Edge Computing Laboratory
Lab Assignment 7

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Title : Study of Classification learning block using a NN Classifier on Edge Devices

Objective: Build a project to detect the keywords using built-in sensor on Nano BLE Sense / Mobile Phone **Tasks:**

- Generate the dataset for keyword
- Configure BLE Sense / Mobile for Edge Impulse
- Building and Training a Model

Study of **Confusion matrix**

Introduction

Edge Impulse is a development platform for machine learning on edge devices, targeted at developers who want to create intelligent device solutions. The "classification block" equivalent in Edge Impulse would typically involve creating a simple machine learning model that can run on an edge device, like classifying sensor data or recognizing a basic pattern.

Materials Required

- Nano BLE Sense Board

Theory

GPIO (General Purpose Input/Output) pins on the Raspberry Pi are used for interfacing with other electronic components. BCM numbering refers to the pin numbers in the Broadcom SOC channel, which is a more consistent way to refer to the GPIO pins across different versions the

Here's a high-level overview of steps you'd follow to create a "Hello World" project on Edge Impulse:

Steps to Configure the Edge Impulse:

1. Create an Account and New Project:
   - Sign up for an Edge Impulse account.
   - Create a new project from the dashboard.
2. Connect a Device:

- You can use a supported development board or your smartphone as a sensor device.
- Follow the instructions to connect your device to your Edge Impulse project.

3. Collect Data:
    - Use the Edge Impulse mobile app or the Web interface to collect data from the onboard sensors.
    - For a "Hello World" project, you could collect accelerometer data, for instance.
4. Create an Impulse:
    - Go to the 'Create impulse' page.
    - Add a processing block (e.g., time-series data) and a learning block (e.g., classification).
    - Save the impulse, which defines the machine learning pipeline.
5. Design a Neural Network:
    - Navigate to the 'NN Classifier' under the 'Learning blocks'.
    - Design a simple neural network. Edge Impulse provides a default architecture that works well for most basic tasks.
6. Train the Model:

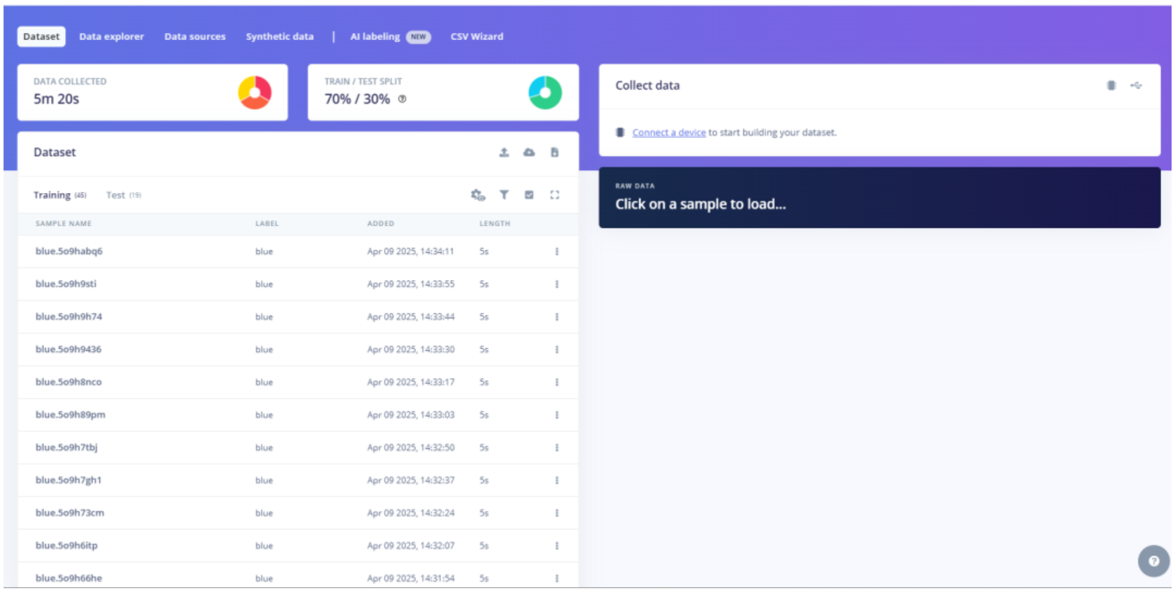
     Click on the 'Start training' button to train your machine learning model with the collected data.
7. Test the Model:

     Once the model is trained, you can test its performance with new data in the 'Model Testing' tab.
8. Deploy the Model:
    - Go to the 'Deployment' tab.
    - Select the deployment method that suits your edge device (e.g., Arduino library, WebAssembly, container, etc.).
    - Follow the instructions to deploy the model to your device.
9. Run Inference:

     With the model deployed, run inference on the edge device to see it classifying data in real-time.
10. Monitor:

    You can monitor the performance of your device through the Edge Impulse studio.

1 .DATASET-



DATA COLLECTED
5m 20s

TRAIN / TEST SPLIT
70% / 30%

Collect data

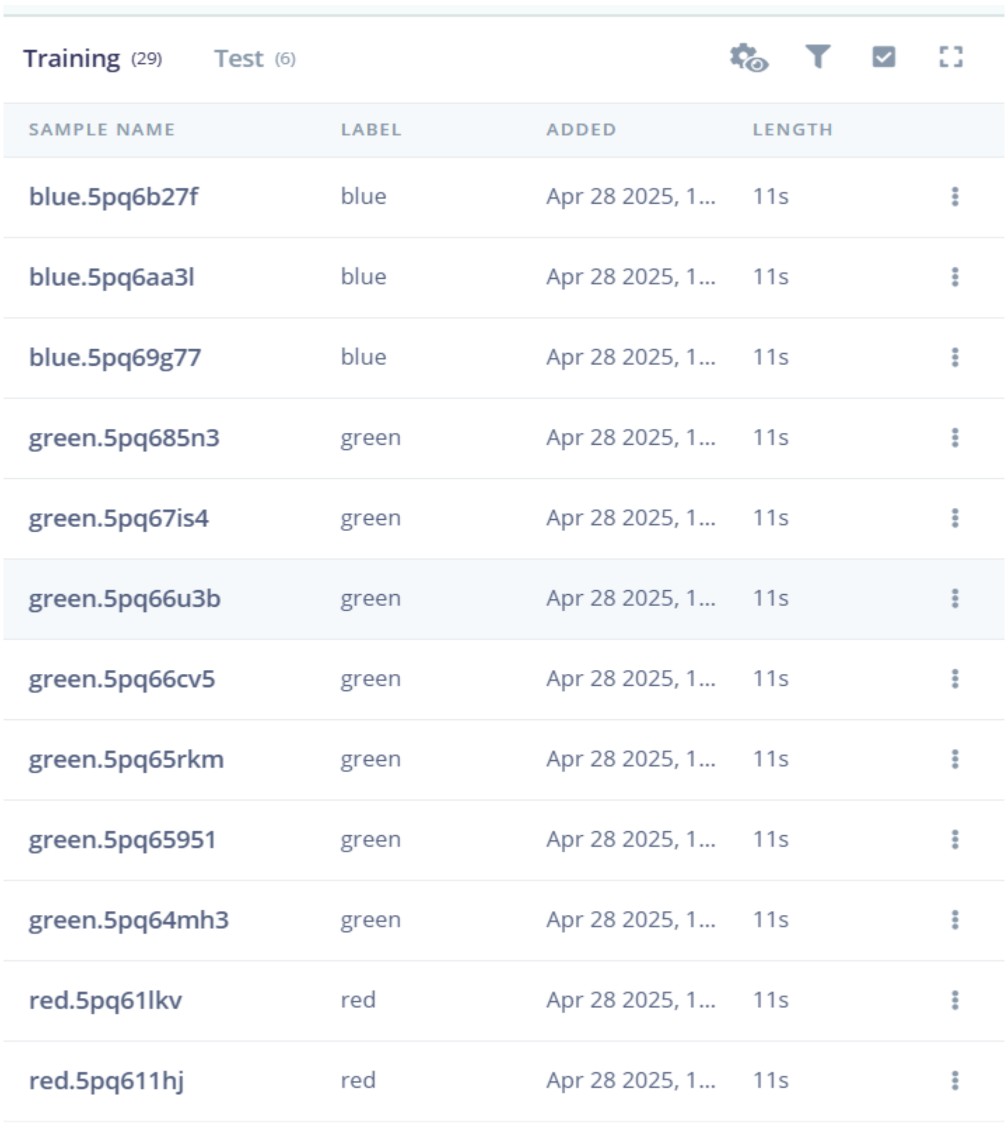
Connect a device to start building your dataset.

