

KeyWord Spotting – Application Development, The Edge Impulse (EI) Approach

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MARQUETTE
UNIVERSITY

BE THE DIFFERENCE.

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Create Your Own Audio Dataset

- Follow the steps in "Tutorial 12_2", Section 3 to create your own dataset.
- You must create a dataset to include (instead of "marquette", "engineering", and "silence") :
 1. Your First Name, e.g., "cris"
 2. Your Last Name, e.g., "ababei"
 3. Silence (with some background noise, such as a faucet running)
- Your audio files should be 1 second long
- Create 50 .wav files for each class

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KWS Classifier Project

Audio Raw Data Analysis

[audio_raw_data_analysis/audio_raw_data_analysis.ipynb](#)
Read also "Tutorial 12_2", Section 2



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3

Nano-33 BLE

Keyword Spotting (KWS) Project

<https://studio.edgeimpulse.com/public/209281/latest>



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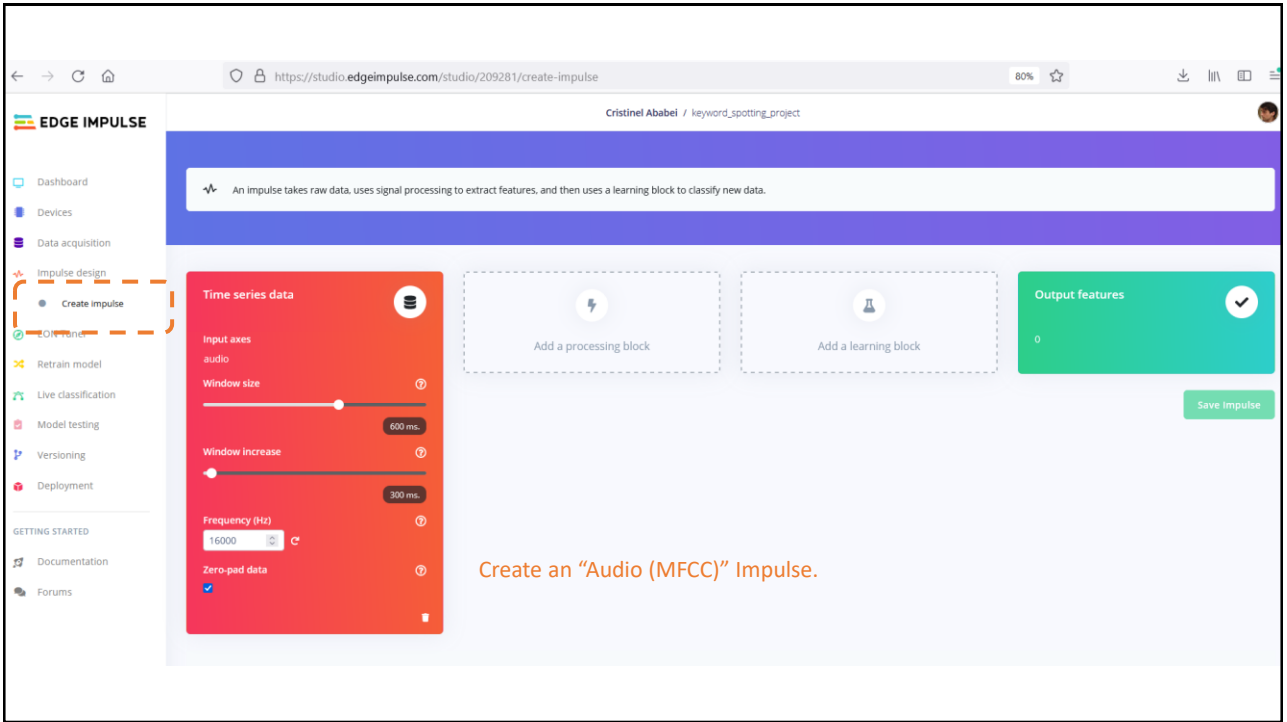
4

Follow the steps of creating an Edgimpulse project; which we learned in a previous lecture.

