

Developing Machine-Learning Applications on the Raspberry Pi Pico

DAY 5: Deploying Machine-Learning Models and Next Steps

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THE SPEAKER



Jacob Beningo

Visit 'Lecturer Profile'

Beningo Embedded Group - President

Focus: Embedded Software Consulting

An independent consultant who specializes in the design of real-time, microcontroller based embedded software.

He has published two books:

- [Reusable Firmware Development](#)
- [MicroPython Projects](#)
- [Embedded Software Design \(https://bit.ly/3PZCtNO\)](https://bit.ly/3PZCtNO)

Writes a weekly blog for DesignNews.com focused on embedded system design techniques and challenges.

Visit www.beningo.com to learn more ...

Visit 'Lecturer Profile' in your console for more details.

Course Sessions

- Getting Started with the Raspberry Pi Pico and Machine Learning
- Machine-Learning Tools and Process Flow
- Collecting Sensor Data Using Edge Impulse
- Designing and Testing a Machine-Learning Model
- **Deploying Machine-Learning Models and Next Steps**

1

Live Classification

Live Classification

EDGE IMPULSE

Dashboard

Devices

Data sources

Data acquisition

Impulse design

- Create impulse
- Spectral features
- NN Classifier

EON Tuner

Retrain model

Live classification

Model testing

Performance calibration

Versioning

Deployment

Classify new data

Connect using WebUSB

Device ⓘ

PicoBoard

Sensor

Inertial

Sample length (ms.)

5000

Frequency

62.5Hz

Start sampling

Live Classification

```
beningo — node /usr/local/bin/edge-impulse-daemon — 80x24
[SER] Device is not connected to remote management API, will use daemon
[WS ] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS ] Connected to wss://remote-mgmt.edgeimpulse.com
[WS ] Device "PicoBoard" is now connected to project "Beningo-CEC-PicoML"
[WS ] Go to https://studio.edgeimpulse.com/studio/145881/acquisition/training to
build your machine learning model!
[WS ] Incoming sampling request {
  path: '/api/testing/data',
  label: 'testing',
  length: 5000,
  interval: 16,
  hmacKey: '653511e0ac563c154fdec263f0ee4c5e',
  sensor: 'Inertial'
}
[SER] Configured upload settings
[SER] Sampling started
[SER] Sampling done
[SER] Device not connected to WiFi directly, reading from buffer (bytes 0 - 9842
, expecting to read ~13122 bytes...
[SER] Reading from buffer OK
[SER] File is 9842 bytes after decoding
[SER] Uploading to https://ingestion.edgeimpulse.com/api/testing/data
[SER] Uploading to https://ingestion.edgeimpulse.com/api/testing/data OK
```