RAW DATA
Click on a sample to load...

Dataset

Training (45) Test (19)

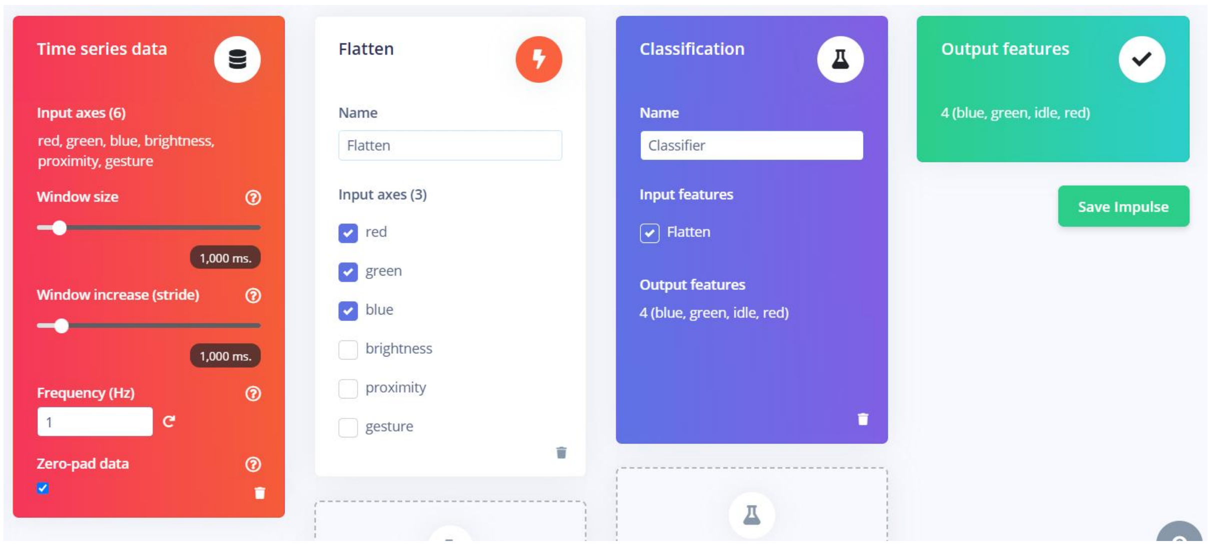
SAMPLE NAME	LABEL	ADDED	LENGTH
blue.5o9habq6	blue	Apr 09 2025, 14:34:11	5s
blue.5o9h9sti	blue	Apr 09 2025, 14:33:55	5s
blue.5o9h9h74	blue	Apr 09 2025, 14:33:44	5s
blue.5o9h9436	blue	Apr 09 2025, 14:33:30	5s
blue.5o9h8nco	blue	Apr 09 2025, 14:33:17	5s
blue.5o9h89pm	blue	Apr 09 2025, 14:33:03	5s
blue.5o9h7tbj	blue	Apr 09 2025, 14:32:50	5s
blue.5o9h7gh1	blue	Apr 09 2025, 14:32:37	5s
blue.5o9h73cm	blue	Apr 09 2025, 14:32:24	5s
blue.5o9h6itp	blue	Apr 09 2025, 14:32:07	5s
blue.5o9h66he	blue	Apr 09 2025, 14:31:54	5s



Training (29) Test (6)

SAMPLE NAME	LABEL	ADDED	LENGTH
blue.5pq6b27f	blue	Apr 28 2025, 1...	11s
blue.5pq6aa3l	blue	Apr 28 2025, 1...	11s
blue.5pq69g77	blue	Apr 28 2025, 1...	11s
green.5pq685n3	green	Apr 28 2025, 1...	11s
green.5pq67is4	green	Apr 28 2025, 1...	11s
green.5pq66u3b	green	Apr 28 2025, 1...	11s
green.5pq66cv5	green	Apr 28 2025, 1...	11s
green.5pq65rkm	green	Apr 28 2025, 1...	11s
green.5pq65951	green	Apr 28 2025, 1...	11s
green.5pq64mh3	green	Apr 28 2025, 1...	11s
red.5pq61lkv	red	Apr 28 2025, 1...	11s
red.5pq611hj	red	Apr 28 2025, 1...	11s

2. Feature Extraction Image



Time series data

Input axes (6)

red, green, blue, brightness, proximity, gesture

Window size: 1,000 ms.

Window increase (stride): 1,000 ms.

Frequency (Hz): 1

Zero-pad data: ✓

Flatten

Name: Flatten

Input axes (3)

- ✓ red
- ✓ green
- ✓ blue
- brightness
- proximity
- gesture

Classification

Name: Classifier

Input features

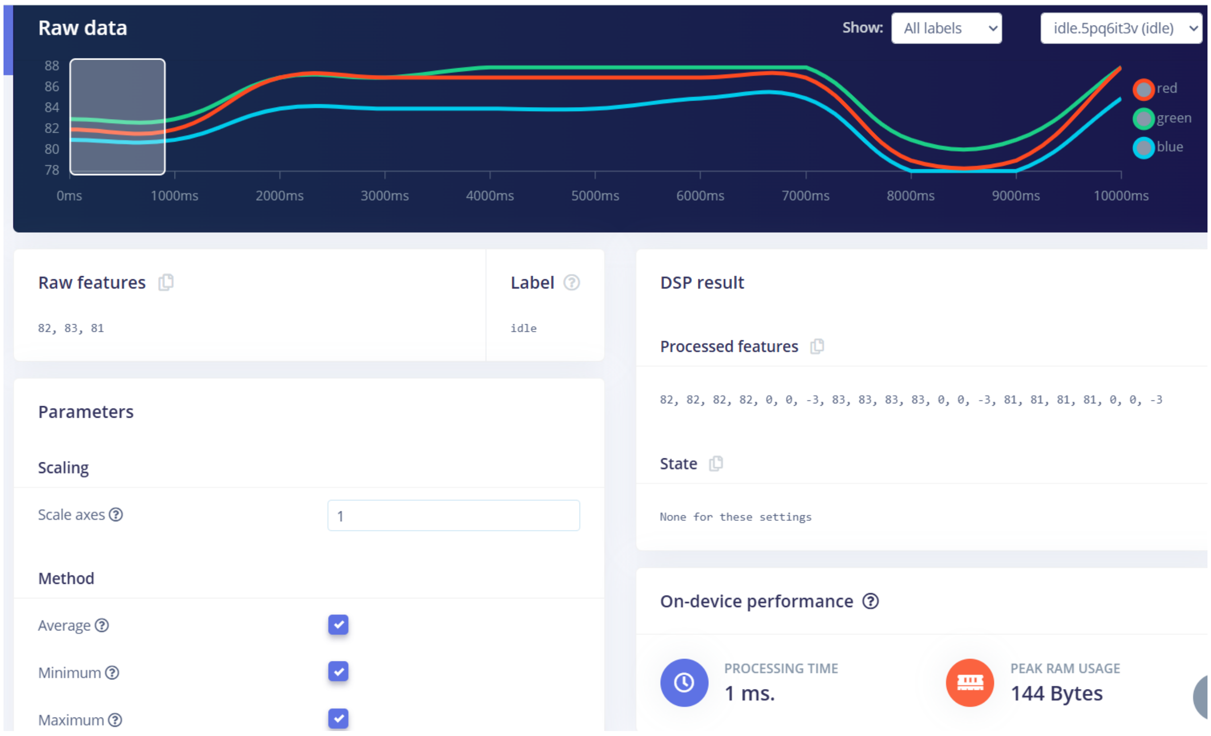
- ✓ Flatten

Output features

4 (blue, green, idle, red)

