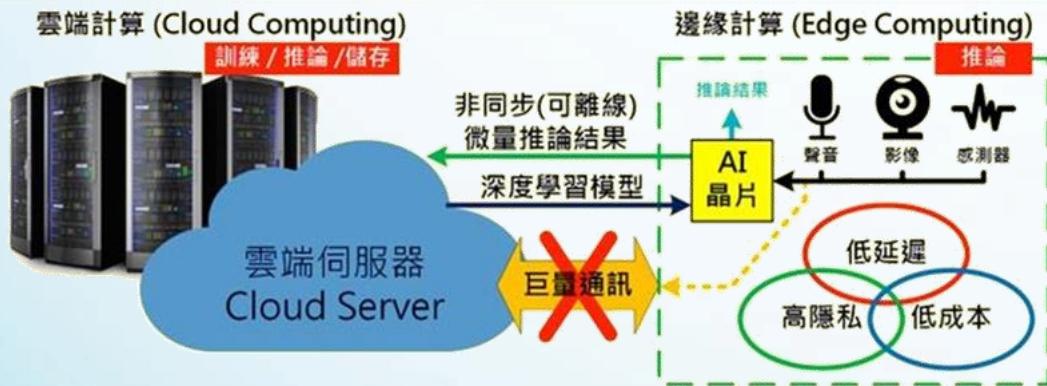


OmniXRI's Edge AI & TinyML 小學堂



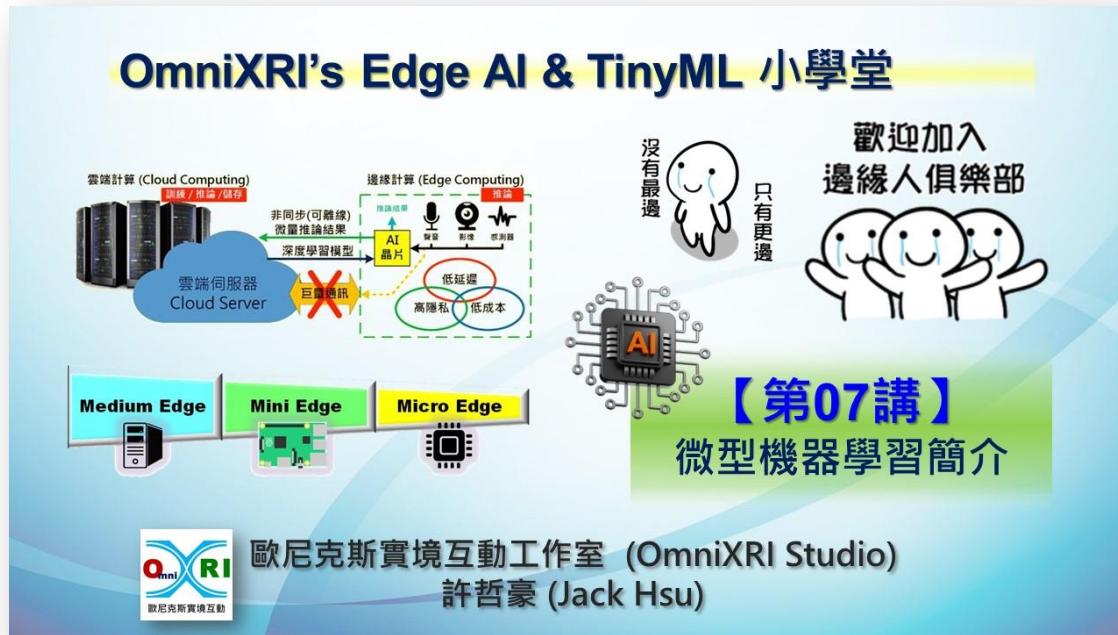
【第12講】

實作案例 — 語音辨識



歐尼克斯實境互動工作室 (OmniXRI Studio)
許哲豪 (Jack Hsu)

TinyML 回顧



OmniXRI's Edge AI & TinyML 小學堂

雲端計算 (Cloud Computing) 雲端伺服器 Cloud Server
邊緣計算 (Edge Computing)
非同步 (可離線) 微量推論結果 深度學習模型
AI 晶片 推論結果
巨量傳訊 延遲
高隱私 低成本

Medium Edge Mini Edge Micro Edge

歡迎加入
邊緣人俱樂部
沒有最邊 只有更邊

【第07講】
微型機器學習簡介

歐尼克斯實境互動工作室 (OmniXRI Studio)
許哲豪 (Jack Hsu)



簡報大綱

2024/4/16

- 7.1. 嵌入式系統與微控制器
- 7.2. TinyML技術現況
- 7.3. TinyML開發平台
- 7.4. TinyML主要應用

本課程完全免費，請勿移作商業用途！
歡迎留言、訂閱、點讚、轉發，讓更多需要的朋友也能一起學習。
完整課程大綱：<https://omnixri.blogspot.com/2024/02/omnixris-edge-ai-tinyml-0.html>
課程直播清單：<https://www.youtube.com/@omnixri1784streams>

課程簡報：

https://github.com/OmniXRI/Edge_AI_TinyML_Course_2024/tree/main/Ch07_TinyML_Introduction

直播網址：<https://youtu.be/5In7UT5pzFs>

簡報大綱

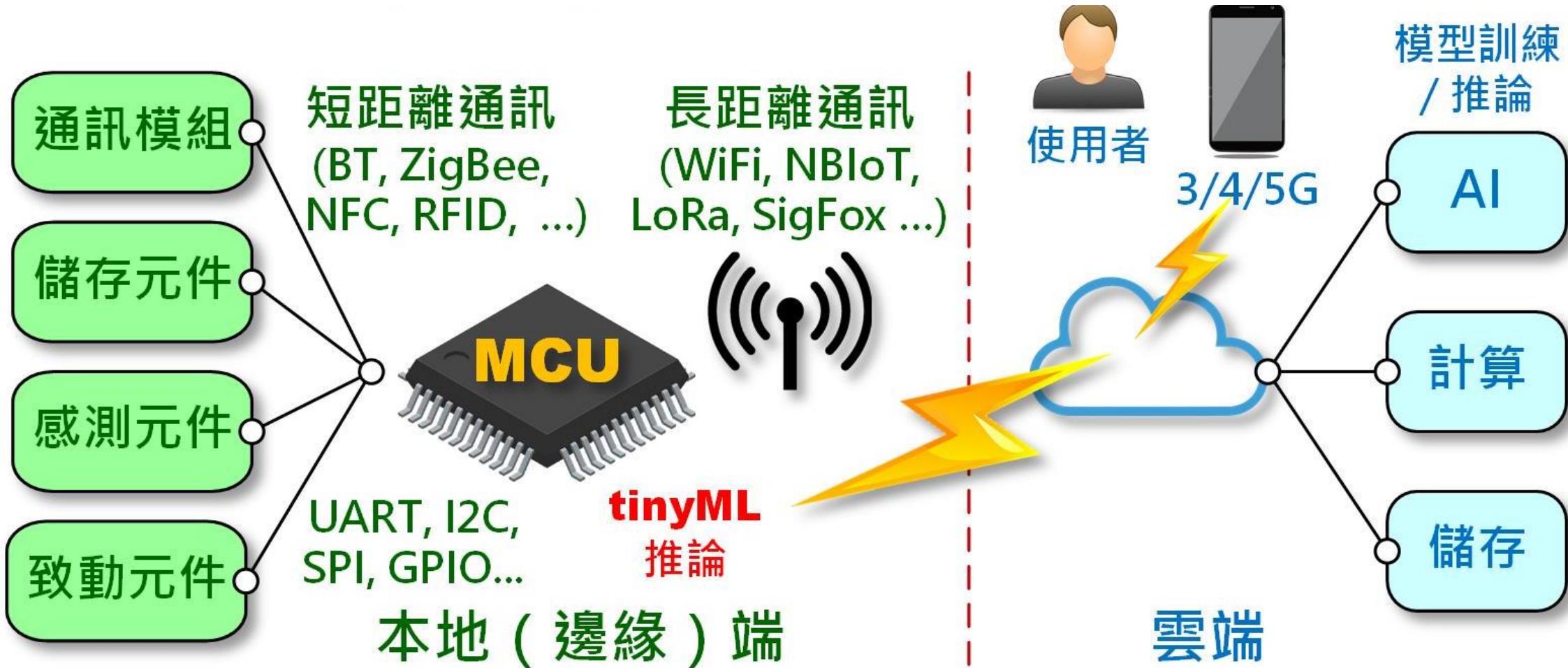


- 12.1. 智慧物聯網與感測技術
- 12.2. 喚醒詞技術簡介
- 12.3. TinyML開發流程與環境
- 12.4. Edge Impulse 喚醒詞案例

本課程完全免費，請勿移作商業用途！
歡迎留言、訂閱、點讚、轉發，讓更多需要的朋友也能一起學習。

完整課程大綱：<https://omnixri.blogspot.com/2024/02/omnixris-edge-ai-tinyml-0.html>
課程直播清單：<https://www.youtube.com/@omnixri1784streams>

傳統智慧物聯網(AIoT)架構



資料來源：<https://omnixri.blogspot.com/2021/09/aiottinymlmcu.html>

OmniXRI 整理繪製, 2021/9/9

傳統型AIoT vs. 新型態TinyML

AIoT

視覺/語音/數據
雲端計算

長距大量通訊
雲端巨量儲存

通用IDE, LIB
專用IDE, SDK

MCU, SBC, PC



tinyML

智慧感測
邊緣裝置運算

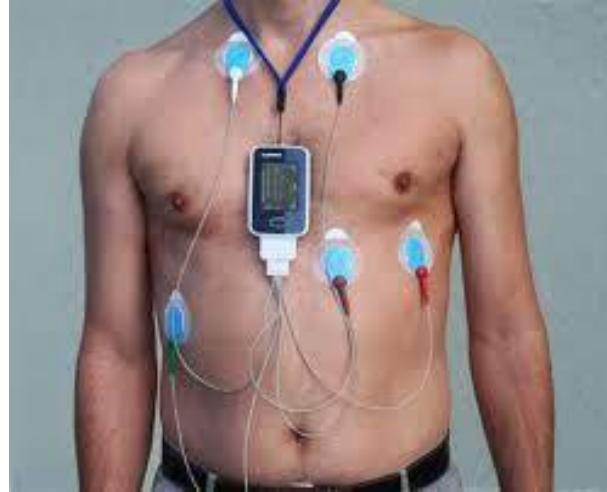
短距小量通訊
邊緣微量儲存

整合型平台
通用IDE, LIB

MCU (+NPU)

資料來源：<https://omnixri.blogspot.com/2022/11/20221110icaiottinyml-ic.html>

常見感測技術



➤ 接觸式

- 貼片—黏貼於身體、手臂上，用以量測電阻、電壓、電流，進而得到各項生理機能數值。

➤ 非接觸式

- 電阻、電容、電感式
- 光電式
- 發射接收式、紅外熱幅射式
- 壓電式
- 電聲式
- 超音波、麥克風
- 微機電式
- 運動類、環境類
- 電磁波式
- 影像式

常見市售感測器實驗模組



溫濕度計



水份計



超音波測距



陽光感測器



光線感測器



空氣品質



土壤濕度計



4通道氣體感測



HCHO感測器



土壤濕度計



氣壓計



溫度計



電容麥克風



長距溫度感測



九軸運動感測



PIR感測器



EMG偵測器

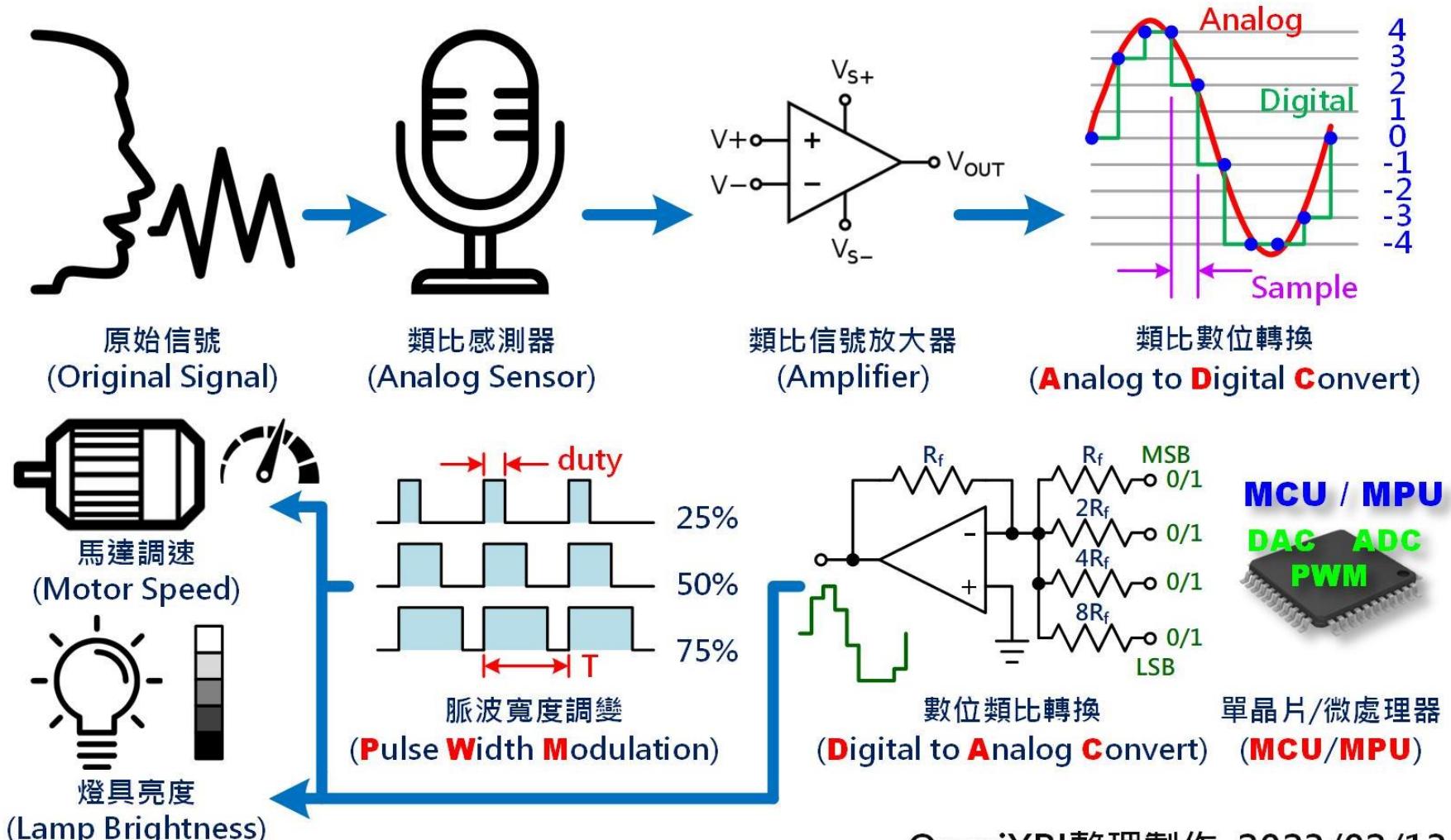


心率計

參考資料：<https://www.seeedstudio.com/category/Grove-c-1003.html>

* 數位輸出、通訊（數值）輸出、類比電壓輸出

感測器類比/數位信號互換



資料來源：<https://omnixri.blogspot.com/2023/02/vmaker-edge-ai-02-ai.html>

喚醒詞偵測

對一小段（數秒）聲音（連續信號）進行分類（辨識）如環境聲音（動物、機械、自然等）、生理訊號、機械振動、感測器變化等。

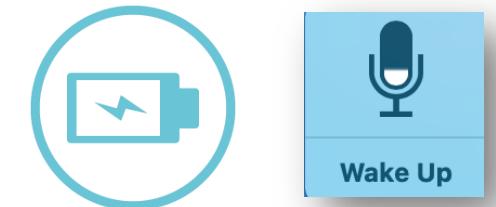
可以是非語言人聲或語音關鍵詞（非句子）。

常見同義詞

- **Keyword Spotting**：語音關鍵詞定位
- **Keyword Detection**：語音關鍵詞偵測
- **Voice Command**：語音命令
- **Wake-Up-Word**：喚醒詞

常見應用

- 智能音箱、動作辨識、生理監看等



案例分享 — 聲控電風扇

正確示範（美女版）



錯誤示範（阿媽版）



正確示範（台灣國語）

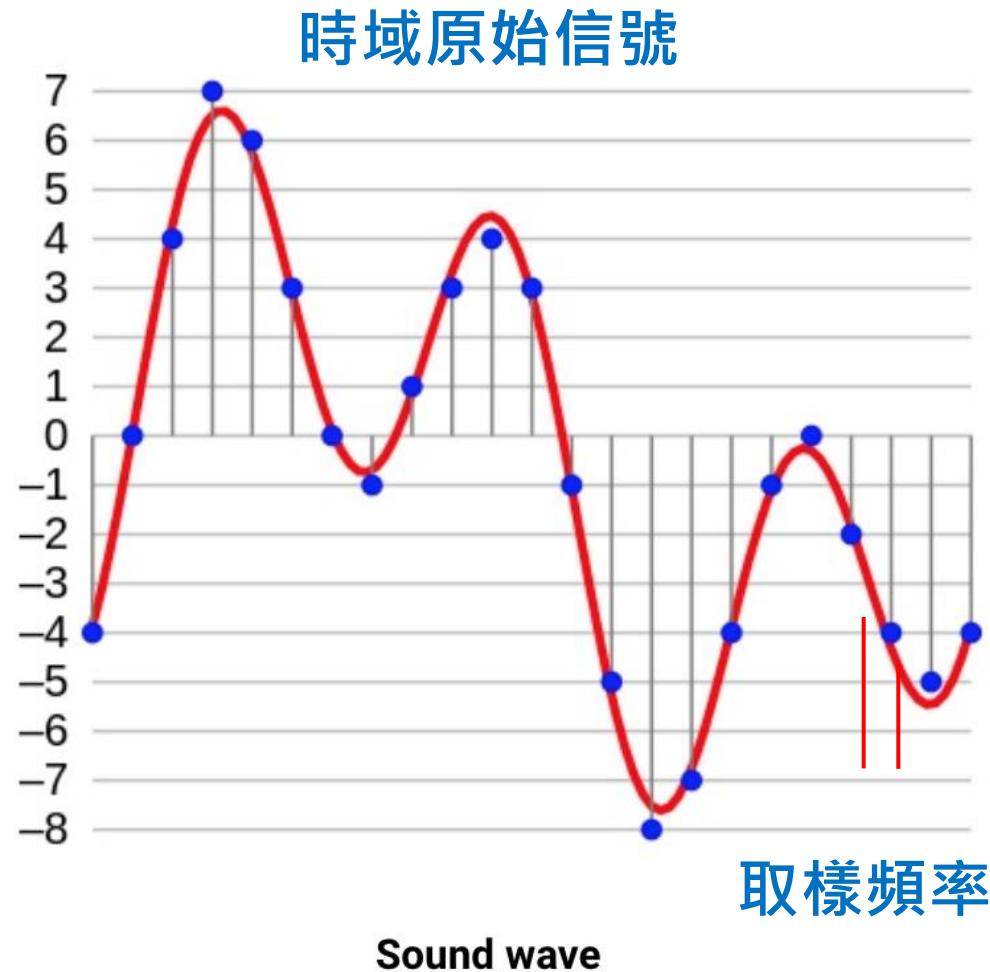


<https://www.youtube.com/shorts/X8yJjRj7Uus>

<https://www.youtube.com/shorts/frDYfeRiz9I>

<https://youtu.be/vpZgt0VQf8Y>

聲音訊號—取樣、量化



量化數位資料
(量化位元數 8 / 12 / 16 bit)



[-4, 0, 4, 7, 6, 3, 0, -1, 1, 3, 4, 3, -1, -5, -8, -7, -4, -1, 0, -2, -4, -5, -4]

資料大小 = 取樣頻率 * 量化位元數

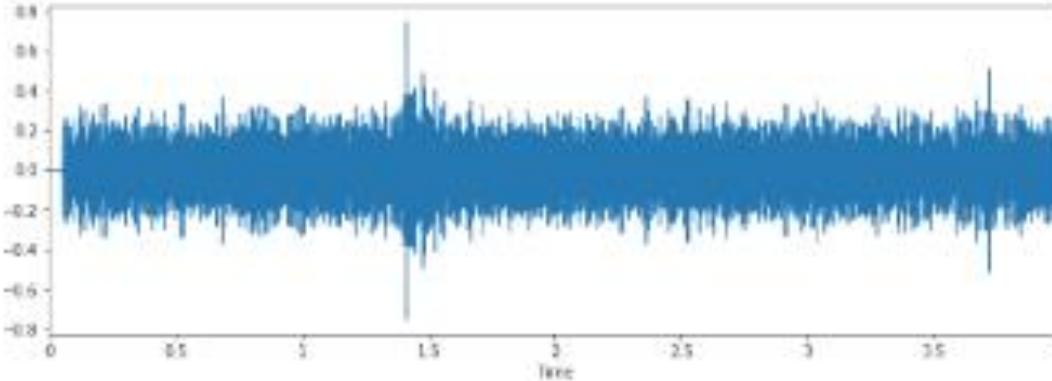
人耳/CD 品質
(16 / 44.1 KHz)

Array

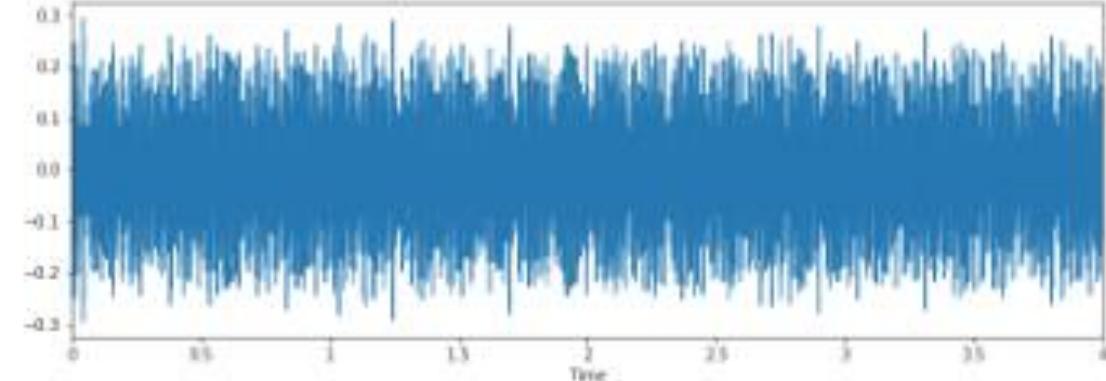
資料來源：<https://mikesmales.medium.com/sound-classification-using-deep-learning-8bc2aa1990b7>

常見聲音訊號波形（時間域）

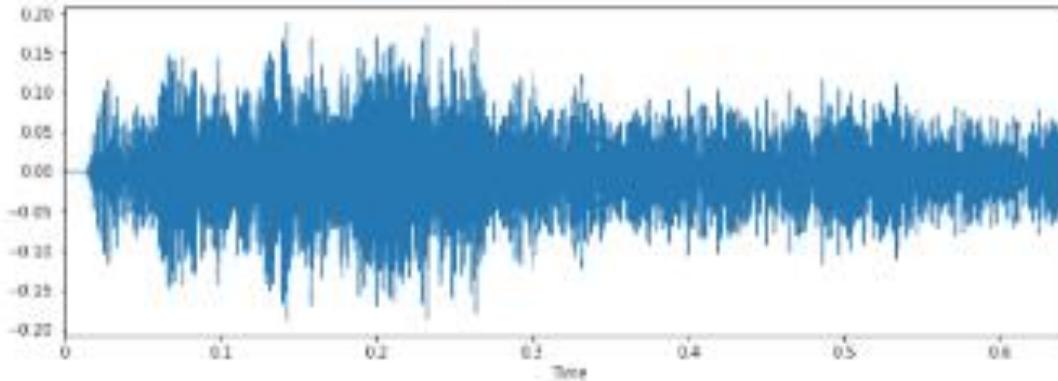
Air Conditioner



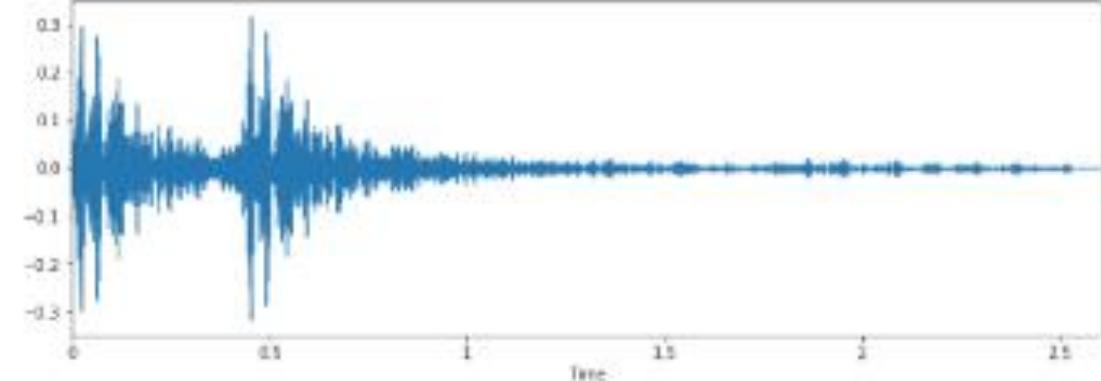
Engine Idling



Car horn



Gunshot



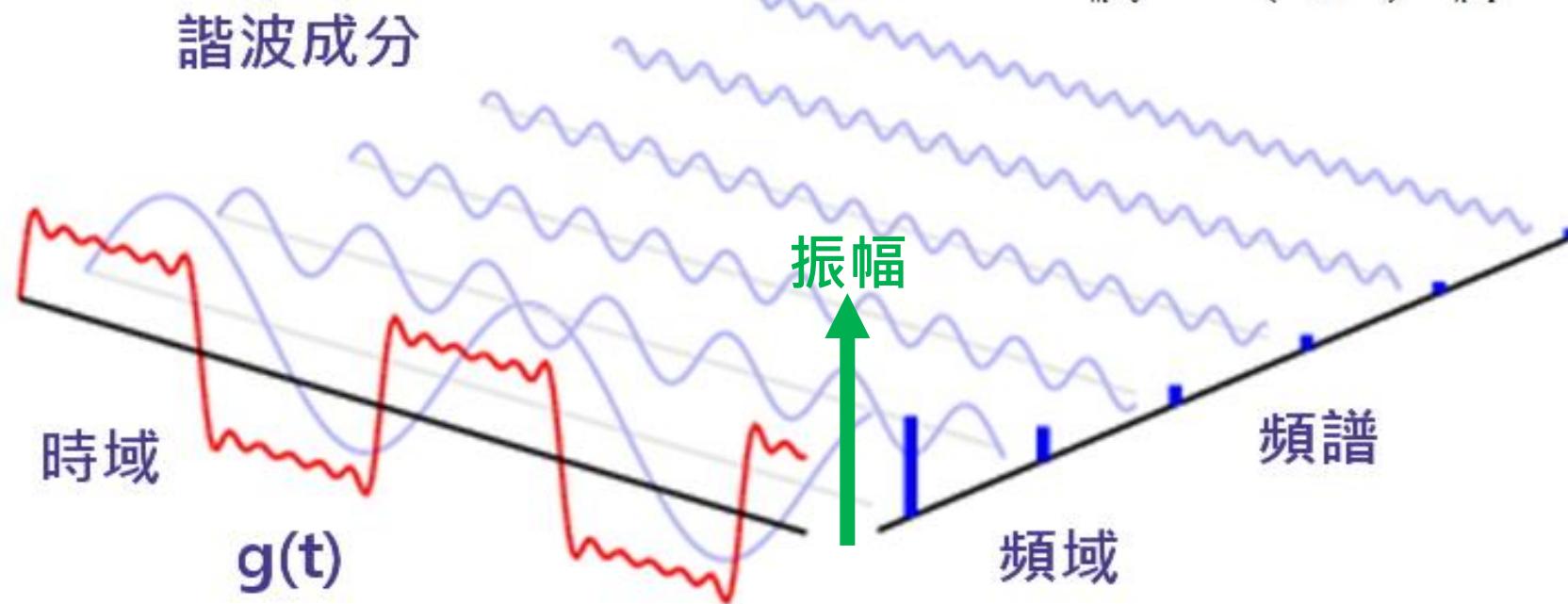
資料來源：<https://mikesmales.medium.com/sound-classification-using-deep-learning-8bc2aa1990b7>