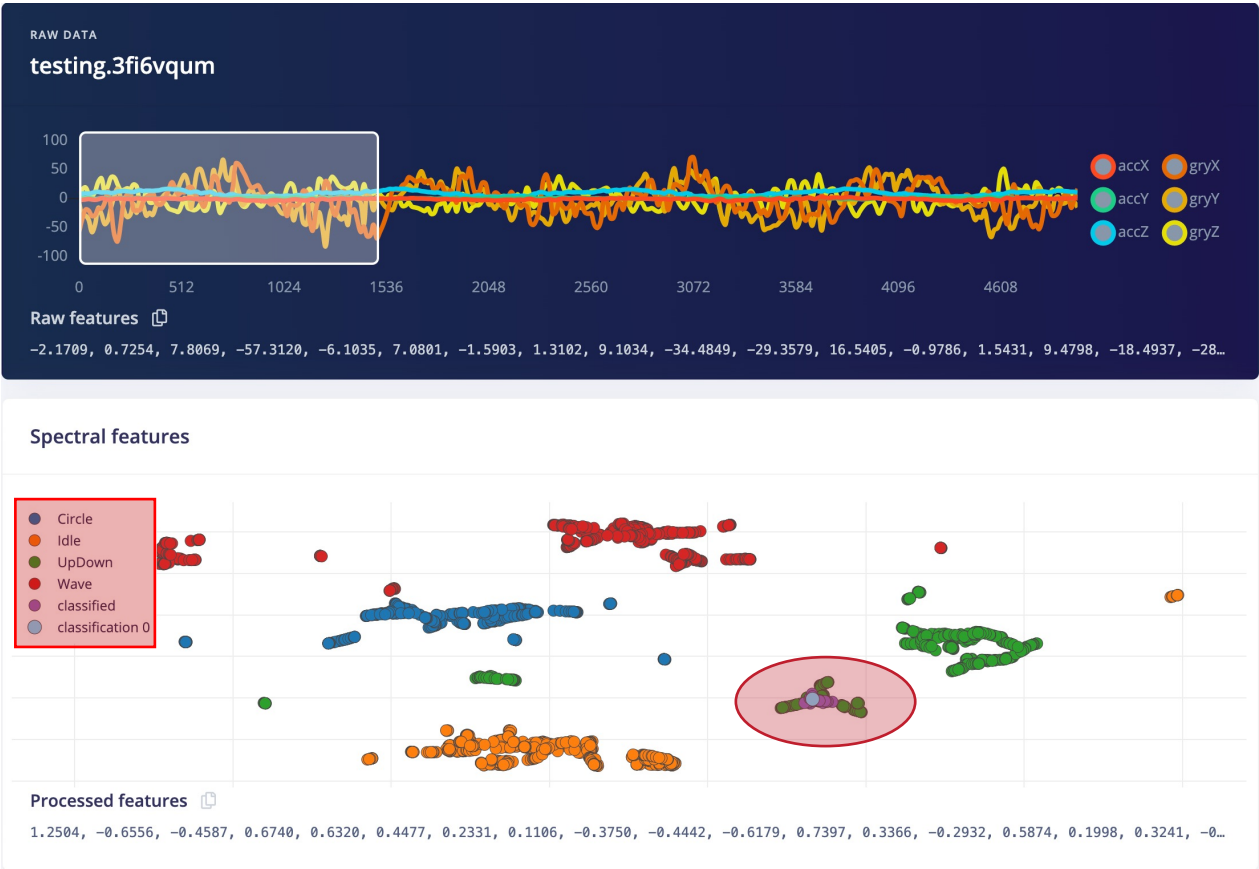
Summary

Name

Expected outcome

CATEGORY	COUNT
Circle	0
Idle	0
UpDown	38
Wave	0
uncertain	0

Live Classification



Live Classification

Summary

Name

testing.3fi7qo6u

Expected outcome

testing

CATEGORY	COUNT
Circle	38
Idle	0
UpDown	0
Wave	0
uncertain	0



Is live classification deploying the model to the Pico?

- 1) Yes
- 2) No
- 3) Not sure

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Deploying to the Pico

Deploying to the Pico

EDGE IMPULSE

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

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



Tensai Flow library



Simplicity Studio Component

Tip: Use Raspberry Pi to simplify data collection and then deploy model to desired target!

Deploying to the Pico

Build firmware

Get a ready-to-go binary for your development board that includes your impulse.



Arduino Nano 33 BLE Sense



Arduino Nicla Vision



Espressif ESP-EYE (ESP32)



Raspberry Pi RP2040



SiLabs xG24 Dev Kit



Infineon PSoC 62S2 Wi-Fi BT Pioneer Kit



Nordic Thingy:53



Linux boards



Custom firmware

Deploying to the Pico

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 target. Or, just click Build to use the currently selected options.



Enable EON™ Compiler

Same accuracy, up to 50% less memory. Open source.