Output features

4 (blue, green, idle, red)



Raw features

```
82, 83, 81
```

Label

```
idle
```

Parameters

Scaling

Scale axes: 1

Method

- Average: ✓
- Minimum: ✓
- Maximum: ✓

DSP result

Processed features

```
82, 82, 82, 82, 0, 0, -3, 83, 83, 83, 83, 0, 0, -3, 81, 81, 81, 81, 0, 0, -3
```

State

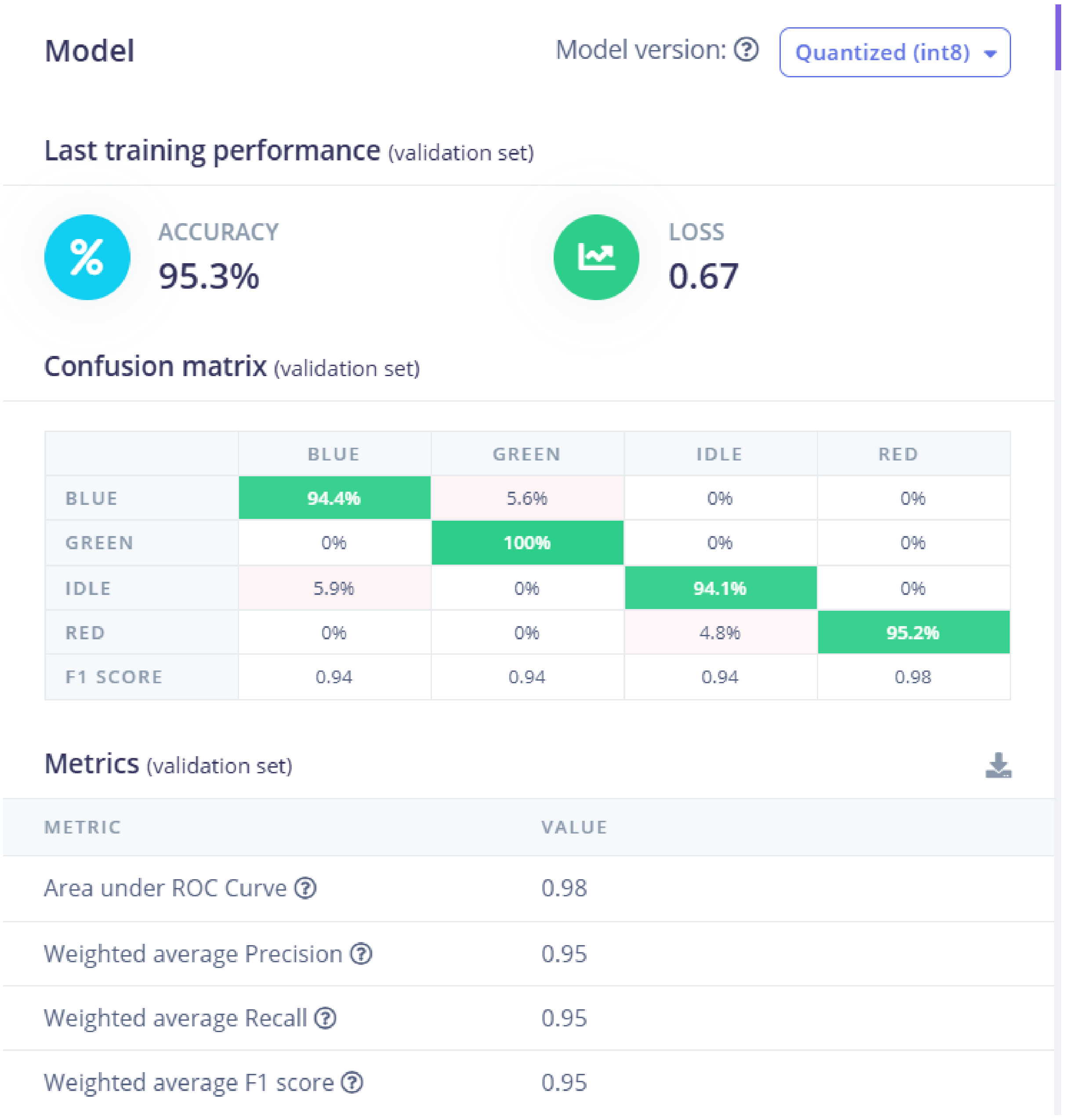
```
None for these settings
```

On-device performance

PROCESSING TIME 1 ms.

PEAK RAM USAGE 144 Bytes

3. Accuracy / Loss Confusion Matrix Image



Model

Model version: ⓘ Quantized (int8)

Last training performance (validation set)

ACCURACY 95.3%

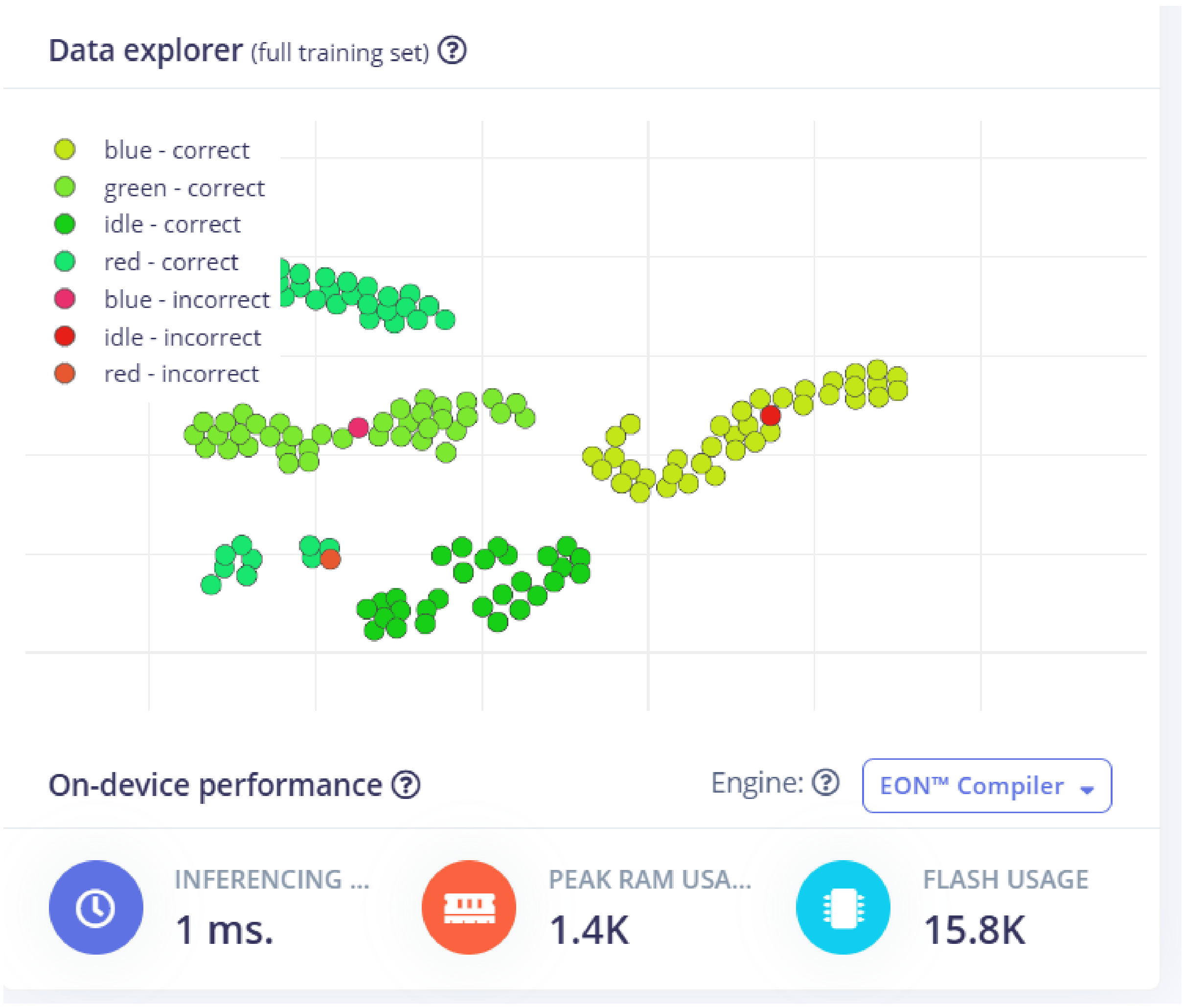
LOSS 0.67

Confusion matrix (validation set)

