

IESTI01 – TinyML

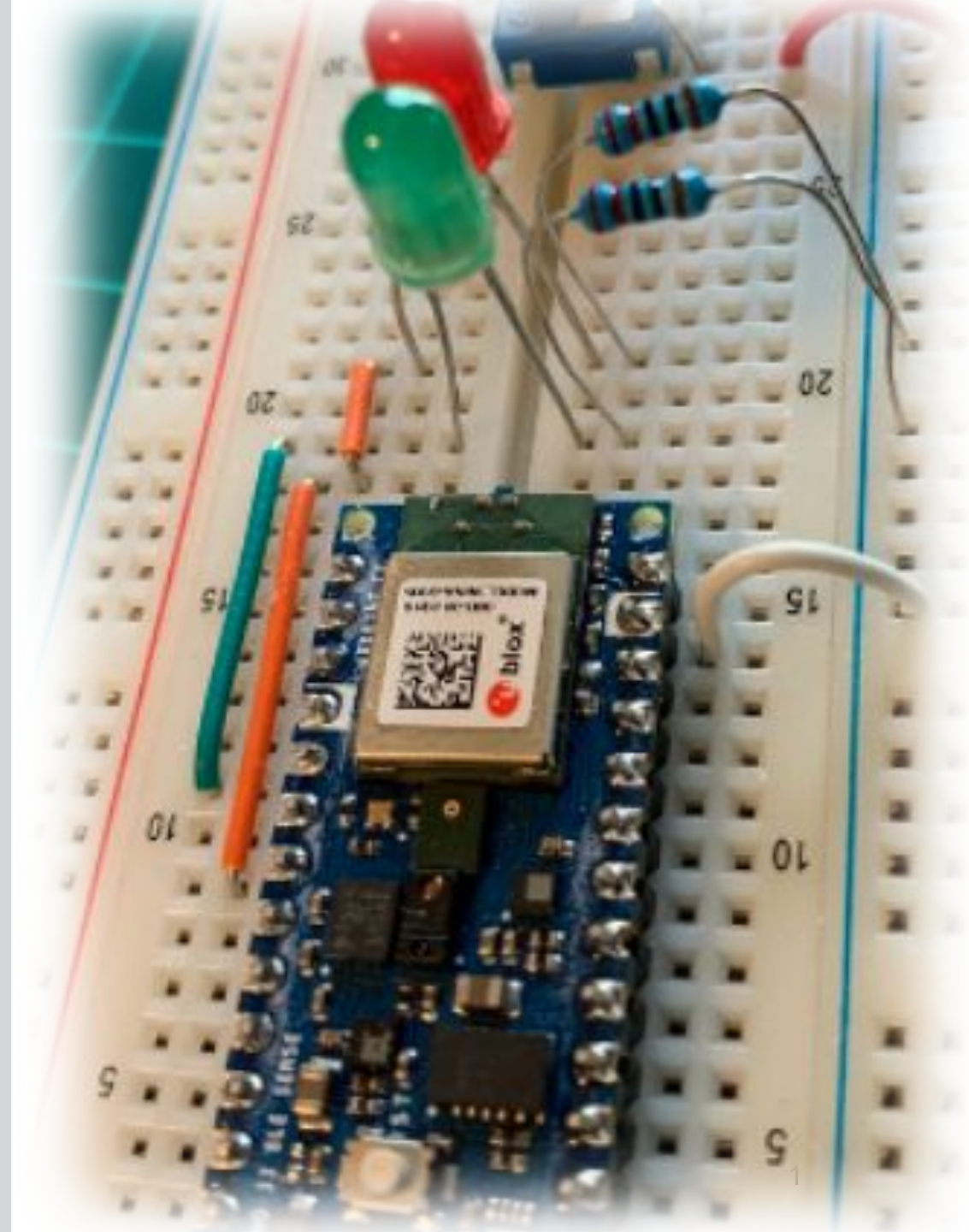
Embedded Machine Learning

24. KeyWord Spotting (KWS) Edge Impulse Studio



Prof. Marcelo Rovai

UNIFEI



Nano-33 BLE

Keyword Spotting (KWS) Project

<https://studio.edgeimpulse.com/public/38744/latest>



Select project - Edge Impulse

studio.edgeimpulse.com/studio/select-project

EDGE IMPULSE

MJRoBot (Marcelo Rovai)

Select project

?

Create project

Enter a name for your new project

IENTI01_Keyword_Spotting_project

Cancel

Create new project

NAME	
MJRoBot (Marcelo Rovai)	
MJRoBot (Marcelo Rovai)	
MJRoBot (Marcelo Rovai)	
MJRoBot (Marcelo Rovai)	
MJRoBot (Marcelo Rovai)	
MJRoBot (Marcelo Rovai) / Sound-Classification-Blender-Faucet	
MJRoBot (Marcelo Rovai) / oi_rovis_kws	
MJRoBot (Marcelo Rovai) / Eggs AI	
MJRoBot (Marcelo Rovai) / Accelerometer-Nano-Ble-IoT	

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Eta Compute ECM3532 AI Vision

OpenMV Cam H7 Plus

Himax WE-I Plus

Nordic Semi nRF52840 DK

Nordic Semi nRF5340 DK

SiLabs Thunderboard Sense 2

Sony's Spresense

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EDGE IMPULSE FOR LINUX

Edge Impulse for Linux

Linux Node.js SDK

Linux Go SDK

Linux C++ SDK

Linux Python SDK

Arduino Nano 33 BLE Sense

The Arduino Nano 33 BLE Sense is a tiny development board with a Cortex-M4 microcontroller, motion sensors, a microphone and BLE - and it's fully supported by Edge Impulse. You'll be able to sample raw data, build models, and deploy trained machine learning models directly from the studio. It's available for around 30 USD from [Arduino](#) and a wide range of distributors.

The Edge Impulse firmware for this development board is open source and hosted on GitHub: [edgeimpulse/firmware-arduino-nano-33-ble-sense](#).



Arduino Nano 33 BLE Sense

Installing dependencies

To set this device up in Edge Impulse, you will need to install the following software:

1. [Edge Impulse CLI](#).

2. [Arduino CLI](#).

• Here's an [instruction video for Windows](#).

• The [Arduino website](#) has instructions for macOS and Linux.

3. On Linux:

• GNU Screen: install for example via `sudo apt install screen`.

Note that the 1. Edge Impulse CLI is not necessary for Arduino Nano-33 if you use WebUSB.

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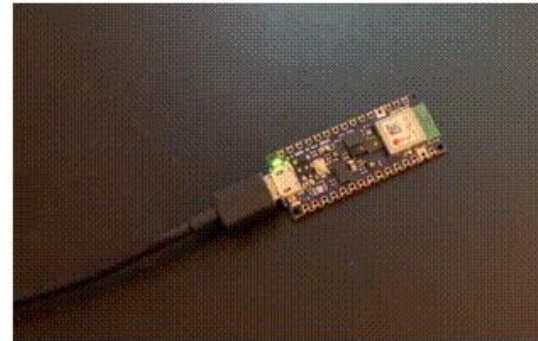
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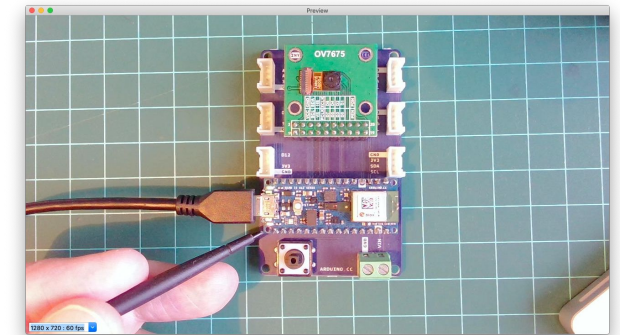


1. Connect the development board to your computer

Use a micro-USB cable to connect the development board to your computer. Then press RESET twice to launch into the bootloader. The on-board LED should start pulsating to indicate this.



Press RESET twice quickly to launch the bootloader on the Arduino Nano 33 BLE Sense.



2. Update the firmware

The development board does not come with the right firmware yet. To update the firmware:

1. [Download the latest Edge Impulse firmware](#), and unzip the file.
2. Open the flash script for your operating system (`flash_windows.bat` , `flash_mac.command` or `flash_linux.sh`) to flash the firmware.
3. Wait until flashing is complete, and press the RESET button once to launch the new firmware.

3. Setting keys

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Nordic Semi nRF5340 DK

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(preview)

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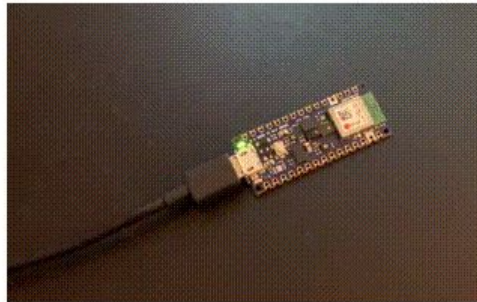
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**1. Connect the development board to your computer**

Use a micro-USB cable to connect the development board to your computer. Then press RESET twice to launch into the bootloader. The on-board LED should start pulsating to indicate this.

