

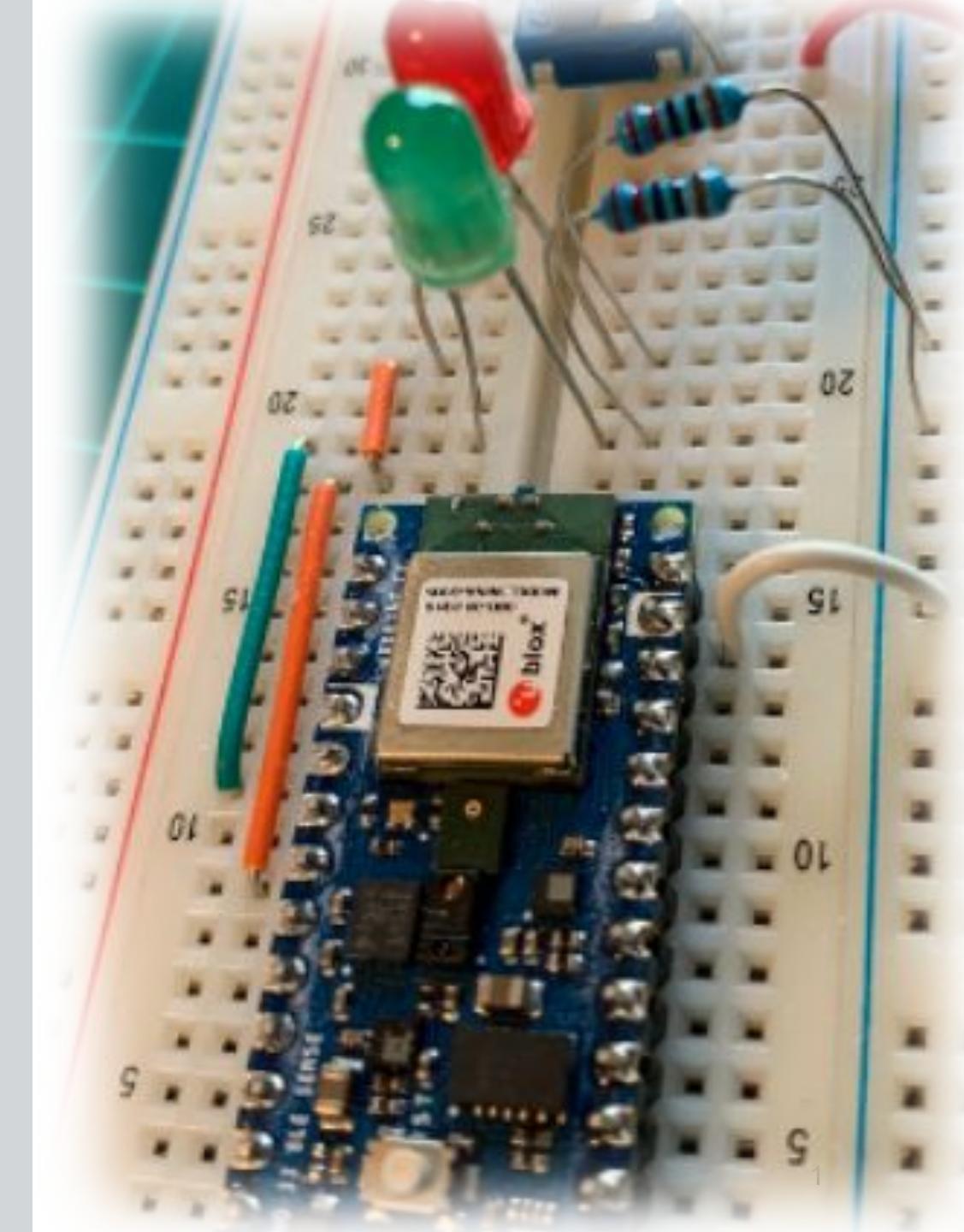
IESTI01 – TinyML

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

IESTI01_Keyword_Spotting_project

Cancel Create new project

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

3

EDGE IMPULSE Home API Reference Log In

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- API and SDK references
- What is embedded ML, anyway?
- Frequently asked questions

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- Overview
- ST B-L475E-IOT01A
- Arduino Nano 33 BLE Sense**
- Eta Compute ECM3532 AI Sensor
- 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
- Arduino Portenta H7 + Vision shield (preview)
- Raspberry Pi 4
- NVIDIA Jetson Nano
- Mobile phone
- Porting guide

COMMUNITY BOARDS

- Seeed Wio Terminal
- Agora Product Development Kit

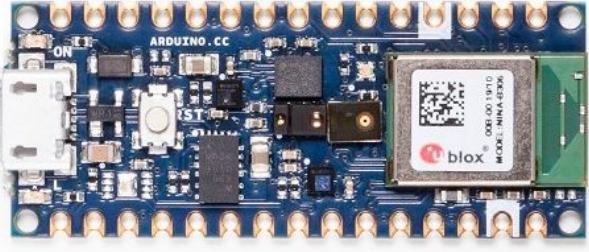
EDGE IMPULSE FOR LINUX

- 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.

DOCUMENTATION

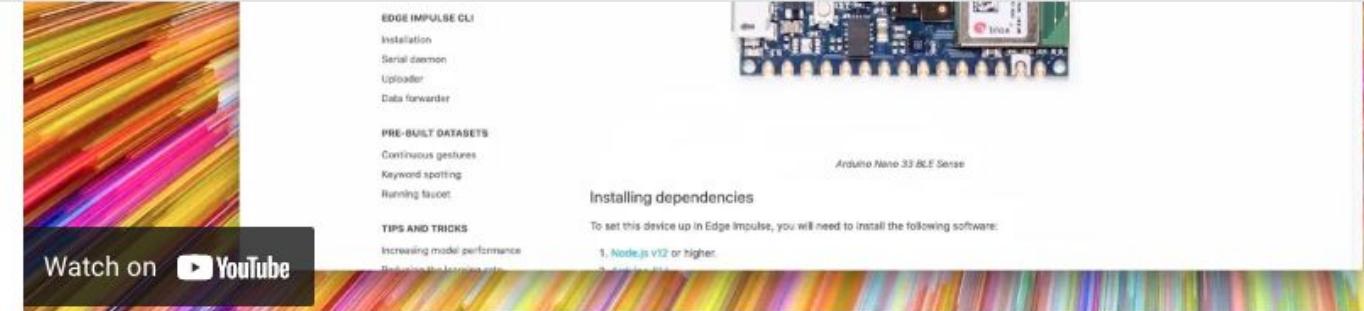
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COMMUNITY BOARDS

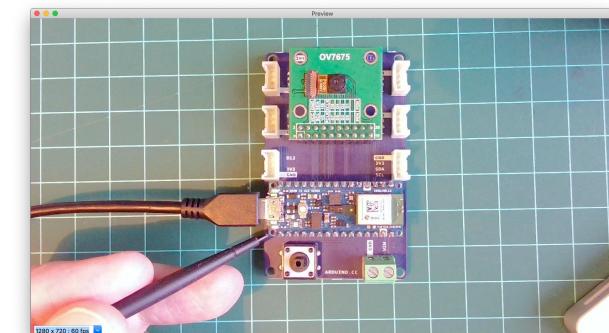
- Seeed Wio Terminal
- Agora Product Development Kit



The screenshot shows the Edge Impulse website with the Arduino Nano 33 BLE Sense development board highlighted. The page includes sections for the Edge Impulse CLI, Pre-built Databases, and Tips & Tricks. A 'Watch on YouTube' button is visible.