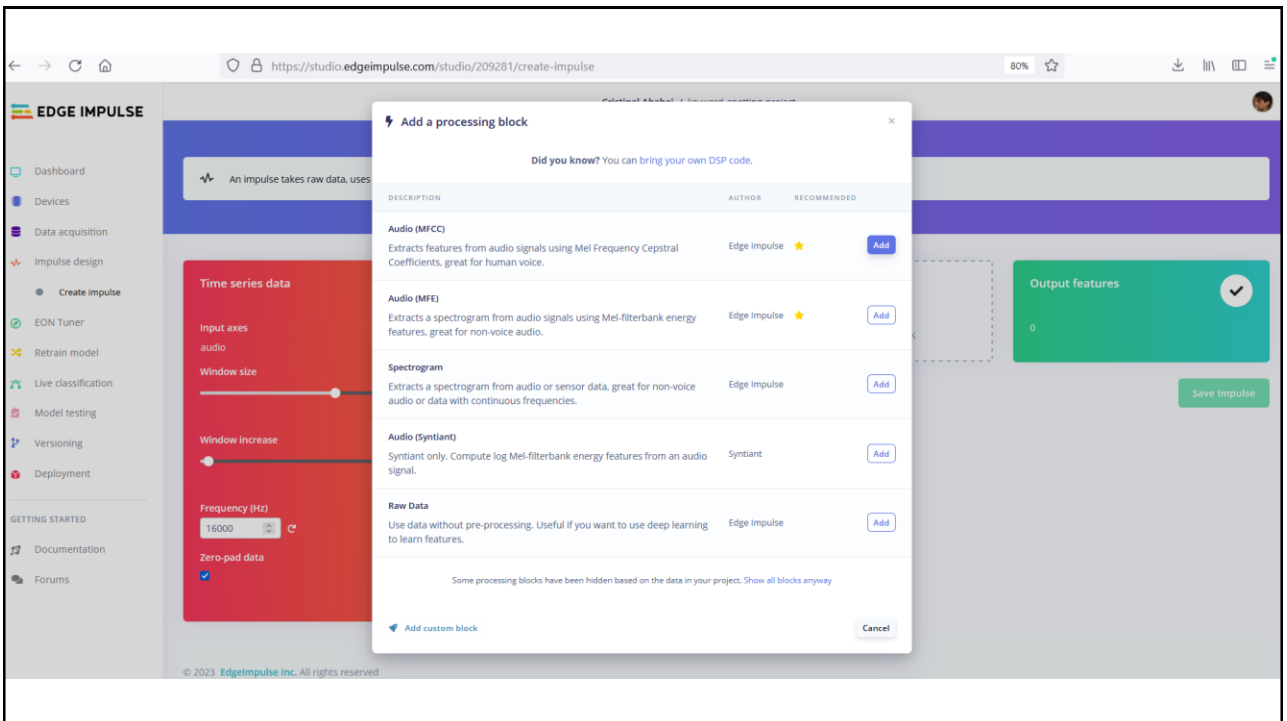
5

Upload 35 .wav files from each category into "Train" and "15" .wav files from each category into "Test" portions of the EI Dataset for project.