	BLUE	GREEN	IDLE	RED
BLUE	94.4%	5.6%	0%	0%
GREEN	0%	100%	0%	0%
IDLE	5.9%	0%	94.1%	0%
RED	0%	0%	4.8%	95.2%
F1 SCORE	0.94	0.94	0.94	0.98

Metrics (validation set)

METRIC	VALUE
Area under ROC Curve ⓘ	0.98
Weighted average Precision ⓘ	0.95
Weighted average Recall ⓘ	0.95
Weighted average F1 score ⓘ	0.95

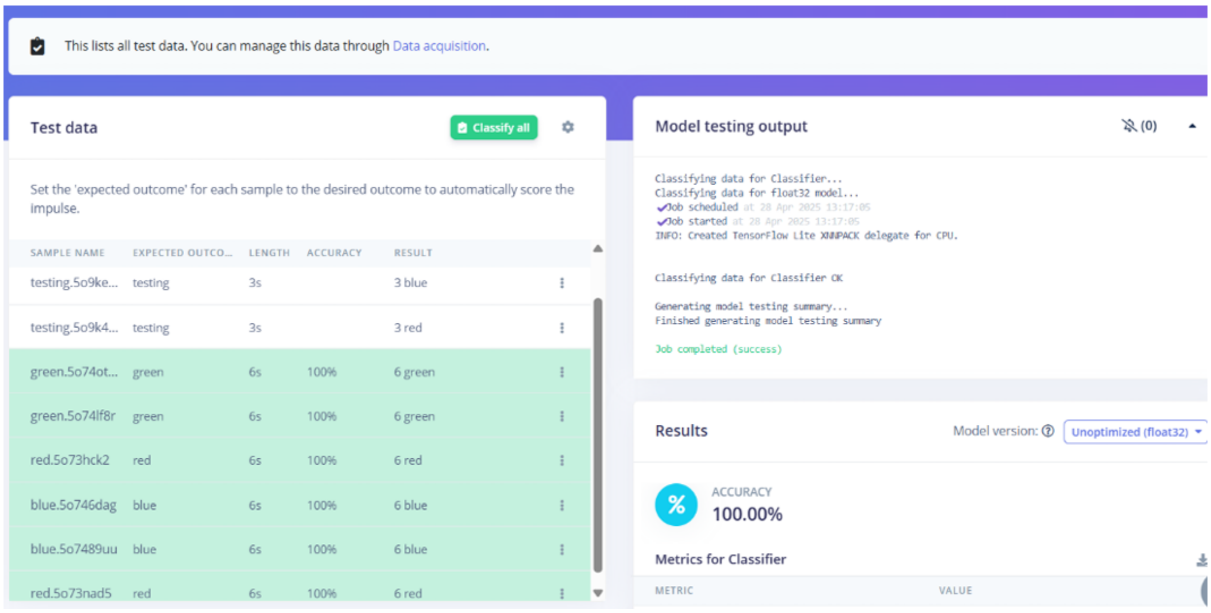


On-device performance

Engine: EON™ Compiler

INFERENCING ...	1 ms.
PEAK RAM USA...	1.4K
FLASH USAGE	15.8K

4. Validation Result


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 OUTCO...	LENGTH	ACCURACY	RESULT
testing.5o9ke...	testing	3s		3 blue
testing.5o9k4...	testing	3s		3 red
green.5o74ot...	green	6s	100%	6 green
green.5o74lf8r	green	6s	100%	6 green
red.5o73hck2	red	6s	100%	6 red
blue.5o746dag	blue	6s	100%	6 blue
blue.5o7489uu	blue	6s	100%	6 blue
red.5o73nad5	red	6s	100%	6 red

Model testing output

```
Classifying data for Classifier...
Classifying data for float32 model...
✓Job scheduled at 28 Apr 2025 13:17:05
✓Job started at 28 Apr 2025 13:17:05
INFO: Created TensorFlow Lite XNNPACK delegate for CPU.


Classifying data for Classifier OK

Generating model testing summary...
Finished generating model testing summary

Job completed (success)
```

Results

Model version: Unoptimized (float32)

