



# Wio Terminal – Part 2

## Hands-on: Gesture Recognition



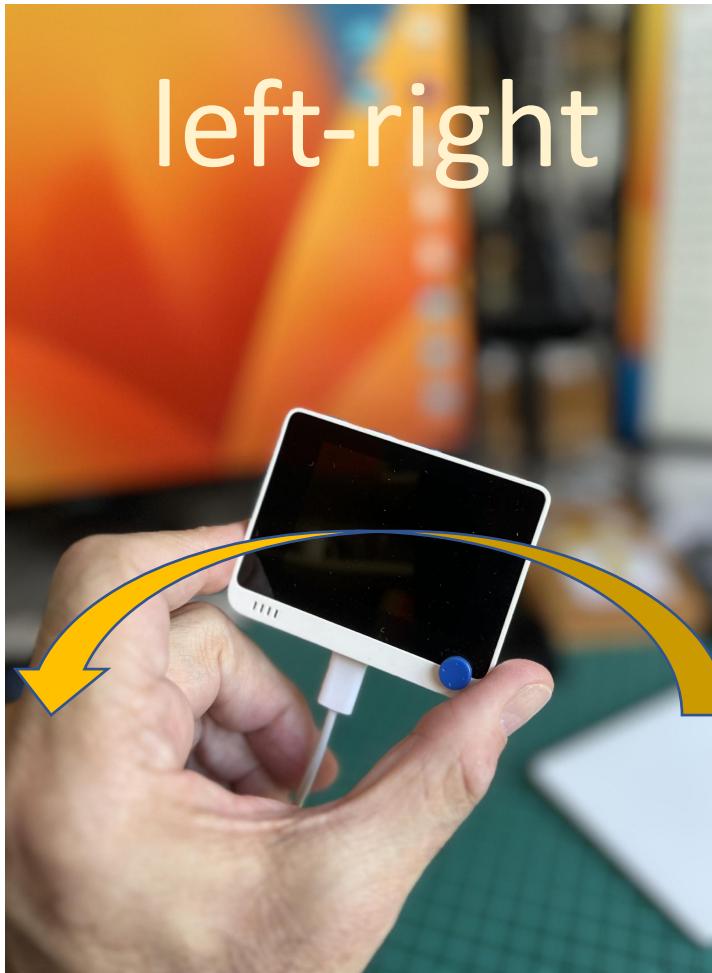
Prof. Marcelo José Rovai  
UNIFEI - Federal University of Itajubá, Brazil  
TinyML4D Academic Network Co-Chair

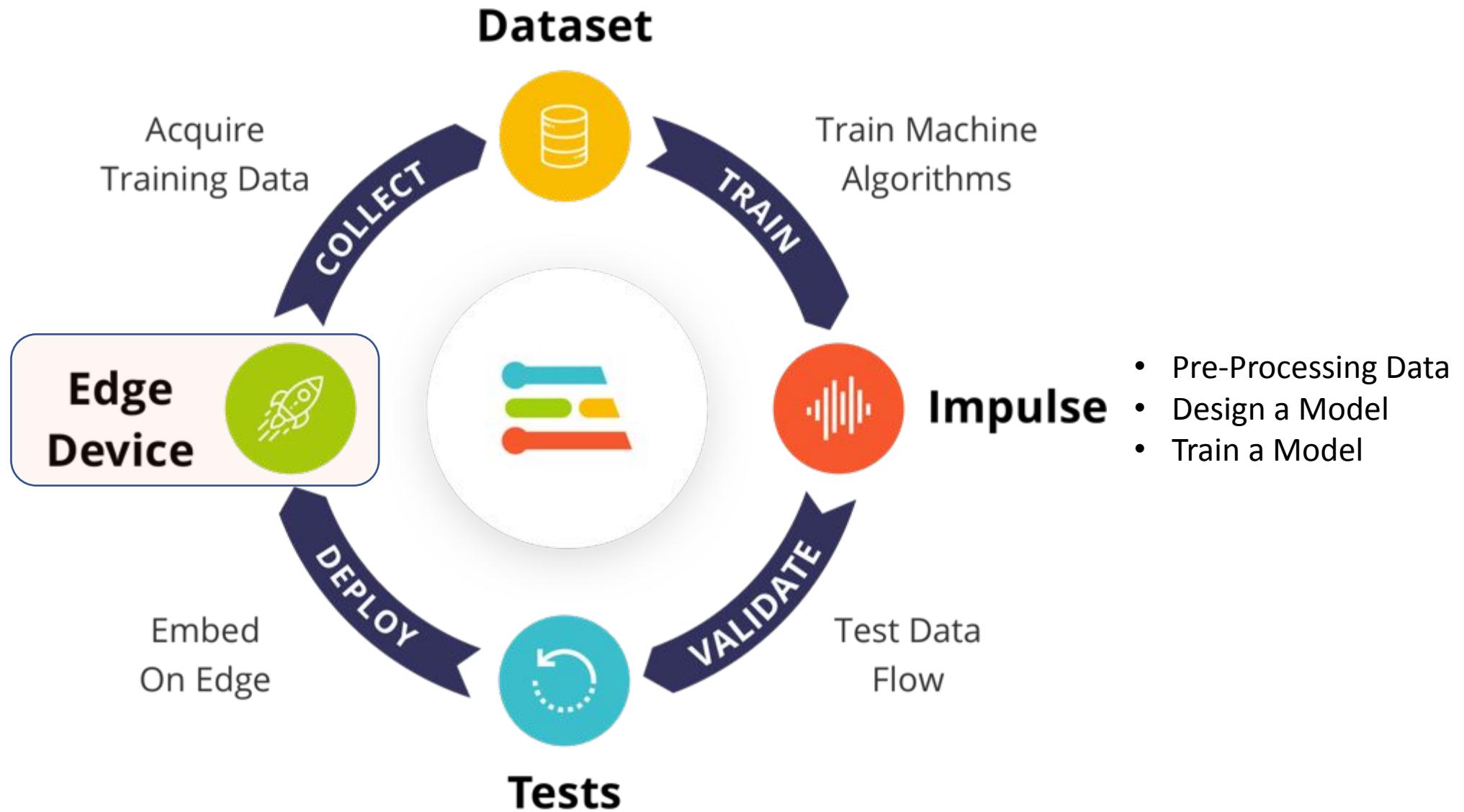


**UNIFEI**

# Hands-on: Gesture Recognition

# Gestures Definition (classes)





AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/acquisition/training?page=1

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

cu.Bluetooth-Incoming-Port

Arduino Nano 33 BLE (cu.usbmodem1101)

Seeed Wio Terminal (cu.usbmodem1101) - Paired

Marcelo Rovai / AAU-Wio-Gesture-Classification

Upload data Export data

Select your device or development board, or upload your existing datasets - Show options

Record new data

Connect using WebUSB

Cancel Connect

The screenshot shows the Edge Impulse Studio web interface. A modal dialog box is open in the center, titled 'studio.edgeimpulse.com wants to connect to a serial port'. It lists three options: 'cu.Bluetooth-Incoming-Port', 'Arduino Nano 33 BLE (cu.usbmodem1101)', and 'Seeed Wio Terminal (cu.usbmodem1101) - Paired'. The third option is highlighted with a blue background. At the bottom of this dialog are two buttons: 'Cancel' and 'Connect', with 'Connect' being highlighted by an orange rectangle. In the background, the main studio interface shows a purple header with the user's name 'Marcelo Rovai / AAU-Wio-Gesture-Classification'. Below the header are tabs for 'Upload data' and 'Export data'. A central panel says 'Select your device or development board, or upload your existing datasets - Show options'. To the right, there's a 'Record new data' section with a note 'No devices connected to the remote management API.' and a 'Connect using WebUSB' button, also highlighted with an orange rectangle.

AAU-Wio-Gesture-Classification

studio.edgeimpulse.com/studio/190030/devices

EDGE IMPULSE

Marcelo Rovai / AAU-Wio-Gesture-Classification

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                            | REMOT... | LAST SEEN       |
|-------------------|-------------------|--------------------|------------------------------------|----------|-----------------|
| 23:D1:FF:14:17:05 | 23:D1:FF:14:17:05 | SEEED_WIO_TERMINAL | Built-in accelerometer, Built-i... | ●        | Today, 17:12:18 |

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Dashboard

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Data sources

Data acquisition

Impulse design

Create impulse

EON Tuner

Retrain model

Live classification

Model testing

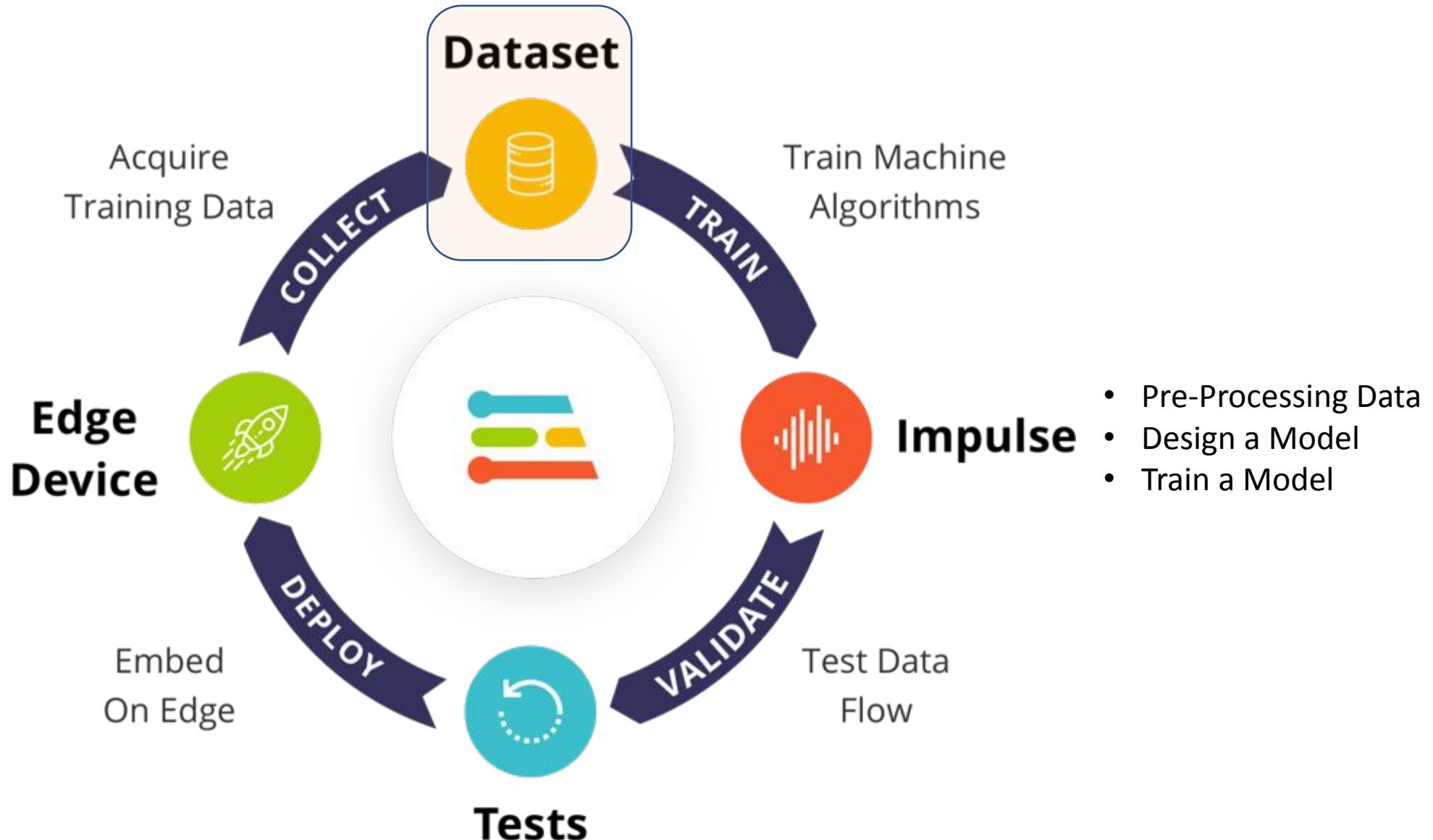
Versioning

Deployment

GETTING STARTED

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AAU-Wio-Gesture-Classifi... X +

studio.edgeimpulse.com/studio/190030/acquisition/training?page=1

EDGE IMPULSE

Marcelo Rovai / AAU-Wio-Gesture-Classification

Training data Test data | Data explorer | Upload data Export data

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

Collected data

No data collected yet

Let's collect some data

Record new data

Device ②  
23:D1:FF:14:17:05

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

Sensor Built-in accelerometer Frequency  
62.5Hz

Start sampling

Dashboard Devices Data sources Data acquisition Impulse design Create impulse EON Tuner Retrain model Live classification Model testing Versioning Deployment