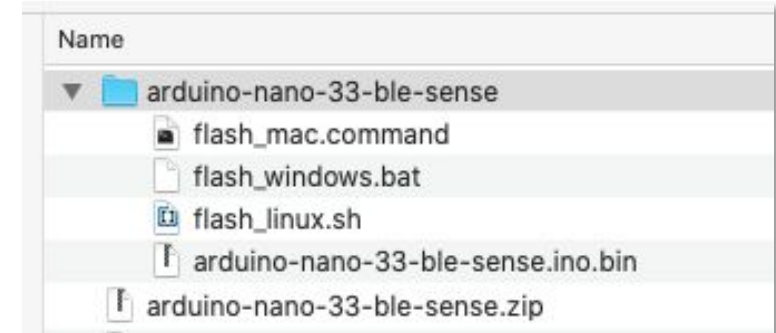
**1**

Press RESET twice quickly to launch the bootloader on the Arduino Nano 33 BLE Sense.

2. Update the firmware

The development board does not come with the right firmware yet. To update the firmware:

1. [Download the latest Edge Impulse firmware](#), and unzip the file.
2. Open the flash script for your operating system (`flash_windows.bat` , `flash_mac.command` or `flash_linux.sh`) to flash the firmware.
3. Wait until flashing is complete, and press the RESET button once to launch the new firmware.

3. Setting keys**2**

```
mjrovai — flash_mac.command — 124x43
Last login: Mon Jun 28 08:58:22 on ttys002
You have new mail.
/Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;

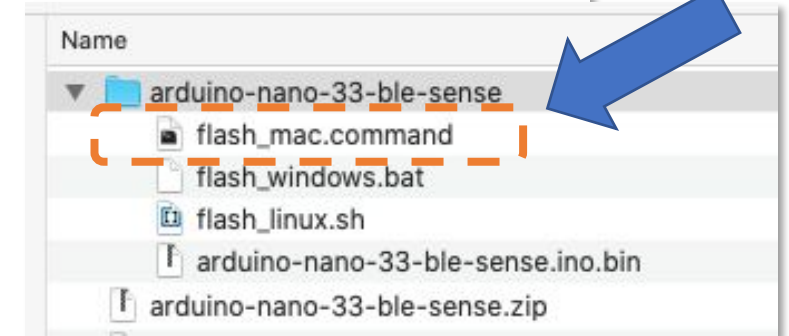
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
(base) MacBook-Pro-de-Marcelo:~ mjrovai$ /Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;
Finding Arduino Mbed core...
Finding Arduino Mbed OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK
Flashing board...
Device       : nRF52840-QIAA
Version      : Arduino Bootloader (SAM-BA extended) 2.0 [Arduino:IKXYZ]
Address      : 0x0
Pages        : 256
Page Size    : 4096 bytes
Total Size   : 1024KB
Planes       : 1
Lock Regions : 0
Locked       : none
Security     : false
Erase flash

Done in 0.001 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 20.533 seconds

Flashed your Arduino Nano 33 BLE development board.
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'
logout
Saving session...
...copying shared history...
...saving history...truncating history files...
...completed.

[Process completed]
```

1. Press Nano-33 Reset button Twice
2. With Nano-33 LED Flashing:



3. Nano-33 LED Stop Flashing

Windows 10

```

Prompt de Comando

Microsoft Windows [versão 10.0.19041.1052]
(c) Microsoft Corporation. Todos os direitos reservados.

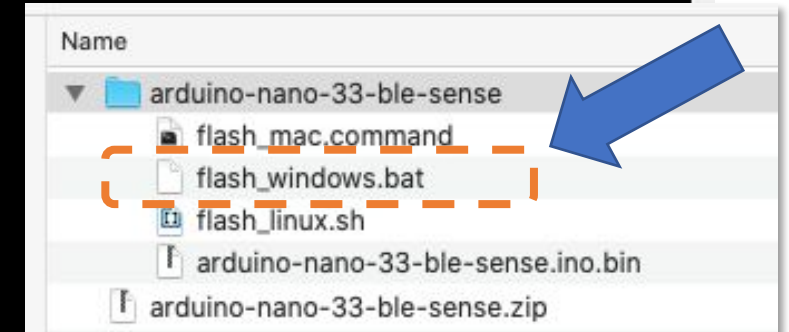
C:\Users\GUILH>arduino-cli
Arduino Command Line Interface (arduino-cli).

Usage:
  arduino-cli [command]

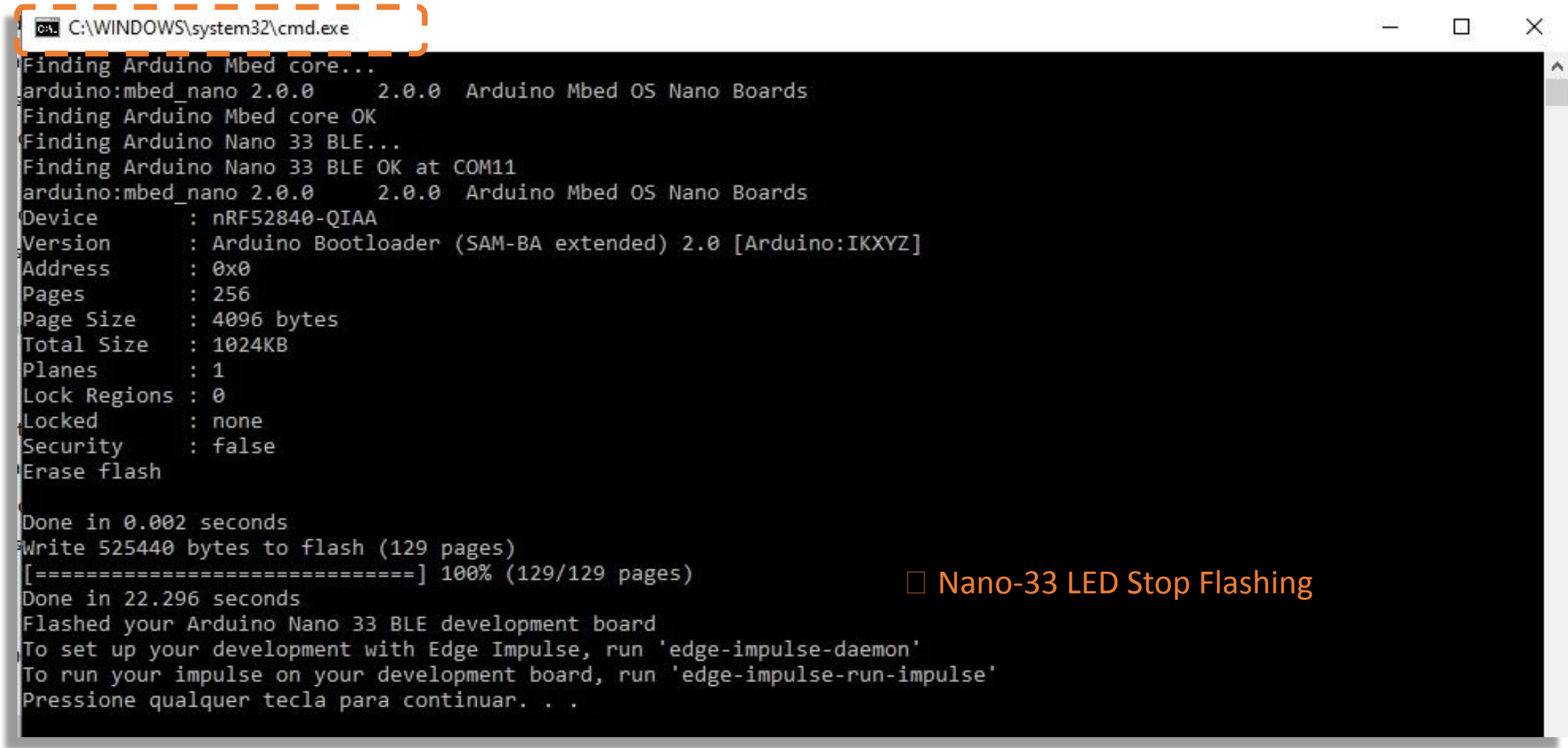
Examples:
  arduino-cli <command> [flags...]

Available Commands:
  board          Arduino board commands.
  burn-bootloader Upload the bootloader.
  cache          Arduino cache commands.
  compile        Compiles Arduino sketches.
  completion     Generates completion scripts
  config         Arduino configuration commands.
  core           Arduino core operations.
  daemon         Run as a daemon on port 50051
  debug          Debug Arduino sketches.
  help           Help about any command
  lib            Arduino commands about libraries.
  outdated       Lists cores and libraries that can be upgraded
  sketch         Arduino CLI sketch commands.
  update         Updates the index of cores and libraries
  upgrade        Upgrades installed cores and libraries.
  upload         Upload Arduino sketches.
  version        Shows version number of Arduino CLI.
```

1. Press Nano-33 Reset button Twice
2. With Nano-33 LED Flashing:



Windows 10



```
C:\WINDOWS\system32\cmd.exe
Finding Arduino Mbed core...
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Finding Arduino Mbed core OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK at COM11
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Device       : nRF52840-QIAA
Version      : Arduino Bootloader (SAM-BA extended) 2.0 [Arduino:IKXYZ]
Address      : 0x0
Pages        : 256
Page Size    : 4096 bytes
Total Size   : 1024KB
Planes       : 1
Lock Regions : 0
Locked       : none
Security     : false
Erase flash

Done in 0.002 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 22.296 seconds
Flashed your Arduino Nano 33 BLE development board
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'
Pressione qualquer tecla para continuar. . .
```

□ Nano-33 LED Stop Flashing

Follow this [video](#) to install the Arduino CLI on Windows 10 and add the 'arduino-cli' binary to your PATH. **This makes the CLI available from any location through the command prompt.**

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

- cu.Bluetooth-Incoming-Port
- cu.MALS
- cu.RovaisAirPods-Wirelessi
- cu.SOC
- Nano 33 BLE (cu.usbmodem144301) - Paired

Cancel Connect

Record new data 2

Connect using WebUSB

No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

Labels: 0

No data collected yet

Let's collect some data

1

Do not forget to connect the Nano with your PC serial via Arduino-CLI, before starting collecting data.