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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- Overview

ST B-L475E-IOT01A

Arduino Nano 33 BLE Sense

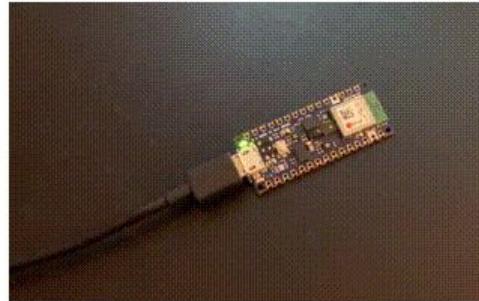
- Eta Compute ECM3532 AI Sensor
- Eta Compute ECM3532 AI Vision
- OpenMV Cam H7 Plus
- Himax WE-I Plus
- Nordic Semi nRF52840 DK
- Nordic Semi nRF5340 DK
- SiLabs Thunderboard Sense 2
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COMMUNITY BOARDS

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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.

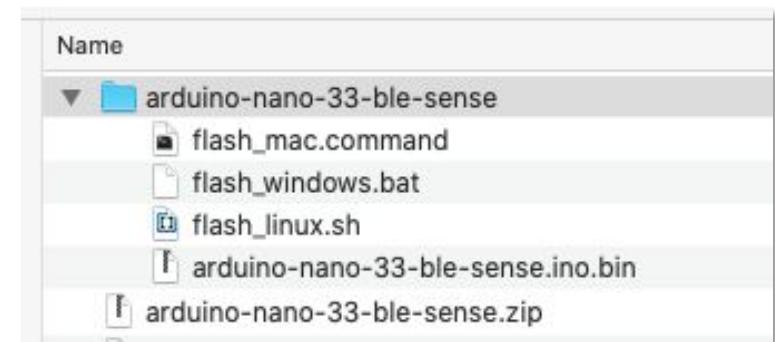
**1**

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

MacOS

```
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;

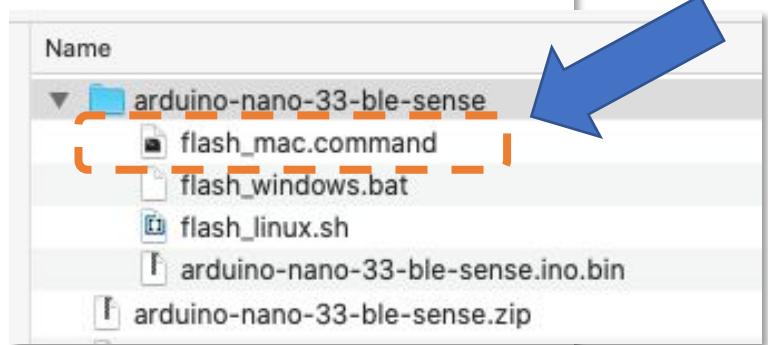
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
(base) MacBook-Pro-de-Marcelo:~ mjrovai$ /Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;
Finding 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.

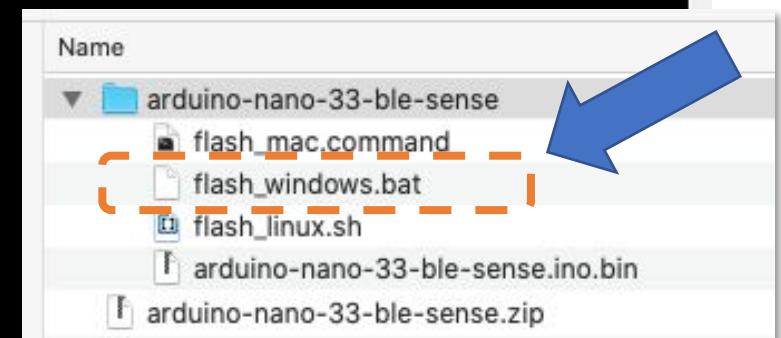
C:\Users\GUILH>arduino-cli
Arduino Command Line Interface (arduino-cli).

Usage:
  arduino-cli [command]

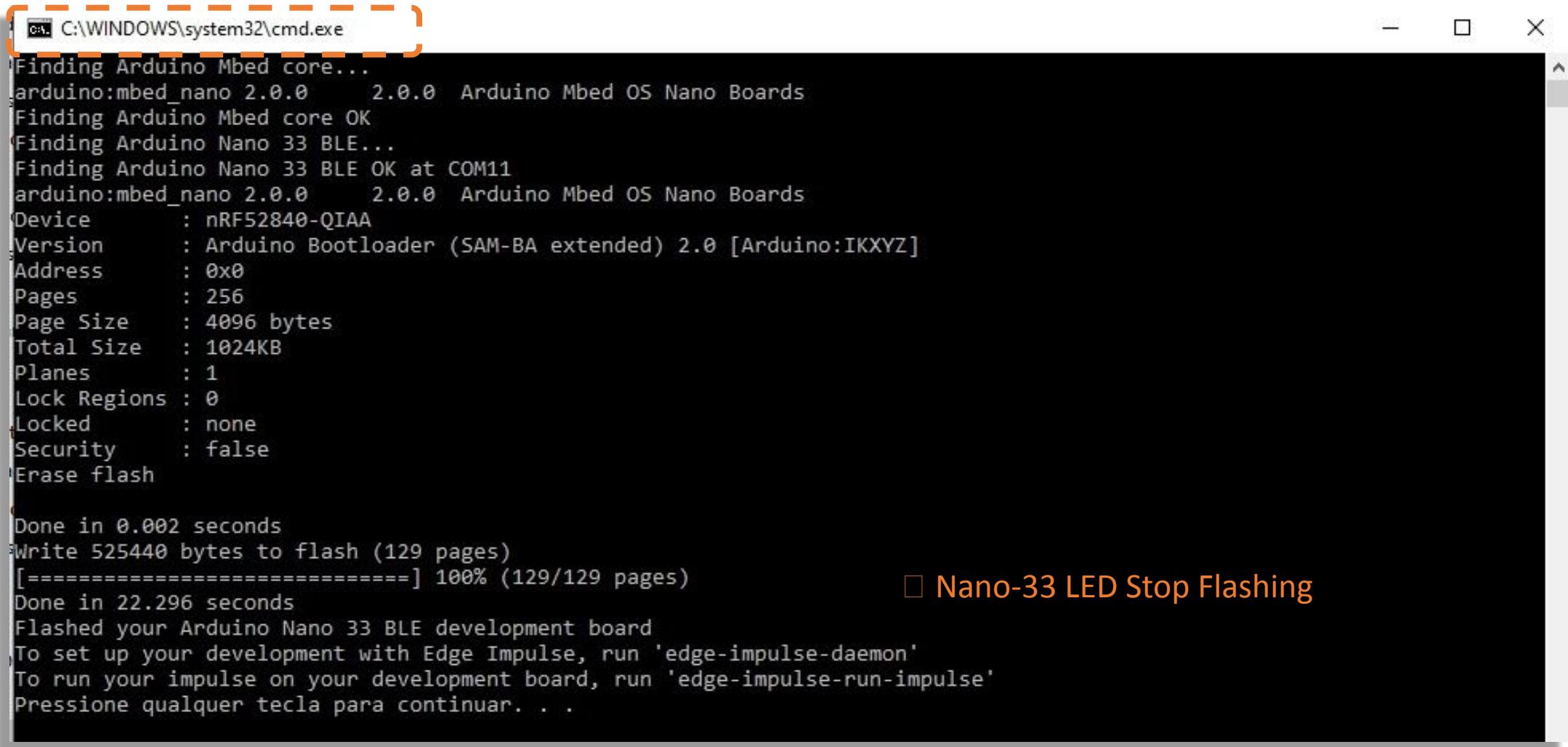
Examples:
  arduino-cli <command> [flags...]

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.**

The screenshot shows the Edge Impulse Studio interface. On the left, a sidebar lists project options like Dashboard, Devices, Data acquisition, and ImpulseNet. The main area displays a "Data acquisition - IESTI01_Key" project titled "POTTING_PROJECT". A modal dialog box is open, asking for permission to connect to a serial port. It lists several ports: cu.Bluetooth-Incoming-Port, cu.MALS, cu.RovaisAirPods-Wireless, cu.SOC, and Nano 33 BLE (cu.usbmodem144301) - Paired. The last item is highlighted with a blue selection bar. Below the list are "Cancel" and "Connect" buttons, with the "Connect" button highlighted by a dashed orange rectangle. The number "3" is placed next to the "Connect" button. The main workspace shows a chart with "LABELS 0" and a message "No data collected yet". A green button labeled "Let's collect some data" is visible. To the right, there's a section for "Record new data" with a note "No devices connected to the remote management API." and a dark blue box with the text "Click on a sample to load...". The number "2" is placed next to the "Record new data" section. At the bottom right, a file browser window is open, showing a folder structure for "arduino-nano-33-ble-sense". The folder contains files: flash_mac.command, flash_windows.bat, flash_linux.sh, arduino-nano-33-ble-sense.ino.bin, and arduino-nano-33-ble-sense.zip. The number "1" is placed next to the file browser window.