GETTING STARTED Documentation Forums



AAU-Wio-Gesture-Classifi: X +

studio.edgeimpulse.com/studio/190030/acquisition/training?page=1

EDGE IMPULSE

Training data | Test data | Data explorer | Upload data | Export data

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 |
|---------------------|------------|-----------------|--------|
| left-right.3psif7uj | left-right | Today, 17:00:58 | 10s    |

Record new data

Device ⓘ  
23:D1:FF:14:17:05

Label  
left-right

Sample length (ms.)  
10000

Sensor  
Built-in accelerometer

Frequency  
62.5Hz

Start sampling

RAW DATA  
left-right.3psif7uj

accX accY accZ

AAU-Wio-Gesture-Classifi X +

studio.edgeimpulse.com/studio/190030/acquisition/training?page=1

EDGE IMPULSE

Training data | Test data | Data explorer | Upload data | Export 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 |
|----------------------|------------|-----------------|--------|
| left-right.3psisd28  | left-right | Today, 17:08:10 | 10s    |
| left-right.3psiqnu8  | left-right | Today, 17:07:15 | 10s    |
| left-right.3psipvrq  | left-right | Today, 17:06:51 | 10s    |
| left-right.3psiparl  | left-right | Today, 17:06:29 | 10s    |
| left-right.3psiogmo  | left-right | Today, 17:06:02 | 10s    |
| left-right.3psinrpp  | left-right | Today, 17:05:41 | 10s    |
| left-right.3psin574  | left-right | Today, 17:05:18 | 10s    |
| left-right.3psimimg  | left-right | Today, 17:04:59 | 10s    |
| left-right.3psihi117 | left-right | Today, 17:01:57 | 10s    |
| left-right.3psif7uj  | left-right | Today, 17:00:58 | 10s    |

Record new data

Device ②  
23:D1:FF:14:17:05

Label  
left-right

Sample length (ms.)  
10000

Sensor  
Built-in accelerometer

Frequency  
62.5Hz

Start sampling

RAW DATA  
**left-right.3psisd28**

accX accY accZ

AAU-Wio-Gesture-Classificatio

Training data Test data | Data explorer | Upload data Export 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 |
|---------------------|------------|-----------------|--------|
| up-down.3psj5ei1    | up-down    | Today, 17:13:06 | 10s    |
| up-down.3psj4jrl    | up-down    | Today, 17:12:39 | 10s    |
| up-down.3psj3omo    | up-down    | Today, 17:12:11 | 10s    |
| up-down.3psj33i8    | up-down    | Today, 17:11:49 | 10s    |
| up-down.3psj2d3h    | up-down    | Today, 17:11:26 | 10s    |
| up-down.3psj1oo0    | up-down    | Today, 17:11:05 | 10s    |
| up-down.3psj145a    | up-down    | Today, 17:10:44 | 10s    |
| up-down.3psj0fec    | up-down    | Today, 17:10:23 | 10s    |
| up-down.3psivrof    | up-down    | Today, 17:10:03 | 10s    |
| up-down.3psiv2oq    | up-down    | Today, 17:09:37 | 10s    |
| left-right.3psisd28 | left-right | Today, 17:08:10 | 10s    |
| left-right.3psiqnu8 | left-right | Today, 17:07:15 | 10s    |

Record new data

Device ⓘ No devices connected

Label up-down Sample length (ms.) 10000

Sensor Frequency

Start sampling

RAW DATA up-down.3psj5ei1

accX accY accZ

AAU-Wio-Gesture-Classifi X

studio.edgeimpulse.com/studio/190030/acquisition/training?page=1

EDGE IMPULSE

Training data | Test data | Data explorer | Upload data | Export 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 |
|------------------|---------|-----------------|--------|
| idle.3psjhp64    | idle    | Today, 17:19:50 | 10s    |
| idle.3psjqg6n    | idle    | Today, 17:19:19 | 10s    |
| idle.3psjg3lj    | idle    | Today, 17:18:55 | 10s    |
| idle.3psjfflj    | idle    | Today, 17:18:35 | 10s    |
| idle.3psjer3m    | idle    | Today, 17:18:14 | 10s    |
| idle.3psje51r    | idle    | Today, 17:17:51 | 10s    |
| idle.3psjdi38    | idle    | Today, 17:17:32 | 10s    |
| idle.3psjctpm    | idle    | Today, 17:17:11 | 10s    |
| idle.3psjc87r    | idle    | Today, 17:16:49 | 10s    |
| idle.3psj8ud7    | idle    | Today, 17:15:01 | 10s    |
| up-down.3psj5ei1 | up-down | Today, 17:13:06 | 10s    |
| up-down.3psj4jrl | up-down | Today, 17:12:39 | 10s    |

Record new data

Device ②  
23:D1:FF:14:17:05

Label  
idle

Sample length (ms.)  
10000

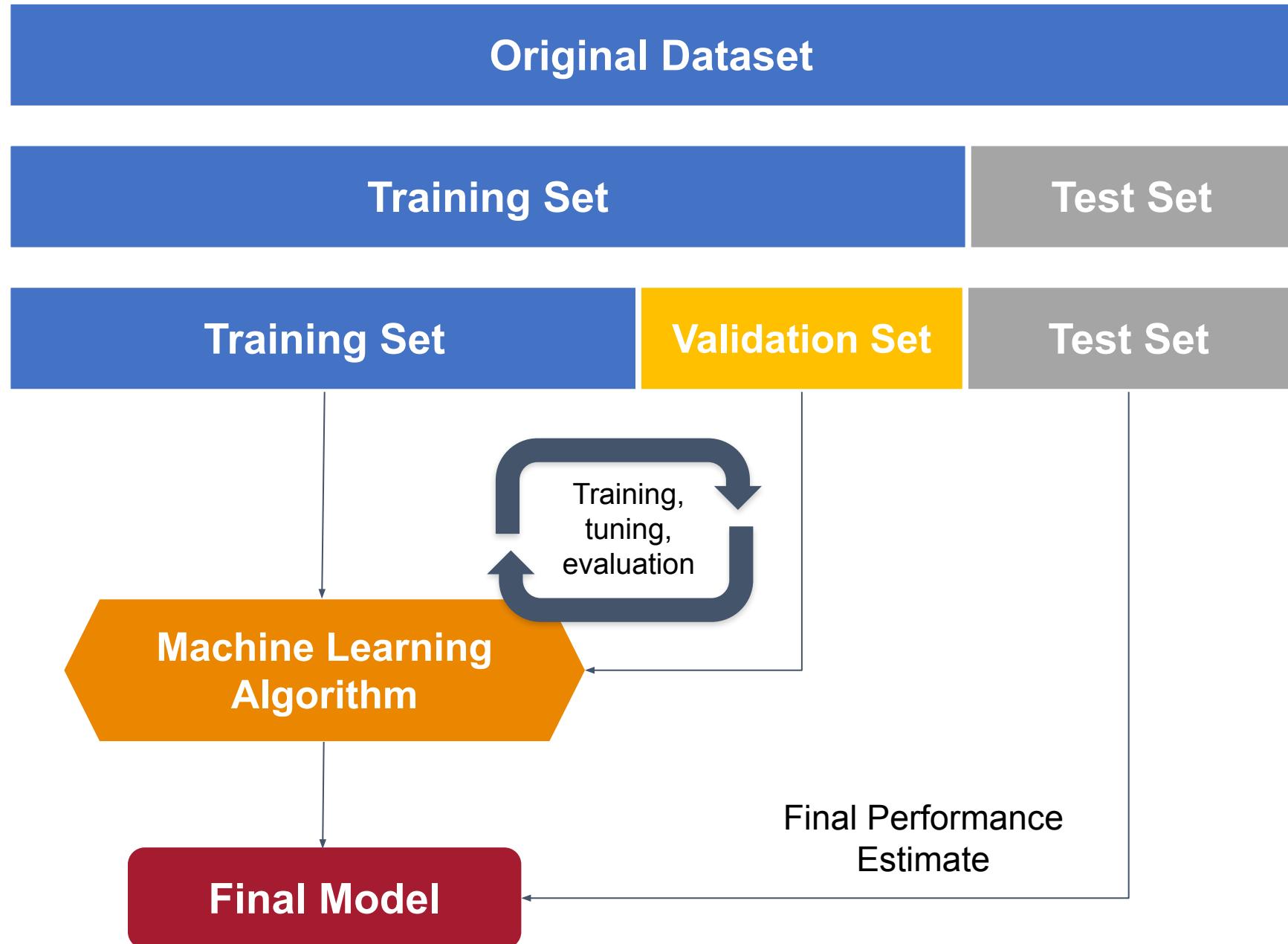
Sensor  
Built-in accelerometer

Frequency  
62.5Hz

Start sampling

RAW DATA  
idle.3psjhp64

accX accY accZ



The screenshot shows the Edge Impulse Studio interface for a project titled "AAU-Wio-Gesture-Classifi". The main dashboard displays "DATA COLLECTED" as 5m 0s and "TRAIN / TEST SPLIT" as 100% / 0%. A "Collected data" table lists 15 samples, all labeled "idle". A context menu is open for the first sample, showing options: Rename, Edit label, Move to test set (highlighted with an orange box), Crop sample, Split sample, Download, and Delete. To the right, a "Record new data" section allows setting the device (23:D1:FF:14:17:05), label (idle), sample length (10000 ms), sensor (Built-in accelerometer), and frequency (62.5Hz). A "Start sampling" button is present. Below, a "RAW DATA" plot for "idle.3psjhp64" shows three channels: accX (red), accY (green), and accZ (blue) over time.

