



Wio Terminal – Part 2

Hands-on: Gesture Recognition



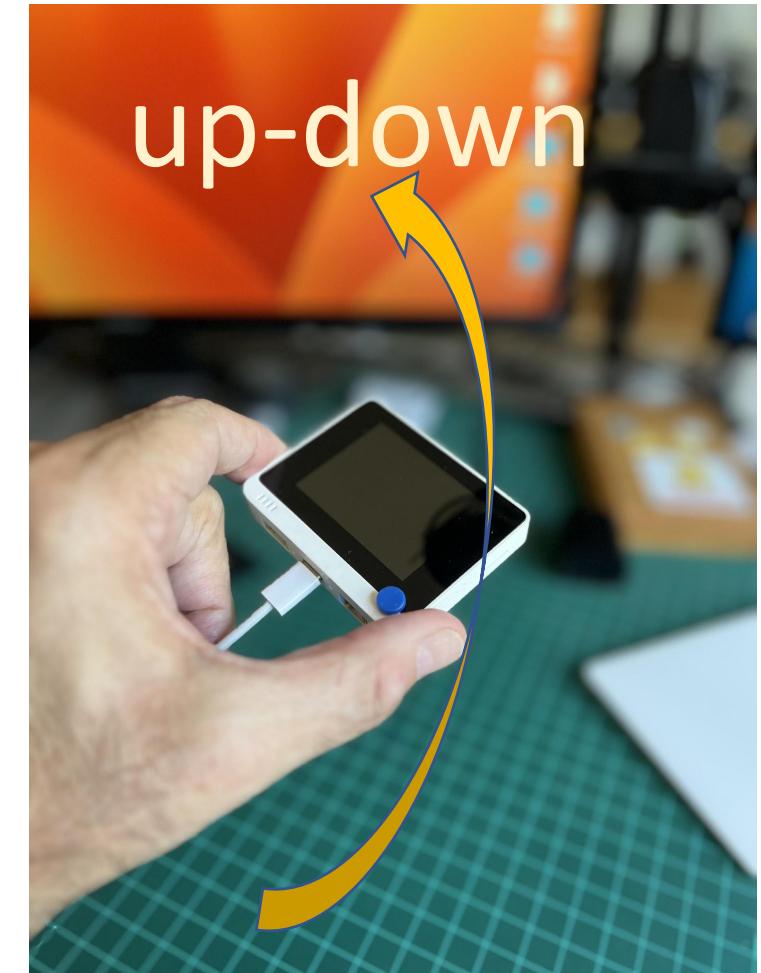
Prof. Marcelo José Rovai
UNIFEI - Federal University of Itajubá, Brazil
TinyML4D Academic Network Co-Chair

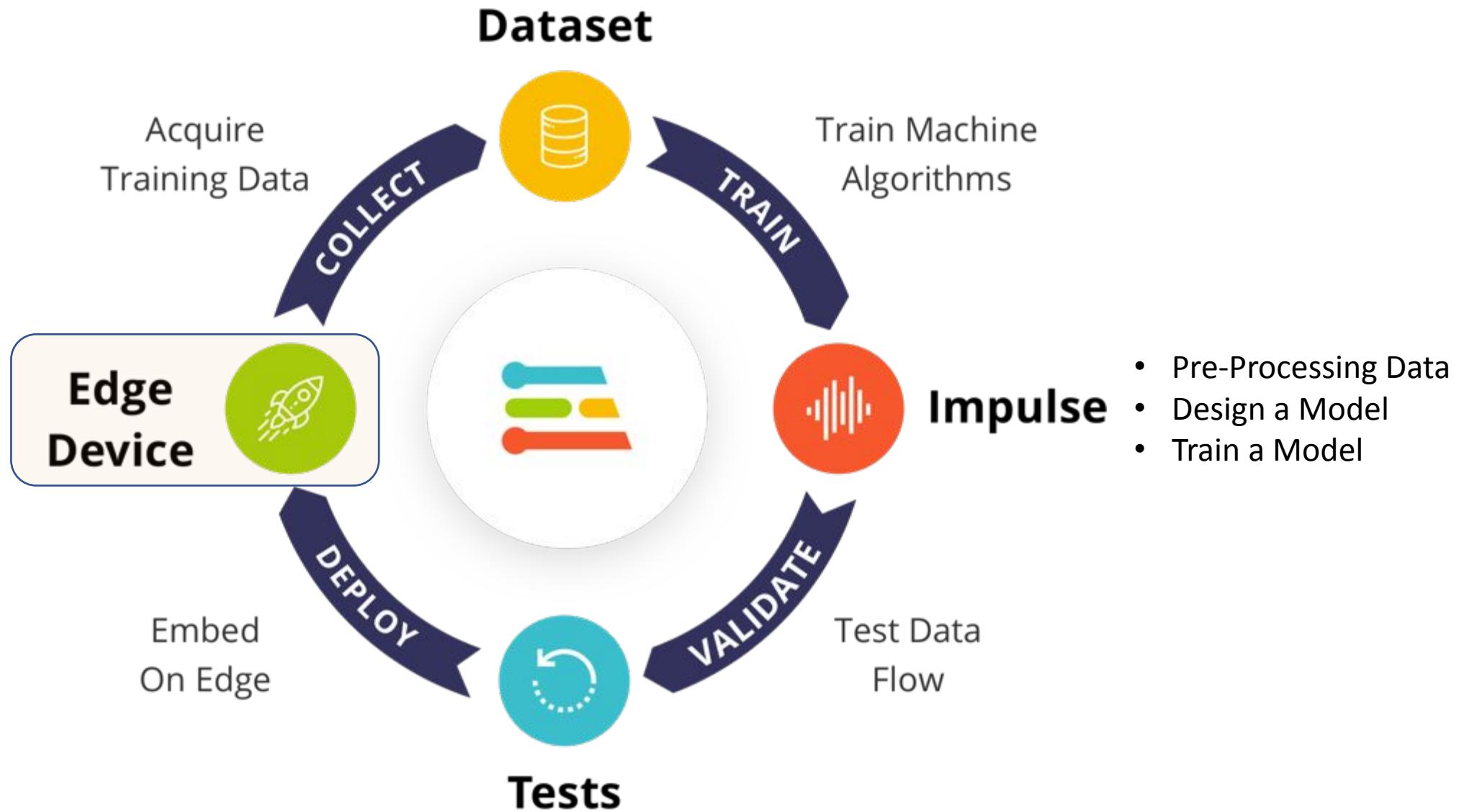


UNIFEI

Hands-on: Gesture Recognition

Gestures Definition (classes)





AAU-Wio-Gesture-Classificatio

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

EDGE IM

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Live classification

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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

The screenshot shows the Edge Impulse Studio interface. A modal dialog box titled 'studio.edgeimpulse.com wants to connect to a serial port' is displayed in the foreground. 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 the dialog are two buttons: 'Cancel' and 'Connect', with 'Connect' being highlighted by an orange rectangle. In the background, the main studio workspace is visible, showing a purple header bar with the user's name 'Marcelo Rovai / AAU-Wio-Gesture-Classification' and navigation links for 'Upload data' and 'Export data'. Below the header is a search bar and a message: 'Select your device or development board, or upload your existing datasets - Show options'. On the right side of the workspace, there is a section titled 'Record new data' with a note: 'No devices connected to the remote management API.' An orange rectangle highlights the 'Connect using WebUSB' button in this section.