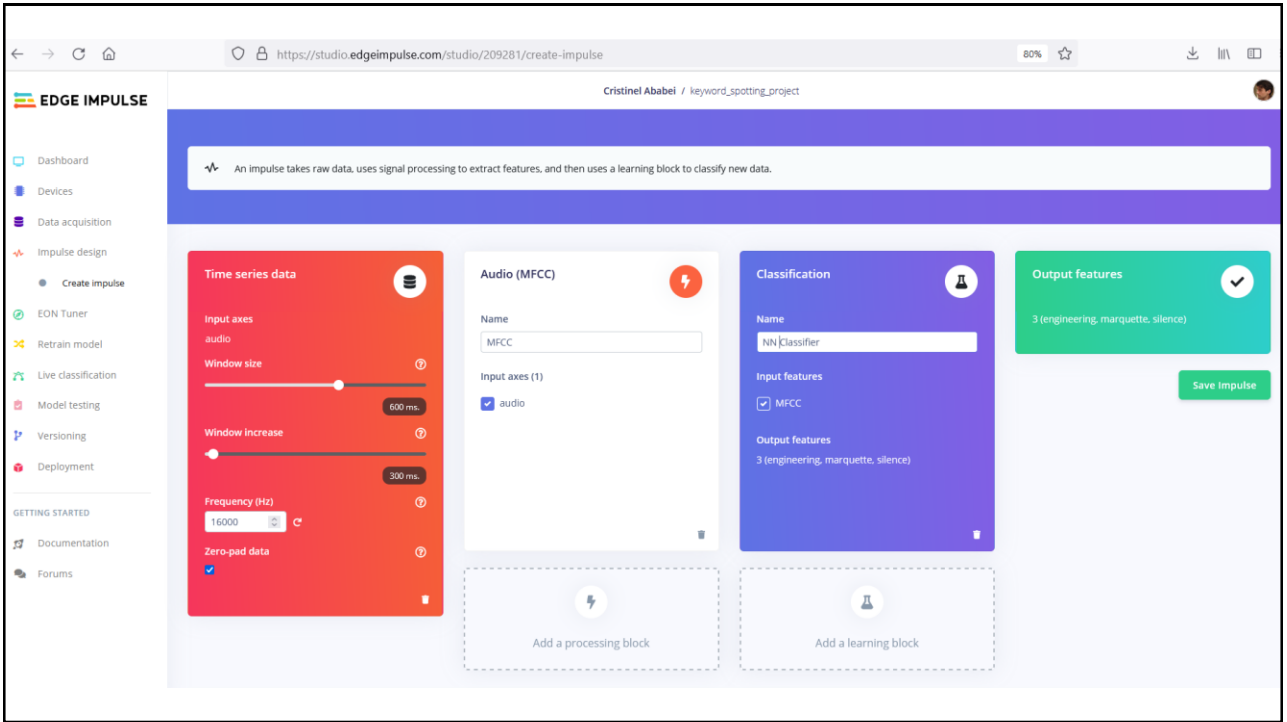
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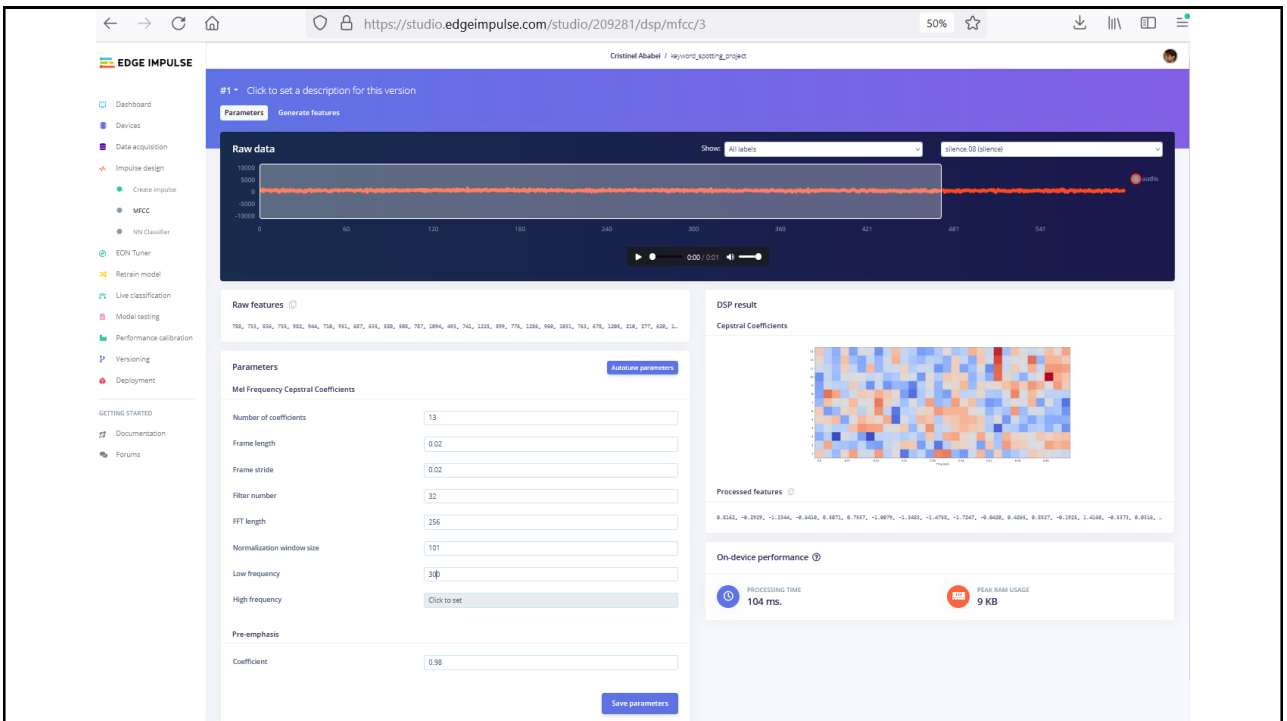
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EDGE IMPULSE