Training data Test data | Data explorer | Upload data Export 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 |
|------------------|---------|-----------------|--------|
| idle.3psjhp64    | idle    | Today, 17:19:50 | 10s    |
| idle.3psjqg6n    | idle    | Today, 17:19:19 | 10s    |
| idle.3psjg3lj    | idle    | Today, 17:18:55 | 10s    |
| idle.3psjffij    | idle    | Today, 17:18:3  |        |
| idle.3psjer3m    | idle    | Today, 17:18:1  |        |
| idle.3psje51r    | idle    | Today, 17:17:5  |        |
| idle.3psjdi38    | idle    | Today, 17:17:3  |        |
| idle.3psjctpm    | idle    | Today, 17:17:1  |        |
| idle.3psjc87r    | idle    | Today, 17:16:4  |        |
| idle.3psj8ud7    | idle    | Today, 17:15:01 | 10s    |
| up-down.3psj5ei1 | up-down | Today, 17:13:06 | 10s    |
| up-down.3psj4jrl | up-down | Today, 17:12:39 | 10s    |

Device 23:D1:FF:14:17:05

Label idle Sample length (ms.) 10000

Sensor Built-in accelerometer Frequency 62.5Hz

Start sampling

RAW DATA  
idle.3psjhp64

accX accY accZ

AAU-Wio-Gesture-Classifi X +

studio.edgeimpulse.com/studio/190030/acquisition/training?page=2

EDGE IMPULSE

Training data Test data | Data explorer | Upload data Export data

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

DATA COLLECTED 4m 0s TRAIN / TEST SPLIT 80% / 20%

Collected data

| SAMPLE NAME         | LABEL      | ADDED           | LENGTH |
|---------------------|------------|-----------------|--------|
| up-down.3psj1oo0    | up-down    | Today, 17:11:05 | 10s    |
| up-down.3psj0fec    | up-down    | Today, 17:10:23 | 10s    |
| up-down.3psivrof    | up-down    | Today, 17:10:03 | 10s    |
| up-down.3psiv2oq    | up-down    | Today, 17:09:37 | 10s    |
| left-right.3psisd28 | left-right | Today, 17:08:10 | 10s    |
| left-right.3psiqnu8 | left-right | Today, 17:07:15 | 10s    |
| left-right.3psipvrq | left-right | Today, 17:06:51 | 10s    |
| left-right.3psiogmo | left-right | Today, 17:06:02 | 10s    |
| left-right.3psinrpp | left-right | Today, 17:05:41 | 10s    |
| left-right.3psin574 | left-right | Today, 17:05:18 | 10s    |
| left-right.3psimimg | left-right | Today, 17:04:59 | 10s    |
| left-right.3psih117 | left-right | Today, 17:01:57 | 10s    |

Record new data

Device ?  
23:D1:FF:14:17:05

Label  
idle

Sample length (ms.)  
10000

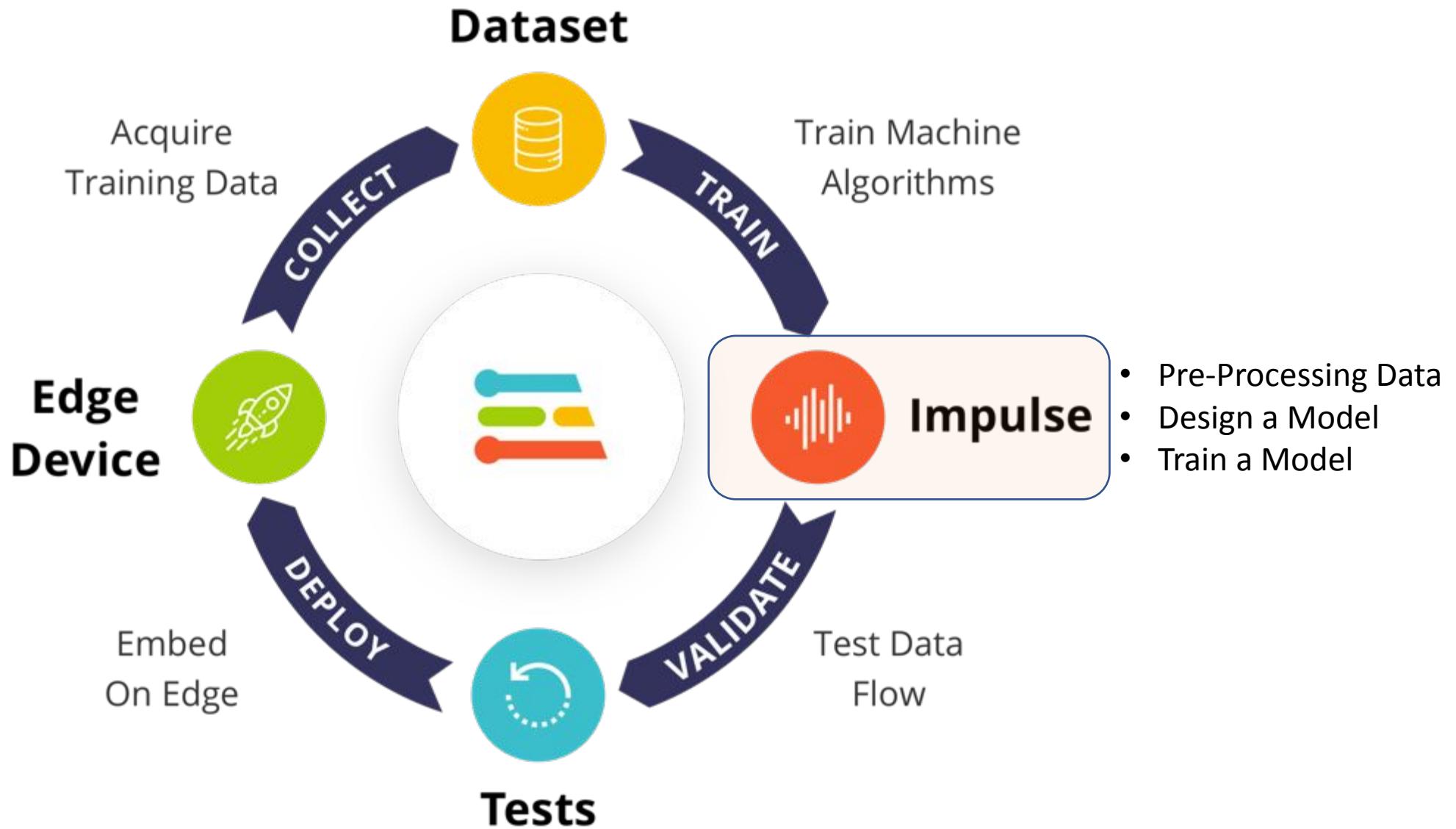
Sensor  
Built-in accelerometer

Frequency  
62.5Hz

Start sampling

RAW DATA  
up-down.3psj1oo0

accX accY accZ



The screenshot shows the Edge Impulse web studio interface. On the left, there's a sidebar with various project management and development tools. The main workspace is titled "Marcelo Bouai / AAU-Wio-Gesture-Classification". A central modal window is open, titled "Add a processing block". Inside, there's a "Did you know?" message: "You can bring your own DSP code." Below this is a table with columns for "DESCRIPTION", "AUTHOR", and "RECOMMENDED". The first row, "Spectral Analysis", is highlighted with an orange box. It has a brief description: "Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time.", the author "Edge Impulse", a star rating, and a blue "Add" button. Other rows include "IMU (Syntiant)", "Flatten", "Spectrogram", and "Raw Data", each with their respective descriptions, authors, ratings, and "Add" buttons. At the bottom of the modal, there's a note: "Some processing blocks have been hidden based on the data in your project. Show all blocks anyway". At the very bottom are "Add custom block" and "Cancel" buttons.

Did you know? You can bring your own DSP code.

| DESCRIPTION   | AUTHOR         | RECOMMENDED |
|---|----------------|-------------|
| <b>Spectral Analysis</b><br>Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time.      | Edge Impulse ★ | Add         |
| IMU (Syntiant)<br>Syntiant only. Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time. | Syntiant ★     | Add         |
| Flatten<br>Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.  | Edge Impulse   | Add         |
| Spectrogram<br>Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.   | Edge Impulse   | Add         |
| Raw Data<br>Use data without pre-processing. Useful if you want to use deep learning to learn features.   | Edge Impulse   | Add         |

Some processing blocks have been hidden based on the data in your project. Show all blocks anyway

Add custom block Cancel

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For details see Appendix: Spectral Analysis

AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/create-impulse

EDGE IMPULSE

An impulse tab

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Create impulse

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Time series data

Input axes (3)  
accX, accY, accZ

Window size

Window increase

Frequency (Hz)  
62,5

Zero-pad data

Add a learning block

Did you know? You can bring your own model in PyTorch, Keras or scikit-learn.

| DESCRIPTION  | AUTHOR   | RECOMMENDED |
|--|--|-------------|
| <b>Classification</b><br>Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.   | Edge Impulse  | <b>Add</b>  |
| <b>Anomaly Detection (K-means)</b><br>Find outliers in new data. Good for recognizing unknown states, and to complement classifiers. Works best with low dimensionality features like the output of the spectral features block. | Edge Impulse  | <b>Add</b>  |
| <b>Regression</b><br>Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.   | Edge Impulse   | <b>Add</b>  |
| <b>Classification (Keras) - BrainChip Akida™</b><br>Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.  | BrainChip  | <b>Add</b>  |

Some learning blocks have been hidden based on the data in your project. Show all blocks anyway

Add a processing block

Output features

3 (idle, left-right, up-down)

Save Impulse

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The screenshot shows the Edge Impulse web studio interface for creating a new impulse. A modal window titled 'Add a learning block' is open, listing various machine learning blocks. The 'Classification' block is highlighted with an orange rectangle. The 'Classification' block description states: 'Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.' It is authored by 'Edge Impulse' and has a yellow star icon. A blue 'Add' button is visible to its right. Other blocks listed include 'Anomaly Detection (K-means)', 'Regression', and 'Classification (Keras) - BrainChip Akida™'. The main workspace on the right shows a purple header bar and a green 'Output features' section indicating 3 categories: 'idle', 'left-right', and 'up-down'. A red 'Save Impulse' button is at the bottom right of the workspace. The left sidebar contains navigation links for Dashboard, Devices, Data sources, Data acquisition, Impulse design, Create impulse, EON Tuner, Retrain model, Live classification, Model testing, Versioning, Deployment, and Documentation/Forums. The bottom footer includes the copyright notice '© 2023 EdgeImpulse Inc. All rights reserved'.

AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/create-impulse

EDGE IMPULSE

Marcelo Rovai / AAU-Wio-Gesture-Classification

Successfully stored impulse. Configure the signal processing and learning blocks in the navigation bar.

Time series data

Input axes (3)  
accX, accY, accZ

Window size  
2000 ms.

Window increase  
200 ms.

Frequency (Hz)  
62,5

Zero-pad data

Spectral Analysis

Name: Spectral features

Input axes (3)  
 accX  
 accY  
 accZ

Classification

Name: Classifier

Input features  
 Spectral features

Output features  
3 (idle, left-right, up-down)

Output features

3 (idle, left-right, up-down)

Save Impulse

Add a processing block

Add a learning block

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AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/dsp/spectral-analysis/3

**Raw data**

Show: All labels up-down.3psj3i8 (up-down)

accX accY accZ

**Raw features**

1.9613, -5.1485, 0.1226, 2.0839, -4.2904, -0.7355, 3.3097, -1.5936, -0.4983, 2.6968, -0.6129, -0.7355, 1.9613, 1.5936, 0.8581...

**Parameters**

**Filter**

Scale axes: 1  
Type: low  
Cut-off frequency: 3  
Order: 6  
Analysis  
FFT length: 16  
Take log of spectrum?   
Overlap FFT frames?