☒

Available optimizations for NN Classifier

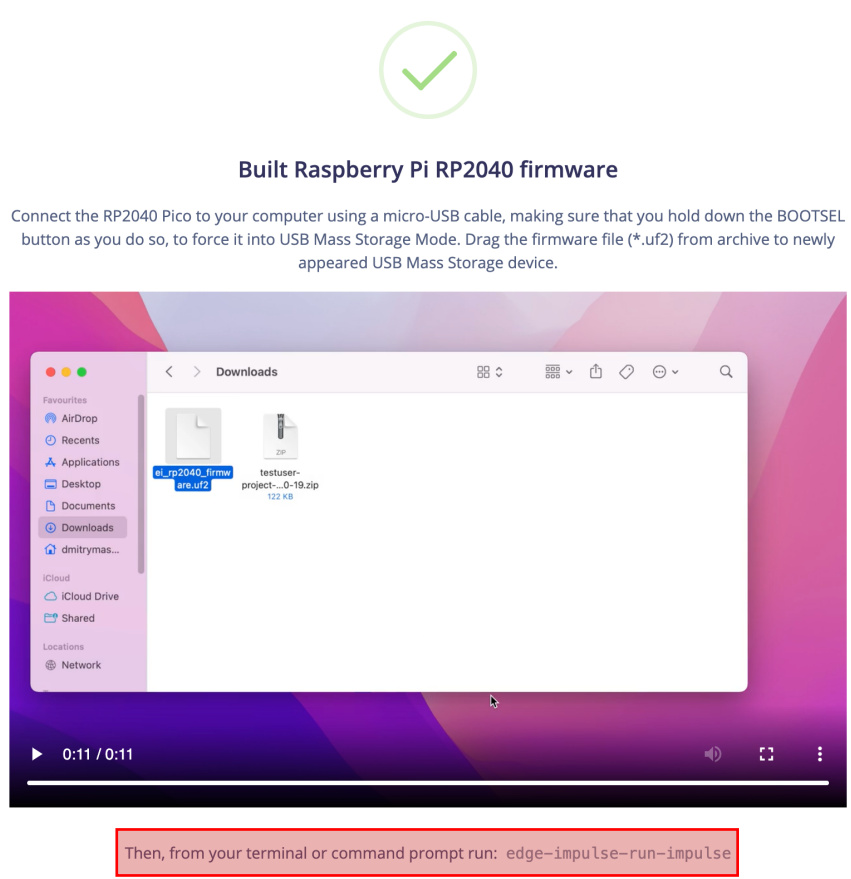
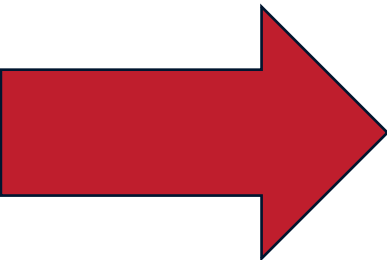
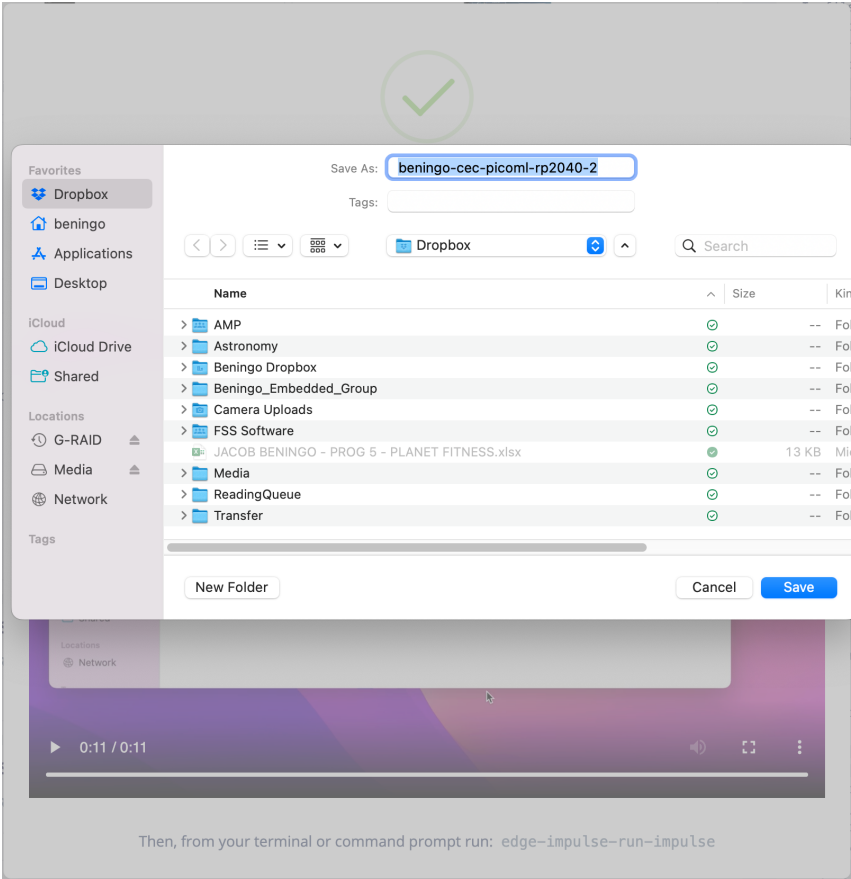
<div>Quantized (int8) ★</div> <div>Currently selected</div> <div>This optimization is recommended for best performance.</div>	RAM USAGE	LATENCY	<div>CONFUSION MATRIX ?</div> <table><tr><td>100</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>100</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>0</td><td>100</td><td>0</td><td>0</td></tr><tr><td>0.7</td><td>0</td><td>9.0</td><td>87.5</td><td>2.9</td></tr></table>					100	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0.7	0	9.0	87.5	2.9
	100	0						0	0	0																	
0	100	0	0	0																							
0	0	100	0	0																							
0.7	0	9.0	87.5	2.9																							
1.8K	1 ms																										
FLASH USAGE	ACCURACY																										
19.1K	-																										

