Wio Terminal – Part 2

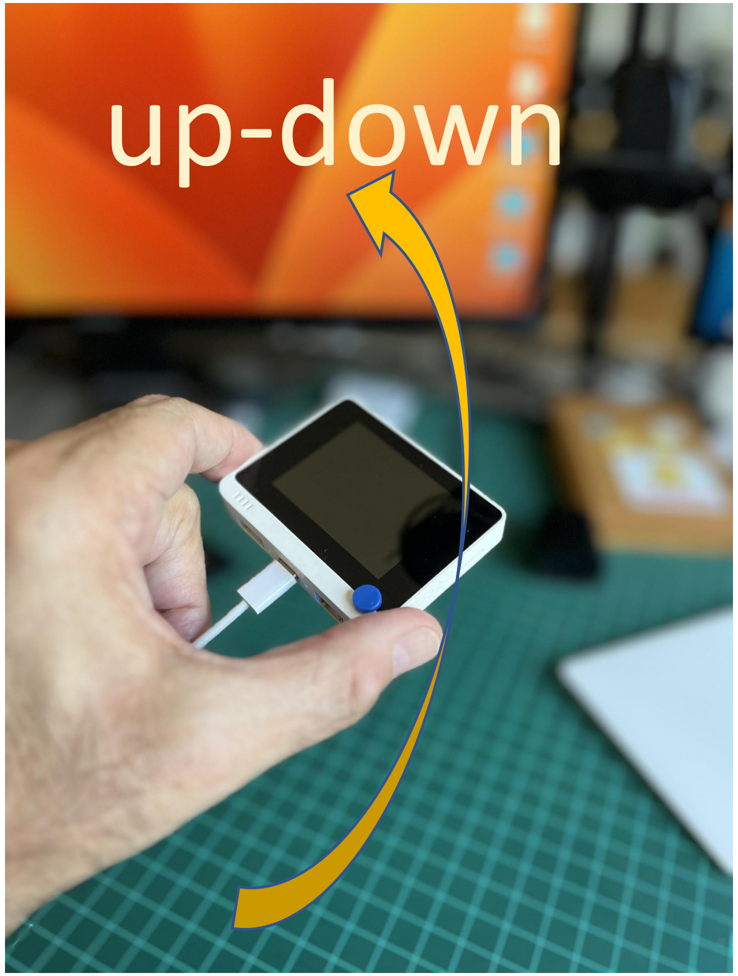
Hands-on: Gesture Recognition

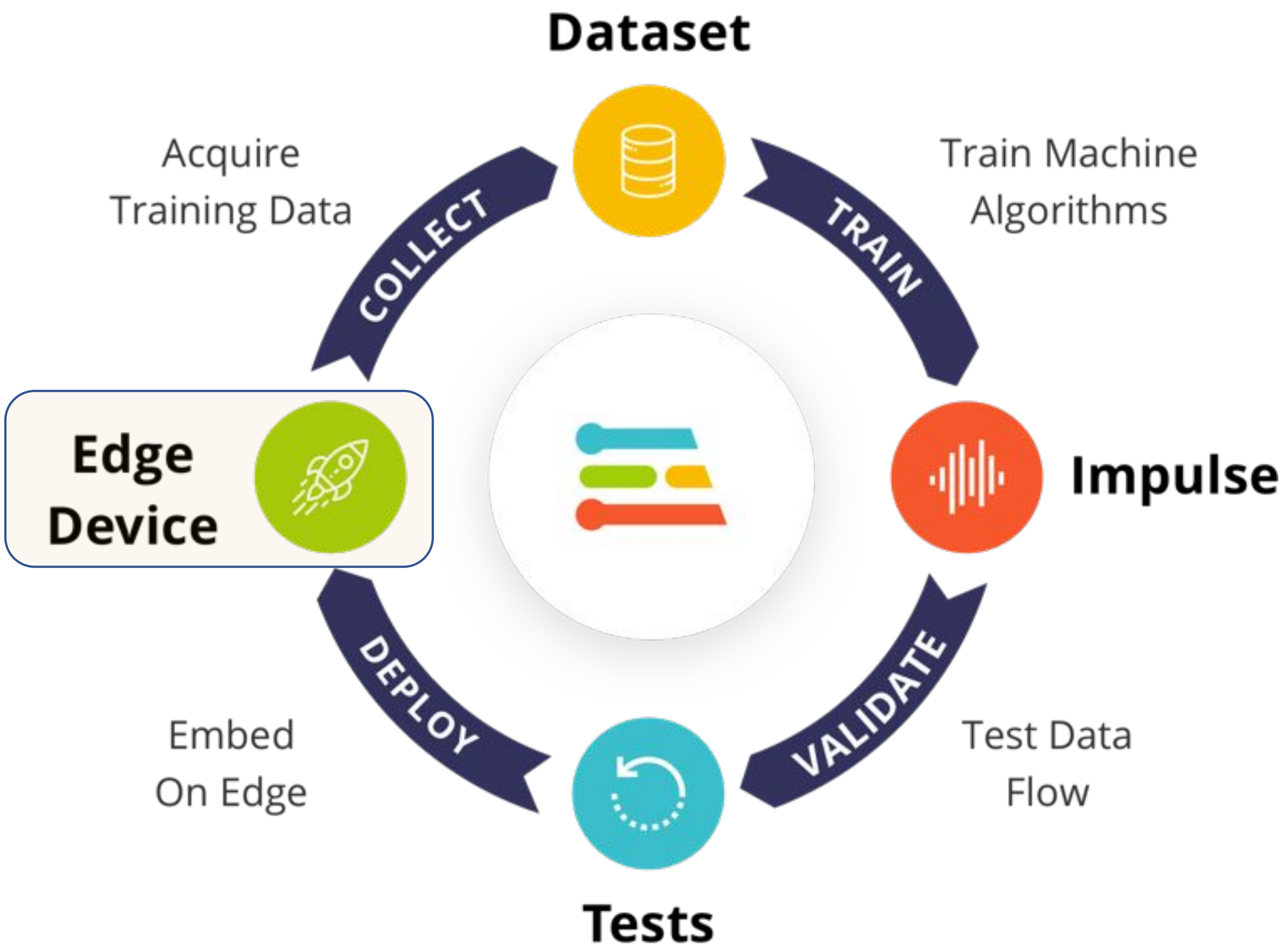
Prof. Marcelo José Rovai
UNIFEI - Federal University of Itajubá, Brazil
TinyML4D Academic Network Co-Chair

Updated @27Apr23

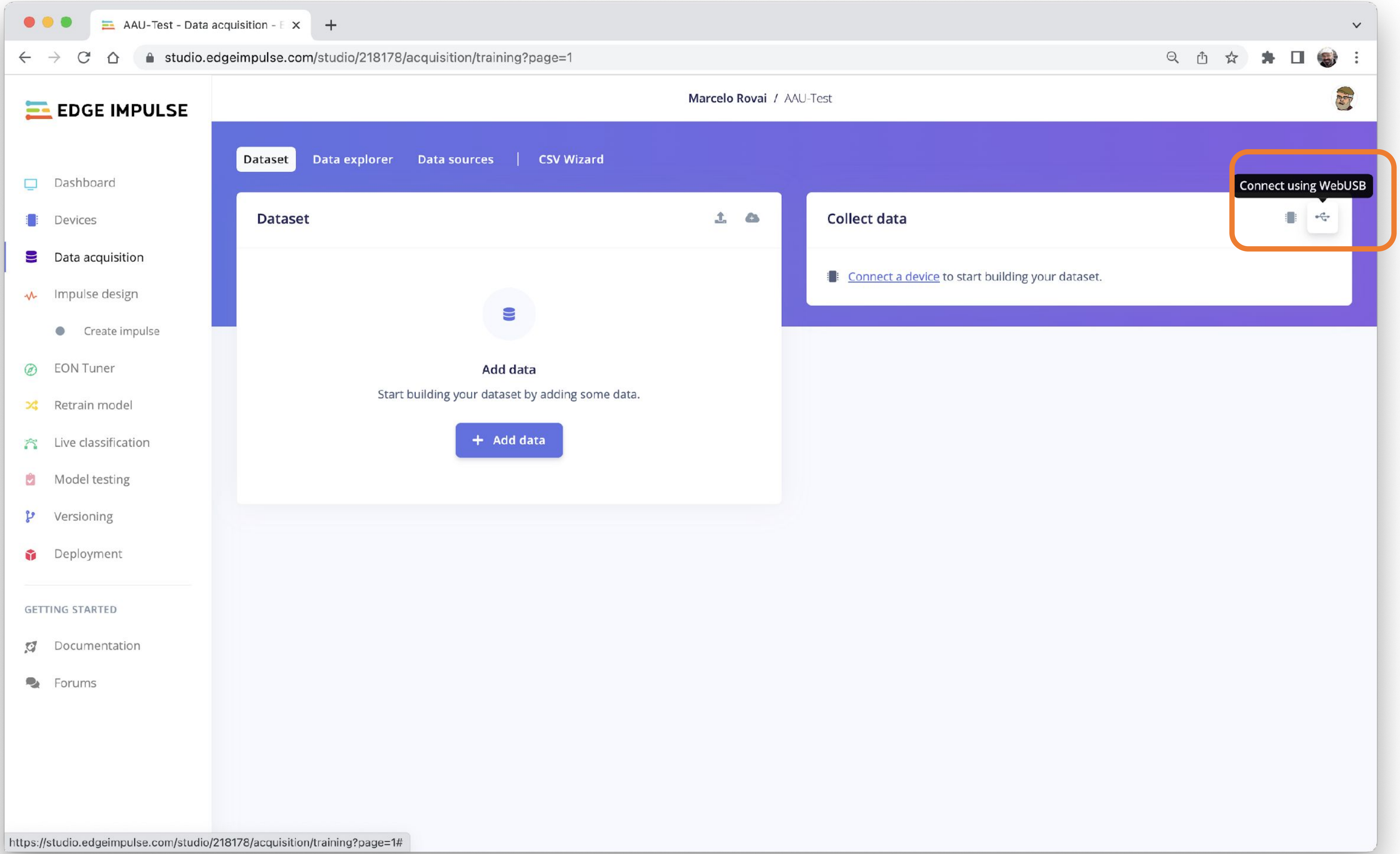
Hands-on: Gesture Recognition

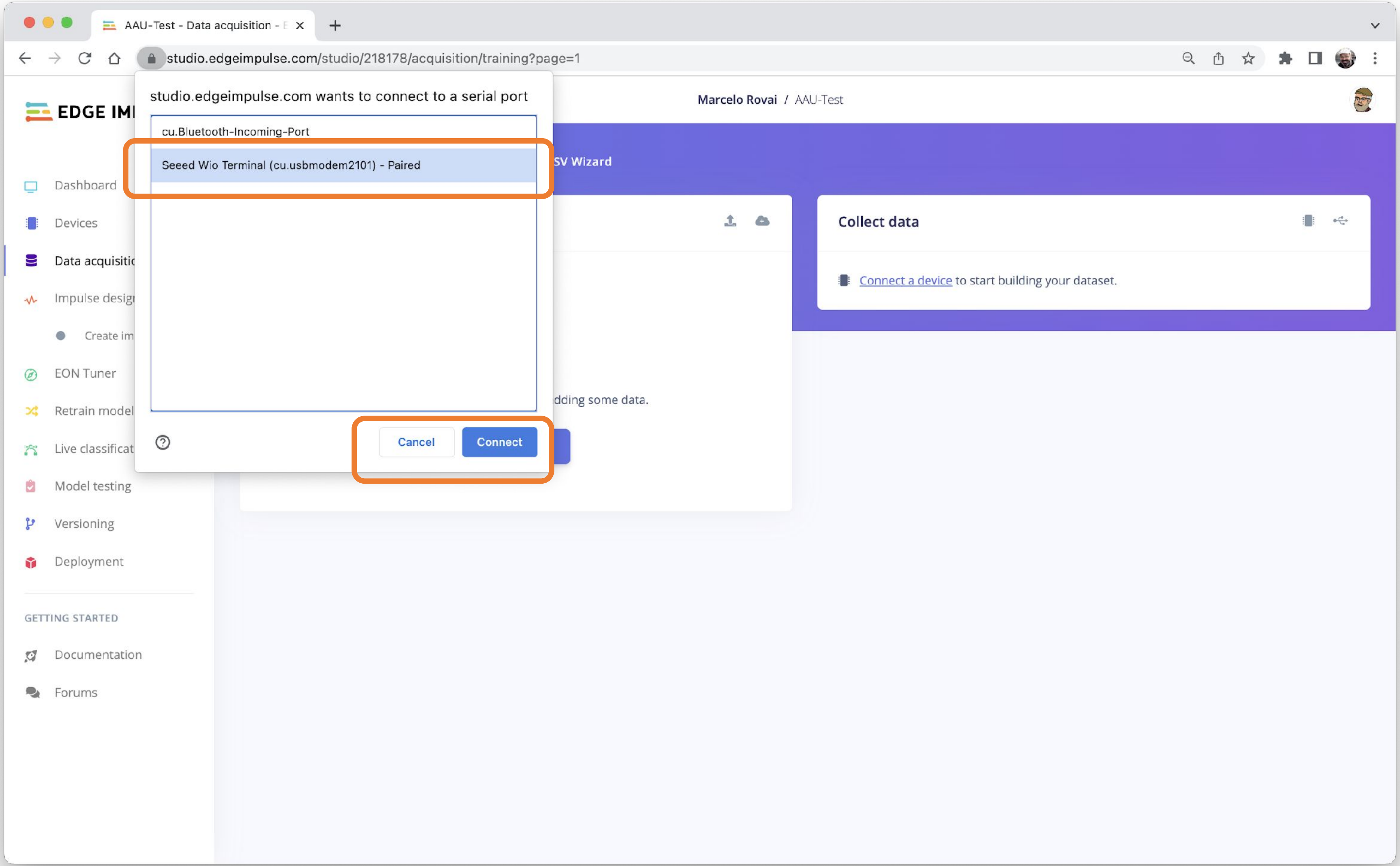
Gestures Definition (classes)