**DSP result**

**Filter response**

dB vs Frequency (Hz): 0.00, 3.17, 6.35, 9.52, 12.70, 15.87, 19.04, 22.22, 25.39, 28.56

**After filter**

Value vs Sample #: 0.00, 208.00, 416.00, 624.00, 832.00, 1040.00, 1248.00, 1456.00, 1664.00, 1872.00

**Spectral power (log)**

Energy vs Frequency (Hz): 0.00, 3.91, 7.81, 11.72, 15.63, 19.53, 23.44, 27.34, 31.25

**Processed features**

1.8486, -8.2229, -0.5477, 1.5663, 10.0053, -0.1990, -1.2094, 2.2725, 1.6845, 0.6518, -0.2239, 1.4267

**On-device performance**

PROCESSING TIME: 16 ms PEAK RAM USAGE: 2 KB

The screenshot shows the Edge Impulse DSP spectral analysis interface. On the left, a sidebar lists various project sections like Dashboard, Devices, Data sources, and Data acquisition. The main area displays raw data plots for three axes (accX, accY, accZ) over time, with a zoomed-in view of the signal. Below this is a 'Raw features' section showing numerical values. The central part of the screen is titled 'Parameters' and contains fields for a 'Filter' (set to Type: low, Cut-off frequency: 3, Order: 6), 'Analysis' (FFT length: 16), and checkboxes for 'Take log of spectrum?' and 'Overlap FFT frames?'. A large orange rectangle highlights this parameter section. To the right, there are four main plots: 'Filter response' (a red line graph), 'After filter' (a multi-colored line graph showing the processed signal), 'Spectral power (log)' (a line graph showing energy vs frequency), and 'Processed features' (a list of numerical values). At the bottom, performance metrics are shown: 'PROCESSING TIME' at 16 ms and 'PEAK RAM USAGE' at 2 KB.

AAU-Wio-Gesture-Classification

studio.edgeimpulse.com/studio/190030/dsp/spectral-analysis/3/generate-features

EDGE IMPULSE

#1 Click to set a description for this version

Parameters Generate features

Training set

Data in training set 4m 0s

Classes 3 (idle, left-right, up-down)

Training windows 1.008

Calculate feature importance

Generate features

Feature explorer

No features generated yet.

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

GETTING STARTED Documentation Forums

Marcelo Rovai / AAU-Wio-Gesture-Classification

A screenshot of the Edge Impulse Studio interface. The main panel shows a 'Training set' configuration with a 'Generate features' button highlighted by a red rectangle. To the right is a 'Feature explorer' section indicating 'No features generated yet.' The left sidebar contains navigation links for various tools like Dashboard, Devices, and Data acquisition, along with a 'Getting Started' section for documentation and forums. The top bar includes standard browser controls and the Edge Impulse logo.

AAU-Wio-Gesture-Classificatio x +

← → C ⌂ ⌂ 🔒 studio.edgeimpulse.com/studio/190030/dsp/spectral-analysis/3/generate-features

EDGE IMPULSE

Parameters Generate features

Training set

Data in training set 4m 0s

Classes 3 (idle, left-right, up-down)

Training windows 1,008

Calculate feature importance

Generate features

Feature generation output

Thu Feb 23 20:28:32 2023 Finished embedding  
Reducing dimensions for visualizations OK

Scheduling job in cluster...  
Container image pulled!  
Job started  
Determining feature importance...  
[1/4] Determining feature importance for all classes...  
[2/4] Determining feature importance for idle...  
[3/4] Determining feature importance for left-right...  
[4/4] Determining feature importance for up-down...  
Determining feature importance OK

Job completed

Feature explorer

idle (blue), left-right (orange), up-down (green)

Feature importance All data

| Feature                            | Importance |
|------------------------------------|------------|
| accY RMS                           | High       |
| accZ Skewness                      | Medium     |
| accY Spectral Power 1.95 - 5.86 Hz | Medium     |
| accZ RMS                           | Medium     |
| accX RMS                           | Medium     |
| accZ Spectral Power 1.95 - 5.86 Hz | Medium     |
| accY Skewness                      | Low        |
| accZ Kurtosis                      | Low        |
| accX Skewness                      | Low        |
| accX Spectral Power 1.95 - 5.86 Hz | Low        |
| accY Kurtosis                      | Low        |

AAU-Wio-Gesture-Classificatio x +

studio.edgeimpulse.com/studio/190030/learning/keras/9

EDGE IMPULSE

Marcelo Rovai / AAU-Wio-Gesture-Classification

#1 ▾ Click to set a description for this version

Neural Network settings

Training settings

Number of training cycles ② 30

Learning rate ② 0.0005

Validation set size ② 20 %

Auto-balance dataset ②

Neural network architecture

Target device

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

Seeed Studio Wio Terminal (Cortex-M4F 120MHz)

Set target device

Model version: ② Quantized (int8)

LOSS 0.13

Confusion matrix (validation set)

|            | IDLE | LEFT-RIGHT | UP-DOWN |
|------------|------|------------|---------|
| IDLE       | 100% | 0%         | 0%      |
| LEFT-RIGHT | 0%   | 92.9%      | 7.1%    |
| UP-DOWN    | 0%   | 6.7%       | 93.3%   |
| F1 SCORE   | 1.00 | 0.94       | 0.93    |

Data explorer (full training set) ②

- idle - correct
- left-right - correct
- up-down - correct
- left-right - incorrect
- up-down - incorrect

Start training

AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/learning/keras/9

**EDGE IMPULSE**

**Training settings**

Number of training cycles ② 30

Learning rate ② 0.0005

Validation set size ② 20 %

Auto-balance dataset ②

**Neural network architecture**

Input layer (12 features)

Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (3 classes)

**Start training**

Calculating performance metrics...  
Calculating inferencing time...  
INFO: Created TensorFlow Lite XNNPACK delegate for CPU.  
Calculating inferencing time OK  
Profiling float32 model...  
Profiling float32 model (tflite)...  
Profiling float32 model (EON)...  
Profiling int8 model...  
Profiling int8 model (tflite)...  
Profiling int8 model (EON)...

Model training complete  
**Job completed**

**Model** Model version: ② Quantized (int8)

Last training performance (validation set)

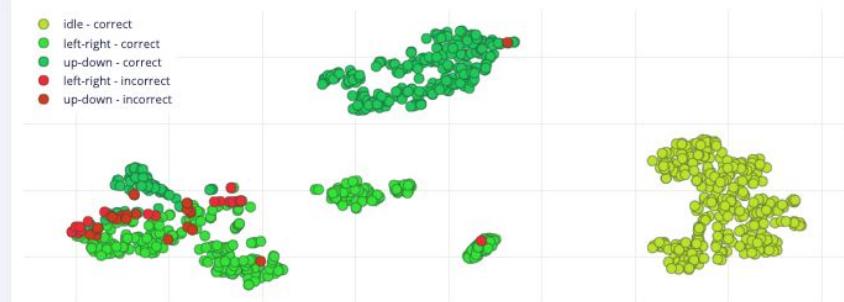
**ACCURACY** 95.5% **LOSS** 0.13

Confusion matrix (validation set)

|            | IDLE | LEFT-RIGHT | UP-DOWN |
|------------|------|------------|---------|
| IDLE       | 100% | 0%         | 0%      |
| LEFT-RIGHT | 0%   | 92.9%      | 7.1%    |
| UP-DOWN    | 0%   | 6.7%       | 93.3%   |
| F1 SCORE   | 1.00 | 0.94       | 0.93    |

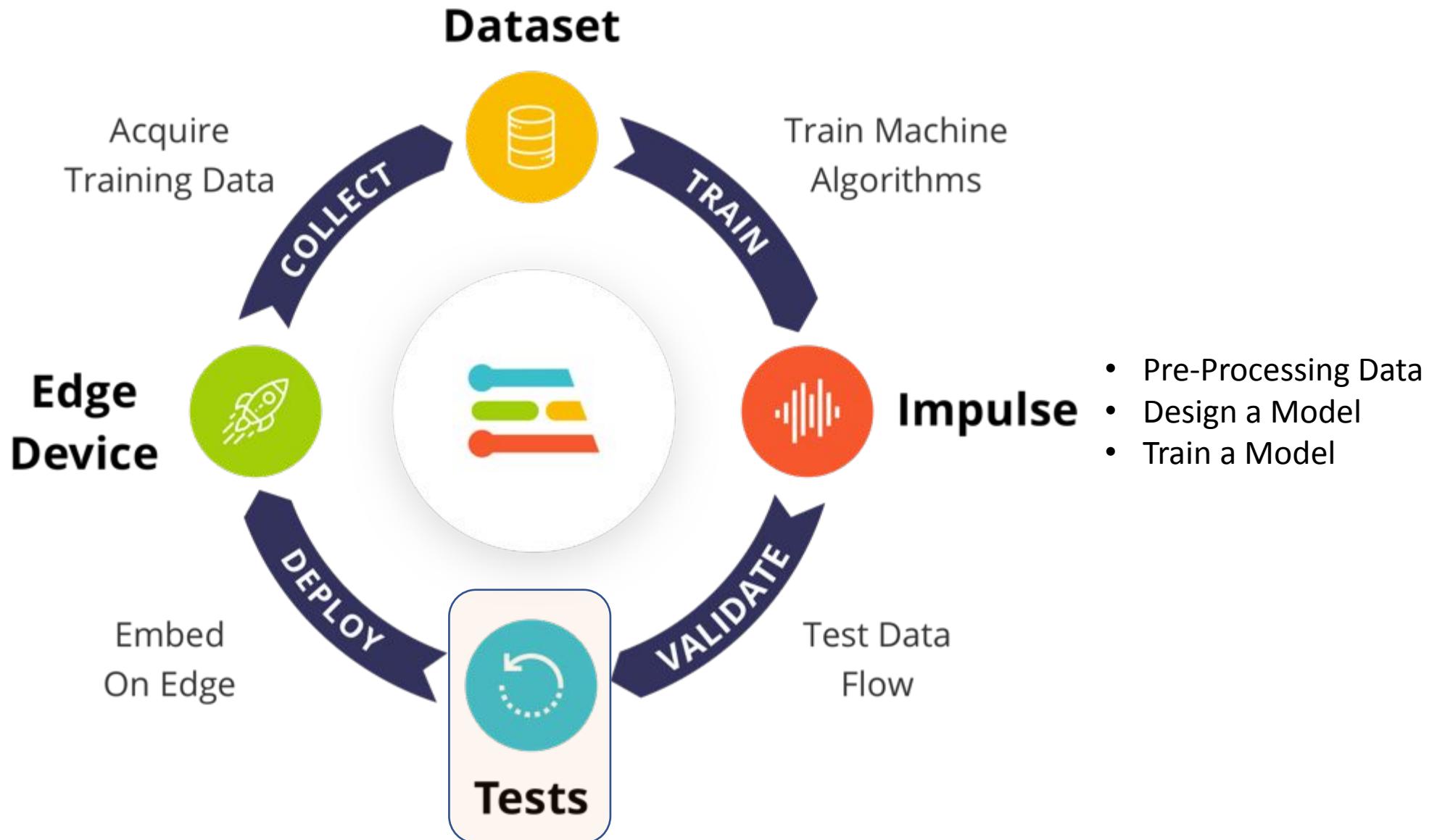
Data explorer (full training set) ②

idle - correct  
left-right - correct  
up-down - correct  
left-right - incorrect  
up-down - incorrect



