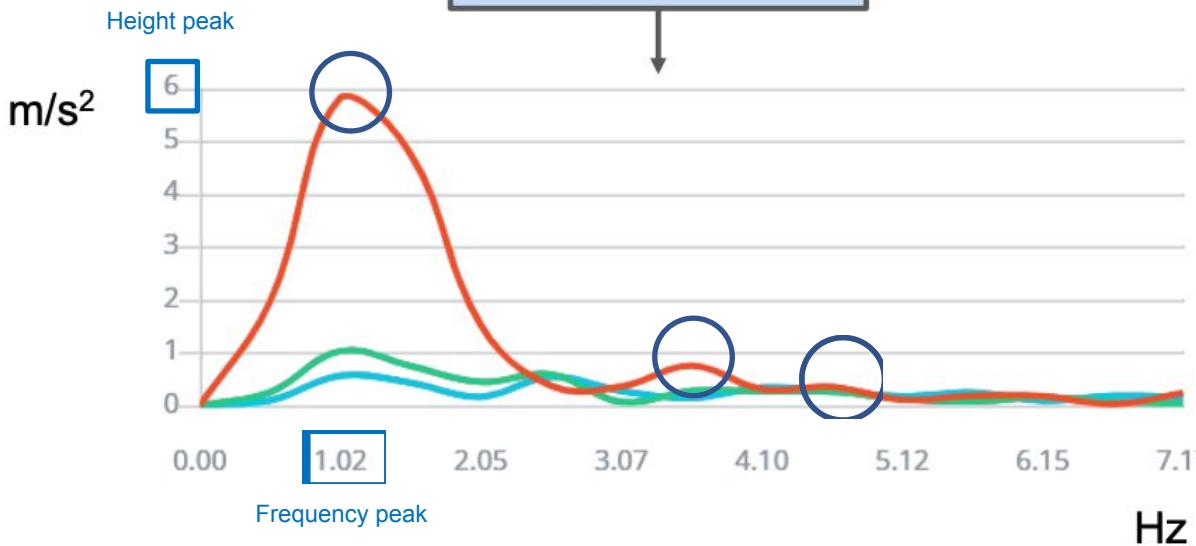
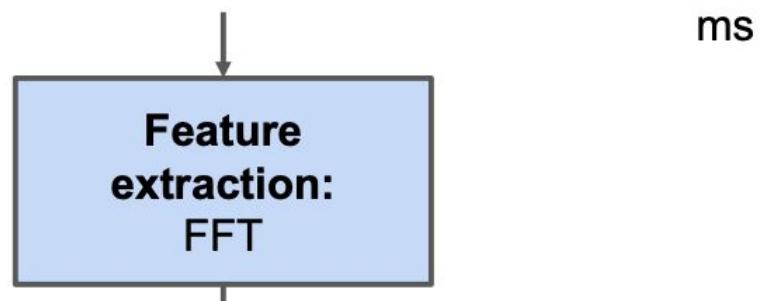
3 RMS



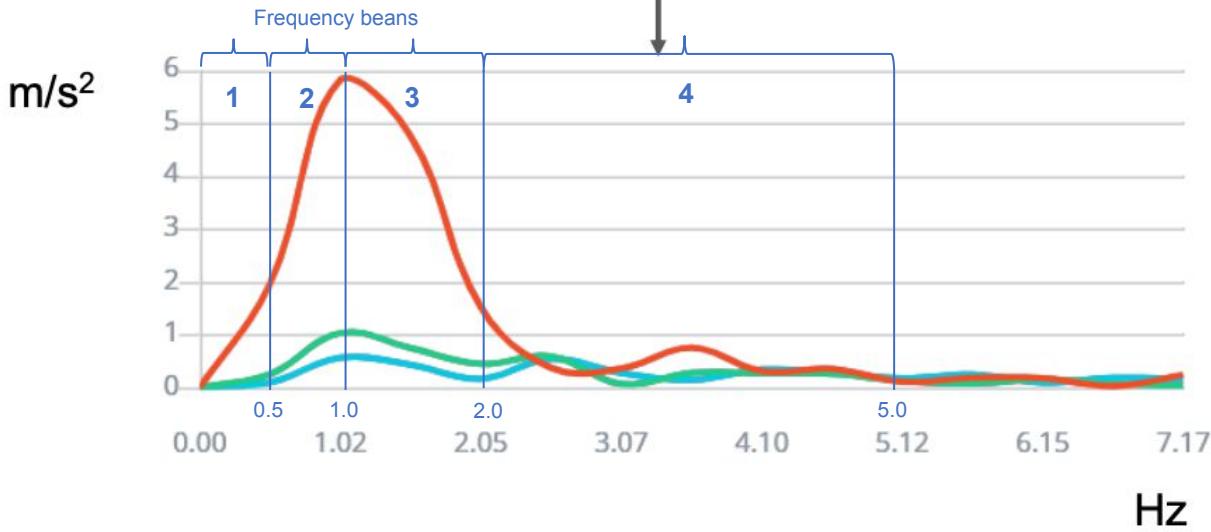
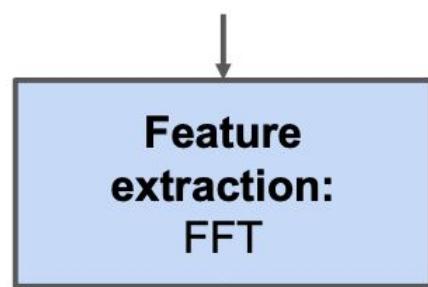
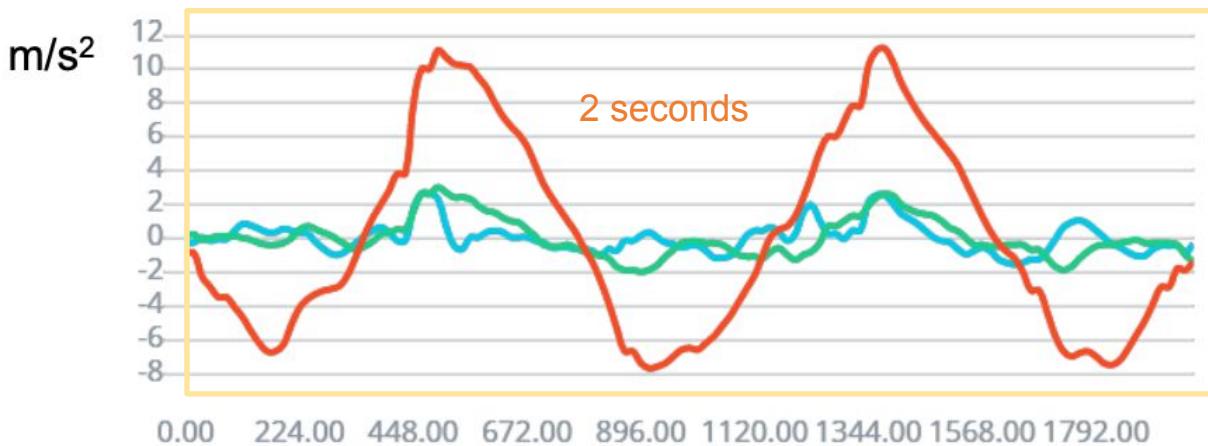


Manual Feature Extraction

3 RMS



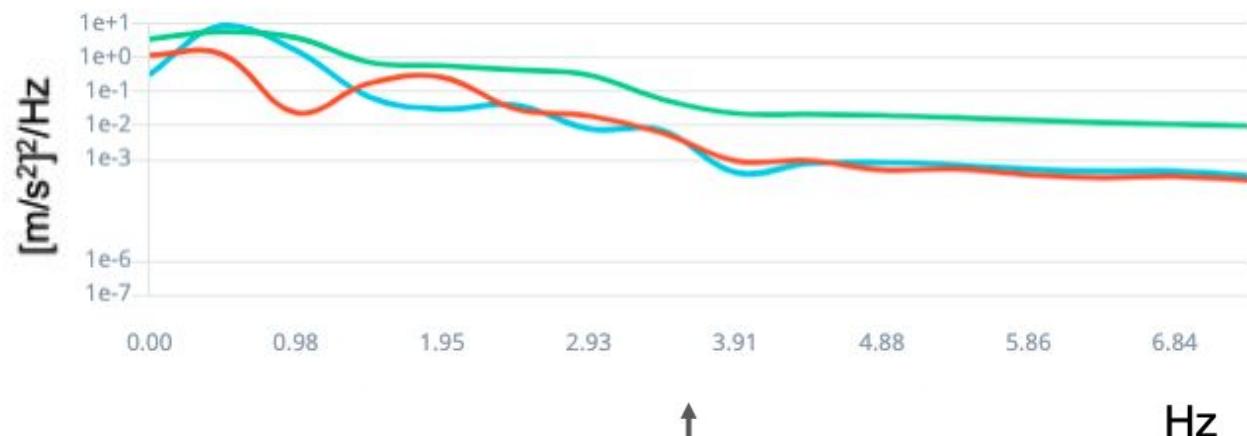
9 Height + 9 Freq. peak values



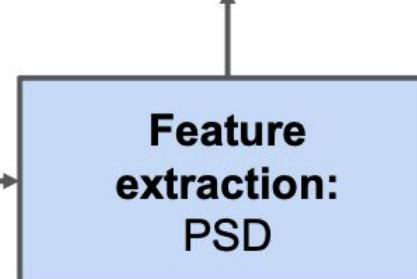
Manual Feature Extraction

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

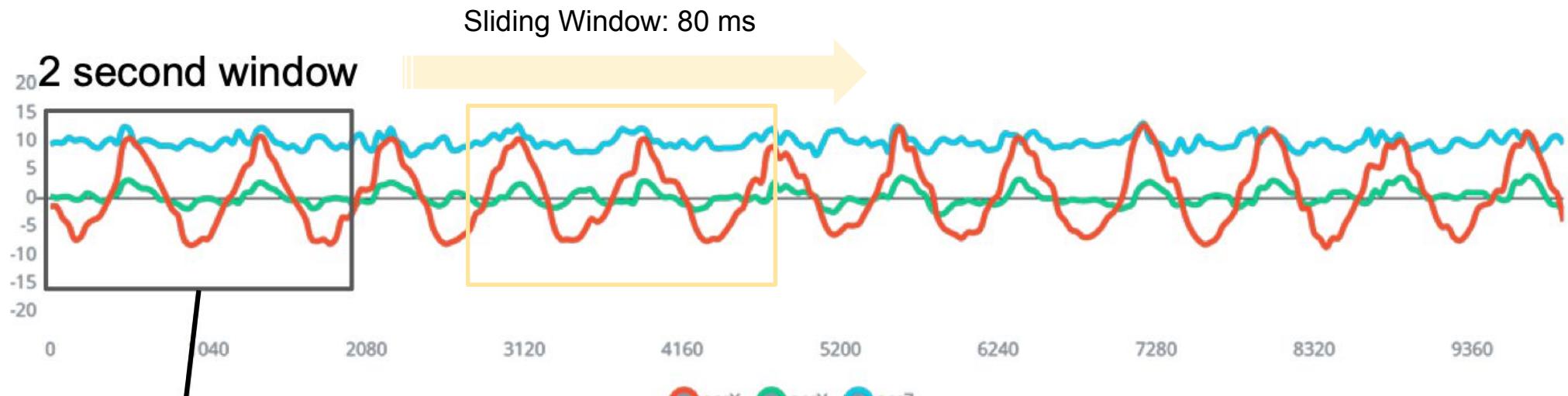
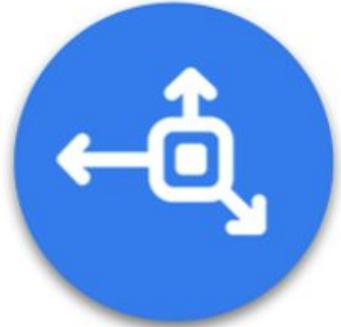
Power Spectral Density (PSD)