Dashboard
Devices
Data acquisition
Impulse design
Create impulse
MFCC
NN Classifier
EON Tuner
Retrain model
Live classification
Model testing
Performance calibration
Versioning
Deployment
GETTING STARTED
Documentation
Forums

https://studio.edgeimpulse.com/studio/209281/dsp/mfcc/3/generate-features

#1 Click to set a description for this version

Parameters **Generate features**

Training set

Data in training set 28s
Classes 3 (engineering, marquette, silence)
Training windows 46

Generate features

Feature explorer

● engineering
● marquette
● silence

Feature generation output

```
Still running...
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
Tue Apr 11 01:12:31 2023 Finished embedding
Reducing dimensions for visualizations OK
Job completed
```

On-device performance

PROCESSING TIME **104 ms.** PEAK RAM USAGE **9 KB**

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EDGE IMPULSE

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https://studio.edgeimpulse.com/studio/209281/learning/keras/5

#1 Click to set a description for this version

Neural Network settings

Training settings
Number of training cycles 100
Learning rate 0.005
Validation set size 20 %
Auto-balance dataset
Audio training options
Data augmentation
Neural network architecture
Architecture presets 1D Convolutional (Default) 2D Convolutional

Input layer (250 neurons)
Batching layer (13 channels)
1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)
Dropout layer (0.25)
1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)
Dropout layer (0.25)
Flatten layer
Add an extra layer
Output layer (3 classes)

Start training

Training output

Last training performance (validation set)

ACCURACY **100.0%** F1 SCORE **0.00**

Confusion matrix (validation set)

	ENGINEERING	MARQUETTE	SILENCE
ENGINEERING	100%	0%	0%
MARQUETTE	0%	100%	0%
SILENCE	0%	0%	100%
F1 SCORE	1.00	1.00	1.00

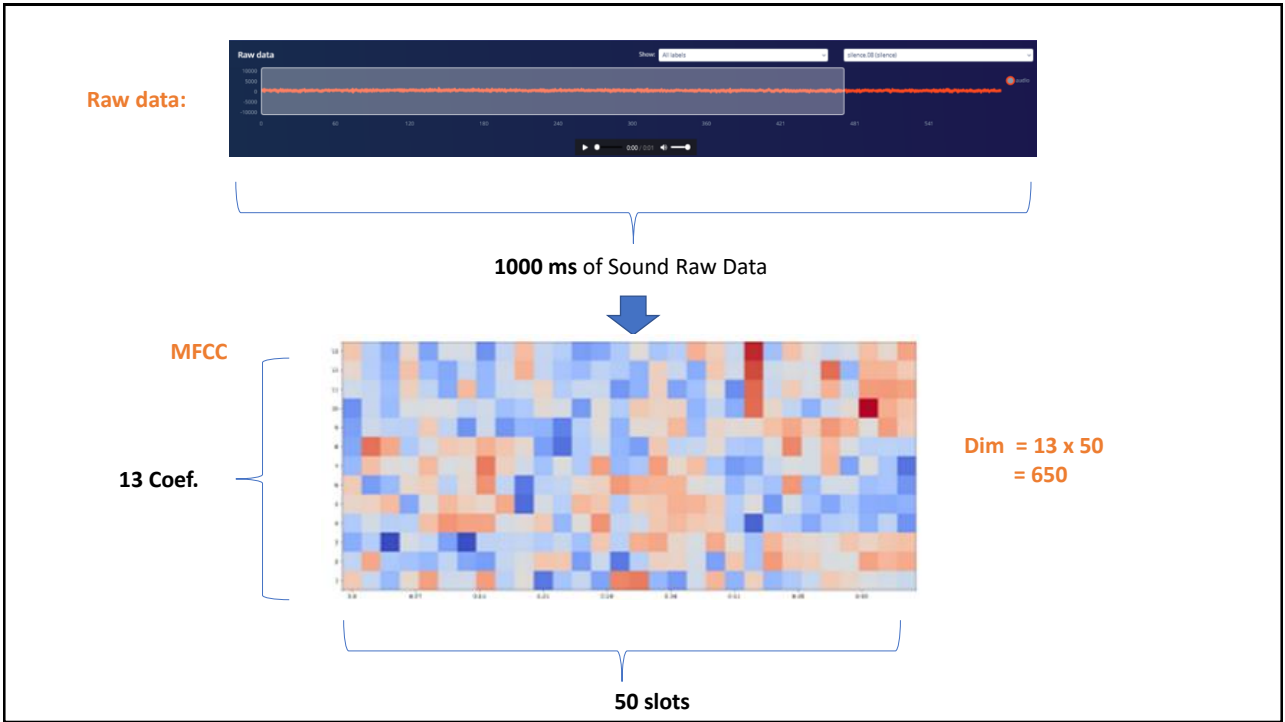
Data explorer (full training set)

