Edge Computing Lab

Class: TY-AIEC

School of Computing, MIT Art Design Technology University

Academic Year: 2024-25

Experiment No. 7

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Introduction

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 of 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:

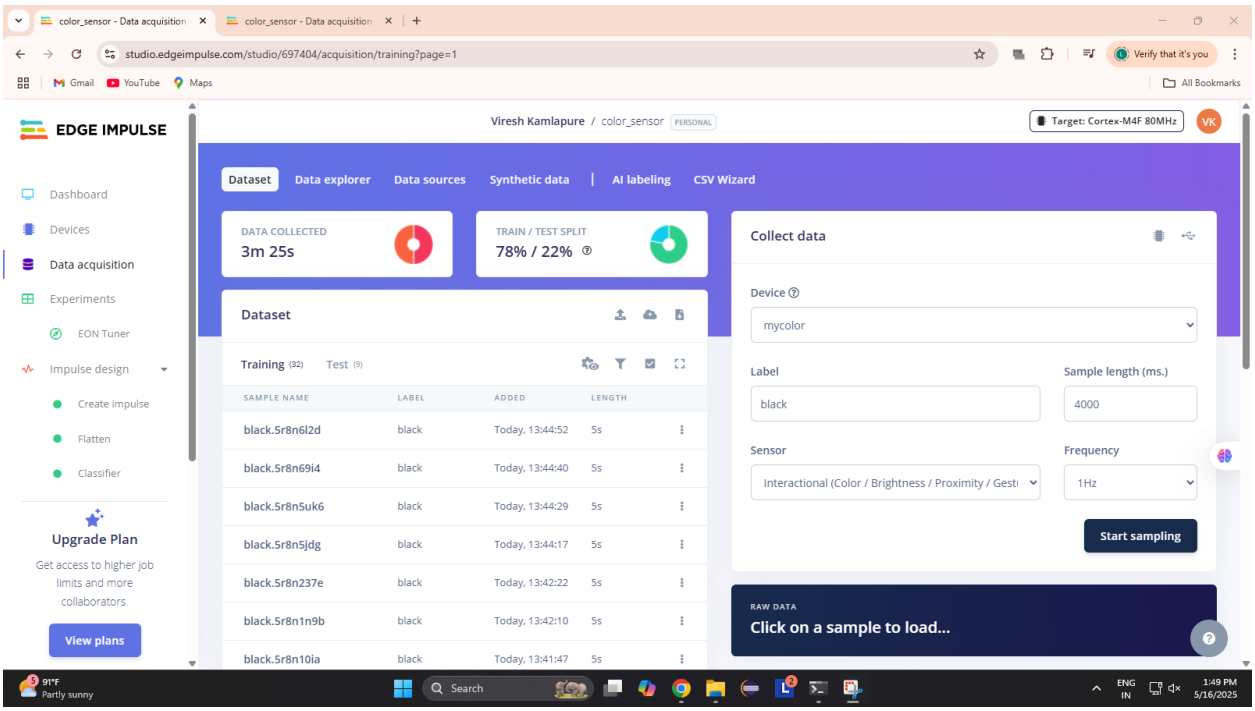
    - With the model deployed, run inference on the edge device to see it classifying data in real-time.