2

3

arduino-nano-33-ble-sense

- flash_mac.command
- flash_windows.bat
- flash_linux.sh
- arduino-nano-33-ble-sense.ino.bin
- arduino-nano-33-ble-sense.zip

OPTIONAL

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EDGE IMPULSE FOR LINUX

Installation

If WebUSB force browser to close, install Edge Impluse CLI

This Edge Impulse CLI is used to control local devices, act as a proxy to synchronise data for devices that don't have an internet connection, and to upload and convert local files. The CLI consists of seven tools:

- [edge-impulse-daemon](#) - configures devices over serial, and acts as a proxy for devices that do not have an IP connection.
- [edge-impulse-uploader](#) - allows uploading and signing local files.
- [edge-impulse-data-forwarder](#) - a very easy way to collect data from any device over a serial connection, and forward the data to Edge Impulse.
- [edge-impulse-run-impulse](#) - show the impulse running on your device.
- [edge-impulse-blocks](#) - create organizational transformation blocks.
- [eta-flash-tool](#) - to flash the Eta Compute ECM3532 AI Sensor.
- [himax-flash-tool](#) - to flash the Himax WE-I Plus.

Connect to devices without the CLI? Recent versions of Google Chrome and Microsoft Edge can connect directly to fully-supported development boards, without the CLI. See [this blog post](#) for more information.

WebUSB

Installation - macOS and Windows

1. Install [Python 3](#) on your host computer.
2. Install [Node.js](#) v14 or higher on your host computer.
 - For Windows users, install the **Additional Node.js tools** when prompted. You may skip this setup if you have Visual Studio 2015 or more.
3. Install the CLI tools via:

```
npm install -g edge-impulse-cli --force
```

You should now have the tools available in your PATH.

Installation - Linux/Ubuntu and Raspbian OS

Edge Impulse CLI

- edge-impulse-daemon --clean
- Enter EI Studio credentials
- Select Project name
- Give a name for your device (optional)

```
mjrovai — node • sudo — 80x40
Last login: Sun Jul  4 12:18:24 on ttys001
You have new mail.

The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
[(base) MacBook-Pro-de-Marcelo:~ mjrovai]$ sudo edge-impulse-daemon --clean
[Password:
Edge Impulse serial daemon v1.12.2
[?] What is your user name or e-mail address (edgeimpulse.com)? rovai@mjrobot.org
[?] What is your password? [hidden]
Endpoints:
  Websocket: wss://remote-mgmt.edgeimpulse.com
  API:       https://studio.edgeimpulse.com/v1
  Ingestion: https://ingestion.edgeimpulse.com

[SER] Connecting to /dev/tty.usbmodem144301
[SER] Serial is connected, trying to read config...
[SER] Clearing configuration
[SER] Clearing configuration OK
[SER] Retrieved configuration
[SER] Device is running AT command version 1.3.0

? To which project do you want to connect this device? MJRoBot (Marcelo Rovai)
  IESTI01 Keyword Spotting project
Setting upload host in device... OK
Configuring remote management settings... OK
Configuring API key in device... OK
Configuring HMAC key in device... OK
[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
[?] What name do you want to give this device? nano
[WS ] Device "nano" is now connected to project "IESTI01_Keyword_Spotting_project"
[WS ] Go to https://studio.edgeimpulse.com/studio/38744/acquisition/training to
build your machine learning model!
```

Devices - IESTI01_Keyword_Sp

studio.edgeimpulse.com/studio/38744/devices

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DEVICES (IESTI01_KEYWORD_SPOTTING_PROJECT)

MJRoBot (Marcelo Rovai)

Your devices

+ Connect a new device

These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.

NAME	ID	TYPE	SENSORS	REMOT...	LAST SEEN
 nano	36:17:55:F9:70:F7	ARDUINO_NANO33BLE	Built-in accelerometer, Built-i...		Today, 12:21:41

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DATA ACQUISITION (IESTI01_KEYWORD_SPOTTING_PROJECT)

Training data

Test data

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

DATA COLLECTED

-

LABELS

0

Collected data

No data collected yet

Let's collect some data

Record new data

Device ?

36:17:55:F9:70:F7

Label

unifei

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

Click on a sample to load...

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DATA COLLECTED
10s

LABELS
1

Collected data

SAMPLE NAME

LABEL

ADDED

LENGTH

unifei.29js37tq

unifei

Today, 18:22:34

10s

<

1

>

Record new data

Device ?

36:17:55:F9:70:F7

Label

unifei

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

unifei.29js37tq

10000

8000

6000

4000

2000

0

-2000

-4000

-6000

-8000

-10000

0

1051

2103

3154

4206

5258

6309

7361

8413

9464

audio

0:10 / 0:10

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DATA COLLECTED
10s

LABELS
1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
unifei.29js37tq	unifei	Today, 18:22:34	10s

Rename

Edit label

Move to test set

Crop sample

Split sample

Download

Download (.WAV)

Delete

Record new data

Device

36:17:55:F9:70:F7

Label

unifei

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

unifei.29js37tq

10000

8000

6000

4000

2000

0

-2000

-4000

-6000

-8000

-10000

0

1051

2103

3154

4206

5258

6309

7361

8413

9464

audio

0:10 / 0:10

https://studio.edgeimpulse.com/studio/38744/acquisition/training?page=1#

EDGE IMPULSE

DATA COLLECTED 10s

LABELS 1

Record new data

Device

Collected data

Split sample 'unifei.29js37tq'

+ Add Segment

Set segment length (ms.): 1000 Apply

1500
1000
500
0
-500
-1000
-1500

0 1013 2027 3041 4054 5068 6082 7096 8109 9123

audio

0:00 / 0:00

Cancel

Shift samples

Split

Sample length (ms.) 10000

Frequency 16000Hz

Start sampling

0:10 / 0:10

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DATA COLLECTED
6s

LABELS
1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	
unifei.29js37tq.s6	unifei	Today, 18:28:22	1s	
unifei.29js37tq.s5	unifei	Today, 18:28:22	1s	
unifei.29js37tq.s4	unifei	Today, 18:28:22	1s	
unifei.29js37tq.s3	unifei	Today, 18:28:22	1s	
unifei.29js37tq.s2	unifei	Today, 18:28:22	1s	
unifei.29js37tq.s1	unifei	Today, 18:28:22	1s	

<

1

>

Record new data

Device

36:17:55:F9:70:F7

Label

unifei

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

unifei.29js37tq.s6

10000

8000

6000

4000

2000

0

-2000

-4000

-6000

-8000

-10000

0

104

208

312

416

520

624

728

832

936

audio

0:00 / 0:00

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Training data

Test data

Did you know?

You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

DATA COLLECTED

1m 37s

LABELS

1

Collected data

Delete selected (2)

Edit labels (2)

Move to test set (2)

	SAMPLE NAME	LABEL	ADDED	LENGTH	
☒	unifei.29lq8ugs	unifei	Today, 12:29:12	10s	⋮
☒	unifei.29lq80v9	unifei	Today, 12:28:42	10s	⋮
☐	unifei.29lq760p	unifei	Today, 12:28:14	10s	⋮
☐	unifei.29lq6a2p	unifei	Today, 12:27:46	10s	⋮
☐	unifei.29lq5fvd	unifei	Today, 12:27:19	10s	⋮
☐	unifei.29lq4m8v	unifei	Today, 12:26:53	10s	⋮
☐	unifei.29lq3t92	unifei	Today, 12:26:27	10s	⋮
☐	unifei.29lq286o	unifei	Today, 12:25:33	10s	⋮
☐	unifei.29jskg44	unifei	Yesterday, 18:31...	10s	⋮
☐	unifei.29js37tq.s6	unifei	Yesterday, 18:28...	1s	⋮

Record new data

Connect using WebUSB

Device

nano

Label

unifei

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

Click on a sample to load...

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DATA COLLECTED
4m 37s

LABELS
3

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	
silence.29lss69b.s4	silence	Today, 13:24:24	1s	
silence.29lss69b.s3	silence	Today, 13:24:24	1s	
silence.29lss69b.s2	silence	Today, 13:24:24	1s	
silence.29lss69b.s1	silence	Today, 13:24:24	1s	
silence.29lss69b.s9	silence	Today, 13:24:12	1s	
silence.29lss69b.s8	silence	Today, 13:24:12	1s	
silence.29lss69b.s7	silence	Today, 13:24:12	1s	
silence.29lss69b.s6	silence	Today, 13:24:12	1s	
silence.29lss69b.s5	silence	Today, 13:24:12	1s	
silence.29lss69b.s4	silence	Today, 13:24:12	1s	
silence.29lss69b.s3	silence	Today, 13:24:12	1s	
silence.29lss69b.s2	silence	Today, 13:24:12	1s	

<

1

2

3

4

5

6

7

...

24

>

Record new data

Connect using WebUSB

Device

nano

Label

silence

Sample length (ms.)