4 Frequency bins per axis



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



375 Raw Features

- Raw Data from sensor

Manual Feature Extraction

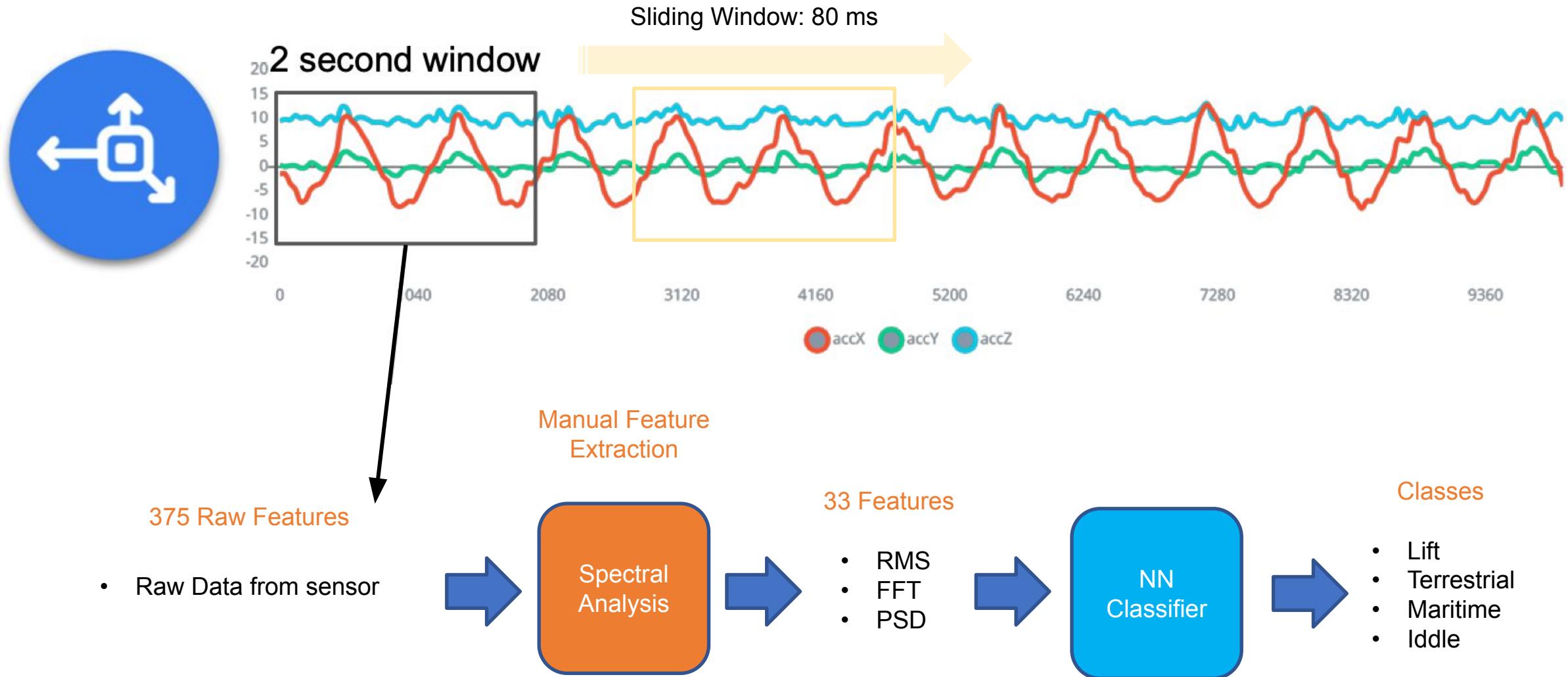
Spectral Analysis

11 Features

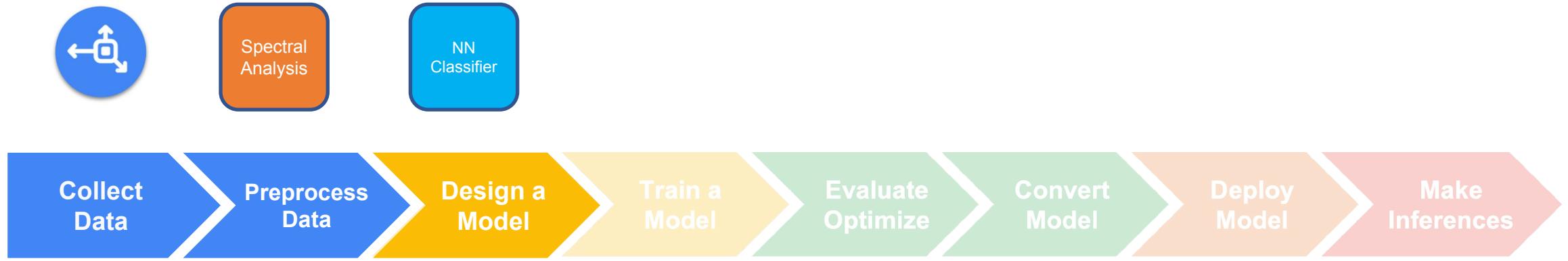
11 Features

11 Features

accX RMS	accY RMS
accX Peak	accY Peak
accX 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 Peak 3 Height
accZ Spectral Power 0.1 - 0.5	accZ Spectral Power 0.5 - 1.0
accZ Spectral Power 0.5 - 1.0	accZ Spectral Power 1.0 - 2.0
accZ Spectral Power 1.0 - 2.0	accZ Spectral Power 2.0 - 5.0
accZ Spectral Power 2.0 - 5.0	



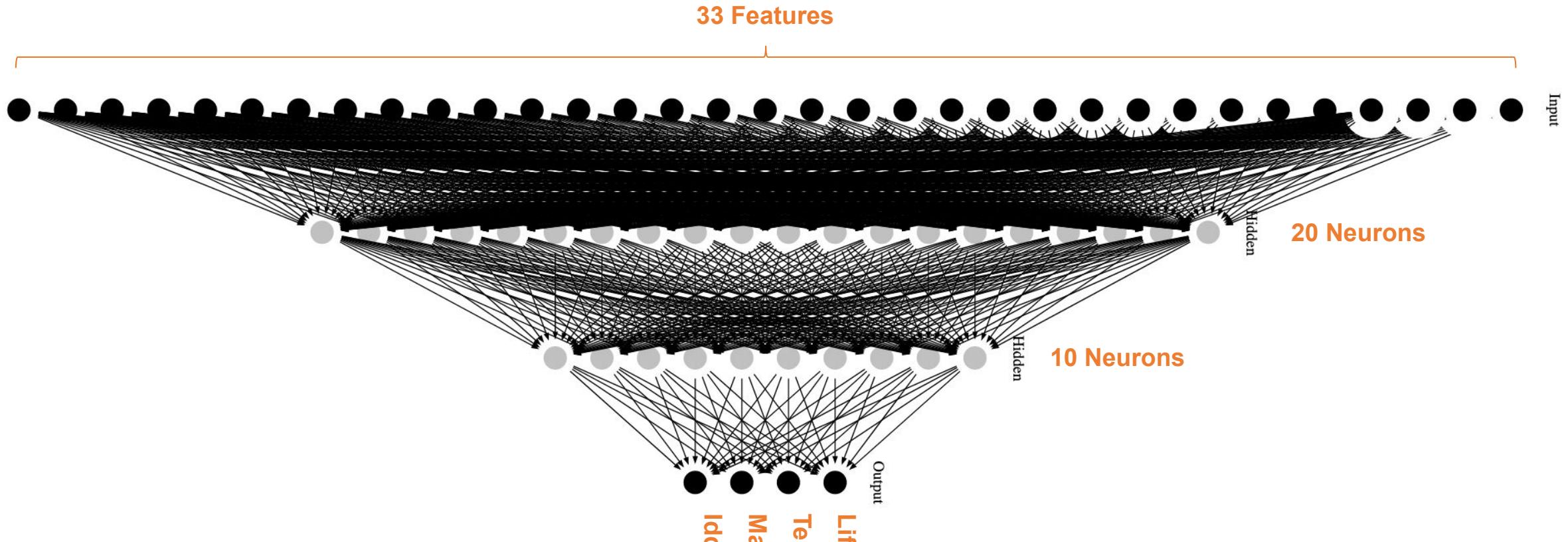
Model Design (NN Classifier)



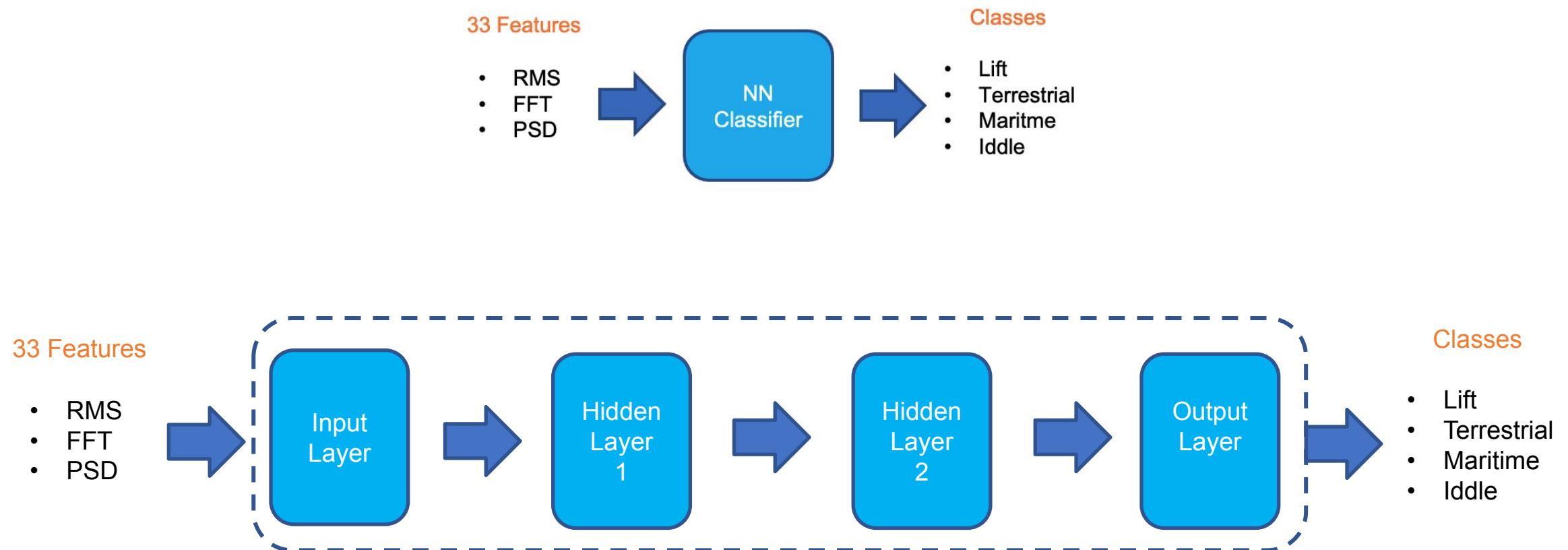
Model Design (NN Classifier)



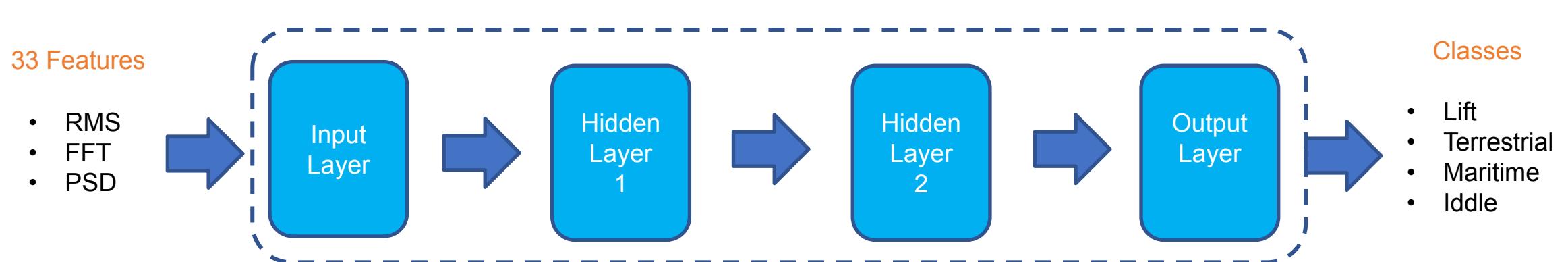
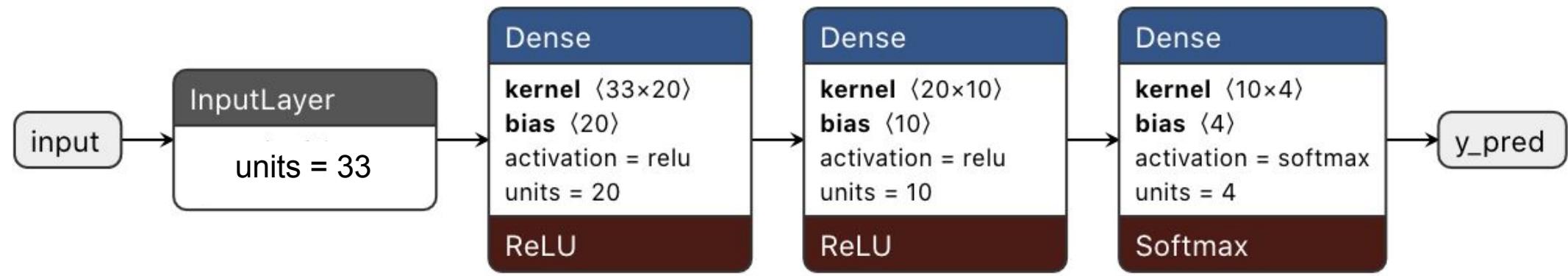
Model Design (DNN Classifier)



Model Design (DNN Classifier)



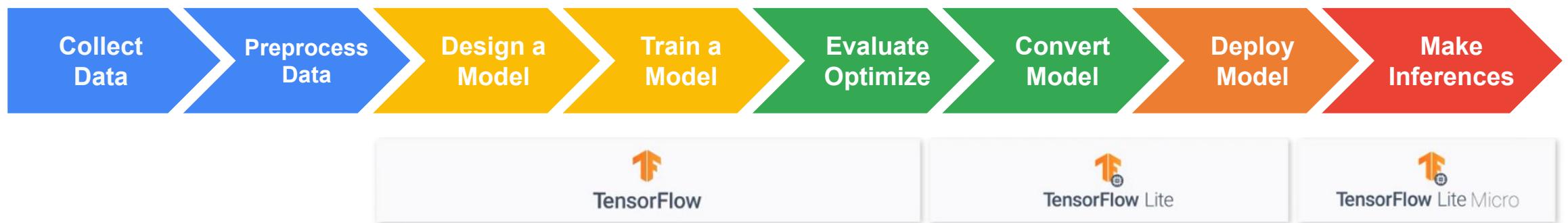
Model Design (DNN Classifier)



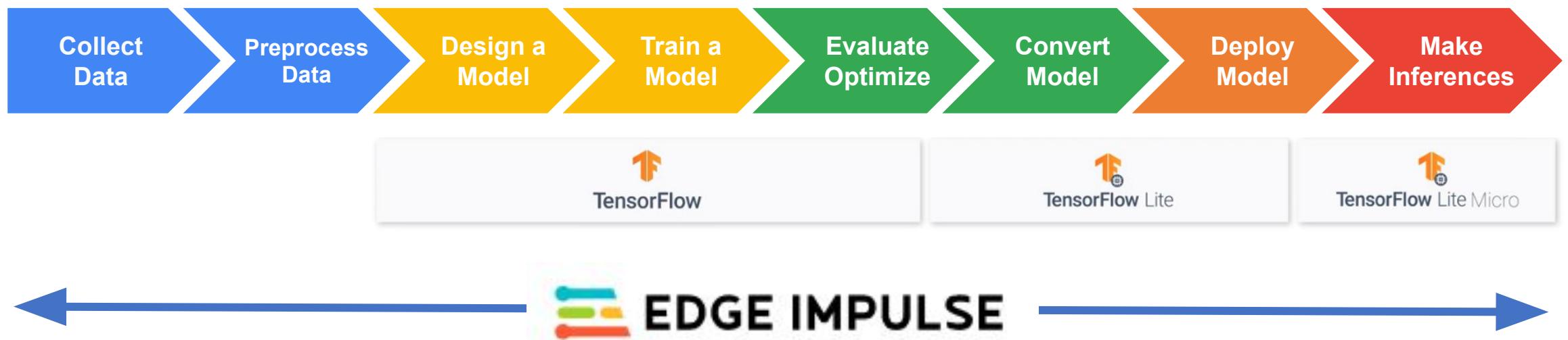
Train, Evaluate, Convert, Deploy the Model