時間域、頻率域轉換

傅立葉級數（轉換）
所有信號都可拆解為不同頻率弦波之組合

$$g(t) = a_0 + \sum_{m=1}^{\infty} a_m \cos\left(\frac{2\pi mt}{T}\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{2\pi nt}{T}\right)$$

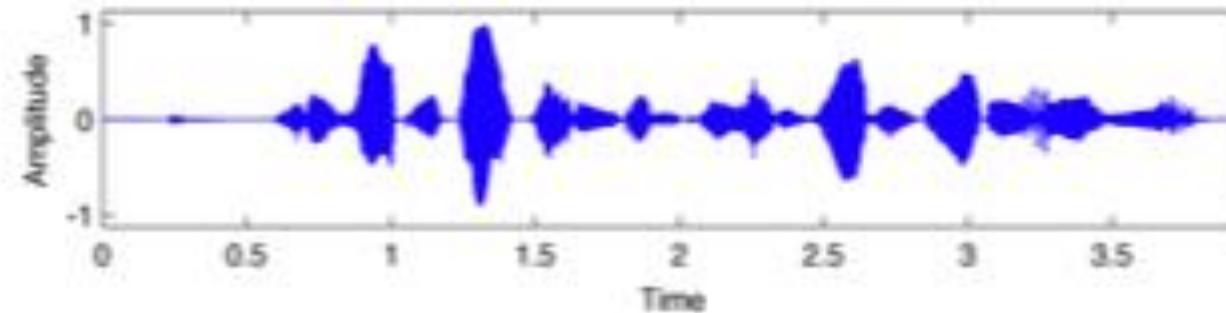
$$= \sum_{m=0}^{\infty} a_m \cos\left(\frac{2\pi mt}{T}\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{2\pi nt}{T}\right)$$



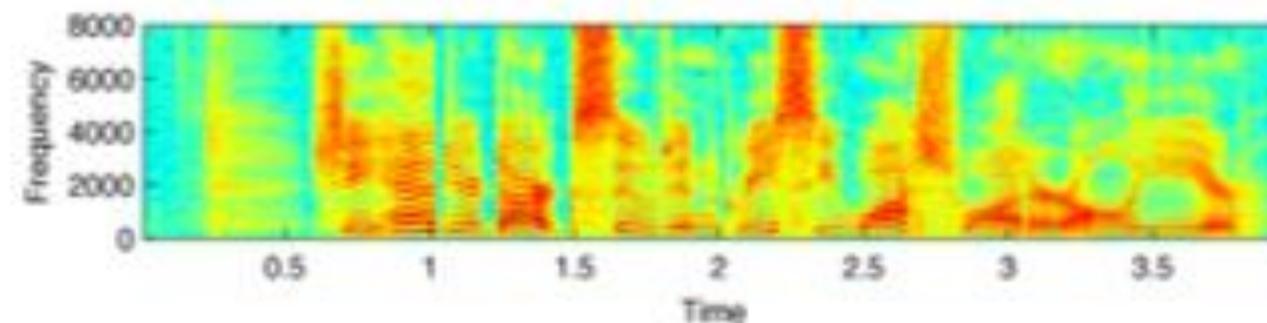
資料來源：https://yhuang1966.blogspot.com/2019/12/praat_5.html

時域、頻譜、梅爾倒頻譜表示法

**Time Domain
Waveform**

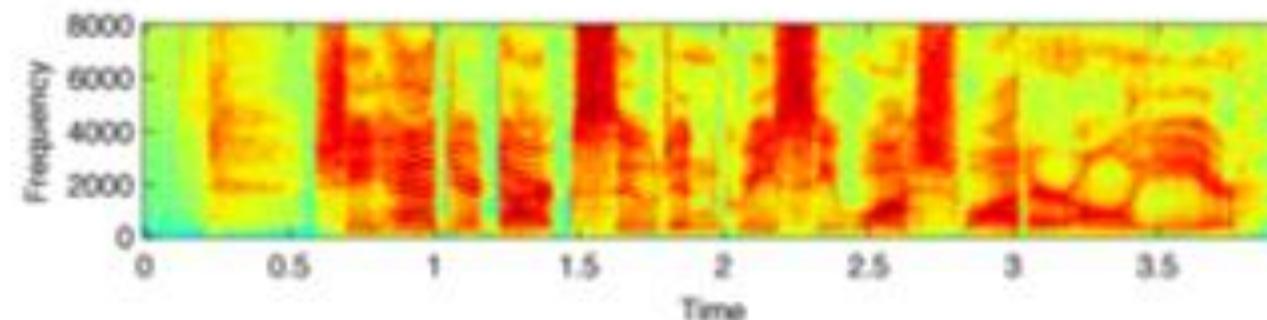


線性
頻譜
Spectrogram



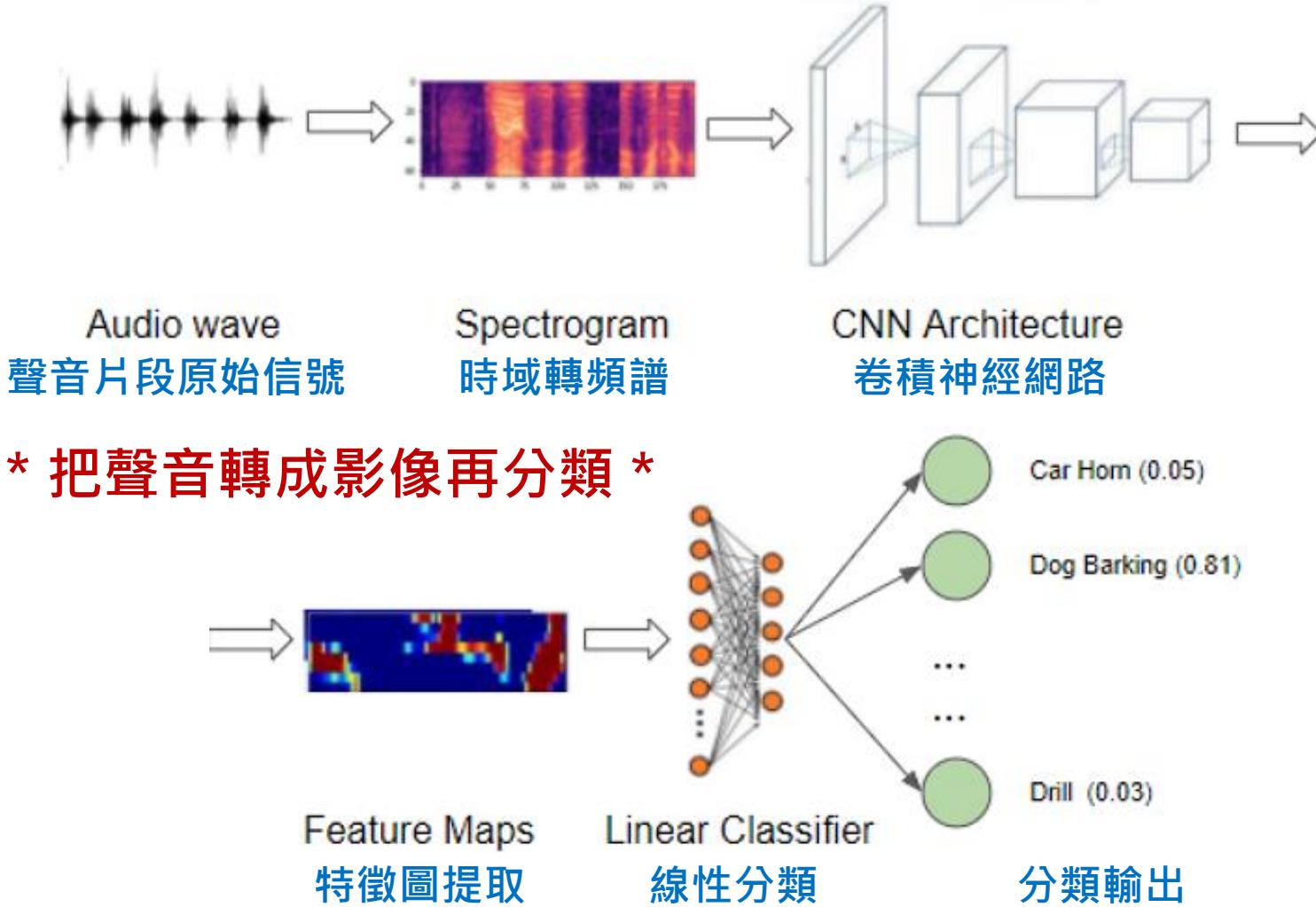
對數
頻譜
**MFCC
Spectrogram**

Mel-Frequency Cepstral
Coefficients (MFCC)



資料來源：<https://mikesmales.medium.com/sound-classification-using-deep-learning-8bc2aa1990b7>

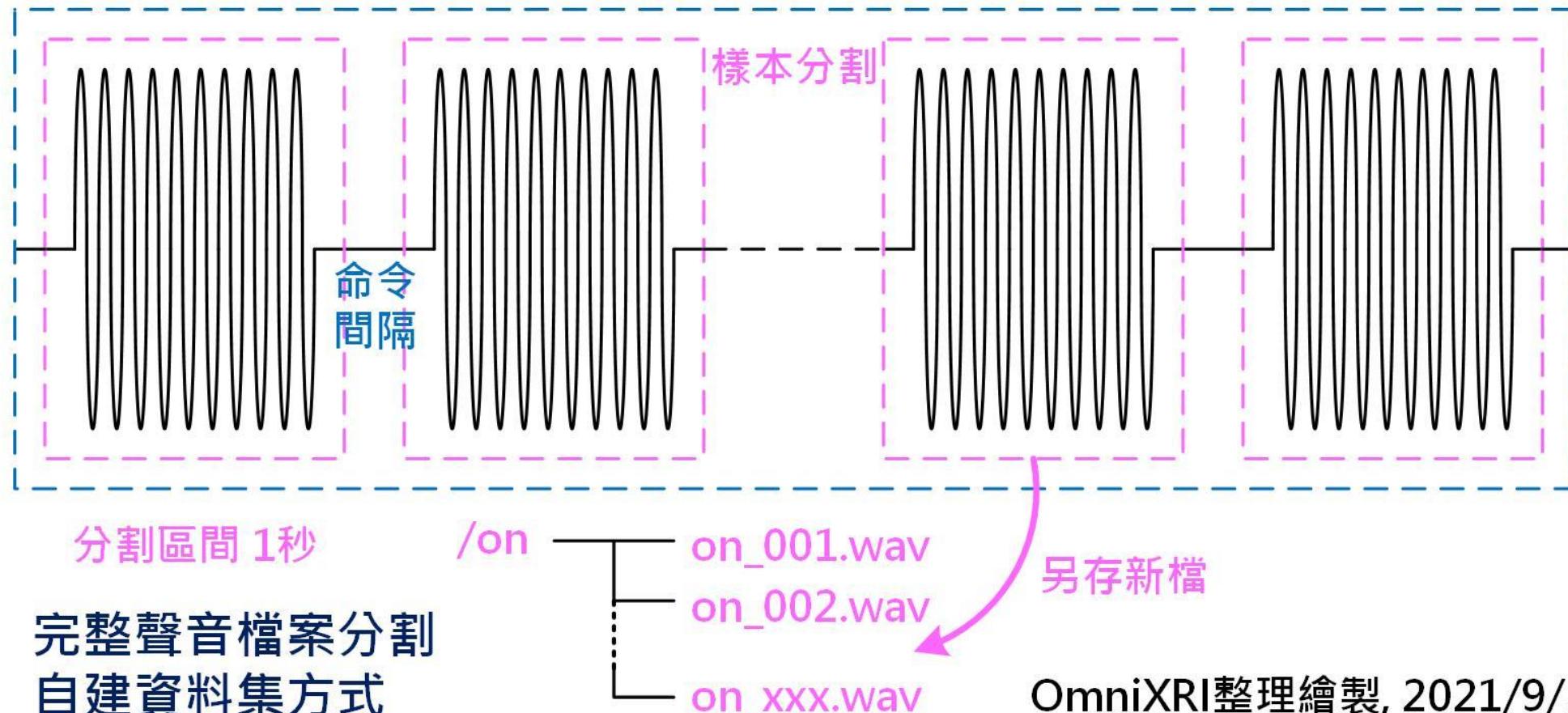
深度學習模型聲音分類



資料來源：<https://towardsdatascience.com/audio-deep-learning-made-simple-sound-classification-step-by-step-cebc936bbe5>

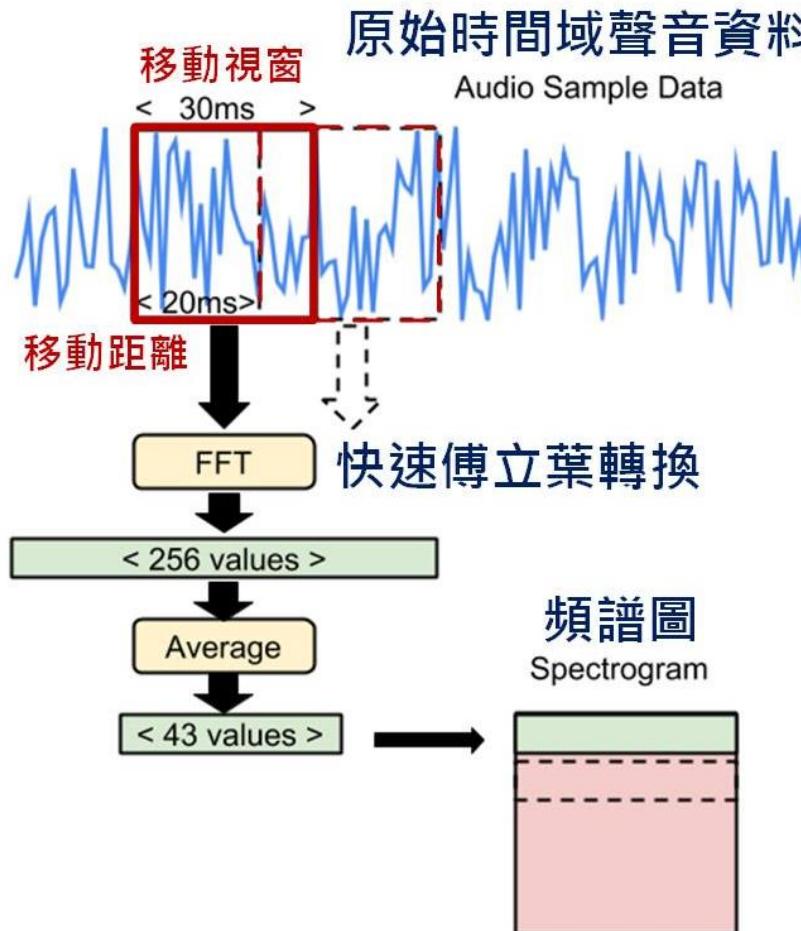
關鍵詞偵測(KWS) 程序(1/3)

完整聲音錄製檔案 (on.wav) – 建議取樣頻率 16KHz · 以非壓縮WAV格式儲存。

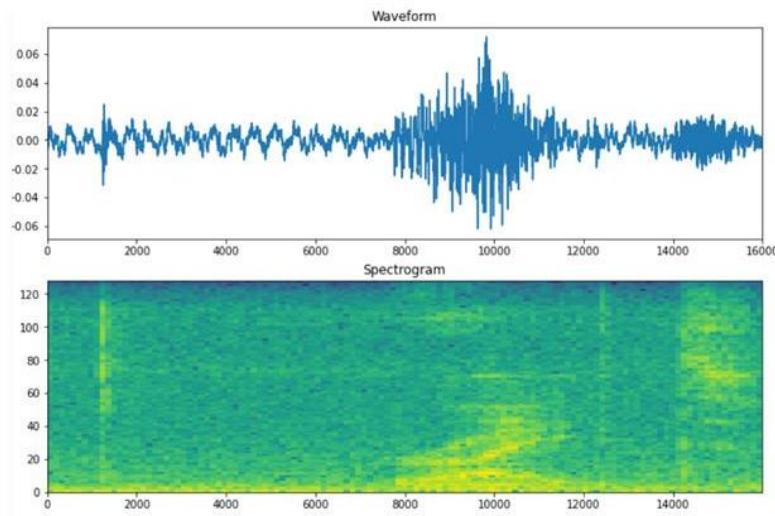


資料來源：<https://github.com/OmniXRI/iThomeIronMan2021/blob/main/Day17.md>

關鍵詞偵測(KWS) 程序 (2/3)



TensorFlow Lite Micro
Micro Speech
聲音頻譜圖轉換範例



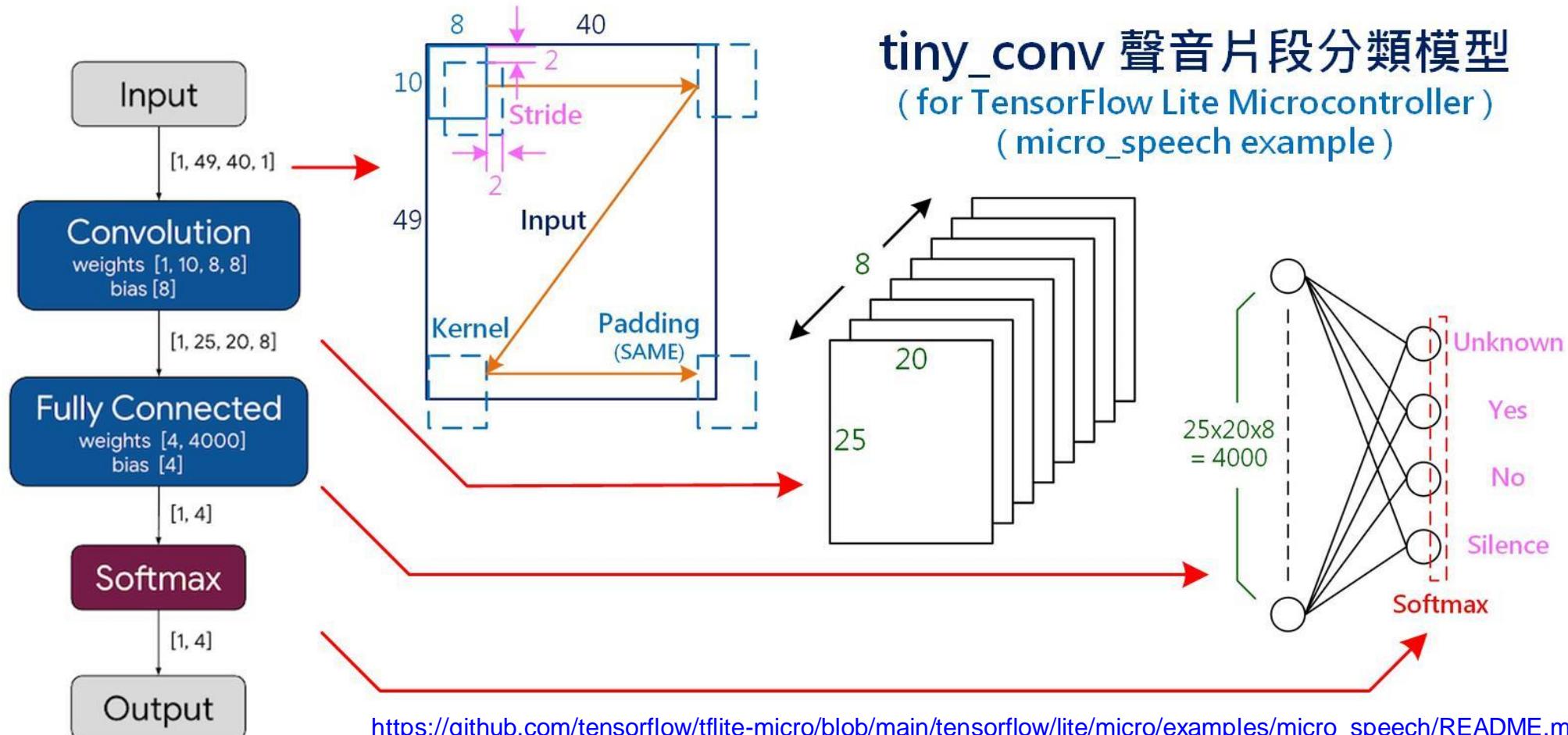
時間域格式

頻譜圖格式

OmniXRI整理繪製, 2021/9/30

資料來源：<https://github.com/OmniXRI/iThomeIronMan2021/blob/main/Day17.md>

關鍵詞偵測(KWS) 程序(3/3)



OmniXRI整理繪製, 2021/9/30

資料來源：<https://github.com/OmniXRI/iThomeIronMan2021/blob/main/Day17.md>

TinyML 開發流程



TinyML 實驗器材及開發平台

Seeed Xiao nRF52840 Sense



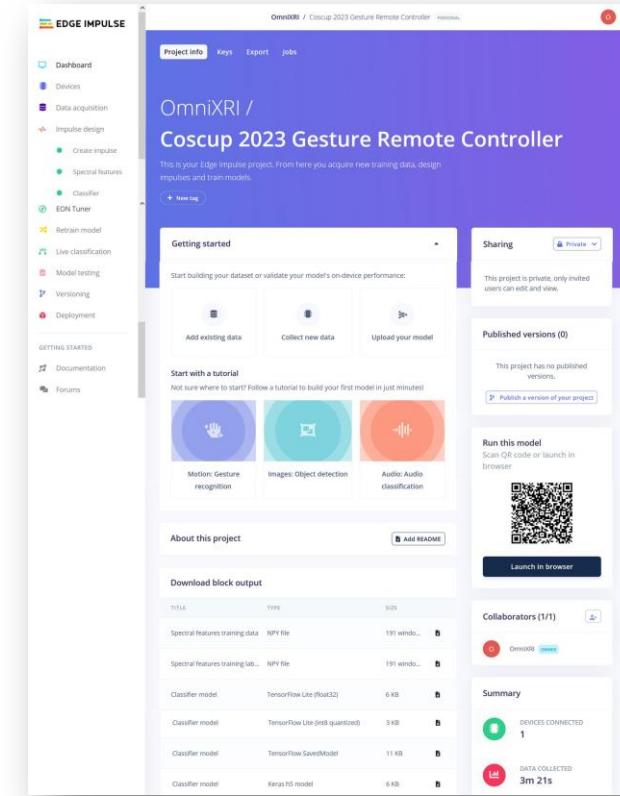
**USB Type C
纜線**



Arduino IDE 2.x



Edge Impulse Studio

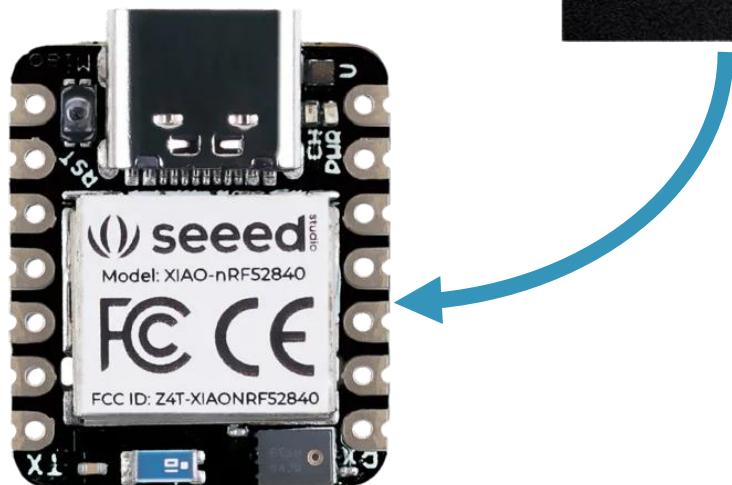


Seeed Studio Xiao (小) 系列

Board	SAMD21	RP2040	nRF52840	nRF52840 Sense	ESP32C3	ESP32S3	ESP32S3 Sense	ESPC6
Processor	Microchip SAM D21	Raspberry RP2040	Nordic nRF52840	Nordic nRF52840	Espressif ESP32-C3	Espressif ESP32-S3R8	Espressif ESP32-S3R8	Espressif ESP32-C6
CPU	CM0+ 48MHz	CM0+ dual 133MHz	CM4F 64MHz	CM4F 64MHz	RISC-V 160MHz	Xtensa LX7 dual 240MHz	Xtensa LX7 dual 240MHz	RISC-V x2 160M/20M
SRAM	32KB	264KB	256KB	256KB	400KB	8MB PSRAM	8MB PSRAM	512KB
Flash(chip)	256KB	✗	1MB	1MB	4MB	✗	✗	4MB
Flash(board)	✗	2MB	2MB	2MB	✗	8MB	8MB+SD	✗
Sensors	✗	✗	✗	IMU,Micphone	✗	✗	Cam,Micphone	✗
Charge IC	✗	✗	✗	✓	✓	✓	✓	✓
BLE	✗	✗	✓	✓	✓	✓	✓	✓
WIFI	✗	✗	✗	✗	✓	✓	✓	WiFi6