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

1 →

OPTIONAL

DOCUMENTATION

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COMMUNITY BOARDS

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EDGE IMPULSE FOR LINUX

Installation

If WebUSB force browser to close, install Edge Impulse 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 -e 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 x +

◀ ▶ C studio.edgeimpulse.com/studio/38744/devices

EDGE IMPULSE MJRoBot (Marcelo Roval)

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

DEVICES (IESTI01_KEYWORD_SPOTTING_PROJECT)

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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GETTING STARTED Documentation Forums



Data acquisition - IESTI01_

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

EDGE IMPULSE

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...

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

GETTING STARTED Documentation Forums

MJRoBot (Marcelo Rovai)

Data acquisition - IESTI01

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

EDGE IMPULSE

DATA COLLECTED
10s

LABELS
1

Collected data

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

Device ②
36:17:55:F9:70:F7

Label
unifei

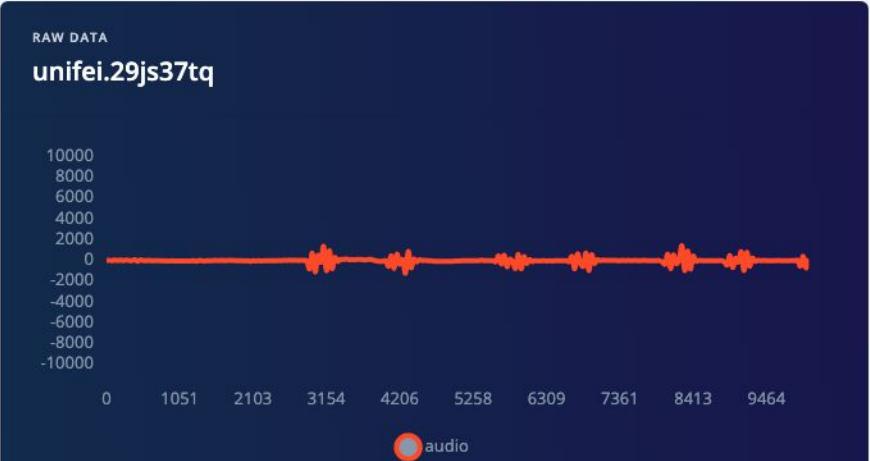
Sample length (ms.)
10000

Sensor
Built-in microphone

Frequency
16000Hz

Start sampling

RAW DATA
unifei.29js37tq



The waveform plot displays raw audio data for the sample 'unifei.29js37tq'. The vertical axis represents amplitude from -10000 to 10000, and the horizontal axis represents time in milliseconds from 0 to 9464. The plot shows a series of sharp, regular spikes at approximately -1500 amplitude, indicating periodic sound events.

0:10 / 0:10

audio

Data acquisition - IESTI01

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

EDGE IMPULSE

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

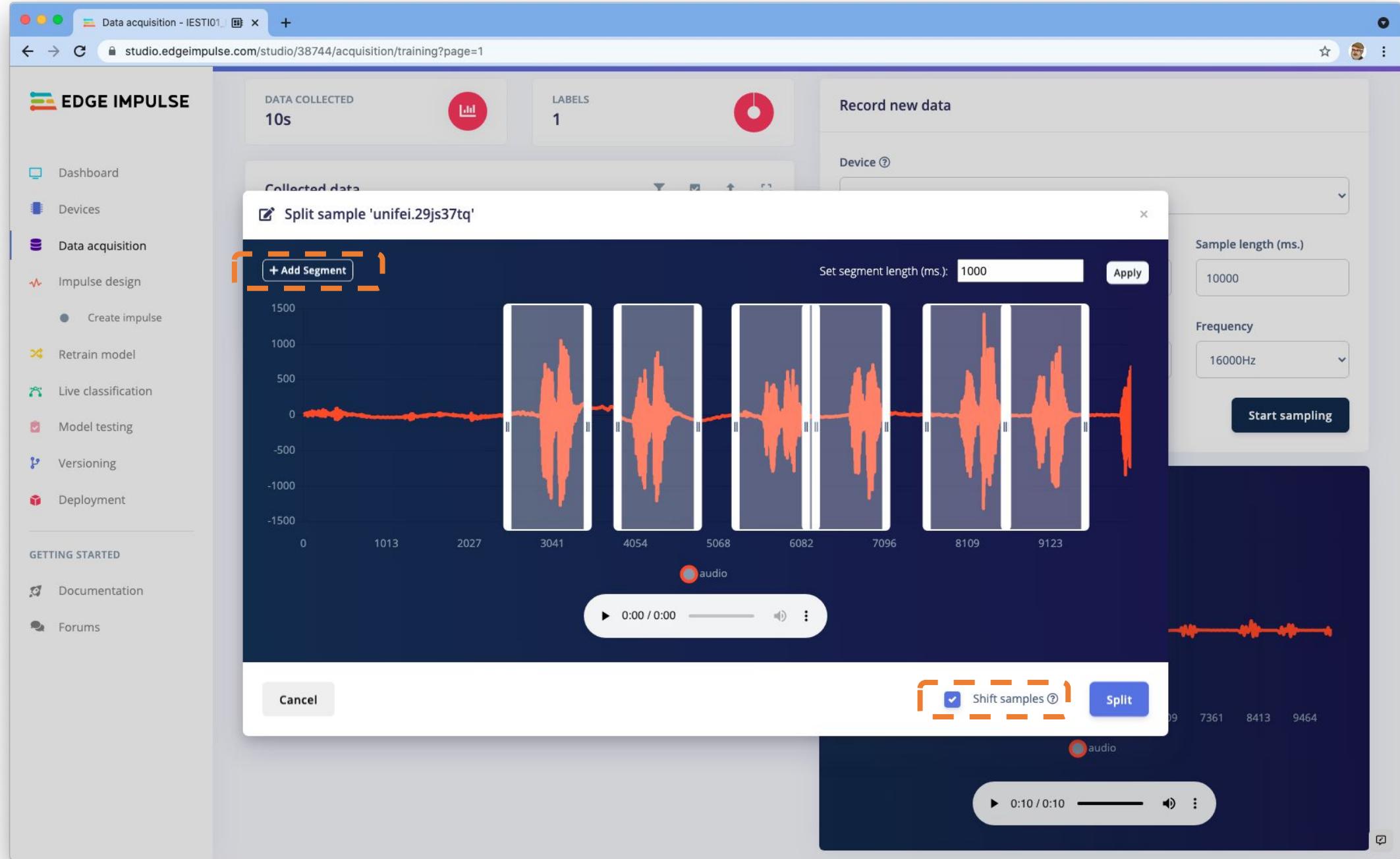
Start sampling

RAW DATA
unifei.29js37tq

audio

▶ 0:10 / 0:10 🔍 ⏪ ⏹

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



Data acquisition - IESTI01

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

EDGE IMPULSE

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	⋮

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

The raw audio waveform plot displays amplitude on the y-axis ranging from -10000 to 10000, and time on the x-axis with markers at 0, 104, 208, 312, 416, 520, 624, 728, 832, and 936. The waveform shows a low-level signal with a sharp, transient spike around the 624 mark, highlighted by a red circle labeled "audio".

▶ 0:00 / 0:00 🔊 ⏮

Data acquisition - IESTI01_Key... [+](#)

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

EDGE IMPULSE