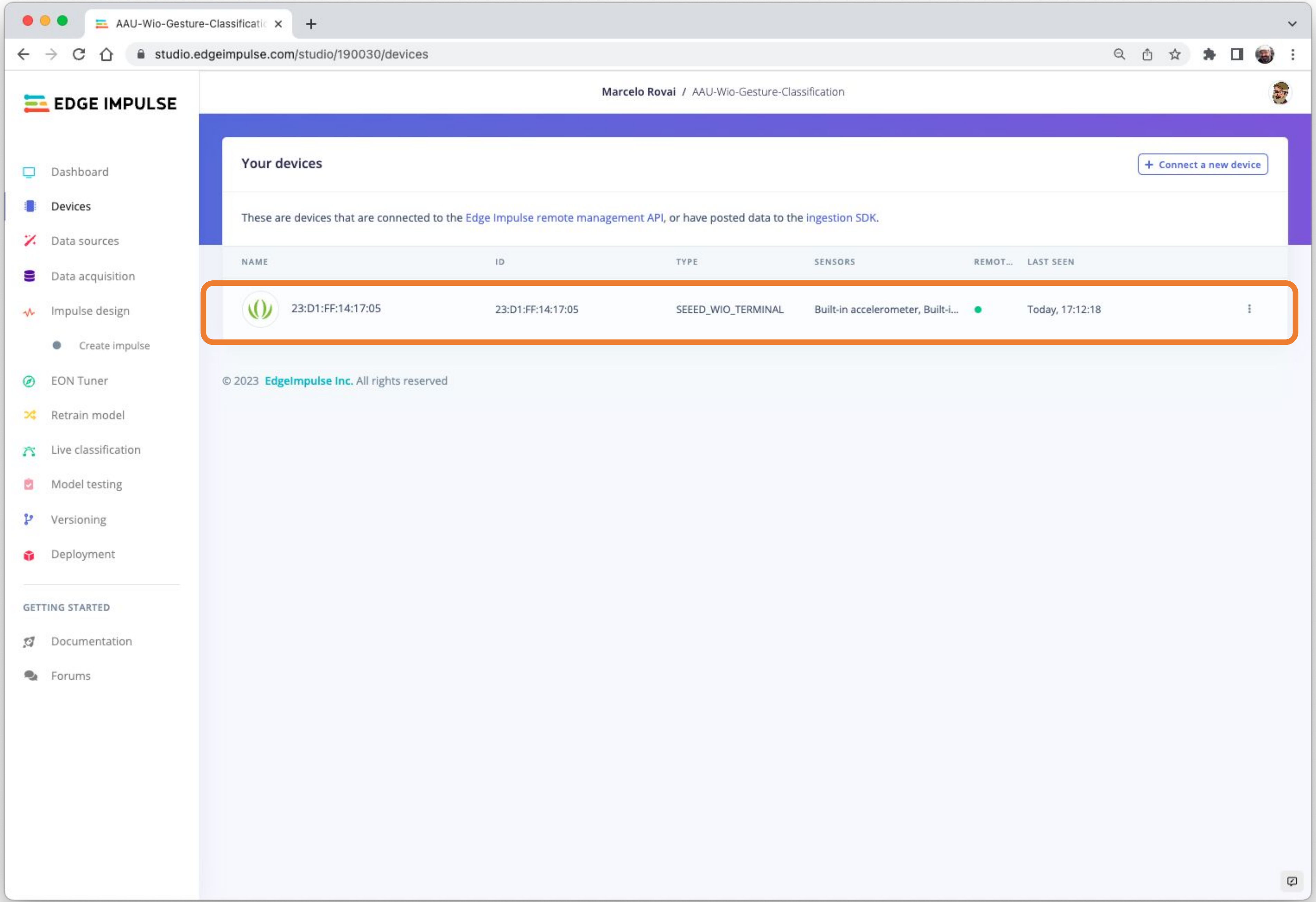


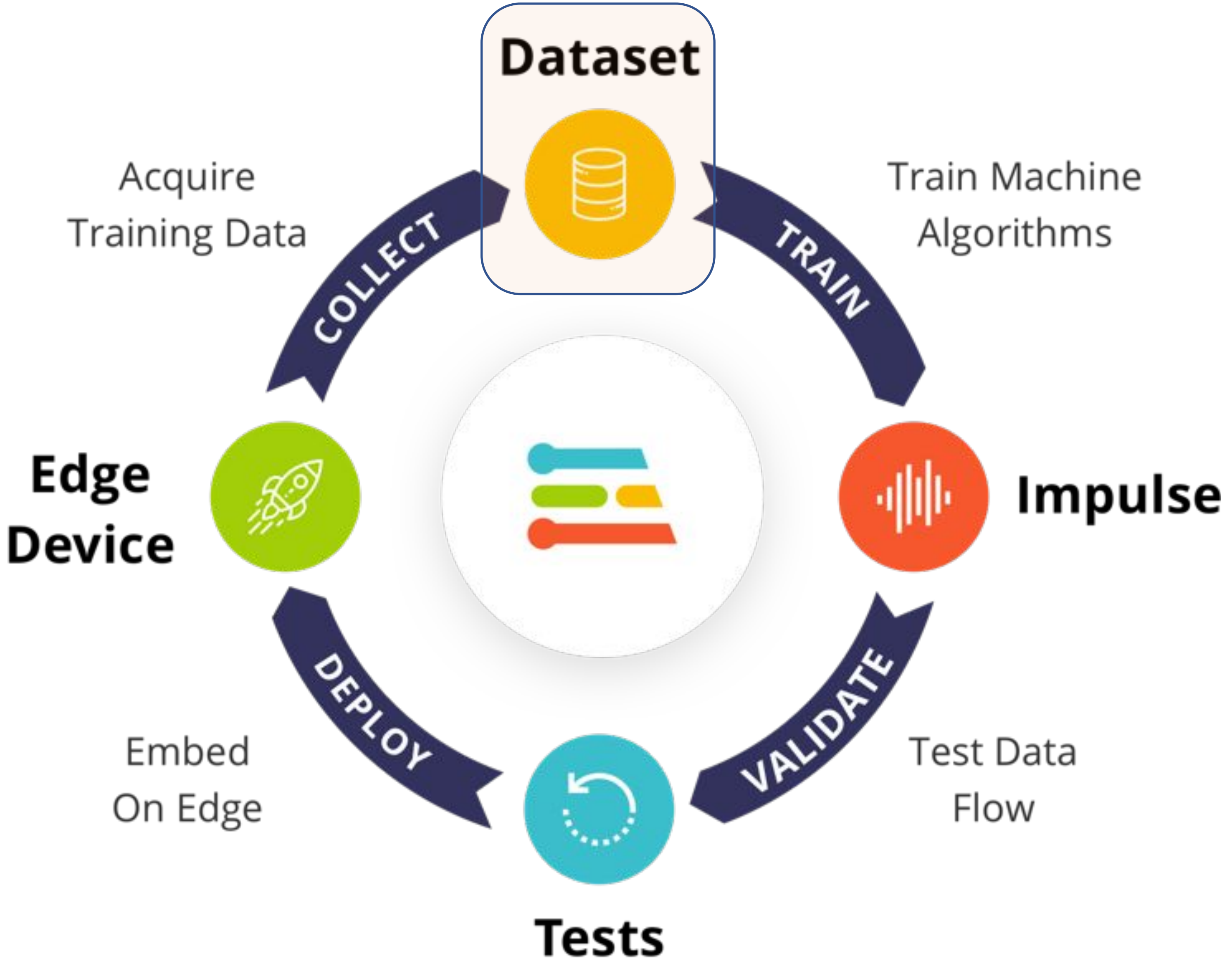


- Pre-Processing Data
- Design a Model
- Train a Model

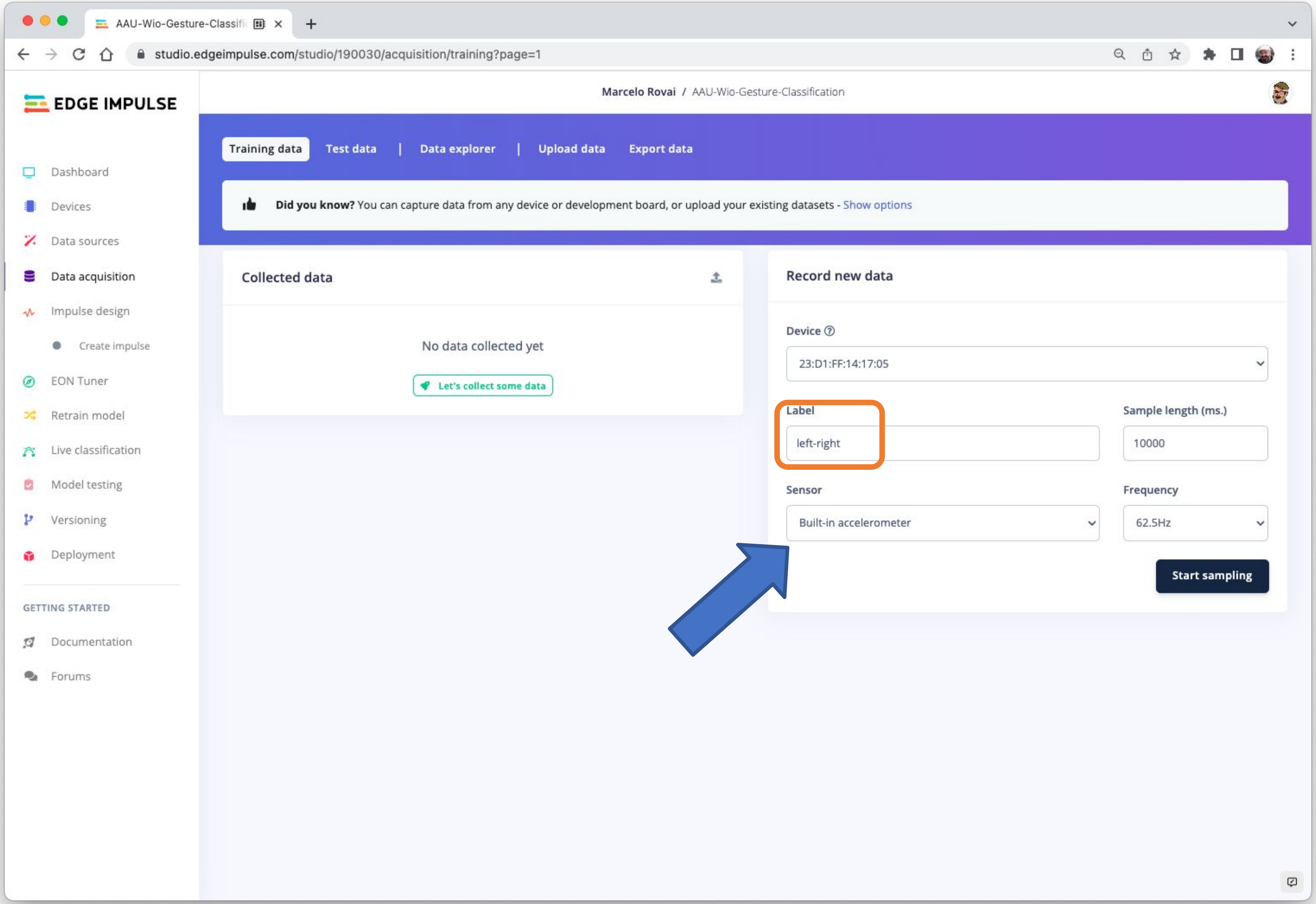

AAU-Test - Data acquisition
studio.edgeimpulse.com/studio/218178/acquisition/training?page=1
EDGE IMPULSE
Marcelo Rovai / AAU-Test
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Dataset
Data explorer
Data sources
CSV Wizard
Dataset
Add data
Start building your dataset by adding some data.
+ Add data
Collect data
Connect using WebUSB
Connect a device to start building your dataset.
https://studio.edgeimpulse.com/studio/218178/acquisition/training?page=1#


AAU-Test - Data acquisition
studio.edgeimpulse.com/studio/218178/acquisition/training?page=1
studio.edgeimpulse.com wants to connect to a serial port
cu.Bluetooth-Incoming-Port
Seeed Wio Terminal (cu.usbmodem2101) - Paired
Cancel
Connect
EDGE IMP
Dashboard
Devices
Data acquisitio
Impulse desig
Create im
EON Tuner
Retrain model
Live classificat
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Marcelo Rovai / AAU-Test
SV Wizard
Collect data
Connect a device to start building your dataset.
dding some data.

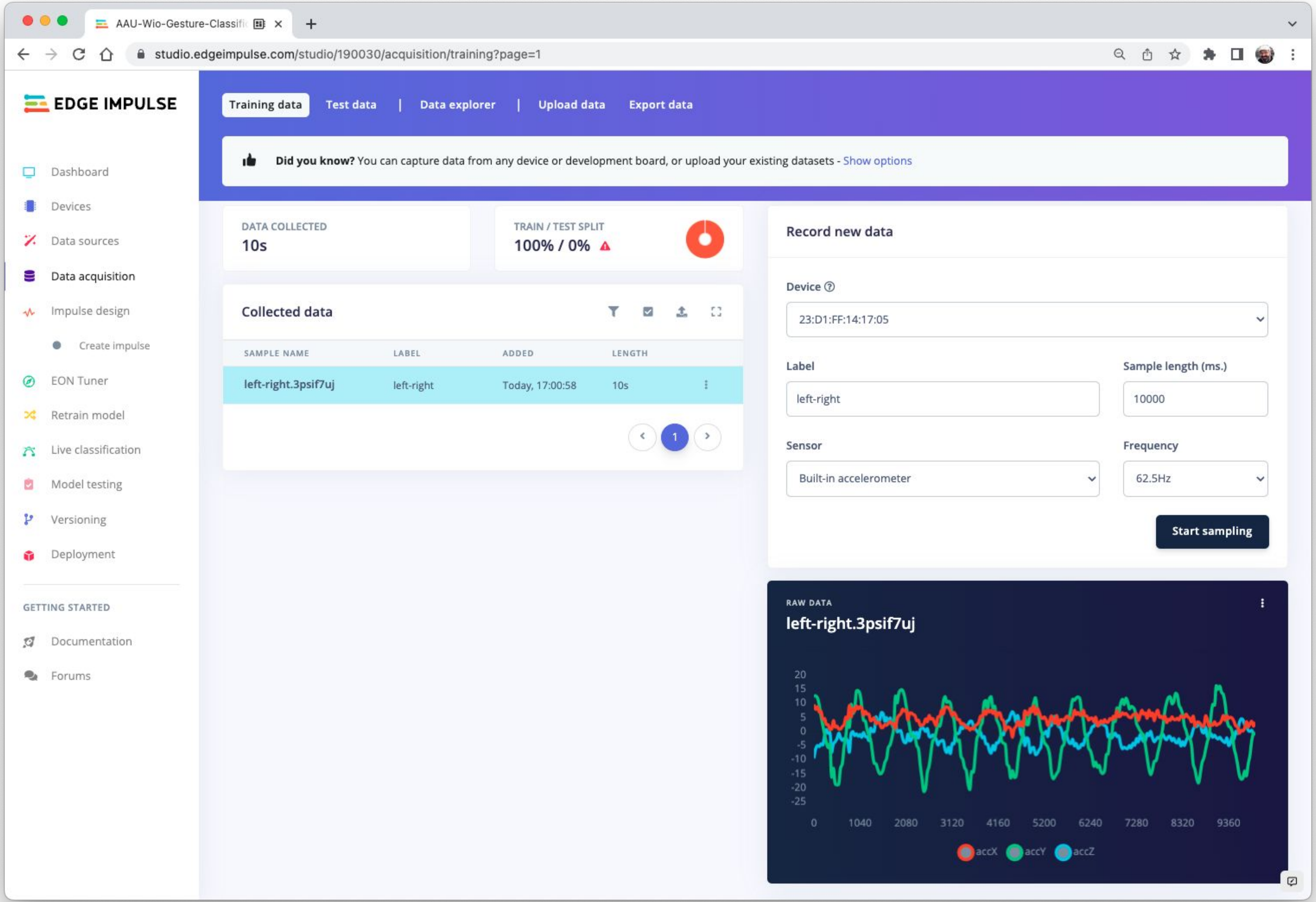

AAU-Wio-Gesture-Classificatic
studio.edgeimpulse.com/studio/190030/devices
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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
© 2023 EdgeImpulse Inc. All rights reserved

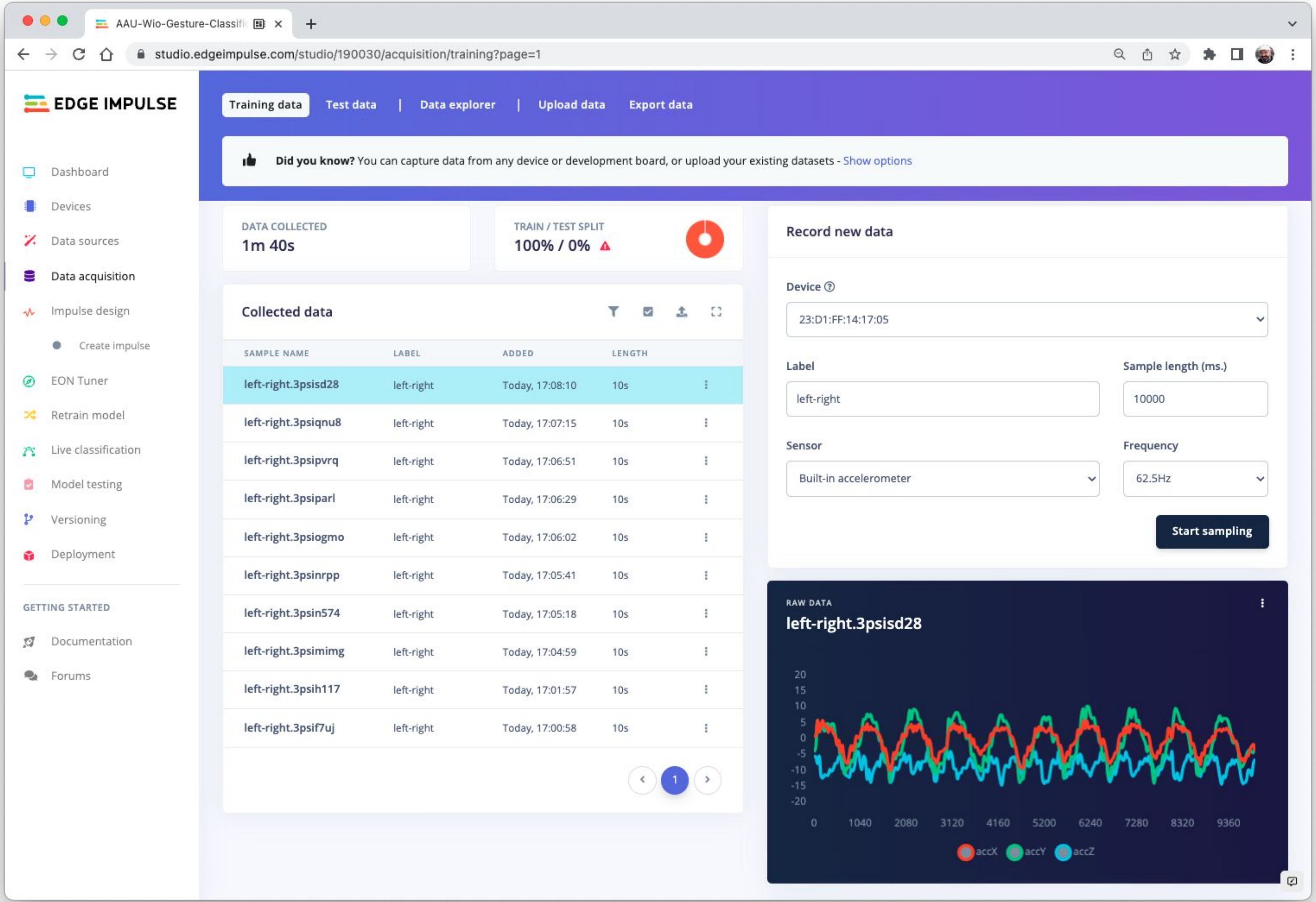


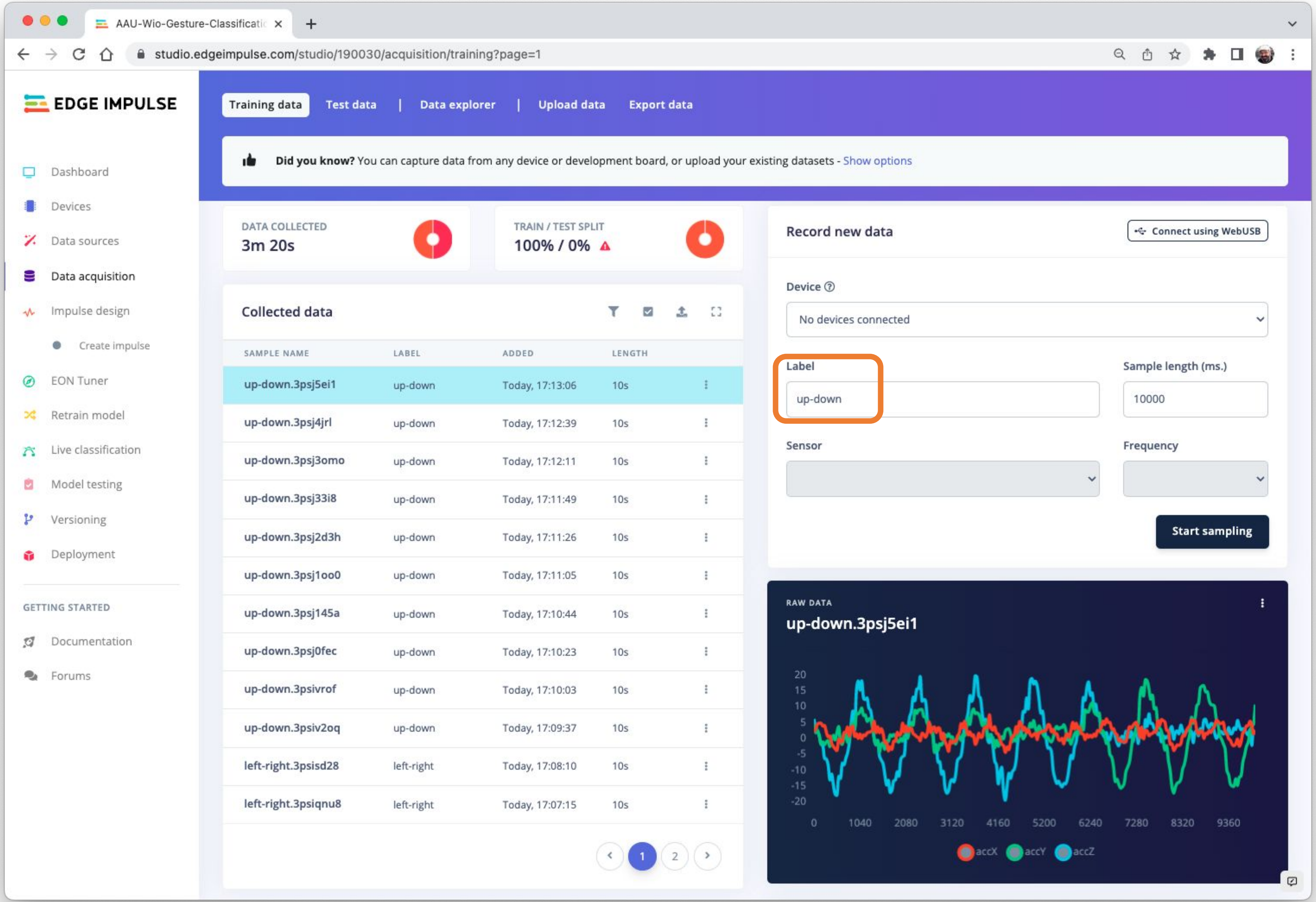
- Pre-Processing Data
- Design a Model
- Train a Model