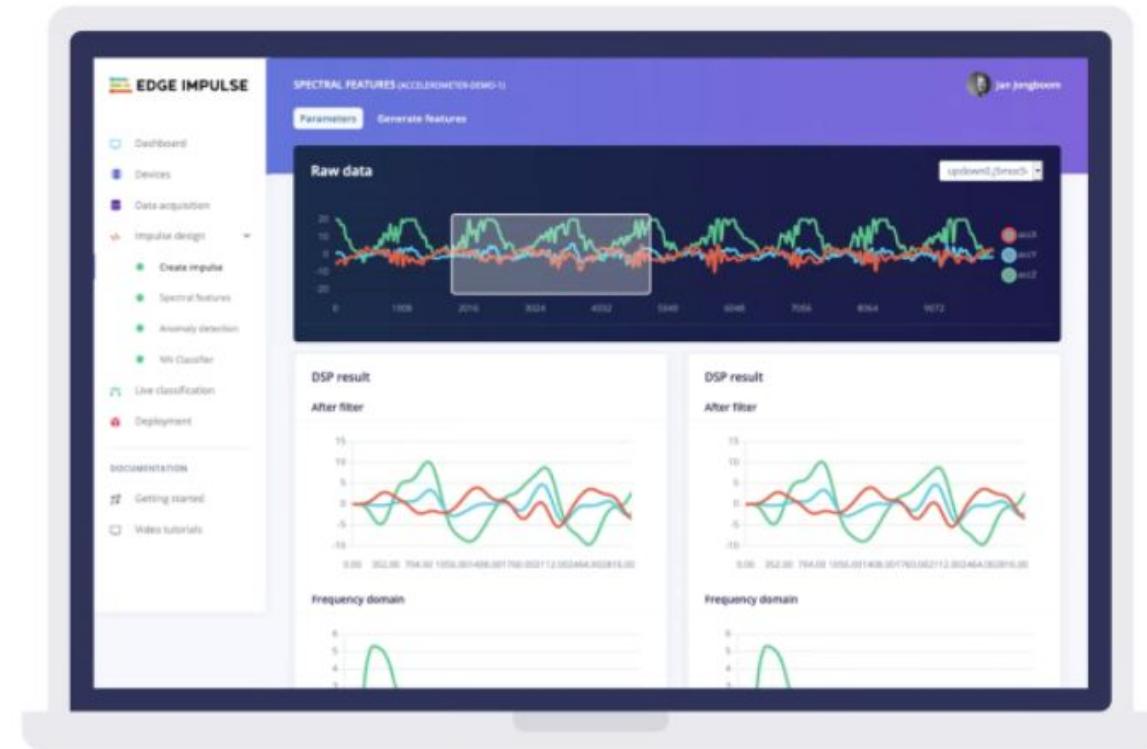
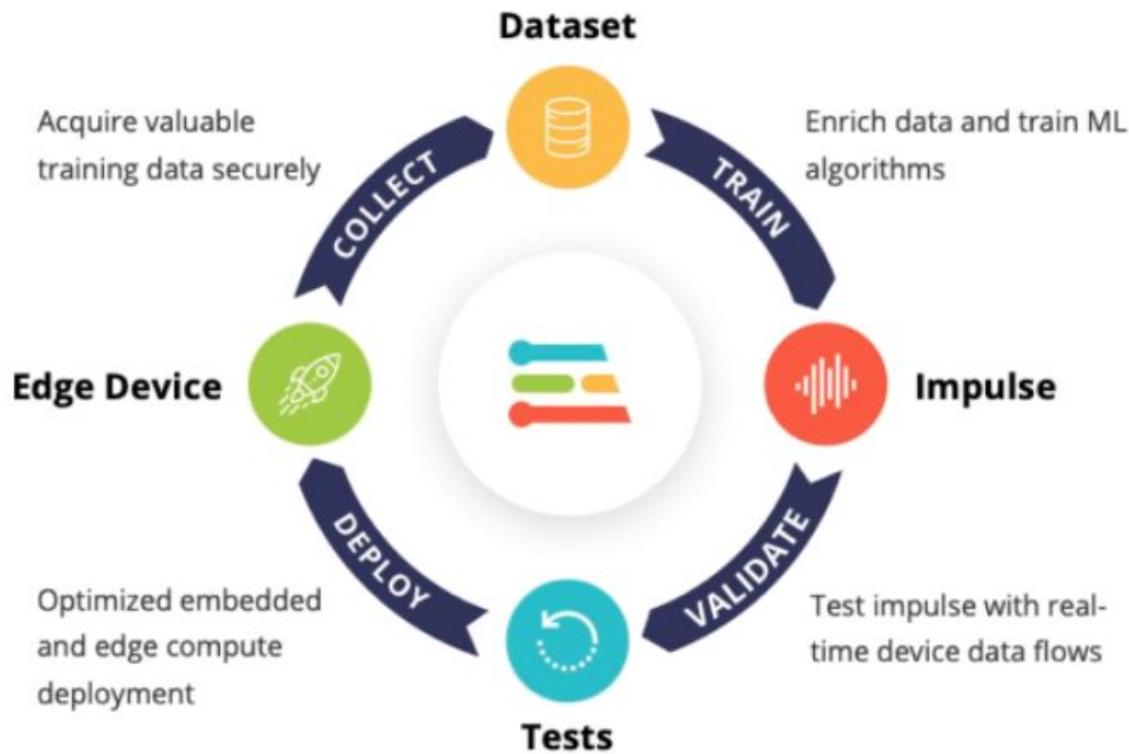
Train, Evaluate, Convert, Deploy the Model



Machine Learning Workflow



EI Studio - Embedded ML platform



Learn more at <http://edgeimpulse.com>



Dashboard - SciTinyML-Motion-Project

studio.edgeimpulse.com/studio/51797

EDGE IMPULSE

Project info Keys Export

MJRoBot (Marcelo Rovai)

Dashboard Devices Data acquisition Impulse design Create impulse Spectral Analysis Neural Network (Ke...) EON Tuner Retrain model Live classification Model testing Versioning Deployment

GETTING STARTED Documentation Forums

MJRoBot (Marcelo Rovai) / SciTinyML-Motion-Project

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

Creating your first impulse (100% complete)

Acquire data

Every Machine Learning project starts with data. You can capture data from a development board or your phone, or import data you already collected.

LET'S COLLECT SOME DATA

Design an impulse

Teach the model to interpret previously unseen data, based on historical data. Use this to categorize new data, or to find anomalies in sensor readings.

GETTING STARTED: CONTINUOUS MOTION RECOGNITION

GETTING STARTED: RESPONDING TO YOUR VOICE

GETTING STARTED: ADDING SIGHT TO YOUR SENSORS

Deploy

Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.

DEPLOY YOUR MODEL

Download block output

Sharing

Your project is private.