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 1m 37s

LABELS 1

Collected data

Device ? 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...

DATA COLLECTED 1m 37s

LABELS 1

Collected data

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	⋮

DATA COLLECTED 1m 37s

LABELS 1

Collected data

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	⋮

DATA COLLECTED 1m 37s

LABELS 1

Collected data

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	⋮

Data acquisition - IESTI01_Keys | Uaiirrior | UNIFEI

studio.edgeimpulse.com/studio/38744/acquisition/training?page=2

EDGE IMPULSE

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

RAW DATA
silence.29lt3rm7.s2

0 104 208 312 416 520 624 728 832 936

audio

▶ 0:00 / 0:00 🔊 ⏮

Record new data

Device ? nano

Label silence Sample length (ms.) 10000

Sensor Built-in microphone Frequency 16000Hz

Start sampling

Create impulse - IESTI01_Keyw X Ualrrorr | UNIFEI x +

studio.edgeimpulse.com/studio/38744/create-impulse

EDGE IMPULSE

CREATE IMPULSE (IESTI01_KEYWORD_SPOTTING_PROJECT)

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

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

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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MJRoBot (Marcelo Rova)

Create impulse - IESTI01_Keyw Ualrrorr | UNIFEI

studio.edgeimpulse.com/studio/38744/create-impulse

EDGE IMPULSE

CREATE IMPULSE (IESTI01)

Add a processing block

An impulse takes

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

MJRoBot (Marcelo Roval)

Output features ✓

Save Impulse

Time series data

Axes
audio

Window size

Window increase

Zero-pad data

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Create impulse - IESTI01_Keyw X Ualrrorr | UNIFEI x +

studio.edgeimpulse.com/studio/38744/create-impulse

EDGE IMPULSE

CREATE IMPULSE (IESTI01_KEYWORD_SPOTTING_PROJECT)

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

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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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MJRoBot (Marcelo Rova)

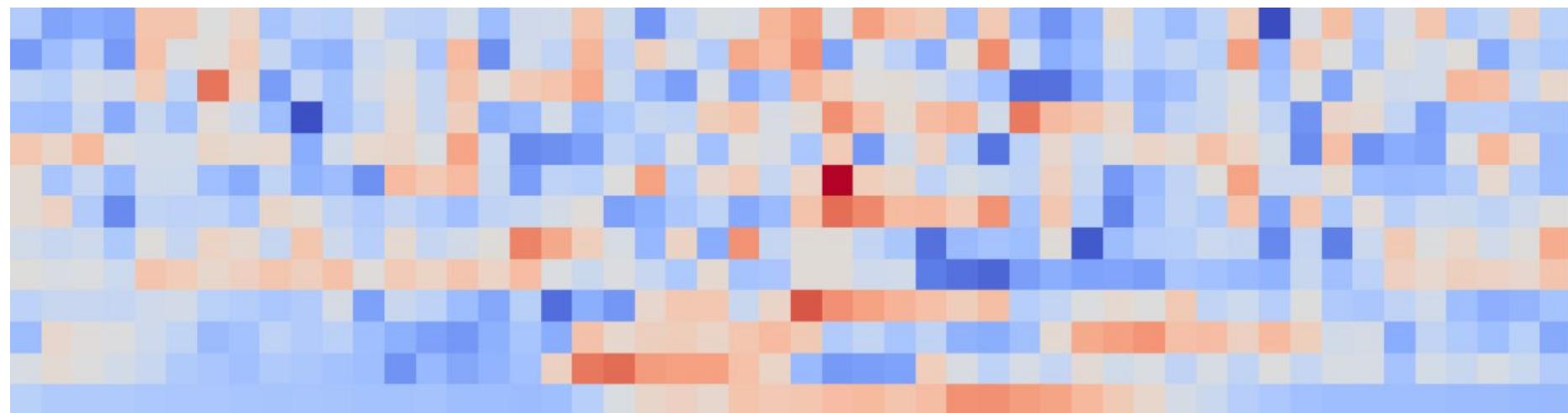
Raw data



1 second of Sound raw data



MFCC



Dim = 13×50
= 650

50 slots

KWS Classifier Project

Audio Raw Data Analysis

[IESTI01 Audio Raw Data Analisys.ipynb](#)



MFCC - IESTI01_Keyword_Spot Ualrrior | UNIFEI

studio.edgeimpulse.com/studio/38744/dsp/mfcc/3/generate-features

EDGE IMPULSE

MFCC (IESTI01_KEYWORD_SPOTTING_PROJECT)

Parameters Generate features

Training set

Data in training set 4m 37s

Classes 3 (iesti, silence, unifei)

Window length 1000 ms.

Window increase 500 ms.

Training windows 253

Generate features

Feature generation output