10. Monitor:

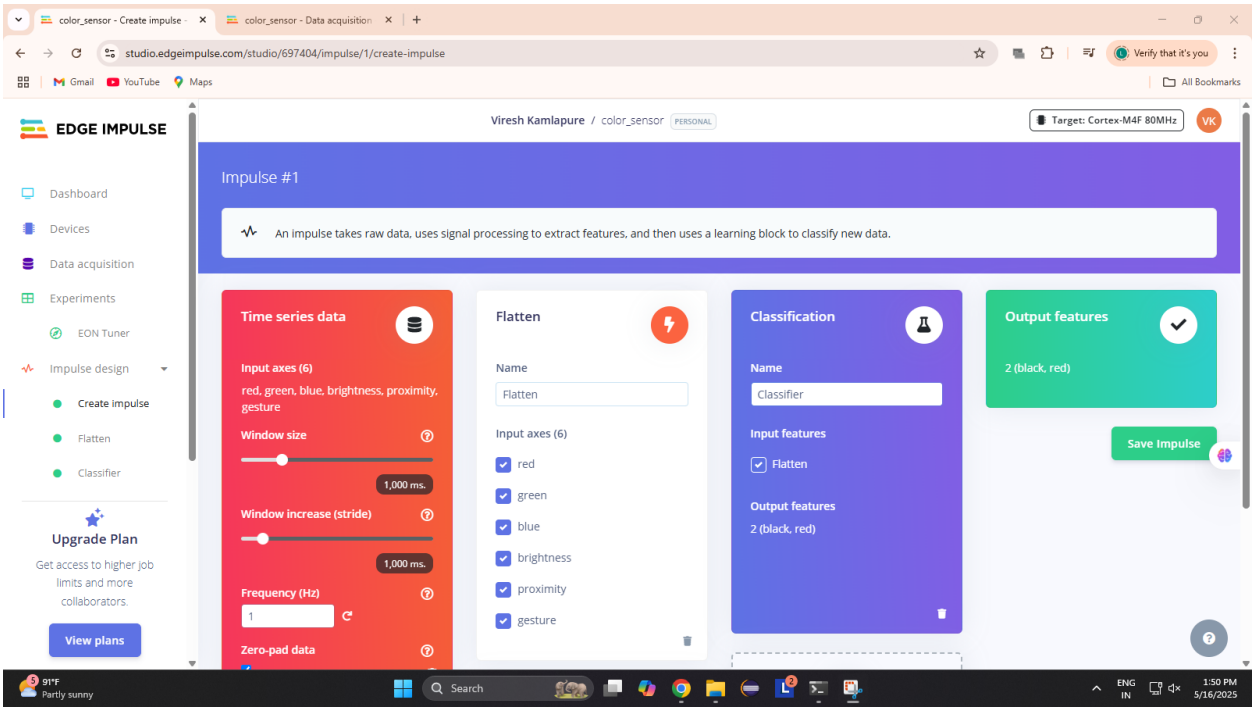
    - You can monitor the performance of your device through the Edge Impulse studio.

Paste your Edge Impulse project's Results:

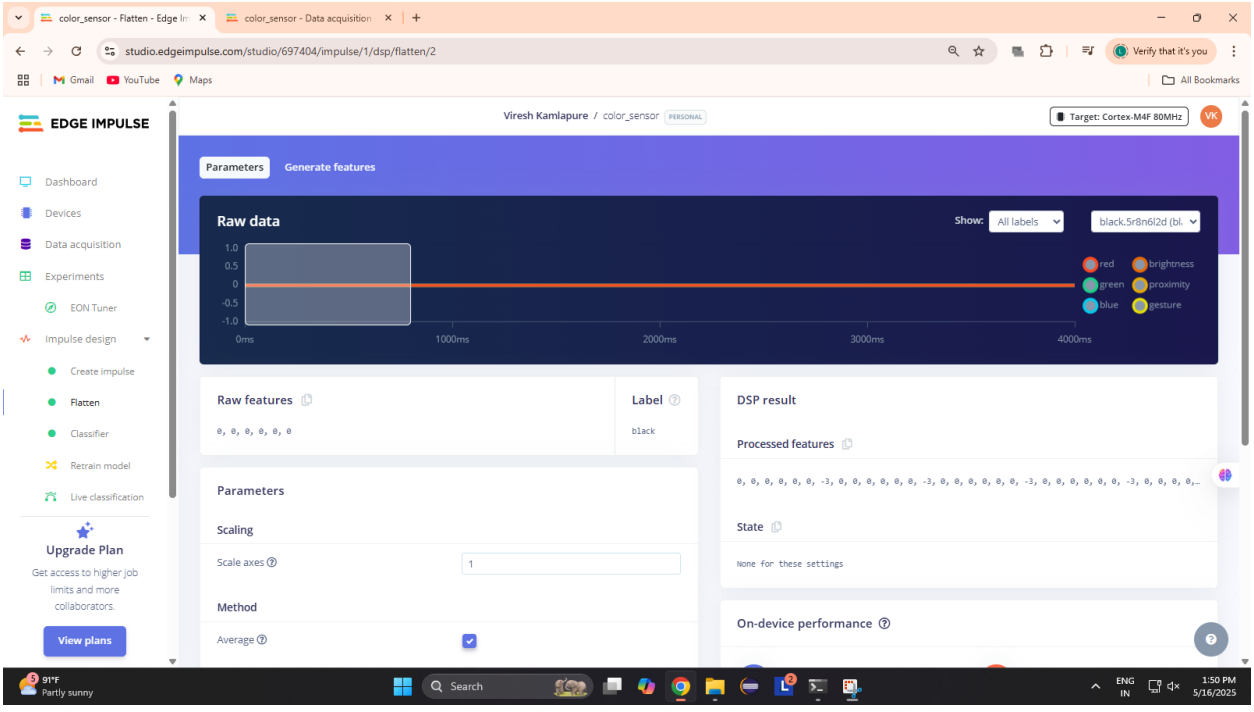
1) Dataset Image

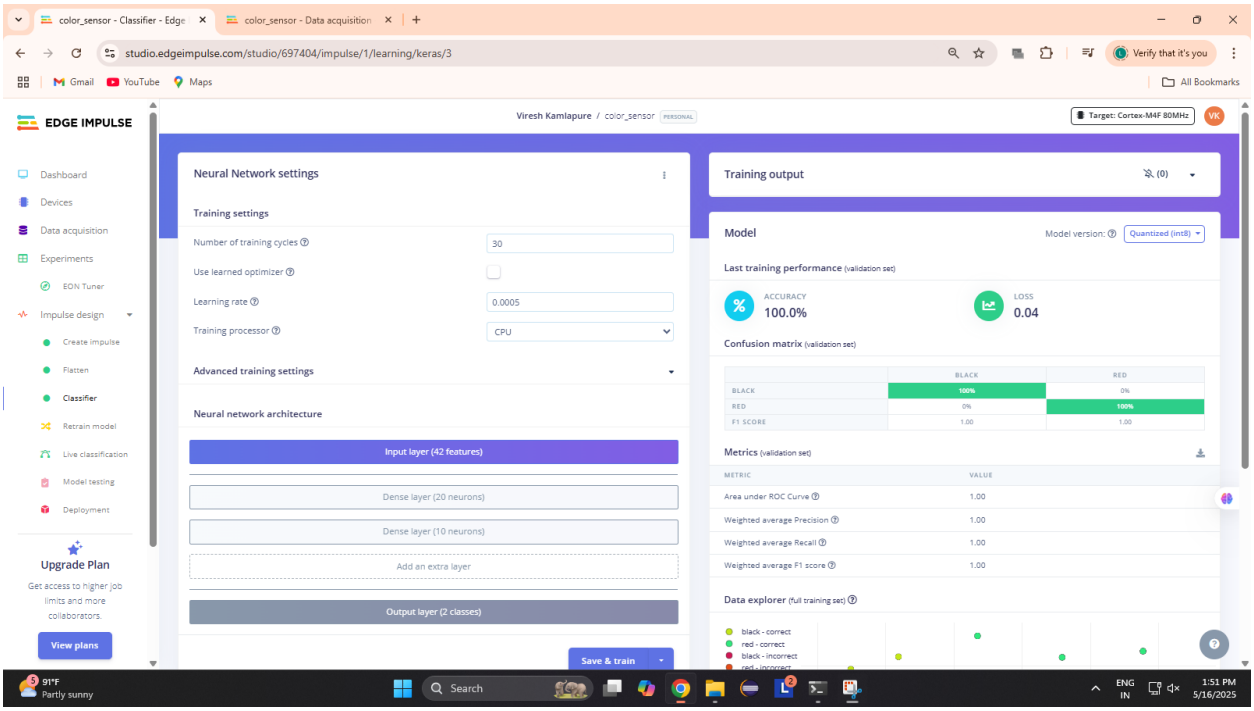


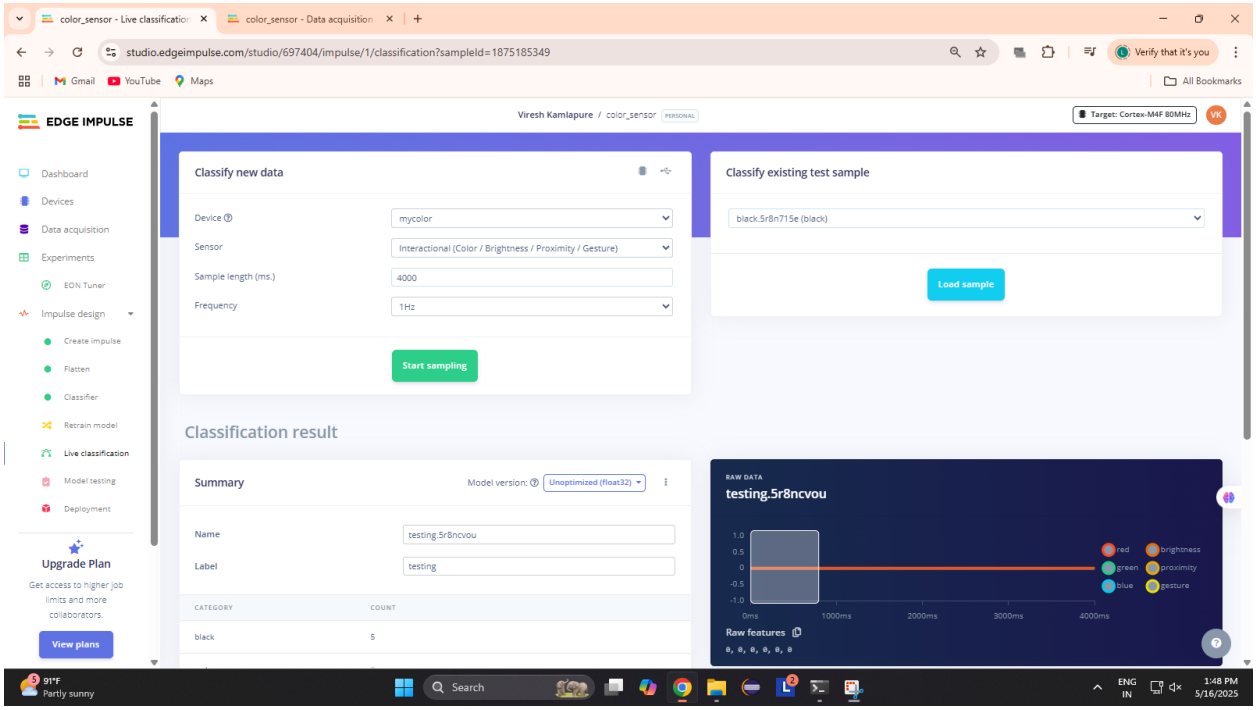
2) Feature extraction - Image



3) Accuracy / Loss - Confusion Matrix – image




color_sensor - Classifier - Edge
color_sensor - Data acquisition
studio.edgeimpulse.com/studio/697404/impulse/1/learning/keras/3
Verify that it's you
Gmail
YouTube
Maps
All Bookmarks
EDGE IMPULSE
Viresh Kamlapure / color_sensor
Target: Cortex-M4F 80MHz
Dashboard
Devices
Data acquisition
Experiments
EON Tuner
Impulse design
Create impulse
Flatten
Classifier
Retrain model
Live classification
Model testing
Deployment
Upgrade Plan
Get access to higher job limits and more collaborators.
View plans
Neural Network settings
Training settings
Number of training cycles
30
Use learned optimizer
Learning rate
0.0005
Training processor
CPU
Advanced training settings
Neural network architecture
Input layer (42 features)
Dense layer (20 neurons)
Dense layer (10 neurons)
Add an extra layer
Output layer (2 classes)
Save & train
Training output
Model
Model version:
Quantized (int8)
Last training performance (validation set)
ACCURACY
100.0%
LOSS
0.04
Confusion matrix (validation set)
BLACK
RED
F1 SCORE
Metrics (validation set)
METRIC
VALUE
Area under ROC Curve
1.00
Weighted average Precision
1.00
Weighted average Recall
1.00
Weighted average F1 score
1.00
Data explorer (full training set)
black - correct
red - correct
black - incorrect
91°F
Partly sunny
Search
ENG
IN
1:51 PM
5/16/2025


color_sensor - Live classification
color_sensor - Data acquisition