On-device performance ②

**INFERENCING TIME** 1 ms. **PEAK RAM USAGE** 1.7K **FLASH USAGE** 15.0K



AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/validation

### EDGE IMPULSE

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

**Test data**

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

| SAMPLE NAME         | EXPECTED OUTCOME | LENGTH | ACCURACY | RESULT                          | ⋮ |
|---------------------|------------------|--------|----------|---------------------------------|---|
| left-right.3psif7uj | left-right       | 10s    | 26%      | 24 uncertain, 11 left-right,... | ⋮ |
| left-right.3psiparl | left-right       | 10s    | 100%     | 42 left-right                   | ⋮ |
| up-down.3psj14...   | up-down          | 10s    | 100%     | 42 up-down                      | ⋮ |
| up-down.3psj4jrl    | up-down          | 10s    | 100%     | 42 up-down                      | ⋮ |
| idle.3psjc87r       | idle             | 10s    | 100%     | 42 idle                         | ⋮ |
| idle.3psjg3lj       | idle             | 10s    | 100%     | 42 idle                         | ⋮ |

**Model testing output**

Copying features from processing blocks...  
 Copying features from DSP block...  
 Copying features from DSP block OK  
 Copying features from processing blocks OK

Classifying data for float32 model...  
 Scheduling job in cluster...  
 Container image pulled!  
 Job started  
 Classifying data for Classifier OK

**Job completed**

**Model testing results**

**ACCURACY** 87.70%

|            | IDLE | LEFT-RIGHT | UP-DOWN | UNCERTAIN |
|------------|------|------------|---------|-----------|
| IDLE       | 100% | 0%         | 0%      | 0%        |
| LEFT-RIGHT | 0%   | 63.1%      | 8.3%    | 28.6%     |
| UP-DOWN    | 0%   | 0%         | 100%    | 0%        |
| F1 SCORE   | 1.00 | 0.77       | 0.96    |           |

**Feature explorer**

idle - correct  
 left-right - correct  
 up-down - correct  
 left-right - incorrect

AAU-Wio-Gesture-Classific

studio.edgeimpulse.com/studio/190030/classification#load-sample-186520015

## EDGE IMPULSE

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

**Classify new data**

Device: 23:D1:FF:14:17:05  
Sensor: Built-in accelerometer  
Sample length (ms.): 10000  
Frequency: 62.5Hz

**Start sampling**

**Classify existing test sample**

left-right.3psif7uj (left-right)

**Load sample**

**Classification result**

**Live classification** (highlighted)

**Model testing**

**Versioning**

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**GETTING STARTED**

**Documentation**

**Forums**

**Summary**

| Name             | testing.3psmj62c |
|------------------|------------------|
| Expected outcome | testing          |
| CATEGORY         | COUNT            |
| idle             | 0                |
| left-right       | 38               |
| up-down          | 0                |
| uncertain        | 4                |

**RAW DATA**  
**testing.3psmj62c**

**Raw features**

7.1098, 1.7162, -0.7355, 7.3550, 1.7162, 0.7355, 6.7421, 1.9613, 1.5936, 6.4969, 2.8194, 1.8387...

**Spectral features**

classified

AAU-Wio-Gesture-Classificatio

studio.edgeimpulse.com/studio/190030/tuner

EDGE IMPULSE

EON Tuner

Using the EON tuner you can effortlessly find the most optimal architecture for your embedded machine-learning application!

Configure target

EON Tuner settings

Target Space

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**Find the optimal architecture for your machine learning model**

The EON™ Tuner will evaluate many candidate model architectures (selected based on your target device and latency requirements) concurrently to help you find the best performing architecture for your application.

The search process can take up to 6 hours to complete. While the EON Tuner is running you can view the progress on this page at any time.

Dataset category: Motion events

Target device: Seeed Studio Wio Terminal (Cortex-M4F 120MHz)

Time per inference (ms): 100

Save

Target

Target not configured

Filters

Status

- Pending (0)
- Running (0)
- Completed (0)
- Failed (0)

DSP type

Network type

View

Data set

- Validation
- Test

Precision

Sort

General

- Accuracy (selected)
- Latency
- RAM
- ROM
- Last updated

F1-score

Precision

Marco Rovai / AAU-Wio-Gesture-Classification

Profile

Dashboard

Devices

Data sources

Data acquisition

Impulse design

- Create impulse
- Spectral features
- Classifier

EON Tuner (selected)

Retrain model

Live classification

Model testing

Versioning

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GETTING STARTED

Documentation

Forums

AAU-Wio-Gesture-Classificatio x +

studio.edgeimpulse.com/studio/190030/tuner

### EDGE IMPULSE

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#### GETTING STARTED

- Documentation
- Forums

**100%** spectr-dense-fb4 Select

**PERFORMANCE**

|         |         |
|---------|---------|
| LATENCY | 100 ms  |
| RAM     | 192 kB  |
| ROM     | 4096 kB |

DSP NN Unused

**ACCURACY**

|      |     |     |
|------|-----|-----|
| idle | 0   | 0   |
| left | 100 | 0   |
| up   | 0   | 100 |
| F1   | 1   | 1   |

INPUT ↳ 10000 ms | ↴ 10000 ms

**SPECTRAL-ANALYSIS** ↳ 64

**CLASSIFICATION** ↳ 0.0005 | 30

| Type    | Filters | Kernel | Rate |
|---------|---------|--------|------|
| dense   | 20      | -      | -    |
| dense   | 10      | -      | -    |
| dropout | -       | -      | 0.5  |

**100%** spectr-dense-78c Select

**PERFORMANCE**

|         |         |
|---------|---------|
| LATENCY | 100 ms  |
| RAM     | 192 kB  |
| ROM     | 4096 kB |

DSP NN Unused

**ACCURACY**

|      |     |     |
|------|-----|-----|
| idle | 0   | 0   |
| left | 100 | 0   |
| up   | 0   | 100 |
| F1   | 1   | 1   |

INPUT ↳ 10000 ms | ↴ 10000 ms

**SPECTRAL-ANALYSIS** ↳ 64

**CLASSIFICATION** ↳ 0.0005 | 30

| Type    | Filters | Kernel | Rate |
|---------|---------|--------|------|
| dense   | 20      | -      | -    |
| dense   | 10      | -      | -    |
| dropout | -       | -      | 0.25 |

**80%** spectr-dense-9bc Select

**PERFORMANCE**

|         |         |
|---------|---------|
| LATENCY | 100 ms  |
| RAM     | 192 kB  |
| ROM     | 4096 kB |

DSP NN Unused

**ACCURACY**

|      |     |     |
|------|-----|-----|
| idle | 0   | 0   |
| left | 50  | 50  |
| up   | 0   | 100 |
| F1   | .67 | .86 |

INPUT ↳ 10000 ms | ↴ 10000 ms

**SPECTRAL-ANALYSIS** ↳ 64

**CLASSIFICATION** ↳ 0.0005 | 30

| Type    | Filters | Kernel | Rate |
|---------|---------|--------|------|
| dense   | 40      | -      | -    |
| dense   | 20      | -      | -    |
| dense   | 10      | -      | -    |
| dropout | -       | -      | 0.25 |

100 ms  
192 kB  
4096 kB

**Filters**

Status

- Pending
- Running
- Completed
- Failed

DSP type

- Spectral analysis

Network type

- Dense

**View**

Data set

- Validation
- Test

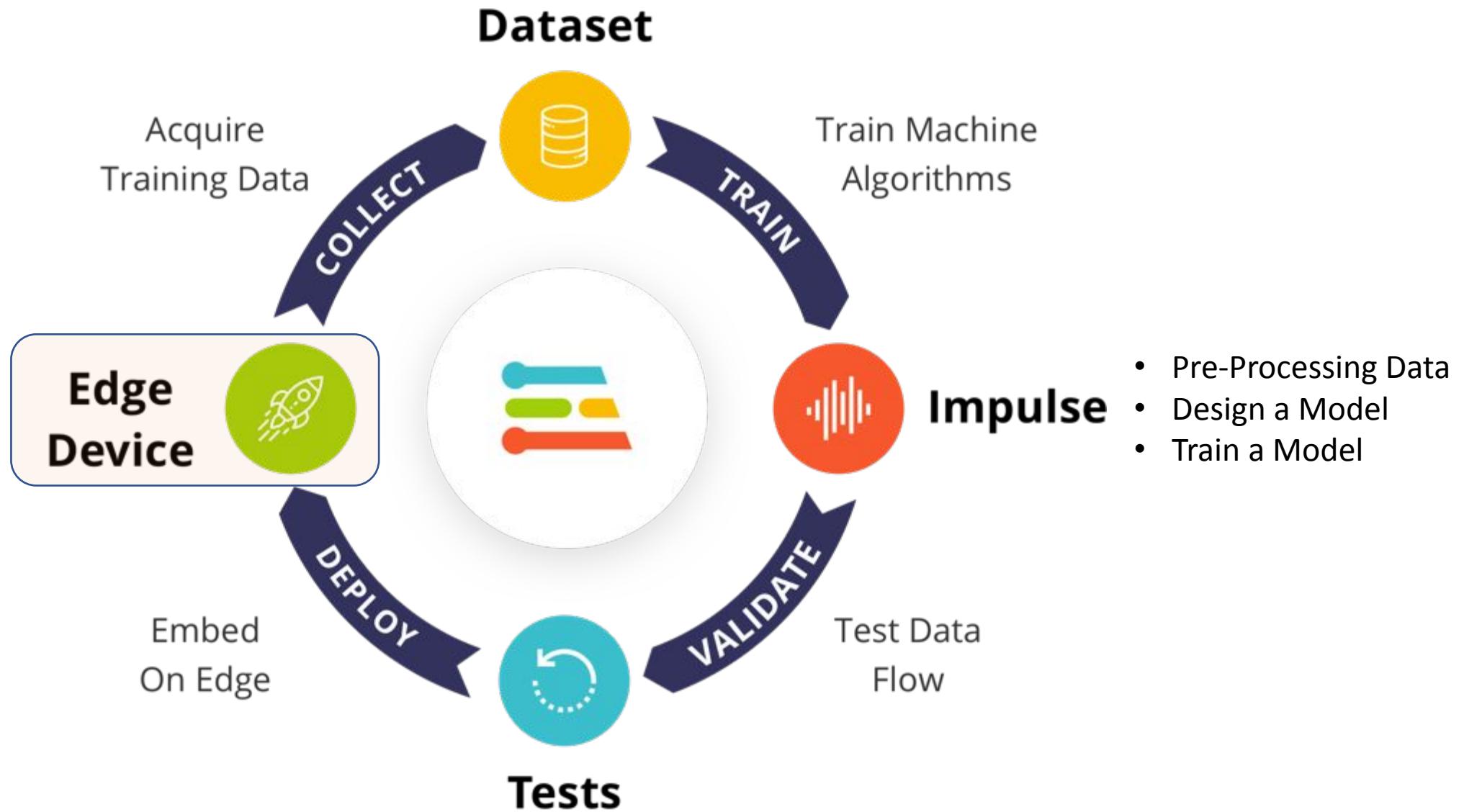
**Precision**

**Sort**

General

- Accuracy
- Latency
- RAM
- ROM
- Last updated

**F1-score**



AAU-Wio-Gesture-Classification

studio.edgeimpulse.com/studio/190030/deployment

Marcelo Rovai / AAU-Wio-Gesture-Classification

## 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          |  Ethos-U library                        |
|  synaptics <sup>®</sup><br>Tensai Flow library |  brainchip<br>MetaTF Model |  TEXAS INSTRUMENTS<br>TIIDL-RT Library |
|  Simplicity Studio Component                  |   |  |

AAU-Wio-Gesture-Classification

studio.edgeimpulse.com/studio/190030/deployment

## EDGE IMPULSE

Mobile phone

Select optimizations (optional)

Model optimizations can increase on-device performance but may reduce accuracy. Click below to analyze optimizations and see the recommended choices for this model.