課程使用開發板，類似Arduino Nano 33 BLE Sense，但只保留麥克風及運動感測器。

Xiao nRF52840 Sense 模組 – CPU



➤ CPU

Nordic nRF52840 (Arm Cortex-M4F @64MHz) , 工作電壓3.3V。

➤ Flash

內建1MB，模組上另外接2MB。

➤ SRAM

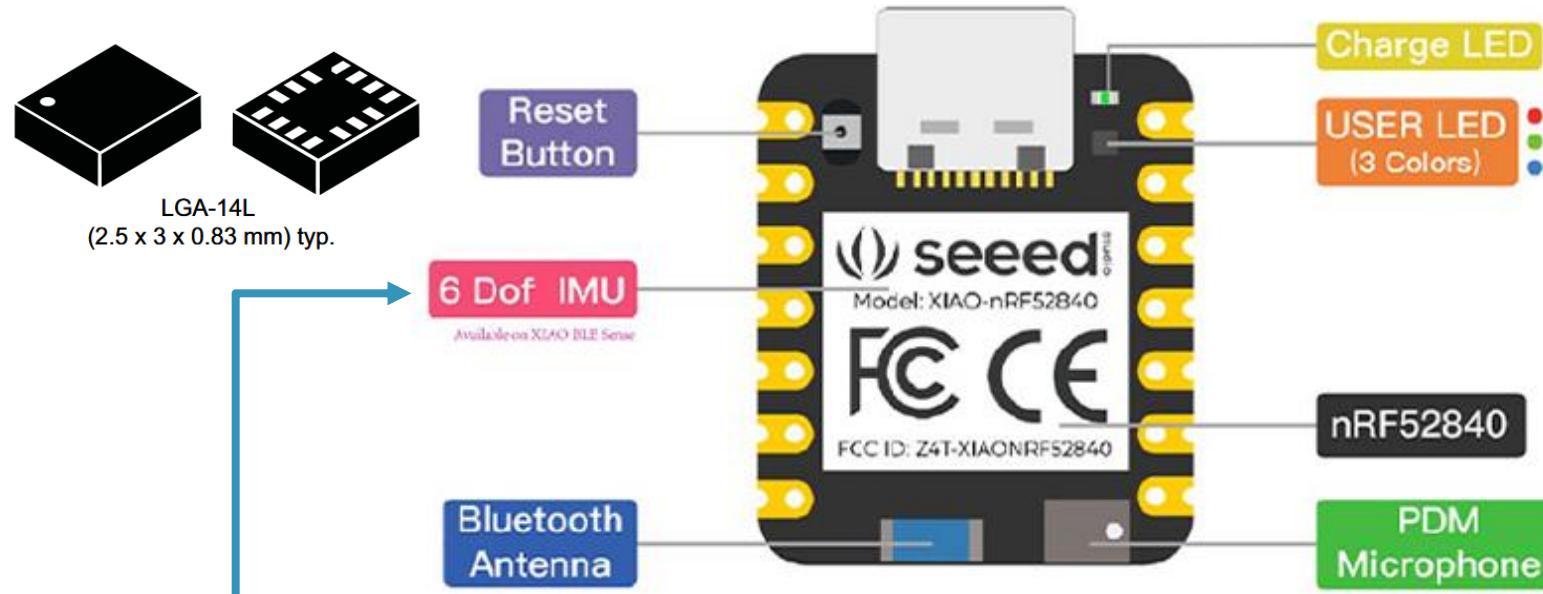
256KB

➤ BLE

藍牙5.0，支援低功耗藍牙(BLE)、藍牙Mesh網狀網路、NFC

資料來源：<https://www.nordicsemi.com/products/nrf52840?lang=zh-TW>

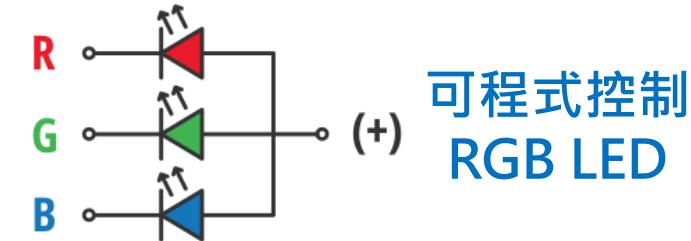
Xiao nRF52840 Sense 模組（正面）



LSM6DS3TR-C

- 3D加速度計 : $\pm 2/\pm 4/\pm 8/\pm 16$ g full scale
- 3D陀螺儀 : $\pm 125/\pm 250/\pm 500/\pm 1000/\pm 2000$ dps full scale
- 工作電壓 : 1.71 V to 3.6 V
- 通訊界面 : SPI & I2 C serial interface

資料來源：https://wiki.seeedstudio.com/XIAO_BLE/



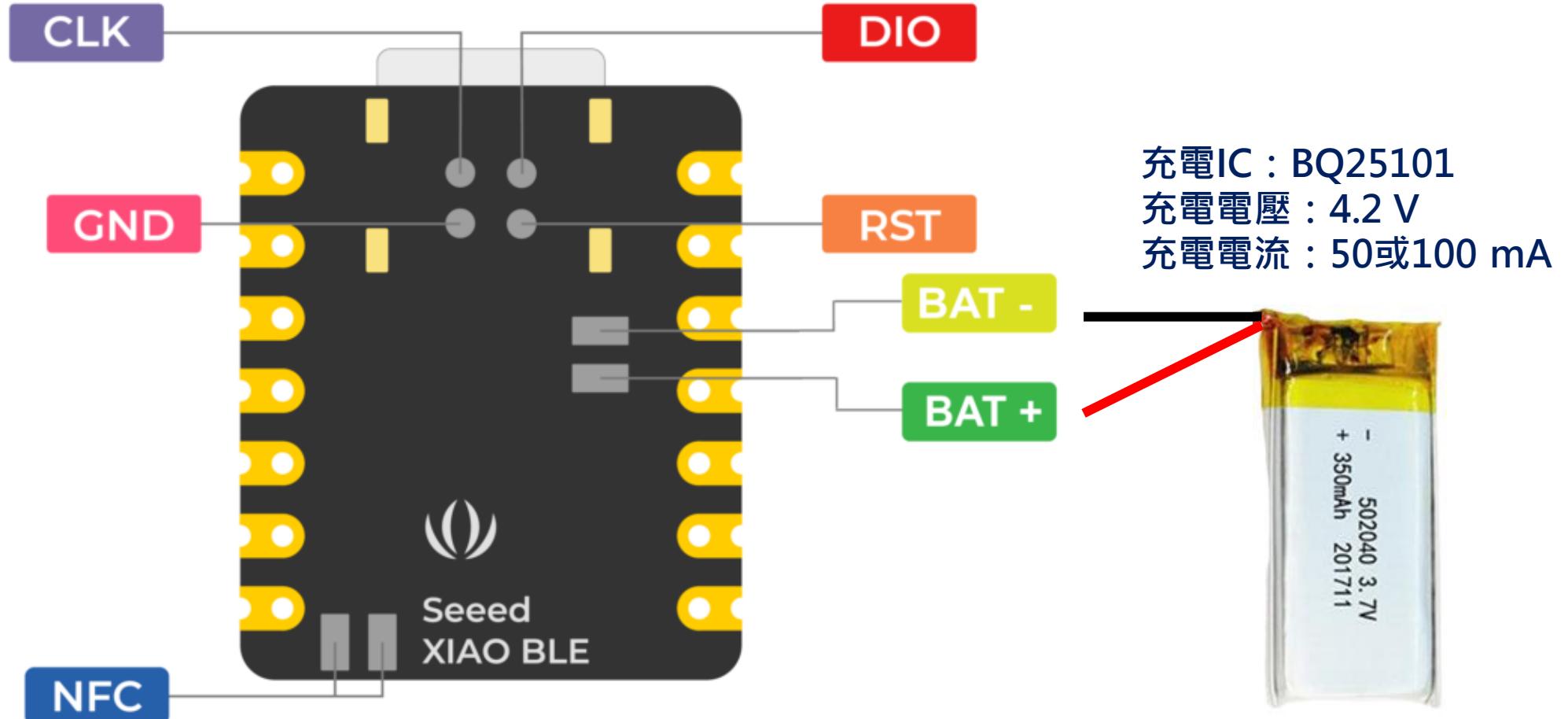
- 超低功耗，深度睡眠時低於5 μ A。
- 迷你尺寸：20mm x 17.5mm (外觀尺寸及接腳相容於其它XIAO系列)

MSM261D3526H1CPM

- 數位麥克風(PDM)
- 尺寸 : 3.5 x 2.65 x 0.94 mm
- 工作電壓 : 1.6 ~ 3.6V
- 通訊界面 : PDM

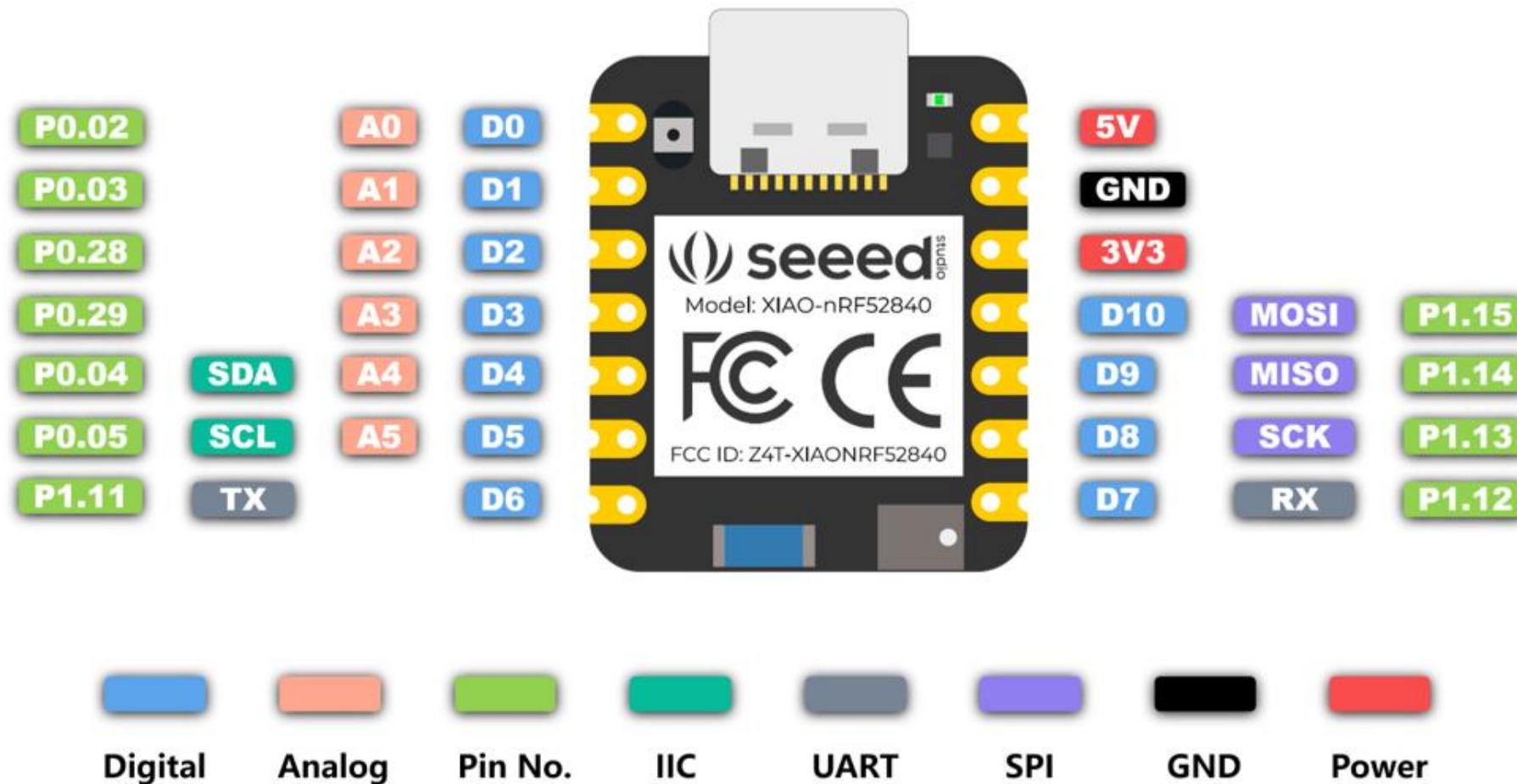


Xiao nRF52840 Sense 模組（反面）



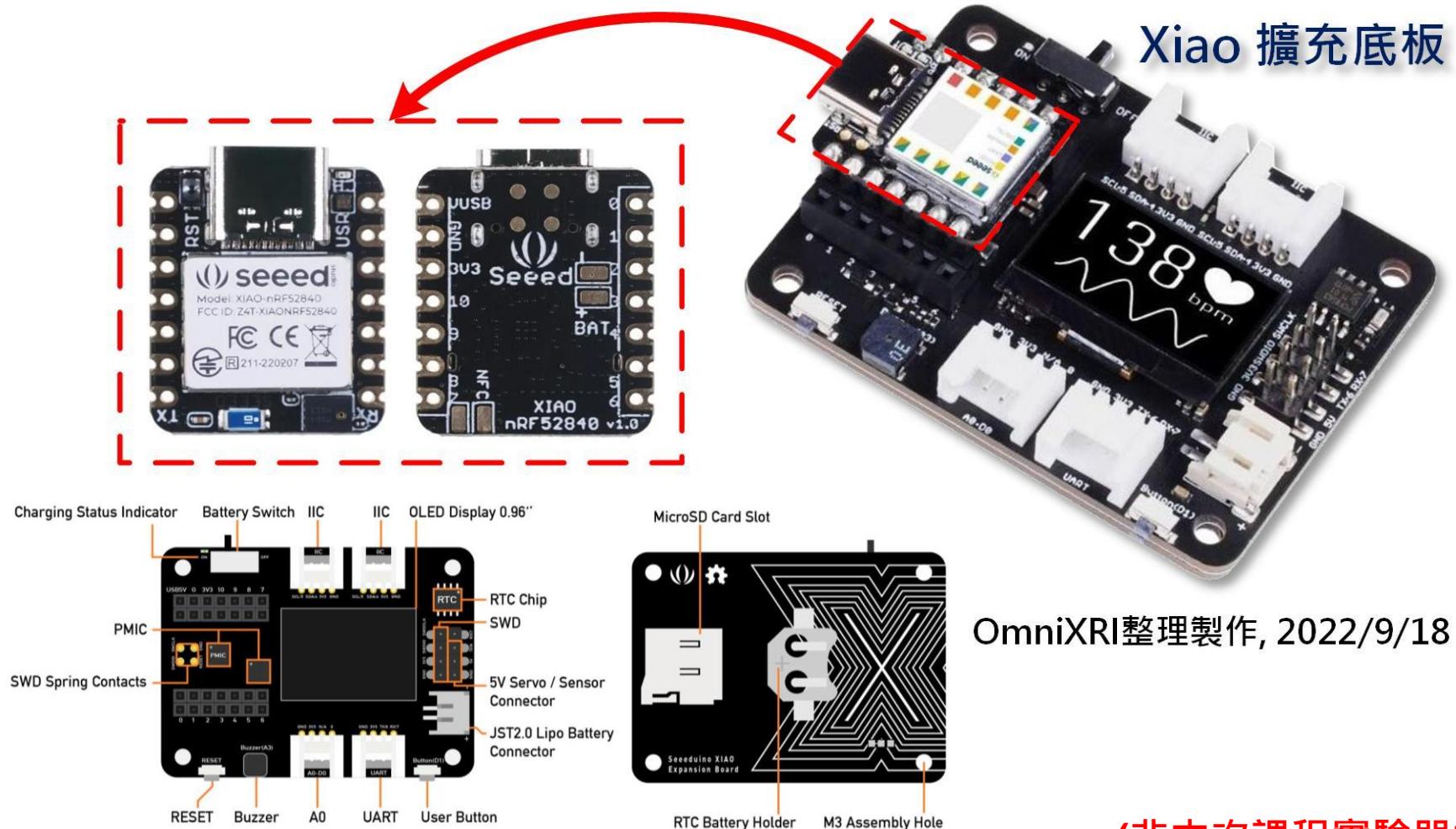
資料來源：https://wiki.seeedstudio.com/XIAO_BLE/

Xiao nRF52840 Sense模組 — 接腳定義圖



資料來源：https://wiki.seeedstudio.com/XIAO_BLE/

Xiao nRF52840 Sense模組 – 擴充底板

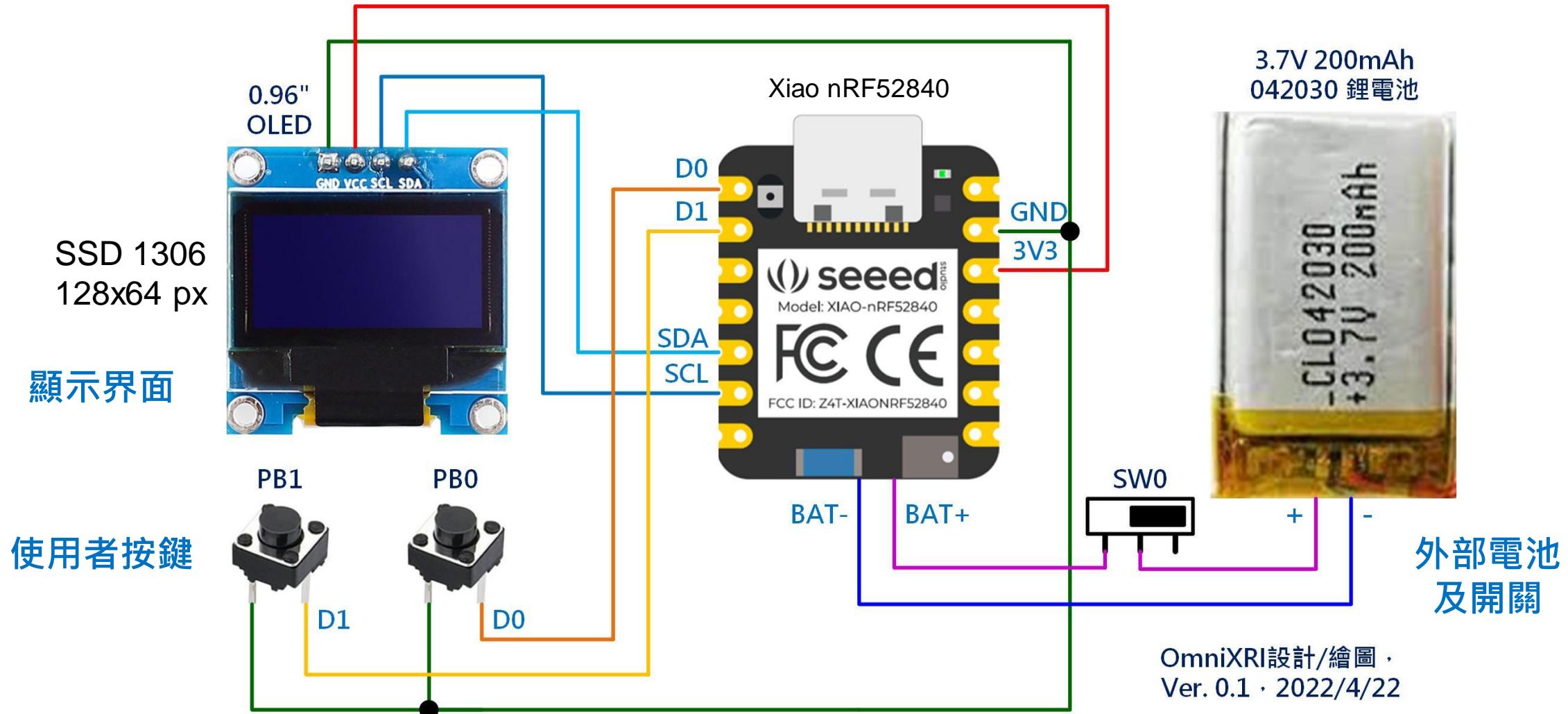


OmniXRI 整理製作, 2022/9/18

(非本次課程實驗器材，僅為補充介紹)

資料來源：<https://wiki.seeedstudio.com/cn/Seeeduino-XIAO-Expansion-Board/>

Xiao nRF52840 Sense 模組 – 參考電路



穿戴式智慧人工智慧裝置 – 參考外形



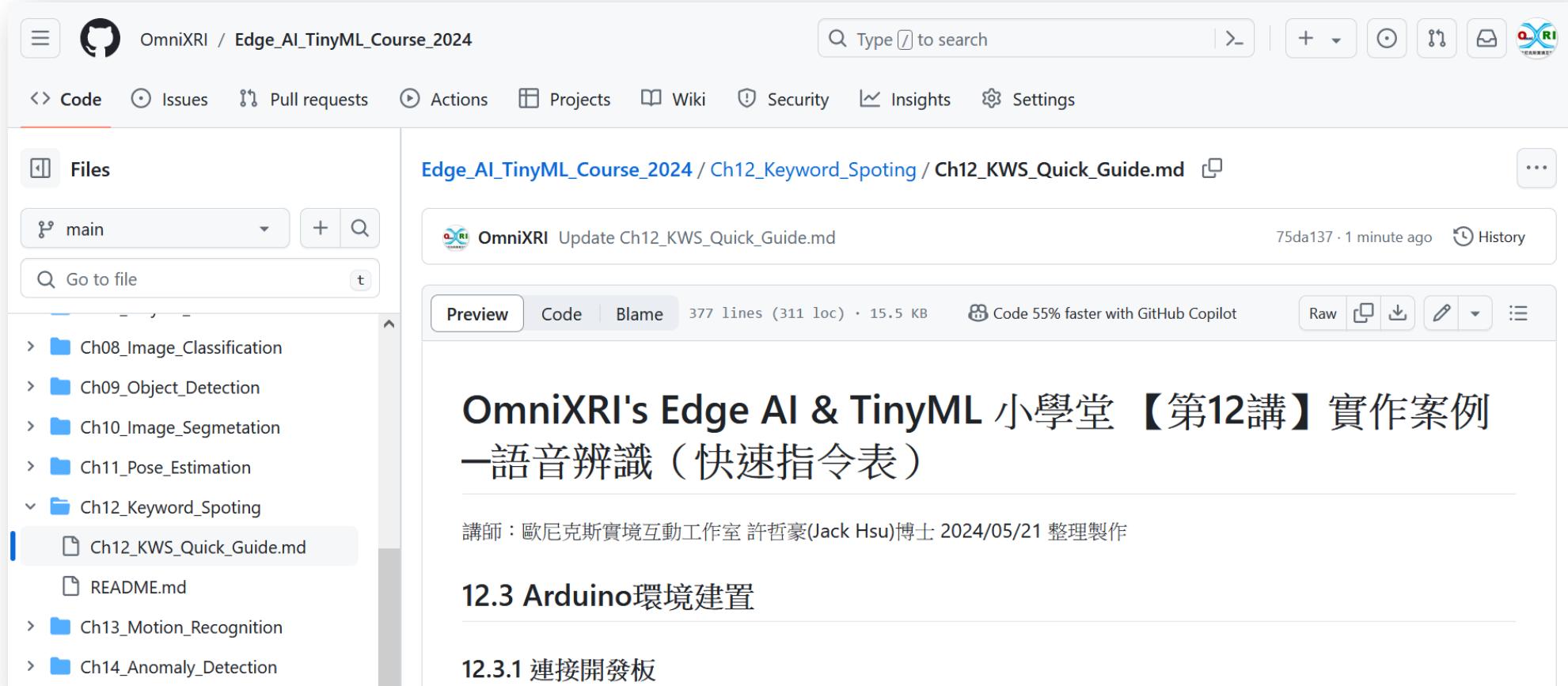
Xiao nRF52840 Sense 模組 — 連接開發板

以 USB Type C 纜線連接電腦和開發板，檢查「裝置管理員」下「連接埠 (COM 和 LPT)」是否有多一個「USB 序列裝置 (COMxx)」。xx即為埠號，會隨電腦即插入USB位置每次都隨機配置。若沒有產生序列裝置，則可快速按開發板「Reset」鍵二次，令其進入模式。