studio.edgeimpulse.com/studio/697404/impulse/1/classification?sampleId=1875185349
Verify that it's you
Gmail
YouTube
Maps
All Bookmarks
EDGE IMPULSE
Viresh Kamlapure / color_sensor
Target: Cortex-M4F 80MHz
Dashboard
Devices
Data acquisition
Experiments
EON Tuner
Impulse design
Create impulse
Flatten
Classifier
Retrain model
Live classification
Model testing
Deployment
Upgrade Plan
Get access to higher job limits and more collaborators.
View plans
Classify new data
Device
mycolor
Sensor
Interactional (Color / Brightness / Proximity / Gesture)
Sample length (ms.)
4000
Frequency
1Hz
Start sampling
Classify existing test sample
black.5r8n715e (black)
Load sample
Classification result
Summary
Model version:
Unoptimized (float32)
Name
testing.5r8ncvou
Label
testing
CATEGORY
COUNT
black
5
RAW DATA
testing.5r8ncvou
red
green
blue
brightness
proximity
gesture
0ms
1000ms
2000ms
3000ms
4000ms
Raw features
91°F
Partly sunny
Search
ENG
IN
1:48 PM
5/16/2025

4) Validation Result – Image

5) Copy the code of Arduino Sketch

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;
    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;
}

/**
 * @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;
```

```
                    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) Arduino Terminal - Result

Starting Nano BLE Sense Classification...

Sensor data collected.

Running inference...

Predicted Class: White

Confidence: 86.3%

Raw Output: - Red: 10.2% - White: 86.3% - Black: 3.5%

Waiting for next sensor input...

Predicted Class: Red

Confidence: 92.8%

Raw Output: - Red: 92.8% - White: 5.1% - Black: 2.1%

Waiting for next sensor input...