Make this project public

Summary

DEVICES CONNECTED 1

DATA COLLECTED 6m 41s

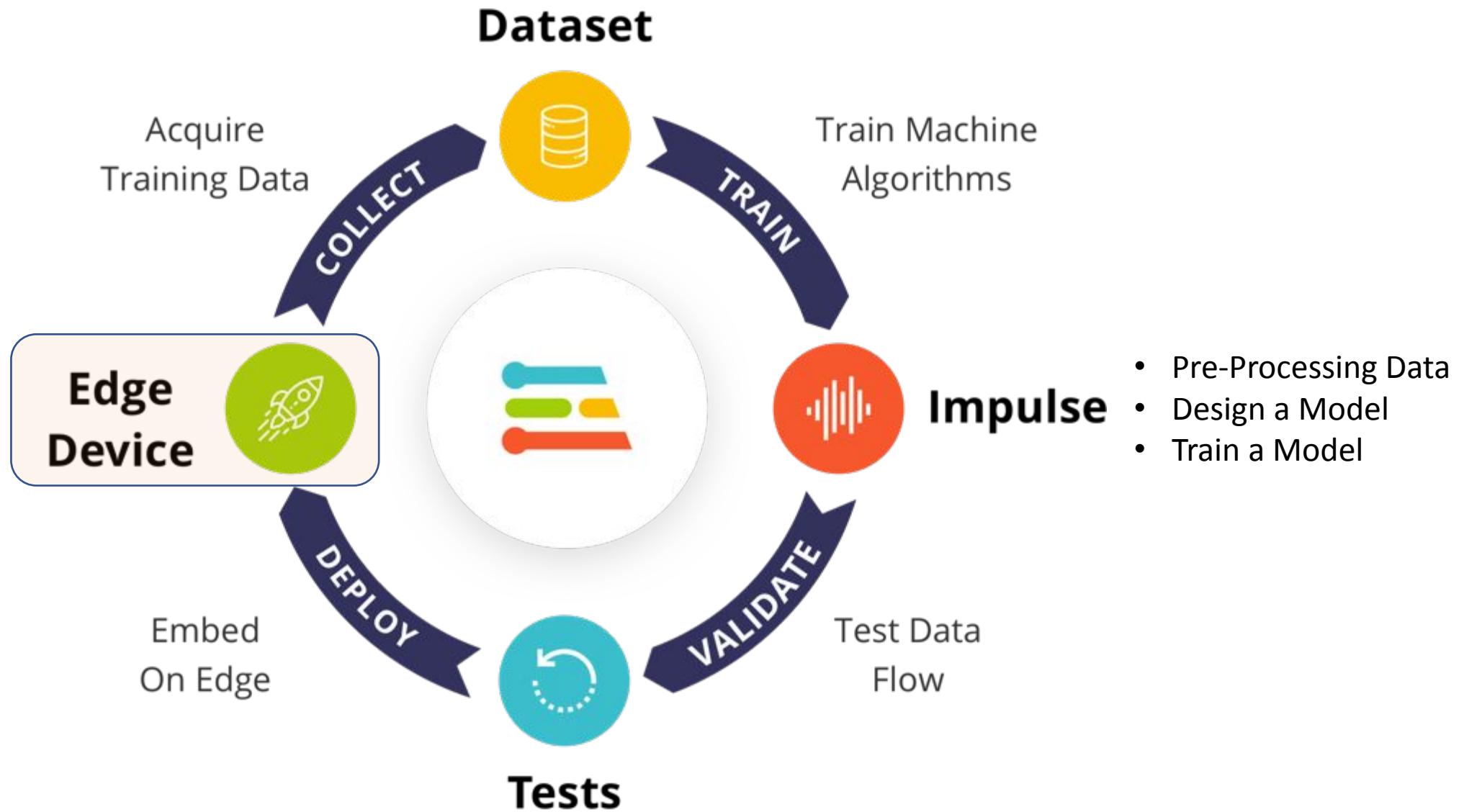
Collaborators

MJRoBot (Marcelo Rovai) OWNER

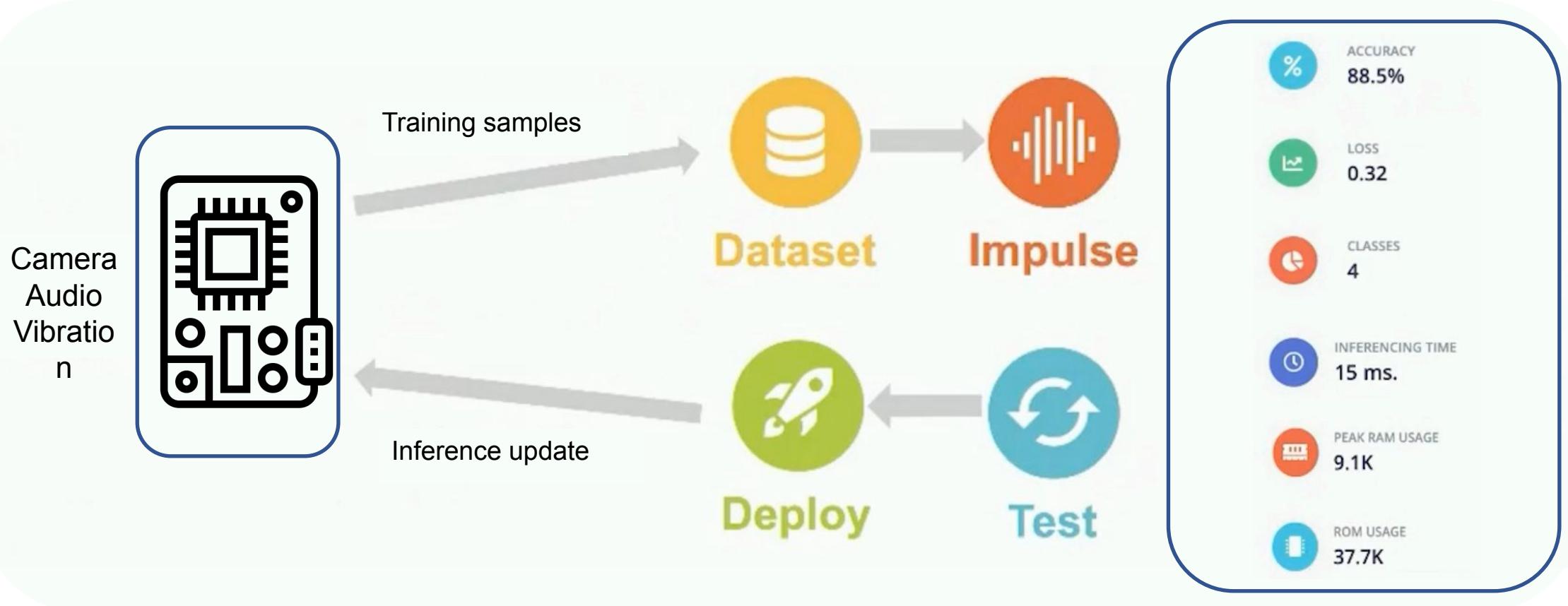
Project info

Project ID 51797

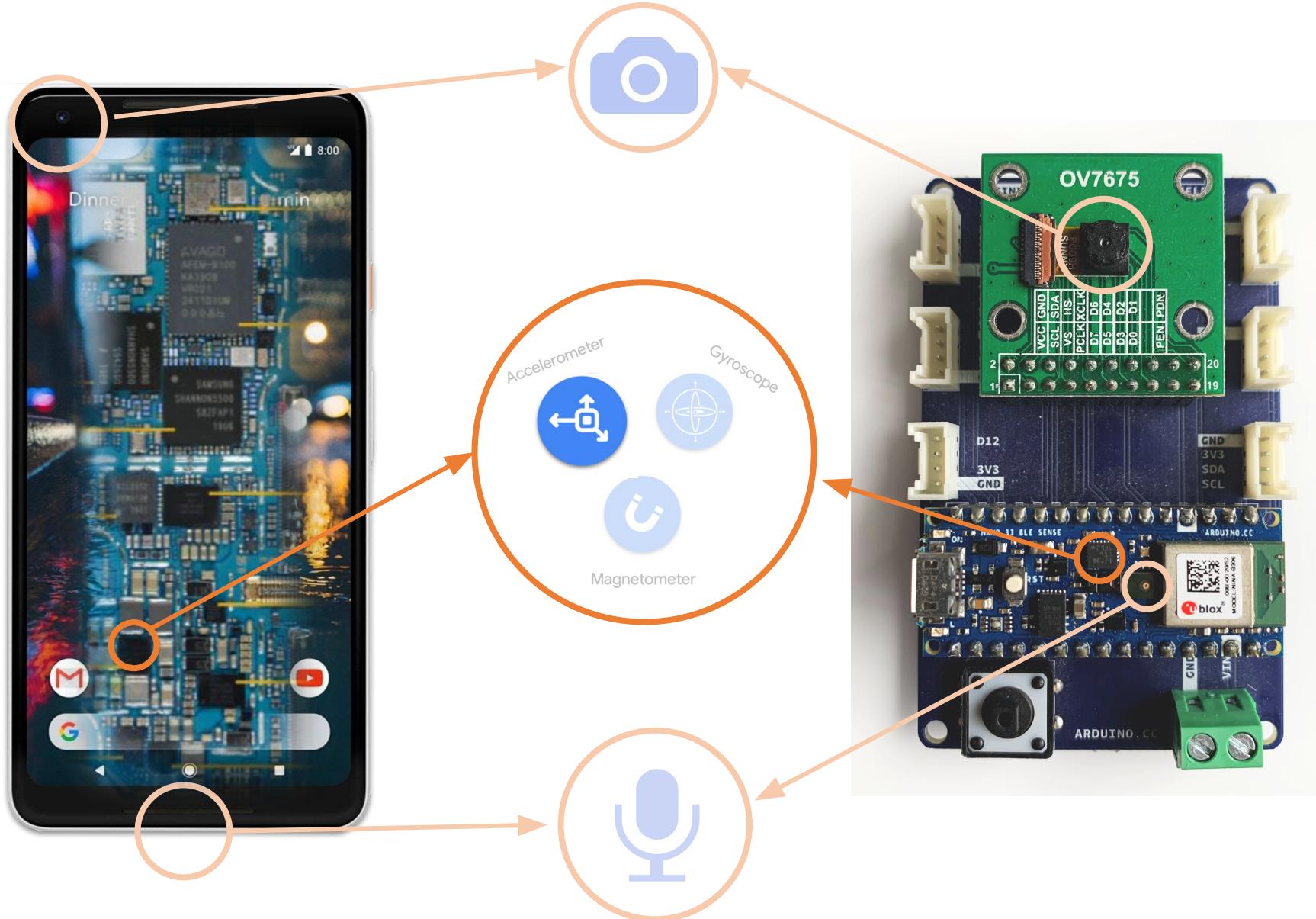
<https://studio.edgeimpulse.com/public/51963/latest>



Data-driven engineering



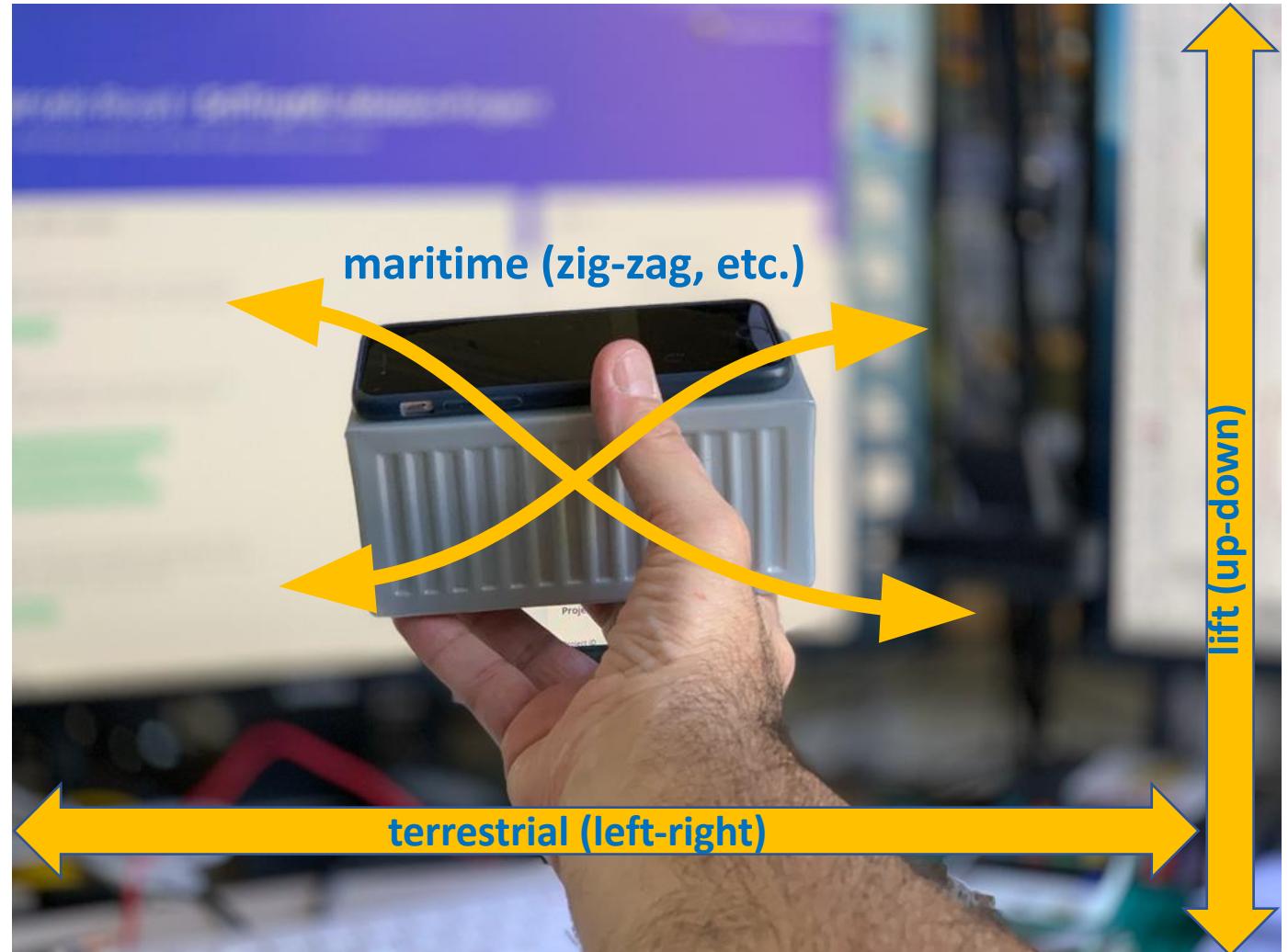
Sensor - IMU (Inertial Measurement Unit)



Motion Classification

Transportation Classes

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



Motion Classification

Transportation Classes

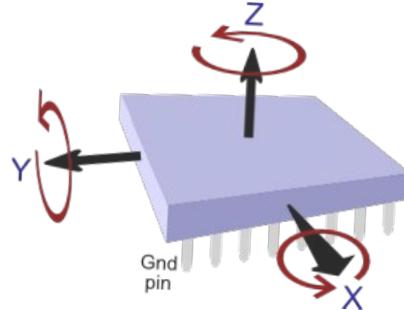
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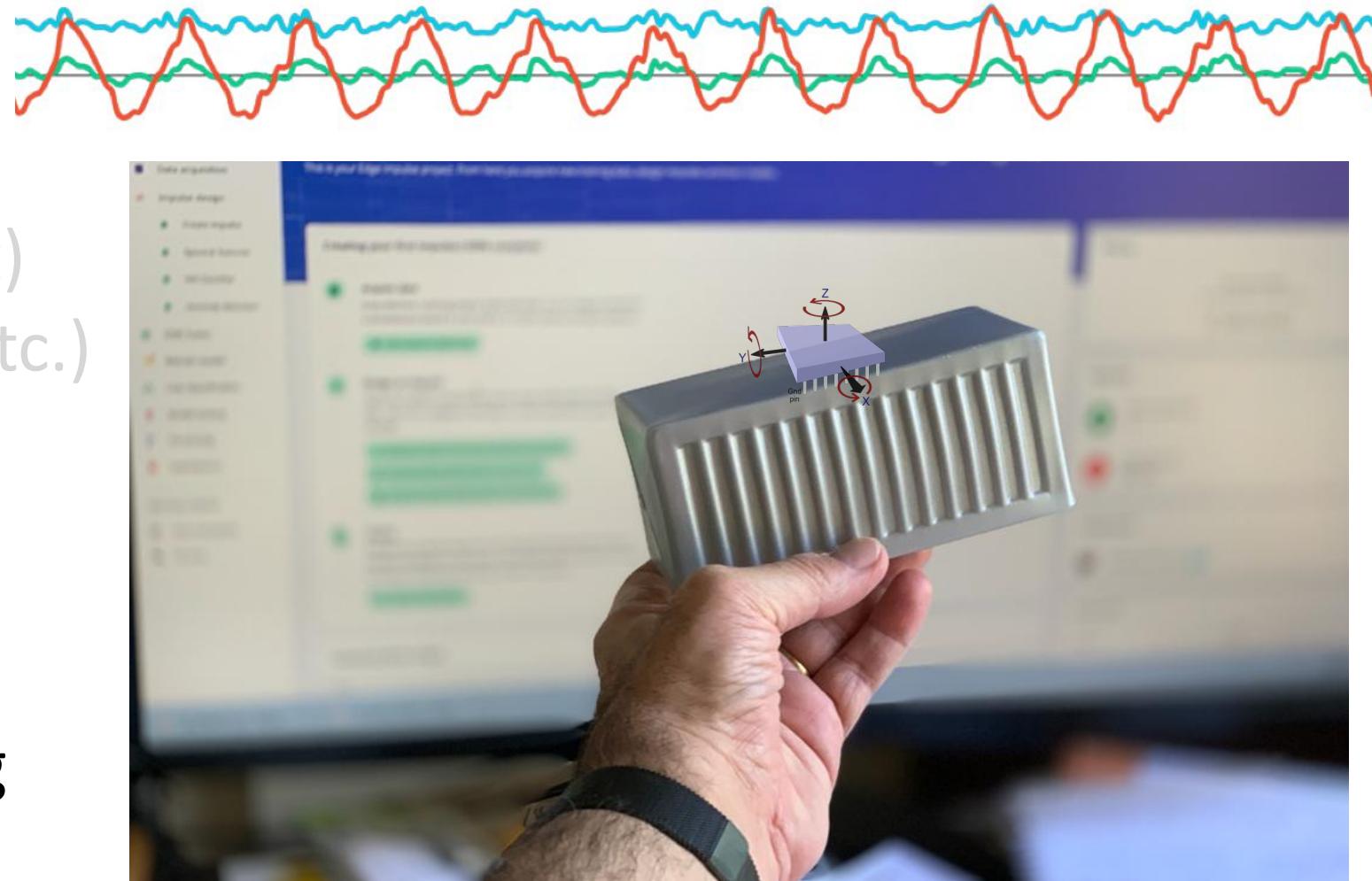
Motion Classification

Transportation Classes

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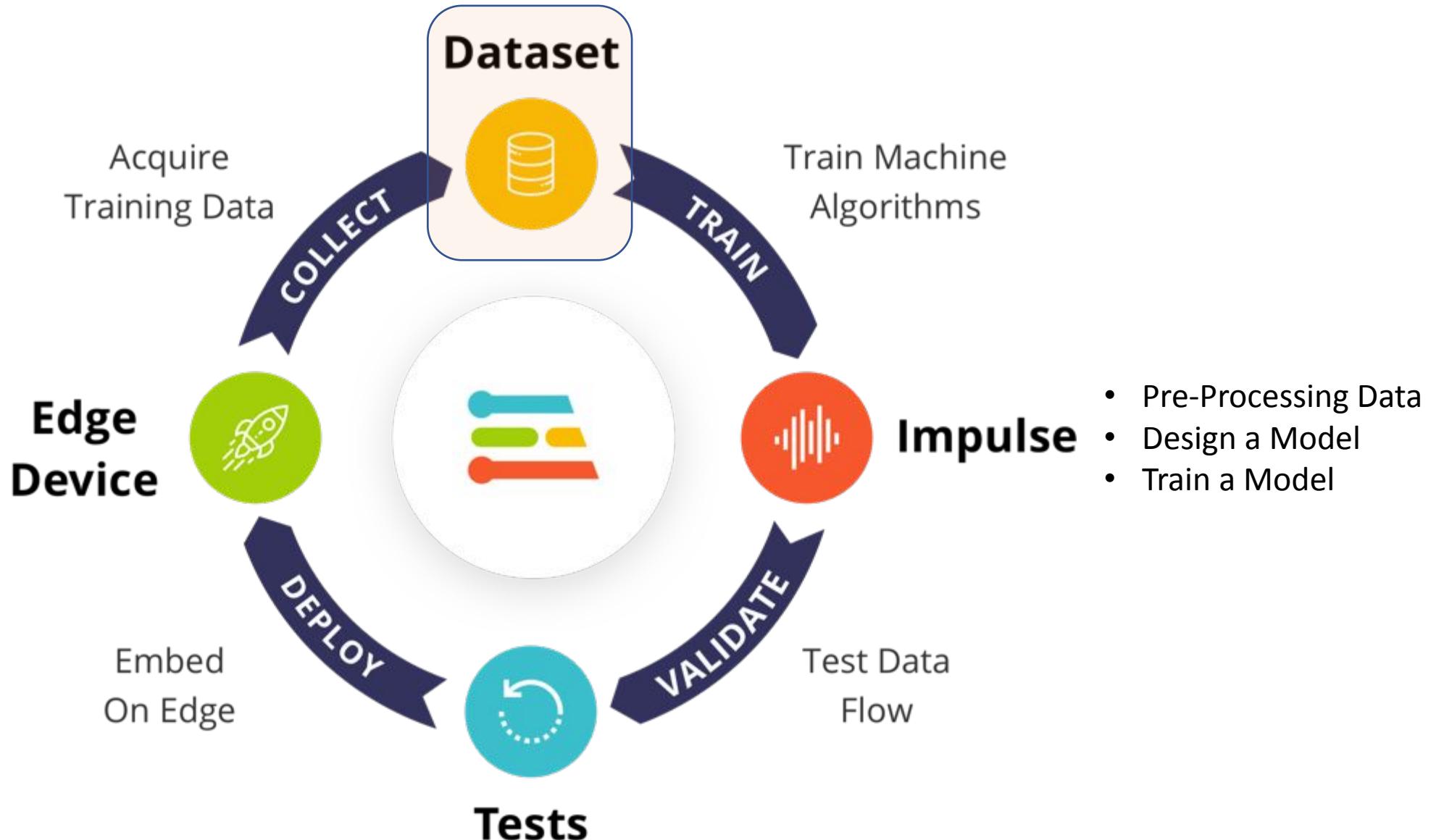