● engineering - correct
● marquette - correct
● silence - correct

On-device performance

INFERRING TIME **3 ms.** PEAK RAM USAGE **4.6K** FLASH USAGE **26.4K**

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Download Arduino Library
ei-keyword_spotting_project-arduino-1.0.5.zip

Optimization	RAM USAGE	FLASH USAGE	LATENCY	ACCURACY
Quantized (int8) <i>Currently selected</i>	4.6K	26.4K	3 ms	-
Unoptimized (float32)	6.4K	20.1K	25 ms	-

Build

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KWS Application

Running it on Arduino!



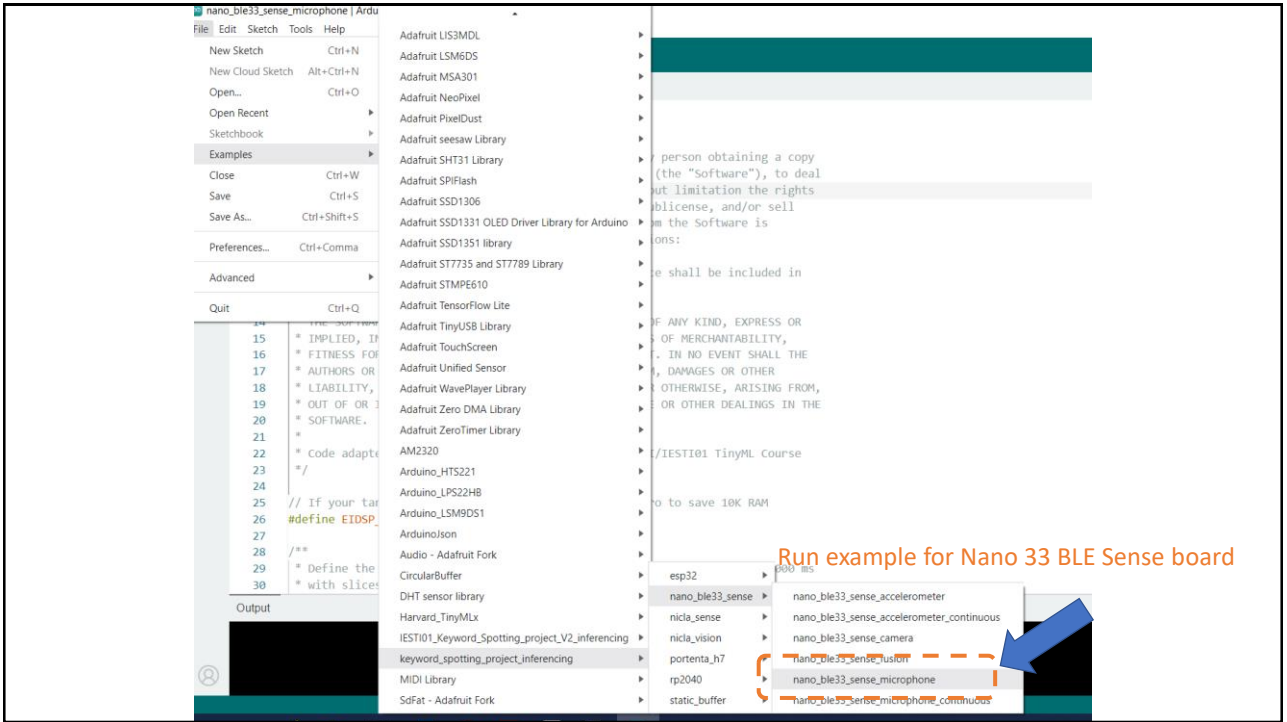
keyword_spotting_example\keyword_spotting_project_inferencing\...\nano_ble33_sense_microphone.ino