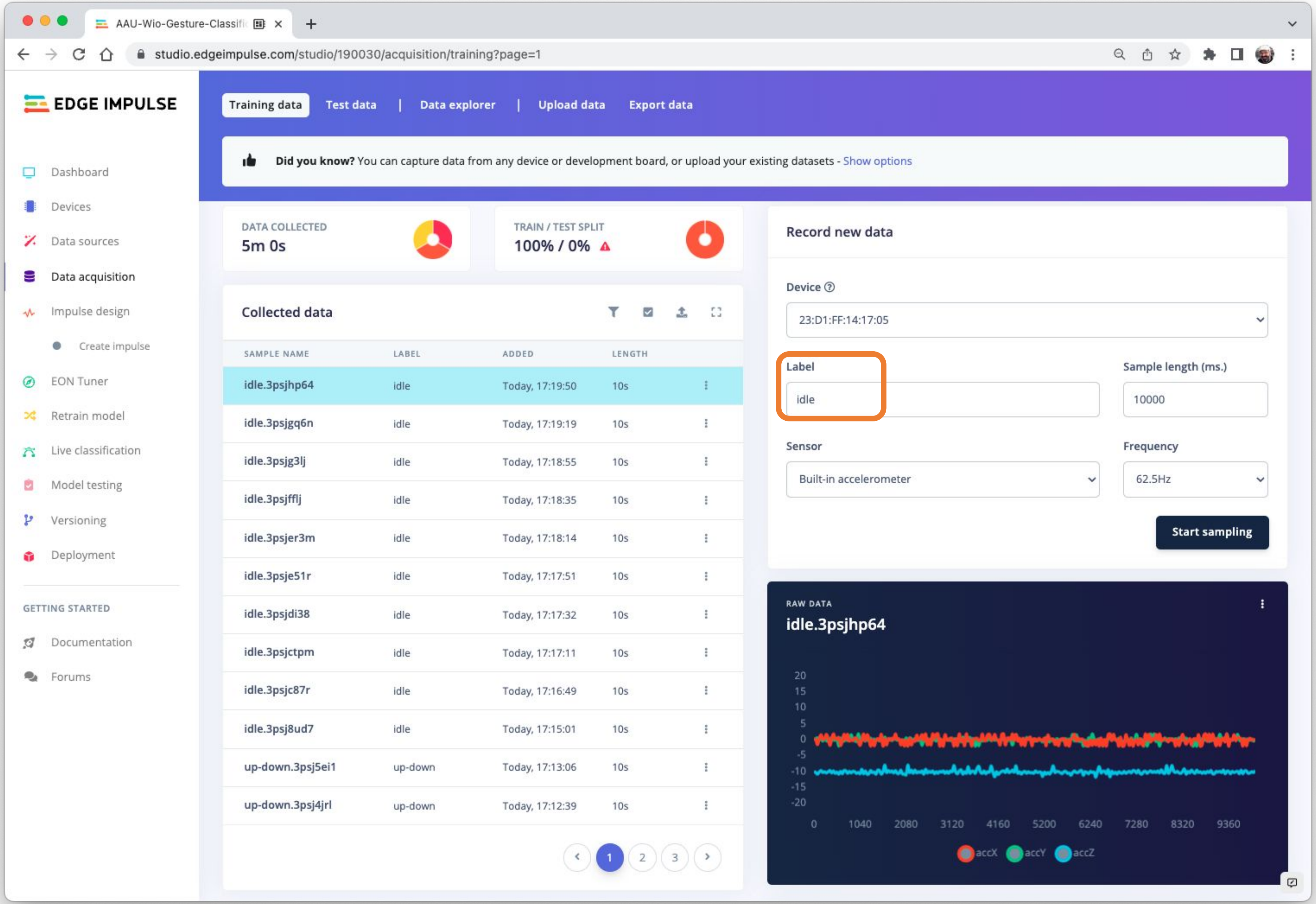


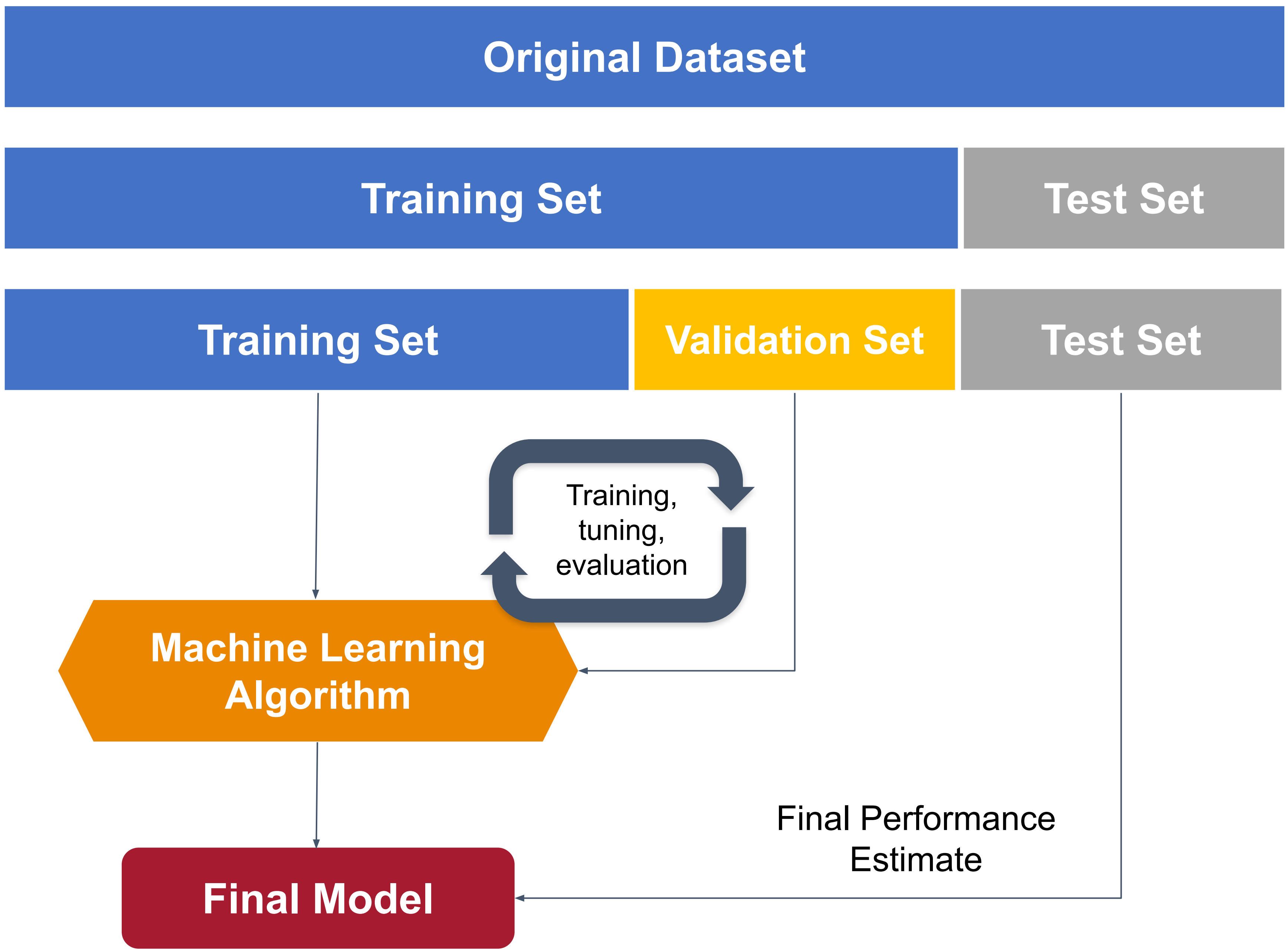
AAU-Wio-Gesture-Classifi
studio.edgeimpulse.com/studio/190030/acquisition/training?page=1
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Collected data
No data collected yet
Let's collect some data
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

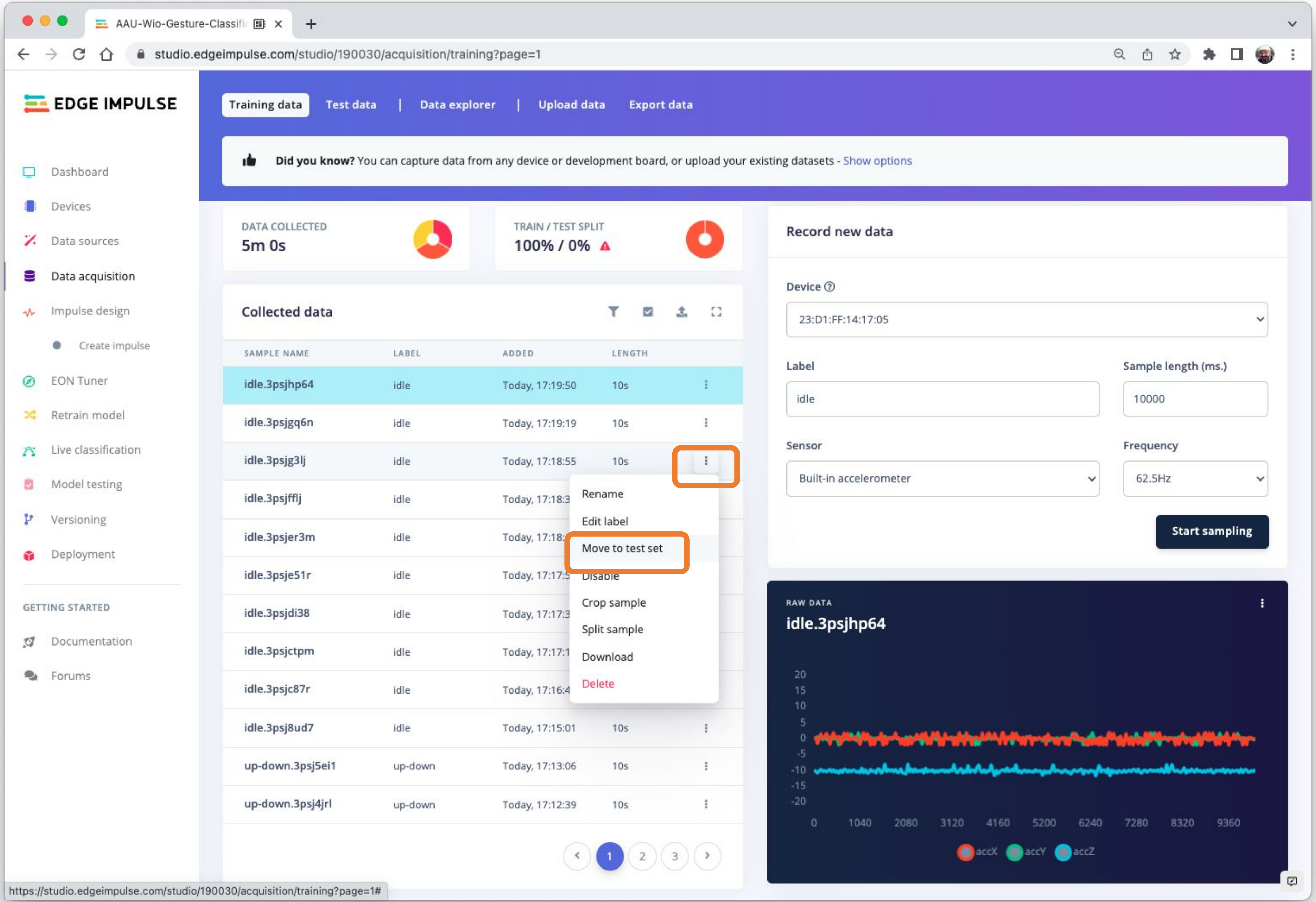

AAU-Wio-Gesture-Classifi
studio.edgeimpulse.com/studio/190030/acquisition/training?page=1
EDGE IMPULSE
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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
1
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
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
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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.3psih117 left-right Today, 17:01:57 10s
left-right.3psif7uj left-right Today, 17:00:58 10s
1
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.3psisd28
20
15
10
5
0
-5
-10
-15
-20
0
1040
2080
3120
4160
5200
6240
7280
8320
9360
accX
accY
accZ

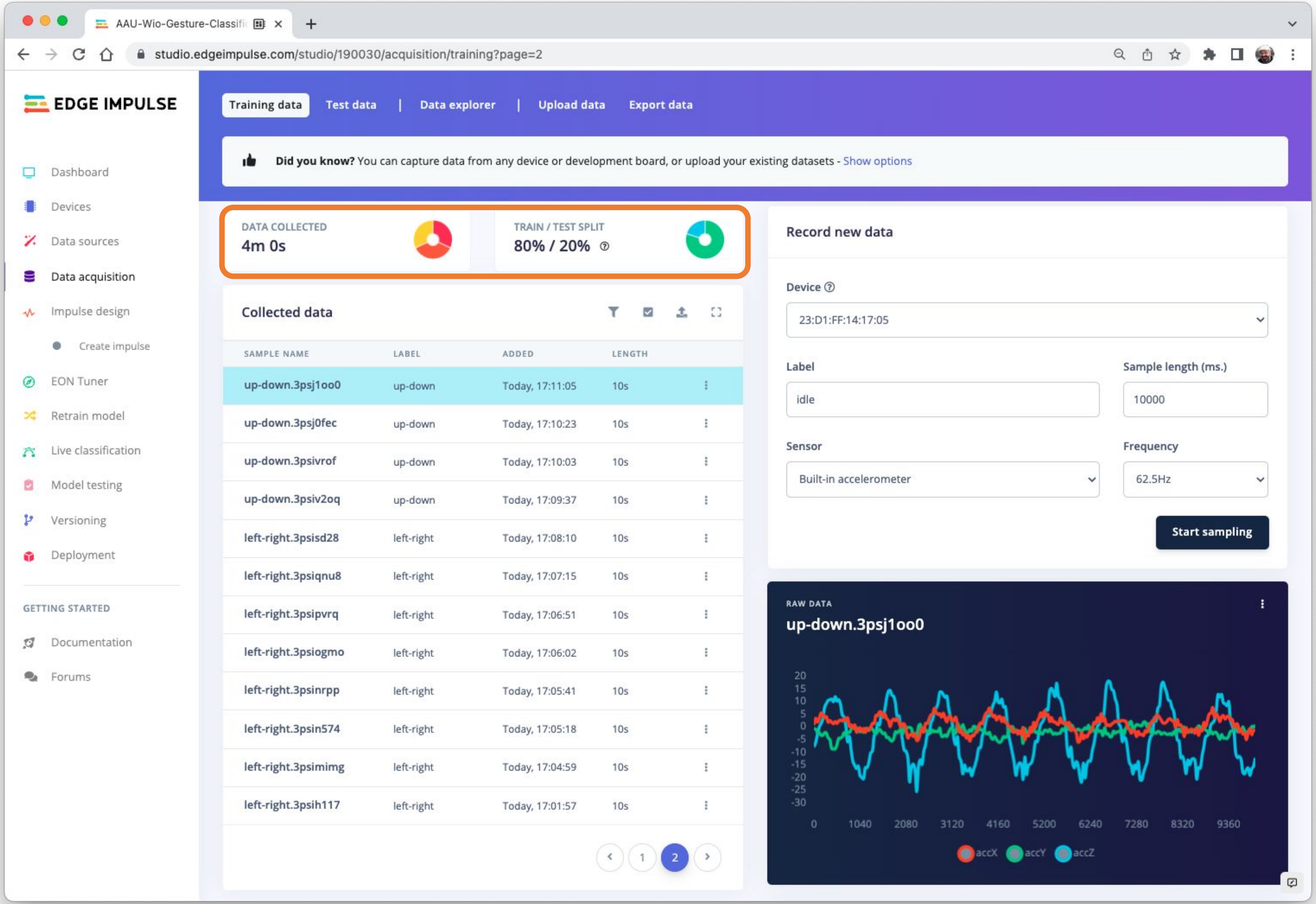

AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/acquisition/training?page=1
EDGE IMPULSE
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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
1
2
Record new data
Connect using WebUSB
Device
No devices connected
Label
up-down
Sample length (ms.)
10000
Sensor
Frequency
Start sampling
RAW DATA
up-down.3psj5ei1
accX
accY
accZ

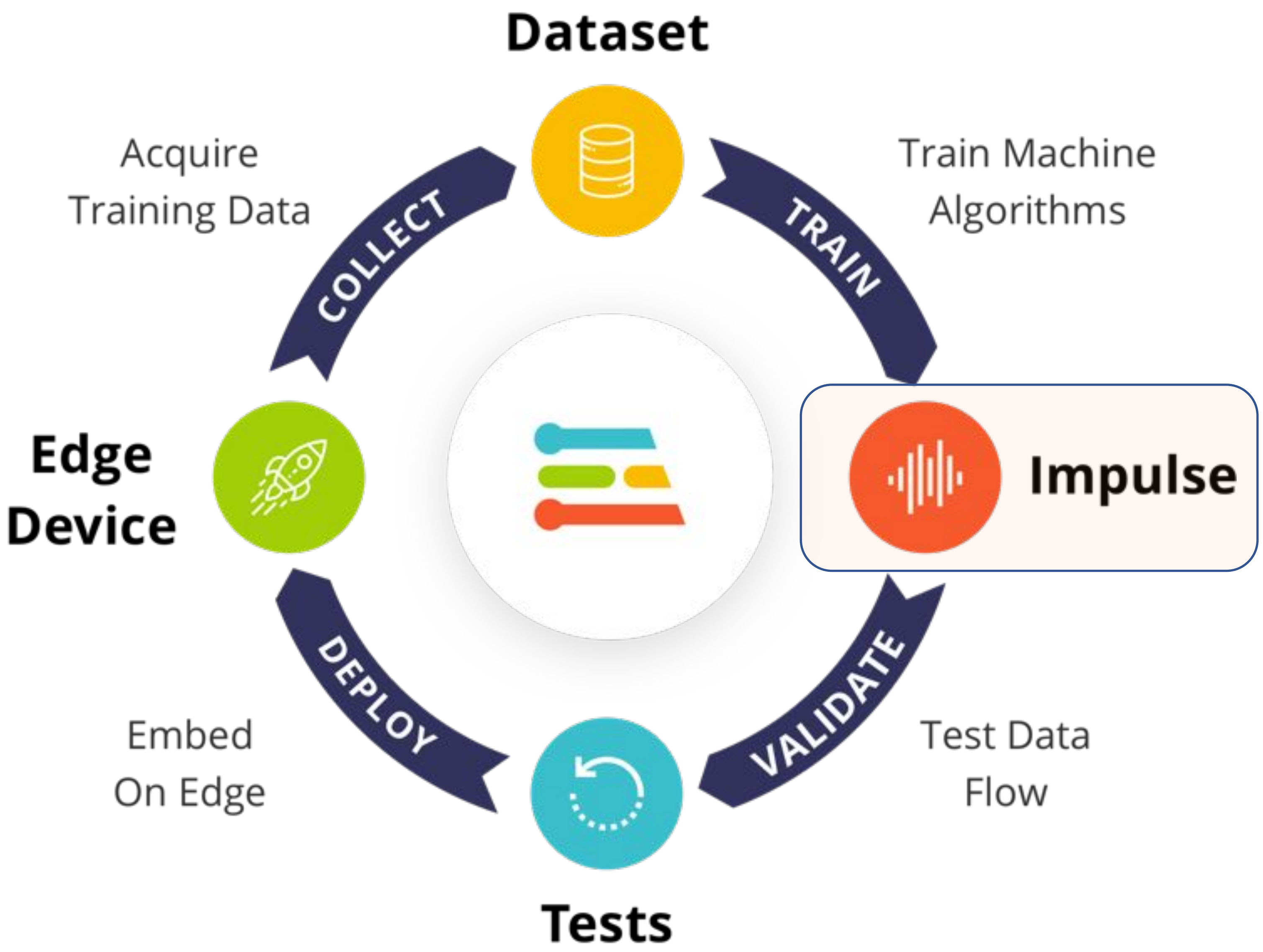

AAU-Wio-Gesture-Classifi
studio.edgeimpulse.com/studio/190030/acquisition/training?page=1
EDGE IMPULSE
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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.3psjgq6n | 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
1 2 3
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
idle.3psjhp64
20 15 10 5 0 -5 -10 -15 -20
0 1040 2080 3120 4160 5200 6240 7280 8320 9360
accX accY accZ


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

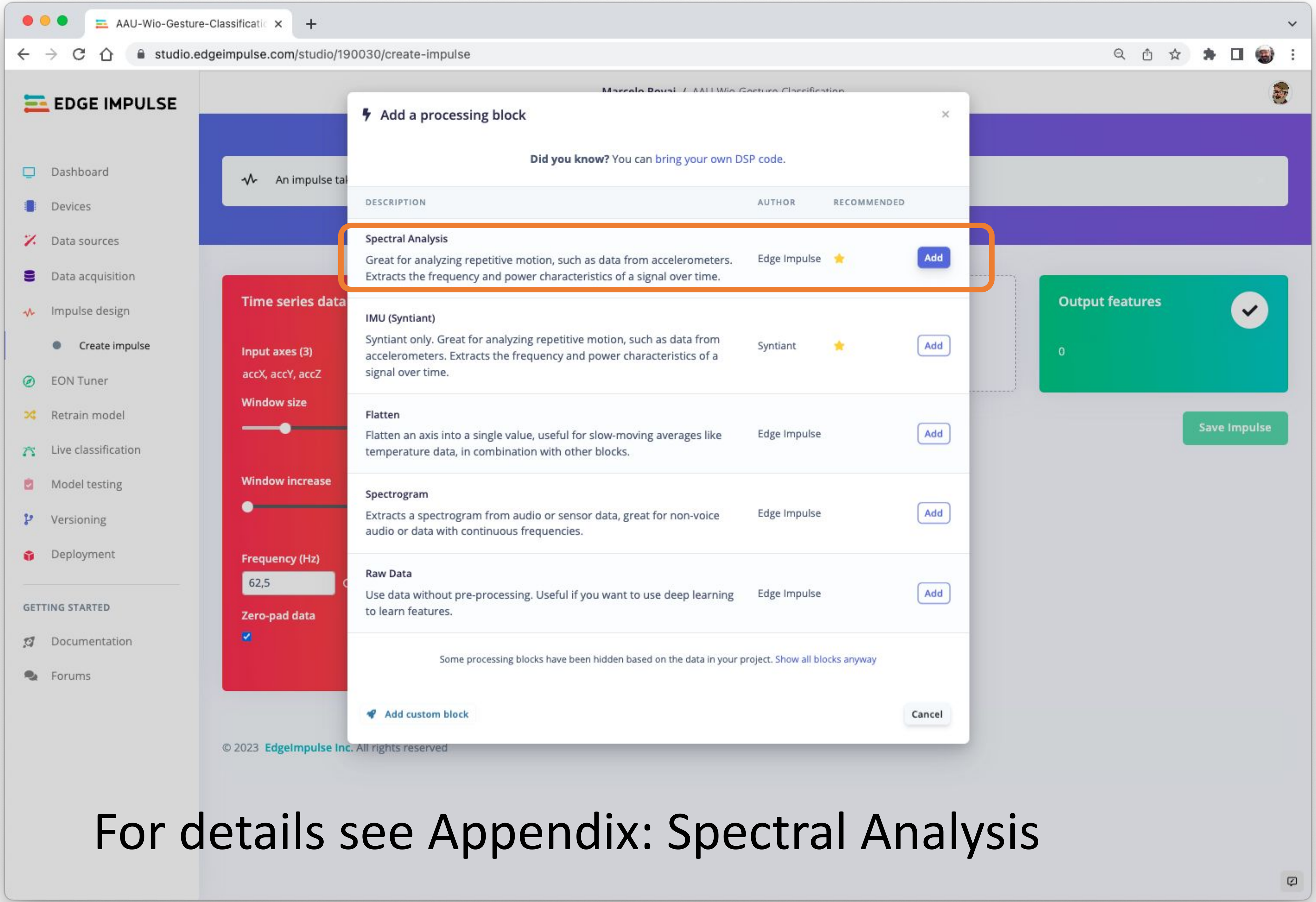


AAU-Wio-Gesture-Classifi
studio.edgeimpulse.com/studio/190030/acquisition/training?page=1
EDGE IMPULSE
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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.3psjgq6n idle Today, 17:19:19 10s
idle.3psjg3lj idle Today, 17:18:55 10s
idle.3psjfflj idle
idle.3psjer3m idle
idle.3psje51r idle
idle.3psjdi38 idle
idle.3psjctpm idle
idle.3psjc87r idle
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
1
2
3
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
idle.3psjhp64
20
15
10
5
0
-5
-10
-15
-20
0
1040
2080
3120
4160
5200
6240
7280
8320
9360
accX
accY
accZ
https://studio.edgeimpulse.com/studio/190030/acquisition/training?page=1#