Data: collect & test using
accelerometer as sensor



Dataset Collection

Using Smart-Phone



Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

DEVICES (TINYML4D - PROJECT SETUP)

Your projects

Collect data

These are the ways you can 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

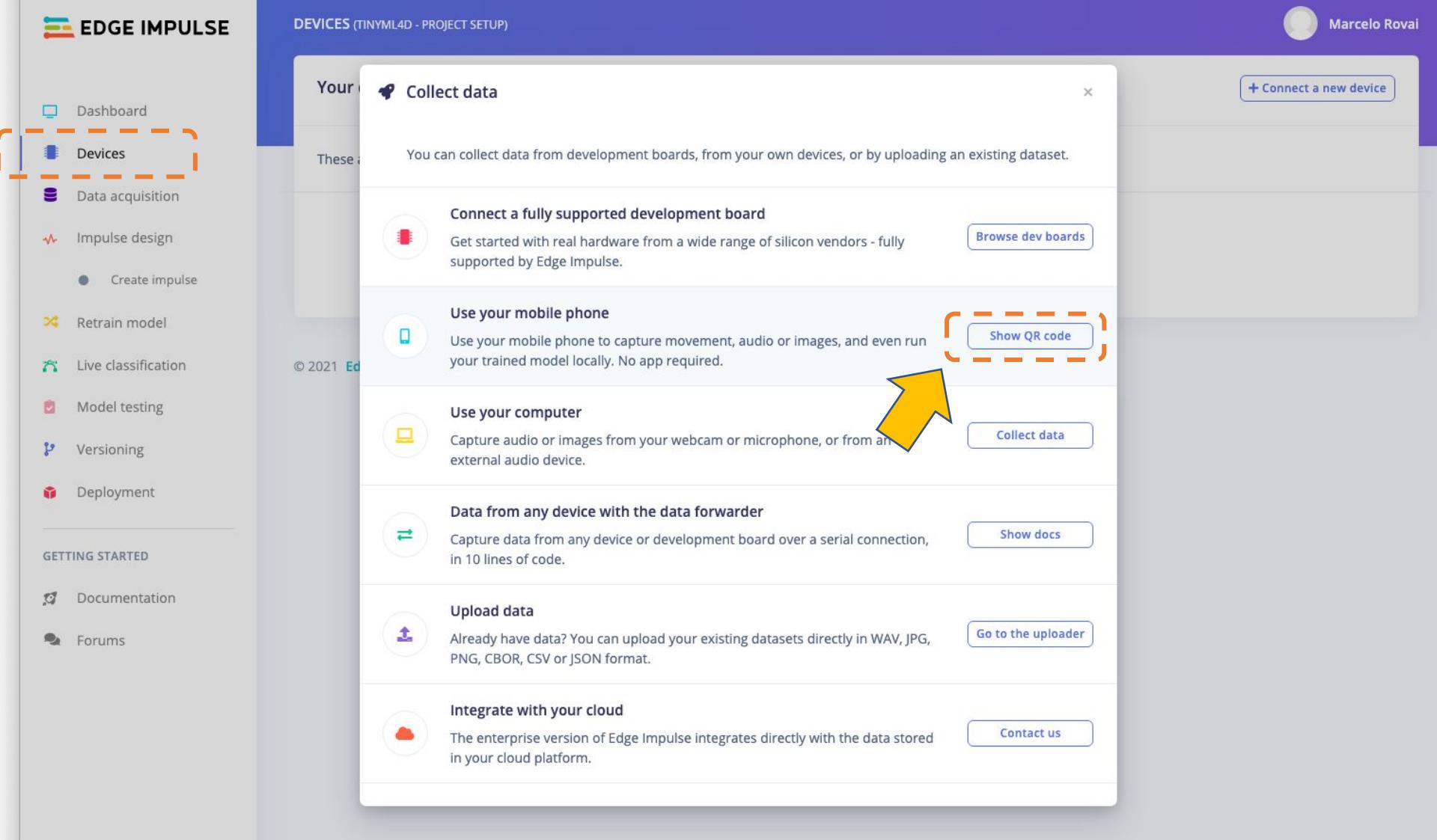
The enterprise version of Edge Impulse integrates directly with the data stored in your cloud platform.

[Contact us](#)

+ Connect a new device

Marcelo Rovai

© 2021 Edge Impulse Inc.



Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

DEVICES (TINYML4D - PROJECT SETUP)

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

Devices

Dashboard

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

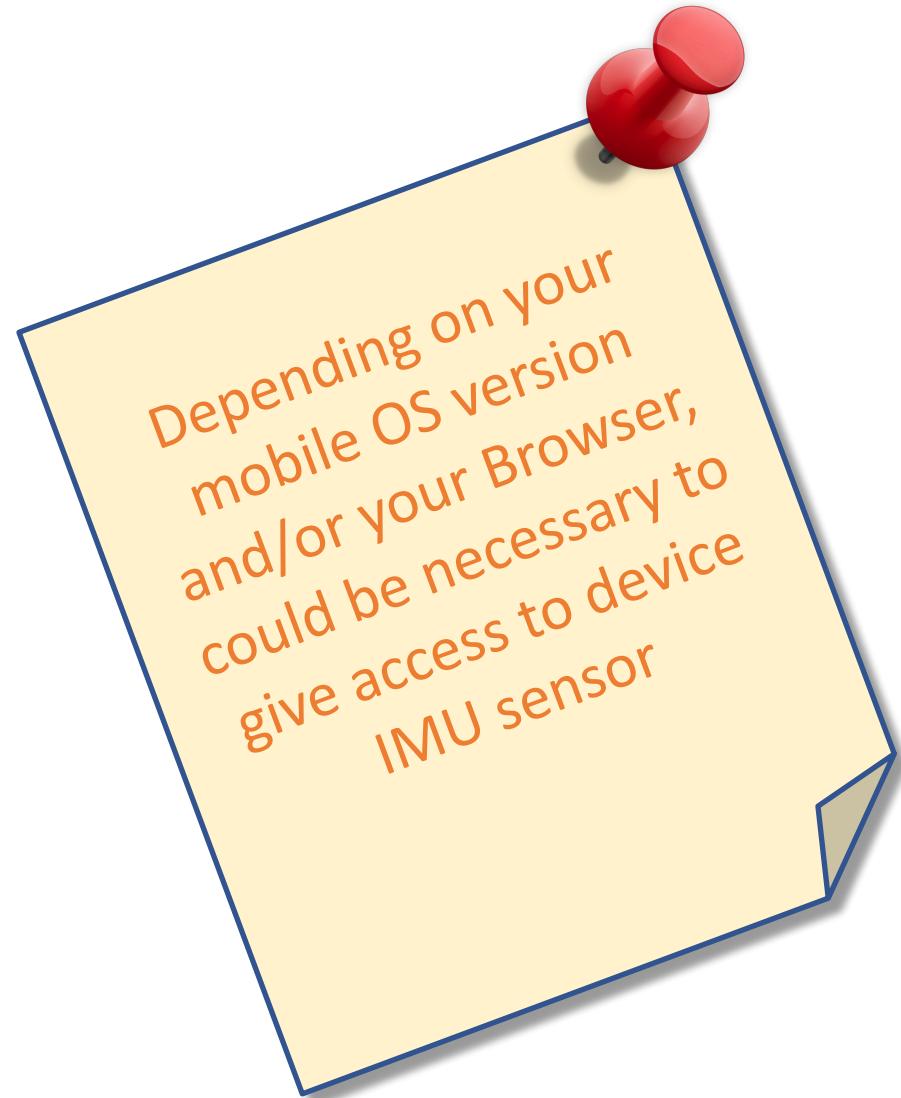
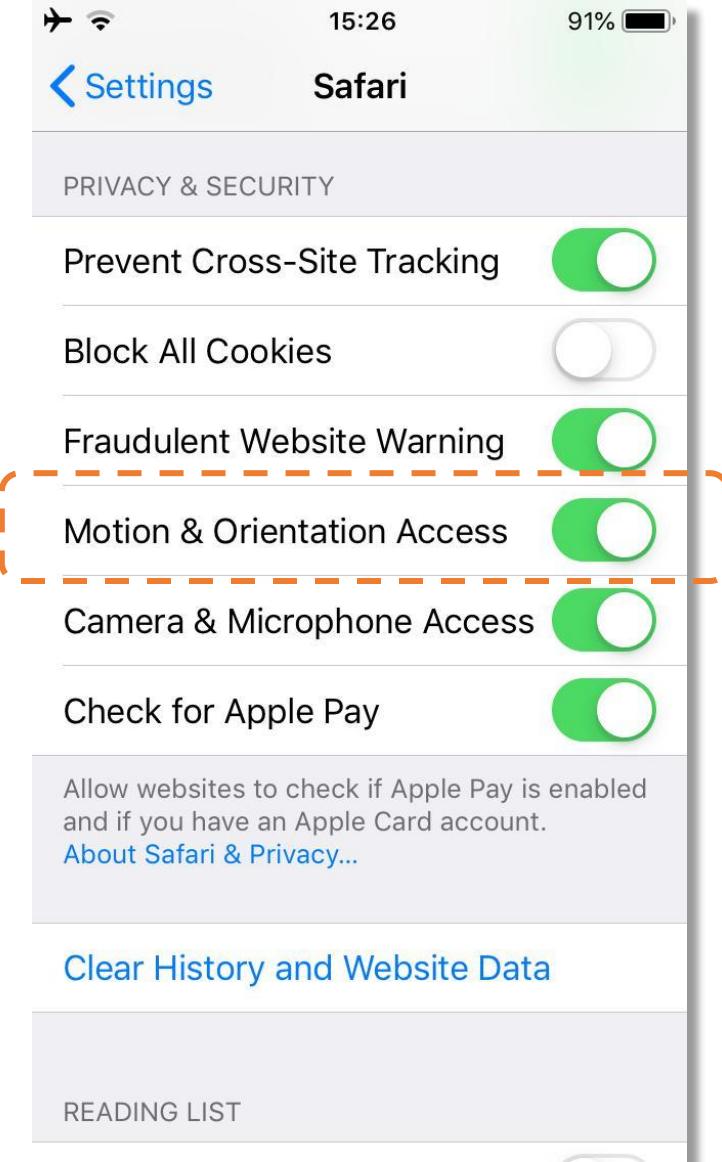
Documentation

Forums

Marcelo Rovai

WEBSITE QR CODE
Open "edgeimpulse.com" in Safari





Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

Devices

Your devices

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, Microphone	...	Today, 12:06:04

+ Connect a new device

Collect data

Device phone_kq6ray4k is now connected

Get started!

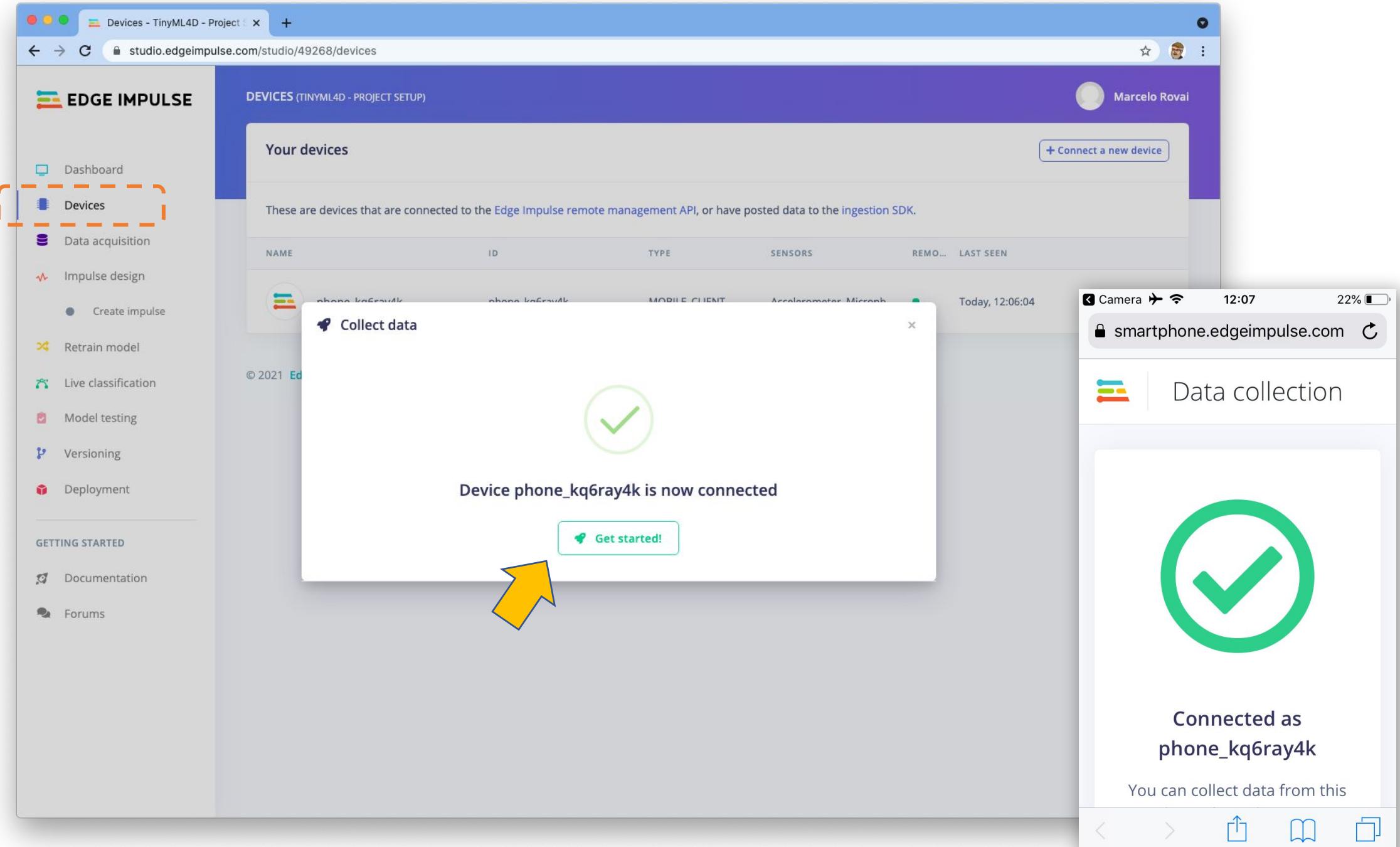
© 2021 Edge Impulse Inc.