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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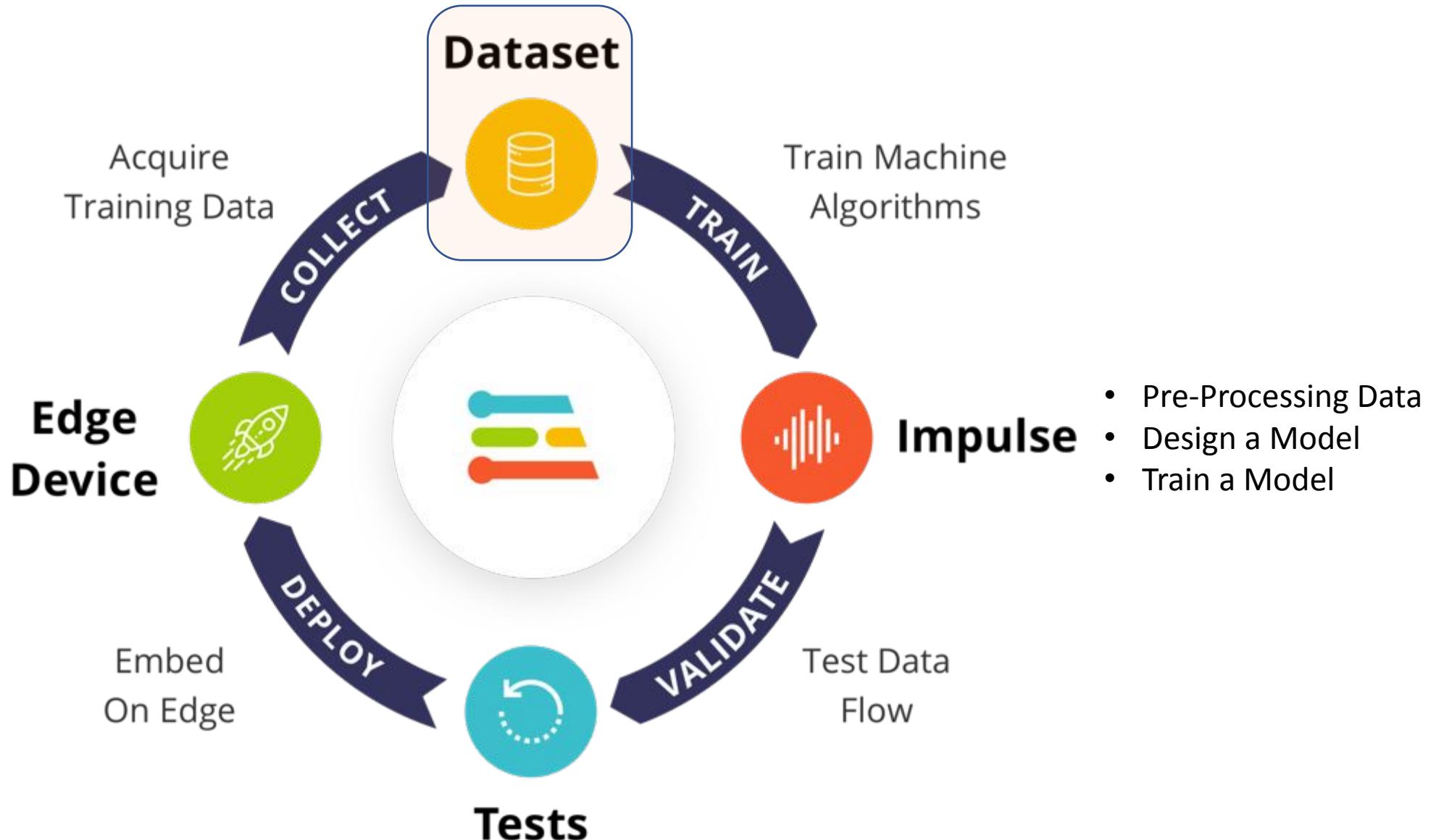
Versioning

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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

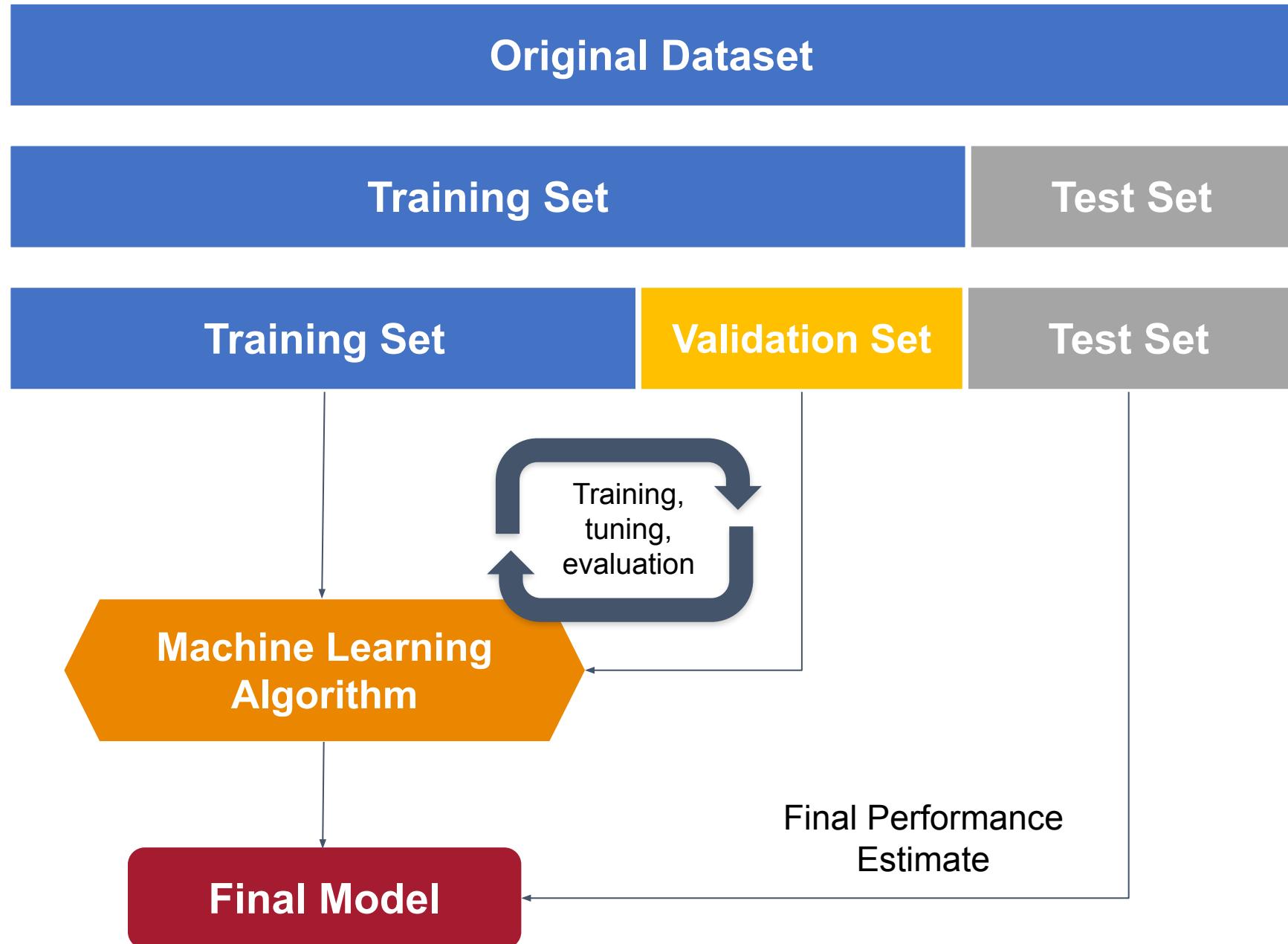
Label Sample length (ms.)