Enable EON™ Com... Same accuracy, up to 10x faster!

Available optimizations for this model

**Quantized (int8) ★** Currently selected

This optimization is recommended for best performance.

**Unoptimized (float32)** Click to select

FLASH USAGE: 13.9K ACCURACY: 87.7% (0 0 100 0)

Estimate for Seeed Studio Wio Terminal (Cortex-M4F 120MHz).

**Build**

### Build output

Creating job... OK (ID: 6576765)  
Scheduling job in cluster...  
Job started  
Writing templates...  
Writing templates OK

in cluster...  
: pulled!  
edgeimpulse SDK...  
edgeimpulse SDK OK  
model...  
model OK  
or and updating headers...  
or and updating headers OK

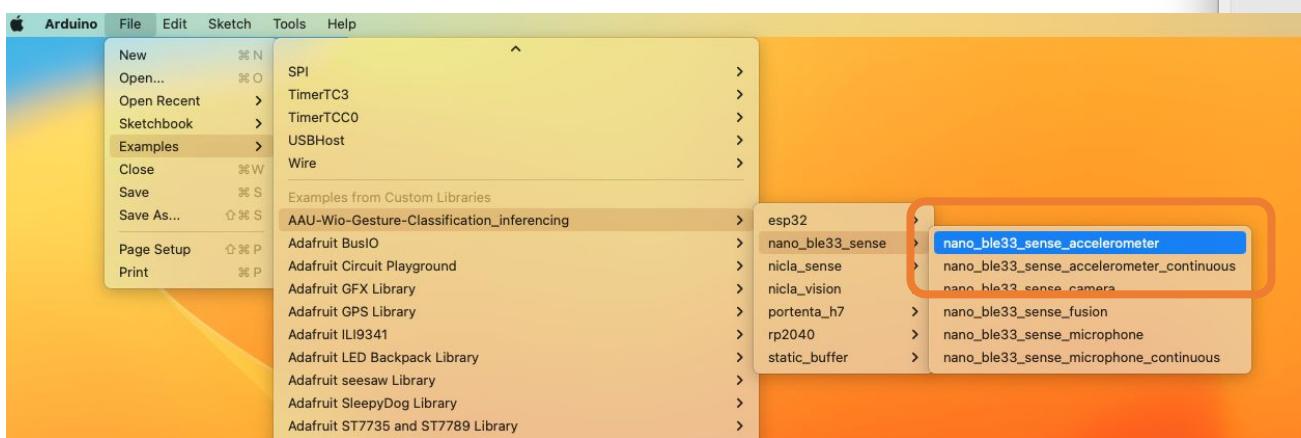
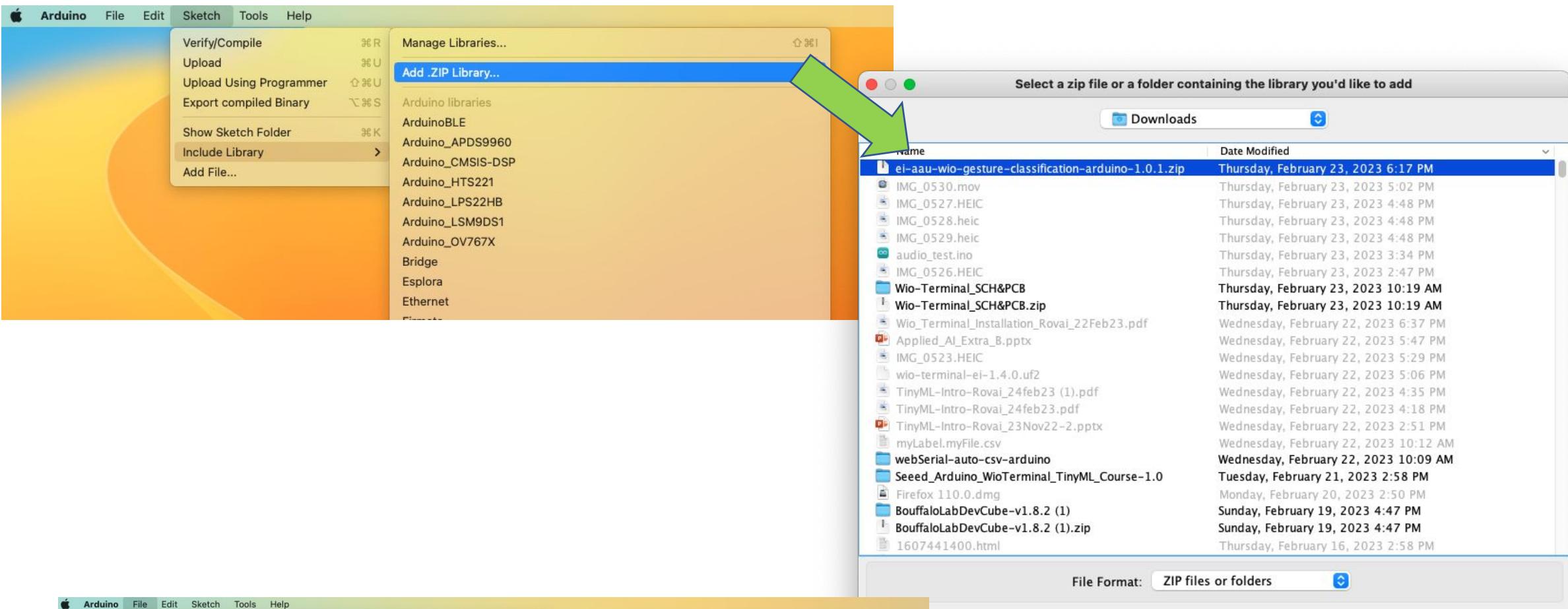
re...  
e OK

**Built Arduino library**

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

Examples can then be found under:  
**File > Examples > AAU-Wio-Gesture-Classification\_inferencing**