OmniXRI 整理製作, 2024/05/09

快速操作指令表

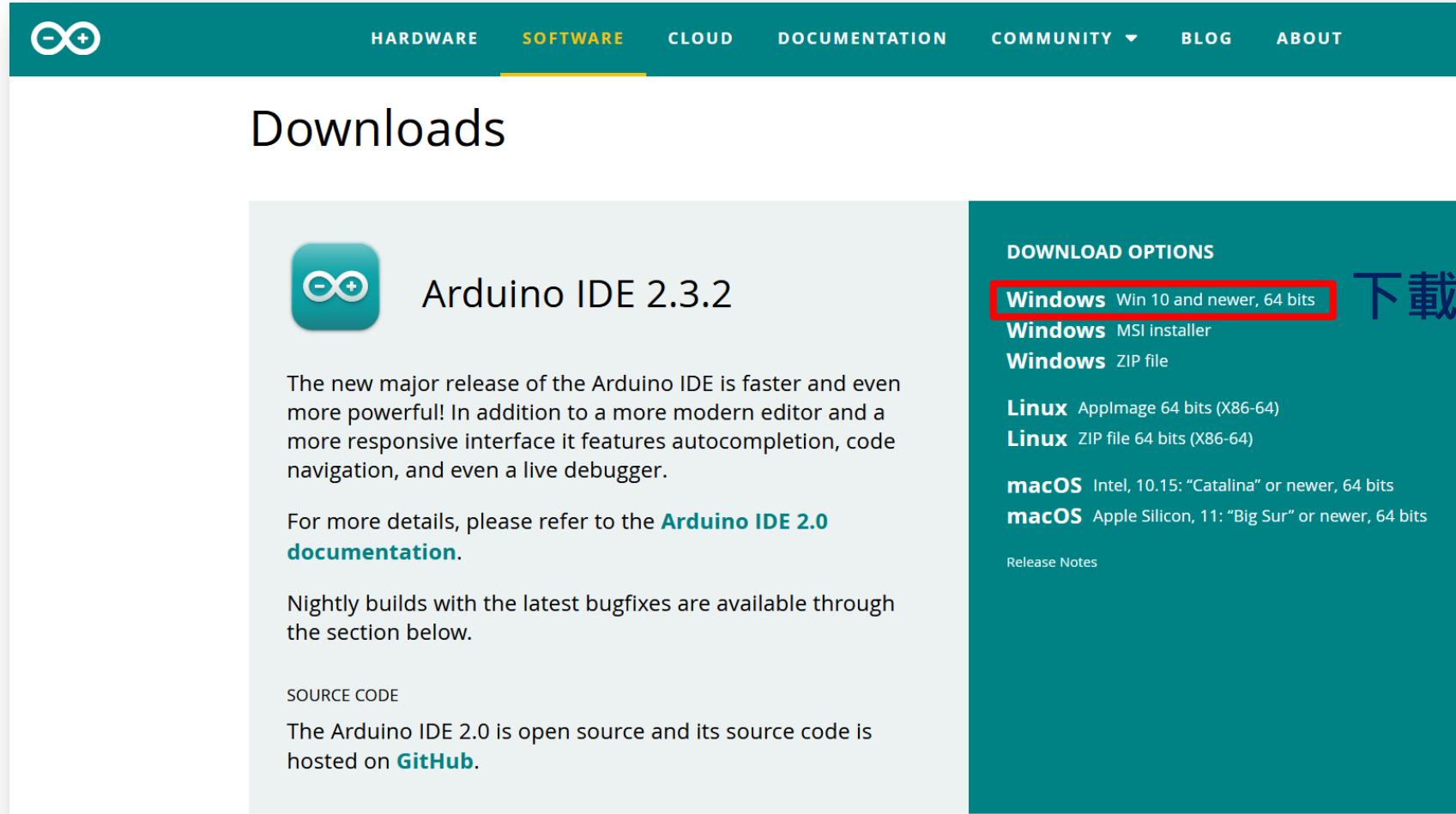


The screenshot shows a GitHub repository interface for the 'Edge_AI_TinyML_Course_2024' project. The repository path is 'OmniXRI / Edge_AI_TinyML_Course_2024'. The current file being viewed is 'Ch12_KWS_Quick_Guide.md'. The file content is as follows:

```
OmniXRI's Edge AI & TinyML 小學堂 【第12講】 實作案例  
—語音辨識（快速指令表）  
  
講師：歐尼克斯實境互動工作室 許哲豪(Jack Hsu)博士 2024/05/21 整理製作  
  
12.3 Arduino環境建置  
  
12.3.1 連接開發板
```

https://github.com/OmniXRI/Edge_AI_TinyML_Course_2024/blob/main/Ch12_KWS_Quick_Guide.md

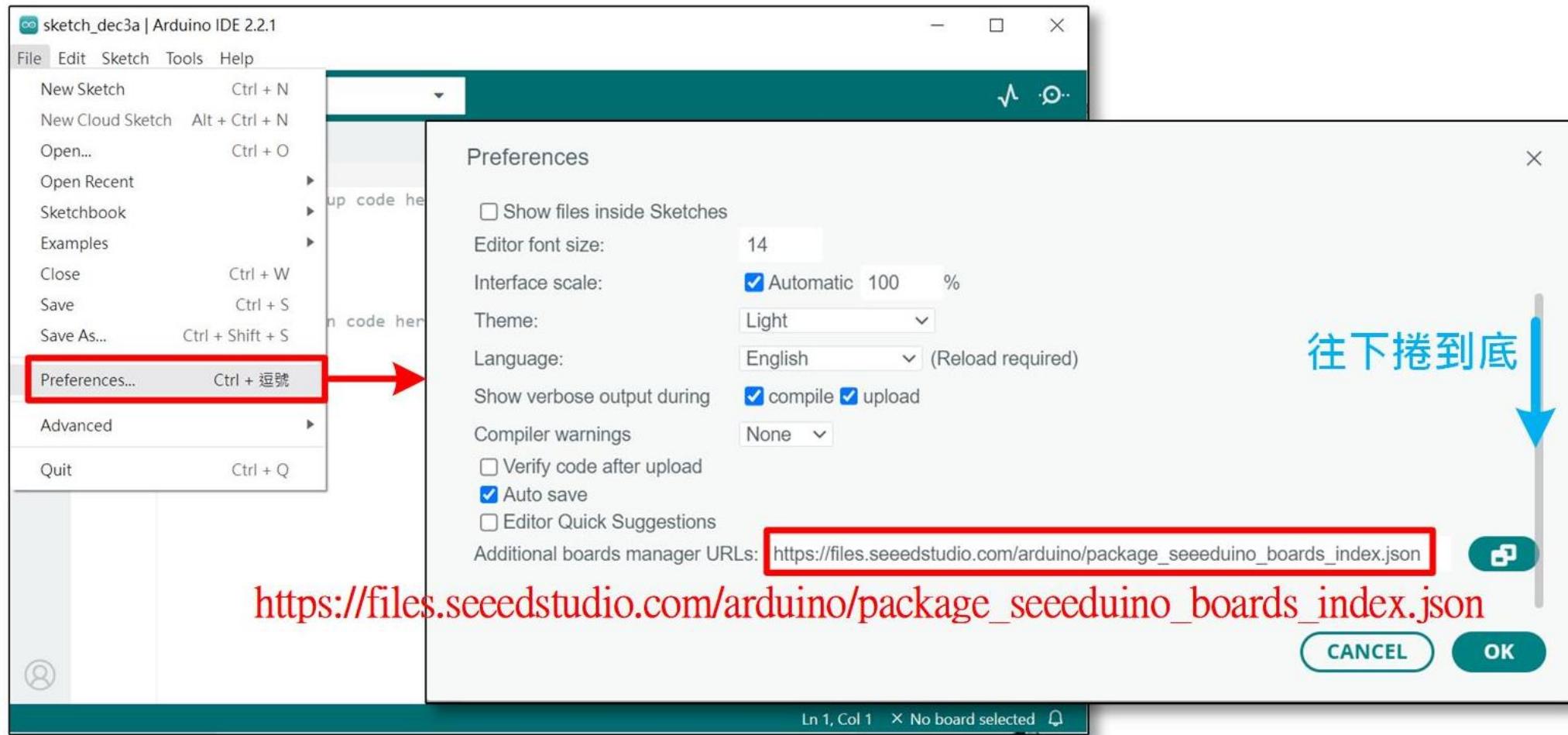
下載並安裝開發環境 Arduino IDE 2.x



The screenshot shows the Arduino Software (IDE) download page. At the top, there's a navigation bar with links for HARDWARE, SOFTWARE (which is highlighted in yellow), CLOUD, DOCUMENTATION, COMMUNITY, BLOG, and ABOUT. Below the navigation bar, the page title is "Downloads". On the left side, there's a section for "Arduino IDE 2.3.2" featuring a small icon of the Arduino logo (an infinity symbol with a minus and plus sign), a brief description of the new features, and a link to the "Arduino IDE 2.0 documentation". Below this, there's a "SOURCE CODE" section linking to GitHub. On the right side, there's a "DOWNLOAD OPTIONS" section with links for Windows (highlighted with a red box), Windows MSI installer, Windows ZIP file, Linux (AppImage and ZIP file), and macOS (Intel and Apple Silicon). There's also a "Release Notes" link at the bottom.

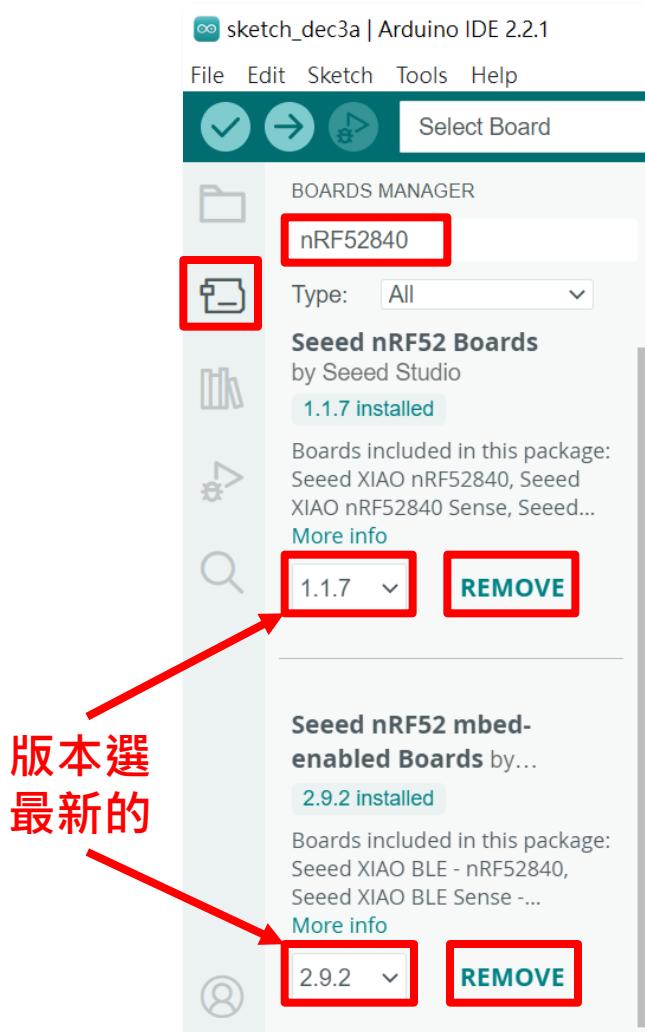
<https://www.arduino.cc/en/software>

Arduino 新增開發板設定



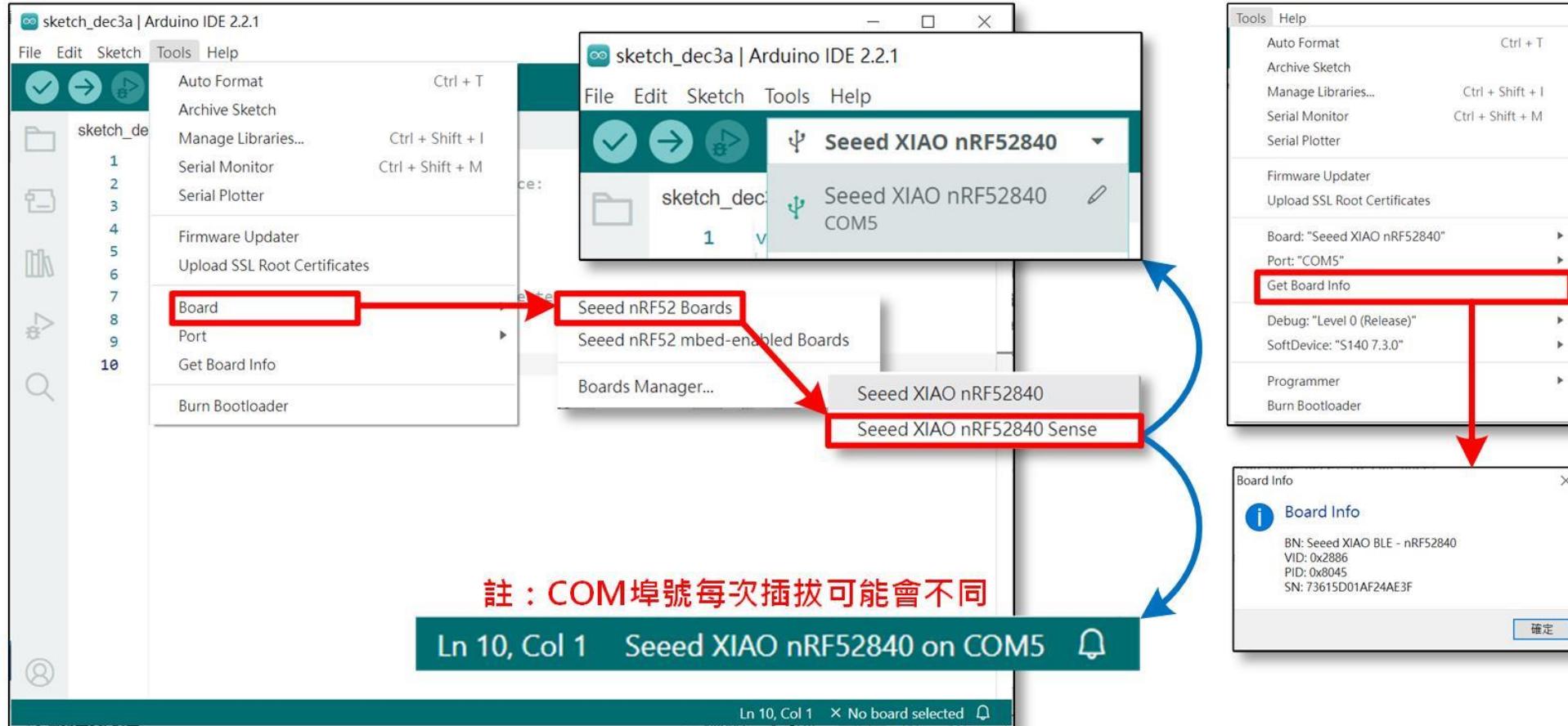
OmniXRI 整理製作, 2023/12/08

安裝Seeed nRF52840函式庫



- 點選選單 Tools > Board > Boards Manager...，或直接點選左側第二個「開發板」圖示。
- 輸入 **nRF52840** 搜尋 Seeed nRF52840 開發板相關函式庫。
- 點選「**INSTALL**」安裝下列二個函式庫。（版本可取最新的）
 - **Seeed nRF52 Boards (BLE, 低功耗功能)**
 - **Seeed nRF52 mbed-enabled Boards (PDM, IMU, ML)**
- 安裝後若不需要時，可點選「**REMOVE**」解除安裝。

指定工作開發板及埠號



- 選擇開發板 Seeed XIAO nRF52840 Sense
- 選擇對應埠號
- 檢查是否連線

OmniXRI整理製作, 2023/12/08

測試程式：LED閃爍

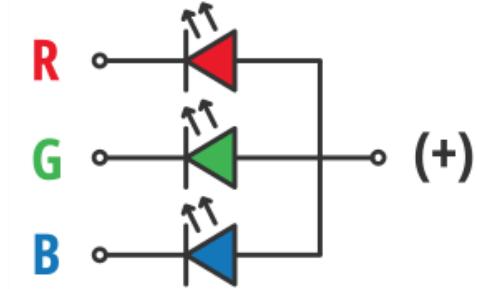
點選選單 **File > Examples > 01.Basics > Blink** 會自動產生下列程式碼

```

① // 初始設置
void setup() {
    pinMode(LED_BUILTIN, OUTPUT); // 預設板上紅色LED為輸出
}

// 無限迴圈
void loop() {
    digitalWrite(LED_BUILTIN, HIGH); // 熄滅LED
    delay(1000); // 等待時間
    digitalWrite(LED_BUILTIN, LOW); // 點亮LED
    delay(1000); // 等待時間
}

```



Active Low (低電位工作)

```

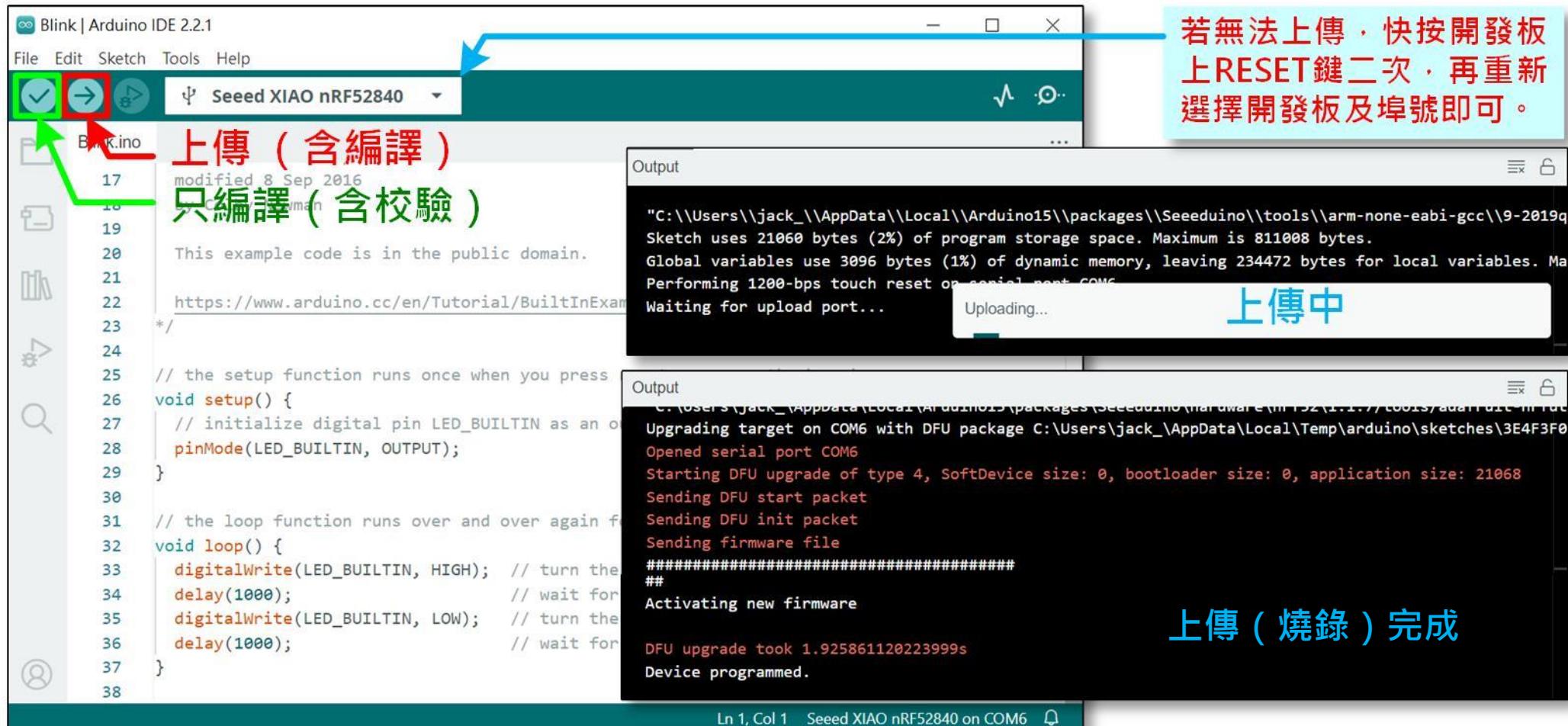
// variant.h 系統變數預設檔
#define LED_BUILTIN (PIN_LED)

#define LED_RED      (11)
#define LED_GREEN    (13)
#define LED_BLUE     (12)

```

練習：紅綠藍LED輪流閃爍

編譯和上傳程式



OmniXRI整理製作, 2023/12/08

無法上傳錯誤排除

輸出錯誤訊息 (通常會發生在連續上傳兩次時)

Output

Possible causes:

- Selected Bootloader version does not match the one on Bluefruit device.
| | Please upgrade the Bootloader or select correct version in Tools->Bootloader.
- Baud rate must be 115200, Flow control must be off.
- Target is not in DFU mode. Ground DFU pin and RESET and release both to enter DFU mode.

註：DFU (Development Firmware Upgrade)

1. 快按兩次「Reset」鍵
2. 到裝置管理員檢查 COM 埠號
3. 檢查 Arduino COM 埠號設定
4. 重新上傳

Reset



Edge Impulse 簡介

MCU等級AI供應商為tinyML主要成員

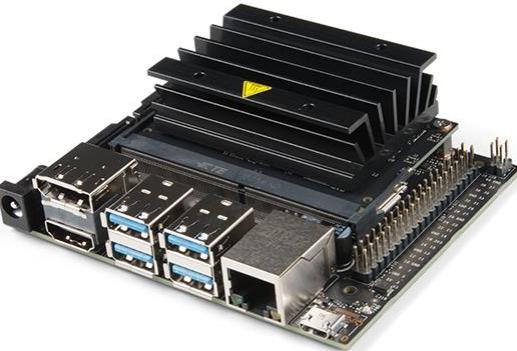
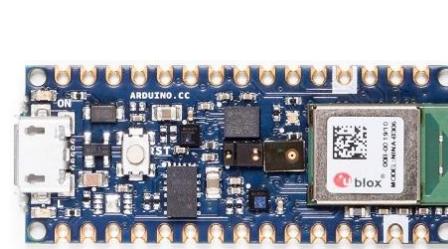
提供眾多API及SDK方便開發應用