Sensor Frequency

Start sampling

RAW DATA
idle.3psjhp64

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, 17:18:3	10s	⋮
idle.3psjer3m	idle	Today, 17:18:2	10s	⋮
idle.3psje51r	idle	Today, 17:17:5	10s	⋮
idle.3psjdi38	idle	Today, 17:17:3	10s	⋮
idle.3psjctpm	idle	Today, 17:17:1	10s	⋮
idle.3psjc87r	idle	Today, 17:16:4	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	⋮

⋮

Rename

Edit label

Move to test set

Disable

Crop sample

Split sample

Download

Delete

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

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

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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

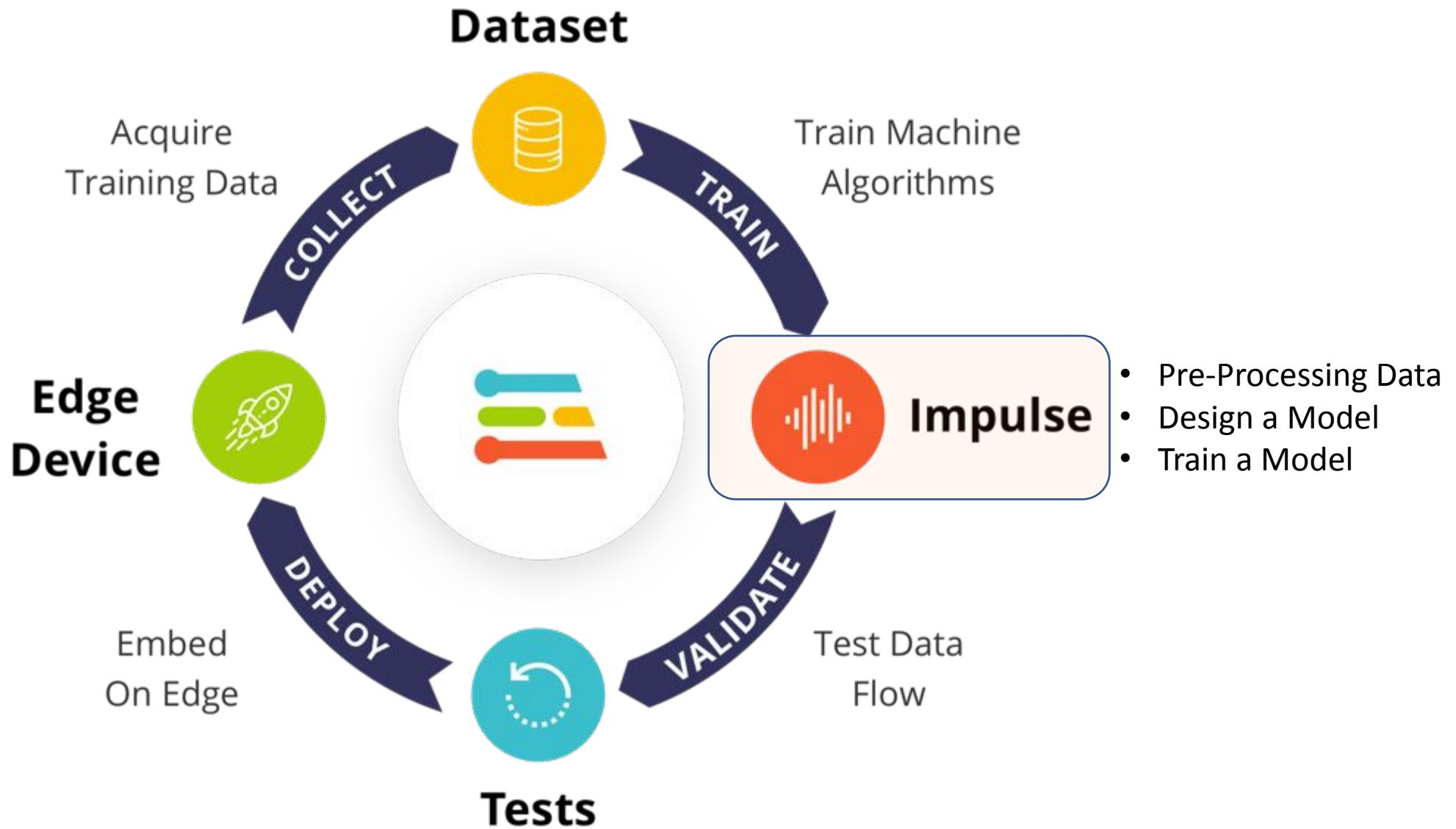
Sensor
Built-in accelerometer

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
Spectral Analysis 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) 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 Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.	Edge Impulse	Add
Spectrogram Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.	Edge Impulse	Add
Raw Data 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

EON Tuner

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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
Classification Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.	Edge Impulse 	Add
Anomaly Detection (K-means) 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 	Add
Regression Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.	Edge Impulse	Add
Classification (Keras) - BrainChip Akida™ Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.	BrainChip	Add

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 area shows a 'Training set' configuration with parameters like 'Data in training set' (4m 0s), 'Classes' (3: idle, left-right, up-down), and 'Training windows' (1.008). A checkbox for 'Calculate feature importance' is checked. A prominent green button labeled 'Generate features' is at the bottom of this section, and it is highlighted with a red rectangular box. To the right, a 'Feature explorer' panel displays the message 'No features generated yet.' At the top, the URL is studio.edgeimpulse.com/studio/190030/dsp/spectral-analysis/3/generate-features. The top navigation bar includes standard browser controls (back, forward, search) and user account information. The sidebar on the left lists various project management and documentation links.