Camera 12:07 22% smartphone.edgeimpulse.com

Data collection

Connected as phone_kq6ray4k

You can collect data from this



Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

DEVICES (TINYML4D - PROJECT SETUP)

Marcelo Rovai

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

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Dashboard

Devices (highlighted with orange dashed box)

Data acquisition

Impulse design

- Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Camera 12:07 22%

smartphone.edgeimpulse.com

Data collection

Connected as phone_kq6ray4k

You can collect data from this



DATA ACQUISITION (TINYML4D - PROJECT SETUP)

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 -

LABELS 0

Record new data

Device ⓘ No devices connected

Label up_down

Sensor

RAW DATA Click on a sample to load...

Connect using WebUSB

12:20 44% smartphone.edgeimpulse.com

Data collection

Not connected

Refresh this page to reconnect to Edge Impulse

The screenshot shows the Edge Impulse Data Acquisition interface for the TinyML4D project. On the left sidebar, 'Data acquisition' is selected. The main area displays a message about capturing data from devices or uploading datasets. Below this, a 'Collected data' section shows 'No data collected yet' and a 'Let's collect some data' button. To the right, a 'Record new data' form is open, showing a 'Device' dropdown set to 'No devices connected'. The 'Label' field contains 'up_down' and the 'Sensor' dropdown is empty. At the bottom, a dark blue bar says 'Click on a sample to load...'. A large orange 'X' icon and the text 'Not connected' are prominently displayed on the right side. The top right corner shows a user profile for Marcelo Rovai and a system status bar with battery level at 44%, time at 12:20, and the URL smartphone.edgeimpulse.com.

Collect Data

The screenshot shows the Edge Impulse Data Acquisition interface. On the left, a sidebar menu includes options like Dashboard, Devices, Data acquisition (highlighted with an orange dashed box), and Create impulse, Spectral Analysis, Neural Network (Ke...). The main area displays 'DATA ACQUISITION (SCITINYML-MOTION-PROJECT)' with tabs for Training data and Test data. A message says 'Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options'. Below is a summary: 'DATA COLLECTED 5m 13s' and 'TRAIN / TEST SPLIT 80% / 20%'. A 'Collected data' table lists 15 entries, mostly labeled 'idle'. To the right, the 'Record new data' section shows a 'Device' dropdown set to 'phone_kq6ray4k', a 'Label' input set to 'maritime' (highlighted with an orange dashed box), a 'Sample length (ms.)' input set to '10000', a 'Sensor' dropdown set to 'Accelerometer' (highlighted with an orange dashed box), a 'Frequency' dropdown set to '62.5Hz', and a large blue 'Start sampling' button. A yellow arrow points to this button. At the bottom, a circular progress bar shows '4s' and a status bar indicates 'smartphone.edgeimpulse.com' and 'Data collection'.

DATA ACQUISITION (SCITINYML-MOTION-PROJECT)

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 13s

TRAIN / TEST SPLIT
80% / 20%

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
idle.2hstvpk2	idle	Oct 14 2021, 17:54:22	10s	⋮
idle.2hstuaut	idle	Oct 14 2021, 17:53:34	10s	⋮
idle.2hstt0q3	idle	Oct 14 2021, 17:53:16	10s	⋮
idle.2hstt9dk	idle	Oct 14 2021, 17:53:00	10s	⋮
idle.2hstp4a	idle	Oct 14 2021, 17:52:43	10s	⋮
idle.2hstrkad	idle	Oct 14 2021, 17:52:06	10s	⋮
idle.2hstr3kf	idle	Oct 14 2021, 17:51:49	10s	⋮
idle.2hstqaj	idle	Oct 14 2021, 17:51:32	10s	⋮
maritime.2hstpku3	maritime	Oct 14 2021, 17:51:01	10s	⋮
maritime.2hsto9ki	maritime	Oct 14 2021, 17:50:16	10s	⋮
maritime.2hstnnqu	maritime	Oct 14 2021, 17:49:58	10s	⋮
maritime.2hstn60c	maritime	Oct 14 2021, 17:49:40	10s	⋮

Record new data

Device: phone_kq6ray4k

Label: maritime

Sample length (ms.): 10000

Sensor: Accelerometer

Frequency: 62.5Hz

Start sampling

Sensor dropdown: Accelerometer (highlighted with an orange dashed box)

Data collection

4s

Recording data

Collect Data

EDGE IMPULSE

DATA ACQUISITION (SCITINYML-MOTION-PROJECT)

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 13s

TRAIN / TEST SPLIT
80% / 20%

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
idle.2hstvpk2	idle	Oct 14 2021, 17:54:22	10s
idle.2hstuaut	idle	Oct 14 2021, 17:53:34	10s
idle.2hstt0q3	idle	Oct 14 2021, 17:53:16	10s
idle.2hstt9dk	idle	Oct 14 2021, 17:53:00	10s
idle.2hstp4a	idle	Oct 14 2021, 17:52:43	10s
idle.2hstrkad	idle	Oct 14 2021, 17:52:06	10s
idle.2hstr3kf	idle	Oct 14 2021, 17:51:49	10s
idle.2hstqaj	idle	Oct 14 2021, 17:51:32	10s
maritime.2hstpku3	maritime	Oct 14 2021, 17:51:01	10s
maritime.2hsto9ki	maritime	Oct 14 2021, 17:50:16	10s
maritime.2hstnnqu	maritime	Oct 14 2021, 17:49:58	10s
maritime.2hstn60c	maritime	Oct 14 2021, 17:49:40	10s

Record new data

Device: phone_kq6ray4k

Label: maritime

Sample length (ms.): 10000

Sensor: Accelerometer

Frequency: 62.5Hz

Start sampling

RAW DATA
maritime.2hstpku3

accX accY accZ

The screenshot shows the Edge Impulse Data Acquisition interface. A blue arrow on the left points to the 'Data acquisition' section in the sidebar. The main area displays a summary of collected data (5m 13s total, 80% train, 20% test split) and a table of individual samples with columns for name, label, added date, and length. To the right, there's a 'Record new data' section with fields for device (set to 'phone_kq6ray4k'), label ('maritime'), sample length (10000 ms), sensor ('Accelerometer'), and frequency (62.5Hz). Below this is a 'RAW DATA' plot titled 'maritime.2hstpku3' showing three stacked time-series signals (accX, accY, accZ) over time steps 1008 to 9075. The plot has a dark background with red, green, and blue lines representing the respective axes.

Collect
Data

Original Dataset

Original Dataset

Collect
Data

Training Set

Test Set

Original Dataset

Training Set

Test Set

Training Set

Validation Set

Test Set

Collect
Data

Original Dataset

Training Set

Test Set

Collect
Data

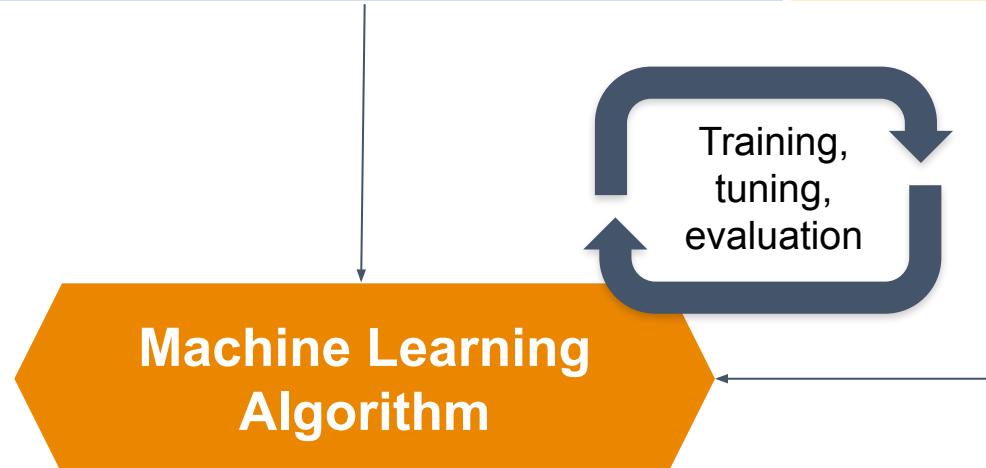
Training Set

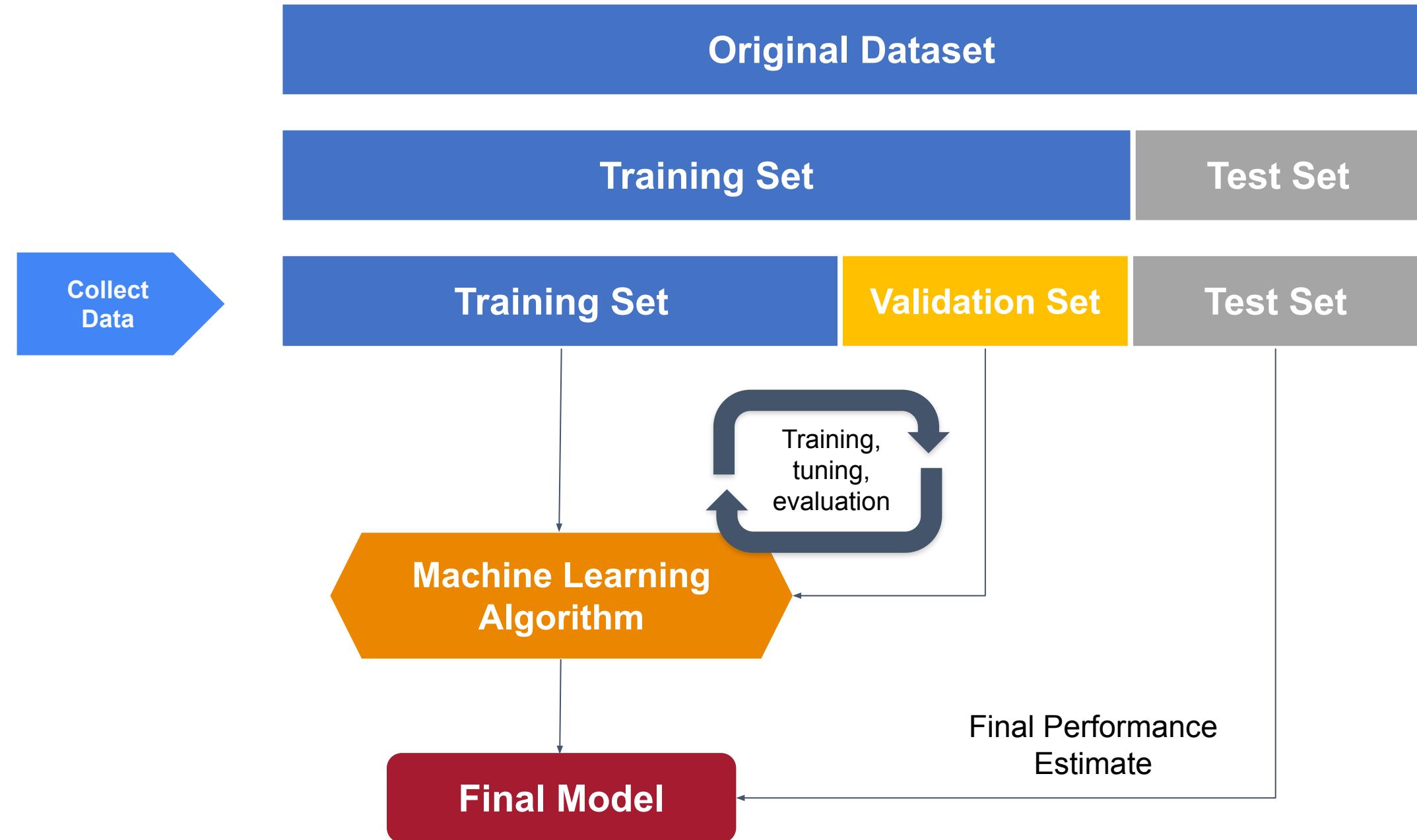
Validation Set

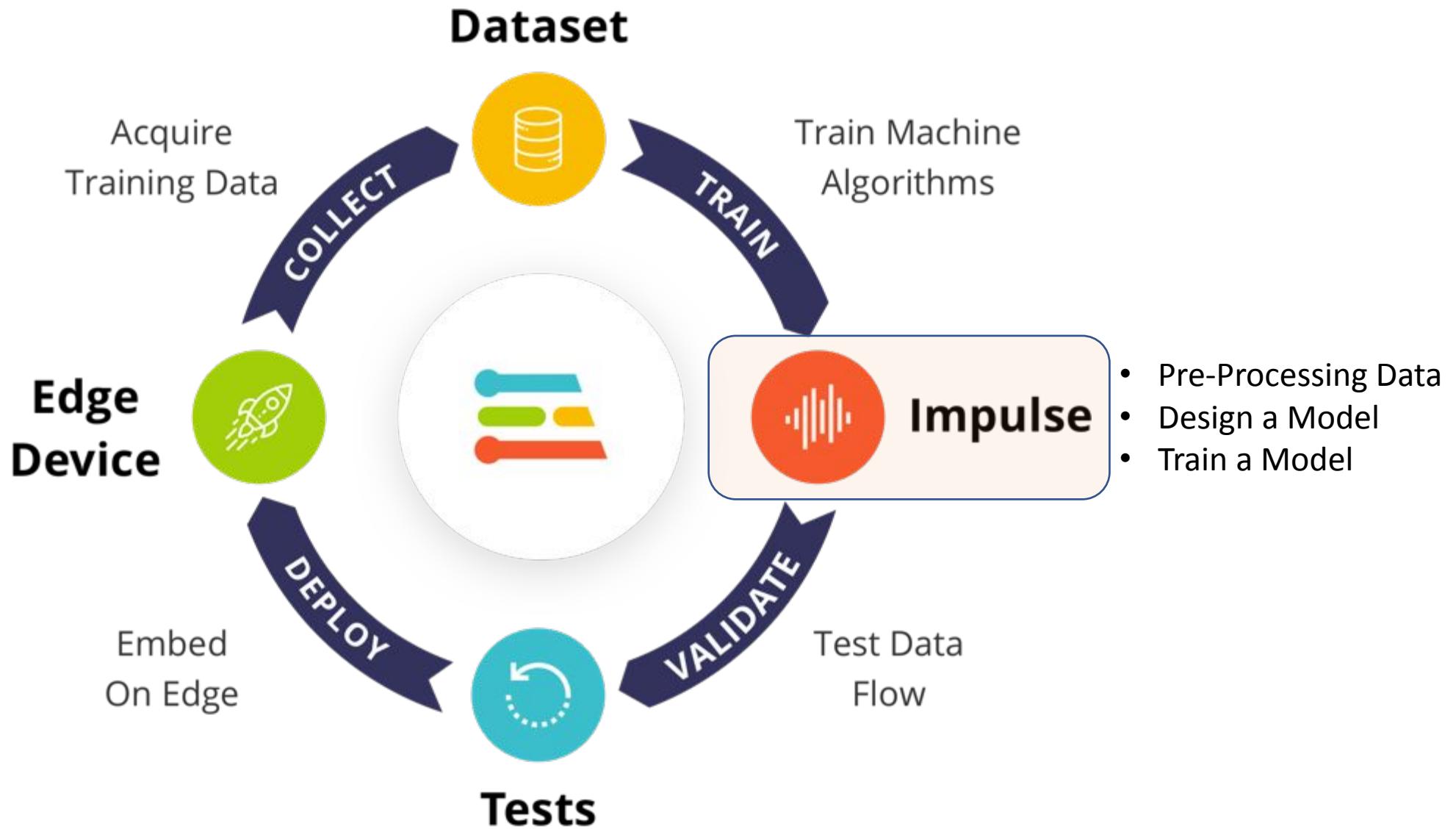
Test Set

Training,
tuning,
evaluation

Machine Learning
Algorithm







Time series data

Axes
accX, accY, accZ

Window size
2000 ms.