ei-aau-wio-gestu....zip ^ Show All X



# Model Inference

# Changing the Arduino code to adapt the Wio Accelerometer

```
nano_ble33_sense_accelerometer | Arduino 1.8.19

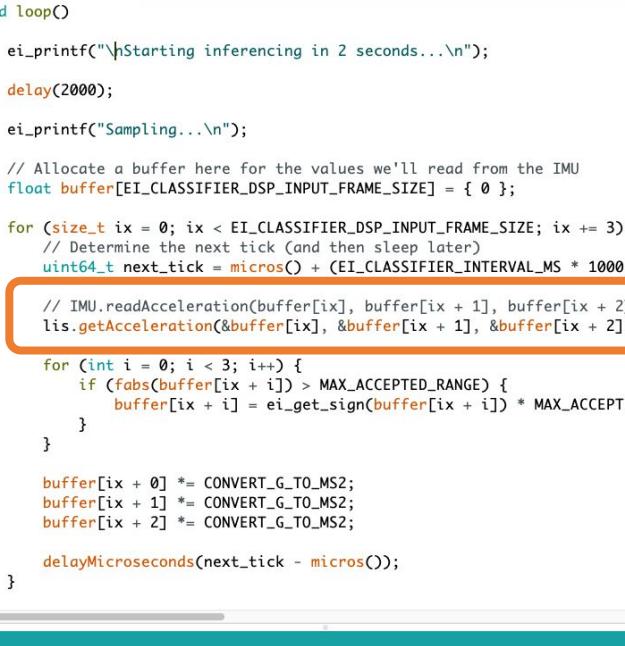
nano_ble33_sense_accelerometer $ 
1/* Edge Impulse ingestion SDK
2 * Copyright (c) 2022 EdgeImpulse Inc.
3 *
4 * Licensed under the Apache License, Version 2.0 (the "License");
5 * you may not use this file except in compliance with the License.
6 * You may obtain a copy of the License at
7 * http://www.apache.org/licenses/LICENSE-2.0
8 *
9 * Unless required by applicable law or agreed to in writing, software
10 * distributed under the License is distributed on an "AS IS" BASIS,
11 * WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
12 * See the License for the specific language governing permissions and
13 * limitations under the License.
14 *
15 */
16
17 /* Includes ----- */
18 #include <AAU-Wio-Gesture-Classification_inferencing.h>
19
20 //include <Arduino_LSM9DS1.h>
21 #include "LIS3DHTR.h"
22 LIS3DHTR<TwoWire> lis;
23
24 /* Constant defines ----- */
25 #define CONVERT_G_TO_MS2 9.80665f
26 #define MAX_ACCEPTED_RANGE 2.0f           // starting 03/2022, models are generated
27
28 /*
29 ** NOTE: If you run into TFLite arena allocation issue.
30 **
31 ** This may be due to memory fragmentation.
32 ** Try defining "-DEI_CLASSIFIER_ALLOCATION_STATIC" in boards.local.txt (create
33 ** if it doesn't exist) and copy this file to
34 ** ADDTINO_CODE_INSTALL_PATH /lib/tflite/boards.local.txt
35 */

Seeeduno Wio Terminal | Master. Enabled: 120 MHz (standard), Small (-Os) (standard), 50 MHz (standard). Arduino. Off. On on /dev/cu.usbmodem1101
```

```
nano_ble33_sense_accelerometer | Arduino 1.8.19

nano_ble33_sense_accelerometer $ 
-- 
51 // put your setup code here, to run once:
52 Serial.begin(115200);
53 // comment out the below line to cancel the wait for USB connection (needed fo
54 while (!Serial);
55 Serial.println("Edge Impulse Inferencing Demo");
56 //
57 // if (!IMU.begin()) {
58 //     ei_printf("Failed to initialize IMU!\r\n");
59 // }
60 // else {
61 //     ei_printf("IMU initialized\r\n");
62 // }
63
64 lis.begin(Wire1);
65
66 if (!lis.available()) {
67 Serial.println("Failed to initialize IMU!");
68 while (1);
69 }
70 else {
71     ei_printf("IMU initialized\r\n");
72 }
73 lis.setOutputDataRate(LIS3DHTR_DATARATE_100HZ); // Setting output data rate to
74 lis.setFullScaleRange(LIS3DHTR_RANGE_16G); // Setting scale range to 2g, selec
75
76
77 if (EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME != 3) {
78     ei_printf("ERR: EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME should be equal to 3 (
79     return;
80 }
81 }
82 /**
83 */

Seeduino Wio Terminal. Master. Enabled. 120 MHz (standard). Small (-Os) (standard). 50 MHz (standard). Arduino. Off. On on /dev/cu.usbmodem1101
```



```
nano_ble33_sense_accelerometer | Arduino 1.8.19

nano_ble33_sense_accelerometer §

98 void loop()
99 {
100     ei_printf("\hStarting inferencing in 2 seconds...\n");
101
102     delay(2000);
103
104     ei_printf("Sampling...\n");
105
106     // Allocate a buffer here for the values we'll read from the IMU
107     float buffer[EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE] = { 0 };
108
109     for (size_t ix = 0; ix < EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE; ix += 3) {
110         // Determine the next tick (and then sleep later)
111         uint64_t next_tick = micros() + (EI_CLASSIFIER_INTERVAL_MS * 1000);
112
113         // IMU.readAcceleration(buffer[ix], buffer[ix + 1], buffer[ix + 2]);
114         lis.getAcceleration(&buffer[ix], &buffer[ix + 1], &buffer[ix + 2]);
115
116         for (int i = 0; i < 3; i++) {
117             if (fabs(buffer[ix + i]) > MAX_ACCEPTED_RANGE) {
118                 buffer[ix + i] = ei_get_sign(buffer[ix + i]) * MAX_ACCEPTED_RANGE;
119             }
120         }
121
122         buffer[ix + 0] *= CONVERT_G_TO_MS2;
123         buffer[ix + 1] *= CONVERT_G_TO_MS2;
124         buffer[ix + 2] *= CONVERT_G_TO_MS2;
125
126         delayMicroseconds(next_tick - micros());
127     }
128 }
```

```
/dev/cu.usbmodem1101
Send

Edge Impulse Inferencing Demo
IMU initialized

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly
idle: 0.61719
left-right: 0.15625
up-down: 0.22266

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly
idle: 0.58984
left-right: 0.22656

 Autoscroll  Show timestamp Both NL & CR
```

```
/dev/cu.usbmodem1101
Send

Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.00000
left-right: 0.01562
up-down: 0.98438

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.00000
left-right: 0.01953
up-down: 0.98047

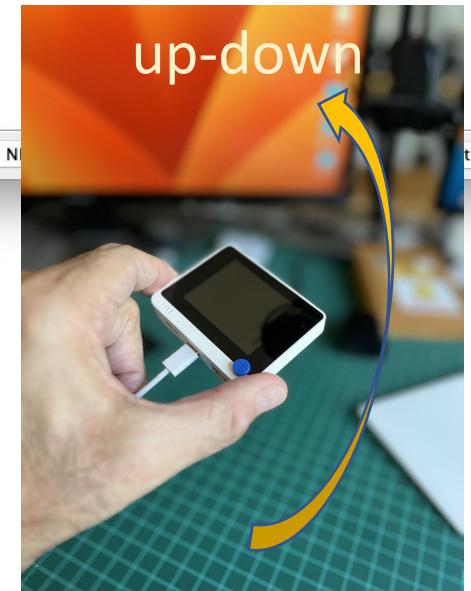
Starting inferencing in 2 seconds...
Sampling...
 Autoscroll  Show timestamp Both NL & CR
```

```
/dev/cu.usbmodem1101
Send

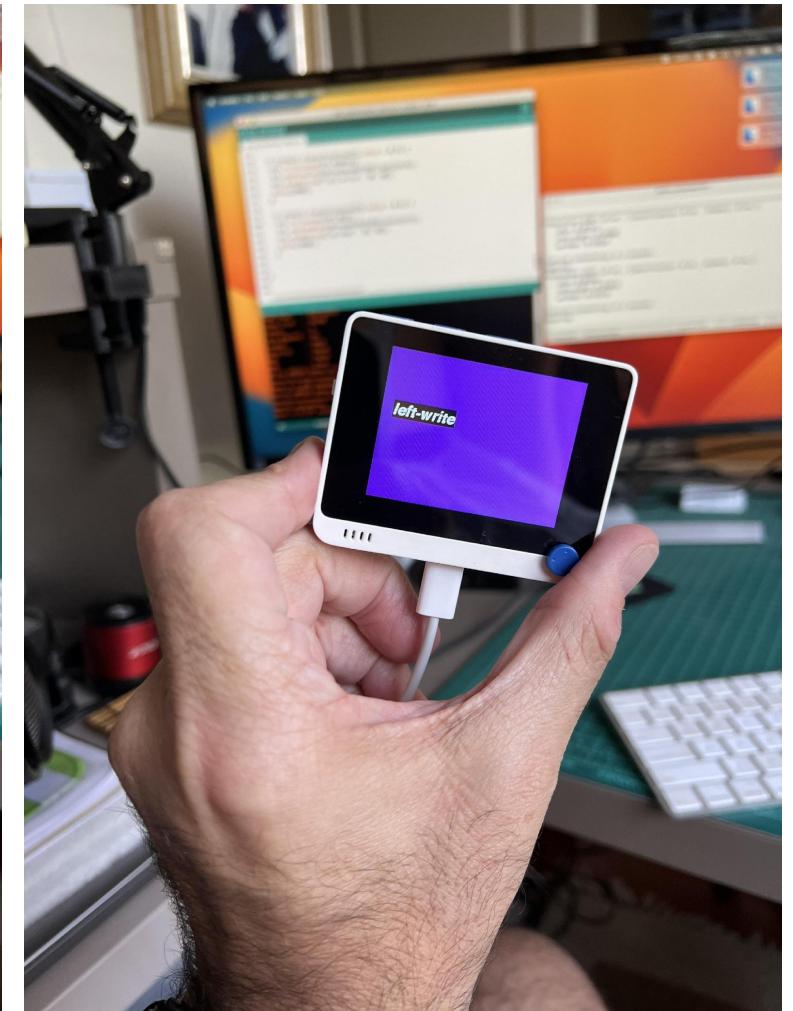
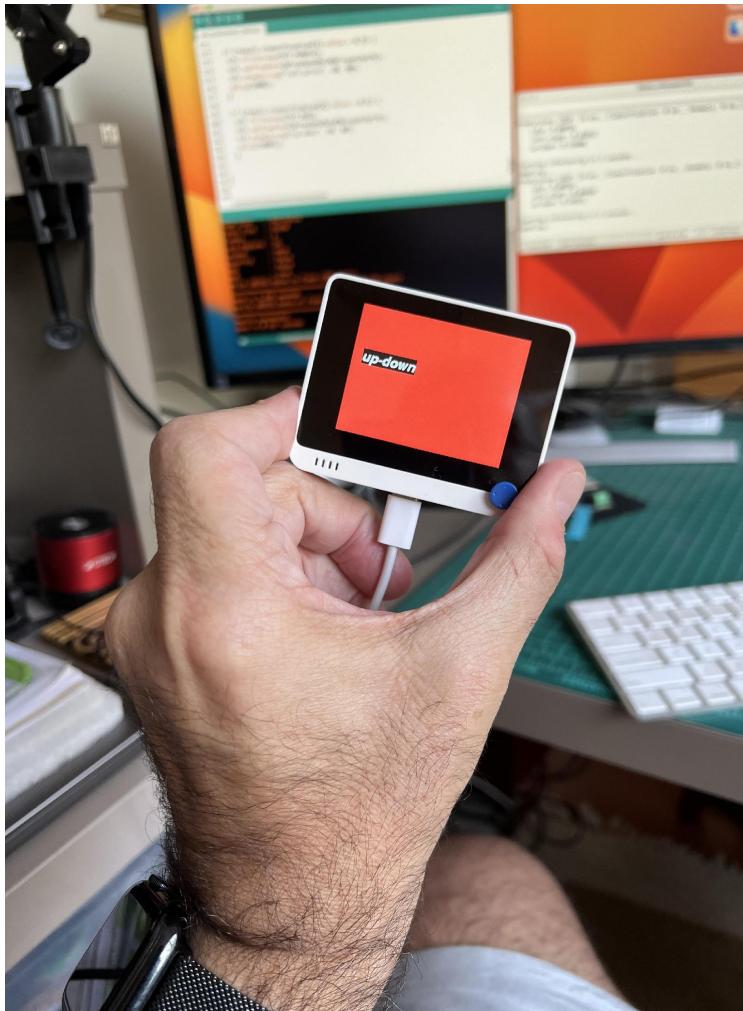
Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.00781
left-right: 0.82812
up-down: 0.16406

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.00391
left-right: 0.85156
up-down: 0.14453

Starting inferencing in 2 seconds...
Sampling...
 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear
```



# Including LCD for off-line Inference



# Appendix

## Spectral Analysis (Google CoLab)

# Edge Impulse - Spectral Analysis Block

Implementation\_version >= 2

- by Marcelo Rovai @ Feb23

## Statistical features per axis/channel:

After filtering via a Butterworth IIR filter (if enabled), **the mean is subtracted from the signal**. Several statistical features (RMS, skewness, kurtosis) are calculated from the filtered signal after the mean has been removed.

- RMS (from Normalized data)
- Skewness
- Kurtosis

## Spectral features per axis/channel:

The filtered signal is passed to the Spectral power section, which computes the FFT in order to compute the spectral features.

- Maximum value from FFT frames for each bin that was not filtered out
- The total number of features will change, depending on how you set the filter and FFT parameters.

<https://docs.edgeimpulse.com/docs/edge-impulse-studio/processing-blocks/spectral-features>

The Total Number of processed Features per axis will be:

- RMS
- Skewness
- Curtosis
- 1/2 of FFT Length (no Filter)

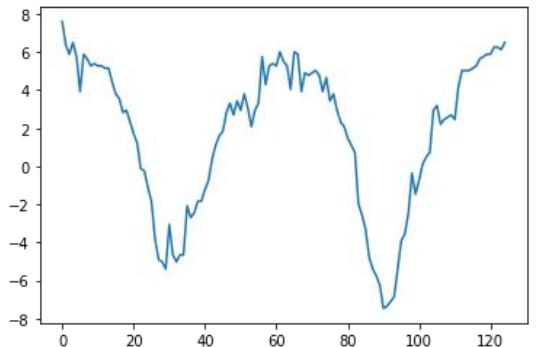
For example,

- for a FFT Length of 64 and filter NONE, the Total Processed Features per axis will be 35
- for a FFT Length of 64 and filter LOW, the Total Processed Features per axis will be lower than 35 depending on Filter Cut-off frequency  
(LOW: skip everything > cutoff; HIGH: skip everything < cutoff)

## Statistical features

```
[ ] 1 import numpy as np
2 import matplotlib.pyplot as plt
3 import seaborn as sns
4 import math
5 from scipy.stats import skew, kurtosis
6 from scipy import signal
7 from sklearn import preprocessing
```

Let's have a datasample of one accelerometer axix (2 seconds window; Sample frequency 62.5Hz)



## Subtracting the mean from data (Used by EI)

Subtracting the mean from a set of data is a common data pre-processing step in statistics and machine learning. The purpose of subtracting the mean from data is to center the data around zero. This is important because it can reveal patterns and relationships that might be hidden if the data is not centered.

Here are some specific reasons why subtracting the mean can be useful:

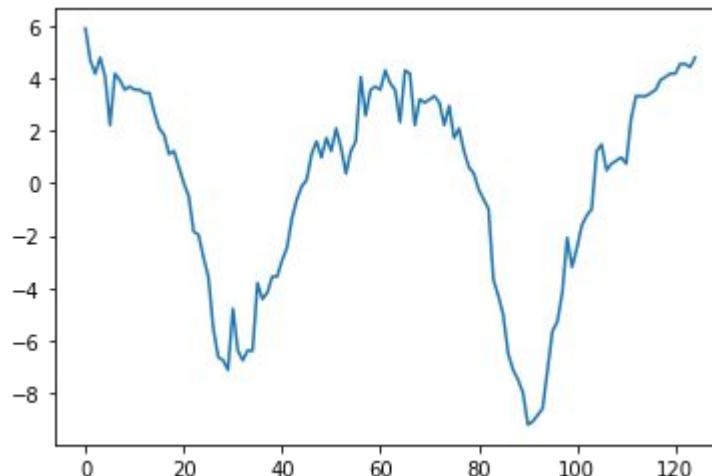
- It simplifies analysis: By centering the data, the mean becomes zero, which can make some calculations simpler and easier to interpret.
- It removes bias: If the data has a bias, subtracting the mean can remove that bias and allow for more accurate analysis.
- It can reveal patterns: Centering the data can help reveal patterns that might be hidden if the data is not centered. For example, if you are analyzing a time series dataset, centering the data can help you identify trends over time.
- It can improve performance: In some machine learning algorithms, centering the data can improve performance by reducing the influence of outliers and making the data more easily comparable. Overall, subtracting the mean is a simple but powerful technique that can be used to improve the analysis and interpretation of data.

```
1 dtmean = sum(data)/len(data)
2 dtmean
```

```
1.7151832000000005
```

```
1 stand_data = data.copy()
2 stand_data = [(x - dtmean) for x in stand_data]
```

```
1 sns.lineplot(x, stand_data);
```



## RMS Calculation

The RMS value of a set of values (or a continuous-time waveform) is the square root of the arithmetic mean of the squares of the values, or the square of the function that defines the continuous waveform. In physics, the RMS current value can also be defined as the "value of the direct current that dissipates the same power in a resistor."