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)

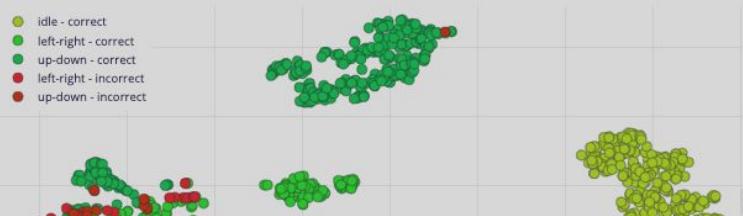
LOSS 0.13

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)

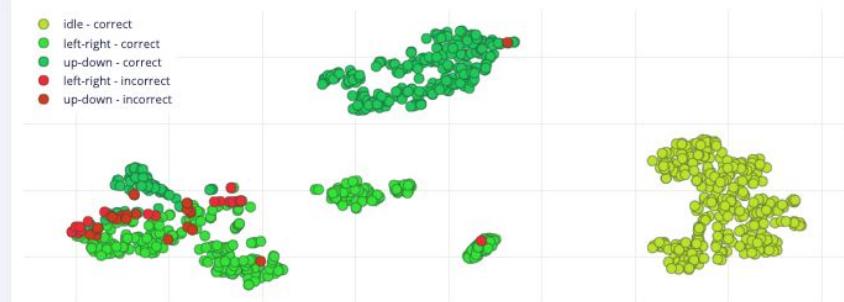
ACCURACY 95.5% **LOSS** 0.13

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

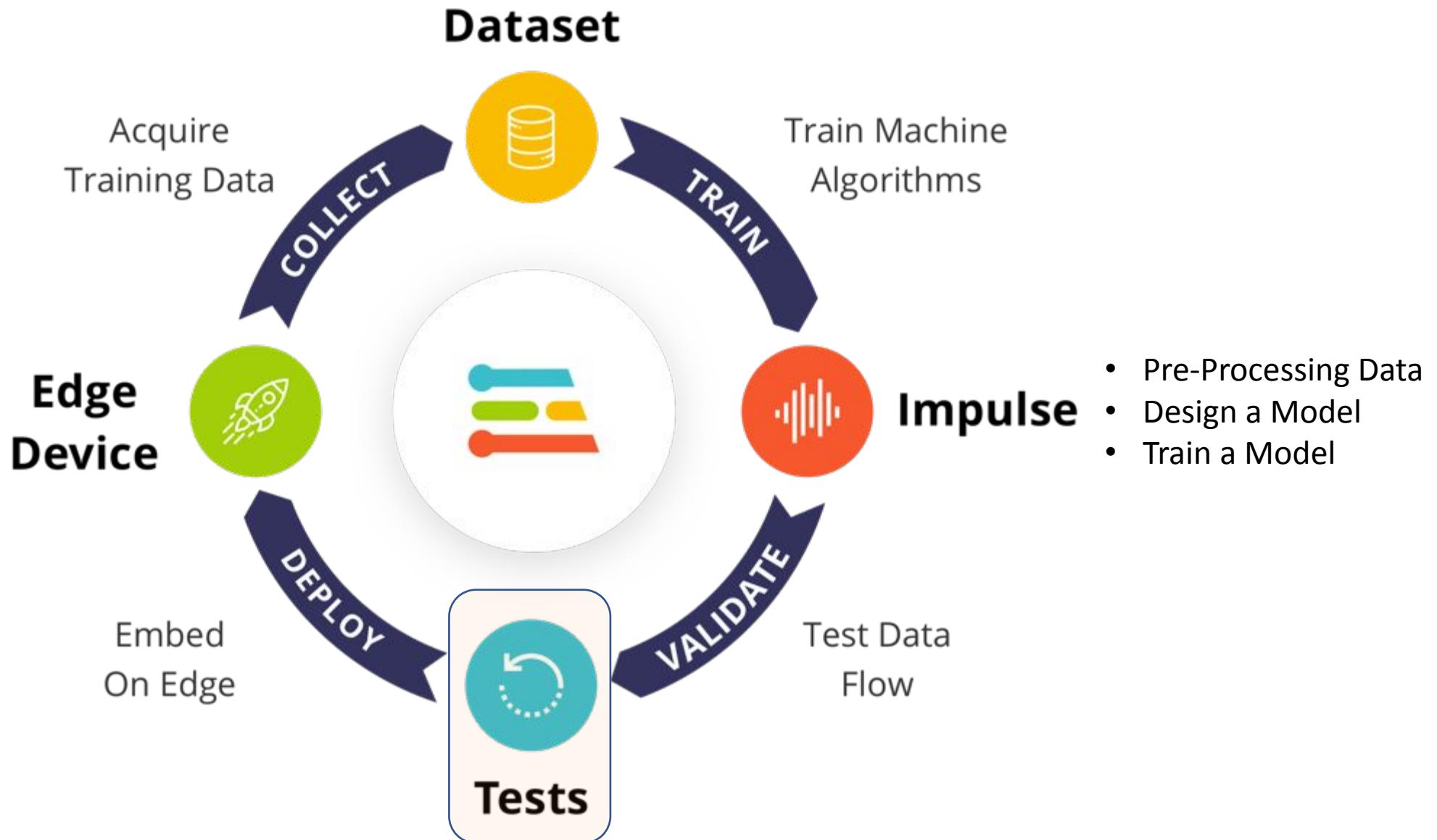
Data explorer (full training set) ②

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)

Classification result

Live classification

Model testing

Versioning

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GETTING STARTED

Documentation

Forums

Summary

Name

Expected outcome

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

Deployment

GETTING STARTED

Documentation

Forums

AAU-Wio-Gesture-Classificatio x +

studio.edgeimpulse.com/studio/190030/tuner

EDGE IMPULSE

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 - Create impulse
 - Spectral features
 - Classifier
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