10000

Sensor

Built-in microphone

Frequency

16000Hz

Start sampling

RAW DATA

silence.29lt3rm7.s2

10000

8000

6000

4000

2000

0

-2000

-4000

-6000

-8000

-10000

0

104

208

312

416

520

624

728

832

936

audio

0:00 / 0:00

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CREATE IMPULSE (IESTI01_KEYWORD_SPOTTING_PROJECT)

MJRoBot (Marcelo Rovai)

An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

Time series data

Axes
audio

Window size
1000 ms.

Window increase
500 ms.

Zero-pad data

Add a processing block

Add a learning block

Output features

Save Impulse

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Create impulse

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CREATE IMPULSE (IESTI01_Keyw

An impulse tak

Time series data

Axes
audio

Window size

Window increase

Zero-pad data

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Add a processing block

DESCRIPTION	AUTHOR	RECOMMENDED	
Audio (MFCC) Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice.	Edgelmulse Inc.	★	Add
Spectrogram EXPERIMENTAL Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.	Edgelmulse Inc.	★	Add
Flatten Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.	Edgelmulse Inc.		Add
Image Preprocess and normalize image data, and optionally reduce the color depth.	Edgelmulse Inc.		Add
Audio (MFE) EXPERIMENTAL Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio.	Edgelmulse Inc.		Add
Spectral Analysis Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time.	Edgelmulse Inc.		Add
Audio (Syntiant) EXPERIMENTAL Syntiant only. Compute log Mel-filterbank energy features from an audio signal.	Edgelmulse Inc.		Add
Raw Data Use data without pre-processing. Useful if you want to use deep learning to learn features.	Edgelmulse Inc.		Add

MJRoBot (Marcelo Rovai)

Output features

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An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

Time series data

axes
audio

Window size
1000 ms.

Window increase
500 ms.

Zero-pad data

Audio (MFCC)

Name
MFCC

Input axes
☒ audio

Neural Network (Keras)

Name
NN Classifier

Input features
☒ MFCC

Output features
3 (iesti, silence, unifei)

Output features
3 (iesti, silence, unifei)

Save Impulse

Add a processing block

Add a learning block

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MFCC (IESTI01_KEYWORD_SPOTTING_PROJECT)

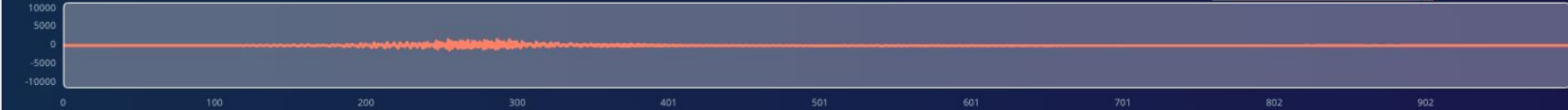
ParametersGenerate features

Raw data

0:01 / 0:01

lesti.29lr1dq7.s5 (lesti)

audio



Raw features

-3, -5, -4, -4, -5, -5, -4, -7, -6, -6, -6, -7, -7, -7, -7, -7, -7, -8, -6, -6, -6, -7, -8, -6, -7, -7, -8, -8, -

Parameters

Mel Frequency Cepstral Coefficients

Number of coefficients

13

Frame length

0.02

Frame stride

0.02

Filter number

32

FFT length

256

Window size

101

Low frequency

300

High frequency

Click to set

Pre-emphasis

Coefficient

0.98

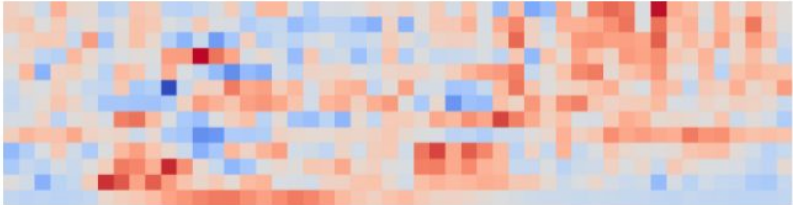
Shift

1

Save parameters

DSP result

Cepstral Coefficients



Processed features

-0.9190, -0.2986, -1.4022, -1.8351, 0.2244, -0.5532, -0.8771, -0.8118, -0.4297, -0.0630, -0.4094, 0.2915, 0.1755, -1.0499, -0.6244, -0.8391, -1.1...

On-device performance

PROCESSING TIME

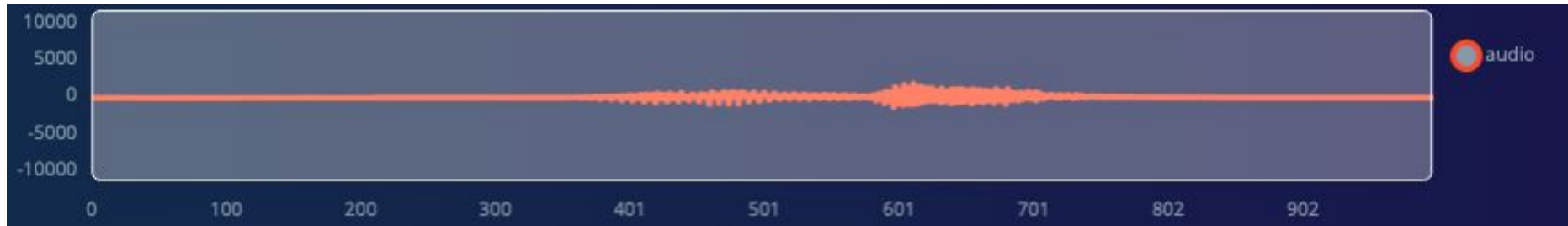
217 ms.

PEAK RAM USAGE

17 KB

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Raw data

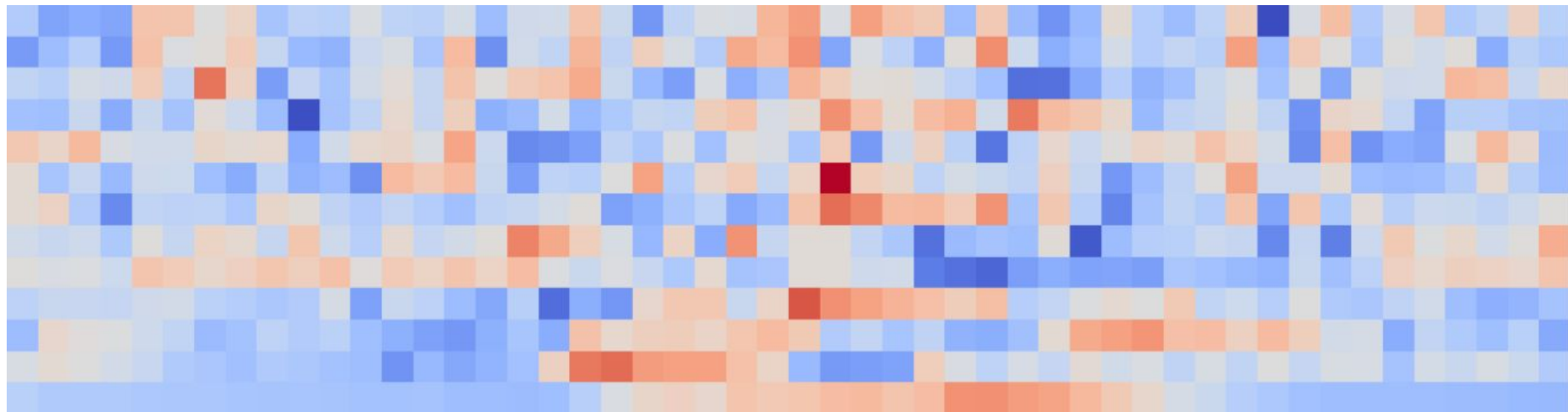


1 second of Sound raw data



MFCC

13 Coef.



50 slots

KWS Classifier Project

Audio Raw Data Analysis

[IESTI01_Audio_Raw_Data_Analisys.ipynb](#)



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MFCC (IESTI01_KEYWORD_SPOTTING_PROJECT)

ParametersGenerate features

Training set

Data in training set4m 37s

Classes3 (iesti, silence, unifei)

Window length1000 ms.

Window increase500 ms.

Training windows253

Generate features

Feature generation output

Sun Jul 4 17:29:51 2021 Construct embedding

completed 0 / 500 epochs

completed 50 / 500 epochs

completed 100 / 500 epochs

completed 150 / 500 epochs

completed 200 / 500 epochs

completed 250 / 500 epochs

completed 300 / 500 epochs

completed 350 / 500 epochs

completed 400 / 500 epochs

completed 450 / 500 epochs

Sun Jul 4 17:29:54 2021 Finished embedding

Reducing dimensions for visualizations OK

Job completed

Feature explorer (253 samples)

X AxisVisualization layer 1

Y AxisVisualization layer 2

Z AxisVisualization layer 3

iesti

silence

unifei

On-device performance

PROCESSING TIME217 ms.