- 動作辨識、關鍵詞偵測、物件偵測等
- 支援多種小型AI及MCU / MPU開發
- 提供豐富線上開發工具



Himax WE-I Plus 33 BLE Sense

資料來源：<https://docs.edgeimpulse.com/docs/>



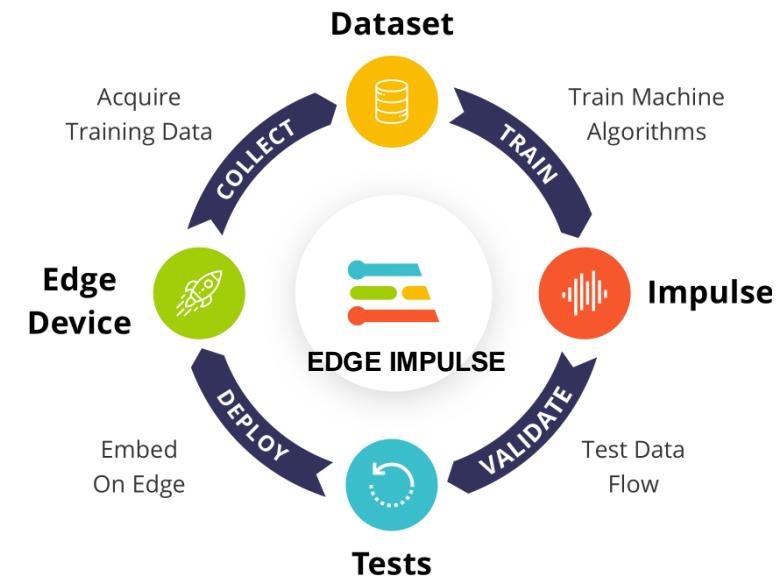
Nvidia Jetson Nano



Raspberry Pi 4



Seeed Xiao
nRF52840 Sense



Edge Impulse 主要功能

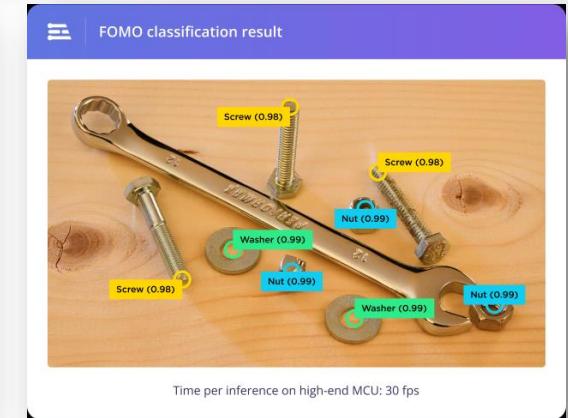
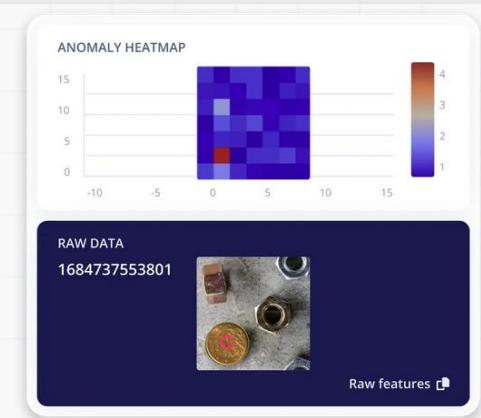
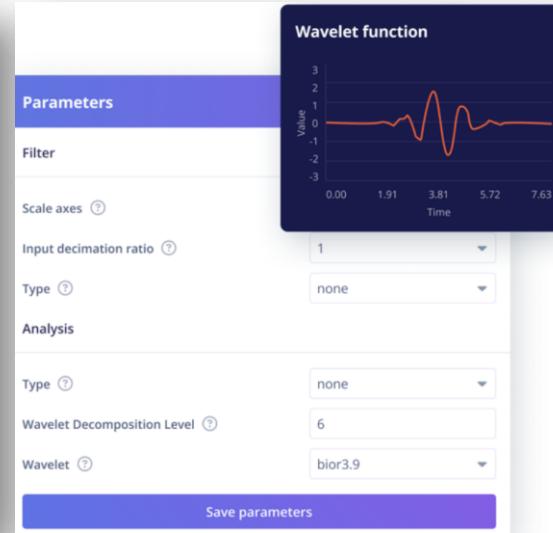
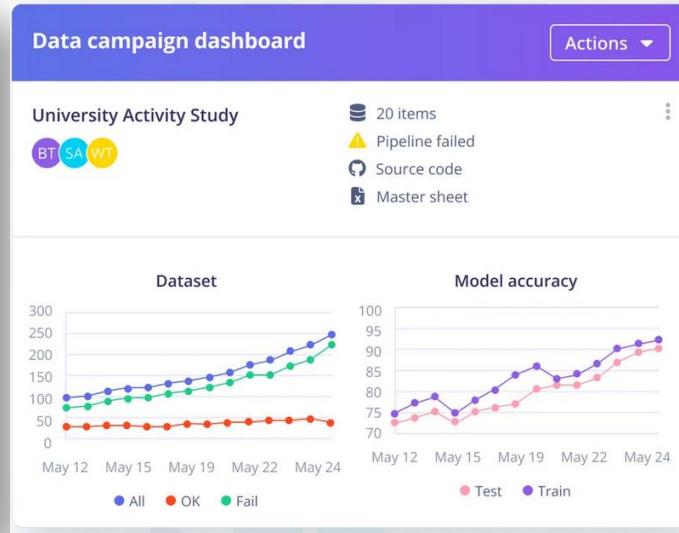
```
# Quick integration for any Python script
import edgeimpulse as ei

# 1. Set API key from Edge Impulse project
ei.API_KEY = "ei_dae2..."

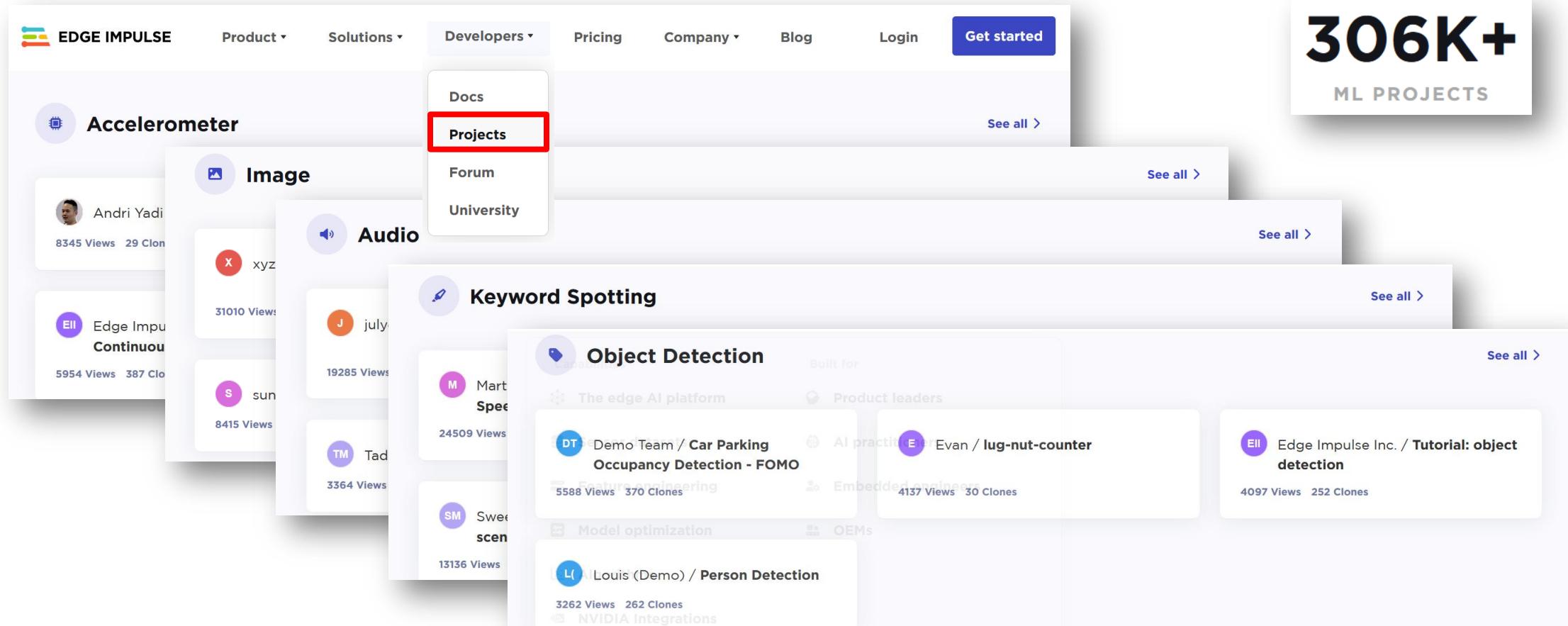
# 2. Profile model performance on target device
results = ei.model.profile(model="/path/to/model",
                           device="cortex-m4f-80mhz")

# 3. View profiling results
results.summary()

# 4. Optimize model and convert to C++ library
from ei.model.output_type import Classification
ei.model.deploy(model="/path/to/model",
               model_output_type=Classification(),
               output_directory="/library")
```



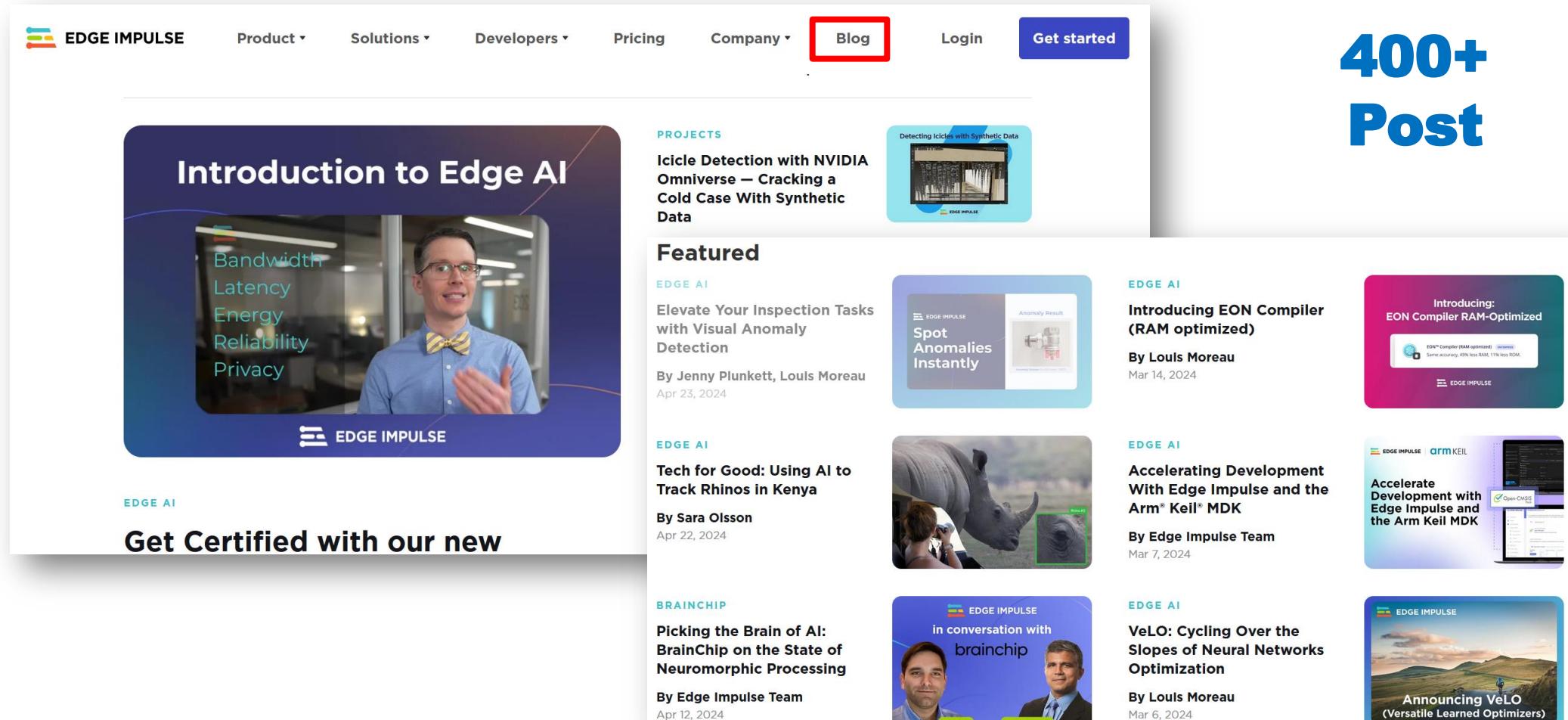
Edge Impulse – 公用專案



The screenshot shows the Edge Impulse website's homepage. At the top, there is a navigation bar with links for Product, Solutions, Developers (which is currently selected), Pricing, Company, Blog, Login, and a prominent blue 'Get started' button. To the right of the navigation is a large statistic box displaying '306K+' ML PROJECTS. Below the navigation, there are several project cards categorized by type: Accelerometer, Image, Audio, Keyword Spotting, Object Detection, and others. Each card displays the project name, author, view count, and clone count. A red box highlights the 'Projects' link in the 'Developers' dropdown menu.

<https://edgeimpulse.com/projects/overview>

Edge Impulse – 部落格文章



The screenshot shows the Edge Impulse blog homepage. At the top, there is a navigation bar with links: EDGE IMPULSE, Product, Solutions, Developers, Pricing, Company, **Blog** (which is highlighted with a red box), Login, and Get started.

The main content area features a large banner for "Introduction to Edge AI" with a video thumbnail of a man speaking. Below the banner, there are several blog posts and project cards:

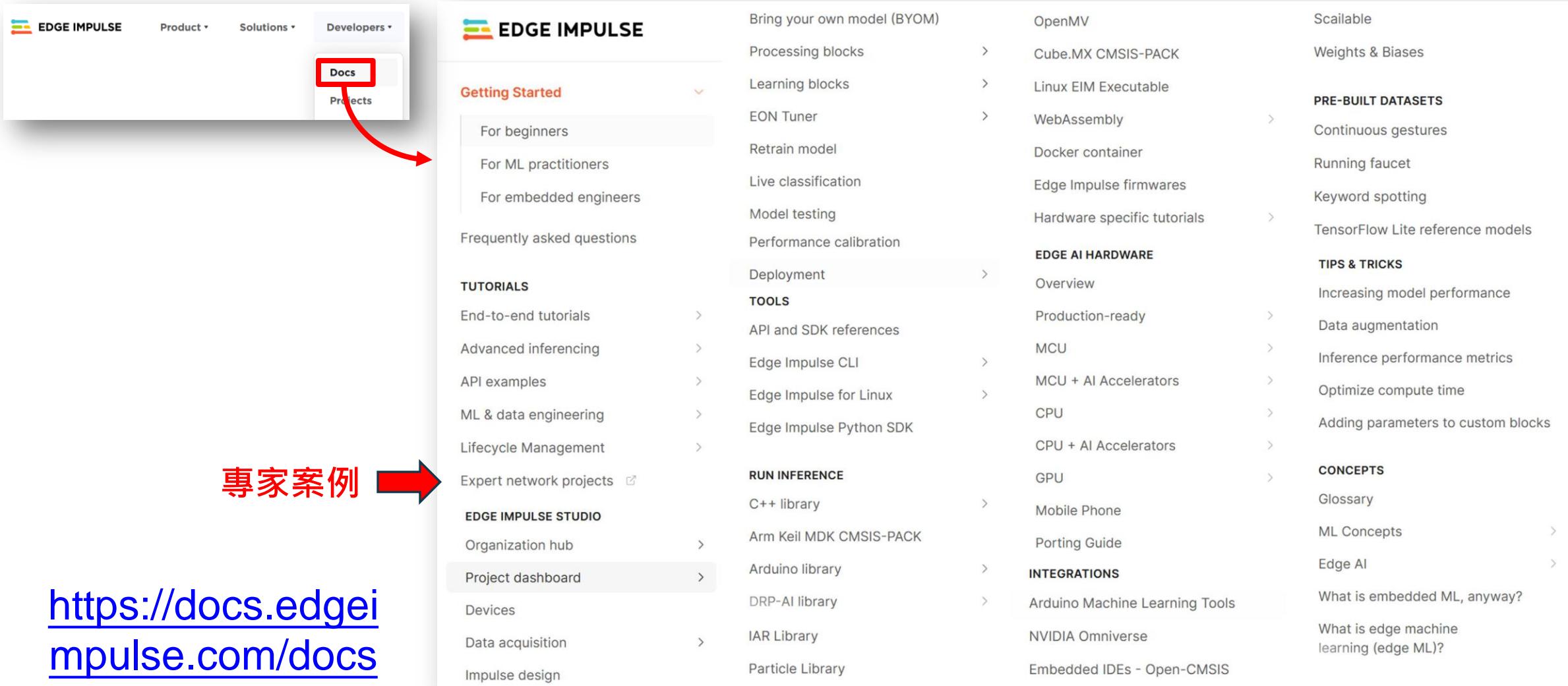
- PROJECTS**: "Icicle Detection with NVIDIA Omniverse – Cracking a Cold Case With Synthetic Data" (Thumbnail: Detecting Icicles with Synthetic Data)
- Featured**:
 - EDGE AI**: "Elevate Your Inspection Tasks with Visual Anomaly Detection" (Thumbnail: Spot Anomalies Instantly)
 - EDGE AI**: "Tech for Good: Using AI to Track Rhinos in Kenya" (Thumbnail: A rhino)
 - BRAINCHIP**: "Picking the Brain of AI: BrainChip on the State of Neuromorphic Processing" (Thumbnail: Two men)
- EDGE AI**: "Introducing EON Compiler (RAM optimized)" (Thumbnail: EON Compiler RAM Optimized)
- EDGE AI**: "Accelerating Development With Edge Impulse and the Arm Keil MDK" (Thumbnail: Accelerate Development with Edge Impulse and the Arm Keil MDK)
- EDGE AI**: "VeLO: Cycling Over the Slopes of Neural Networks Optimization" (Thumbnail: Announcing VeLO (Versatile Learned Optimizers))

On the left side of the page, there is a sidebar with the text "Get Certified with our new" followed by the "EDGE AI" logo.

400+ Post

<https://edgeimpulse.com/blog/>

Edge Impulse – 說明文件



<https://docs.edgeimpulse.com/docs>

Docs (highlighted with a red box)

專家案例 (highlighted with a red box)

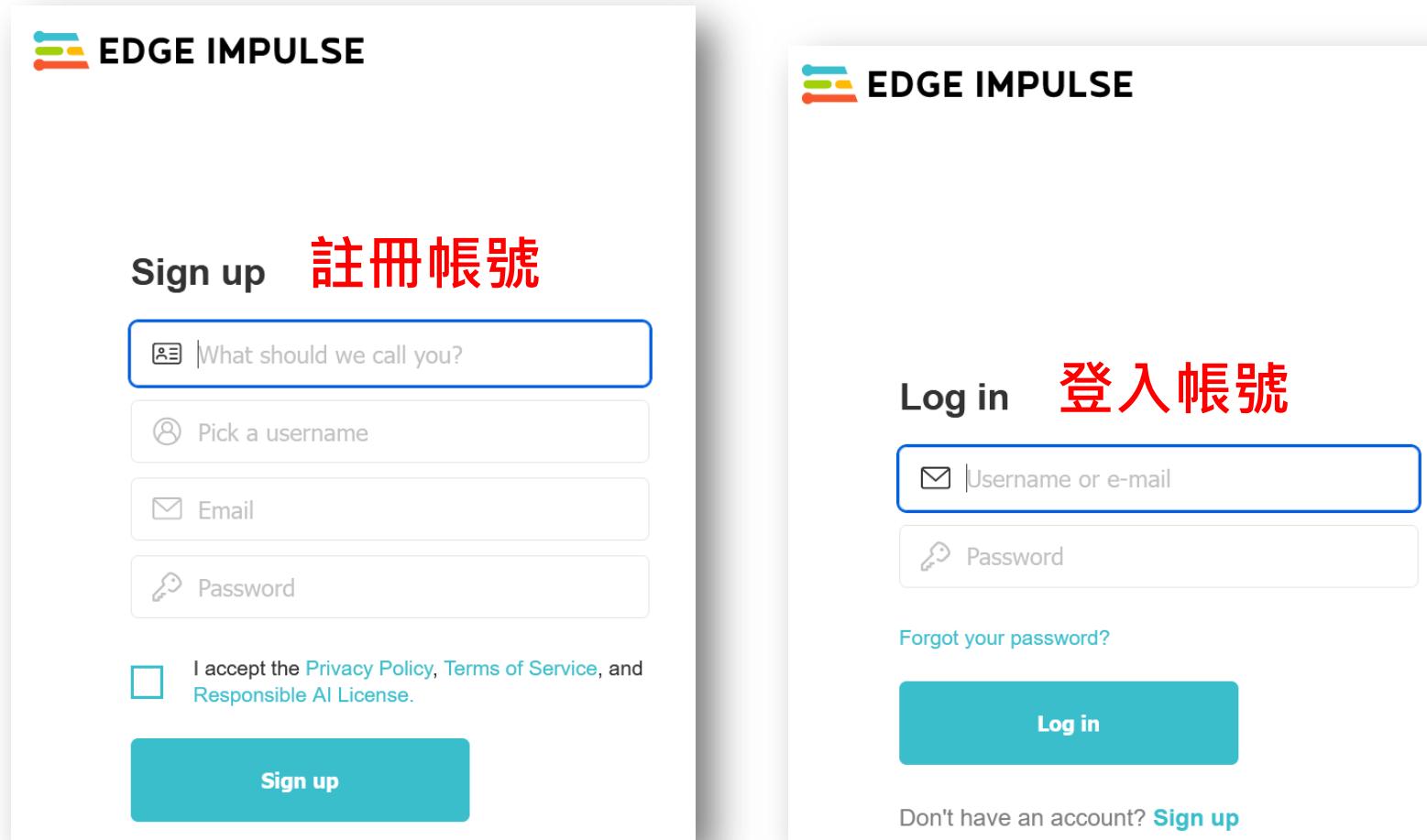
Category	Sub-Category	Description	Related Topics
Getting Started	For beginners	Processing blocks, Learning blocks, EON Tuner, Retrain model, Live classification, Model testing, Performance calibration	OpenMV, Cube.MX CMSIS-PACK, Linux EIM Executable, WebAssembly, Docker container, Edge Impulse firmwares, Hardware specific tutorials, Overview, Production-ready, MCU, MCU + AI Accelerators, CPU, CPU + AI Accelerators, GPU, Mobile Phone, Porting Guide, Arduino Machine Learning Tools, NVIDIA Omniverse, Embedded IDEs - Open-CMSIS
	For ML practitioners		
	For embedded engineers		
	Frequently asked questions		
	TUTORIALS	End-to-end tutorials, Advanced inferencing, API examples, ML & data engineering, Lifecycle Management, Expert network projects	
	EDGE IMPULSE STUDIO	Organization hub, Project dashboard, Devices, Data acquisition, Impulse design	
	RUN INFERENCE	C++ library, Arm Keil MDK CMSIS-PACK, Arduino library, DRP-AI library, IAR Library, Particle Library	
	TOOLS	API and SDK references, Edge Impulse CLI, Edge Impulse for Linux, Edge Impulse Python SDK	
	INTEGRATIONS		
	CONCEPTS	Glossary, ML Concepts, Edge AI, What is embedded ML, anyway?, What is edge machine learning (edge ML)?	

Edge Impulse – Expert network projects

- Featured Machine Learning Projects
- Prototype and Concept Projects
- Image Projects
- Audio Projects
- Predictive Maintenance & Fault Classification
- Accelerometer & Activity Projects
- Air Quality & Environmental Projects
- Novel Sensor Projects
- Software Integration Demos

<https://edge-impulse.gitbook.io/experts>

註冊/登入 Edge Impulse 帳號



The image shows two side-by-side screenshots of the Edge Impulse web interface. The left screenshot is titled "Sign up 註冊帳號" and features fields for "What should we call you?", "Pick a username", "Email", and "Password". It includes a checkbox for accepting the Privacy Policy, Terms of Service, and Responsible AI License, and a "Sign up" button. The right screenshot is titled "Log in 登入帳號" and features fields for "Username or e-mail" and "Password". It includes a "Forgot your password?" link, a "Log in" button, and a "Don't have an account? Sign up" link at the bottom.

<https://studio.edgeimpulse.com/login>

免費帳號使用限制

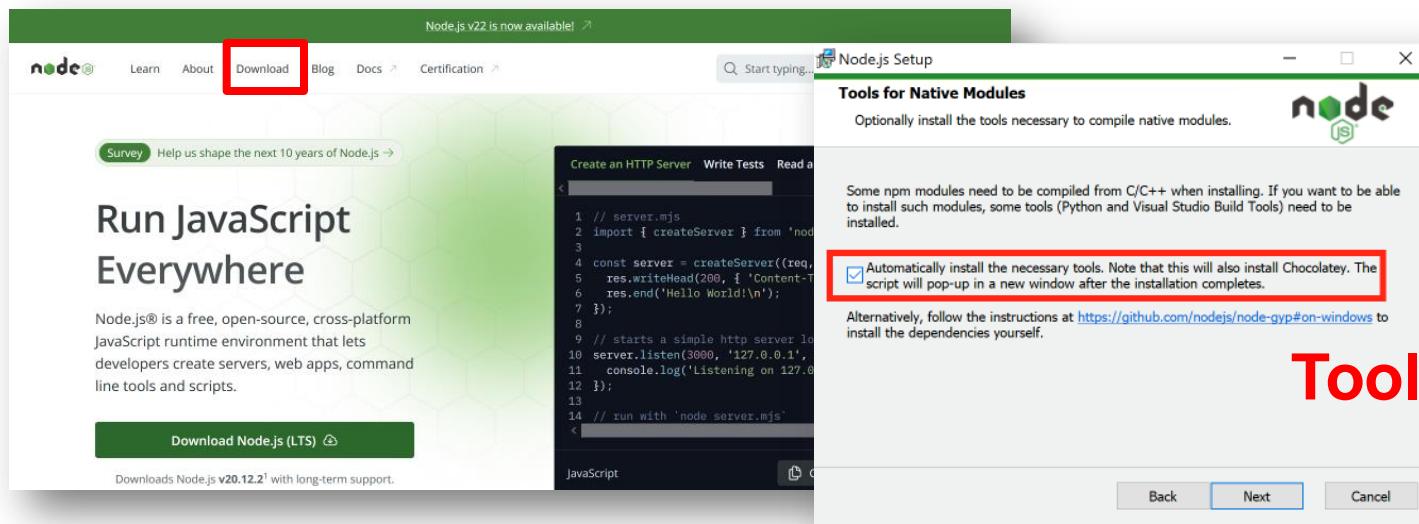
- 2組私人專案
- 公用專案不限
- 最多**3個**成員
- 每個專案**4GB**或**4小時**資料
- 每個專案計算時間**20分鐘**
- EON Tuner, Compiler 有限制