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

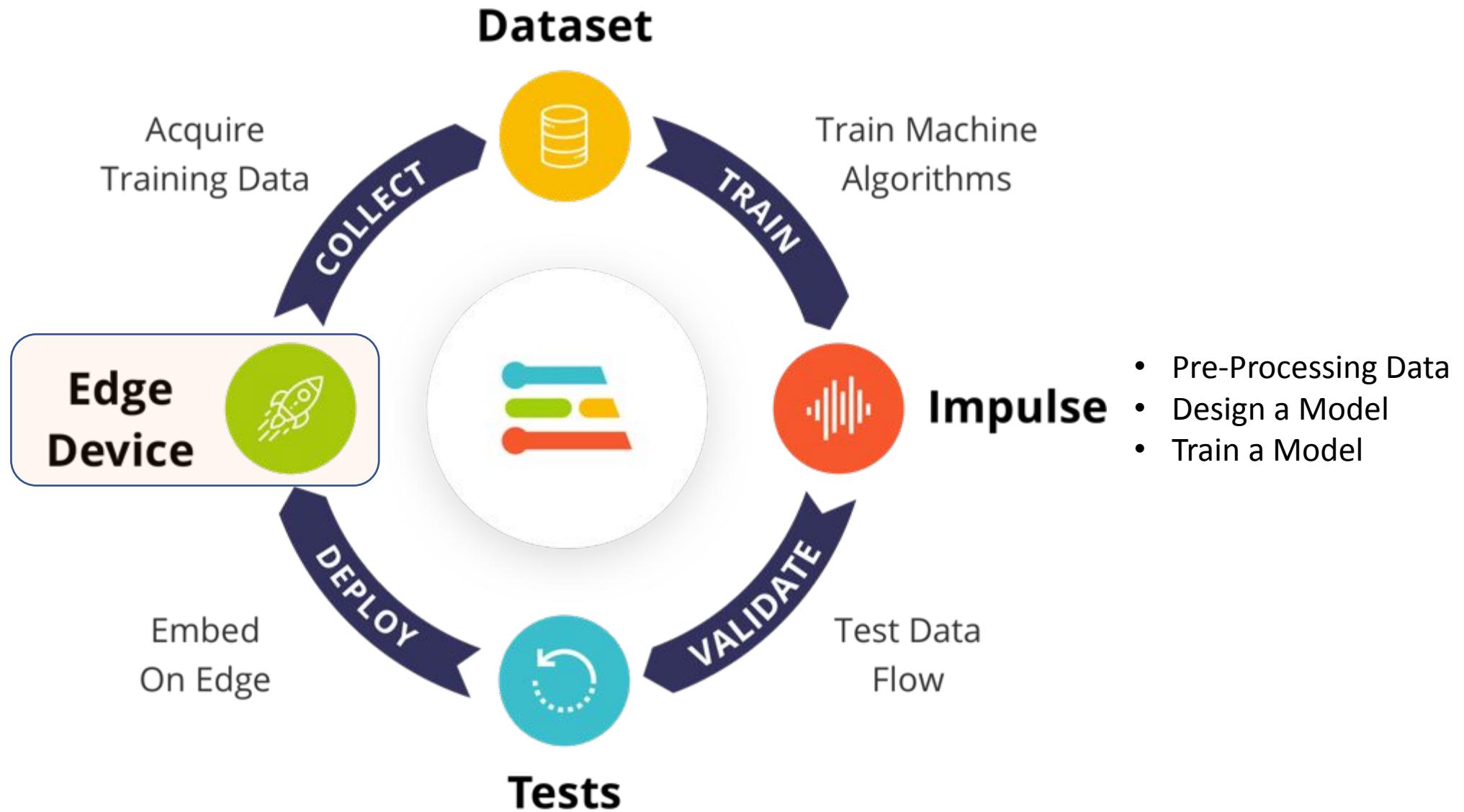
Precision

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 [®] Tensai Flow library	 brainchip MetaTF Model	 TEXAS INSTRUMENTS 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 your project.

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%
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

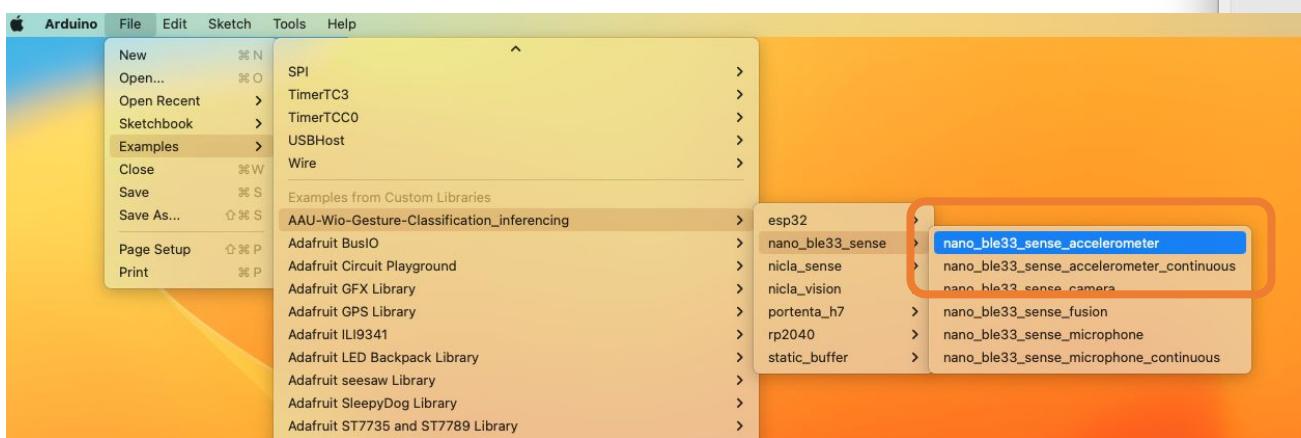
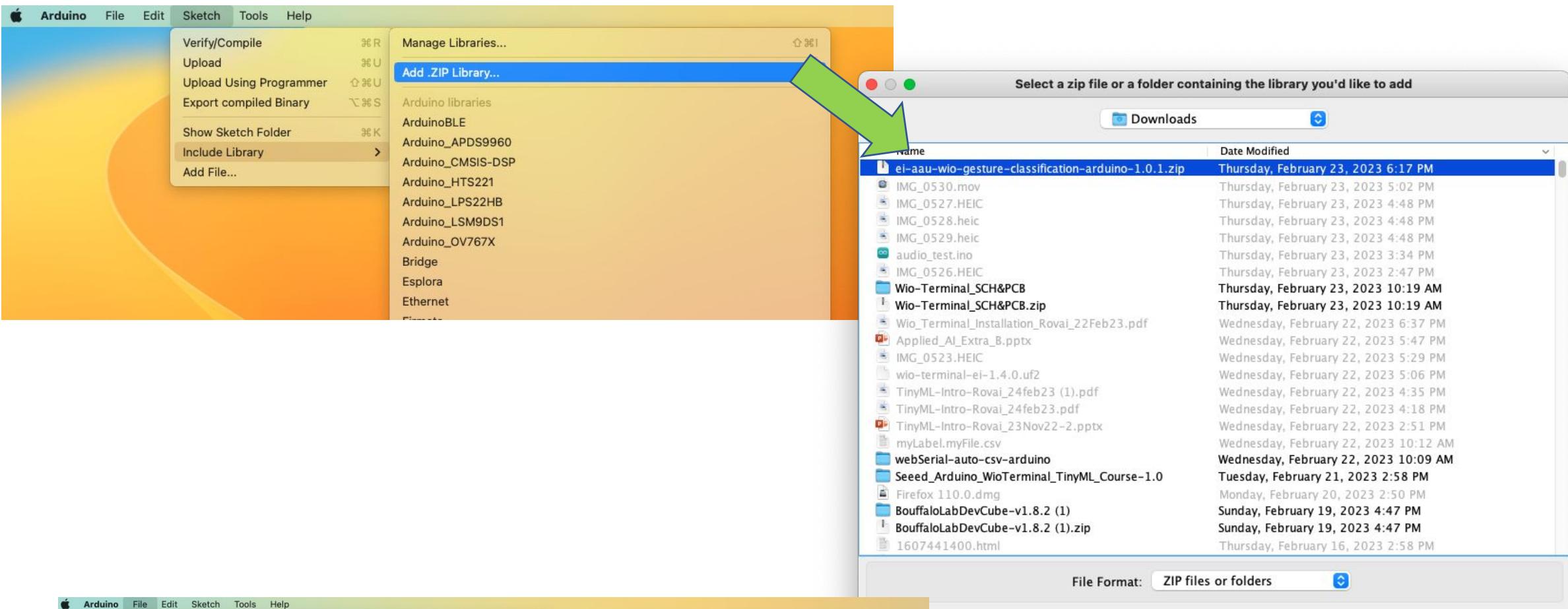
in cluster...
: pulled!
edgeimpulse SDK...
edgeimpulse SDK OK

model...
model OK

or and updating headers...
or and updating headers OK

re...
re OK

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 5

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

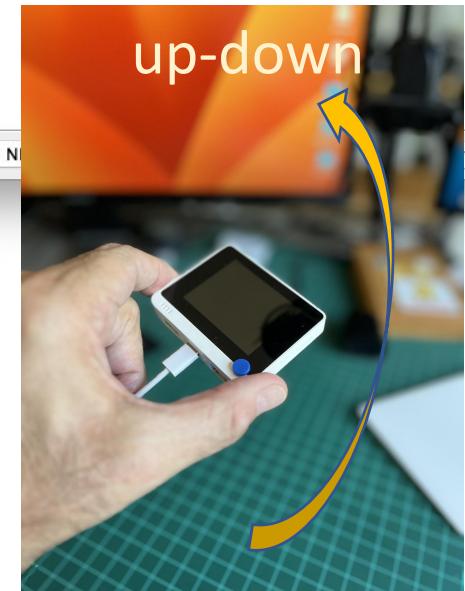
Starting inferencing in 2 seconds...
Sampling...
 Autoscroll  Show timestamp Both NL & CR
```