PEAK RAM USAGE17 KB

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NN CLASSIFIER (IESTI01_KEYWORD_SPOTTING_PROJECT)

#1 Click to set a description for this version

Neural Network settings

Training settings

Number of training cycles 100

Learning rate 0.005

Minimum confidence rating 0.60

Audio training options

Data augmentation

Neural network architecture

Architecture presets 1D Convolutional (Default) 2D Convolutional

Input layer (650 features)

Reshape layer (13 columns)

1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)

Dropout (rate 0.25)

1D conv / pool layer (16 neurons, 3 kernel size, 1 layer)

Dropout (rate 0.25)

Flatten layer

Add an extra layer

Output layer (3 features)

Start training

Training output

Saving best performing model...
Converting TensorFlow Lite float32 model...
Converting TensorFlow Lite int8 quantized model with float32 input and output...
Converting TensorFlow Lite int8 quantized model with int8 input and output...
Calculating performance metrics...
Profiling float32 model...
Profiling float32 model (tf-lite)...
Profiling float32 model (EON)...
Profiling int8 model...
Profiling int8 model (tf-lite)...
Profiling int8 model (EON)...
Model training complete
Job completed

Model

Model version: Quantized (int8)

Last training performance (validation set)

ACCURACY 100.0%
LOSS 0.02

Confusion matrix (validation set)

	IESTI	SILENCE	UNIFEI
IESTI	100%	0%	0%
SILENCE	0%	100%	0%
UNIFEI	0%	0%	100%
F1 SCORE	1.00	1.00	1.00

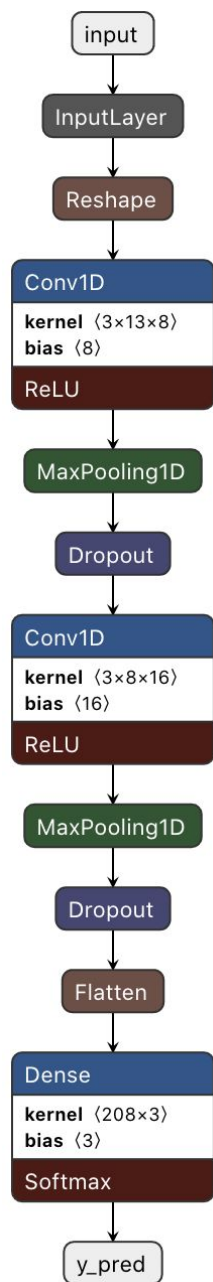
Feature explorer (full training set)

iesti - correct
silence - correct
unifei - correct

Visualization layer 3

Visualization layer 2

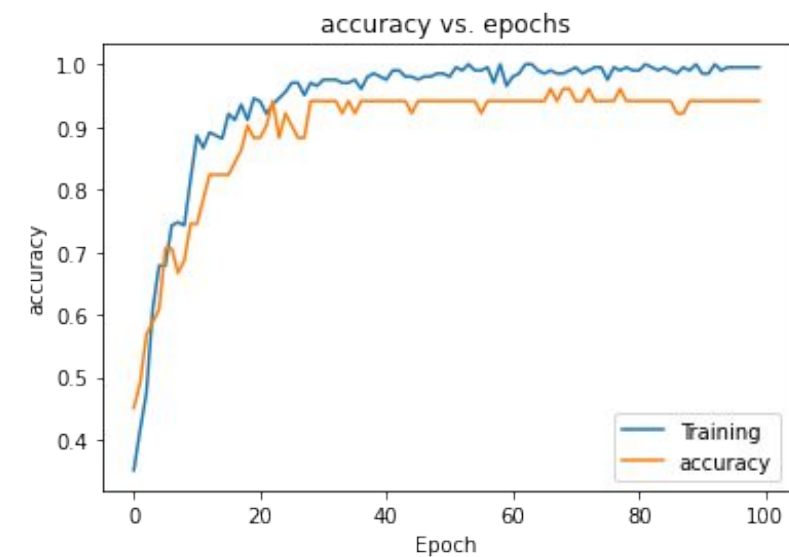
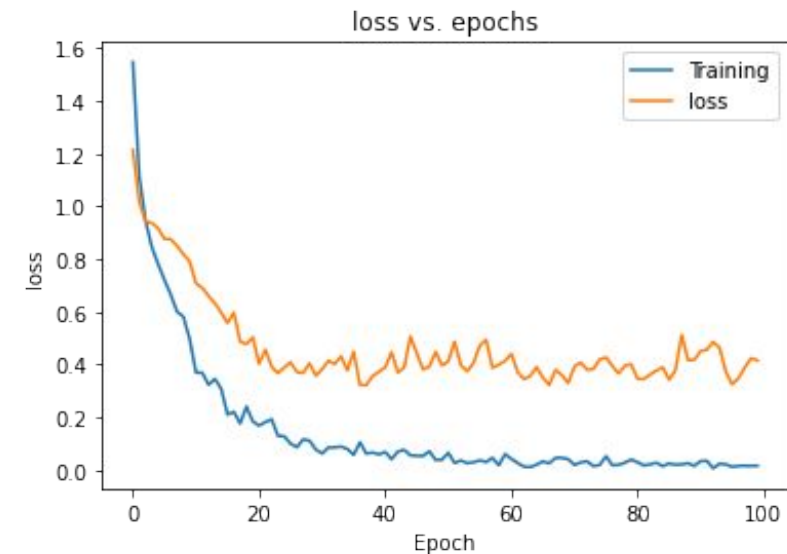
Visualization layer 1



Model: "sequential"

Layer (type)	Output Shape	Param #
reshape (Reshape)	(None, 50, 13)	0
conv1d (Conv1D)	(None, 50, 8)	320
max_pooling1d (MaxPooling1D)	(None, 25, 8)	0
dropout (Dropout)	(None, 25, 8)	0
conv1d_1 (Conv1D)	(None, 25, 16)	400
max_pooling1d_1 (MaxPooling1D)	(None, 13, 16)	0
dropout_1 (Dropout)	(None, 13, 16)	0
flatten (Flatten)	(None, 208)	0
y_pred (Dense)	(None, 3)	627

Total params: 1,347
Trainable params: 1,347
Non-trainable params: 0



Model testing - IESTI01_Keywo

studio.edgeimpulse.com/studio/38744/validation

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MODEL TESTING (IESTI01_KEYWORD_SPOTTING_PROJECT)

This lists all test data. You can manage this data through Data acquisition.

Test data

Classify all

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

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
testing.29lufkik	silence	10s	84%	16 silence, 1 iesti, 1 unifei, 1 unc...
testing.29lu6v0r	iesti	10s	52%	10 iesti, 4 silence, 3 unifei, 2 unc...
testing.29lu1guk	unifei	10s	57%	11 unifei, 3 iesti, 3 silence, 2 unc...
silence.29lspi7j.s10	silence	1s	100%	1 silence
silence.29lspi7j.s9	silence	1s	100%	1 silence
silence.29lspi7j.s8	silence	1s	100%	1 silence
silence.29lspi7j.s7	silence	1s	100%	1 silence
silence.29lspi7j.s6	silence	1s	100%	1 silence
silence.29lspi7j.s5	silence	1s	100%	1 silence
silence.29lspi7j.s4	silence	1s	100%	1 silence
silence.29lspi7j.s3	silence	1s	100%	1 silence
silence.29lspi7j.s2	silence	1s	100%	1 silence
silence.29lspi7j.s1	silence	1s	100%	1 silence
silence.29lt4rkv.s9	silence	1s	100%	1 silence
silence.29lt4rkv.s8	silence	1s	100%	1 silence
silence.29lt4rkv.s7	silence	1s	100%	1 silence
silence.29lt4rkv.s6	silence	1s	100%	1 silence

Model testing output

Created features

Generating features for MFCC OK

Classifying data for NN Classifier...

Copying features from DSP block...

Copying features from DSP block OK

Classifying data for float32 model...

Scheduling job in cluster...

Job started

Classifying data for NN Classifier OK

Job completed

Model testing results

ACCURACY 80.56%

	IESTI	SILENCE	UNIFEI	UNCERTAIN
IESTI	69.7%	12.1%	12.1%	6.1%
SILENCE	2.6%	92.1%	2.6%	2.6%
UNIFEI	8.1%	8.1%	78.4%	5.4%

Feature explorer

iesti - correct

silence - correct

unifei - correct

iesti - incorrect

silence - incorrect

unifei - incorrect

Visualization layer 3

Visualization layer 2

Visualization layer 1

31

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Eta Compute ECM3532 AI Vision

Nordic nRF52840 DK + IKS02A1

Linux boards

SiLabs Thunderboard Sense 2

Nordic nRF5340 DK + IKS02A1

Himax WE-1 Plus

Sony's Spresense

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

Quantized (int8) ★

Currently selected

This optimization is recommended for best performance.

RAM USAGE

4.4K

LATENCY

4 ms

CONFUSION MATRIX

69.7	12.1	12.1	6.1
2.6	94.7	2.6	0
8.1	8.1	78.4	5.4

FLASH USAGE

30.2K

ACCURACY

81.48%

Unoptimized (float32)

Click to select

RAM USAGE

8.0K

LATENCY

18 ms

CONFUSION MATRIX

69.7	12.1	12.1	6.1
2.6	92.1	2.6	2.6
8.1	8.1	78.4	5.4

FLASH USAGE

33.2K

ACCURACY

80.56%

Estimate for Cortex-M4F 80MHz (ST IoT Discovery Kit)

Build

Build output

Creating job... OK (ID: 1851368)

Generating features for MFCC...

Not generating new features: features already generated and no options or files have changed.

Generating features for MFCC OK

Classifying data for NN Classifier...

Copying features from DSP block...

Copying features from DSP block OK

Classifying data for float32 model...

Classifying data for int8 model...

Scheduling job in cluster...