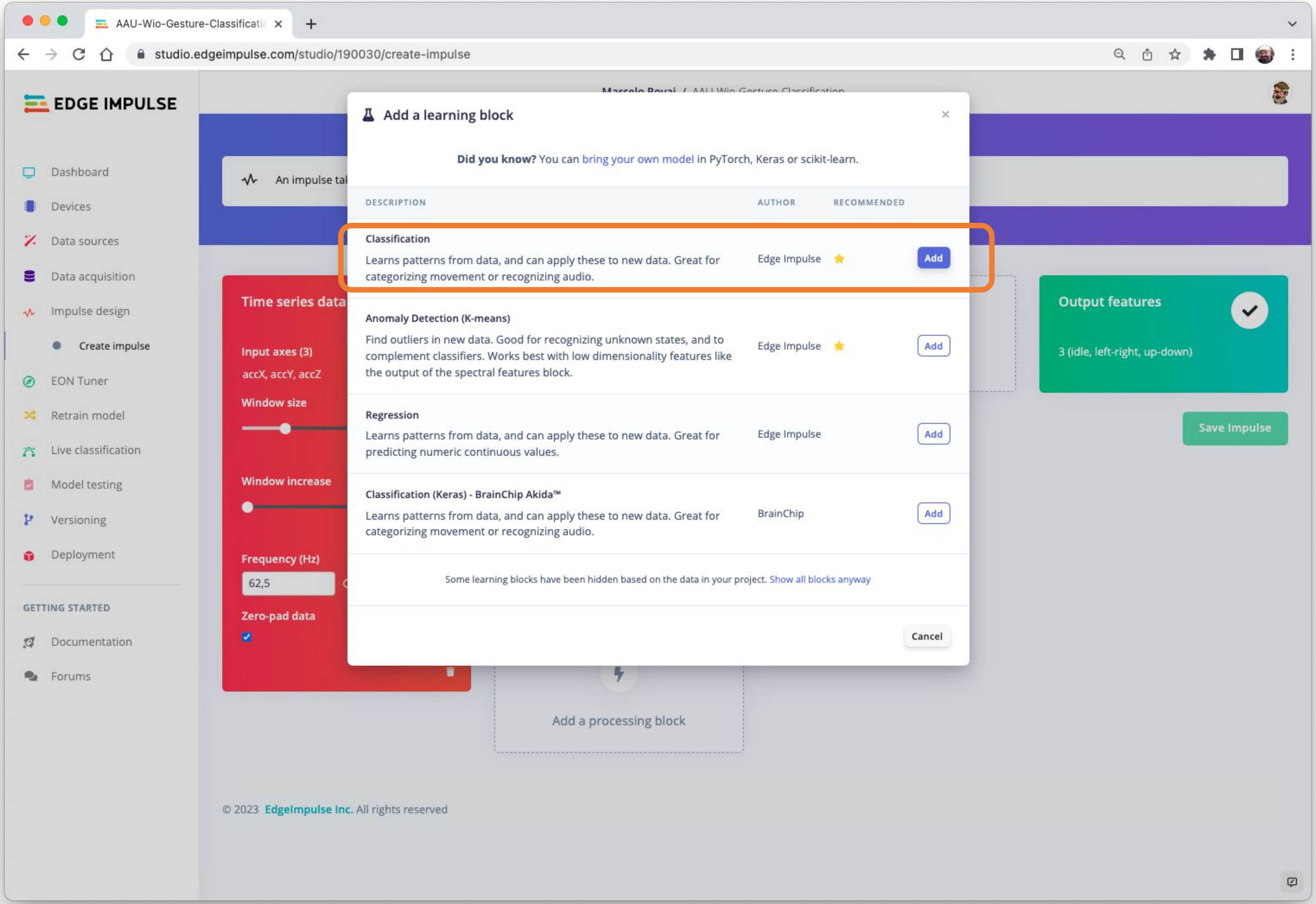

AAU-Wio-Gesture-Classifi
studio.edgeimpulse.com/studio/190030/acquisition/training?page=2
EDGE IMPULSE
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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
1
2
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
20
15
10
5
0
-5
-10
-15
-20
-25
-30
0
1040
2080
3120
4160
5200
6240
7280
8320
9360
accX
accY
accZ

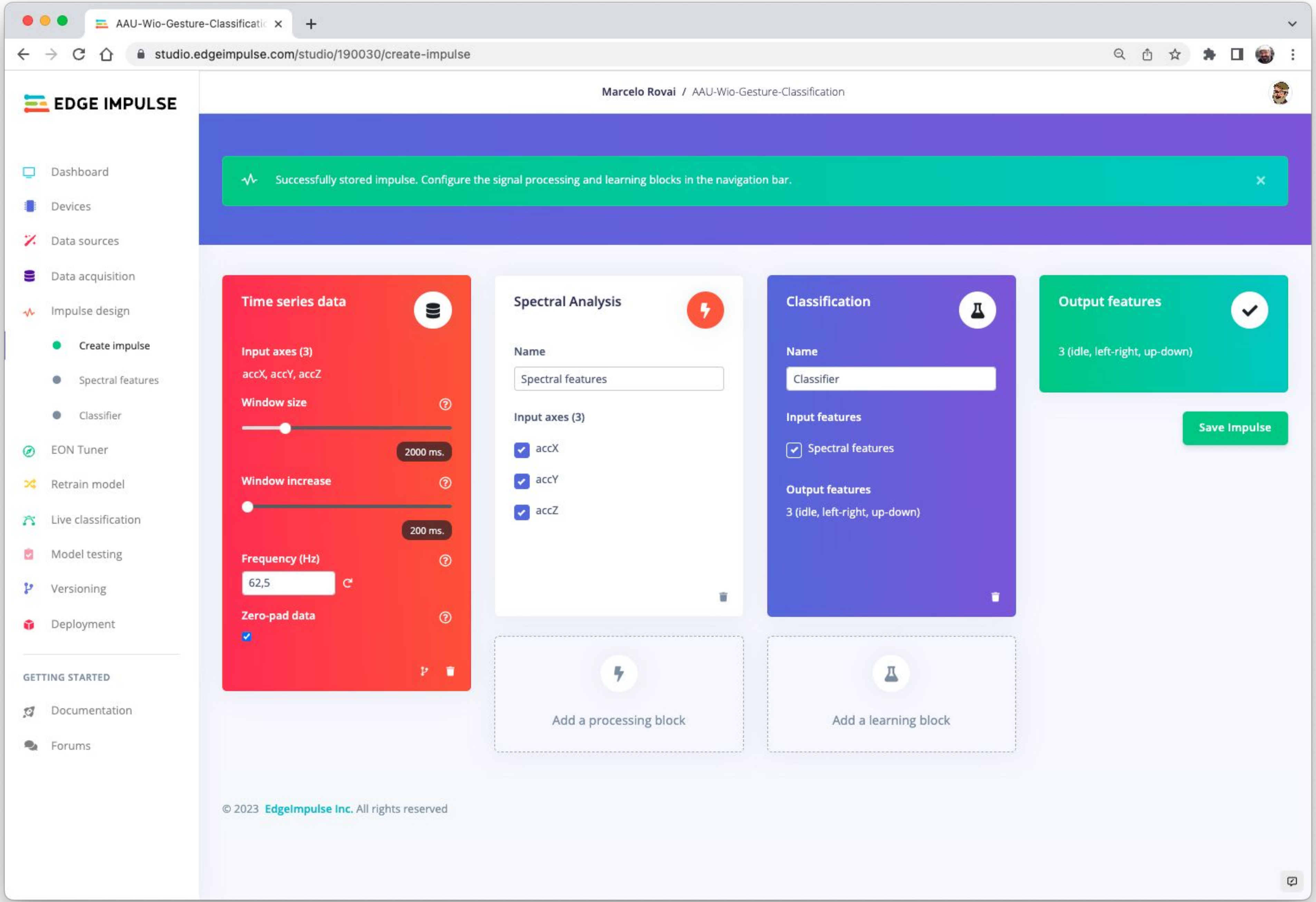


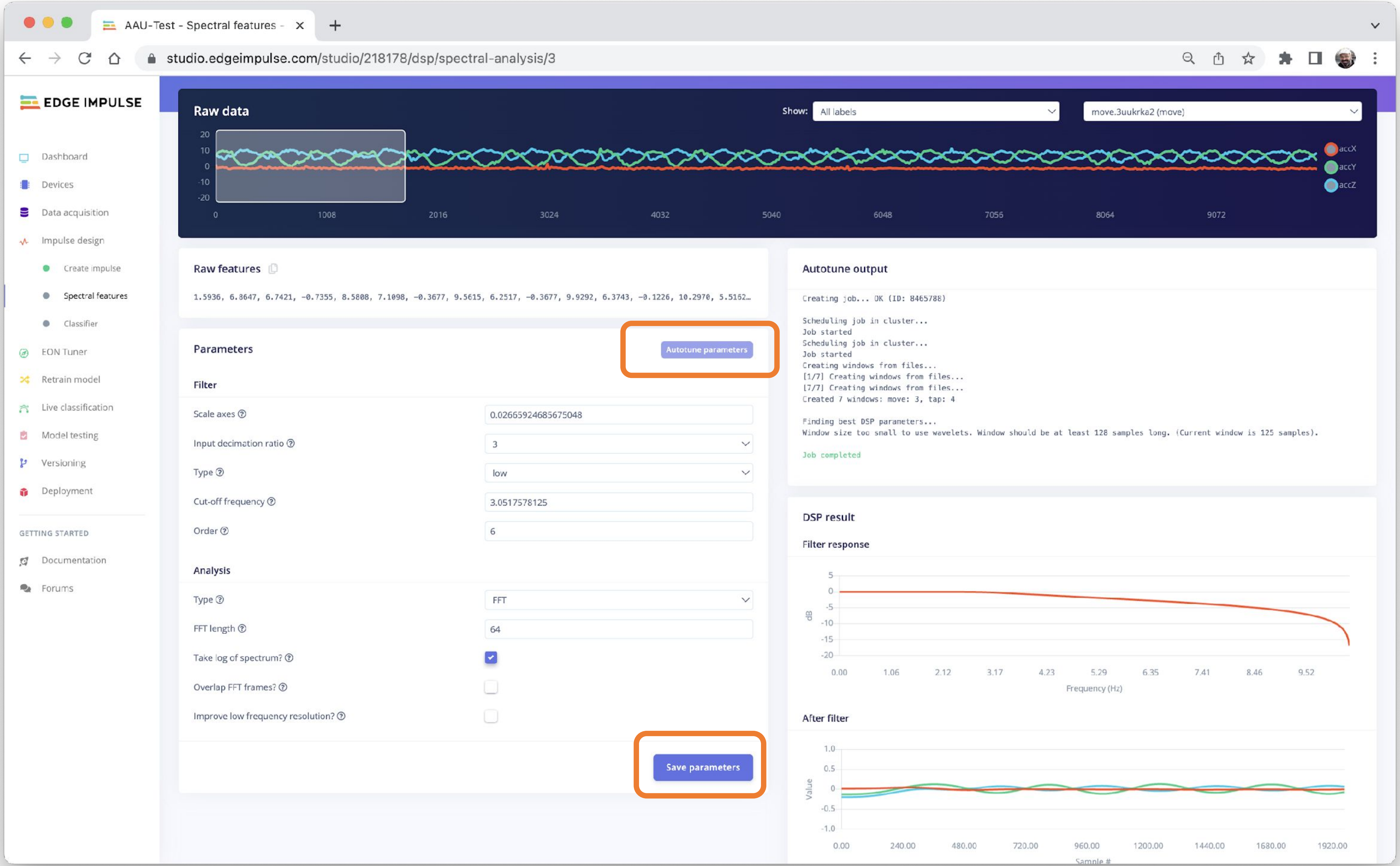
- Pre-Processing Data
- Design a Model
- Train a Model

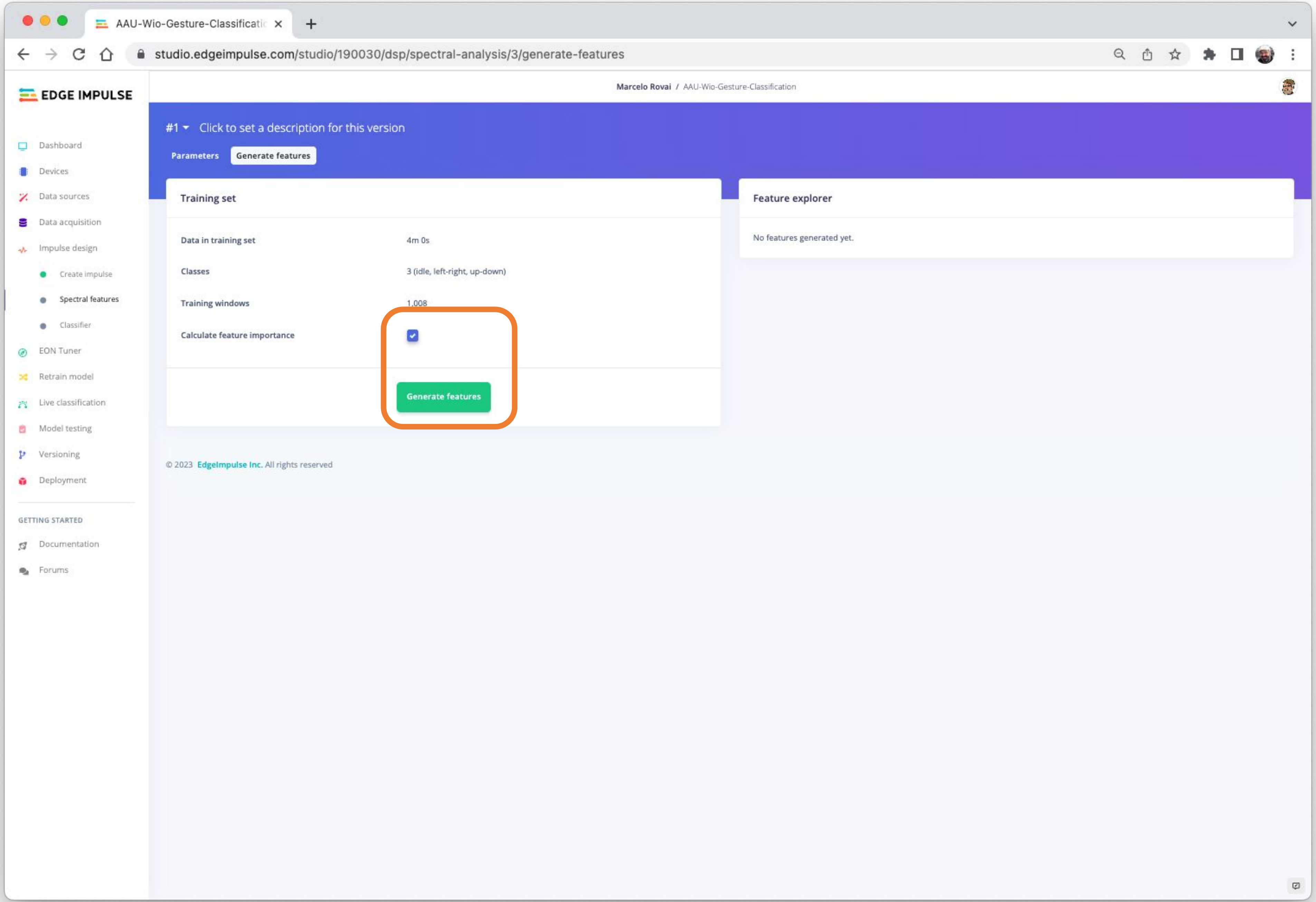


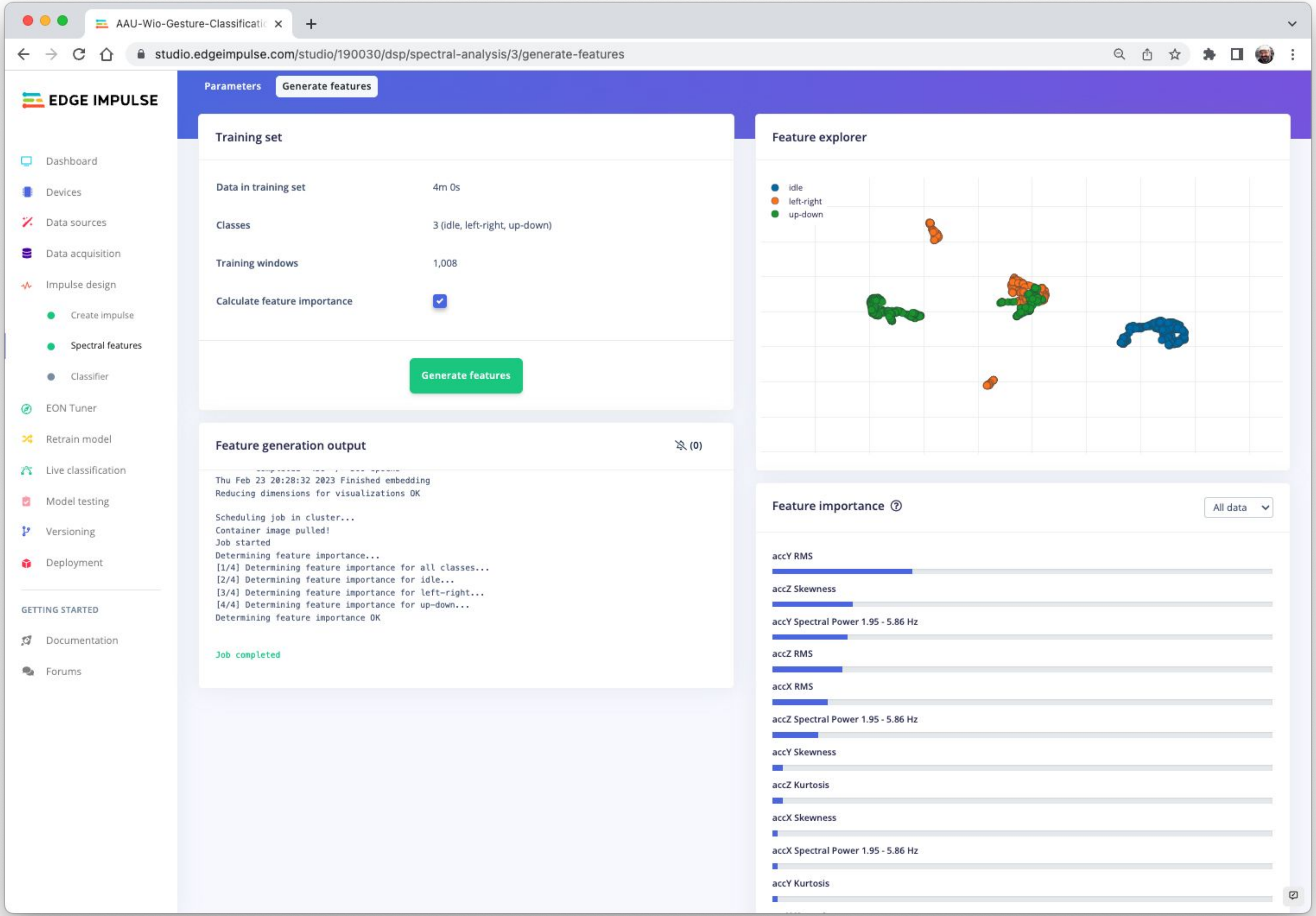
For details see Appendix: Spectral Analysis