```
/dev/cu.usbmodem1101
Send

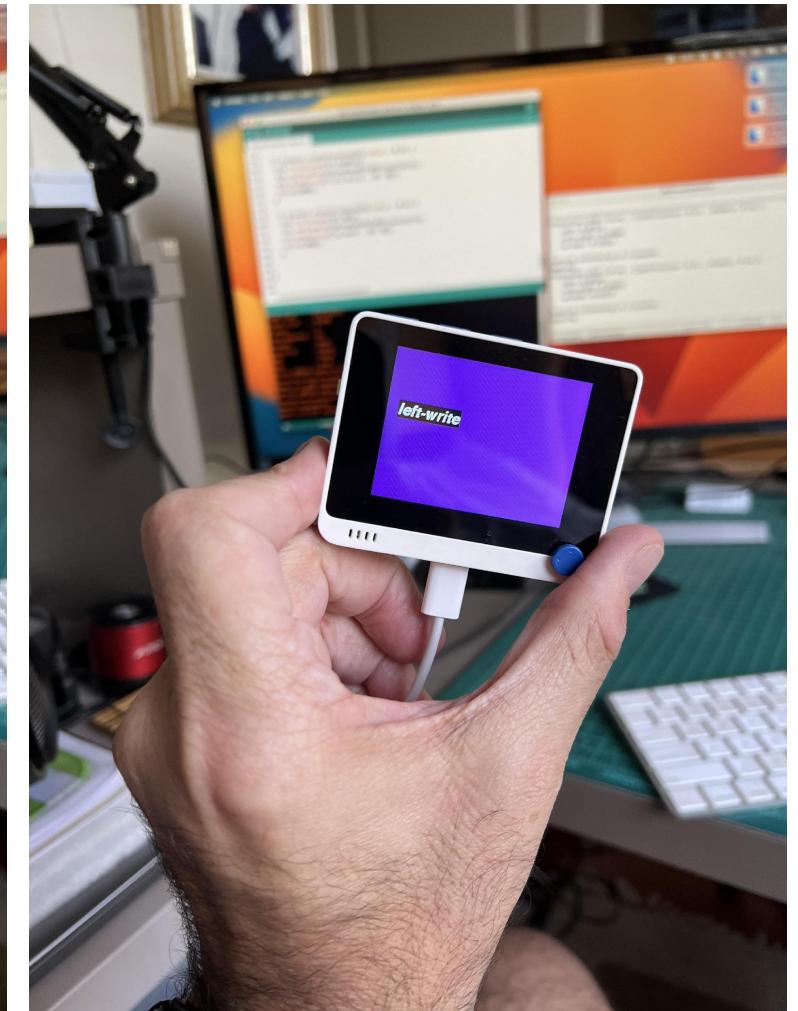
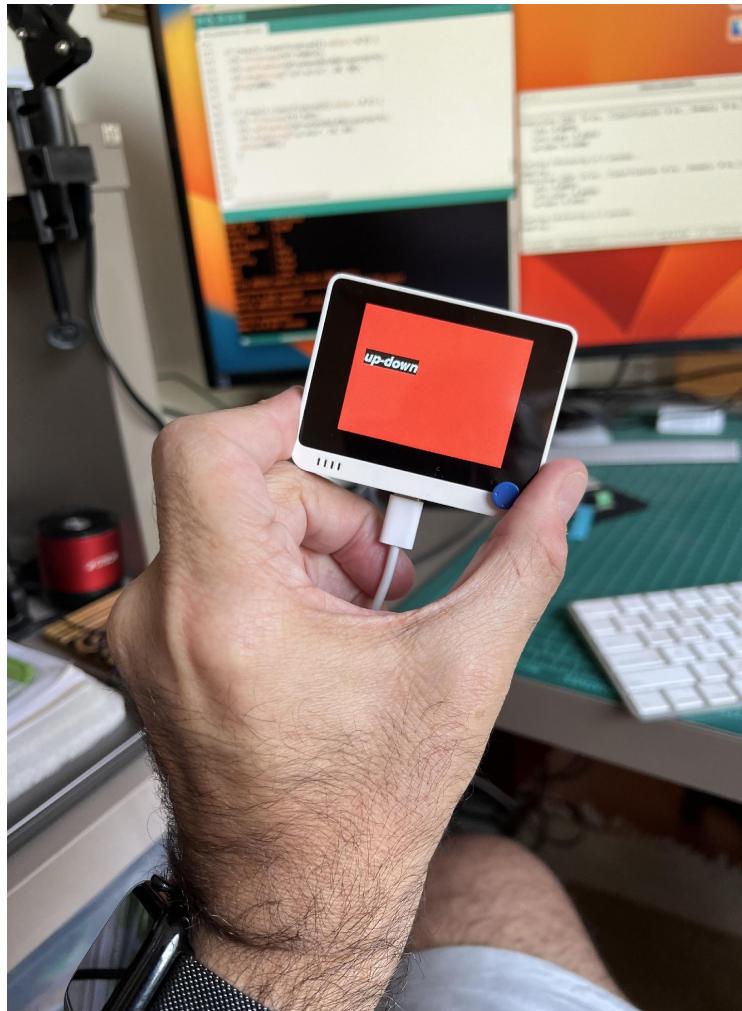
Predictions (DSP: 24 ms., Classification: 0 ms., Anomaly: 0 ms.):
idle: 0.00781
left-right: 0.82812
up-down: 0.16406