ACCURACY
100.00%

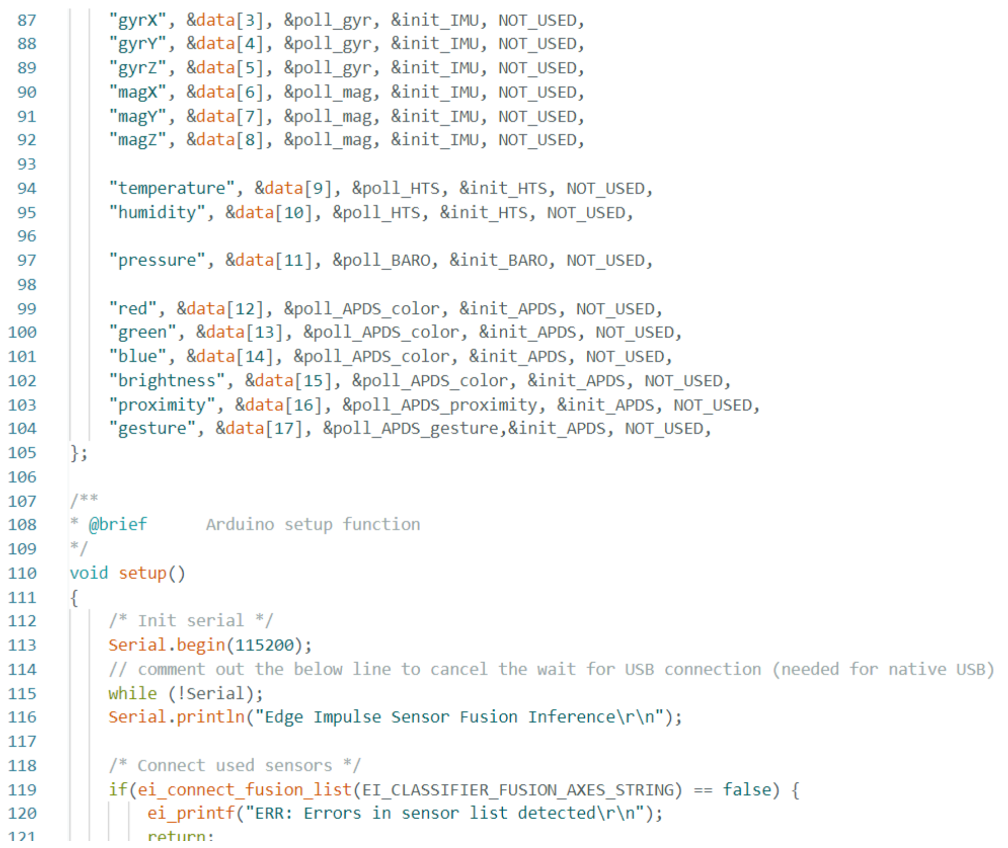
Metrics for Classifier

METRIC	VALUE

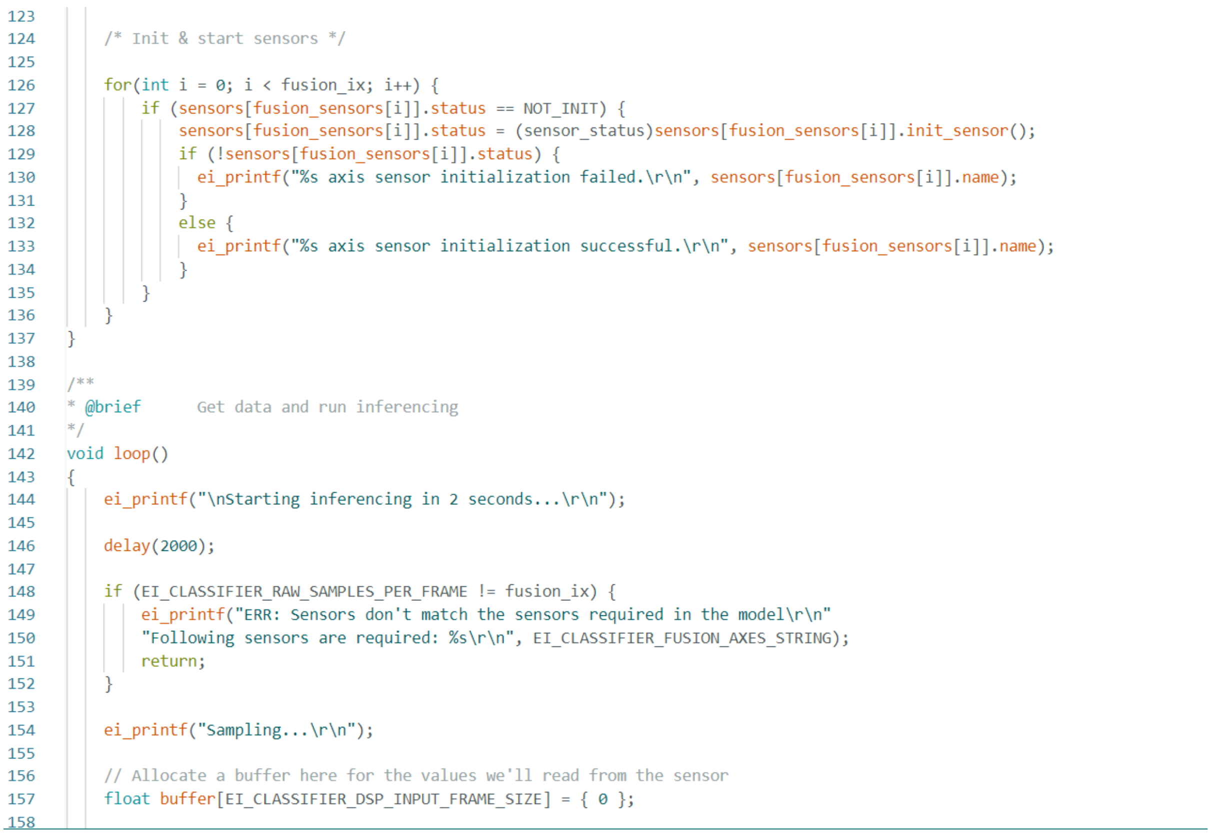
5.CODE-

nano_ble33_sense_fusion.ino

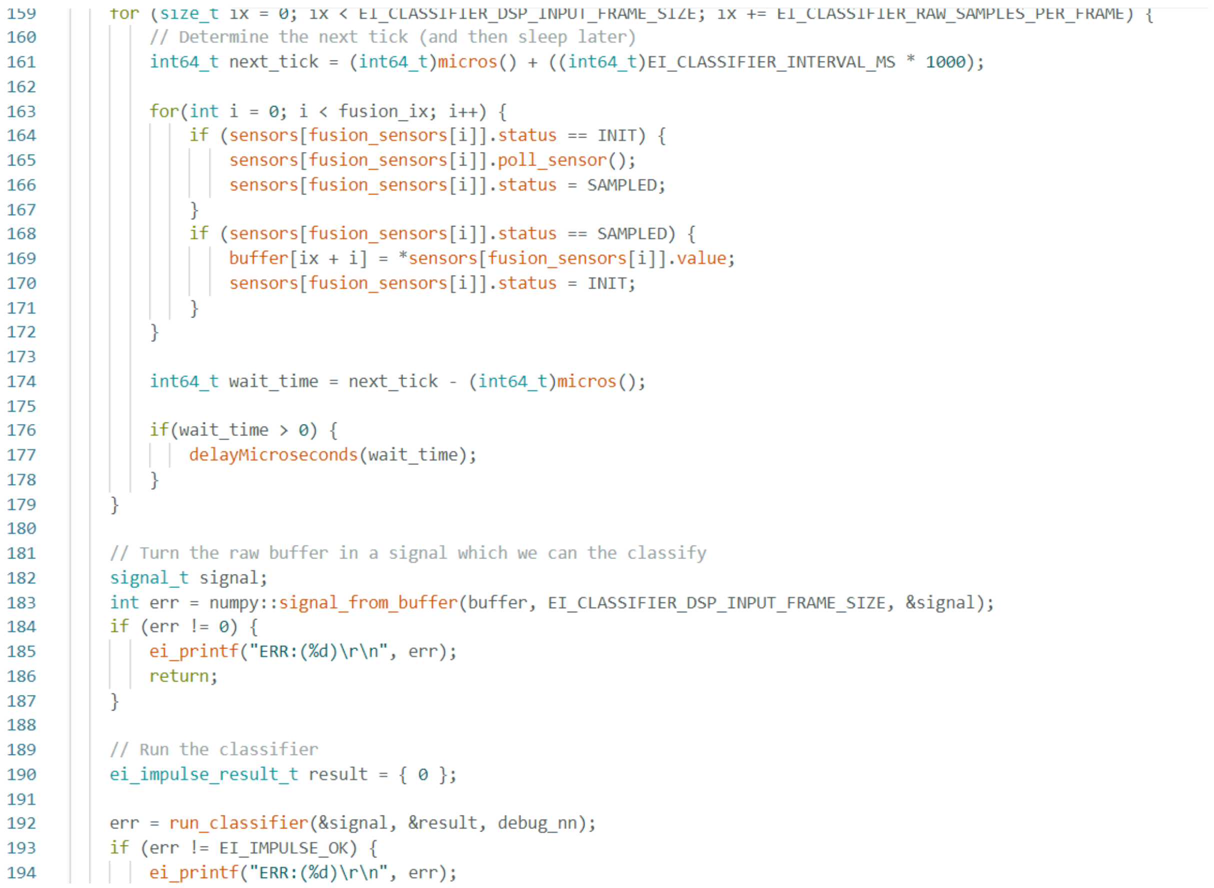
```
/* Includes ---------------------------------------------------------------- */
#include <vidya_khopade-project-1_inferencing.h>
#include <Arduino_LSM9DS1.h> //Click here to get the library: https://www.arduino.cc/reference/en/libraries/arduino_lsm9ds1/
#include <Arduino_LPS22HB.h> //Click here to get the library: https://www.arduino.cc/reference/en/libraries/arduino_lps22hb/
#include <Arduino_HTS221.h> //Click here to get the library: https://www.arduino.cc/reference/en/libraries/arduino_hts221/
#include <Arduino_APDS9960.h> //Click here to get the library: https://www.arduino.cc/reference/en/libraries/arduino_apds9960/

enum sensor_status {
    NOT_USED = -1,
    NOT_INIT,
    INIT,
    SAMPLED
};

/** Struct to link sensor axis name to sensor value function */
typedef struct{
    const char *name;
    float *value;
    uint8_t (*poll_sensor)(void);
    bool (*init_sensor)(void);
    sensor_status status;
} eiSensors;

/* Constant defines -------------------------------------------------------- */
#define CONVERT_G_TO_MS2    9.80665f

/**
 * When data is collected by the Edge Impulse Arduino Nano 33 BLE Sense
 * firmware, it is limited to a 2G range. If the model was created with a
 * different sample range, modify this constant to match the input values.
 * See https://github.com/edgeimpulse/firmware-arduino-nano-33-ble-sense/blob/master/src/sensors/ei_lsm9ds1.cpp
 * for more information.
 */
#define MAX_ACCEPTED_RANGE  2.0f

/** Number sensor axes used */
#define N_SENSORS     18

/* Forward declarations ------------------------------------------------------- */
float ei_get_sign(float number);

bool init_IMU(void);
bool init_HTS(void);
bool init_BARO(void);
bool init_APDS(void);

uint8_t poll_acc(void);
uint8_t poll_gyr(void);
uint8_t poll_mag(void);
uint8_t poll_HTS(void);
uint8_t poll_BARO(void);
uint8_t poll_APDS_color(void);
uint8_t poll_APDS_proximity(void);
uint8_t poll_APDS_gesture(void);

/* Private variables ------------------------------------------------------- */
static const bool debug_nn = false; // Set this to true to see e.g. features generated from the raw signal

static float data[N_SENSORS];
static bool ei_connect_fusion_list(const char *input_list);

static int8_t fusion_sensors[N_SENSORS];
static int fusion_ix = 0;

/** Used sensors value function connected to label name */
eiSensors sensors[] =
{
    "accX", &data[0], &poll_acc, &init_IMU, NOT_USED,
    "accY", &data[1], &poll_acc, &init_IMU, NOT_USED,
    "accZ", &data[2], &poll_acc, &init_IMU, NOT_USED,
```