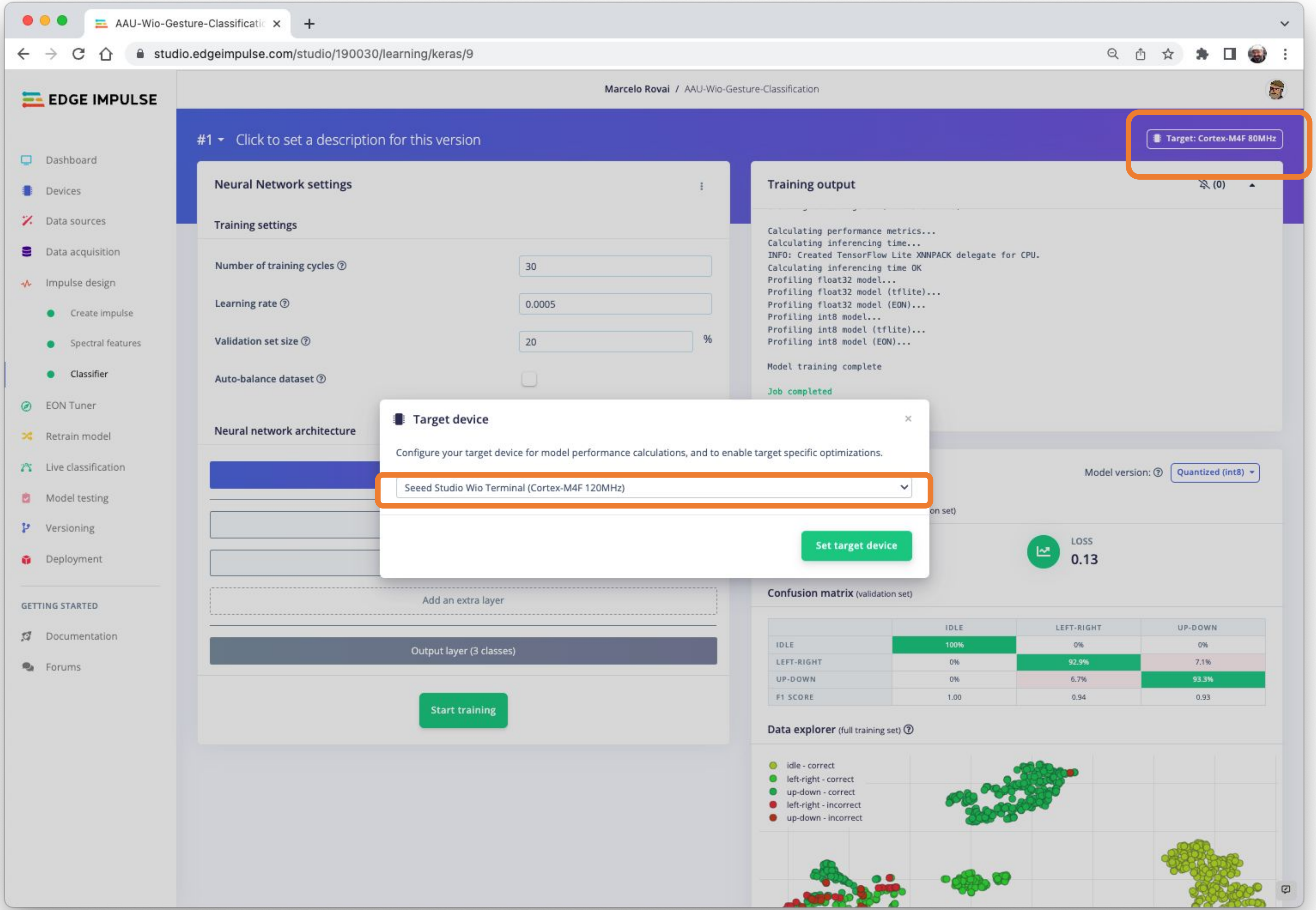

AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/create-impulse
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Time series data
Input axes (3)
accX, accY, accZ
Window size
Window increase
Frequency (Hz)
62,5
Zero-pad data
Add a processing block
Output features
3 (idle, left-right, up-down)
Save Impulse
© 2023 EdgeImpulse Inc. All rights reserved
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
Cancel

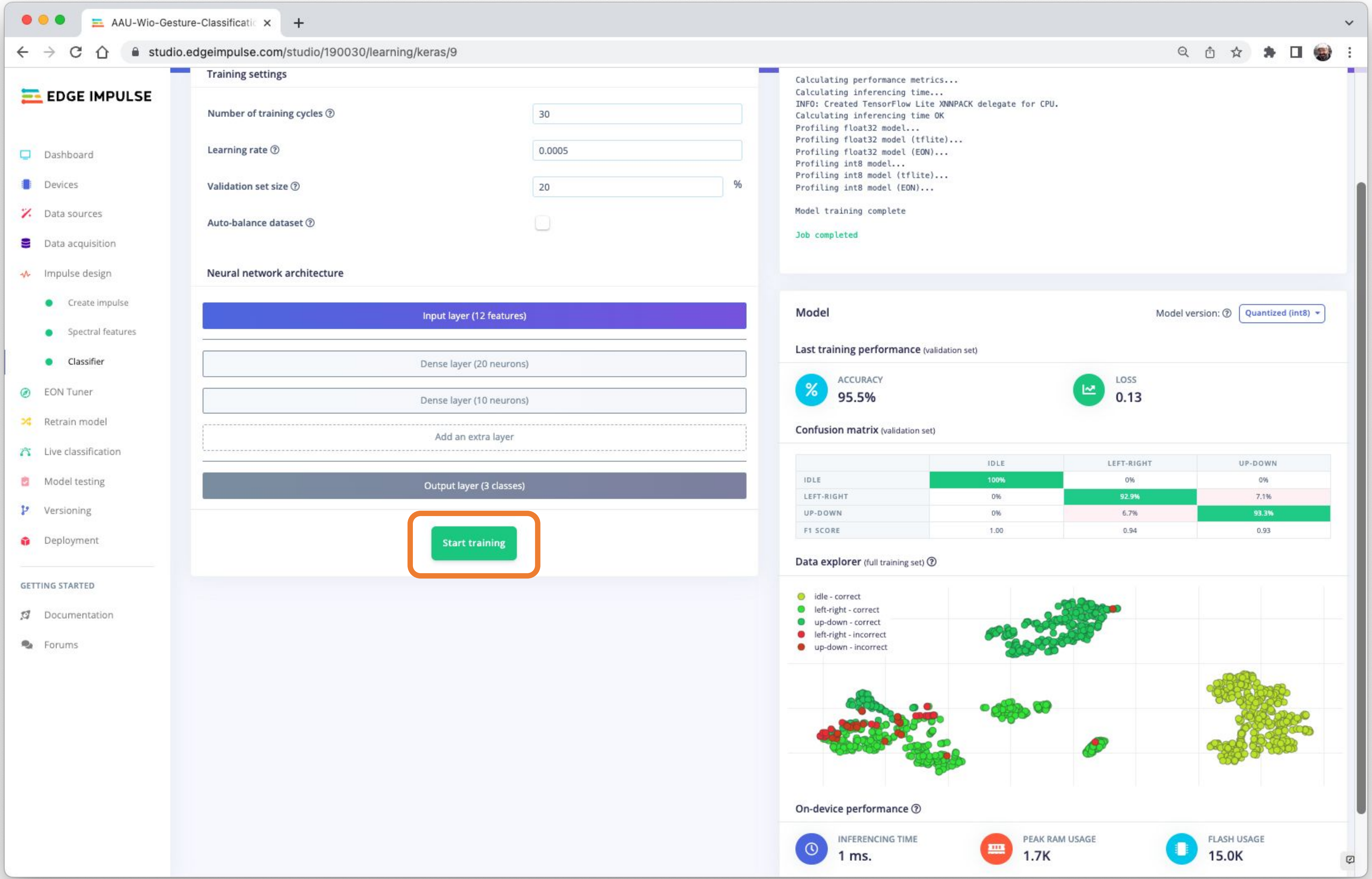

AAU-Wio-Gesture-Classificatio
studio.edgeimpulse.com/studio/190030/create-impulse
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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
© 2023 EdgeImpulse Inc. All rights reserved


AAU-Test - Spectral features -
studio.edgeimpulse.com/studio/218178/dsp/spectral-analysis/3
EDGE IMPULSE
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Raw data
Show:
All labels
move.3uukrka2 (move)
accX
accY
accZ
Raw features
1.5936, 6.8647, 6.7421, -0.7355, 8.5808, 7.1098, -0.3677, 9.5615, 6.2517, -0.3677, 9.9292, 6.3743, -0.1226, 10.2970, 5.5162...
Parameters
Autotune parameters
Filter
Scale axes
0.02665924685675048
Input decimation ratio
3
Type
low
Cut-off frequency
3.0517578125
Order
6
Analysis
Type
FFT
FFT length
64
Take log of spectrum?
Overlap FFT frames?
Improve low frequency resolution?
Save parameters
Autotune output
Creating job... OK (ID: 8465788)
Scheduling job in cluster...
Job started
Scheduling job in cluster...
Job started
Creating windows from files...
[1/7] Creating windows from files...
[7/7] Creating windows from files...
Created 7 windows: move: 3, tap: 4
Finding best DSP parameters...
Window size too small to use wavelets. Window should be at least 128 samples long. (Current window is 125 samples).
Job completed
DSP result
Filter response
Frequency (Hz)
After filter
Sample #

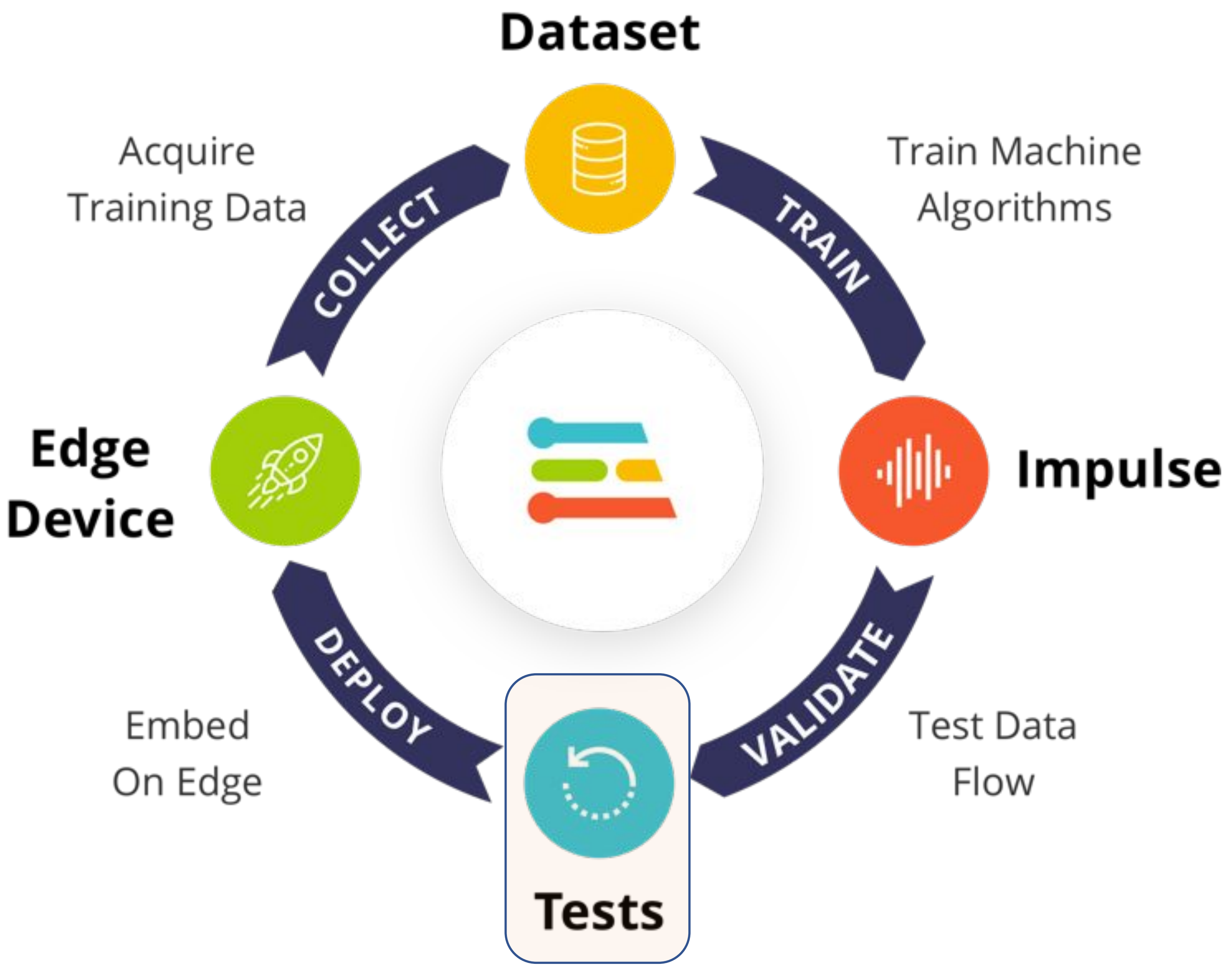

AAU-Wio-Gesture-Classificatic
studio.edgeimpulse.com/studio/190030/dsp/spectral-analysis/3/generate-features
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
#1 Click to set a description for this version
Parameters
Generate features
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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.
© 2023 EdgeImpulse Inc. All rights reserved


AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/dsp/spectral-analysis/3/generate-features
EDGE IMPULSE
Parameters
Generate features
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
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
(0)
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
left-right
up-down
Feature importance
All data
accY RMS
accZ Skewness
accY Spectral Power 1.95 - 5.86 Hz
accZ RMS
accX RMS
accZ Spectral Power 1.95 - 5.86 Hz
accY Skewness
accZ Kurtosis
accX Skewness
accX Spectral Power 1.95 - 5.86 Hz
accY Kurtosis

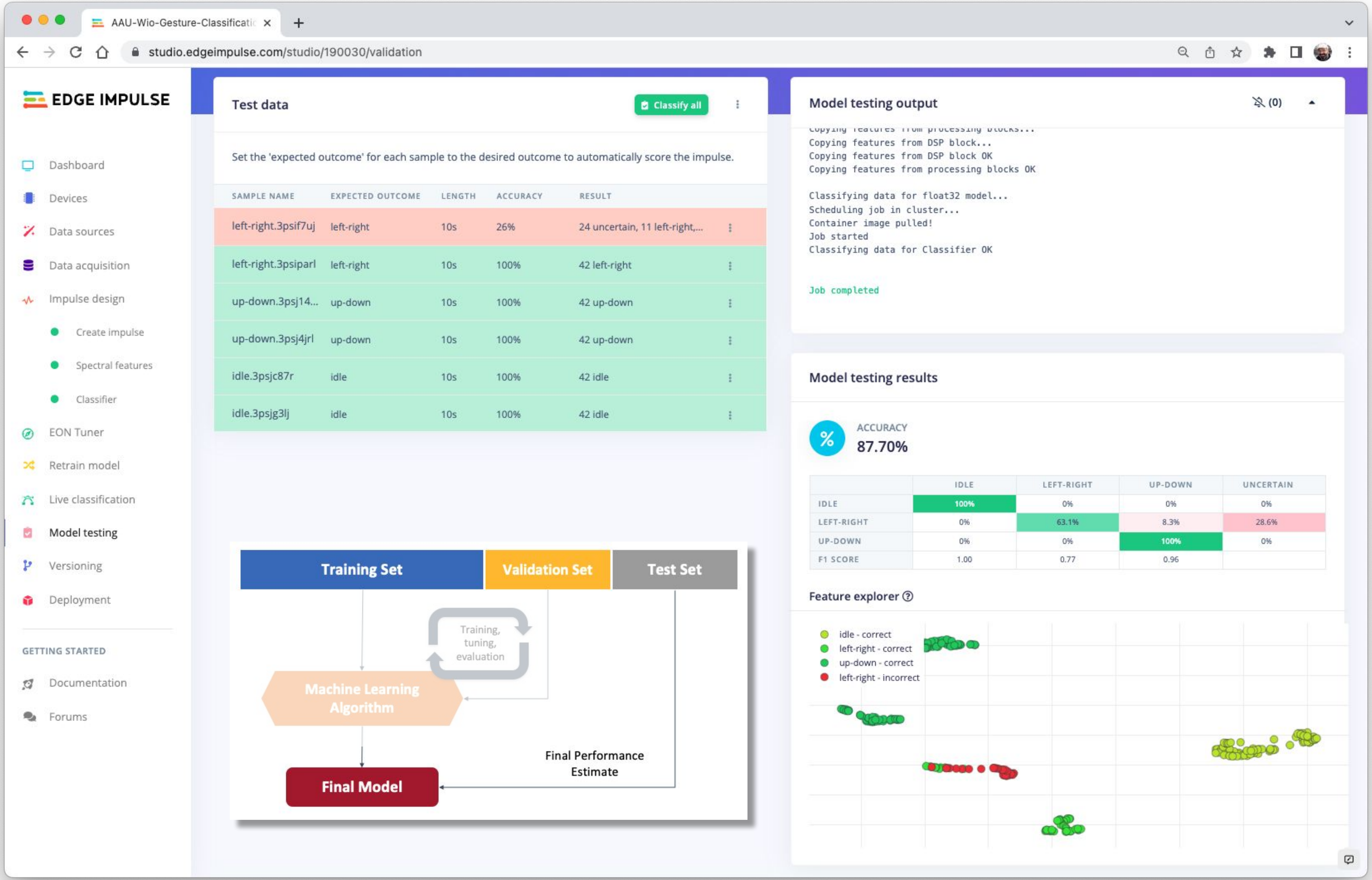

AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/learning/keras/9
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
#1 Click to set a description for this version
Target: Cortex-M4F 80MHz
Neural Network settings
Training settings
Number of training cycles
30
Learning rate
0.0005
Validation set size
20
%
Auto-balance dataset
Neural network architecture
Add an extra layer
Output layer (3 classes)
Start training
Training output
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
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:
Quantized (int8)
LOSS
0.13
Confusion matrix (validation set)
IDLE
LEFT-RIGHT
UP-DOWN
F1 SCORE
100%
0%
92.9%
7.1%
6.7%
93.3%
1.00
0.94
0.93
Data explorer (full training set)
idle - correct
left-right - correct
up-down - correct
left-right - incorrect
up-down - incorrect