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

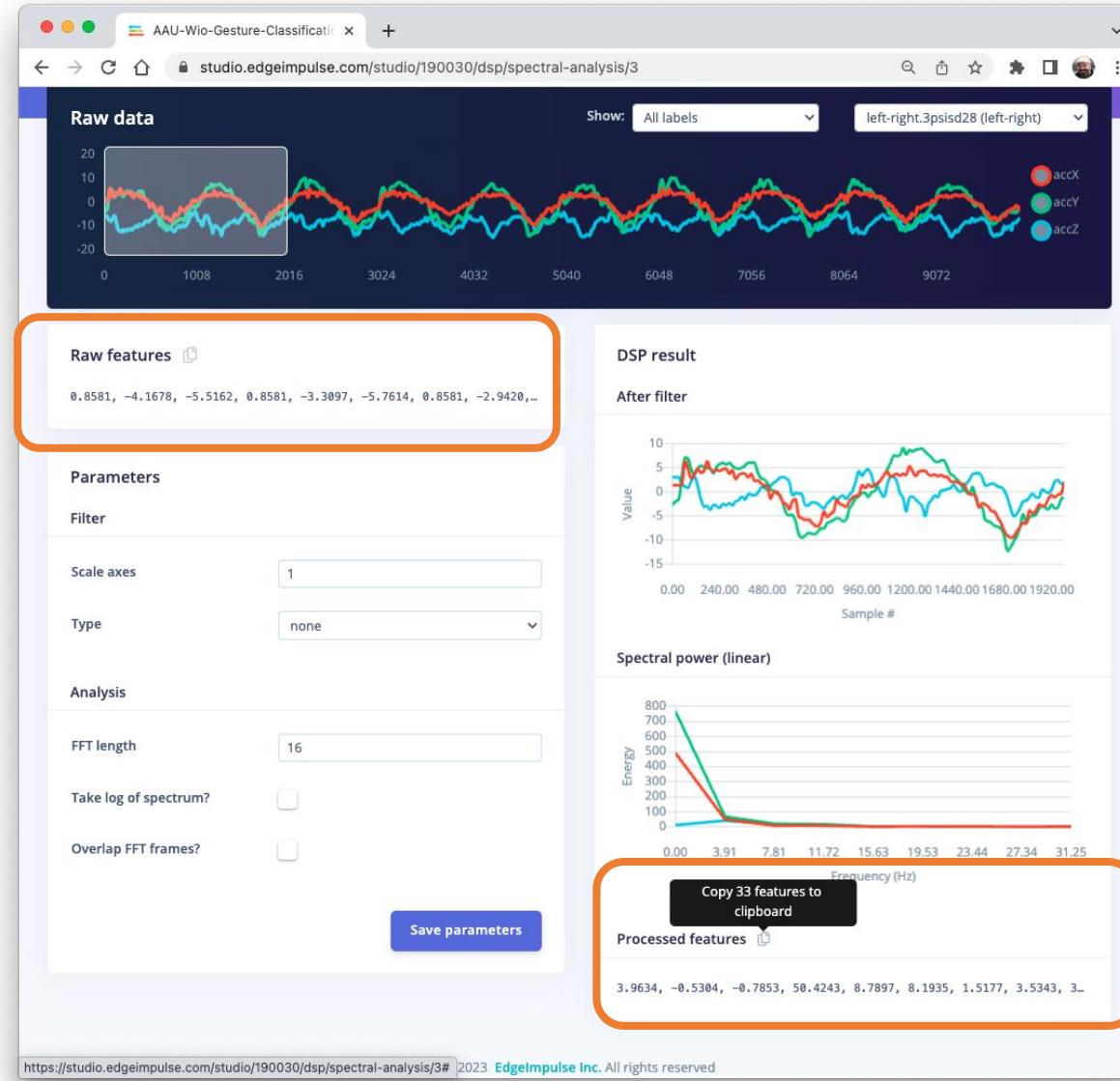
Spectral Analysis (Google CoLab)

Edge Impulse – Spectral Analysis

2 seconds window
62.5 Hz Sample Freq



375 raw features



33 processed features

- 3 Statistical features/axis → 9 feat.
- 8 Spectral Features (Freq)/ axis → 24
- Total Processed Features = 9+34 = 33

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
- 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 16 and filter NONE, the Total Processed Features **per axis** will be 11 (3 + 8)
- for a FFT Length of 16 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)

Subtracting the mean from data

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.

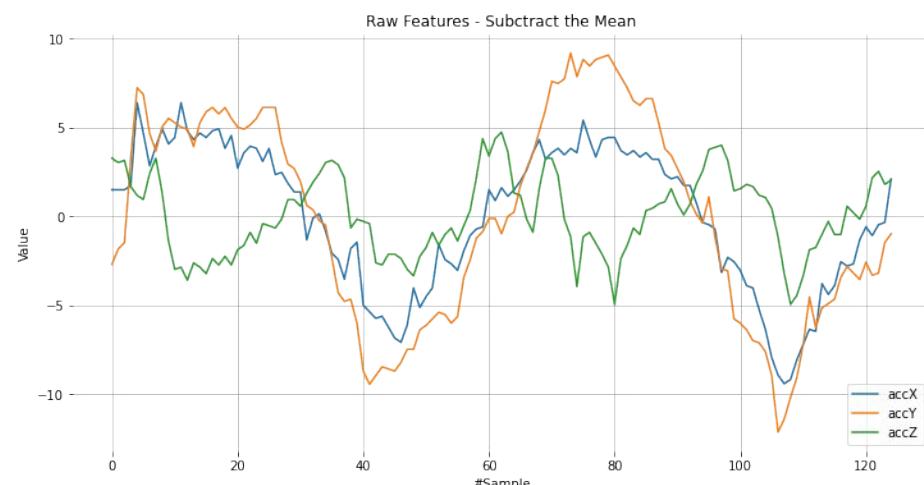
Here are some specific reasons why subtracting the mean can be useful:

- 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(x)/len(x)) for x in sensors]
2 [print('mean_'+x+'= ', round(y, 4)) for x,y in zip(axis, dtmean)][0]

mean_accX= -0.6198
mean_accY= -1.4524
mean_accZ= -8.7701
```

```
1 accX = [(x - dtmean[0]) for x in accX]
2 accY = [(x - dtmean[1]) for x in accY]
3 accZ = [(x - dtmean[2]) for x in accZ]
4 sensors = [accX, accY, accZ]
```



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 original raw data and after subtracting the mean

```
1 # Using numpy and standartized data (subtracting mean)
2 rms = [np.sqrt(np.mean(np.square(x))) for x in sensors]
3 [print('rms_'+x+'= ', round(y, 4)) for x,y in zip(axis, rms)][0]
```

```
rms_accX= 3.9634
rms_accY= 5.7088
rms_accZ= 2.2405
```

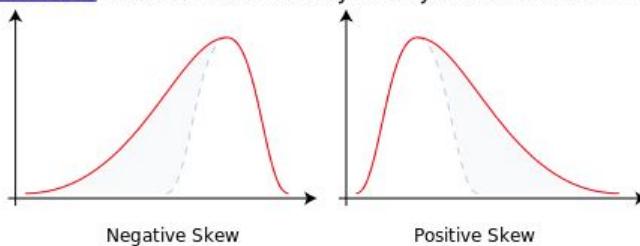
```
1 # Compare with Edge Impulse result features
2 features[0:N_feat:N_feat_axis]
```

```
[3.9634, 5.7088, 2.2405]
```

Skewness and kurtosis calculation

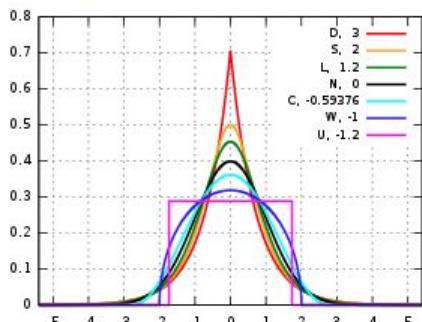
In statistics, skewness and kurtosis are two ways to measure the **shape of a distribution**.

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



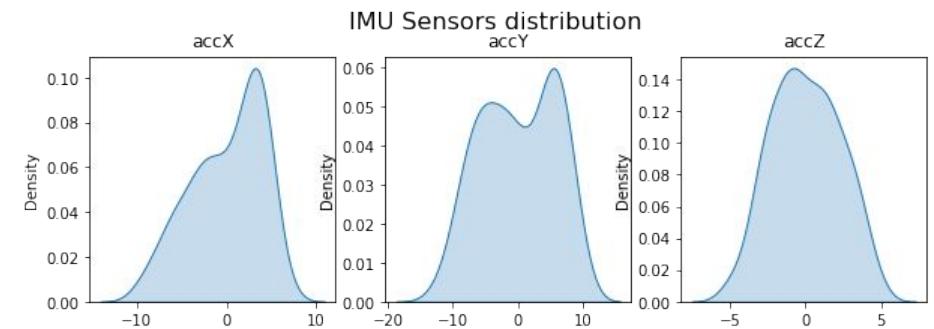
- A negative skew indicates that the tail is on the left side of the distribution, which extends towards more negative values.
- A positive skew indicates that the tail is on the right side of the distribution, which extends towards more positive values.
- A value of zero indicates that there is no skewness 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 0.
- If a given distribution has a kurtosis is negative, 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 positive, 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 are the same for original raw data and after subtracting the mean