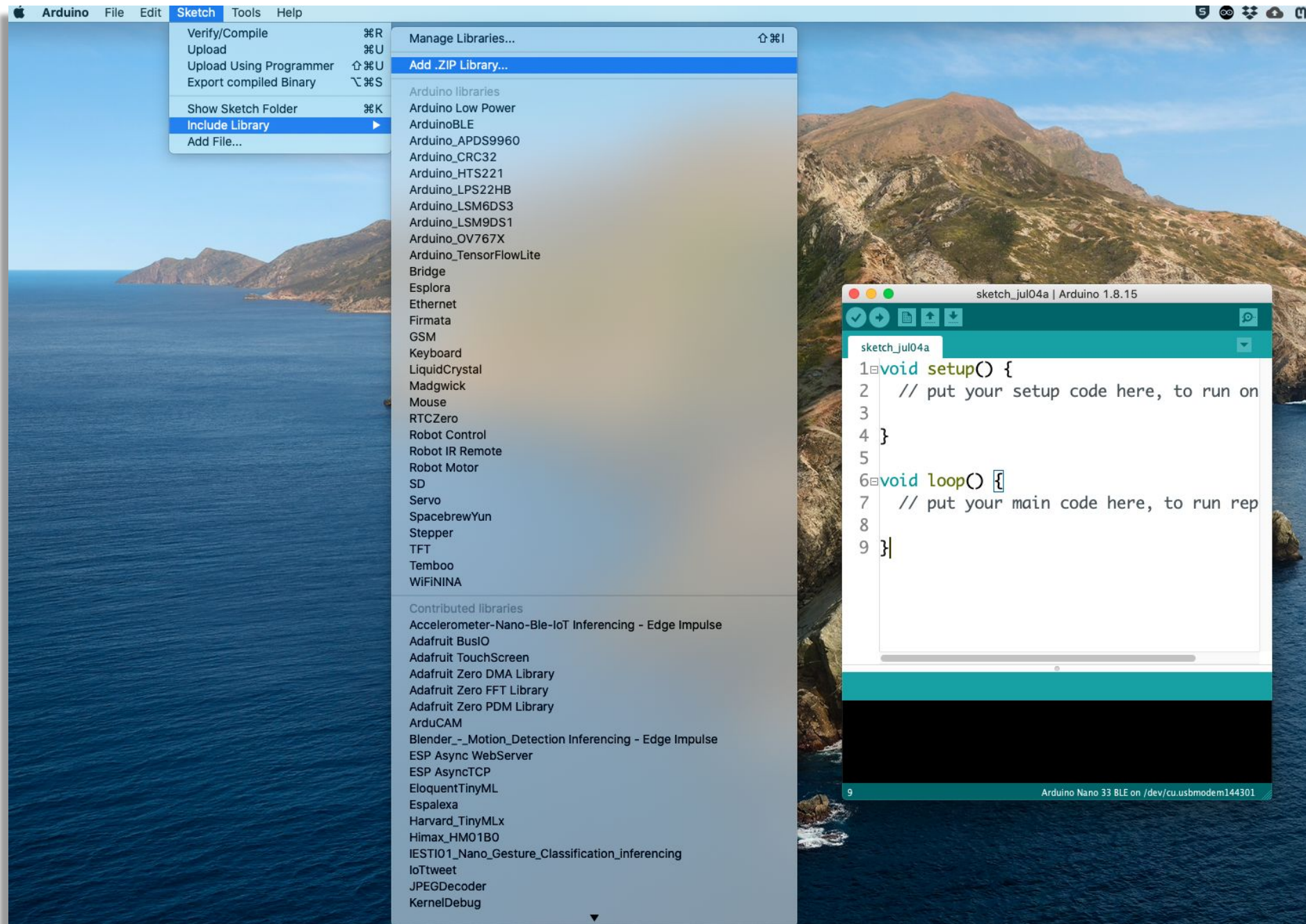
Scheduling job in cluster...