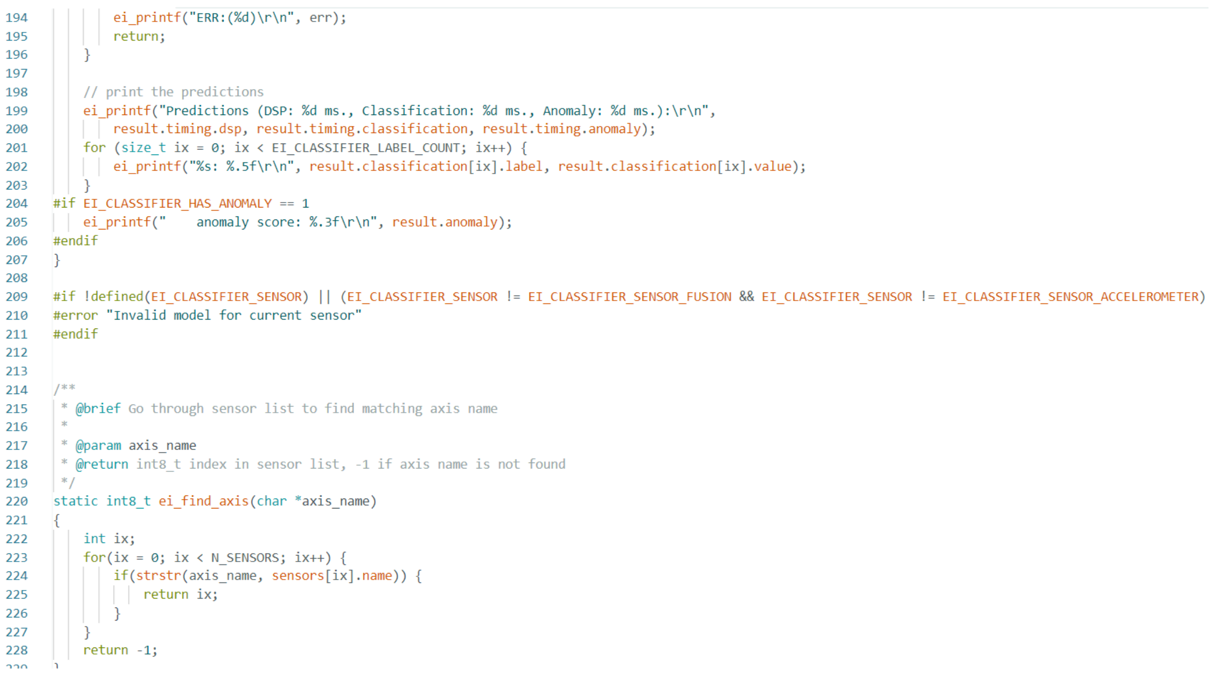
```
    "gyrX", &data[3], &poll_gyr, &init_IMU, NOT_USED,
    "gyrY", &data[4], &poll_gyr, &init_IMU, NOT_USED,
    "gyrZ", &data[5], &poll_gyr, &init_IMU, NOT_USED,
    "magX", &data[6], &poll_mag, &init_IMU, NOT_USED,
    "magY", &data[7], &poll_mag, &init_IMU, NOT_USED,
    "magZ", &data[8], &poll_mag, &init_IMU, NOT_USED,

    "temperature", &data[9], &poll_HTS, &init_HTS, NOT_USED,
    "humidity", &data[10], &poll_HTS, &init_HTS, NOT_USED,

    "pressure", &data[11], &poll_BARO, &init_BARO, NOT_USED,

    "red", &data[12], &poll_APDS_color, &init_APDS, NOT_USED,
    "green", &data[13], &poll_APDS_color, &init_APDS, NOT_USED,
    "blue", &data[14], &poll_APDS_color, &init_APDS, NOT_USED,
    "brightness", &data[15], &poll_APDS_color, &init_APDS, NOT_USED,
    "proximity", &data[16], &poll_APDS_proximity, &init_APDS, NOT_USED,
    "gesture", &data[17], &poll_APDS_gesture,&init_APDS, NOT_USED,
};

/**
* @brief      Arduino setup function
*/
void setup()
{
    /* Init serial */
    Serial.begin(115200);
    // comment out the below line to cancel the wait for USB connection (needed for native USB)
    while (!Serial);
    Serial.println("Edge Impulse Sensor Fusion Inference\r\n");

    /* Connect used sensors */
    if(ei_connect_fusion_list(EI_CLASSIFIER_FUSION_AXES_STRING) == false) {
        ei_printf("ERR: Errors in sensor list detected\r\n");
        return;
```



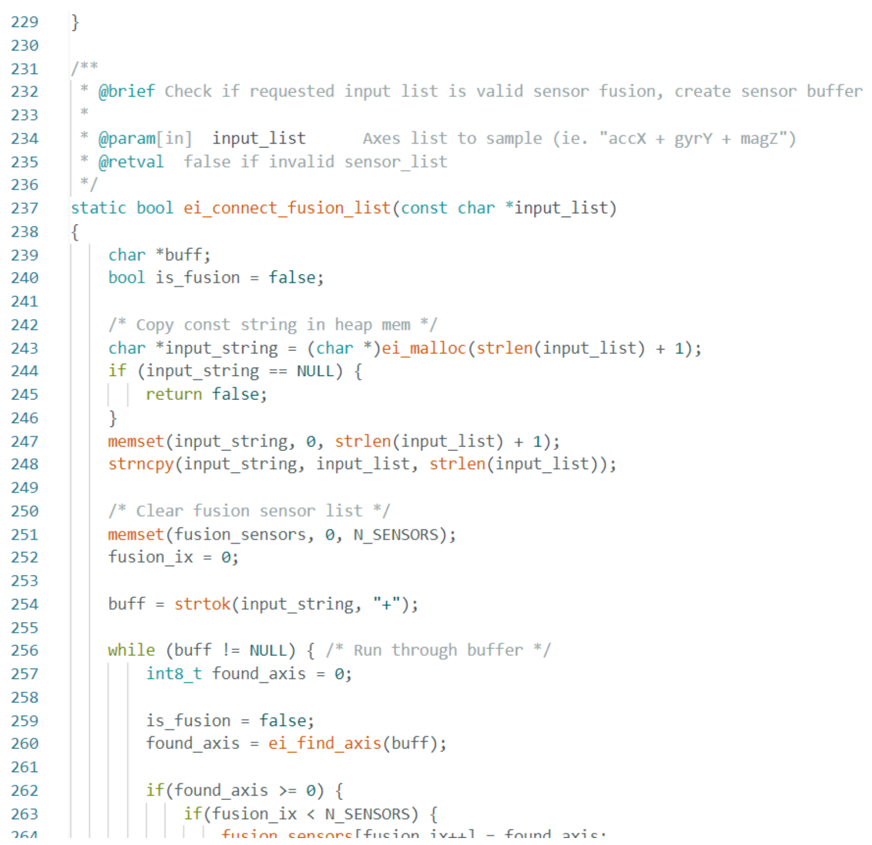
```

    /* Init & start sensors */

    for(int i = 0; i < fusion_ix; i++) {
        if (sensors[fusion_sensors[i]].status == NOT_INIT) {
            sensors[fusion_sensors[i]].status = (sensor_status)sensors[fusion_sensors[i]].init_sensor();
            if (!sensors[fusion_sensors[i]].status) {
              ei_printf("%s axis sensor initialization failed.\r\n", sensors[fusion_sensors[i]].name);
            }
            else {
              ei_printf("%s axis sensor initialization successful.\r\n", sensors[fusion_sensors[i]].name);
            }
        }
    }
}

/**
* @brief      Get data and run inferencing
*/
void loop()
{
    ei_printf("\nStarting inferencing in 2 seconds...\r\n");

    delay(2000);

    if (EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME != fusion_ix) {
        ei_printf("ERR: Sensors don't match the sensors required in the model\r\n"
        "Following sensors are required: %s\r\n", EI_CLASSIFIER_FUSION_AXES_STRING);
        return;
    }

    ei_printf("Sampling...\r\n");

    // Allocate a buffer here for the values we'll read from the sensor
    float buffer[EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE] = { 0 };