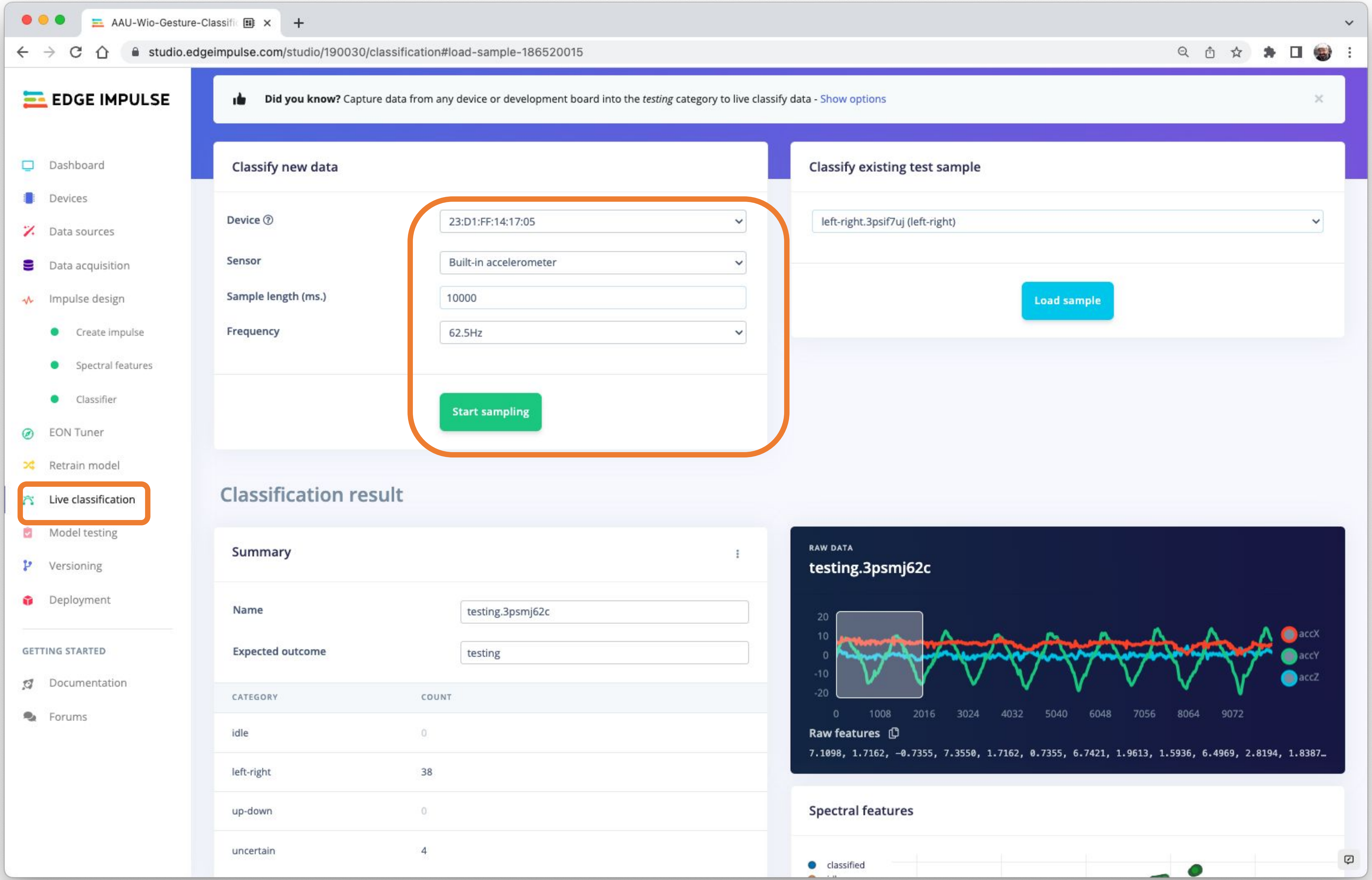
AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/learning/keras/9
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Training settings
Number of training cycles
30
Learning rate
0.0005
Validation set size
20
%
Auto-balance dataset
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:
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)
idle - correct
left-right - correct
up-down - correct
left-right - incorrect
up-down - incorrect
On-device performance
INFERENCING TIME
1 ms.
PEAK RAM USAGE
1.7K
FLASH USAGE
15.0K

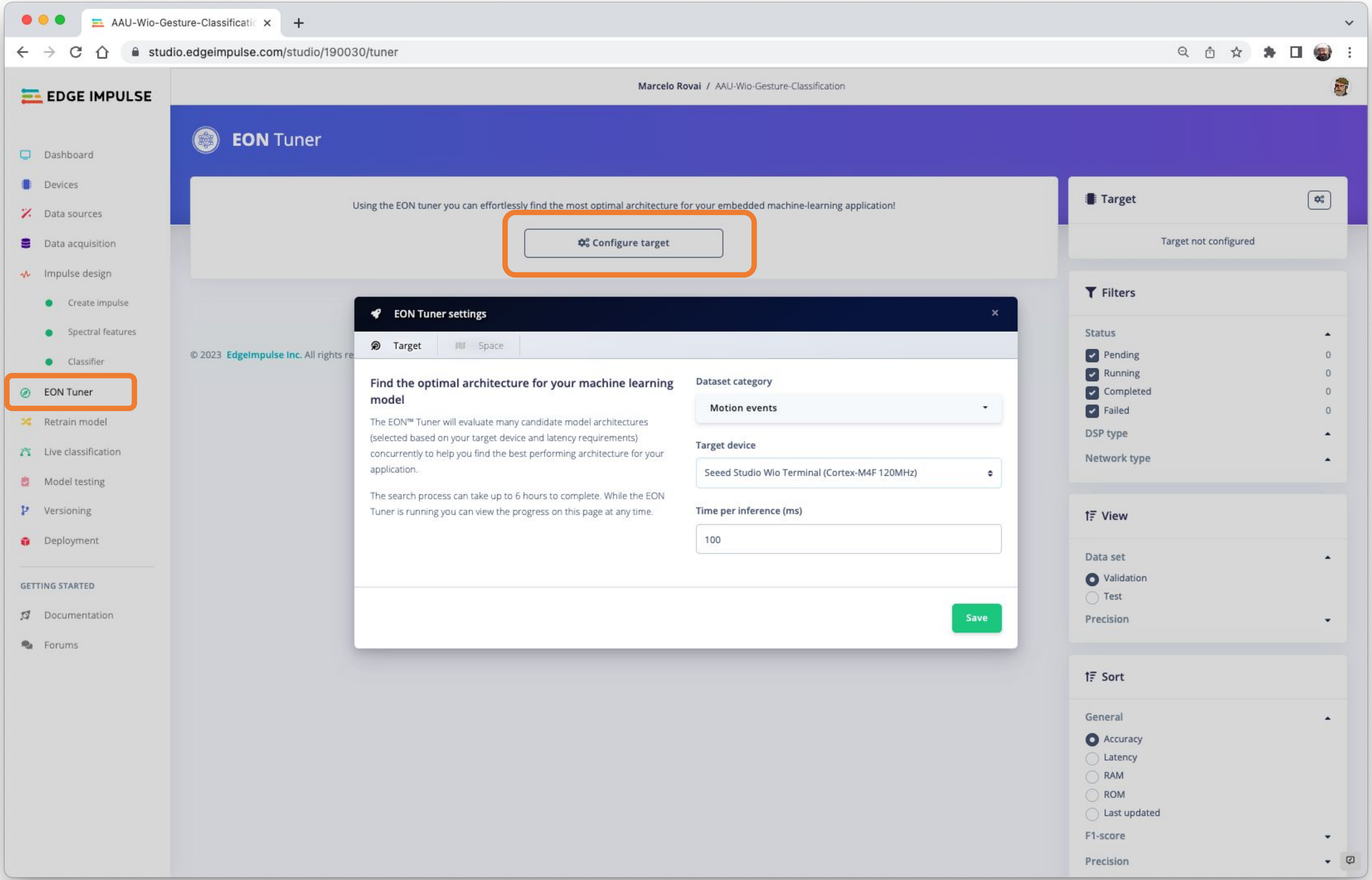


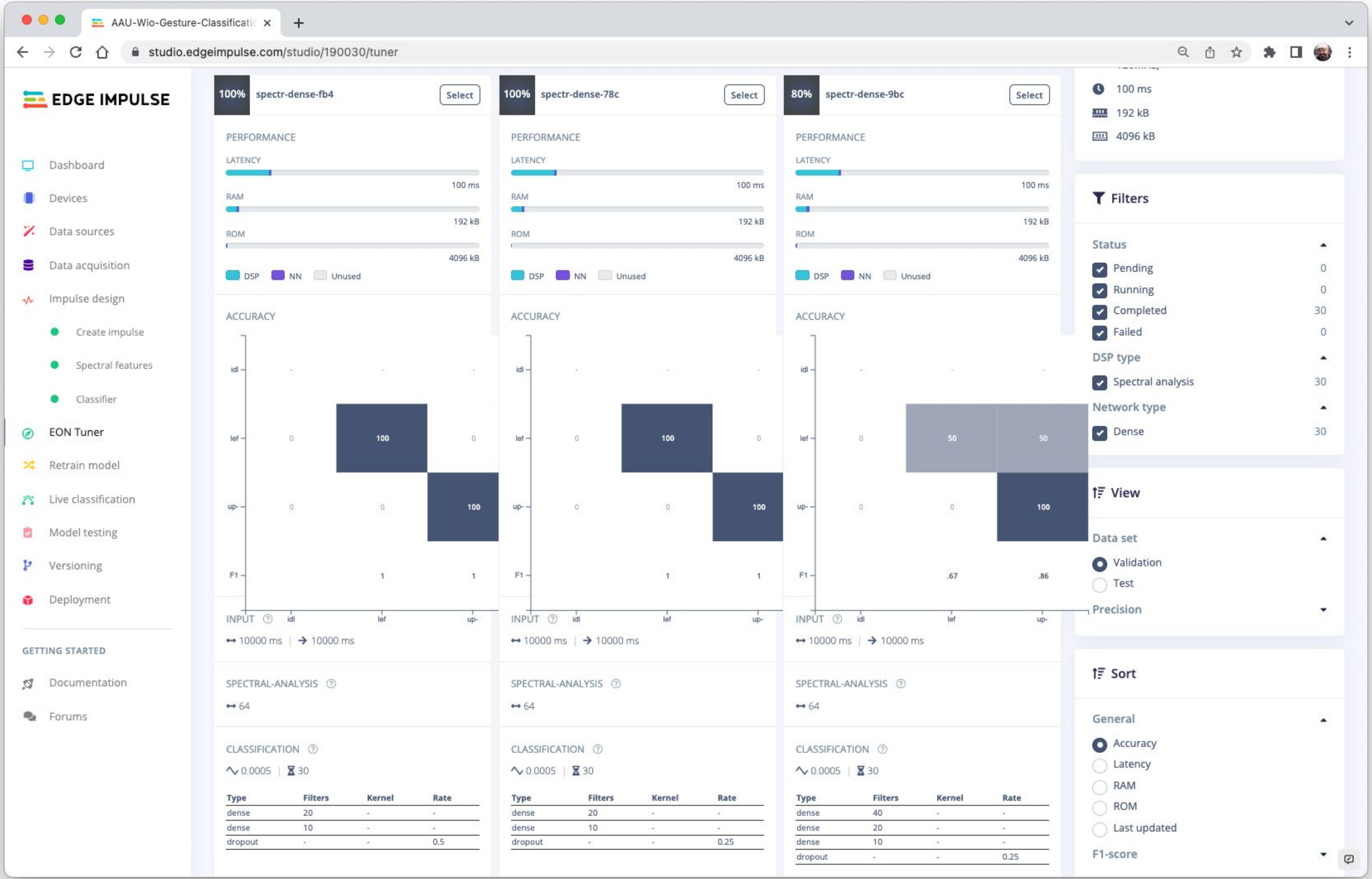
- Pre-Processing Data
- Design a Model
- Train a Model



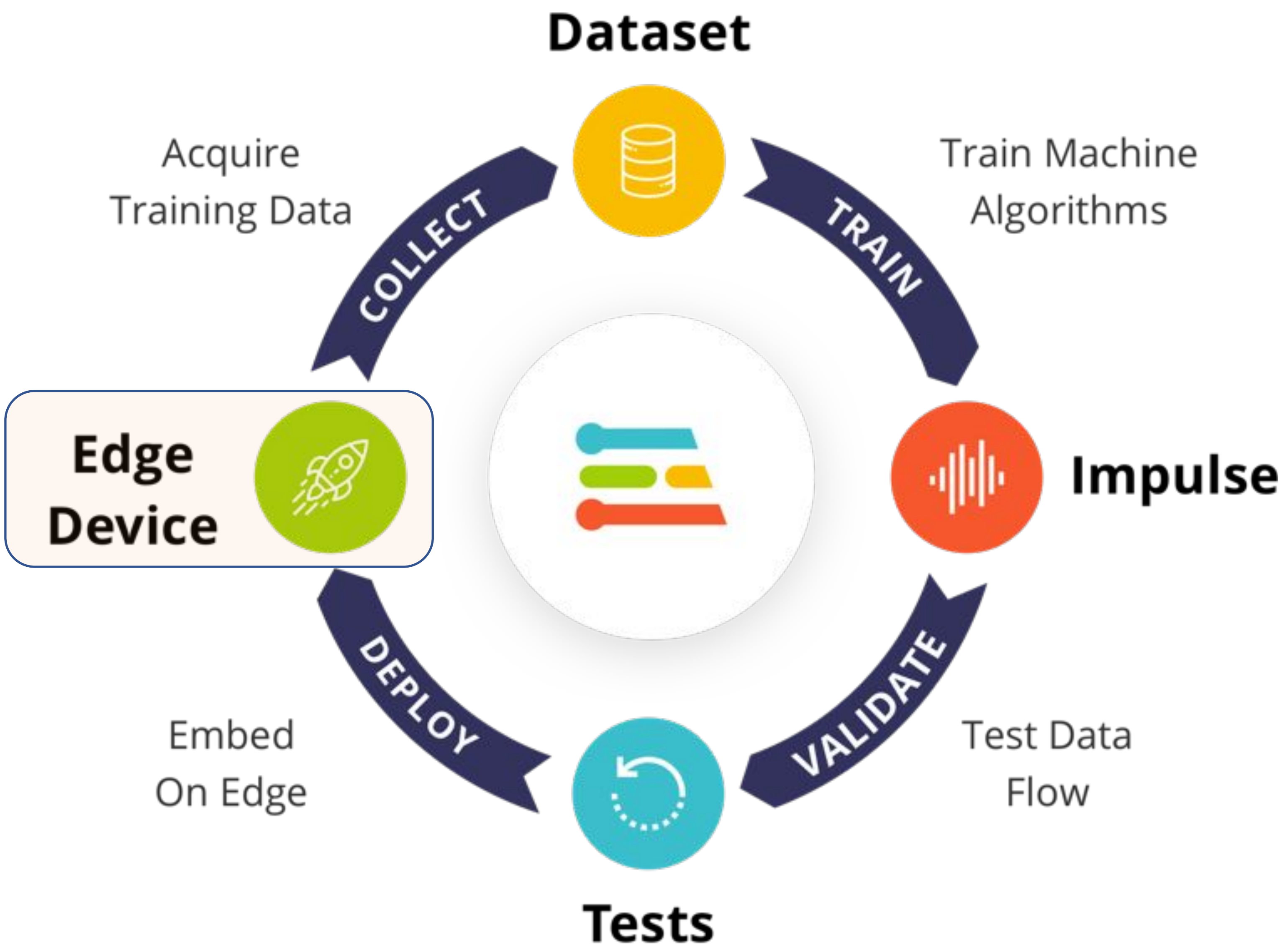
AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/validation
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Test data
Classify all
Set the 'expected outcome' for each sample to the desired outcome to automatically score the impulse.
SAMPLE NAME
EXPECTED OUTCOME
LENGTH
ACCURACY
RESULT
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
Training Set
Validation Set
Test Set
Training, tuning, evaluation
Machine Learning Algorithm
Final Model
Final Performance Estimate
Model testing output
(0)
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-Classifi
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
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
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
Summary
Name
testing.3psmj62c
Expected outcome
testing
CATEGORY
COUNT
idle
0
left-right
38
up-down
0
uncertain
4
RAW DATA
testing.3psmj62c
accX
accY
accZ
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

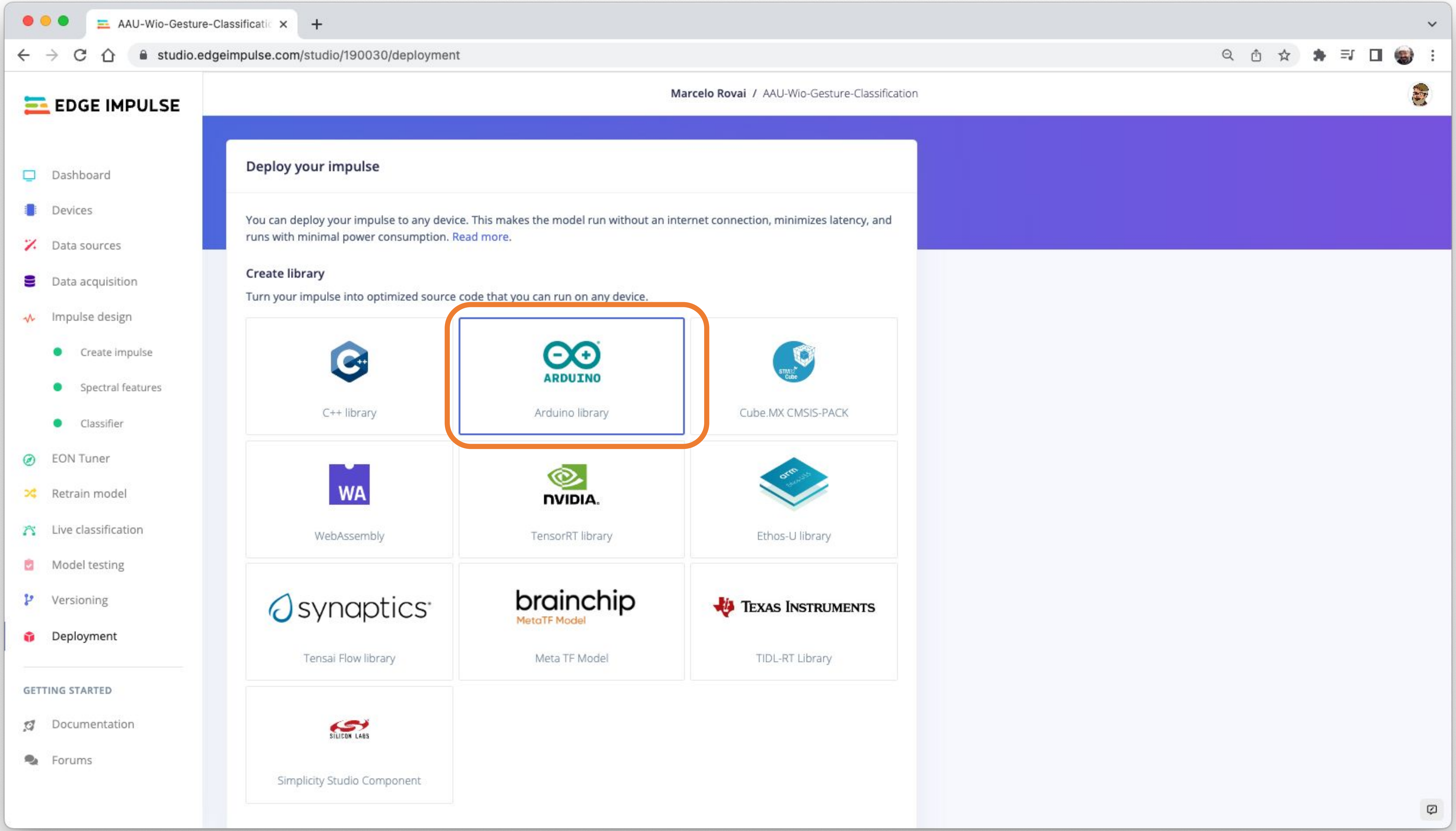

AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/tuner
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
EON Tuner
Using the EON tuner you can effortlessly find the most optimal architecture for your embedded machine-learning application!
Configure target
© 2023 EdgeImpulse Inc. All rights re
EON Tuner settings
Target
Space
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
Latency
RAM
ROM
Last updated
F1-score
Precision