下載及安裝必要工具

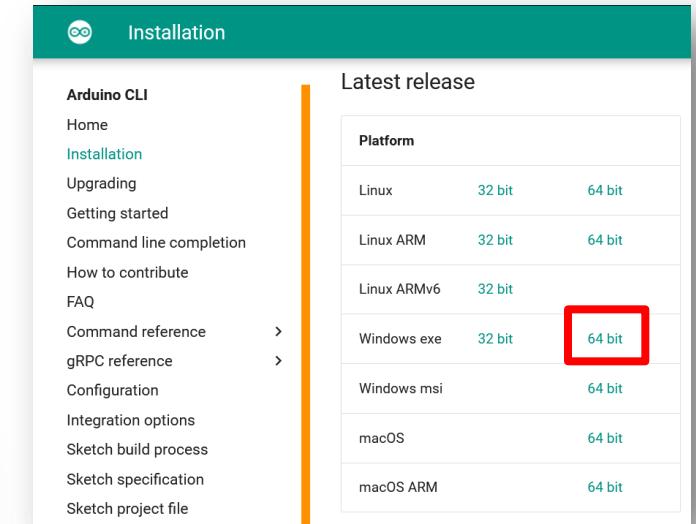
1. Python 3.x



2. Node.js (建議安裝v18.20.2 LTS)



3. Arduino CLI



**安裝時要注意
記得一定要勾選
Tools for Native Modules
以 node -v 及 npm -v
檢查安裝好的版本**

安裝 Edge Impulse 工作環境

➤ 安裝Edge Impulse CLI

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

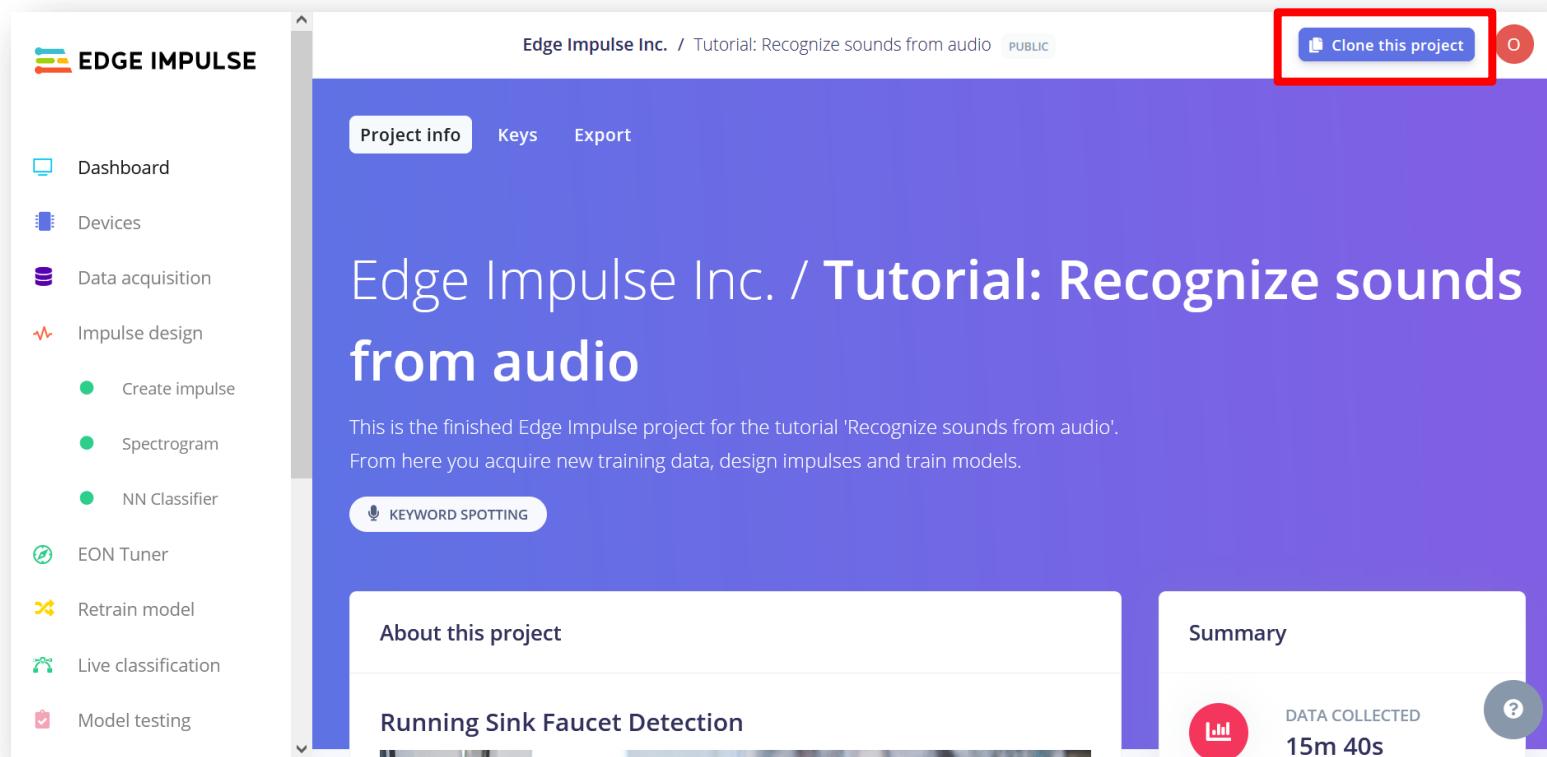
➤ 安裝完成後會得到下列工具

- **edge-impulse-daemon** 透過 COM 埠和雲端平台連接
- **edge-impulse-uploader** 允許上傳本機檔案
- **edge-impulse-data-forwarder** 透過 COM 埠上傳開發板感測器數值
- **edge-impulse-run-impulse** 顯示裝置上運行的模型
- **edge-impulse-blocks** 建立自定義區塊
- **himax-flash-tool** 燒錄 Haimax WE-I Plus

<https://docs.edgeimpulse.com/docs/tools/edge-impulse-cli/cli-installation>

啟動公用專案範例 – 水流聲辨識

Edge Impulse Inc. / Tutorial: Recognize sounds from audio



The screenshot shows the Edge Impulse project page for the tutorial 'Recognize sounds from audio'. The top navigation bar includes 'Project info', 'Keys', and 'Export'. A red box highlights the 'Clone this project' button. The main content area features the title 'Edge Impulse Inc. / Tutorial: Recognize sounds from audio from audio' and a description: 'This is the finished Edge Impulse project for the tutorial 'Recognize sounds from audio''. It also mentions 'From here you acquire new training data, design impulses and train models.' Below the title are buttons for 'KEYWORD SPOTTING', 'About this project', and 'Running Sink Faucet Detection'. A summary section indicates 'DATA COLLECTED 15m 40s'.

複製專案到
個人帳號

水流聲辨識



<https://studio.edgeimpulse.com/public/14301/latest>

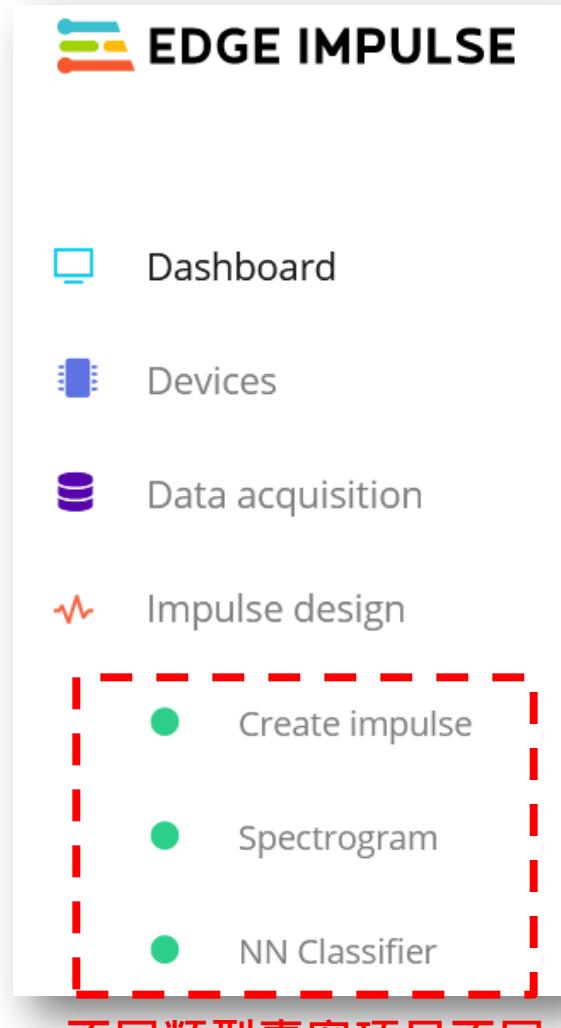
專案工作流程



水流聲辨識

1. 準備開發板
2. 收集資料
3. 建立資料集
4. 設計及選用模型
5. 配置MFE模塊
6. 配置神經網路
7. 分類新資料
8. 模型測試
9. 模型故障排除
10. 部署到指定裝置

Edge Impulse Studio — 專案功能表

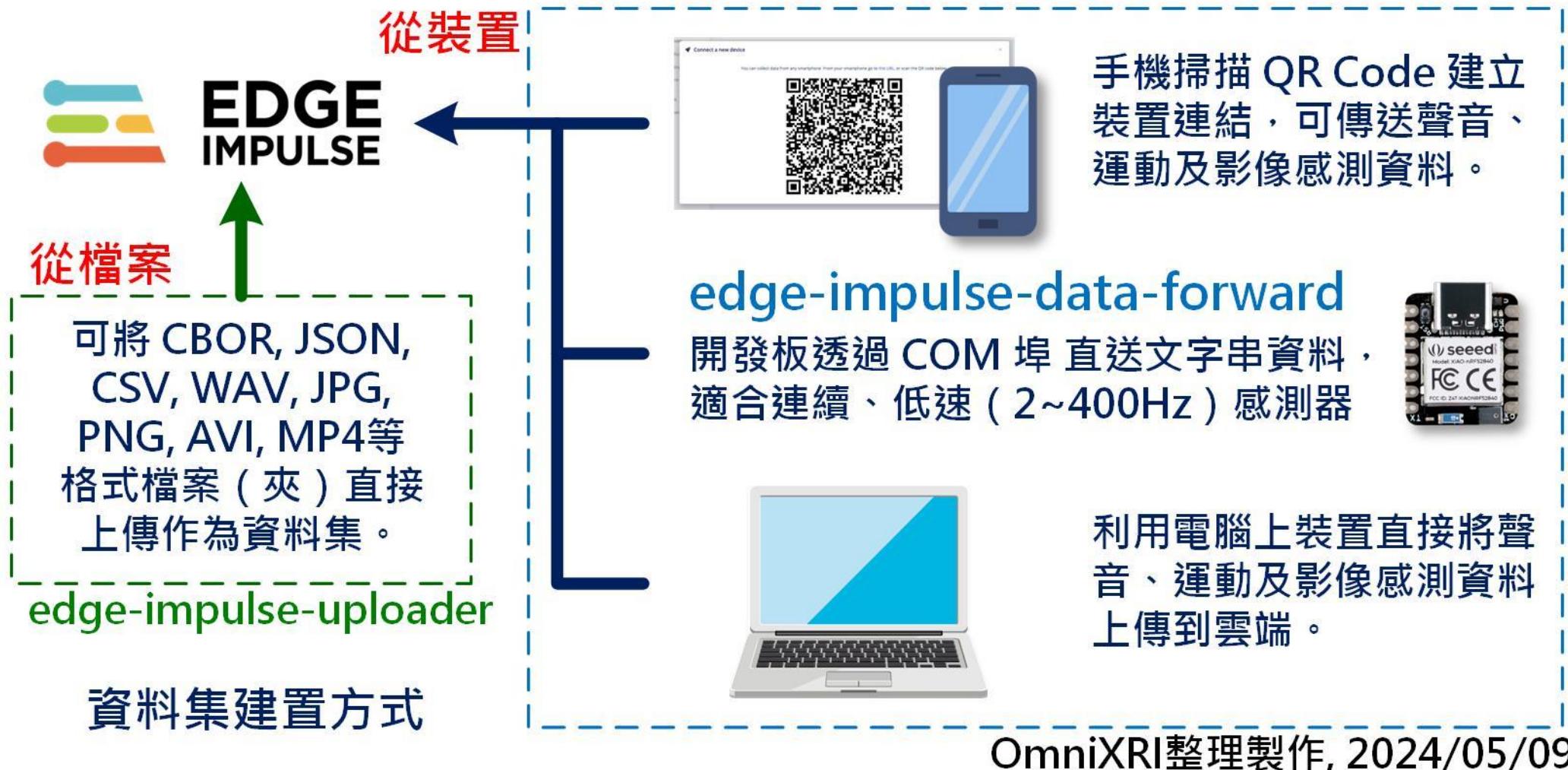


專案儀錶板
連線裝置
資料擷取
流程設計
建立流程
資料頻譜
神經網路分類器

- EON Tuner
- Retrain model
- Live classification
- Model testing
- Performance calibration
- Versioning
- Deployment

EON調整器
重新訓練模型
立即分類
模型測試
效能效正
版本管理
程式部署

Edge Impulse 資料集建置方式

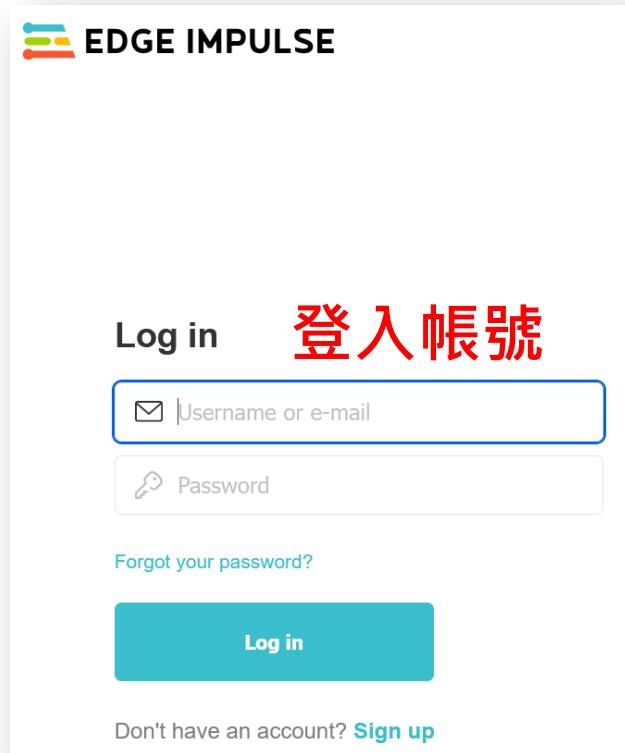
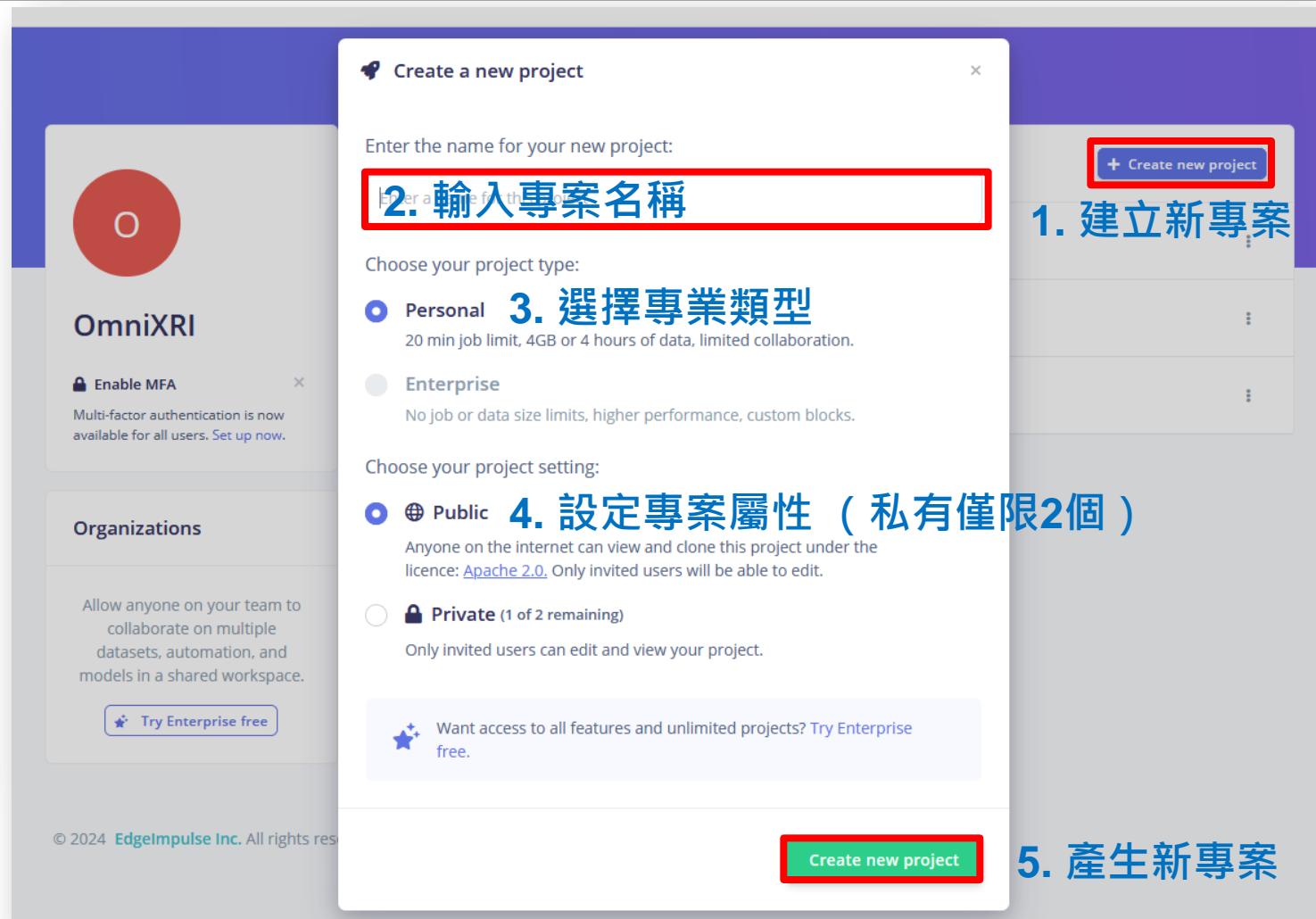


12.4. Edge Impulse 喚醒詞案例



- 建立專案
- 選用模型
- 裝置連線
- 設定參數
- 收集資料
- 特徵提取
- 上傳資料
- 訓練模型
- 分割標註
- 部署測試

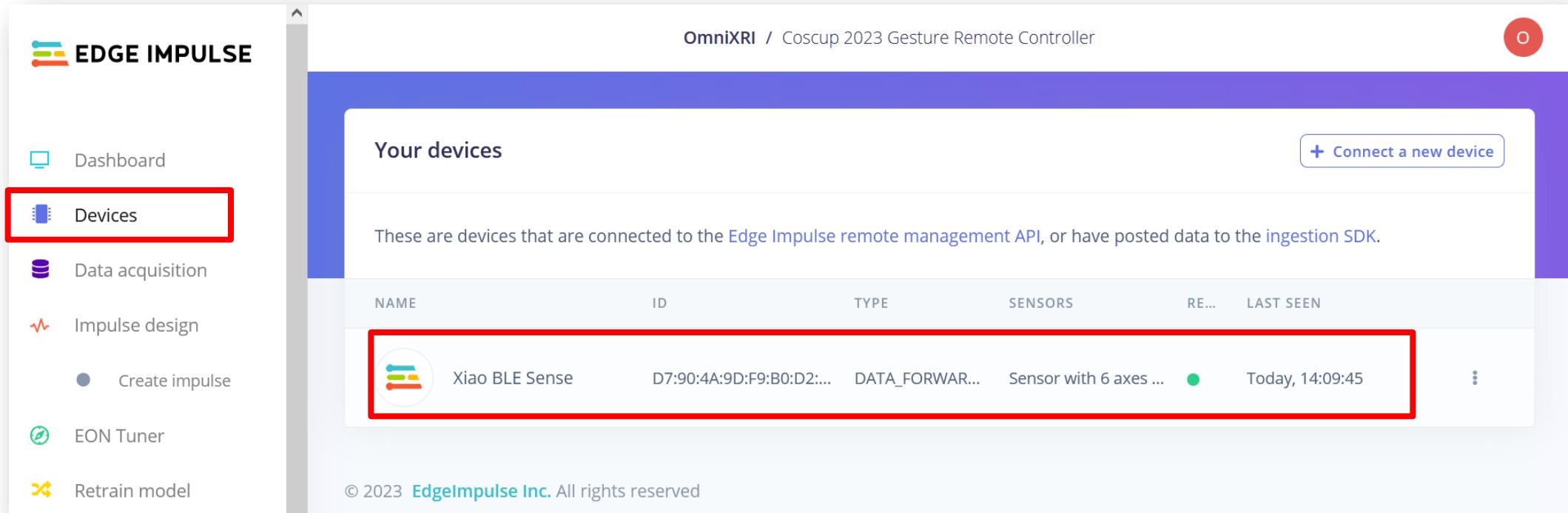
建立 Edge Impulse 新專案

The screenshot shows a "Create a new project" dialog box overlaid on the Edge Impulse interface. The dialog has a purple header with the text "Create a new project". Inside, there is a text input field containing "2. 輸入專案名稱" (Input project name), which is highlighted with a red border. Below this is a section titled "Choose your project type:" with two radio button options: "Personal" (selected) and "Enterprise". The "Personal" option is described as having a 20 min job limit, 4GB or 4 hours of data, and limited collaboration. The "Enterprise" option is described as having no job or data size limits, higher performance, and custom blocks. Next is a section titled "Choose your project setting:" with two radio button options: "Public" (selected) and "Private". The "Public" option is described as allowing anyone on the internet to view and clone the project under the Apache 2.0 license. The "Private" option is described as allowing only invited users to edit and view the project. At the bottom right of the dialog is a green "Create new project" button, which is also highlighted with a red border.

參考資料：<https://wiki.seeedstudio.com/cn/XIAO-BLE-PDM-EI/>

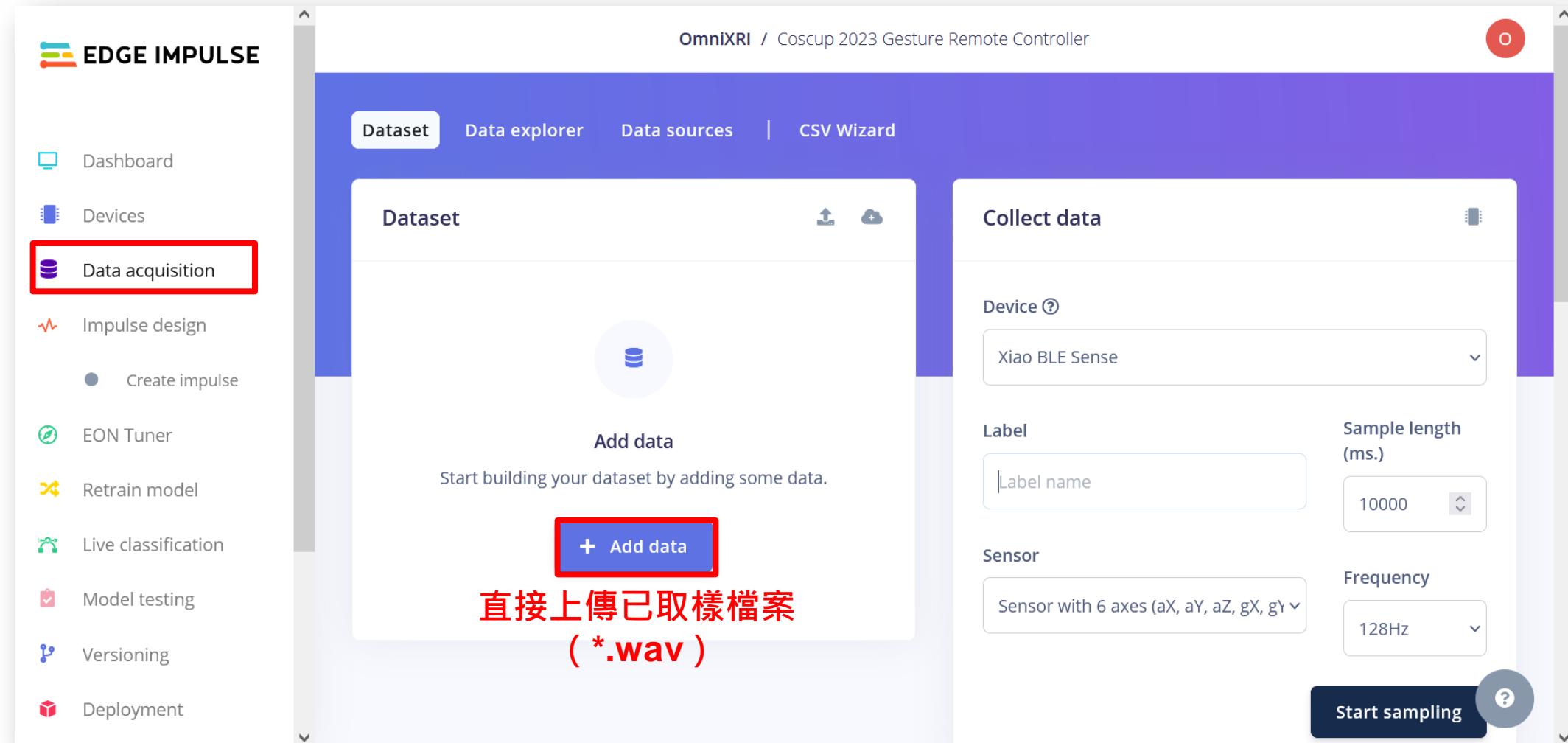
檢查裝置是否已連線



The screenshot shows the Edge Impulse web interface. On the left, a sidebar menu includes 'EDGE IMPULSE' (with a bar icon), 'Dashboard' (with a chart icon), 'Devices' (with a device icon, highlighted with a red box), 'Data acquisition' (with a database icon), 'Impulse design' (with a gear icon), 'Create impulse' (with a circle icon), 'EON Tuner' (with a tuning fork icon), and 'Retrain model' (with a cross icon). The main area is titled 'OmniXRI / Coscup 2023 Gesture Remote Controller'. It features a purple header bar with a red circular badge containing the number '0'. Below it, a white card titled 'Your devices' contains the text: 'These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.' A blue button labeled '+ Connect a new device' is on the right. A table lists connected devices with columns: NAME, ID, TYPE, SENSORS, RE..., and LAST SEEN. One row is highlighted with a red box: 'Xiao BLE Sense' (with a device icon), 'D7:90:4A:9D:F9:B0:D2...', 'DATA_FORWARDER...', 'Sensor with 6 axes ...', a green dot, and 'Today, 14:09:45'. At the bottom, a copyright notice reads '© 2023 EdgeImpulse Inc. All rights reserved'.