```
still running...
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 Axis: Visualization layer 1, Y Axis: Visualization layer 2, Z Axis: Visualization layer 3

On-device performance

PROCESSING TIME 217 ms.

PEAK RAM USAGE 17 KB

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NN Classifier - IESTI01_Keywo... +

studio.edgeimpulse.com/studio/38744/learning/keras/5

MJRoBot (Marcelo Rovai)

NN CLASSIFIER (iesti01_KEYWORD_SPOTTING_PROJECT)

#1 Click to set a description for this version

EDGE IMPULSE

- Dashboard
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Neural Network settings

Training settings

Number of training cycles

Learning rate

Minimum confidence rating

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 (tflite)...
 Profiling float32 model (EON)...
 Profiling int8 model...
 Profiling int8 model (tflite)...
 Profiling int8 model (EON)...

Model training complete
Job completed

Model

Model version:

Last training performance (validation set)

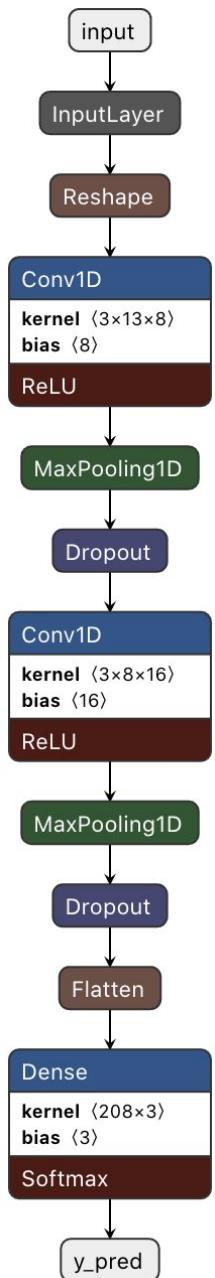
% ACCURACY 100.0%	graph LOSS 0.02
-----------------------------------	---------------------------------

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)

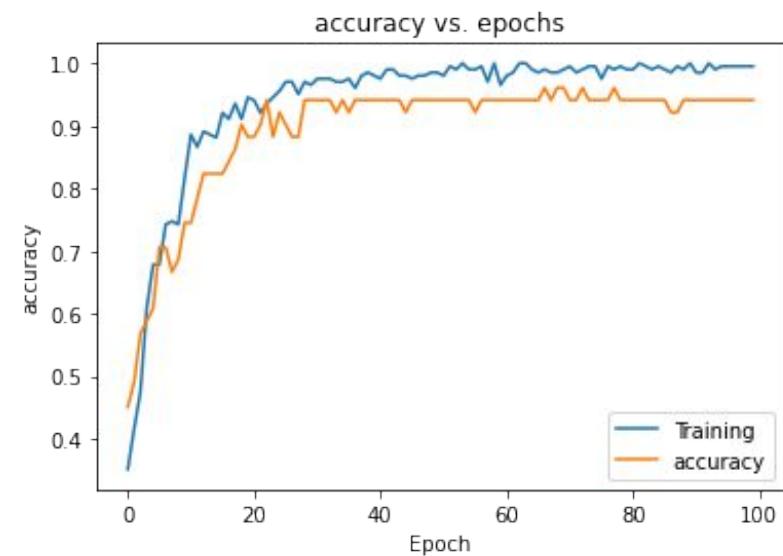
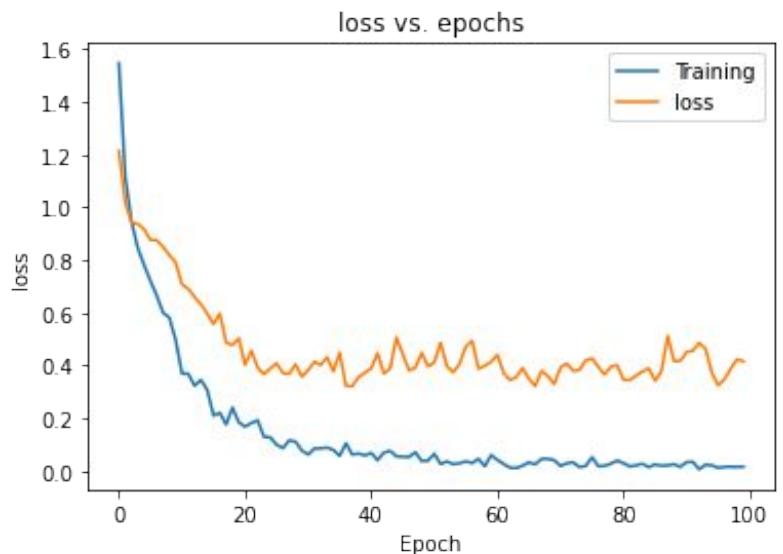
Legend:
● iesti - correct
● silence - correct
● unifei - correct



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 (MaxPooling1 (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



Live classification - IESTI01_Ke

studio.edgeimpulse.com/studio/38744/classification#load-sample-35698157

EDGE IMPULSE

Classify new data

Device: nano
Sensor: Built-in microphone
Sample length (ms.): 10000
Frequency: 16000Hz

[Start sampling](#)

Classify existing test sample

testing.29lu6v0r (iesti)

[Load sample](#)

Classification result

Summary

Name	testing.29lu6v0r
Expected outcome	silence
CATEGORY	COUNT
iesti	1
silence	16
unifei	1
uncertain	1

Detailed result

TIMESTAMP	TESTI	SILENCE	UNIFEI
0	0	1.00	0
500	0	1.00	0
1000	0	1.00	0
1500	0	1.00	0
2000	0.19	0.59	0.22
2500	0	1.00	0
3000	0.01	0.95	0.03

Raw DATA

testing.29lu6v0r (audio)

0:01 / 0:01

Raw features

```
1, 0, -2, -4, -6, -6, -4, 1, -1, -1, -1, 1, -1, -3, -2, -1, -1, -2, -2, 1, -1, -1, -1, -2, -3, -3, -2, -3, 2, 2, 2, 3, 2, 2, 2, 5, 7, -
```

MFCC (272 samples)

X Axis: Visualization layer 1
Y Axis: Visualization layer 2
Z Axis: Visualization layer 3

classified
iesti
silence
unifei
classification 4

Processed features

```
1.1280, -0.0686, -0.0853, 1.2996, 0.1440, -1.0248, -0.3983, -0.7610, -1.0223, -0.1558, 0.1156, -0.5995, 0.0343, 0.9696, 0.6107, 0.4964, 0.9162, -
```

Model testing - IESTI01_Keywo

studio.edgeimpulse.com/studio/38744/validation

EDGE IMPULSE

MODEL TESTING (IESTI01_KEYWORD_SPOTTING_PROJECT)

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

Test data

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

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
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

Legend:

- iesti - correct
- silence - correct
- unifei - correct
- iesti - incorrect
- silence - incorrect
- unifei - incorrect

Deployment - IESTI01_Keyword

studio.edgeimpulse.com/studio/38744/deployment

EDGE IMPULSE

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- Documentation
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Eta Compute ECM3532 AI Vision



SiLabs Thunderboard Sense 2



Himax WE-i Plus



Nordic nRF52840 DK + IKS02A1



Nordic nRF5340 DK + IKS02A1



Sony's Spresense



Linux boards

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) ★ <input type="button" value="Currently selected"/> <p>This optimization is recommended for best performance.</p>	RAM USAGE 4.4K FLASH USAGE 30.2K	LATENCY 4 ms ACCURACY 81.48%	CONFUSION MATRIX <table border="1"> <tr> <td>69.7</td> <td>12.1</td> <td>12.1</td> <td>6.1</td> </tr> <tr> <td>2.6</td> <td>94.7</td> <td>2.6</td> <td>0</td> </tr> <tr> <td>8.1</td> <td>8.1</td> <td>78.4</td> <td>5.4</td> </tr> </table>	69.7	12.1	12.1	6.1	2.6	94.7	2.6	0	8.1	8.1	78.4	5.4
69.7	12.1	12.1	6.1												
2.6	94.7	2.6	0												
8.1	8.1	78.4	5.4												
Unoptimized (float32) <input type="button" value="Click to select"/>	RAM USAGE 8.0K FLASH USAGE 33.2K	LATENCY 18 ms ACCURACY 80.56%	CONFUSION MATRIX <table border="1"> <tr> <td>69.7</td> <td>12.1</td> <td>12.1</td> <td>6.1</td> </tr> <tr> <td>2.6</td> <td>92.1</td> <td>2.6</td> <td>2.6</td> </tr> <tr> <td>8.1</td> <td>8.1</td> <td>78.4</td> <td>5.4</td> </tr> </table>	69.7	12.1	12.1	6.1	2.6	92.1	2.6	2.6	8.1	8.1	78.4	5.4
69.7	12.1	12.1	6.1												
2.6	92.1	2.6	2.6												
8.1	8.1	78.4	5.4												