Window increase
80 ms.

Frequency (Hz)
62.5

Zero-pad data

Spectral Analysis

Name
Spectral Analysis

Input axes
 accX
 accY
 accZ

Neural Network (Keras)

Name
Neural Network (Keras)

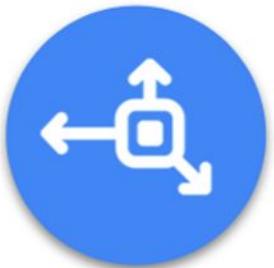
Input features
 Spectral Analysis

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

Output features

4 (idle, lift, maritime, terrestrial)

Save Impulse



Spectral Analysis



NN Classifier



Classes

- Lift
- Terrestrial
- Maritime
- Idle

Preprocess Data

Spectral Analysis - SciTinyML - [+](#)

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

EDGE IMPULSE

- Dashboard
- Devices
- Data acquisition
- Impulse design
 - Create impulse
 - Spectral Analysis
 - Neural Network (Keras)
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

GETTING STARTED

- Documentation
- Forums

Raw data

Raw features

375 Raw Features

Parameters

Scaling

Scale axes

Filter

Type: low

Cut-off frequency: 3

Order: 6

Spectral power

FFT length: 128

No. of peaks: 3

Peaks threshold: 0.1

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

RMS

FFT

PSD

Save parameters

33 Processed Features

DSP result

After filter

Frequency domain

Spectral power

Processed features

On-device performance

PROCESSING TIME: 8 ms.

PEAK RAM USAGE: 5 KB

maritime.2hstrnnq (maritime)

accX
accY
accZ

3.2285, -2.5962, -12.0225, 3.2527, -3.5232, -11.5629, 3.1483, -3.7275, -11.2436, 2.9637, -4.2394, -10.8071, 3.3431, -4.90...

3.5920, 0.4960, 3.3689, 1.4881, 2.3761, 0.0000, 0.0000, 1.1670, 0.3126, 0.3889, 0.0327, 5.0896, 0.9921, 6.0548, 2.4802, 1...

Preprocess Data

Spectral Analysis - SciTinyML - +

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

EDGE IMPULSE

SPECTRAL ANALYSIS (SCITINYML-MOTION-PROJECT)

#1 ▾ EON Tuner Primary

Parameters Generate features

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

Feature explorer (3,132 samples) ?

X Axis accX RMS ▼

Y Axis accY RMS ▼

Z Axis accZ RMS ▼

idle (blue)

lift (orange)

maritime (green)

terrestrial (red)

On-device performance ?

PROCESSING TIME 8 ms.

PEAK RAM USAGE 5 KB

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Design a Model

Neural Network (Keras) - SciTI

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

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral Analysis
- Neural Network (Ker...

EON Tuner

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Neural Network settings

Training settings

Number of training cycles ⑦ EPOCHS 30

Learning rate ⑦ 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

```
graph TD; input --> InputLayer[InputLayer]; InputLayer --> Dense1[Dense<br/>kernel 33x20<br/>bias 20]; Dense1 --> ReLU1[ReLU]; ReLU1 --> Dense2[Dense<br/>kernel 20x10<br/>bias 10]; Dense2 --> ReLU2[ReLU]; ReLU2 --> Dense3[Dense<br/>kernel 10x4<br/>bias 4]; Dense3 --> Softmax[Softmax]; Softmax --> y_pred[y_pred];
```

Train a Model

Neural Network (Keras) - SciTI

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

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral Analysis
- Neural Network (Keras)

EON Tuner

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Neural Network settings

Training settings

Number of training cycles ② EPOCHS 30

Learning rate ② Lr 0.0005

Neural network architecture

Input layer (33 features)

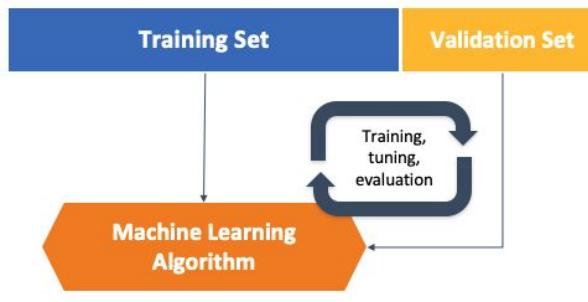
Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (4 features)

Start training



Training output

Model

Model version: ② Quantized (int8)

Last training performance (validation set)

ACCURACY 99.7% LOSS 0.01

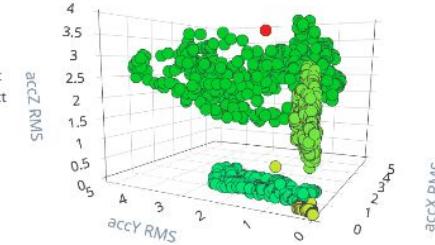
Confusion matrix (validation set)

	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) ②

accX RMS accY RMS accZ RMS

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



On-device performance ②

INFERRING TIME 1 ms. PEAK RAM USAGE 1.7K FLASH USAGE 19.0K

**Evaluate
Optimize**

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 features)

Start training

Training Set | **Validation Set**

Machine Learning Algorithm

Training, tuning, evaluation

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

3D scatter plot showing feature distribution:

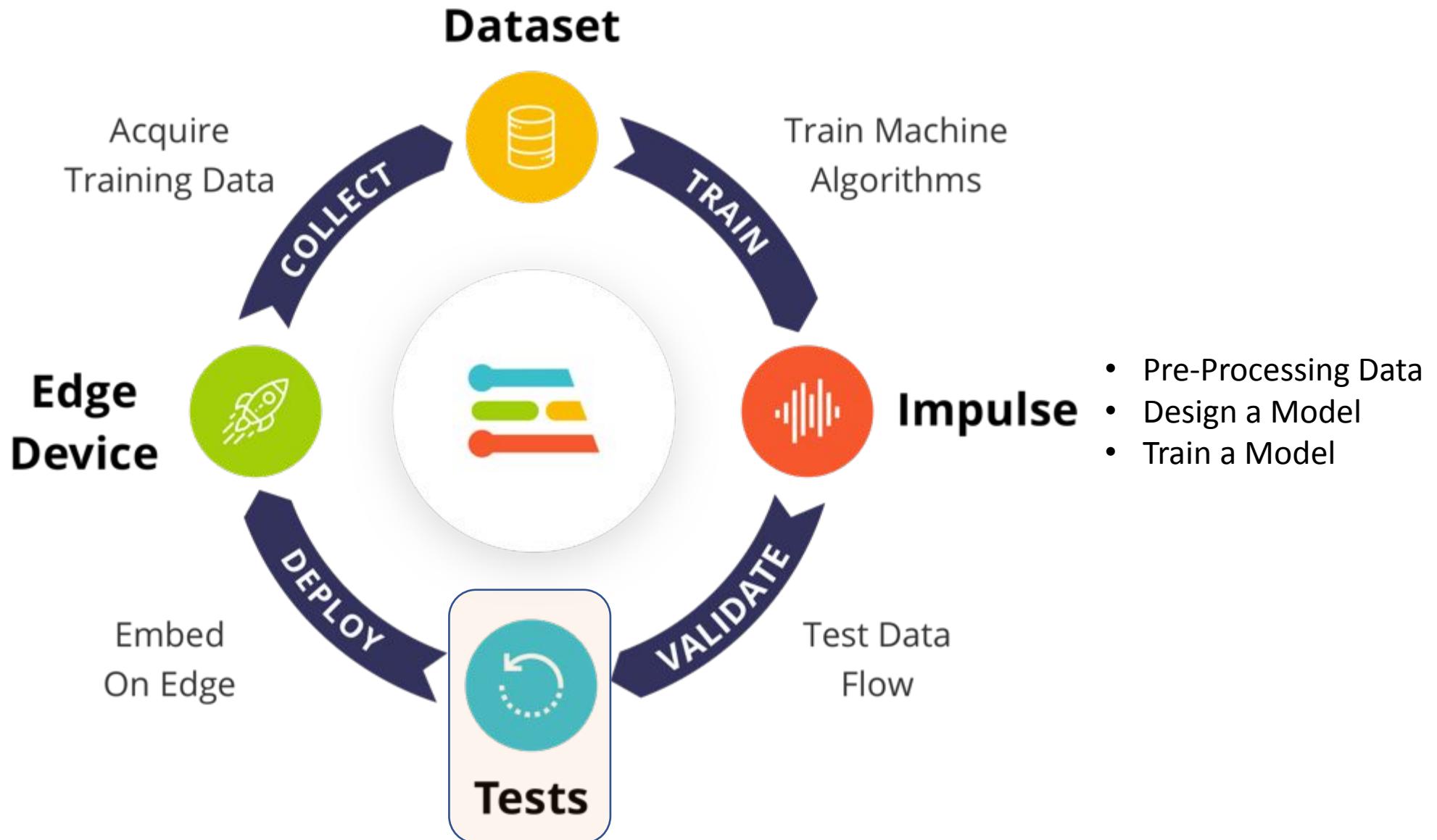
Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz), compiled with Edge Impulse EON™ compiler

On-device performance

INFERENCING TIME: 1 ms.

PEAK RAM USAGE: 1.7K

FLASH USAGE: 19.0K



**Evaluate
Optimize**

Model testing - SciTinyML-Motion-Project

studio.edgeimpulse.com/studio/51797/validation

EDGE IMPULSE

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 OUTCOME	LENGTH	ACCURACY	RESULT	...
testing.2hvft...	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