<div>Unoptimized (float32)</div> <div>Click to select</div>	RAM USAGE	LATENCY	<div>CONFUSION MATRIX ?</div> <table><tr><td>100</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>100</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>0</td><td>100</td><td>0</td><td>0</td></tr><tr><td>0.7</td><td>0</td><td>9.0</td><td>87.5</td><td>2.9</td></tr></table>					100	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0.7	0	9.0	87.5	2.9
	100	0						0	0	0																	
0	100	0	0	0																							
0	0	100	0	0																							
0.7	0	9.0	87.5	2.9																							
2.0K	1 ms																										
FLASH USAGE	ACCURACY																										
19.8K	96.88%																										

Estimate for Raspberry Pi RP2040 (Cortex-M0+ 133MHz)

Build

Deploying to the Pico



What deployment mechanism is most interesting to you?

- Library
- Compiled firmware
- Other

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Running the Impulse

Running the Impulse

```
beningo — node /usr/local/bin/edge-impulse-run-impulse — 80x24
[WS ] Incoming sampling request {
  path: '/api/testing/data',
  label: 'testing',
  length: 5000,
  interval: 16,
  hmacKey: '653511e0ac563c154fdec263f0ee4c5e',
  sensor: 'Inertial'
}
[SER] Configured upload settings
[SER] Sampling started
[SER] Sampling done
[SER] Device not connected to WiFi directly, reading from buffer (bytes 0 - 9962
, expecting to read ~13282 bytes...
[SER] Reading from buffer OK
[SER] File is 9962 bytes after decoding
[SER] Uploading to https://ingestion.edgeimpulse.com/api/testing/data
[SER] Uploading to https://ingestion.edgeimpulse.com/api/testing/data OK
^C[SER] Received stop signal, stopping application... Press CTRL+C again to forc
e quit.
beningo@Jacobs-MacBook-Pro ~ % edge-impulse-run-impulse
Edge Impulse impulse runner v1.16.0
? Which device do you want to connect to?
  /dev/tty.usbserial-A700e6DP (FTDI)
> /dev/tty.usbmodem32141401 (Raspberry Pi)
```

```
beningo — -zsh — 83x24
[SER] Serial is connected, trying to read config...
[SER] Retrieved configuration
[SER] Device is running AT command version 1.7.0
[SER] Started inferencing, press CTRL+C to stop...
LSE
ERR: Failed to find sensor 'accX + accY + accZ + gryX + gryY + gryZ' in the sensor
list
> ^C[SER] Received stop signal, trying to stop inferencing... Press CTRL+C again to
force quit.
[SER] Failed to stop inferencing ENXIO: no such device or address, write
beningo@Jacobs-MacBook-Pro ~ % edge-impulse-run-impulse
Edge Impulse impulse runner v1.16.0
? Which device do you want to connect to? /dev/tty.usbmodem32141401 (Raspberry Pi)
[SER] Connecting to /dev/tty.usbmodem32141401
[SER] Serial is connected, trying to read config...
[SER] Retrieved configuration
[SER] Device is running AT command version 1.7.0
[SER] Started inferencing, press CTRL+C to stop...
LSE
ERR: Failed to find sensor 'accX + accY + accZ + gryX + gryY + gryZ' in the sensor
list
> ^C[SER] Received stop signal, trying to stop inferencing... Press CTRL+C again to
force quit.
beningo@Jacobs-MacBook-Pro ~ %
```


Running the Impulse

```
Starting inferencing in 2 seconds...
Sampling... Storing in file name: /fs/device-classification261
Tensor shape: 4
Predictions (DSP: 17 ms., Classification: 1 ms., Anomaly: 0 ms.):
  idle: 0.00004
  snake: 0.00012
  updown: 0.00009
  wave: 0.99976
  anomaly score: 0.032
Finished inferencing, raw data is stored in '/fs/device-classification261'. Use AT+UPL
```

How quickly will you pursue your next ML project?

- Next week
- Within the next 3 months
- Within the next 3 – 6 months
- More than 6 months from now
- I don't know

4 Going Further

Thank you for attending

Please consider the resources below:

- www.beningo.com
 - Blog, White Papers, Courses
 - Embedded Bytes Newsletter
 - <http://bit.ly/1BAHYXm>
 - Embedded Software Design
 - <https://bit.ly/3PZCtNO>



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