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

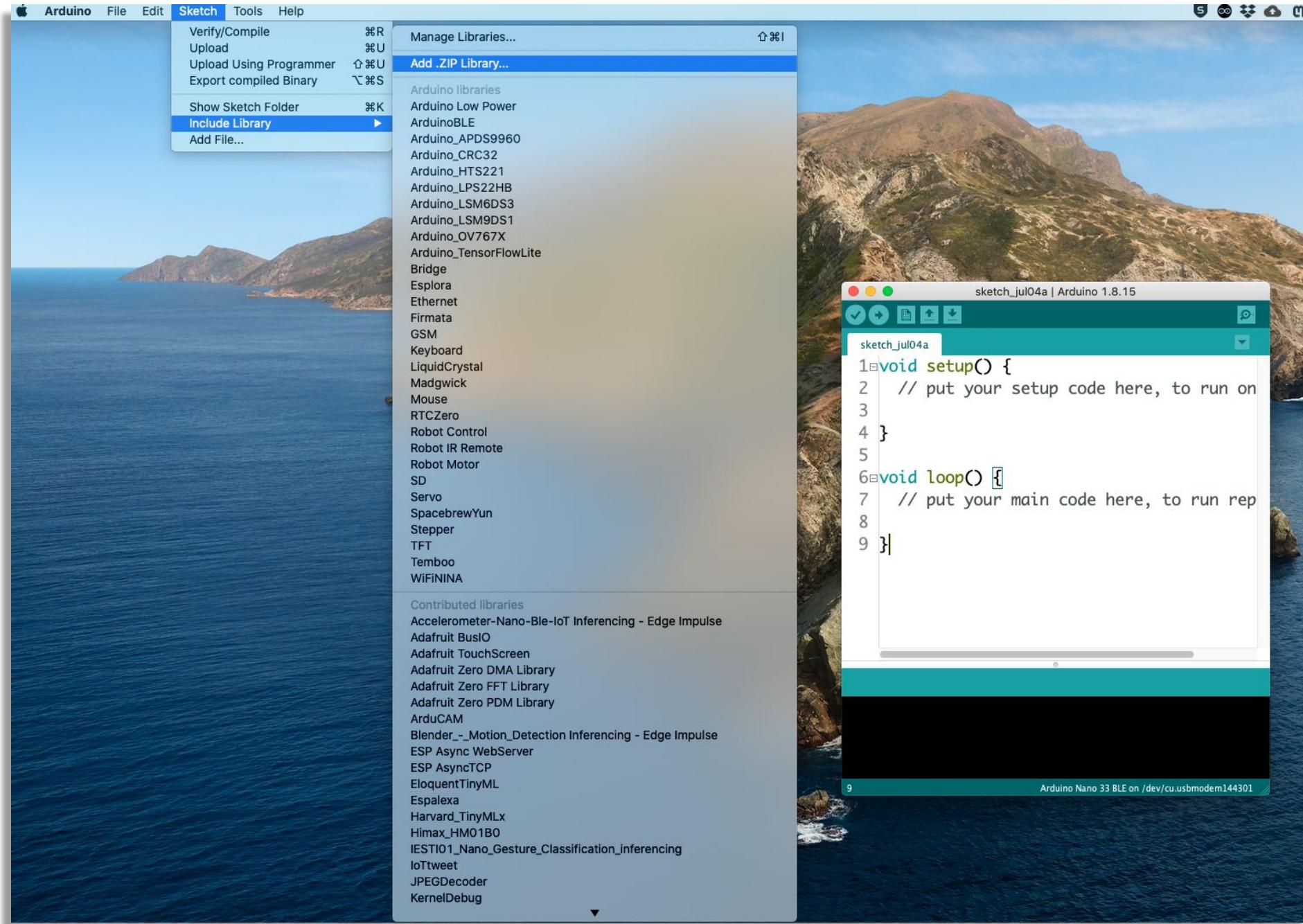
Build

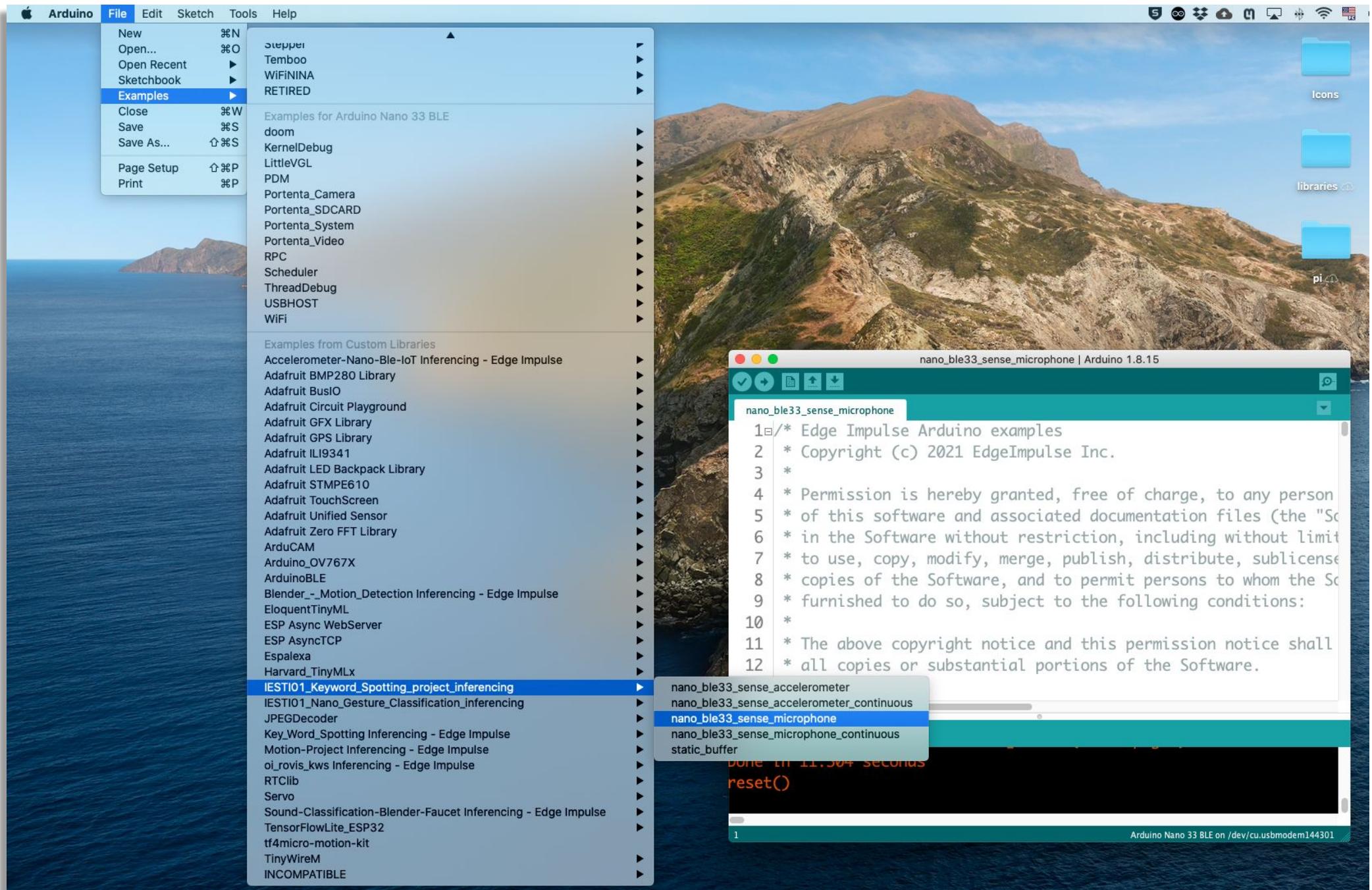
Build output

```

Creating job... OK (ID: 1051368)
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
  
```





```
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 201 ms., Classification: 6 ms., Anomaly: 0 ms.):
  iesti: 0.00000
  silence: 0.99609
  unifei: 0.00000
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 201 ms., Classification: 6 ms., Anomaly: 0 ms.):
  iesti: 0.00391
  silence: 0.01562
  unifei: 0.98047
Starting inferencing in 2 seconds...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Clear output

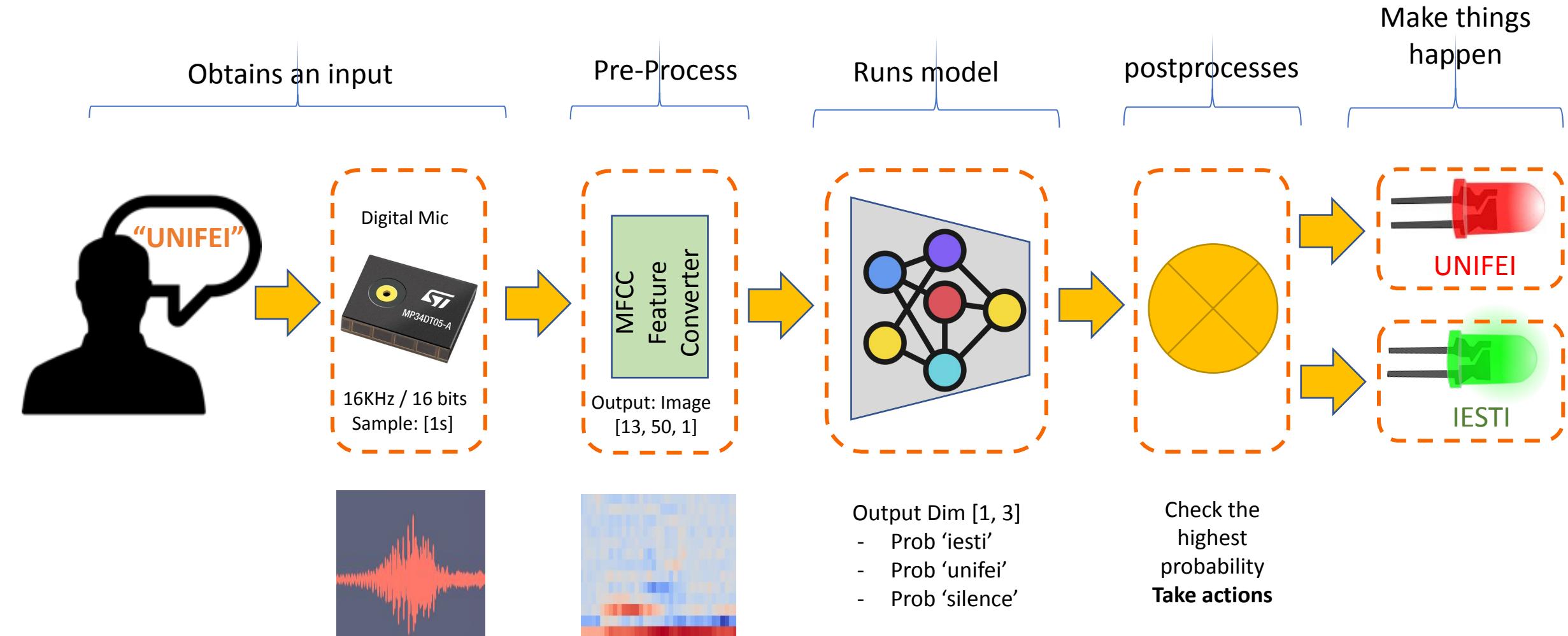
KWS Classifier Project

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

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(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
```

The screenshot shows the Arduino IDE interface with the following details:

- Title Bar:** nano_ble33_sense_microphone_leds | Arduino 1.8.15
- Code Editor:** The main window displays the C++ code for the sketch. The code includes functions for turning off LEDs and turning them on based on a predicted index (0, 1, or 2). It uses digital pins LEDR, LEDG, and LEDB.
- Status Bar:** Shows the message "Done uploading." followed by a progress bar indicating the upload is at 98% completion (70/71 pages).
- Bottom Status:** Displays the text "write(addr=0x34, size=0x1000)" and "writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)".
- Page Number:** The page number 78 is visible at the bottom left.
- Page Footer:** The footer text reads "Arduino Nano 33 BLE on /dev/cu.usbmodem144301".