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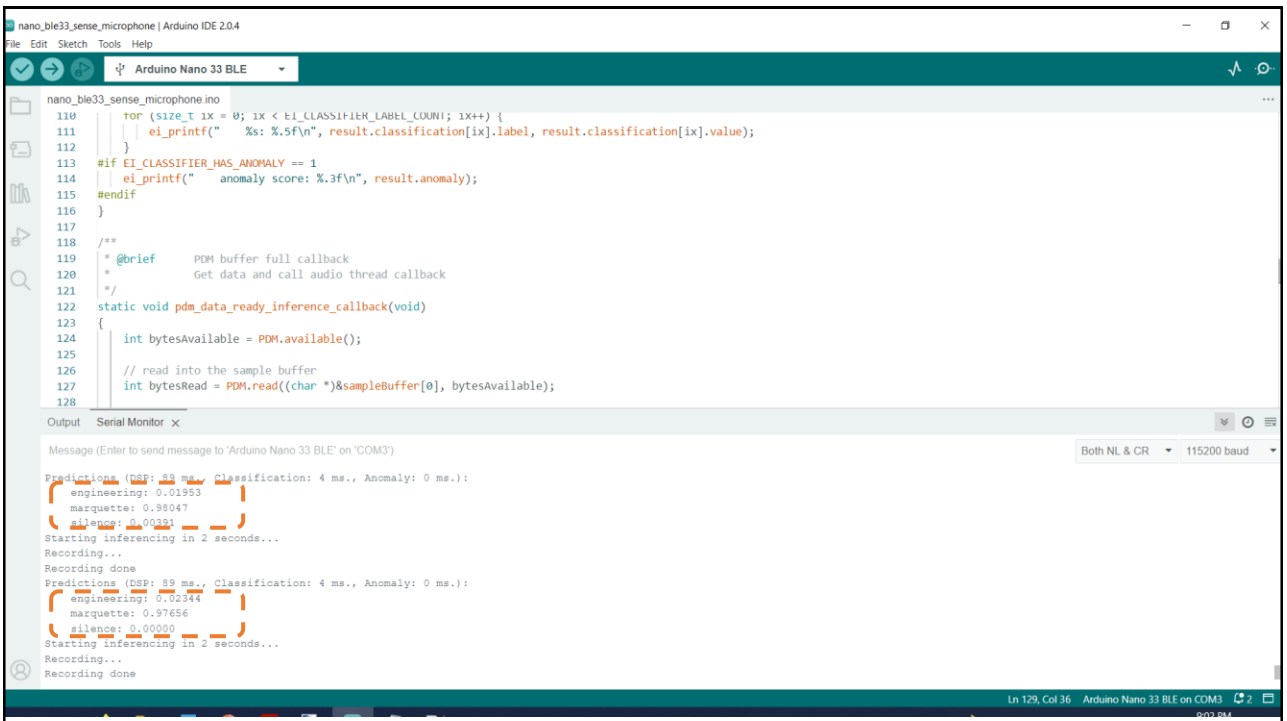
15