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

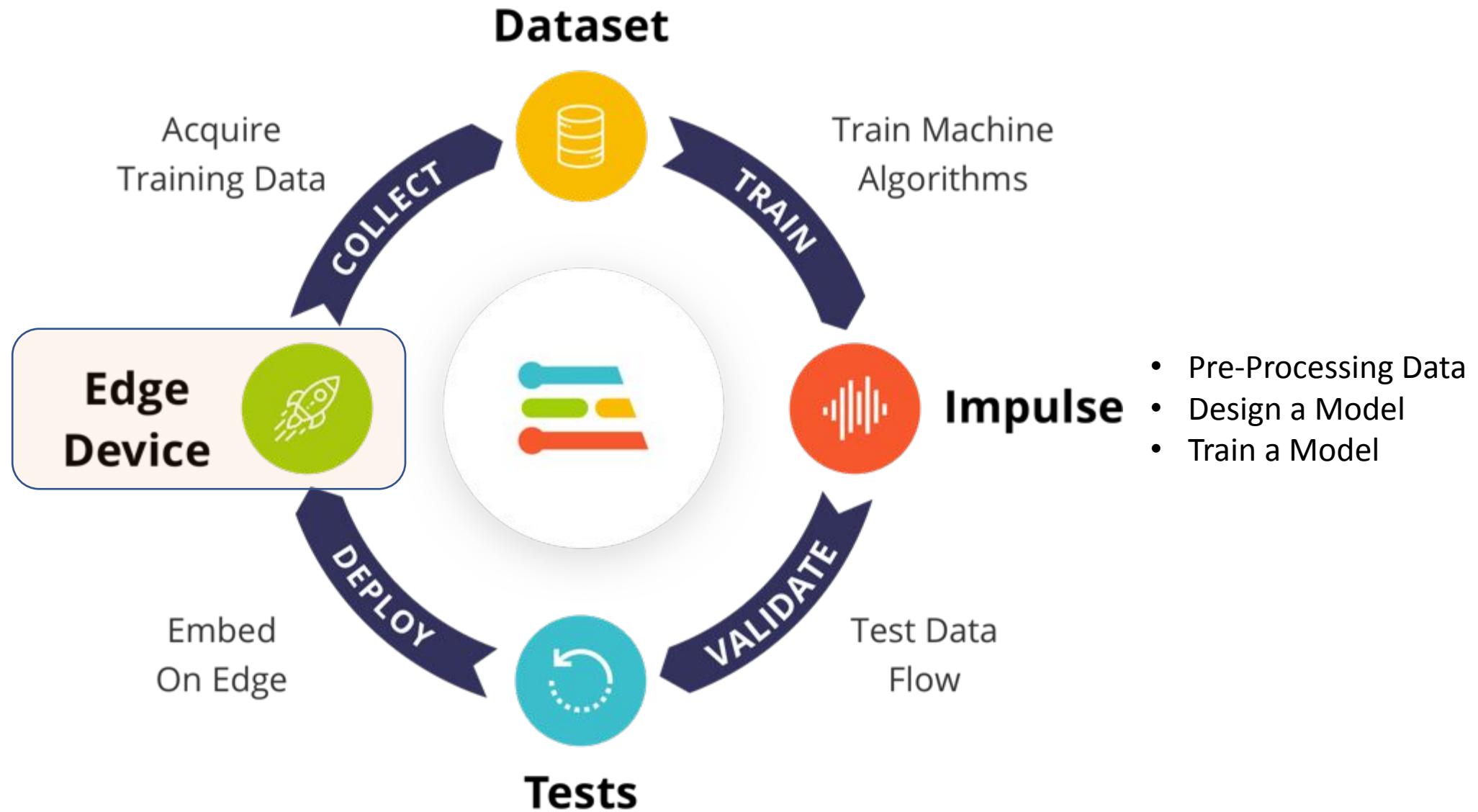
Final Performance Estimate

Training Set Validation Set Test Set

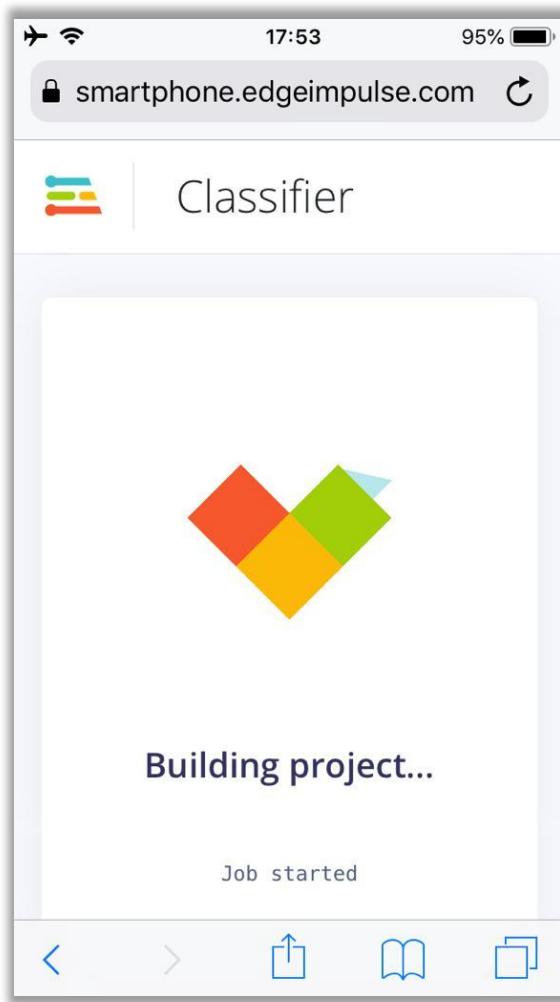
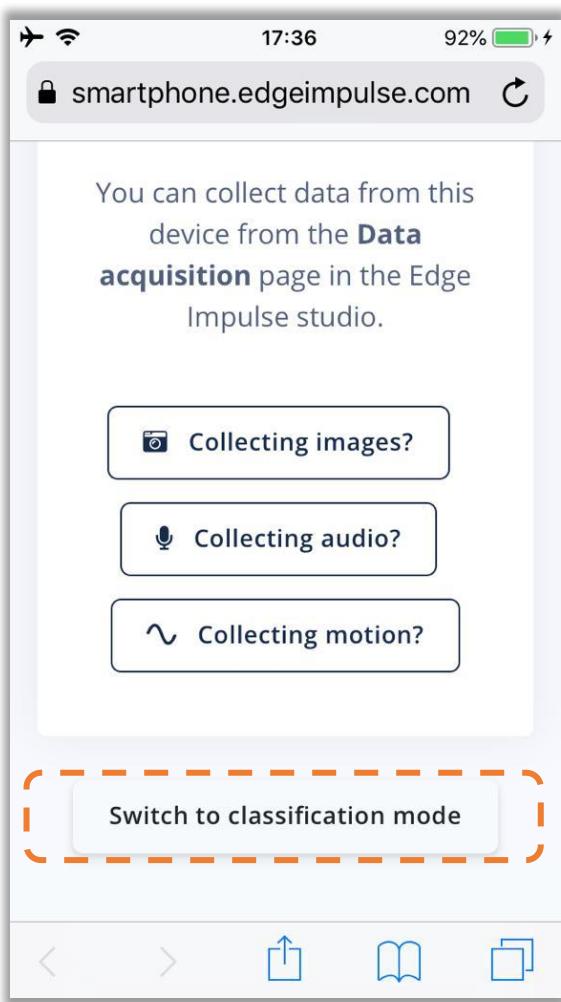
Machine Learning Algorithm

Final Model

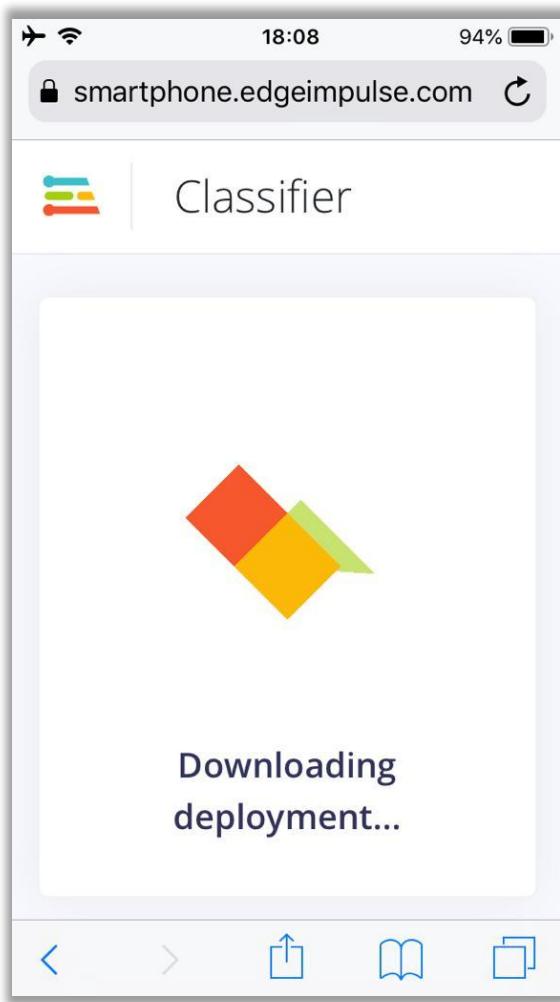
Training, tuning, evaluation



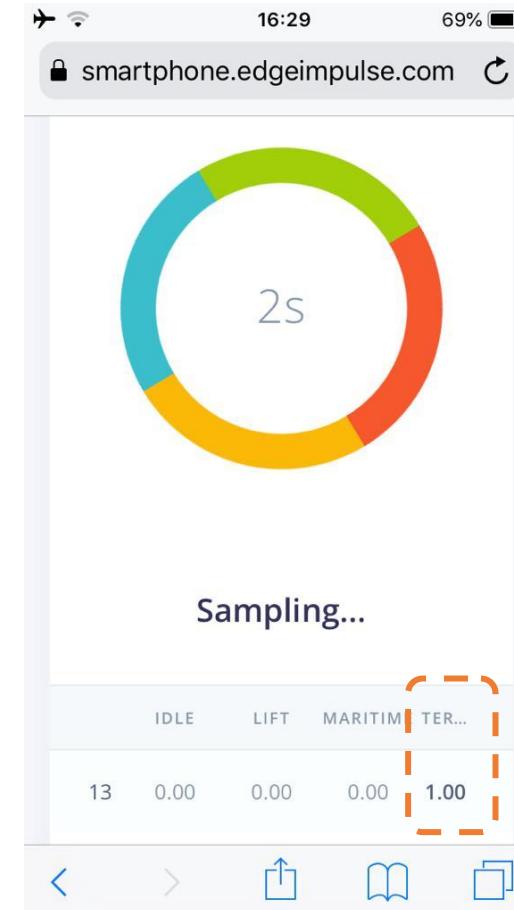
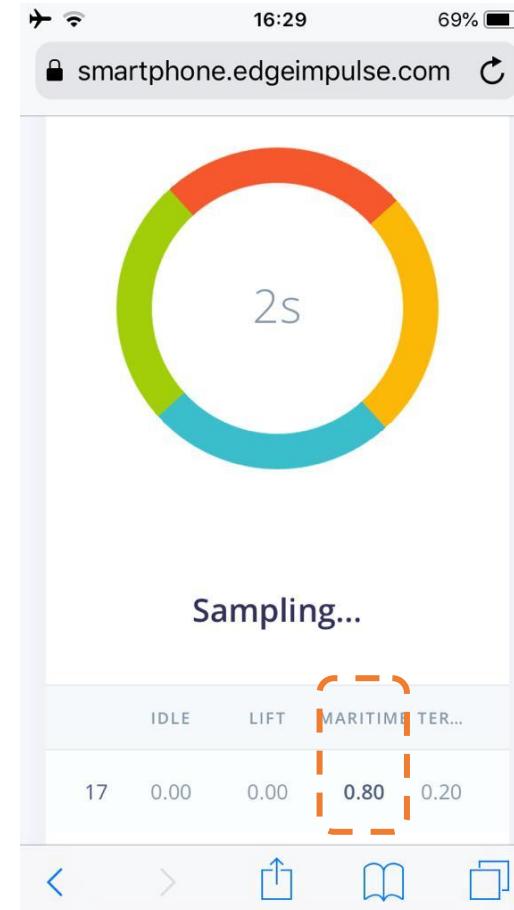
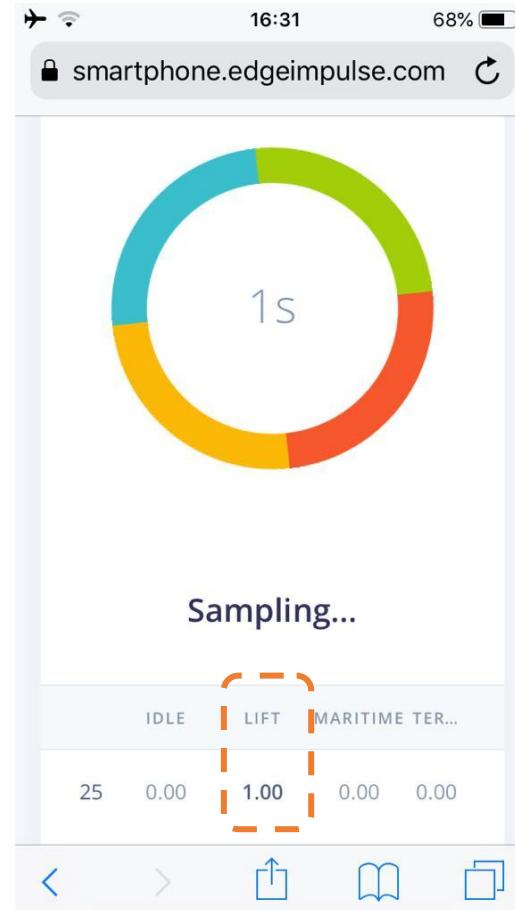
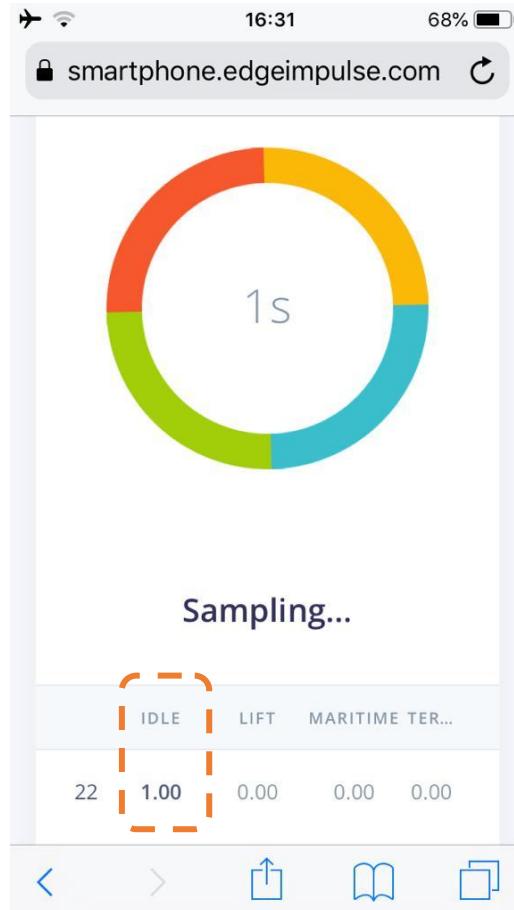
Convert Model



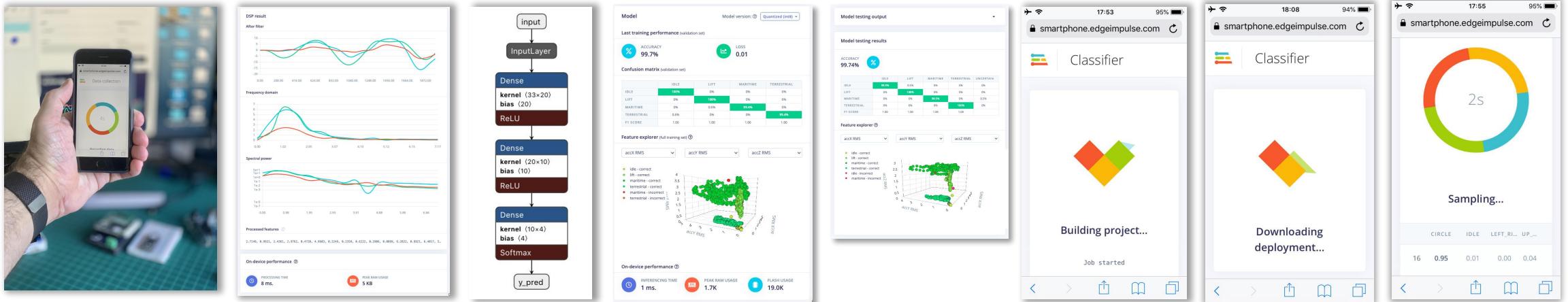
Deploy Model



Make Inferences

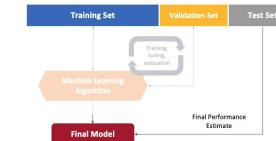
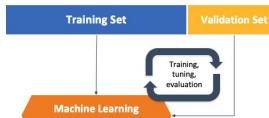


Motion Classification - Summary



Spectral Analysis

NN Classifier



Reading Material

Main references

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

I want to thank **Shawn Hymel** and **Edge Impulse**, **Pete Warden** and **Laurence Moroney** from Google, Professor **Vijay Janapa Reddi** and **Brian Plancher** from Harvard, and the rest of the **TinyMLEdu** team for preparing the excellent material on TinyML that is the basis of this course at UNIFEI.

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

Thanks



UNIFEI