```
1 skew = [skew(x, bias=False) for x in sensors]
2 [print('skew_'+x+'= ', round(y, 4)) for x,y in zip(axis, skew)][0]
```

```
skew_accX= -0.5369
skew_accY= -0.1421
skew_accZ= 0.0297
```

```
1 # Compare with Edge Impulse result features
2 features[1:N_feat:N_feat_axis]
```

```
[-0.5304, -0.1404, 0.0294]
```

```
1 kurt = [kurtosis(x, bias=False) for x in sensors]
2 [print('kurt_'+x+'= ', round(y, 4)) for x,y in zip(axis, kurt)][0]
```

```
kurt_accX= -0.7681
kurt_accY= -1.2076
kurt_accZ= -0.7694
```

```
1 # Compare with Edge Impulse result features
2 features[2:N_feat:N_feat_axis]
```

```
[-0.7853, -1.2074, -0.7866]
```

Spectral features

```
[53] 1 FFT_Length = 16
     2 N = 125
     3 fs = 62.5
```

Once the sampled window usually is larger than the FFT size, the window will be broken into frames (or "sub-windows"), and the FFT is calculated from each frame.

FFT length - The FFT size. This determines the number of FFT bins as well as the resolution of frequency peaks that you can separate. A lower number means more signals will average together in the same FFT bin, but also reduces the number of features and model size. A higher number will separate more signals into separate bins, but generates a larger model.

Welch's method

<https://docs.scipy.org/doc/scipy-0.14.0/reference/generated/scipy.signal.welch.html>

To split the signal on frequency domain in bins and calculate the power spectrum for each bin, we should use a method called **Welch's method**.

This method divides the signal into overlapping segments, applies a window function to each segment, computes the periodogram of each segment using DFT, and averages them to obtain a smoother estimate of the power spectrum.

```

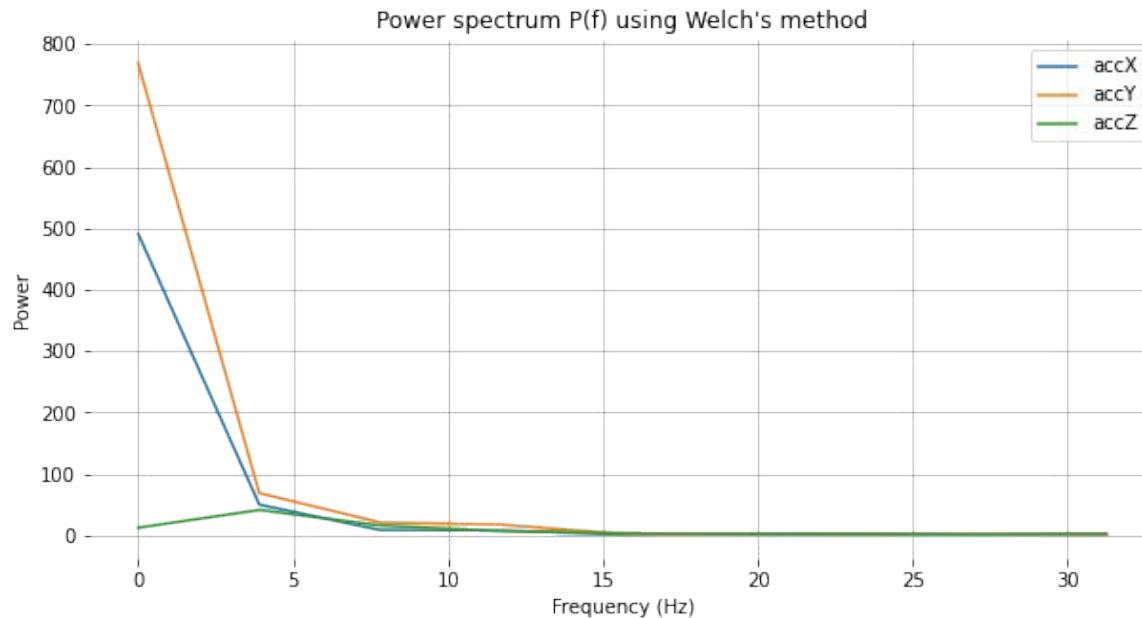
1 # Function used by Edge Impulse instead of scipy.signal.welch().
2 def welch_max_hold(fx, sampling_freq, nfft, n_overlap):
3     n_overlap = int(n_overlap)
4     spec_powers = [0 for _ in range(nfft//2+1)]
5     ix = 0
6     while ix <= len(fx):
7         # Slicing truncates if end_idx > len, and rfft will auto zero pad
8         fft_out = np.abs(np.fft.rfft(fx[ix:ix+nfft], nfft))
9         spec_powers = np.maximum(spec_powers, fft_out**2/nfft)
10        ix = ix + (nfft-n_overlap)
11    return np.fft.rfftfreq(nfft, 1/sampling_freq), spec_powers

```

```

1 fax,Pax = welch_max_hold(accX, fs, FFT_Lenght, 0)
2 fay,Pay = welch_max_hold(accY, fs, FFT_Lenght, 0)
3 faz,Paz = welch_max_hold(accZ, fs, FFT_Lenght, 0)

```



```

1 print("EI Processed features (accX): ")
2 print(features[3:N_feat_axis][0:])
3 print("\nCalculated features:")
4 [print(round(x, 4)) for x in Pax[1:]][0]

```

EI Processed features (accX):
[50.4243, 8.7897, 8.1935, 1.5177, 3.5343, 3.3766, 1.9297, 1.5027]

Calculated features:

Feature Value
50.424
8.7899
8.1934
1.5177
3.5343
3.3766
1.9297
1.5026

```

1 print("EI Processed features (accY): ")
2 print(features[14:22][0:])
3 print("\nCalculated features:")
4 [print(round(x, 4)) for x in Pay[1:]][0]

```

EI Processed features (accY):
[69.059, 21.2278, 17.7782, 2.7987, 2.6348, 1.9958, 2.1017, 2.5395]

Calculated features:

Feature Value
69.0591
21.228
17.778
2.7988
2.6348
1.9958
2.1018
2.5396

```

1 print("EI Processed features (accZ): ")
2 print(features[25:][0:])
3 print("\nCalculated features:")
4 [print(round(x, 4)) for x in Paz[1:]][0]

```

EI Processed features (accZ):
[41.5583, 16.427, 7.1384, 3.8891, 2.4171, 1.9213, 1.8393, 3.6101]

Calculated features:

Feature Value
41.5583
16.427
7.1384
3.8892
2.4172
1.9212
1.8393
3.6103

Thanks



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