Install Arduino Library
Gets installed in:
M:\arduino221\libraries\libraries

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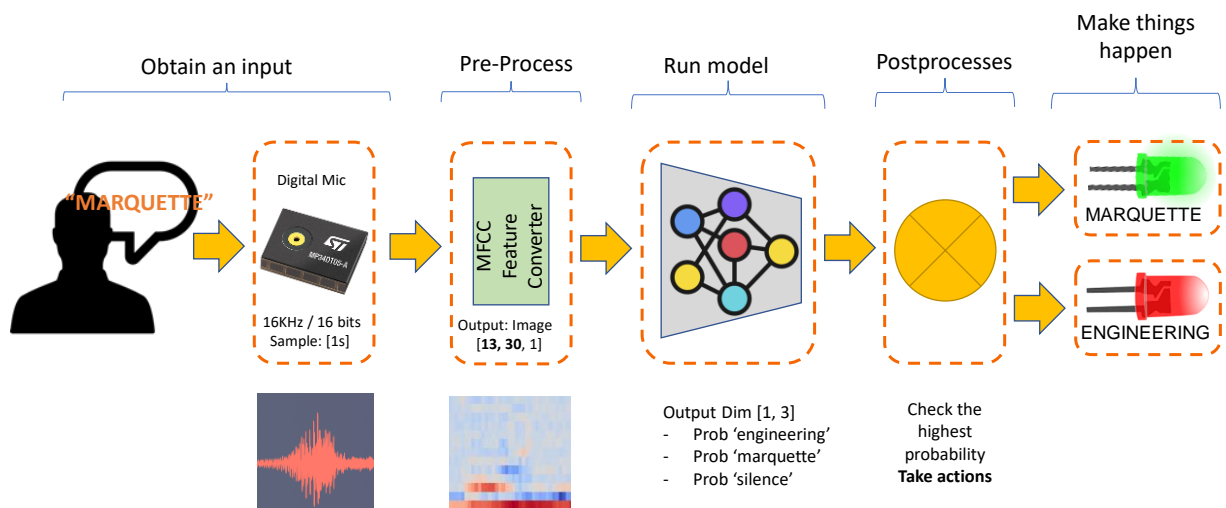
18

Change Arduino Application to Drive RGB LEDs

- Create a copy of the Arduino Application:
 - keyword_spotting_example\keyword_spotting_project_inferencing\examples\nano_ble33_sense\nano_ble33_sense_microphone
- as:
 - keyword_spotting_example\keyword_spotting_project_inferencing\examples\nano_ble33_sense\nano_ble33_sense_microphone_v2
- And, modify `nano_ble33_sense_microphone_v2.ino` to control the RGB LEDs such that:
 - **LEDG** is turn on when “marquette” is detected
 - **LEDR** is turn on when “engineering” is detected

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KeyWord Spotting (KWS) - Inference



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nano_ble33_sense_microphone_v2 | Arduino IDE 2.0.4
File Edit Sketch Tools Help
Arduino Nano 33 BLE
nano_ble33_sense_microphone_v2.ino
50
51 /**
52  * @brief   Arduino setup function
53  */
54 void setup()
55 {
56     // put your setup code here, to run once:
57     Serial.begin(115200);
58     // comment out the below line to cancel the wait for USB connection (needed for native USB)
59     while (!Serial);
60
61
62     Serial.println("EECE4710 - KWS Project");
63     // Pins for the built-in RGB LEDs on the Arduino Nano 33 BLE Sense
64     pinMode(LED_R, OUTPUT);
65     pinMode(LED_G, OUTPUT);
66     pinMode(LED_B, OUTPUT);
67
68     // Ensure the LED is off by default.
69     // Note: The RGB LEDs on the Arduino Nano 33 BLE
70     // Sense are on when the pin is LOW, off when HIGH.
71     digitalWrite(LED_R, HIGH);
72     digitalWrite(LED_G, HIGH);
73     digitalWrite(LED_B, HIGH);
74
75
76     // summary of inferencing settings (from model_metadata.h)
77     ei_printf("Inferencing settings:\n");
78     ei_printf("\tInterval: %.2f ms.\n", (float)EI_CLASSIFIER_INTERVAL_MS);
79     ei_printf("\tFrame size: %d\n", EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE);
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81 }
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```