```



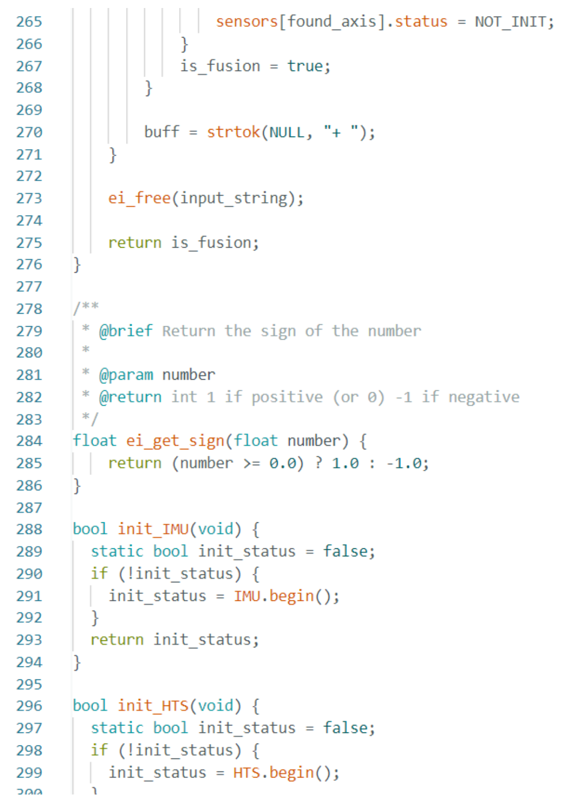
```
    for (size_t ix = 0; ix < EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE; ix += EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME) {
        // Determine the next tick (and then sleep later)
        int64_t next_tick = (int64_t)micros() + ((int64_t)EI_CLASSIFIER_INTERVAL_MS * 1000);

        for(int i = 0; i < fusion_ix; i++) {
            if (sensors[fusion_sensors[i]].status == INIT) {
                sensors[fusion_sensors[i]].poll_sensor();
                sensors[fusion_sensors[i]].status = SAMPLED;
            }
            if (sensors[fusion_sensors[i]].status == SAMPLED) {
                buffer[ix + i] = *sensors[fusion_sensors[i]].value;
                sensors[fusion_sensors[i]].status = INIT;
            }
        }

        int64_t wait_time = next_tick - (int64_t)micros();

        if(wait_time > 0) {
            delayMicroseconds(wait_time);
        }
    }

    // Turn the raw buffer in a signal which we can the classify
    signal_t signal;
    int err = numpy::signal_from_buffer(buffer, EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE, &signal);
    if (err != 0) {
        ei_printf("ERR:(%d)\r\n", err);
        return;
    }

    // Run the classifier
    ei_impulse_result_t result = { 0 };

    err = run_classifier(&signal, &result, debug_nn);
    if (err != EI_IMPULSE_OK) {
        ei_printf("ERR:(%d)\r\n", err);
```



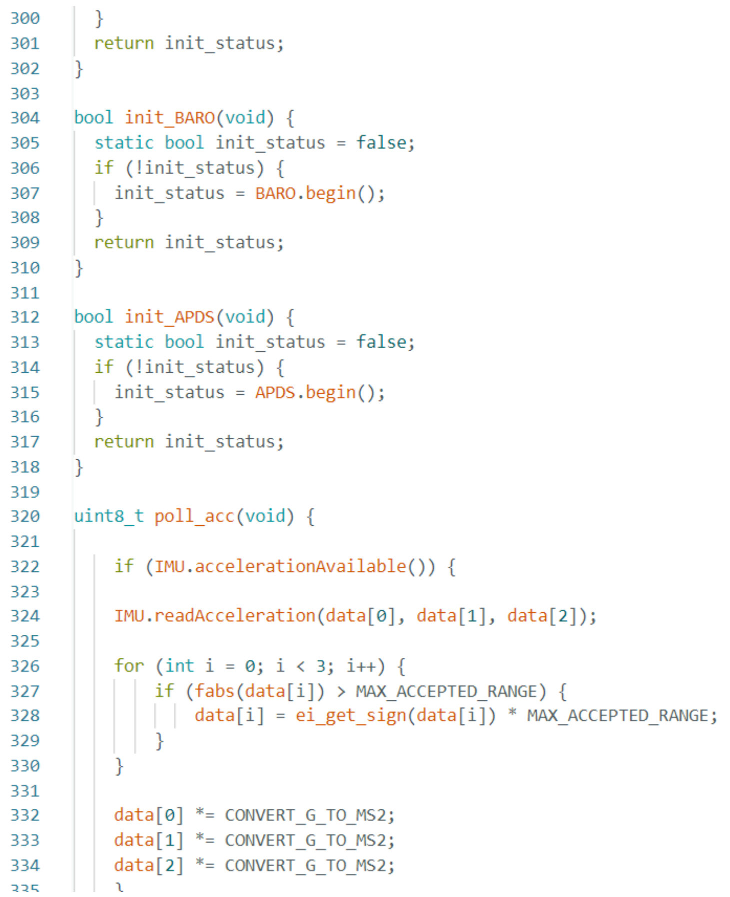
```
        ei_printf("ERR:(%d)\r\n", err);
        return;
    }

    // print the predictions
    ei_printf("Predictions (DSP: %d ms., Classification: %d ms., Anomaly: %d ms.):\r\n",
        result.timing.dsp, result.timing.classification, result.timing.anomaly);
    for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
        ei_printf("%s: %.5f\r\n", result.classification[ix].label, result.classification[ix].value);
    }
#if EI_CLASSIFIER_HAS_ANOMALY == 1
    ei_printf("    anomaly score: %.3f\r\n", result.anomaly);
#endif
}

#if !defined(EI_CLASSIFIER_SENSOR) || (EI_CLASSIFIER_SENSOR != EI_CLASSIFIER_SENSOR_FUSION && EI_CLASSIFIER_SENSOR != EI_CLASSIFIER_SENSOR_ACCELEROMETER)
#error "Invalid model for current sensor"
#endif


/**
 * @brief Go through sensor list to find matching axis name
 *
 * @param axis_name
 * @return int8_t index in sensor list, -1 if axis name is not found
 */
static int8_t ei_find_axis(char *axis_name)
{
    int ix;
    for(ix = 0; ix < N_SENSORS; ix++) {
        if(strstr(axis_name, sensors[ix].name)) {
            return ix;
        }
    }
    return -1;
```