In the case of a set of n values  $\{x_1, x_2, \dots, x_n\}$ , the RMS is:

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

NOTE that the RMS value is different for Normalized and Not Normalized data

```
[ ] 1 # Using regular python and not normalize data
2 rms = 0
3 for i in range(N):
4     rms = rms + data[i]**2
5 rms = rms / N
6 rms = math.sqrt(rms)
7 print("rms = ", rms)
```

rms = 4.290552222723783

```
[ ] 1 # Using regular python and standartized data
2 for i in range(N):
3     rms = rms + stand_data[i]**2
4 rms = rms / N
5 rms = math.sqrt(rms)
6 print("rms = ", rms)
```

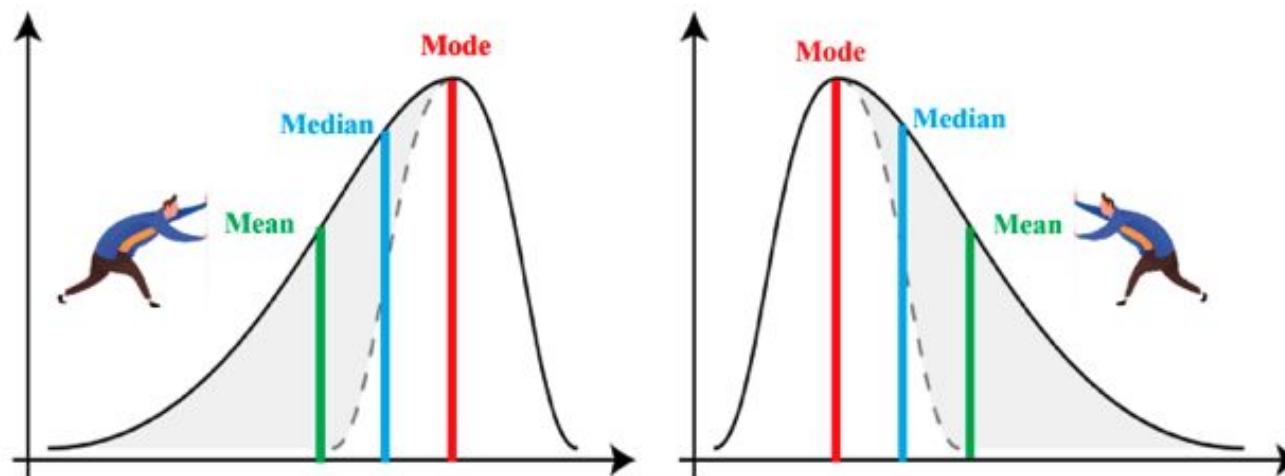
rms = 3.9328087884307004

# Skewness and kurtosis calculation

<https://towardsdatascience.com/skewness-kurtosis-simplified-1338e094fc85>

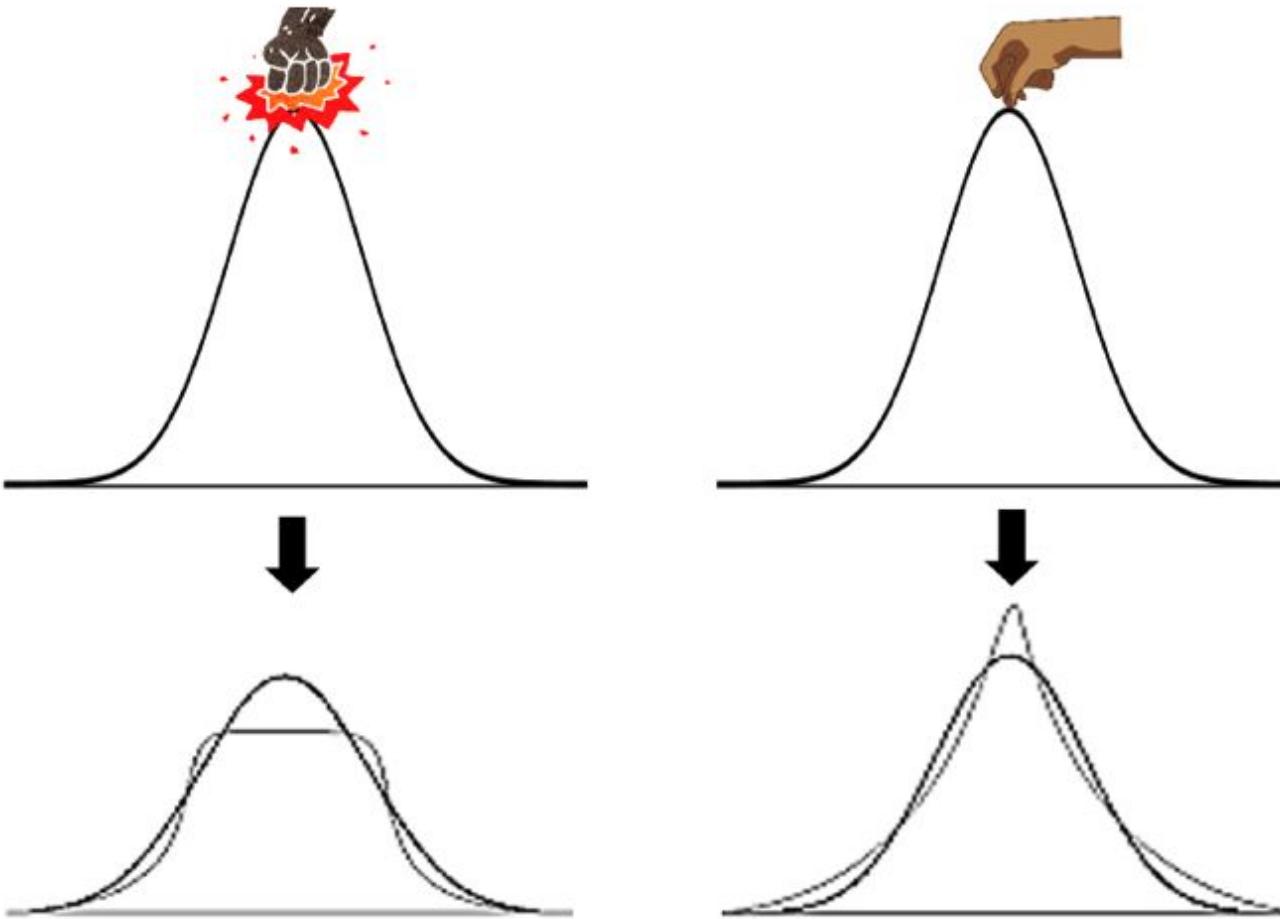
In statistics, skewness and kurtosis are two ways to measure the **shape of a distribution**.

**Skewness** is a measure of the asymmetry of a distribution. This value can be positive or negative.



- A negative skew indicates that the tail is on the left side of the distribution, which extends towards more negative values.
- A positive skew indicates that the tail is on the right side of the distribution, which extends towards more positive values.
- A value of zero indicates that there is no skewness in the distribution at all, meaning the distribution is perfectly symmetrical.

**Kurtosis** is a measure of whether or not a distribution is heavy-tailed or light-tailed relative to a normal distribution.

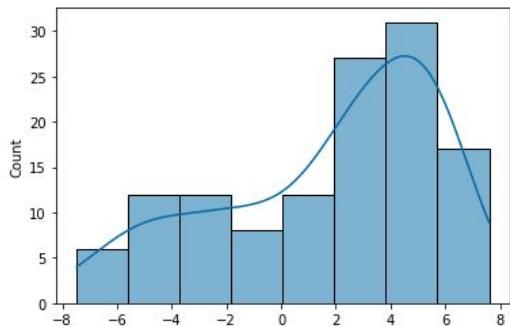


- The kurtosis of a normal distribution is 3.
- If a given distribution has a kurtosis of less than 3, it is said to be platykurtic, which means it tends to produce fewer and less extreme outliers than the normal distribution.
- If a given distribution has a kurtosis greater than 3, it is said to be leptokurtic, which means it tends to produce more outliers than the normal distribution.

NOTE that the Skewness and Kurtosis values is the same for Normalized and Not Normalized data

Let's see the data distribution and the Skewness and kurtosis calculation

```
[ ] 1 sns.histplot(data,kde=True);
```

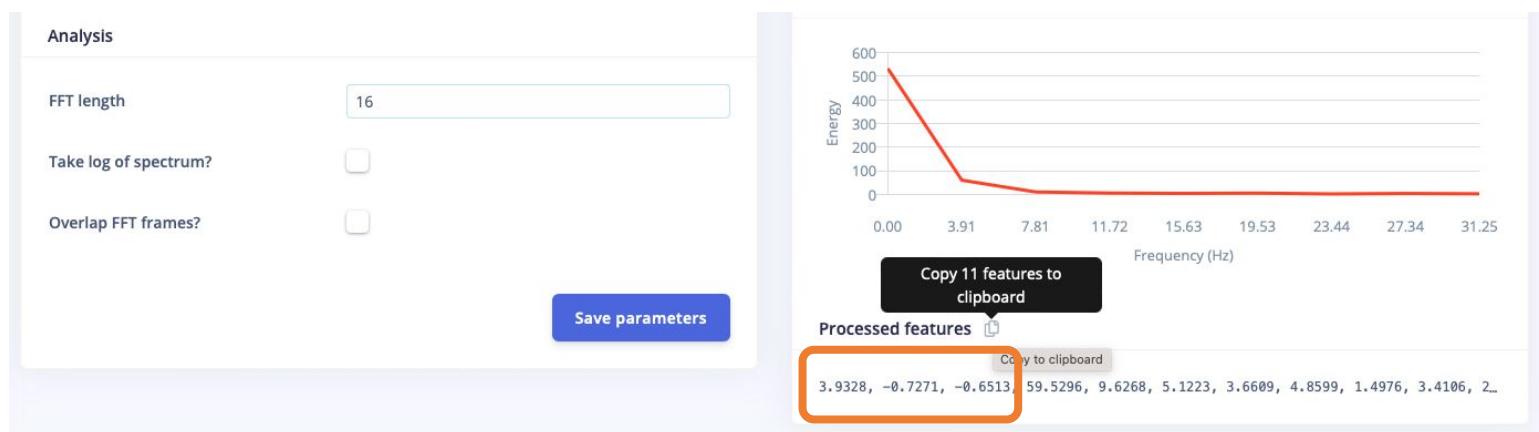


```
[ ] 1 print("skewness = ", skew(data, bias=False))
2 print("kurtosis = ", kurtosis(data, bias=False))

skewness = -0.7359427285604101
kurtosis = -0.6285390741135903
```

In the example, the processed features will be 11 (RMS, Skewness, Kurtosis and FFT Length / 2):

- RMS: 3.93
- Skewness: -0.74
- Kurtosis: -0.63
- and 8 values calculated from the FFT process



# Thanks



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