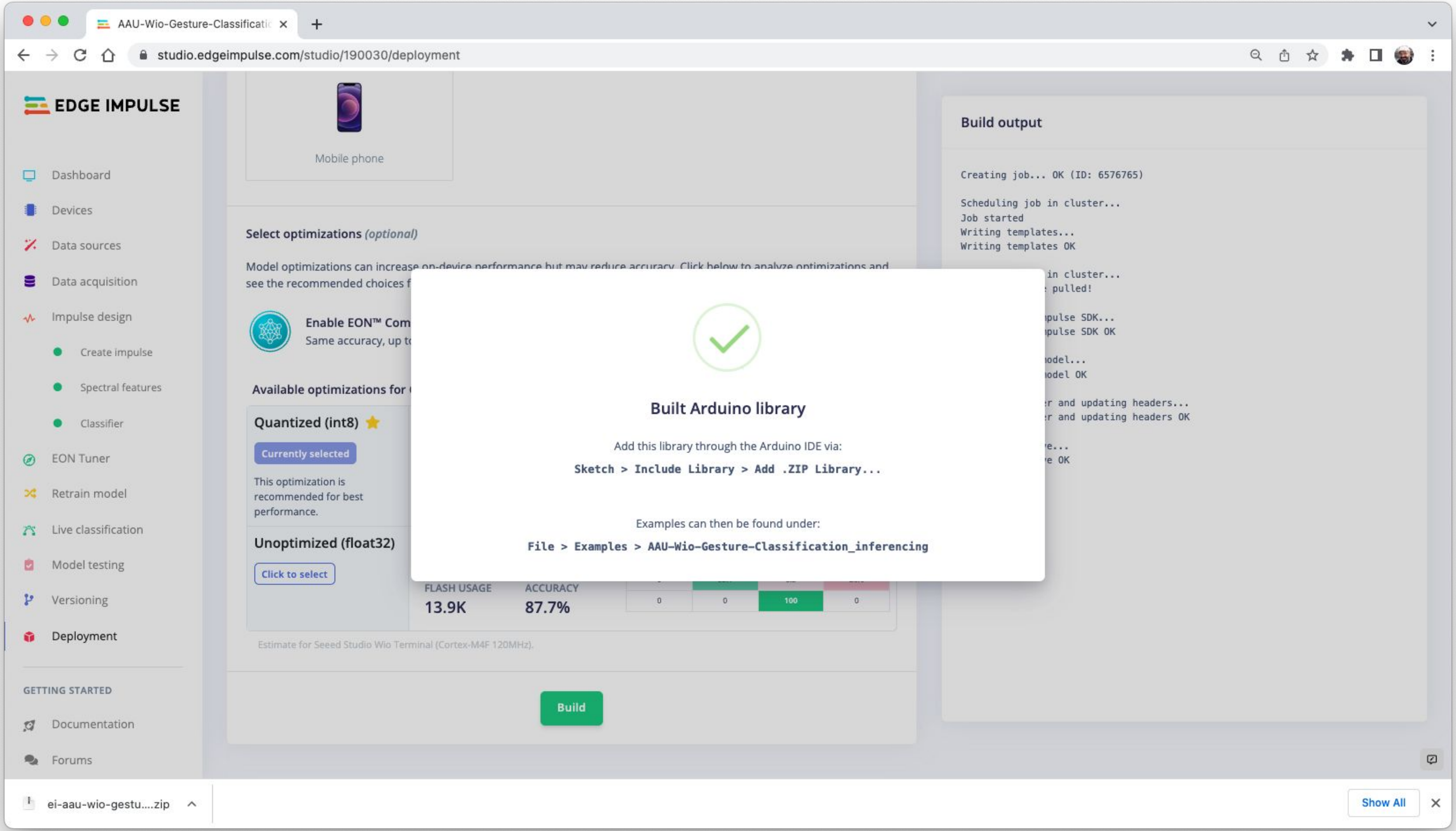


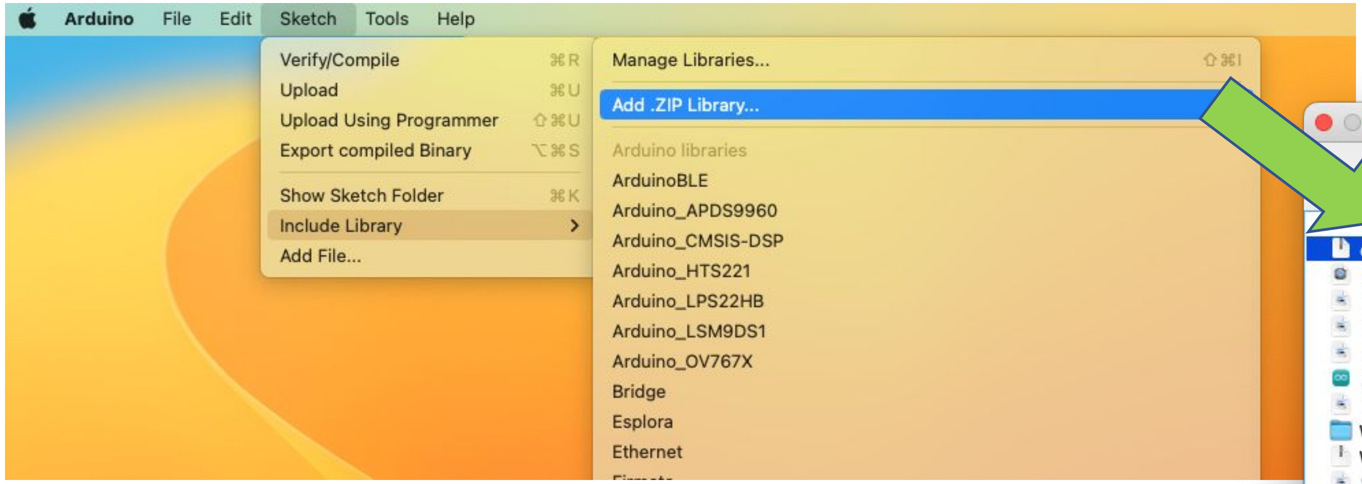
AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/tuner
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Spectral features
Classifier
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
100% spectr-dense-fb4 Select
100% spectr-dense-78c Select
80% spectr-dense-9bc Select
PERFORMANCE
LATENCY
100 ms
RAM
192 kB
ROM
4096 kB
DSP NN Unused
ACCURACY
idl
lef
up-
F1
INPUT
10000 ms | 10000 ms
SPECTRAL-ANALYSIS
64
CLASSIFICATION
0.0005 | 30
Type Filters Kernel Rate
dense 20 - -
dense 10 - -
dropout - - 0.5
dropout - - 0.25
dense 40 - -
Filters
Status
Pending 0
Running 0
Completed 30
Failed 0
DSP type
Spectral analysis 30
Network type
Dense 30
View
Data set
Validation
Test
Precision
Sort
General
Accuracy
Latency
RAM
ROM
Last updated
F1-score

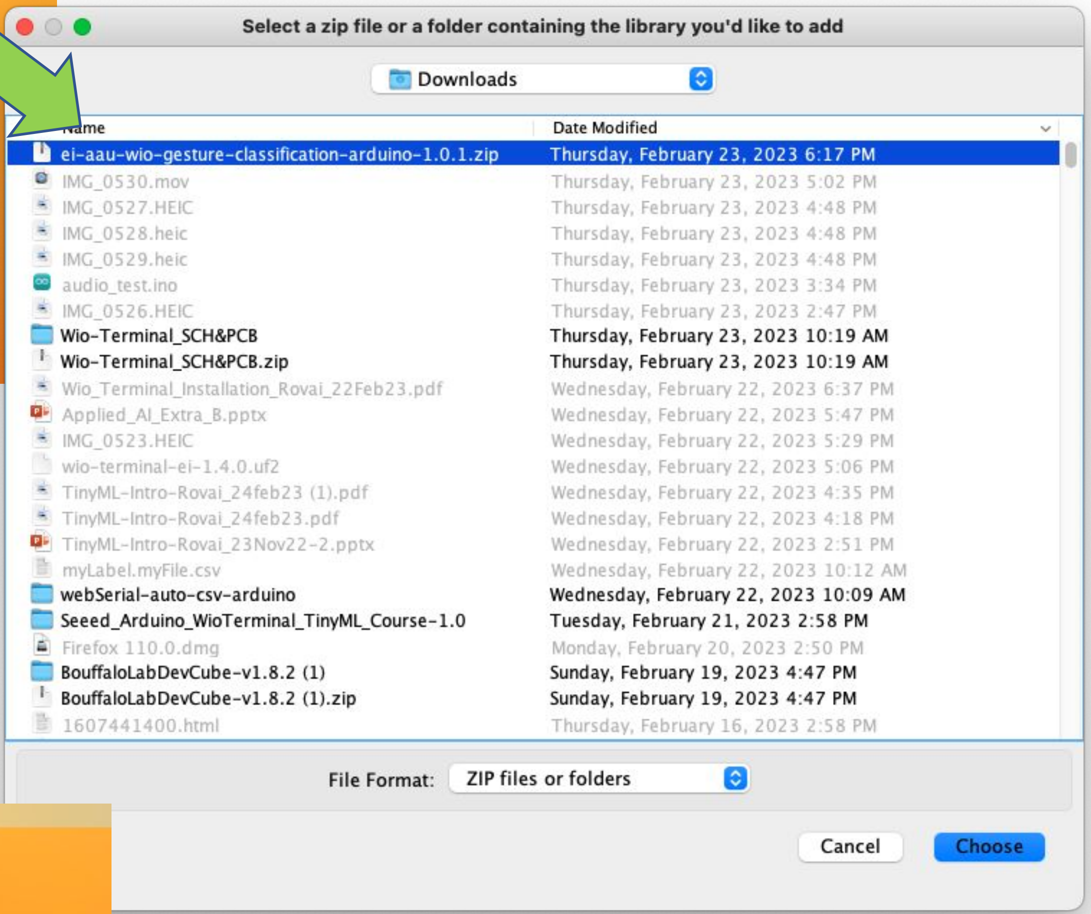


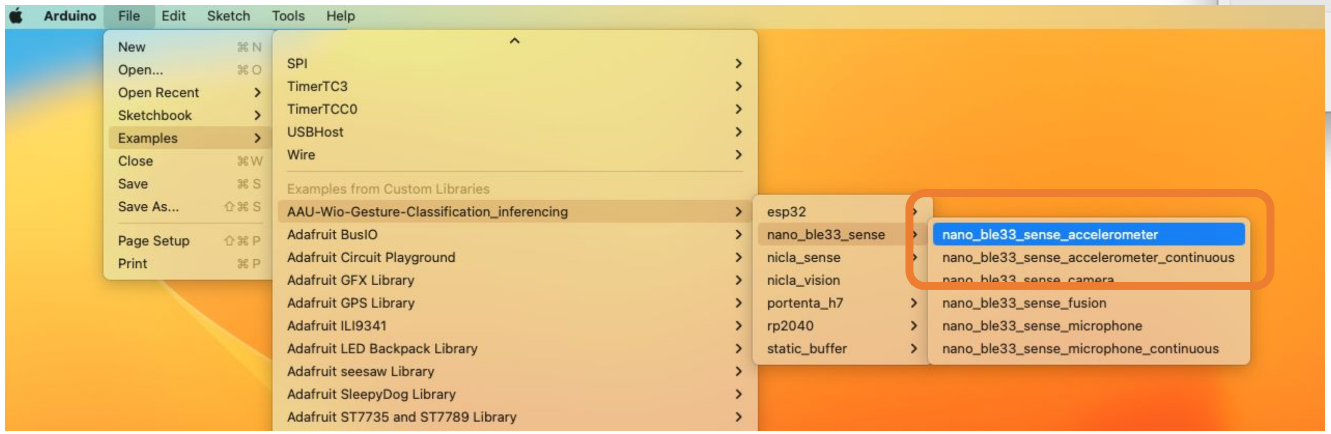
- Pre-Processing Data
- Design a Model
- Train a Model


AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/deployment
EDGE IMPULSE
Marcelo Rovai / AAU-Wio-Gesture-Classification
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
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
Arduino library
Cube.MX CMSIS-PACK
WA
WebAssembly
NVIDIA.
TensorRT library
Ethos-U library
synaptics
Tensai Flow library
brainchip
MetaTF Model
Meta TF Model
Texas Instruments
TIDL-RT Library
Simplicity Studio Component


AAU-Wio-Gesture-Classificati
studio.edgeimpulse.com/studio/190030/deployment
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
GETTING STARTED
Documentation
Forums
Mobile phone
Select optimizations (optional)
Enable EON™ Com
Same accuracy, up t
Available optimizations for
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
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

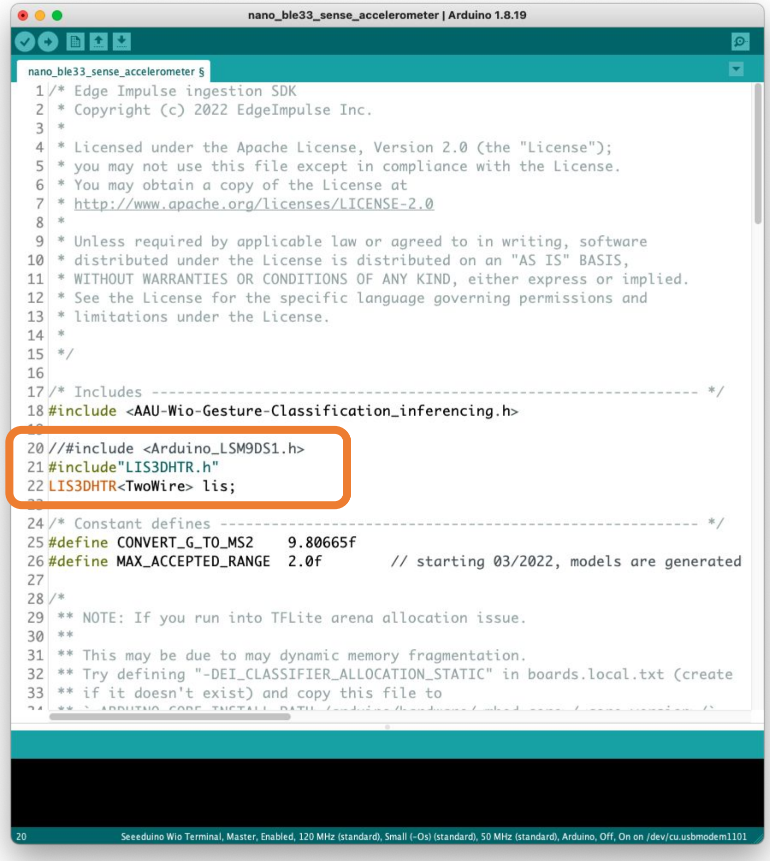

Arduino File Edit Sketch Tools Help
Verify/Compile ⌘R
Upload ⌘U
Upload Using Programmer ⇧⌘U
Export compiled Binary ⌥⌘S
Show Sketch Folder ⌘K
Include Library
Add File...
Manage Libraries... ⇧⌘I
Add .ZIP Library...
Arduino libraries
ArduinoBLE
Arduino_APDS9960
Arduino_CMSIS-DSP
Arduino_HTS221
Arduino_LPS22HB
Arduino_LSM9DS1
Arduino_OV767X
Bridge
Esplora
Ethernet

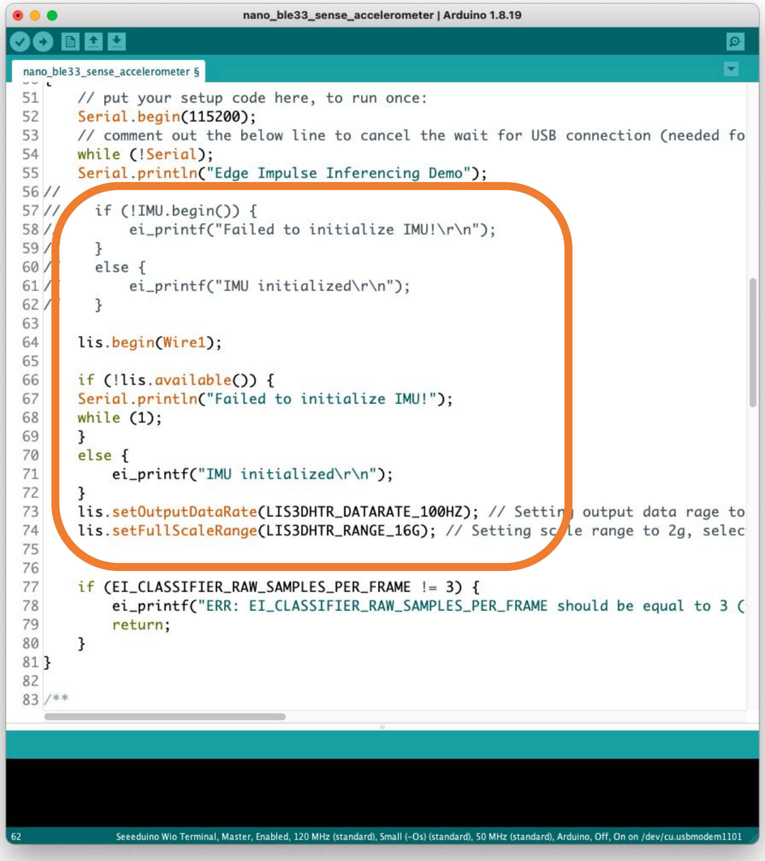

Select a zip file or a folder containing the library you'd like to add
Downloads
Name
Date Modified
ei-aau-wio-gesture-classification-arduino-1.0.1.zip Thursday, February 23, 2023 6:17 PM
IMG_0530.mov Thursday, February 23, 2023 5:02 PM
IMG_0527.HEIC Thursday, February 23, 2023 4:48 PM
IMG_0528.heic Thursday, February 23, 2023 4:48 PM
IMG_0529.heic Thursday, February 23, 2023 4:48 PM
audio_test.ino Thursday, February 23, 2023 3:34 PM
IMG_0526.HEIC Thursday, February 23, 2023 2:47 PM
Wio-Terminal_SCH&PCB Thursday, February 23, 2023 10:19 AM
Wio-Terminal_SCH&PCB.zip Thursday, February 23, 2023 10:19 AM
Wio_Terminal_Installation_Rovai_22Feb23.pdf Wednesday, February 22, 2023 6:37 PM
Applied_AI_Extra_B.pptx Wednesday, February 22, 2023 5:47 PM
IMG_0523.HEIC Wednesday, February 22, 2023 5:29 PM
wio-terminal-ei-1.4.0.uf2 Wednesday, February 22, 2023 5:06 PM
TinyML-Intro-Rovai_24feb23 (1).pdf Wednesday, February 22, 2023 4:35 PM
TinyML-Intro-Rovai_24feb23.pdf Wednesday, February 22, 2023 4:18 PM
TinyML-Intro-Rovai_23Nov22-2.pptx Wednesday, February 22, 2023 2:51 PM
myLabel.myFile.csv Wednesday, February 22, 2023 10:12 AM
webSerial-auto-csv-arduino Wednesday, February 22, 2023 10:09 AM
Seeed_Arduino_WioTerminal_TinyML_Course-1.0 Tuesday, February 21, 2023 2:58 PM
Firefox 110.0.dmg Monday, February 20, 2023 2:50 PM
BouffaloLabDevCube-v1.8.2 (1) Sunday, February 19, 2023 4:47 PM
BouffaloLabDevCube-v1.8.2 (1).zip Sunday, February 19, 2023 4:47 PM
1607441400.html Thursday, February 16, 2023 2:58 PM
File Format: ZIP files or folders
Cancel
Choose