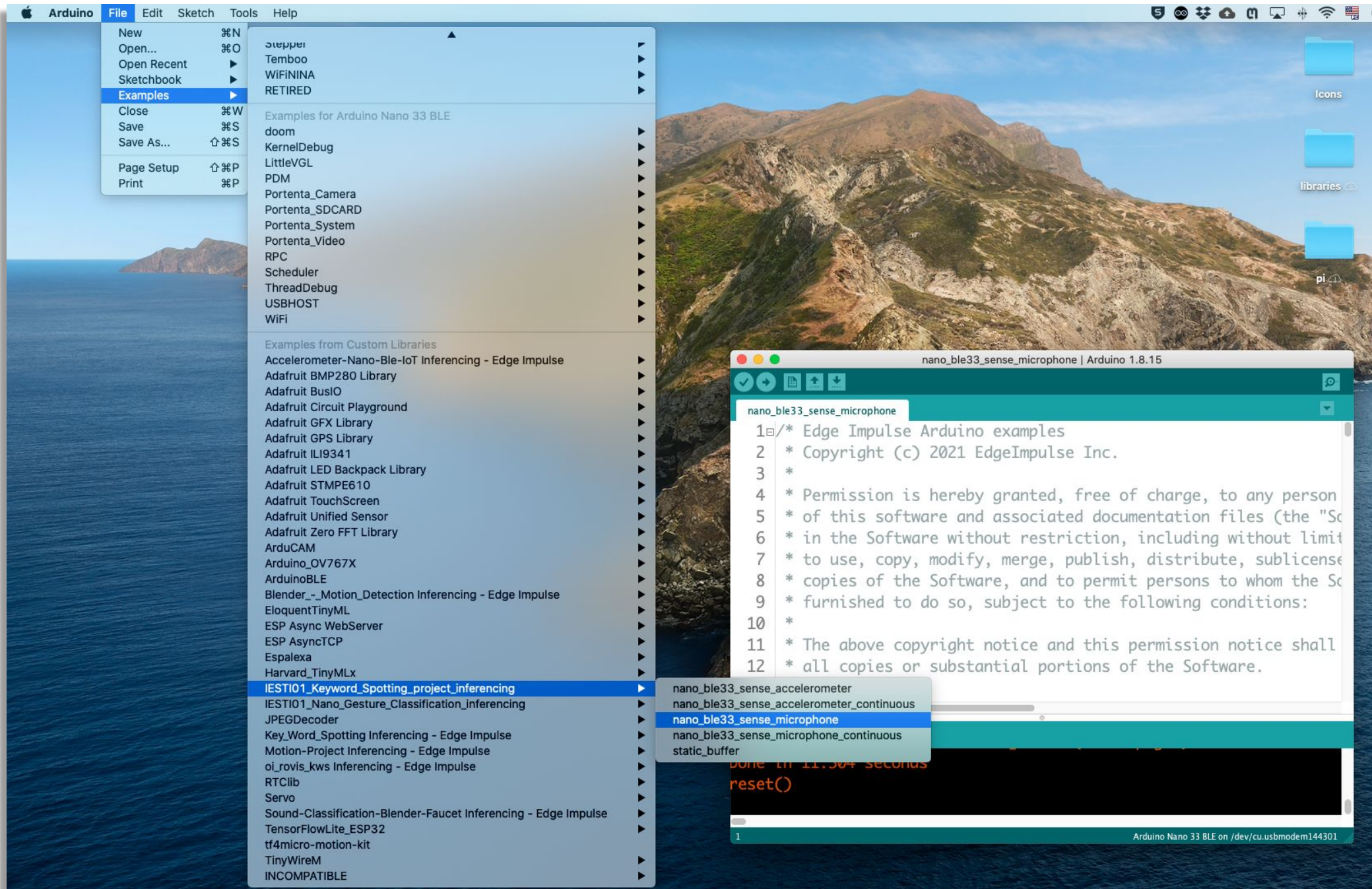
Job started

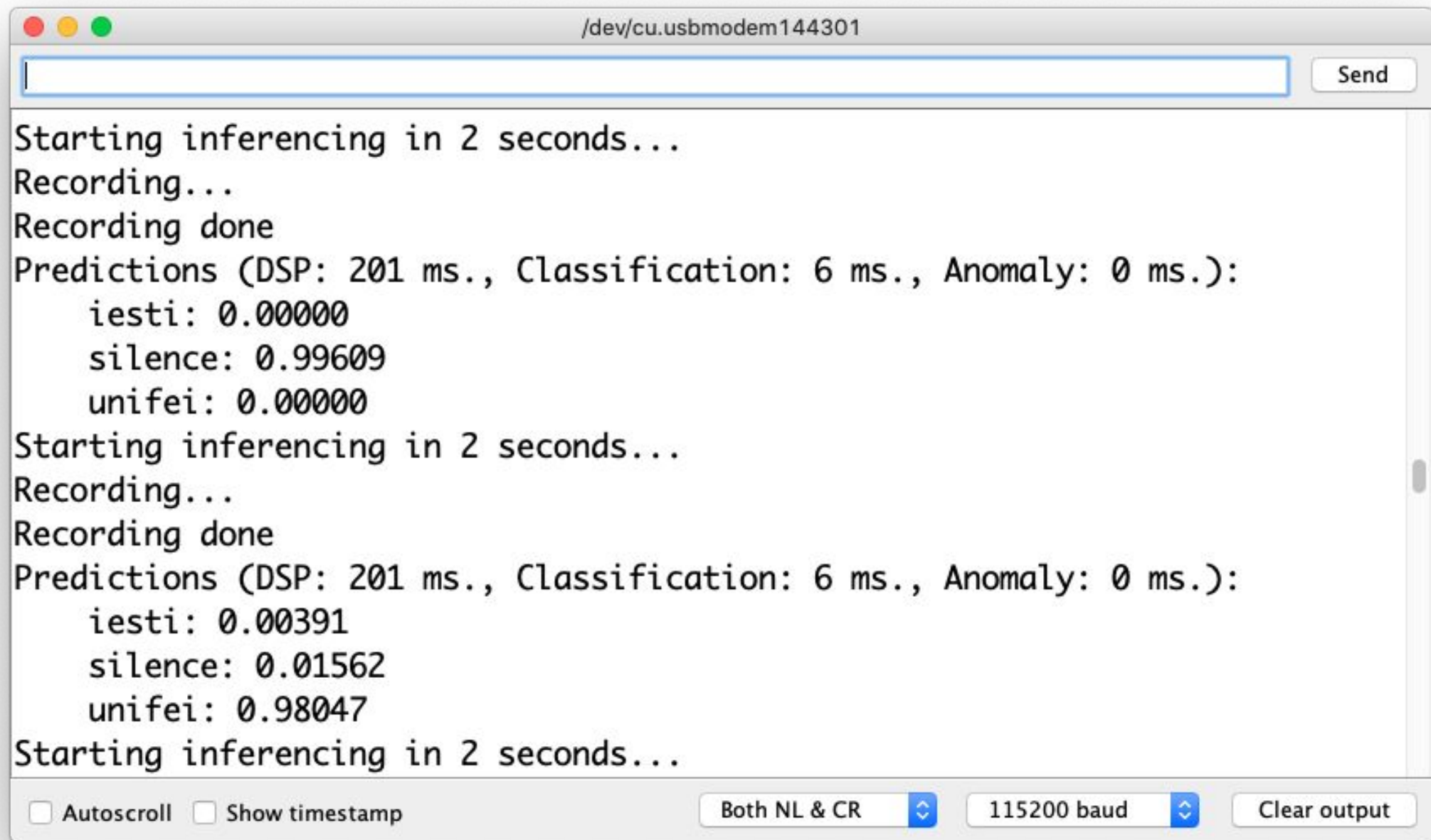
Job started

Job completed

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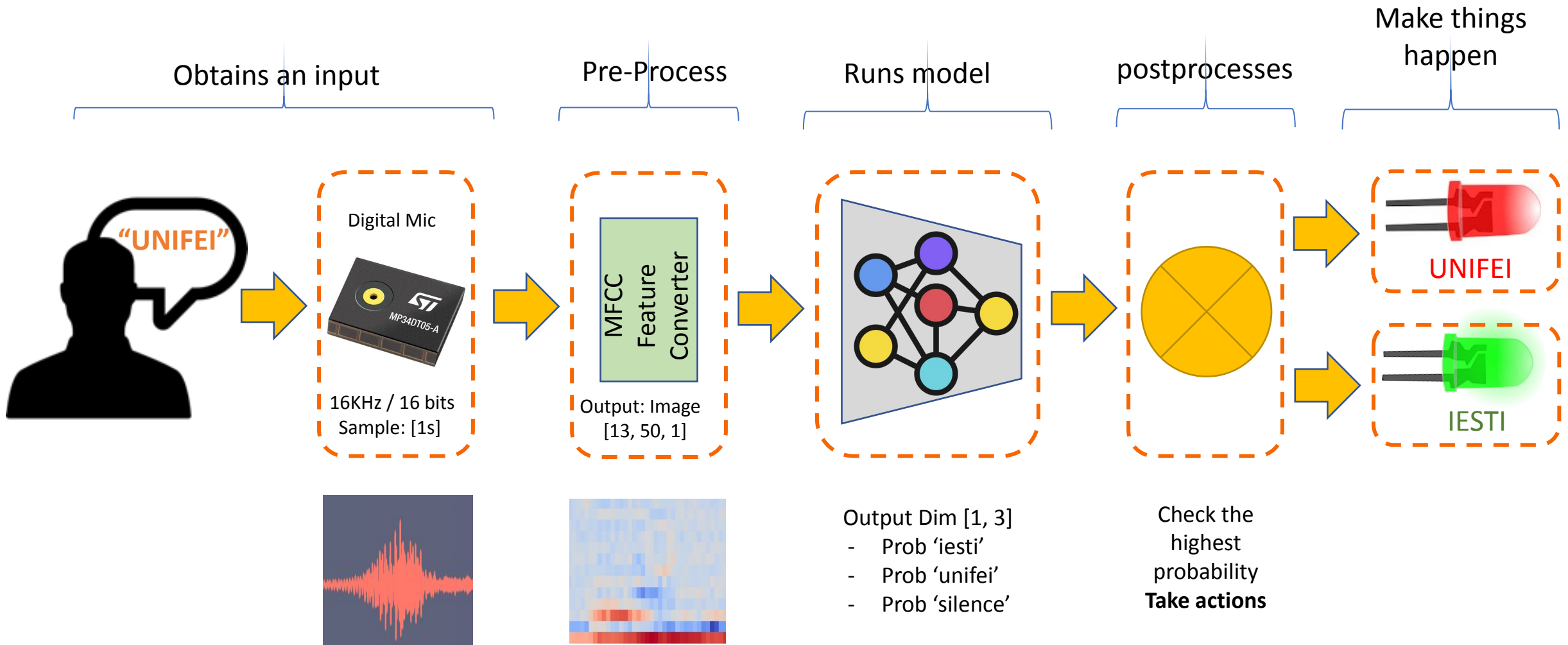
KWS Classifier Project

Looking “Under the hood”

[ei-iesti01_keyword_spotting_project-nn-classifier.ipynb](#)



KeyWord Spotting (KWS) - Inference



Project Video: <https://youtu.be/XnFYz-RSNe8>

```
nano_ble33_sense_microphone_leds | Arduino 1.8.15
nano_ble33_sense_microphone_leds $
42 /**
43  * @brief      Arduino setup function
44  */
45 void setup()
46 {
47     Serial.begin(115200);
48     while (!Serial);
49
50     Serial.println("IESTI01 - KWS Project");
51     // Pins for the built-in RGB LEDs on the Arduino Nano 33 BLE Sense
52     pinMode(LED_R, OUTPUT);
53     pinMode(LED_G, OUTPUT);
54     pinMode(LED_B, OUTPUT);
55
56     // Ensure the LED is off by default.
57     // Note: The RGB LEDs on the Arduino Nano 33 BLE
58     // Sense are on when the pin is LOW, off when HIGH.
59     digitalWrite(LED_R, HIGH);
60     digitalWrite(LED_G, HIGH);
61     digitalWrite(LED_B, HIGH);
62
63     // summary of inferencing settings (from model_metadata.h)
64     ei_printf("Inferencing settings:\n");
65     ei_printf("\tInterval: %.2f ms.\n", (float)EI_CLASSIFIER_INTERVAL_MS);
66     ei_printf("\tFrame size: %d\n", EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE);
67     ei_printf("\tSample length: %d ms.\n", EI_CLASSIFIER_RAW_SAMPLE_COUNT / 16);
68     ei_printf("\tNo. of classes: %d\n", sizeof(ei_classifier_inferencing_categories) / sizeof(ei_class));
69
70     if (microphone_inference_start(EI_CLASSIFIER_RAW_SAMPLE_COUNT) == false) {
71         ei_printf("ERR: Failed to setup audio sampling\r\n");
72         return;
73     }
74 }
```

Done uploading.

```
[===== ] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(src_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
```

46 Arduino Nano 33 BLE on /dev/cu.usbmodem144301

```
nano_ble33_sense_microphone_leds | Arduino 1.8.15
nano_ble33_sense_microphone_leds $
77 /**
78  * @brief      Special Postprocess function for RGB LEDs
79  */
80
81 void turn_off_leds(){
82     digitalWrite(LED_R, HIGH);
83     digitalWrite(LED_G, HIGH);
84     digitalWrite(LED_B, HIGH);
85 }
86
87 /**
88  * iesti:  [0] ==> Green ON
89  * Silence: [1] ==> All OFF
90  * unifei: [2] ==> Red ON
91  */
92
93 void turn_on_leds(int pred_index) {
94     switch (pred_index)
95     {
96     case 0:
97         turn_off_leds();
98         digitalWrite(LED_G, LOW);
99         break;
100
101     case 1:
102         turn_off_leds();
103         break;
104
105     case 2:
106         turn_off_leds();
107         digitalWrite(LED_R, LOW);
108         break;
109     }
110 }
111
Done uploading.
[===== ] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
78 Arduino Nano 33 BLE on /dev/cu.usbmodem144301
```

```
nano_ble33_sense_microphone_leds | Arduino 1.8.15
nano_ble33_sense_microphone_leds $
112 void loop()
113 {
114     ei_printf("Starting inferencing in 2 seconds...\n");
115     delay(2000);
116     ei_printf("Recording...\n");
117
118     bool m = microphone_inference_record();
119     if (!m) {
120
121     ei_printf("Recording done\n");
122
123     signal_t signal;
124     signal.total_length = EI_CLASSIFIER_RAW_SAMPLE_COUNT;
125     signal.get_data = &microphone_audio_signal_get_data;
126     ei_impulse_result_t result = { 0 };
127
128     EI_IMPULSE_ERROR r = run_classifier(&signal, &result, debug_nn);
129     if (r != EI_IMPULSE_OK) {
130
131     // print the predictions
132     ei_printf("Predictions ");
133     ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
134               result.timing.dsp, result.timing.classification, result.timing.anomaly);
135     ei_printf(": \n");
136
137     int pred_index = 0; // Initialize pred_index
138     float pred_value = 0; // Initialize pred_value
139
140     for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
141         // ei_printf("  %s: %.5f\n", result.classification[ix].label, result.classification[ix].value);
142         if (result.classification[ix].value > pred_value){
143             pred_index = ix;
144             pred_value = result.classification[ix].value;
145         }
146     }
147     ei_printf(": \n");
148     ei_printf(" PREDICTION: ==> %s with probability %.2f\n",
149               result.classification[pred_index].label, pred_value);
150     ei_printf(": \n");
151     turn_on_leds(pred_index);
152 }
153 }
154 }
155 }
156 }
157 }
```