nano_ble33_sense_microphone_leds | Arduino 1.8.15

```
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 }
```

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

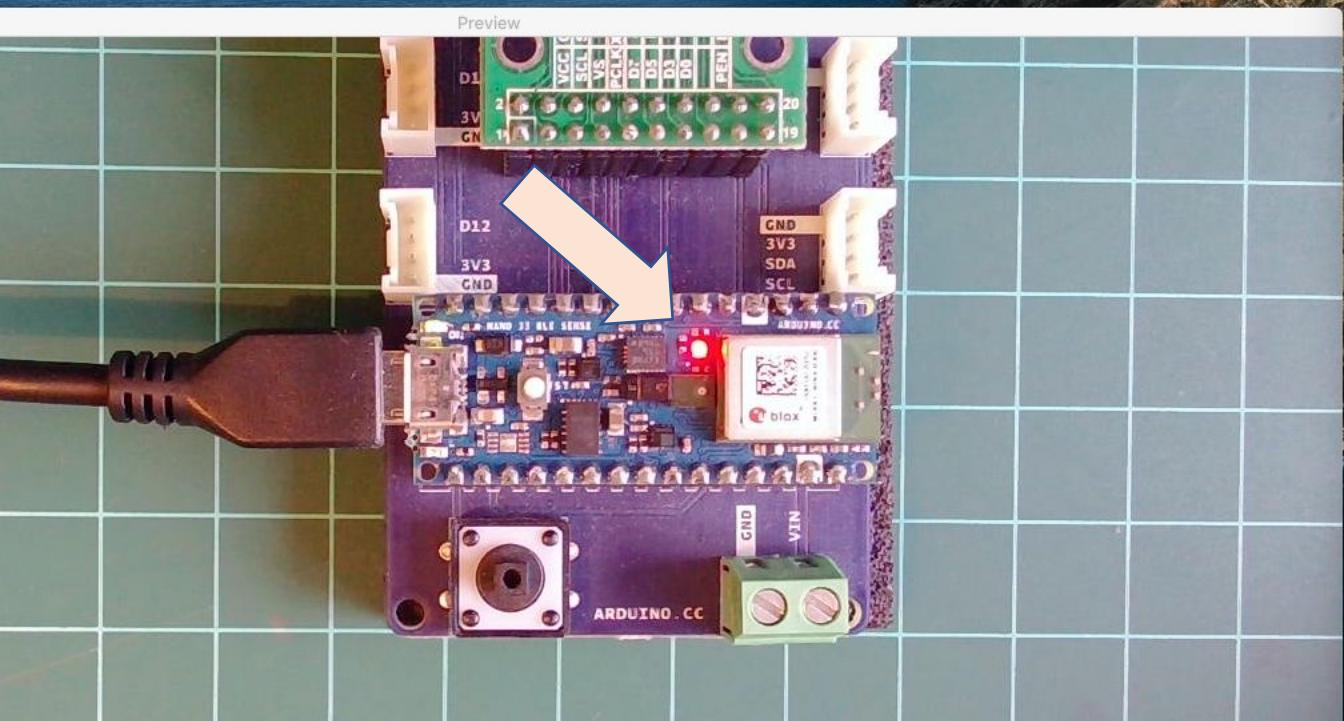
Recording...
 Recording done
 Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):
 :
 PREDICTION: ==> silence with probability 1.00
 :
 Starting inferencing in 2 seconds...
 Recording...
 Recording done
 Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):
 :
 PREDICTION: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

```

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.anoma
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, resu
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

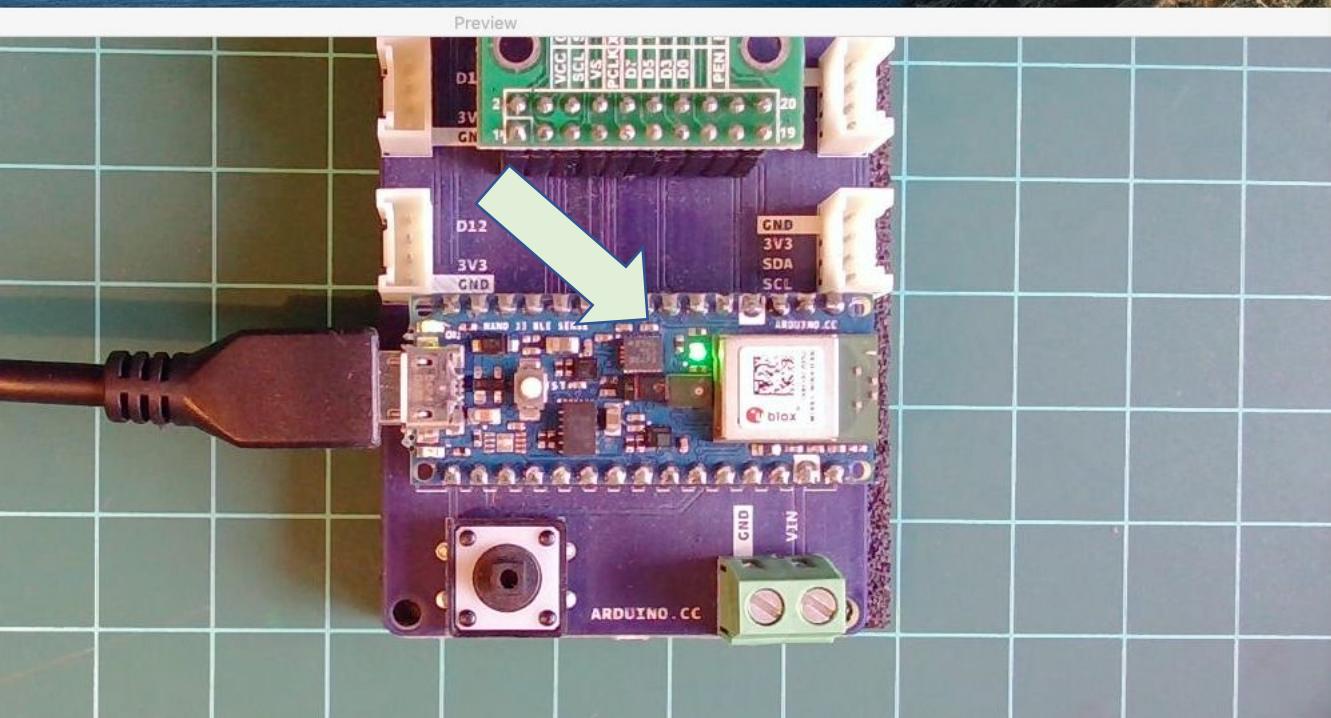
Recording...
 Recording done
 Predictions (DSP: 196 ms., Classification: 7 ms., Anomaly: 0 ms.):
 :
 PREDICTION: ==> silence with probability 1.00
 :
 Starting inferencing in 2 seconds...
 Recording...
 Recording done
 Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):
 :
 PREDICTION: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

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.anoma
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, resu
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);

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()
```

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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