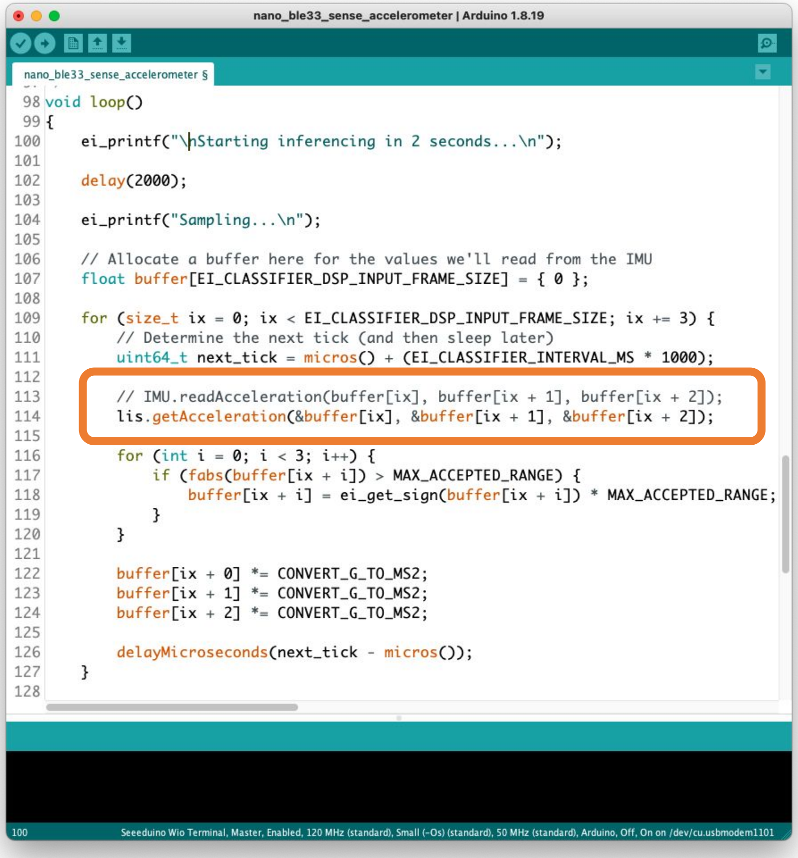

Arduino File Edit Sketch Tools Help
New ⌘N
Open... ⌘O
Open Recent
Sketchbook
Examples
Close ⌘W
Save ⌘S
Save As... ⇧⌘S
Page Setup ⇧⌘P
Print ⌘P
SPI
TimerTC3
TimerTCC0
USBHost
Wire
Examples from Custom Libraries
AAU-Wio-Gesture-Classification_inferencing
Adafruit BusIO
Adafruit Circuit Playground
Adafruit GFX Library
Adafruit GPS Library
Adafruit ILI9341
Adafruit LED Backpack Library
Adafruit seesaw Library
Adafruit SleepyDog Library
Adafruit ST7735 and ST7789 Library
esp32
nano_ble33_sense
nicla_sense
nicla_vision
portenta_h7
rp2040
static_buffer
nano_ble33_sense_accelerometer
nano_ble33_sense_accelerometer_continuous
nano_ble33_sense_camera
nano_ble33_sense_fusion
nano_ble33_sense_microphone
nano_ble33_sense_microphone_continuous

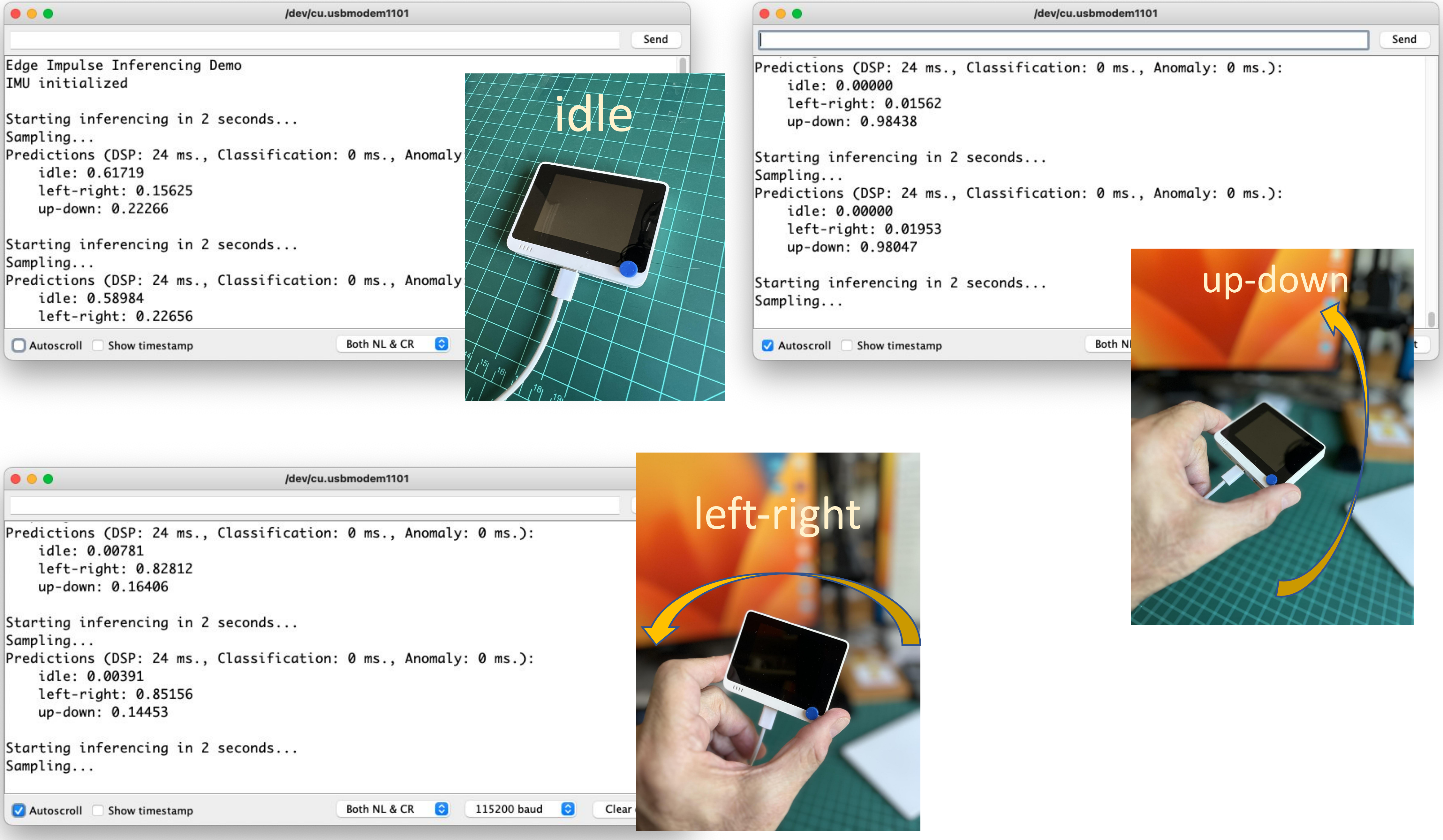
Model Inference

Changing the Arduino code to adapt the Wio Accelerometer








/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
idle
/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
up-down
/dev/cu.usbmodem1101
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
left-right

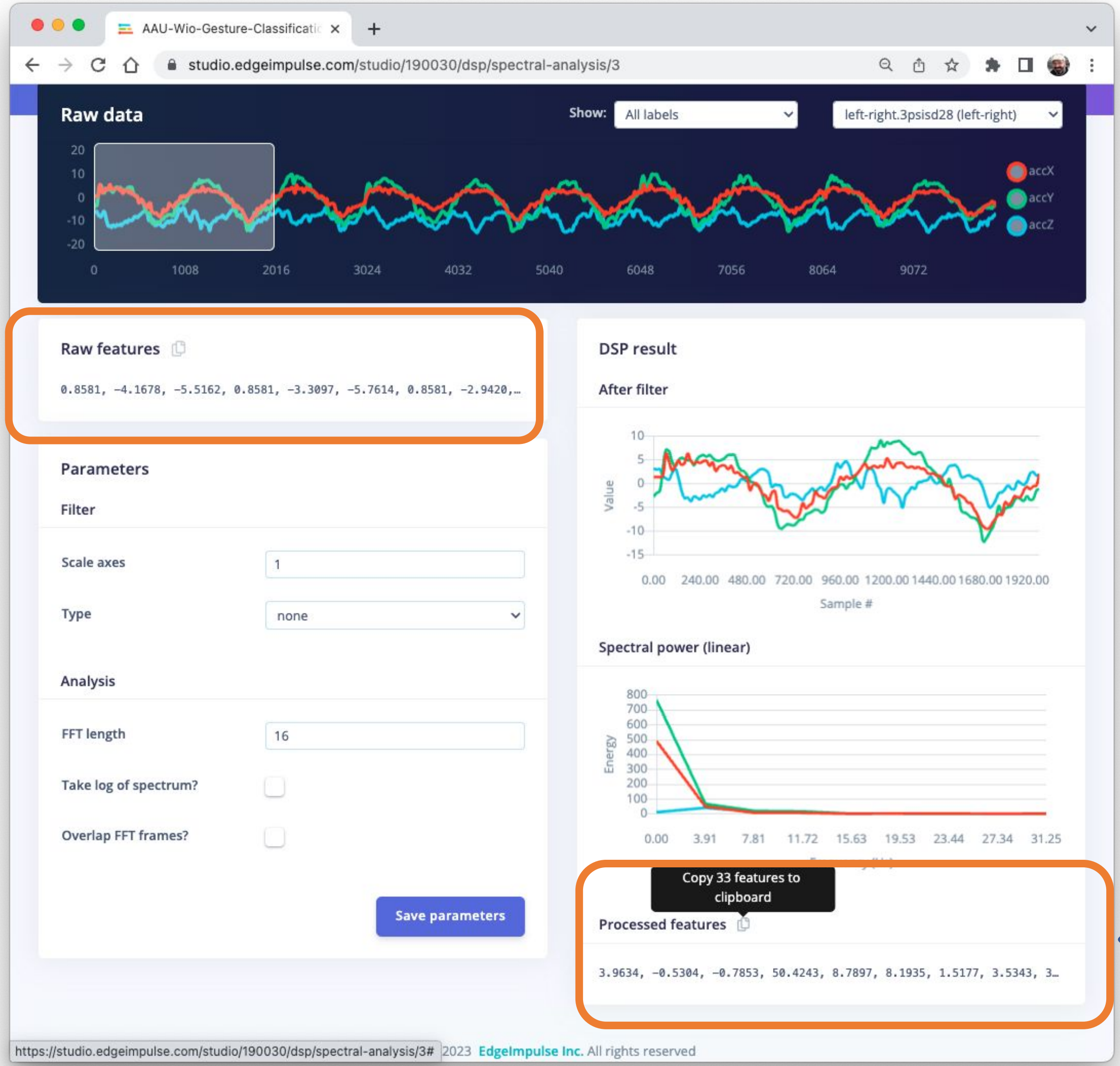
Including LCD for off-line Inference

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 Featues **per axis** will be:

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

For example,

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

Subtrating 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.

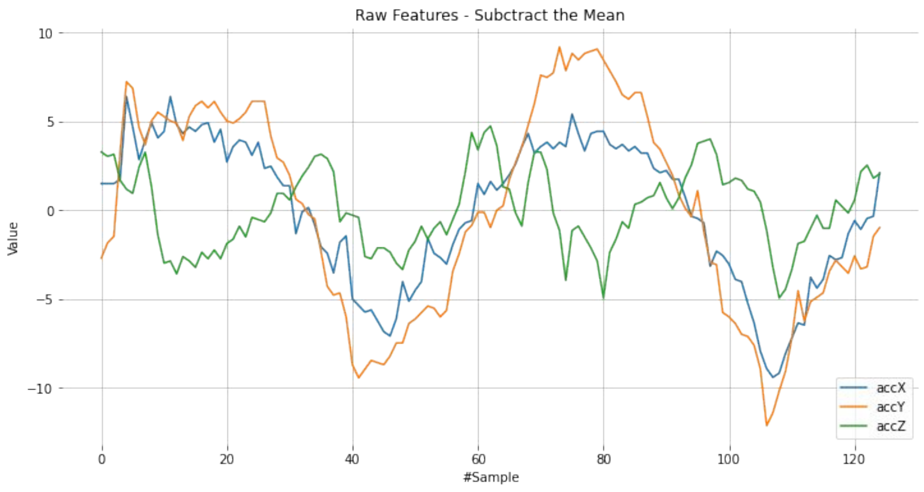
Here are some specific reasons why subtracting the mean can be useful:

- 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.

```
dtmean = [(sum(x)/len(x)) for x in sensors]
[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
```

```
accX = [(x - dtmean[0]) for x in accX]
accY = [(x - dtmean[1]) for x in accY]
accZ = [(x - dtmean[2]) for x in accZ]
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:

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

`NOTE that the RMS value is different for original raw data and after subtracting the mean`

```
# Using numpy and standartized data (subtracting mean)
rms = [np.sqrt(np.mean(np.square(x))) for x in sensors]
[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
```

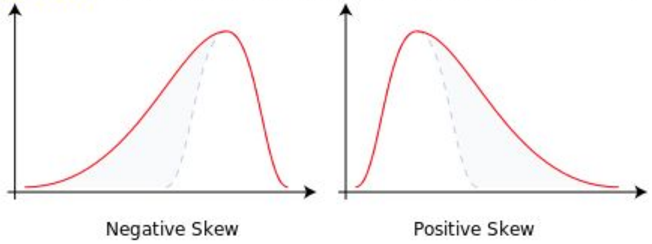
```
# Compare with Edge Impulse result features
features[0:N_feat:N_feat_axis]
```

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

Skewness and kurtosis calculation

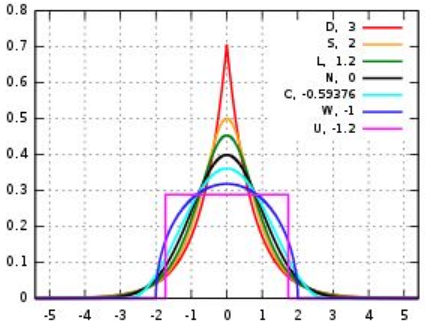
In statistics, skewness and kurtosis are two ways to measure the **shape of a distribution**.

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



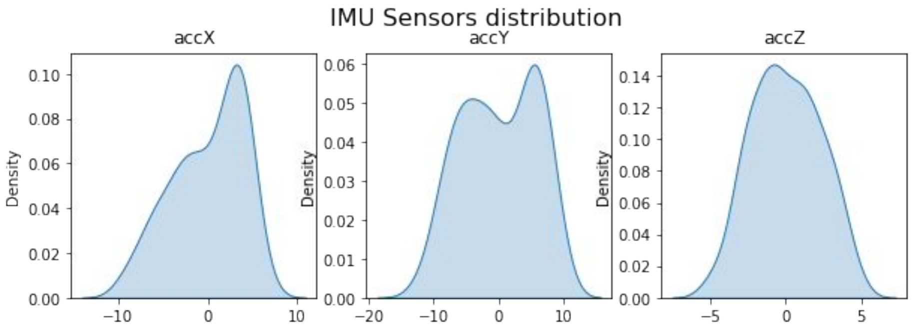
- A negative skew indicates that the tail is on the left side of the distribution, which extends towards more negative values.
- A positive skew indicates that the tail is on the right side of the distribution, which extends towards more positive values.
- A value of zero indicates that there is no skewness 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 playkurtic, 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`




```
skew = [skew(x, bias=False) for x in sensors]
[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
```

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

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

```
kurt = [kurtosis(x, bias=False) for x in sensors]
[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
```

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

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

Spectral features

```
[53] FFT_Lenght = 16
     N = 125
     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

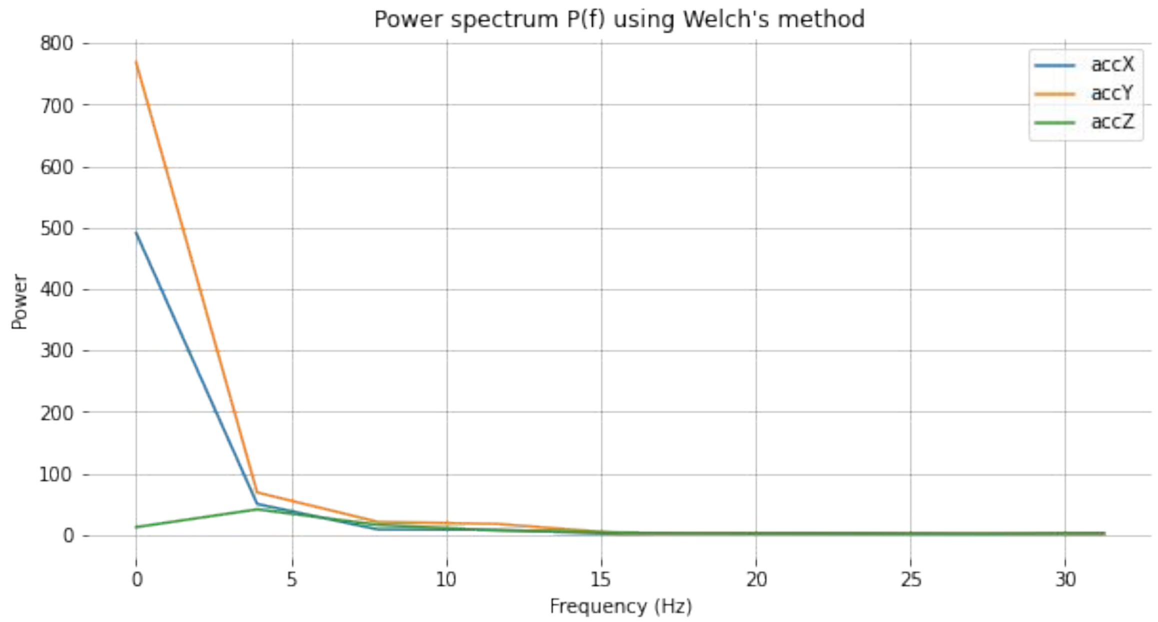
https://docs.scipy.org/doc/scipy-0.14.0/reference/generated/scipy.signal.welch.html

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.

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

```python
fax,Pax = welch_max_hold(accX, fs, FFT_Lenght, 0)
fay,Pay = welch_max_hold(accY, fs, FFT_Lenght, 0)
faz,Paz = welch_max_hold(accZ, fs, FFT_Lenght, 0)
```




```python
print("EI Processed features (accX): ")
print(features[3:N_feat_axis][0:])
print("\nCalculated features:")
[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:
50.424
8.7899
8.1934
1.5177
3.5343
3.3766
1.9297
1.5026
```

```python
print("EI Processed features (accY): ")
print(features[14:22][0:])
print("\nCalculated features:")
[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:
69.0591
21.228
17.778
2.7988
2.6348
1.9958
2.1018
2.5396
```

```python
print("EI Processed features (accZ): ")
print(features[25:][0:])
print("\nCalculated features:")
[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:
41.5583
16.427
7.1384
3.8892
2.4172
1.9212
1.8393
3.6103
```

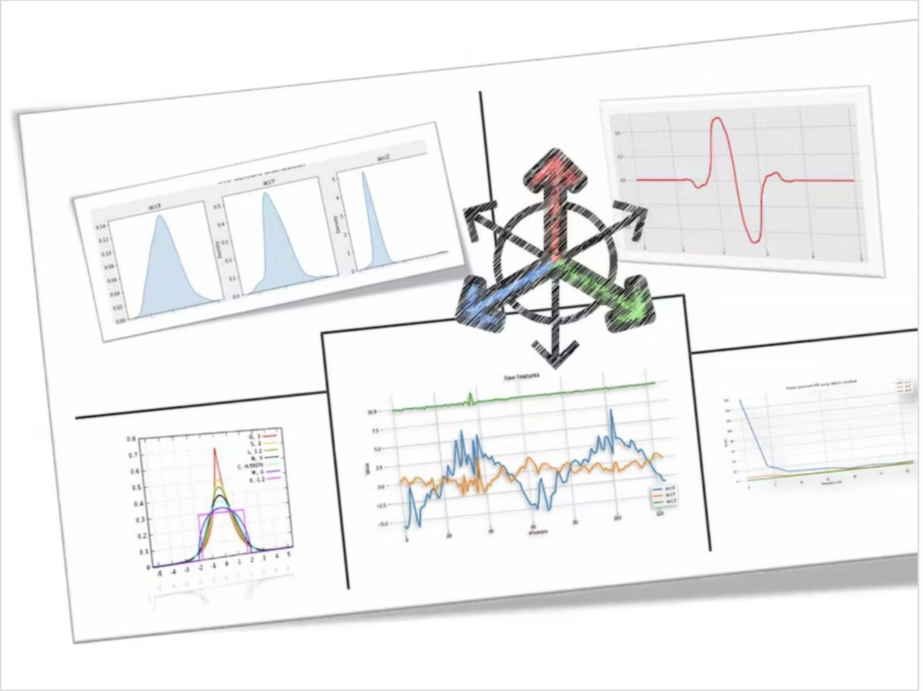
For a detailed tutorial on DSP, see the tutorial:

https://www.hackster.io/mjrobot/tinyml-under-the-hood-spectral-analysis-94676c

TinyML under the hood: Spectral Analysis

Extracting meaningful features from time-series signals. How does Edge Impulse Spectral Block work?

Intermediate | Full instructions provided | 4 hours | 738



Thanks