- 若不需使用手機、電腦或開發板即時取得感測器內容，則可略過本項目。
- 若需使用開發板即時傳送感測器內容，則必需啟動 **edge-impulse-daemon** 或 **edge-impulse-data-forwarder**，將裝置連線到雲端。
- Xiao nRF52840 Sense非Edge Impulse官方支援開發板，僅能使用 **data-forwarder** 連線。

開始收集資料



The screenshot shows the Edge Impulse web interface. On the left sidebar, the 'Data acquisition' option is highlighted with a red box. The main area is titled 'OmniXRI / Coscup 2023 Gesture Remote Controller'. It features a 'Dataset' tab, a central 'Dataset' section with an 'Add data' button, and a 'Collect data' section on the right. The 'Collect data' section includes fields for 'Device' (set to 'Xiao BLE Sense'), 'Label' (with a placeholder 'Label name'), 'Sample length (ms.)' (set to 10000), 'Sensor' (set to 'Sensor with 6 axes (aX, aY, aZ, gX, gY)'), and 'Frequency' (set to 128Hz). A large red text overlay at the bottom center reads '直接上傳已取樣檔案 (*.wav)'.

從裝置上傳資料限制

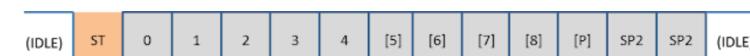
- 假設以 16 bit (2 Byte) 表示資料寬度 (ADC 9~16 bit)，取樣頻率 16 KHz，則一秒鐘就產生 26 Kbyte 原始資料。若存成 *.wav 格式檔案，則還需加上 44 Byte 檔頭格式，合計 32,044 Byte。
- 假設 COM 通訊速度設為 115,200 bps，傳送一個字元 (8 bit)，加上一位啟始，一位結束，無同位位元檢測 (俗稱N81)，即每秒最多傳送11,520 Byte。
- 一筆資料 2 Byte 需5個字元表示，如 “FFFF,”，綜合上述內容，則一秒鐘最多傳送 2,304 筆資料，則使用 **edge-impulse-data-forwarder** 進行即時上傳仍**無法滿足**每秒 16,000 筆資料需求。

WAV 檔頭定義

起始位址 (位元組)	區塊名稱	區塊大小 (位元組)	端序	區塊內容
0	區塊編號	4	大	“RIFF”
4	總區塊大小	4	小	=N+36
8	檔案格式	4	大	“WAVE”
12	子區塊 1 標籤	4	大	“fmt ”
16	子區塊 1 大小	4	小	16
20	音訊格式	2	小	1(PCM)
22	聲道數量	2	小	1(單聲道) 2(立體聲)
24	取樣頻率	4	小	取樣點/秒 (Hz)
28	位元(組)率	4	小	=取樣頻率*位元深度/8
32	區塊對齊	2	小	4
34	位元深度	2	小	取樣位元深度
36	子區塊 2 標籤	4	大	“data”
40	子區塊 2 大小	4	小	N (=位元(組)*秒數*聲道數量)
44	資料	=N	小	<音訊資料由此開始>

資料來源：<https://zh.wikipedia.org/zh-tw/WAV>

COM 資料傳送格式



ST : Start bit, always low
 0~7: Data bit
 P : Parity bit
 SP : Stop bit, always high

資料來源：<https://albert-oma.blogspot.com/2012/03/uart.html>

直接上傳資料集(1/2)

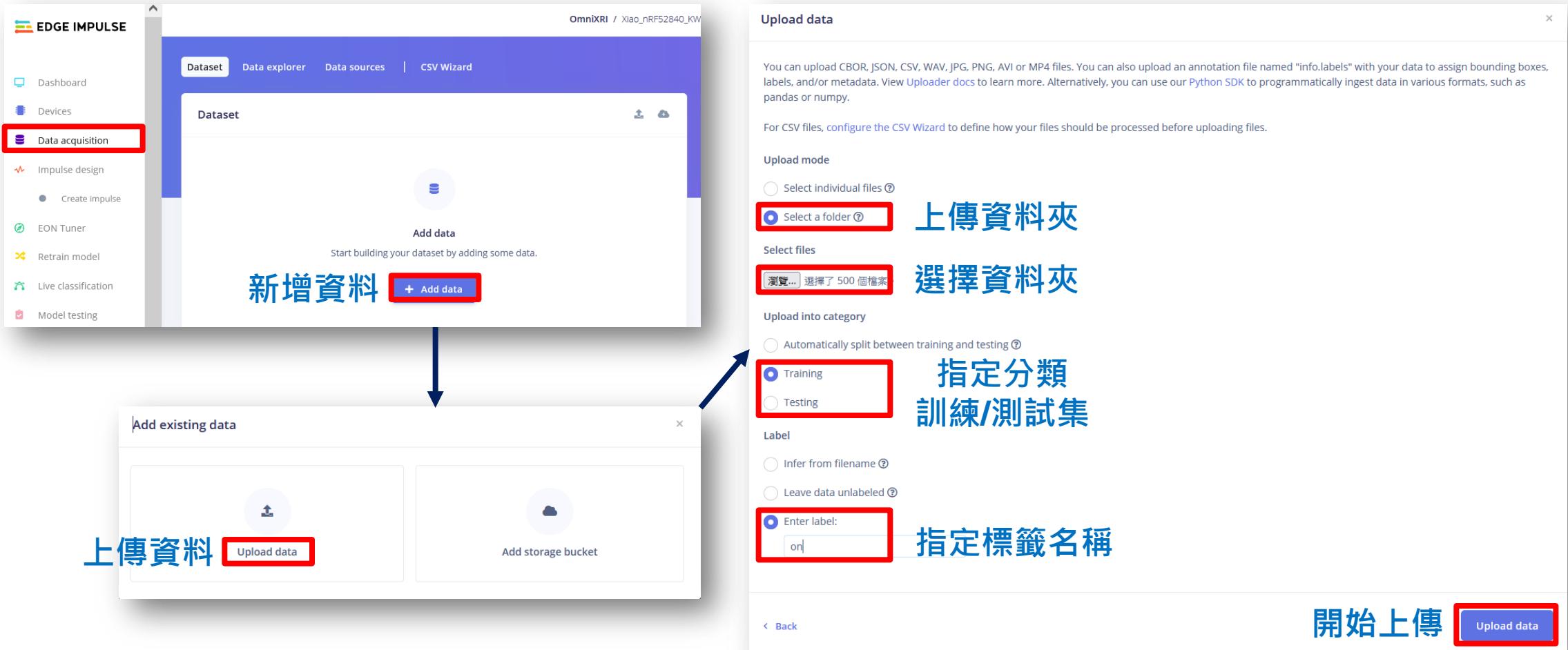
- 可使用手機、電腦或開發板等裝置上麥克風錄音存檔後，再直接上傳到 Edge Impulse Studio 上進行分割、標註。
- 除自錄外，亦可使用公用資料集，如 [Google Speech commands dataset](#)，取其部份作為實驗用資料集。這個資料集包含常用數字、方向、開關、常用字等英文命令，每個命令長度1秒，共35類，另加「背景噪音」分類。
- 本實驗摘錄部份內容，可下載後直接上傳。

Google Speech Commands Dataset

Word	Number of Utterances	Go	3,880	Seven	3,998
Backward	1,664	Happy	2,054	Sheila	2,022
Bed	2,014	House	2,113	Six	3,860
Bird	2,064	Learn	1,575	Stop	3,872
Cat	2,031	Left	3,801	Three	3,727
Dog	2,128	Marvin	2,100	Tree	1,759
Down	3,917	Nine	3,934	Two	3,880
Eight	3,787	No	3,941	Up	3,723
Five	4,052	Off	3,745	Visual	1,592
Follow	1,579	On	3,845	Wow	2,123
Forward	1,557	One	3,890	Yes	4,044
Four	3,728	Right	3,778	Zero	4,052

(包括數字、方向、開關、常用字等，每個命令長度1秒，共35類，另加「背景噪音」分類)

直接上傳資料集 (2/2)



The screenshot shows the Edge Impulse web interface for dataset management. A red box highlights the 'Data acquisition' menu item in the sidebar. A blue arrow points from the 'Add data' button in the main dataset view to the 'Upload data' dialog. The 'Upload mode' section is highlighted with a red box, showing 'Select a folder' selected. A blue arrow points from the 'Select files' button to the 'Select a folder' input field. The 'Upload into category' section shows 'Training' selected with a red box. A blue arrow points from the 'Enter label:' input field to the 'Training' selection. The 'Upload data' button at the bottom right is also highlighted with a red box.

新增資料

上傳資料夾

選擇資料夾

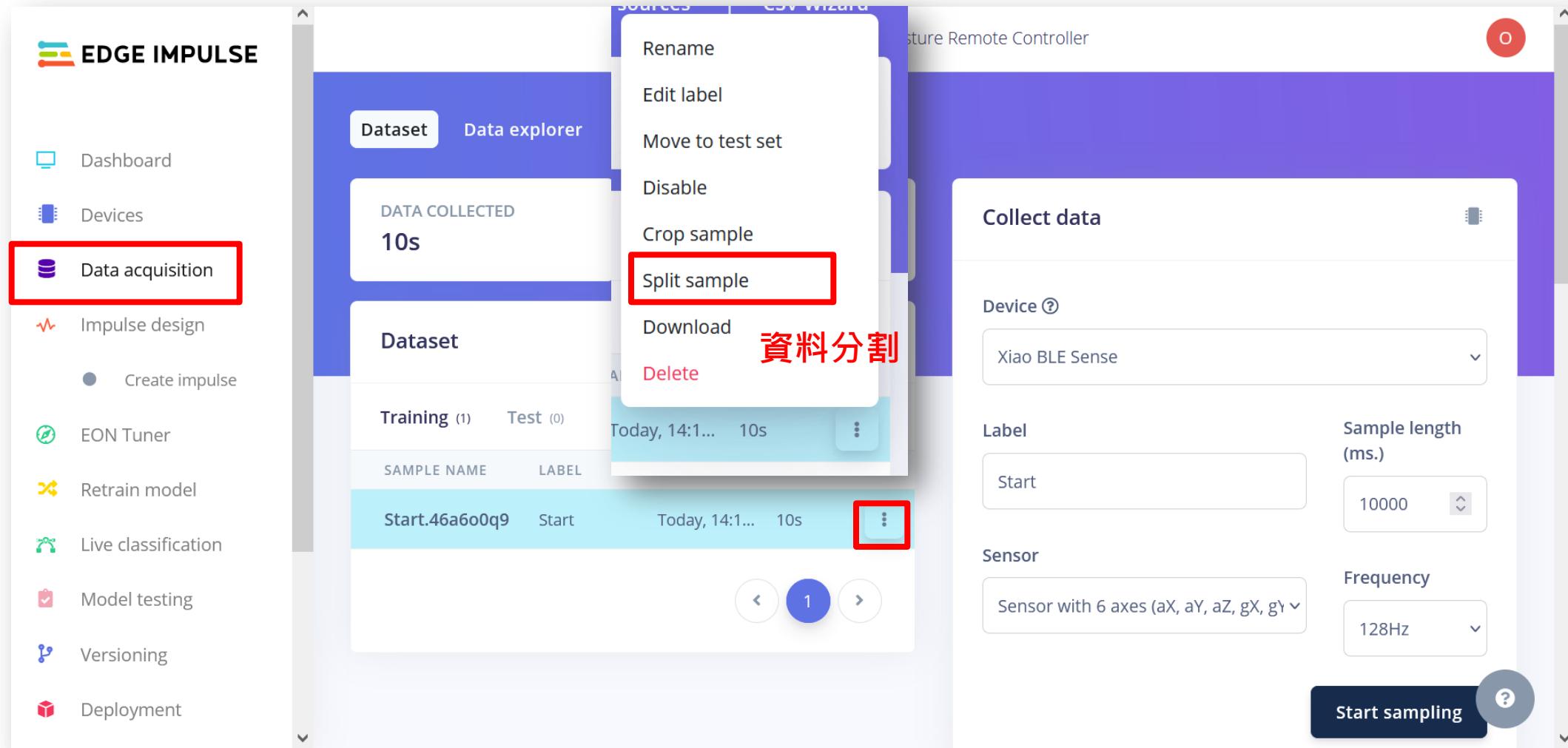
指定分類訓練/測試集

指定標籤名稱

開始上傳

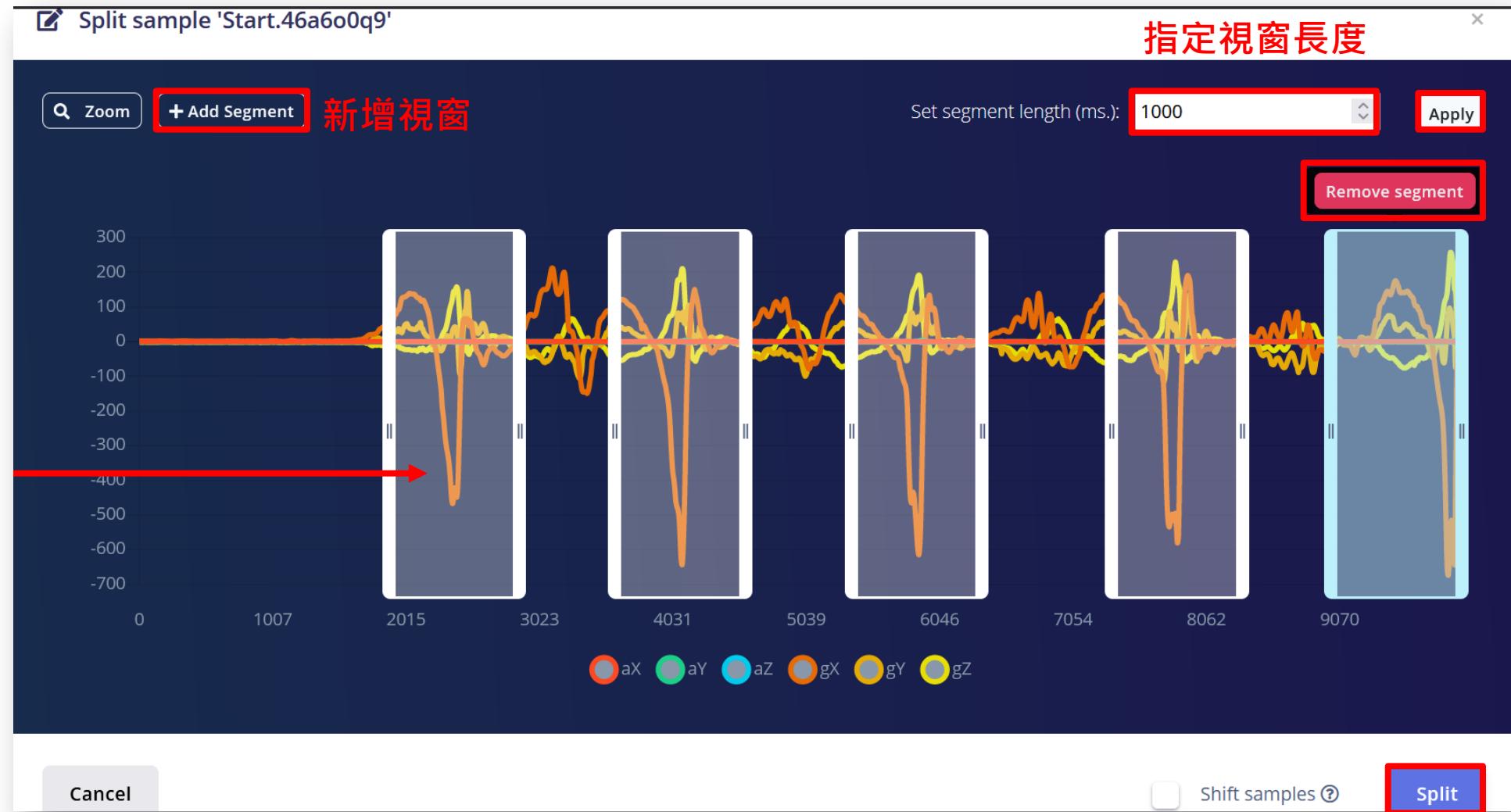
實驗用資料集：<https://drive.google.com/file/d/1awBgM7YAbnhJS3EcWI-vPUpzOgTveA3U/view?usp=sharing>

大量收集樣本並分割成獨立可訓練樣本

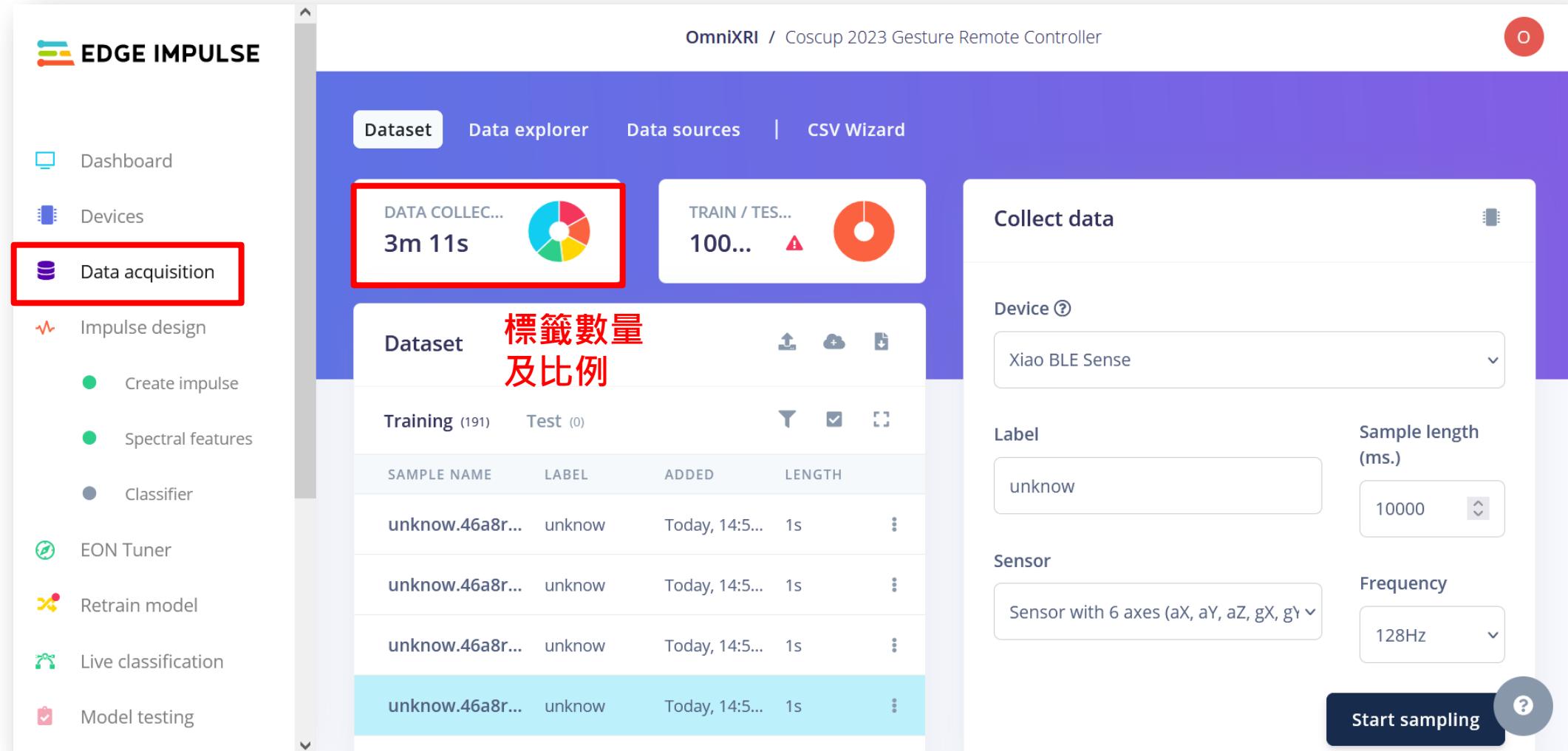


The screenshot shows the Edge Impulse web interface. On the left sidebar, the 'Data acquisition' option is selected and highlighted with a red box. In the main area, the 'Data explorer' tab is active, displaying a dataset titled 'Dataset' with a collection time of '10s'. A context menu is open over this dataset, with the 'Split sample' option highlighted and also enclosed in a red box. To the right of the menu, the text '資料分割' (Data Splitting) is overlaid in red. The 'Collect data' panel on the right shows settings for a 'Xiao BLE Sense' device, a 'Start' label, a sample length of 10000 ms, a sensor with 6 axes, and a frequency of 128Hz. A large blue button at the bottom right says 'Start sampling'.

原始資料與自動分割



反複收集分割，建立完整資料集



OmniXRI / Coscup 2023 Gesture Remote Controller

Dataset **Data explorer** **Data sources** | **CSV Wizard**

DATA COLLECT... **TRAIN / TES...**

3m 11s **100...**

標籤數量及比例

Device ? **Xiao BLE Sense**

Label **unknow**

Sample length (ms.) **10000**

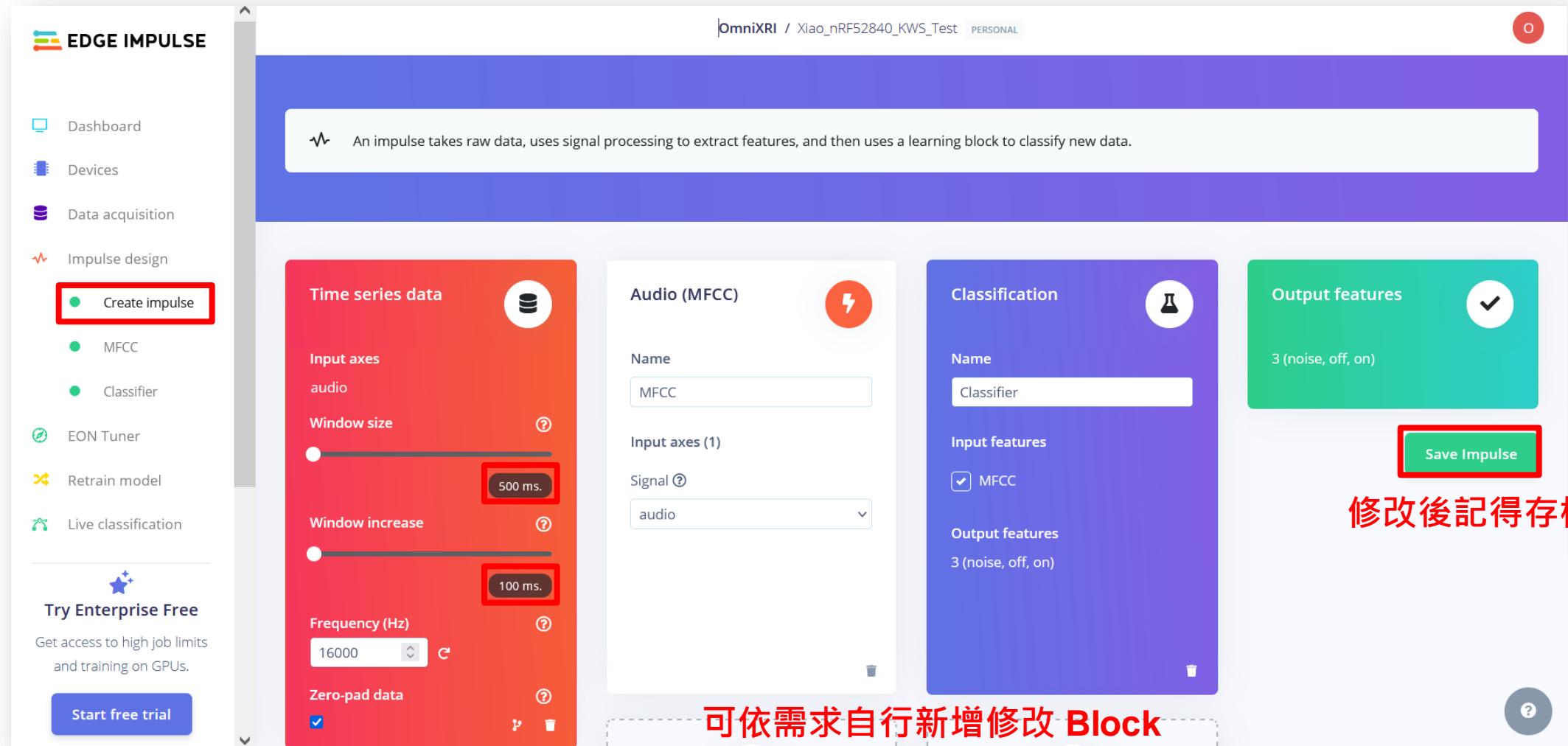
Sensor **Sensor with 6 axes (aX, aY, aZ, gX, gY)**

Frequency **128Hz**

Start sampling

SAMPLE NAME	LABEL	ADDED	LENGTH
unknow.46a8r...	unknow	Today, 14:5...	1s
unknow.46a8r...	unknow	Today, 14:5...	1s
unknow.46a8r...	unknow	Today, 14:5...	1s
unknow.46a8r...	unknow	Today, 14:5...	1s

選擇模型及設定必要參數



The screenshot shows the Edge Impulse interface for creating a new impulse. The left sidebar has 'Create impulse' selected. The main area is divided into four sections:

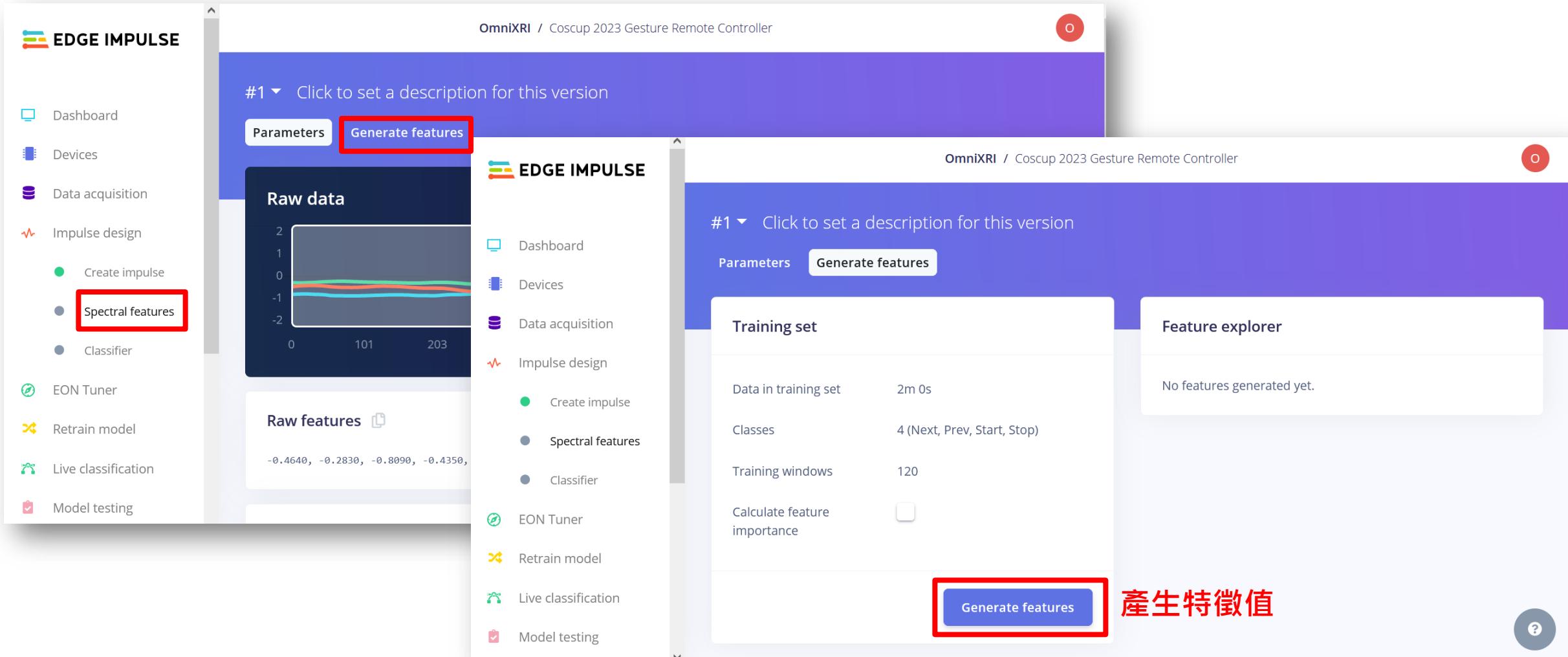
- Time series data**: Configurable with 'Input axes' (audio), 'Window size' (500 ms), 'Window increase' (100 ms), 'Frequency (Hz)' (16000), and 'Zero-pad data' (checked).
- Audio (MFCC)**: Contains a 'Name' field set to 'MFCC' and an 'Input axes (1)' section with 'Signal' set to 'audio'.
- Classification**: Contains a 'Name' field set to 'Classifier' and an 'Input features' section with 'MFCC' checked. It also lists 'Output features' as '3 (noise, off, on)'.
- Output features**: Shows the output features as '3 (noise, off, on)'.