nano_ble33_sense_microphone_v2 | Arduino IDE 2.0.4
File Edit Sketch Tools Help
Arduino Nano 33 BLE

nano_ble33_sense_microphone_v2.ino
153 void turn_off_leds()
154 {
155     digitalWrite(LED_R, HIGH);
156     digitalWrite(LED_G, HIGH);
157     digitalWrite(LED_B, HIGH);
158 }
159
160 /**
161  * @brief    turn_on_leds function used to turn on the RGB LEDs
162  * @param[in] pred_index
163  *           engineering: [0] ==> Red ON
164  *           marquette: [1] ==> Green ON
165  *           silence: [2] ==> All OFF
166  */
167 void turn_on_leds(int pred_index)
168 {
169     switch (pred_index)
170     {
171     case 0:
172         turn_off_leds();
173         digitalWrite(LED_R, LOW);
174         break;
175     case 1:
176         turn_off_leds();
177         digitalWrite(LED_G, LOW);
178         break;
179     case 2:
180
181

```

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```

nano_ble33_sense_microphone_v2 | Arduino IDE 2.0.4
File Edit Sketch Tools Help
Arduino Nano 33 BLE

nano_ble33_sense_microphone_v2.ino
130     for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
131         if (result.classification[ix].value > pred_value){
132             pred_index = ix;
133             pred_value = result.classification[ix].value;
134         }
135     }
136     ei_printf("\n");
137     ei_printf(" PREDICTION: ==> %s with probability %.2f\n",
138             result.classification[pred_index].label, pred_value);
139     ei_printf("\n");
140     turn_on_leds (pred_index);
141
142
143 #if EI_CLASSIFIER_HAS_ANOMALY == 1
144     ei_printf("    anomaly score: %.3f\n", result.anomaly);
145 #endif

```

Output Serial Monitor x

```

Message (Enter to send message to 'Arduino Nano 33 BLE' on 'COM3')
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 88 ms., Classification: 4 ms., Anomaly: 0 ms.):
:
: PREDICTION: ==> marquette with probability 0.87
:
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 88 ms., Classification: 4 ms., Anomaly: 0 ms.):
:
: PREDICTION: ==> engineering with probability 0.88
:
Starting inferencing in 2 seconds...
Recording...
Recording done

```

Run updated example for Nano 33 BLE Sense board

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KWS Classifier Project

Looking “Under the Hood”

`keyword_spotting_example\
keyword_spotting_project_nn_classifier.ipynb`



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25

Credits

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 - <https://github.com/Mjrovai/UNIFEI-IESTI01-TinyML-2022.1>
 - Prof. Vijay Janapa Reddi - CS249r: Tiny Machine Learning, Applied Machine Learning on Embedded IoT Devices, Harvard
 - <https://sites.google.com/g.harvard.edu/tinyml/home>
 - Prof. Rahul Mangharam – ESE3600: Tiny Machine Learning, Univ. of Pennsylvania
 - <https://tinyml.seas.upenn.edu/#>
 - Prof. Brian Plancher - Harvard CS249r: Tiny Machine Learning (TinyML), Barnard College, Columbia University
 - https://a2r-lab.org/courses/cs249r_tinyml/

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References

- Additional references from where information and other teaching materials were gathered include:

- Applications & Deploy textbook: “TinyML” by Pete Warden, Daniel Situnayake
 - <https://www.oreilly.com/library/view/tinyml/9781492052036/>
- Deploy textbook “TinyML Cookbook” by Gian Marco Iodice
 - <https://github.com/PacktPublishing/TinyML-Cookbook>
- Jason Brownlee
 - <https://machinelearningmastery.com/>
- TinyMLedu
 - <https://tinyml.seas.harvard.edu/>
- Professional Certificate in Tiny Machine Learning (TinyML) – edX/Harvard
 - <https://www.edx.org/professional-certificate/harvardx-tiny-machine-learning>
- Introduction to Embedded Machine Learning - Coursera/Edge Impulse
 - <https://www.coursera.org/learn/introduction-to-embedded-machine-learning>
- Computer Vision with Embedded Machine Learning - Coursera/Edge Impulse
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