Done uploading.

```
[=====] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
```

115 Arduino Nano 33 BLE on /dev/cu.usbmodem144301

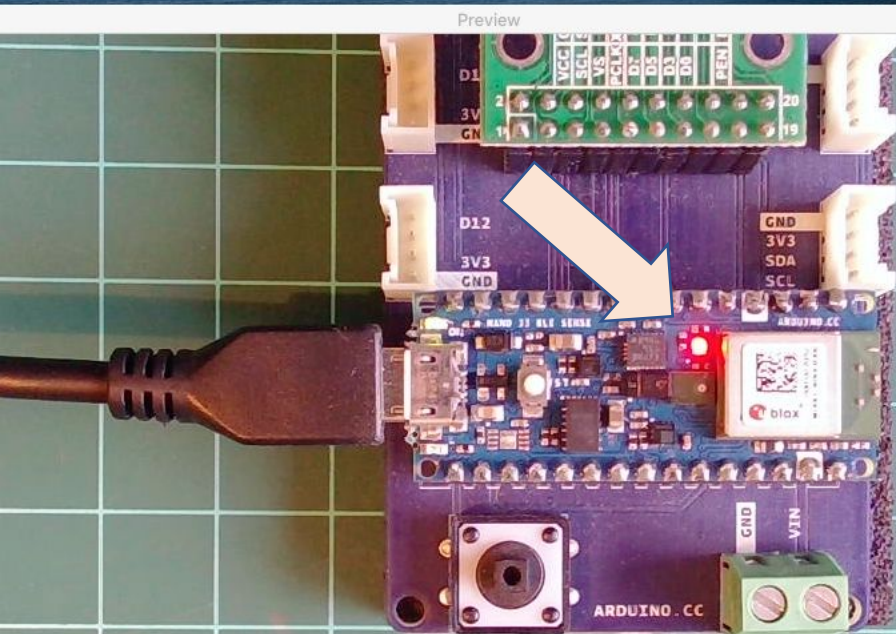
```

/dev/cu.usbmodem144301

Recording...
Recording done
Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):
:
  PREDICTION: ==> silence with probability 1.00
:
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):
:
  PREDICTION: ==> unifei with probability 0.92
:
Starting inferencing in 2 seconds...

☒ Autoscroll ☐ Show timestamp
Both NL & CR 115200 baud Clear output

```



```

nano_ble33_sense_microphone_leds | Arduino 1.8.15

nano_ble33_sense_microphone_leds $
130 signal.get_data = &microphone_audio_signal_get_data;
131 ei_impulse_result_t result = { 0 };
132
133 EI_IMPULSE_ERROR r = run_classifier(&signal, &result, debug_nn);
134 if (r != EI_IMPULSE_OK) {
135     ei_printf("ERR: Failed to run classifier (%d)\n", r);
136     return;
137 }
138
139 // print the predictions
140 ei_printf("Predictions ");
141 ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
142     result.timing.dsp, result.timing.classification, result.timing.anomaly);
143 ei_printf(": \n");
144
145 int pred_index = 0; // Initialize pred_index
146 float pred_value = 0; // Initialize pred_value
147
148 for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
149     // ei_printf("  %s: %.5f\n", result.classification[ix].label, result.classification[ix].value);
150     if (result.classification[ix].value > pred_value){
151         pred_index = ix;
152         pred_value = result.classification[ix].value;
153     }
154 }
155 ei_printf(": \n");
156 ei_printf(" PREDICTION: ==> %s with probability %.2f\n",
157     result.classification[pred_index].label, pred_value);
158 ei_printf(": \n");
159 turn_on_leds (pred_index);
160

Done uploading.
[===== ] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
Done in 11.279 seconds
reset()

157

```

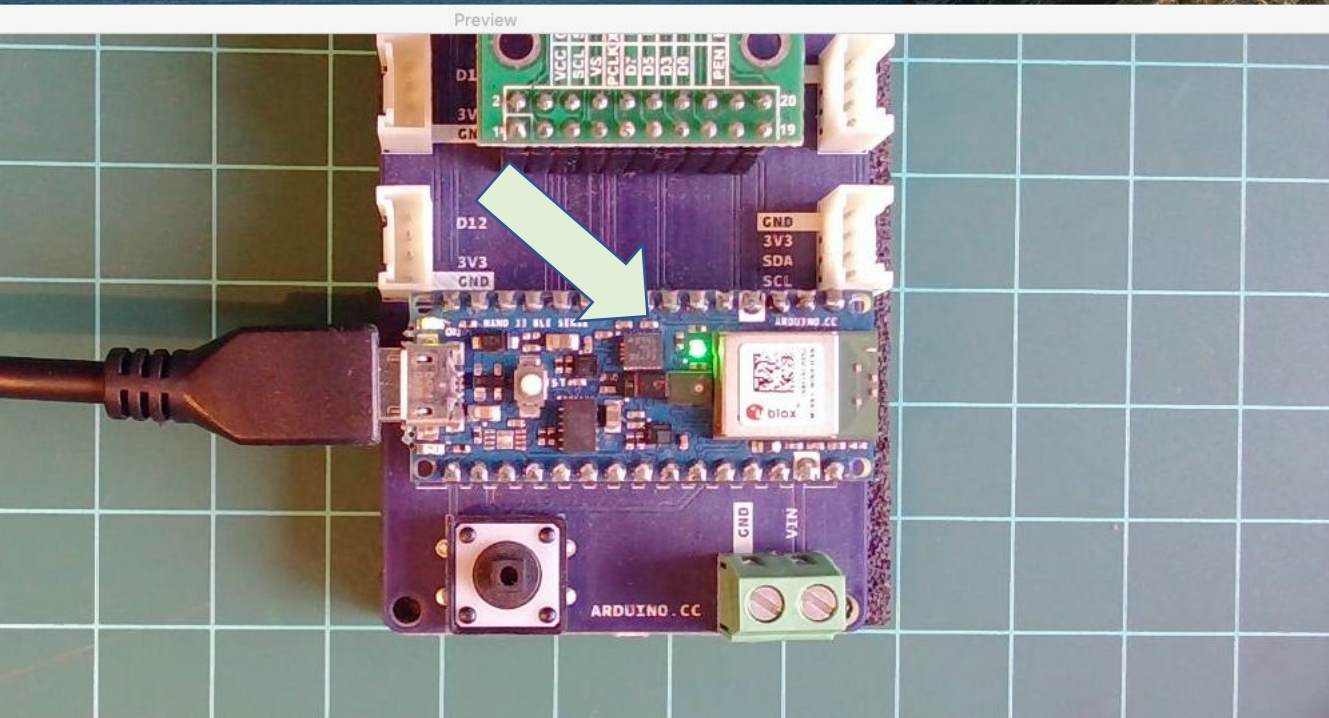
```

/dev/cu.usbmodem144301

Recording...
Recording done
Predictions (DSP: 196 ms., Classification: 7 ms., Anomaly: 0 ms.):
:
  PREDICTION: ==> silence with probability 1.00
:
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):
:
  PREDICTION: ==> iesti with probability 0.82
:
Starting inferencing in 2 seconds...

☒ Autoscroll ☐ Show timestamp
Both NL & CR 115200 baud Clear output

```



```

nano_ble33_sense_microphone_leds | Arduino 1.8.15

nano_ble33_sense_microphone_leds $
130 signal.get_data = &microphone_audio_signal_get_data;
131 ei_impulse_result_t result = { 0 };
132
133 EI_IMPULSE_ERROR r = run_classifier(&signal, &result, debug_nn);
134 if (r != EI_IMPULSE_OK) {
135     ei_printf("ERR: Failed to run classifier (%d)\n", r);
136     return;
137 }
138
139 // print the predictions
140 ei_printf("Predictions ");
141 ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
142     result.timing.dsp, result.timing.classification, result.timing.anomaly);
143 ei_printf(": \n");
144
145 int pred_index = 0; // Initialize pred_index
146 float pred_value = 0; // Initialize pred_value
147
148 for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
149     // ei_printf("  %s: %.5f\n", result.classification[ix].label, result.classification[ix].value);
150     if (result.classification[ix].value > pred_value){
151         pred_index = ix;
152         pred_value = result.classification[ix].value;
153     }
154 }
155 ei_printf(": \n");
156 ei_printf(" PREDICTION: ==> %s with probability %.2f\n",
157     result.classification[pred_index].label, pred_value);
158 ei_printf(": \n");
159 turn_on_leds (pred_index);
160

Done uploading.
[===== ] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
Done in 11.279 seconds
reset()

157
Arduino Nano 33 BLE on /dev/cu.usbmodem144301

```

Reading Material

Main references

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

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Thanks



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