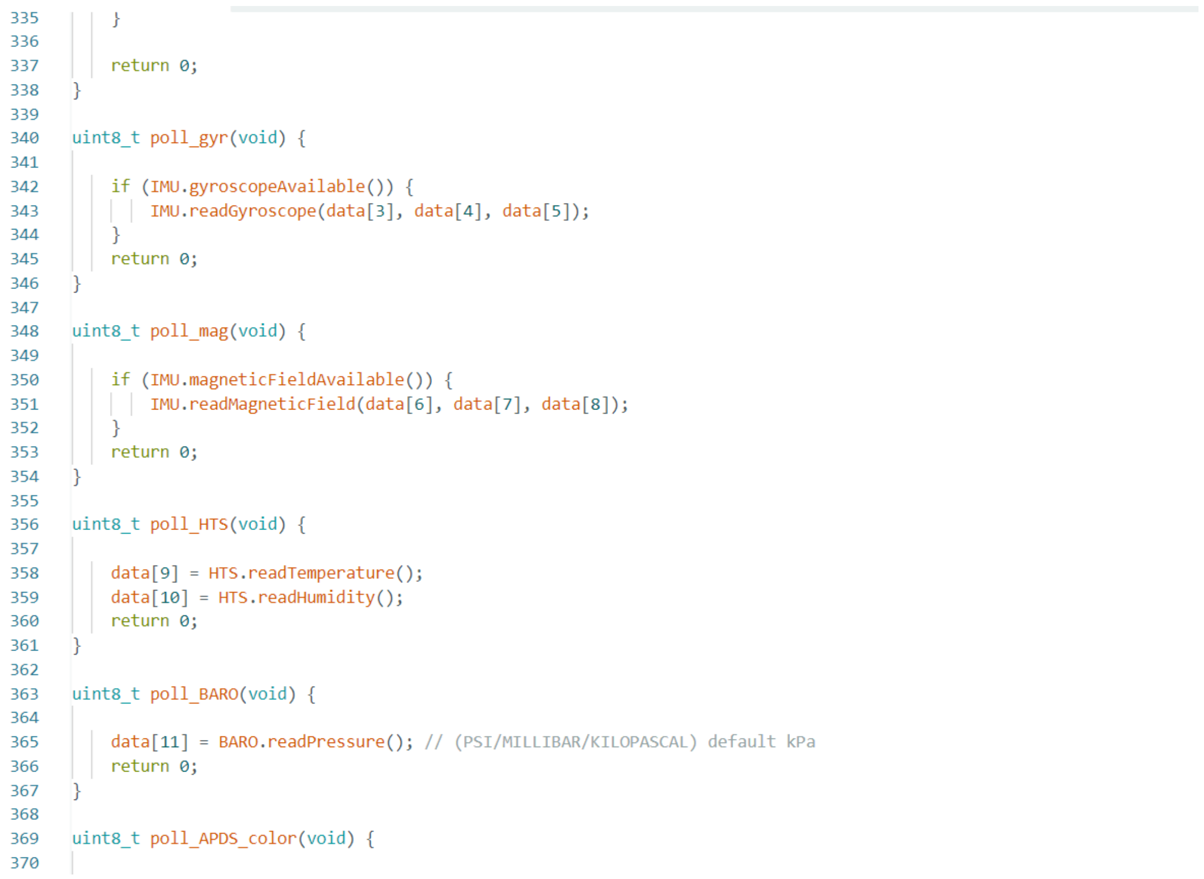
```c
}

/**
 * @brief Check if requested input list is valid sensor fusion, create sensor buffer
 *
 * @param[in]  input_list      Axes list to sample (ie. "accX + gyrY + magZ")
 * @retval  false if invalid sensor_list
 */
static bool ei_connect_fusion_list(const char *input_list)
{
    char *buff;
    bool is_fusion = false;

    /* Copy const string in heap mem */
    char *input_string = (char *)ei_malloc(strlen(input_list) + 1);
    if (input_string == NULL) {
        return false;
    }
    memset(input_string, 0, strlen(input_list) + 1);
    strncpy(input_string, input_list, strlen(input_list));

    /* Clear fusion sensor list */
    memset(fusion_sensors, 0, N_SENSORS);
    fusion_ix = 0;

    buff = strtok(input_string, "+");

    while (buff != NULL) { /* Run through buffer */
        int8_t found_axis = 0;

        is_fusion = false;
        found_axis = ei_find_axis(buff);

        if(found_axis >= 0) {
            if(fusion_ix < N_SENSORS) {
                fusion_sensors[fusion_ix++] = found_axis;
```



```c
                sensors[found_axis].status = NOT_INIT;
            }
            is_fusion = true;
        }

        buff = strtok(NULL, "+ ");
    }

    ei_free(input_string);

    return is_fusion;
}

/**
 * @brief Return the sign of the number
 *
 * @param number
 * @return int 1 if positive (or 0) -1 if negative
 */
float ei_get_sign(float number) {
    return (number >= 0.0) ? 1.0 : -1.0;
}

bool init_IMU(void) {
  static bool init_status = false;
  if (!init_status) {
    init_status = IMU.begin();
  }
  return init_status;
}

bool init_HTS(void) {
  static bool init_status = false;
  if (!init_status) {
    init_status = HTS.begin();
  }
```



```
  }
  return init_status;
}

bool init_BARO(void) {
  static bool init_status = false;
  if (!init_status) {
    init_status = BARO.begin();
  }
  return init_status;
}

bool init_APDS(void) {
  static bool init_status = false;
  if (!init_status) {
    init_status = APDS.begin();
  }
  return init_status;
}

uint8_t poll_acc(void) {

    if (IMU.accelerationAvailable()) {

    IMU.readAcceleration(data[0], data[1], data[2]);

    for (int i = 0; i < 3; i++) {
        if (fabs(data[i]) > MAX_ACCEPTED_RANGE) {
            data[i] = ei_get_sign(data[i]) * MAX_ACCEPTED_RANGE;
        }
    }

    data[0] *= CONVERT_G_TO_MS2;
    data[1] *= CONVERT_G_TO_MS2;
    data[2] *= CONVERT_G_TO_MS2;
```



```
    }

    return 0;
}

uint8_t poll_gyr(void) {

    if (IMU.gyroscopeAvailable()) {
        IMU.readGyroscope(data[3], data[4], data[5]);
    }
    return 0;
}

uint8_t poll_mag(void) {

    if (IMU.magneticFieldAvailable()) {
        IMU.readMagneticField(data[6], data[7], data[8]);
    }
    return 0;
}

uint8_t poll_HTS(void) {

    data[9] = HTS.readTemperature();
    data[10] = HTS.readHumidity();
    return 0;
}

uint8_t poll_BARO(void) {

    data[11] = BARO.readPressure(); // (PSI/MILLIBAR/KILOPASCAL) default kPa
    return 0;
}

uint8_t poll_APDS_color(void) {

```

```
uint8_t poll_APDS_color(void) {

    int temp_data[4];
    if (APDS.colorAvailable()) {
        APDS.readColor(temp_data[0], temp_data[1], temp_data[2], temp_data[3]);

        data[12] = temp_data[0];
        data[13] = temp_data[1];
        data[14] = temp_data[2];
        data[15] = temp_data[3];
    }
}

uint8_t poll_APDS_proximity(void) {

    if (APDS.proximityAvailable()) {
        data[16] = (float)APDS.readProximity();
    }
    return 0;
}

uint8_t poll_APDS_gesture(void) {
    if (APDS.gestureAvailable()) {
        data[17] = (float)APDS.readGesture();
    }
    return 0;
}
```

6. Output

```
Starting Nano BLE Sense Classification...

Sensor data collected.
Running inference...

Predicted Class: Green

Confidence: 86.3%

Raw Output:
- Red: 10.2%
- Green: 86.3%
- Blue: 3.5%

Waiting for next sensor input...


Predicted Class: Red
Confidence: 92.8%

Raw Output:
- Red: 92.8%
- Green: 5.1%
- Blue: 2.1%

Waiting for next sensor input...
```