A red box highlights the 'Save Impulse' button at the bottom right. A red box also highlights the '100 ms.' input for the window increase. A red box highlights the '500 ms.' input for the window size. A red box highlights the 'MFCC' input for the classification section. A red box highlights the 'MFCC' input for the audio section. A red box highlights the 'noise, off, on' output features. A red box highlights the 'Save Impulse' button. A red box highlights the '100 ms.' input for the window increase. A red box highlights the '500 ms.' input for the window size. A red box highlights the 'MFCC' input for the classification section. A red box highlights the 'MFCC' input for the audio section. A red box highlights the 'noise, off, on' output features. A red box highlights the 'Save Impulse' button.

修改後記得存檔

可依需求自行新增修改 Block

提取資料特徵



The screenshot shows the OmniXRI Edge Impulse interface for creating a gesture remote controller. The left sidebar lists various options: Dashboard, Devices, Data acquisition, Impulse design, Create impulse (highlighted with a red box), Spectral features (highlighted with a red box), Classifier, EON Tuner, Retrain model, Live classification, and Model testing.

The main area displays two panels. The left panel, titled '#1 Click to set a description for this version', contains tabs for 'Parameters' and 'Generate features'. It shows a 'Raw data' section with a spectrogram plot and a 'Raw features' section listing values: -0.4640, -0.2830, -0.8090, -0.4350. The right panel, also titled '#1 Click to set a description for this version', has tabs for 'Parameters' and 'Generate features'. It shows a 'Training set' section with details: Data in training set (2m 0s), Classes (4 (Next, Prev, Start, Stop)), Training windows (120), and a checkbox for Calculate feature importance. A large red box highlights the 'Generate features' button at the bottom of the right panel. Below this button, the text '產生特徵值' (Generate features) is overlaid in red.

提取特徵結果

Feature generation output

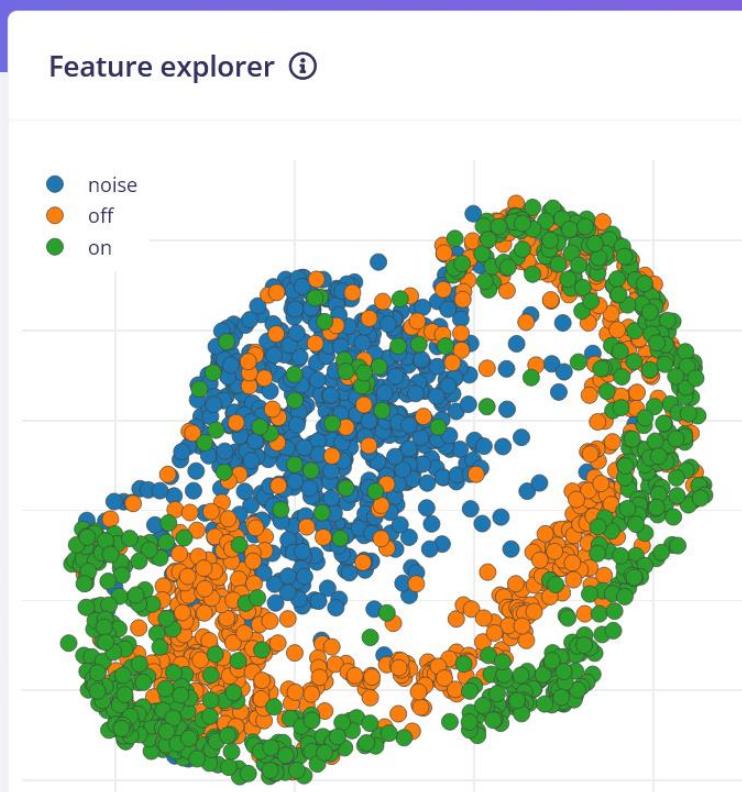
still running...

```
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
```

Fri Jul 28 06:54:26 2023 Finished embedding
Reducing dimensions for visualizations OK

Job completed

Feature explorer ⓘ



On-device performance ⓘ

PROCESSING TIME	PEAK RAM USAGE
19 ms.	6 KB

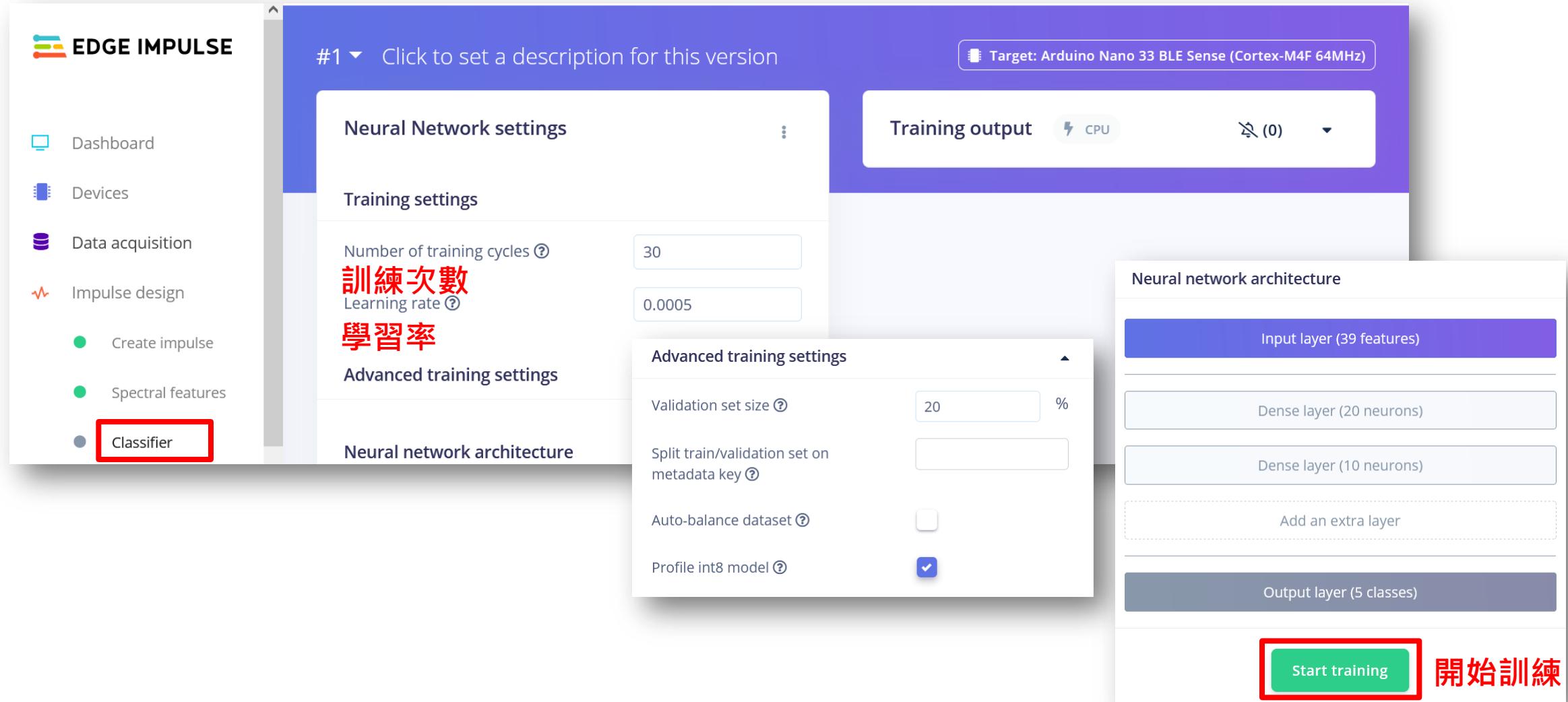
以指定的硬體進行資源使用及推論時間估測

2024/05/21

OmniXRI's Edge AI & TinyML 小學堂_【第12講】實作案例 – 語音辨識_OmniXRI_JackHsu

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設定分類訓練相關參數



The screenshot shows the Edge Impulse web interface for setting up a classifier. The left sidebar has a red box around the 'Classifier' option. The main area is titled '#1 Click to set a description for this version'. It includes sections for 'Neural Network settings', 'Training settings', 'Advanced training settings', and 'Neural network architecture'. The 'Training output' section indicates the target is an Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz) running on CPU. The 'Neural network architecture' section shows a stack of layers: Input layer (39 features), Dense layer (20 neurons), Dense layer (10 neurons), and Output layer (5 classes). A green box highlights the 'Start training' button at the bottom right.

EDGE IMPULSE

#1 Click to set a description for this version

Target: Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz)

Neural Network settings

Training settings

Number of training cycles ② 30

訓練次數

Learning rate ② 0.0005

學習率

Advanced training settings

Validation set size ② 20 %

Split train/validation set on metadata key ②

Auto-balance dataset ②

Profile int8 model ②

Neural network architecture

Input layer (39 features)

Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (5 classes)

Start training 開始訓練

Dashboard

Devices

Data acquisition

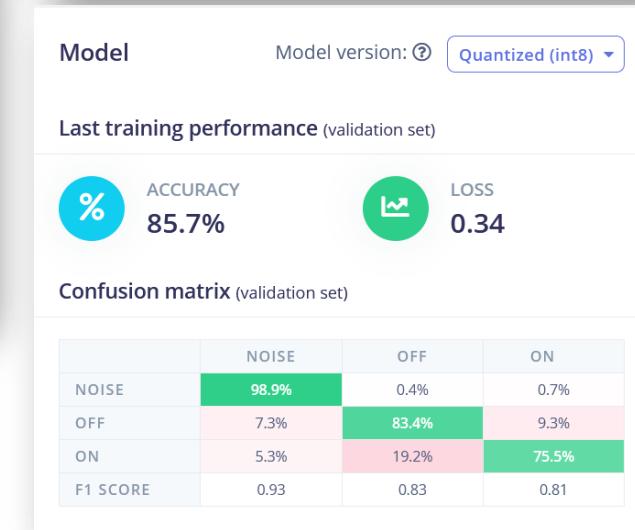
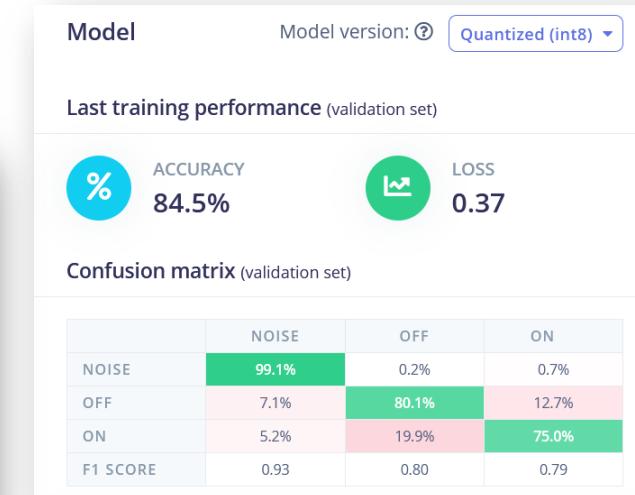
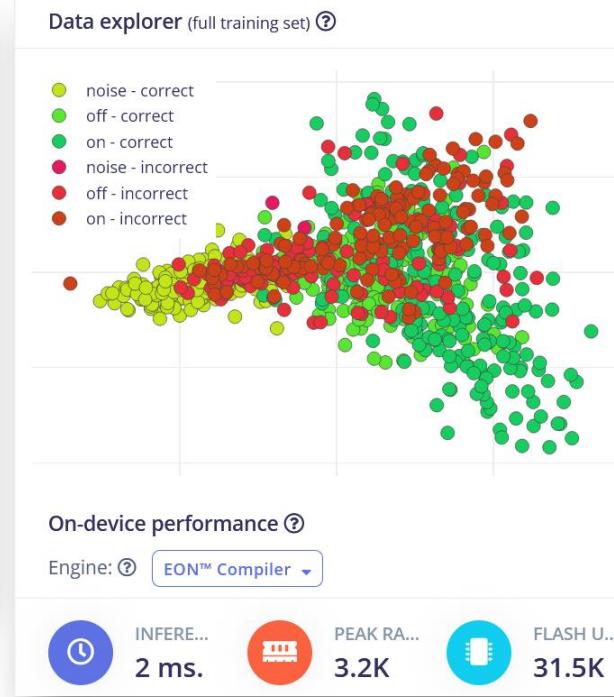
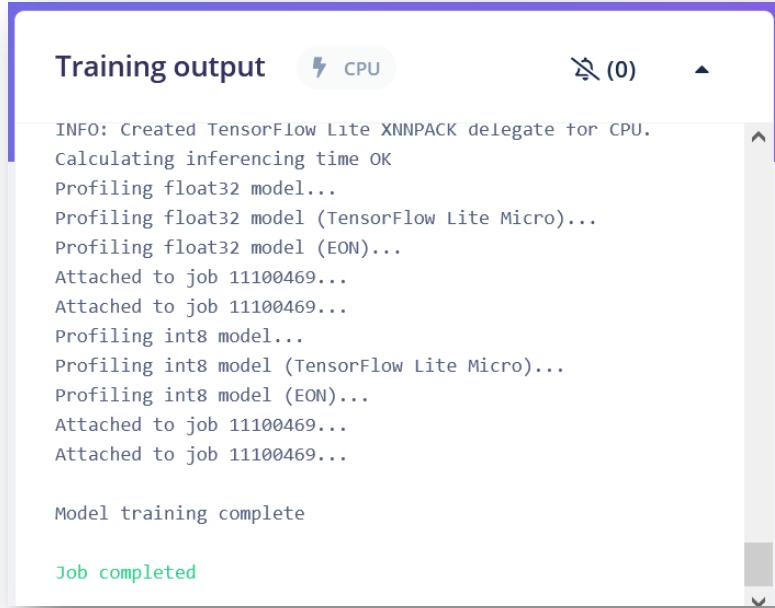
Impulse design

Create impulse

Spectral features

Classifier

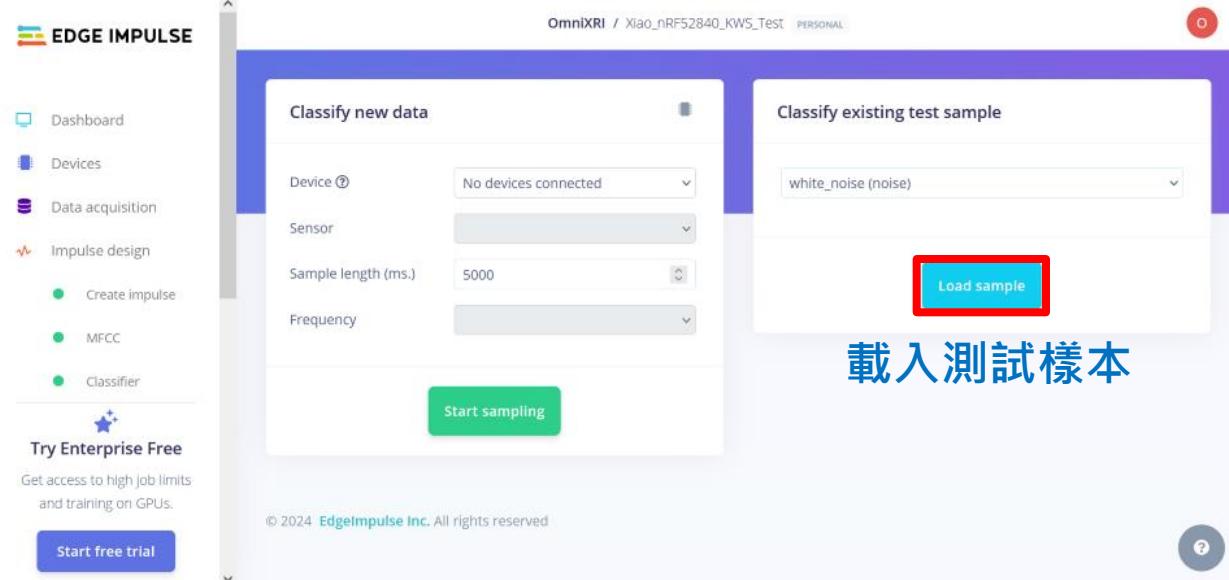
開始進行模型訓練及結果顯示



30
Epoch
結果

100
Epoch
結果

線上測試（從內建測試集）



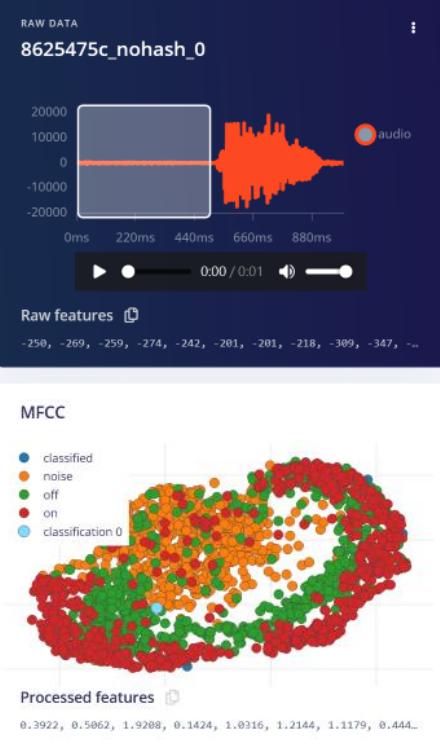
載入測試樣本

Load sample

Classification result

Summary	
Name	8625475c_nohash_0
Label	on
CATEGORY	COUNT
noise	1
off	1
on	3
uncertain	1

Detailed result			
TIMESTAMP	NOISE	OFF	ON
0	0.93	0.04	0.03
100	0	0.60	0.40
200	0	0.44	0.56
300	0	0.01	0.99
400	0	0	1.00
500	0	0	1.00



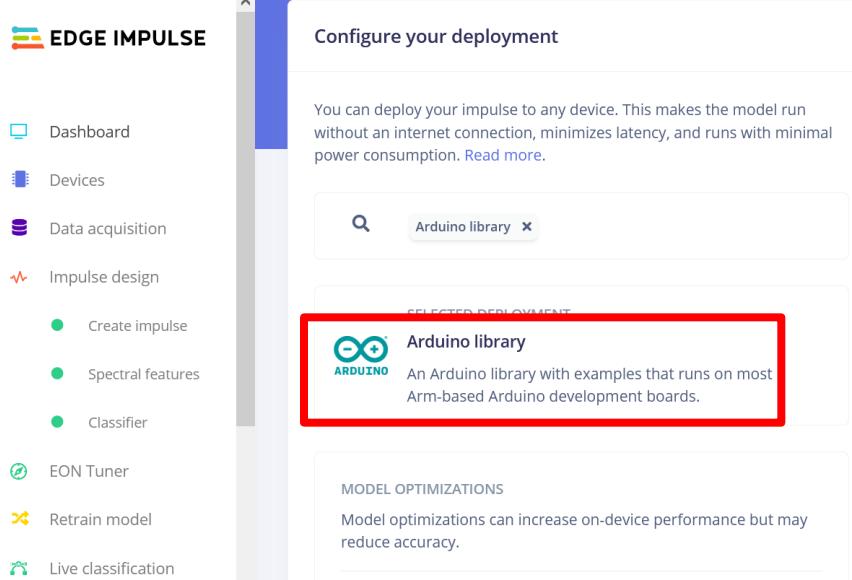
Raw DATA
8625475c_nohash_0

Raw features

MFCC

Processed features

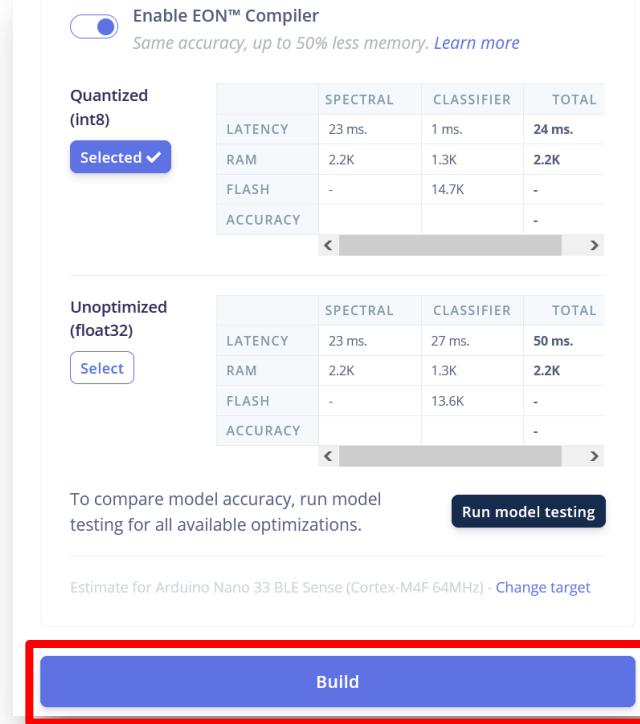
選擇部署種類及設定參數



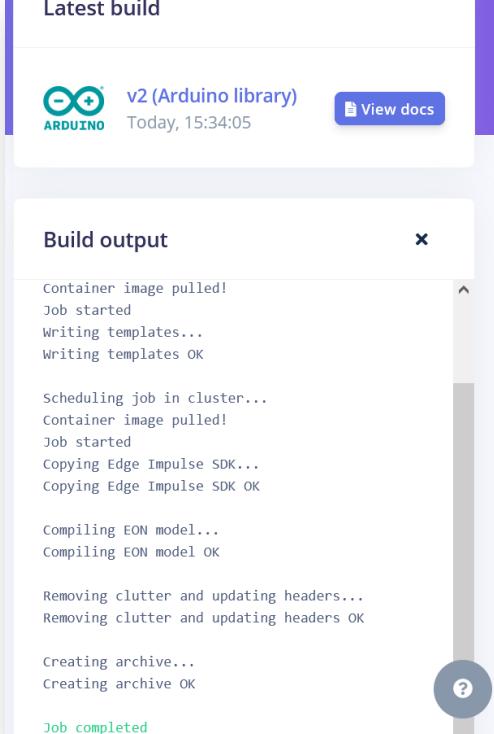
Built Arduino library

Add this library through the Arduino IDE via:
Sketch > Include Library > Add .ZIP Library...

Examples can then be found under:
File > Examples > Coscup_2023_Gesture_Remote_Controller_inferencing



Build



Latest build

v2 (Arduino library) Today, 15:34:05

Build output

Container image pulled!
Job started
Writing templates...
Writing templates OK

Scheduling job in cluster...
Container image pulled!
Job started
Copying Edge Impulse SDK...
Copying Edge Impulse SDK OK

Compiling EON model...
Compiling EON model OK

Removing clutter and updating headers...
Removing clutter and updating headers OK

Creating archive...
Creating archive OK

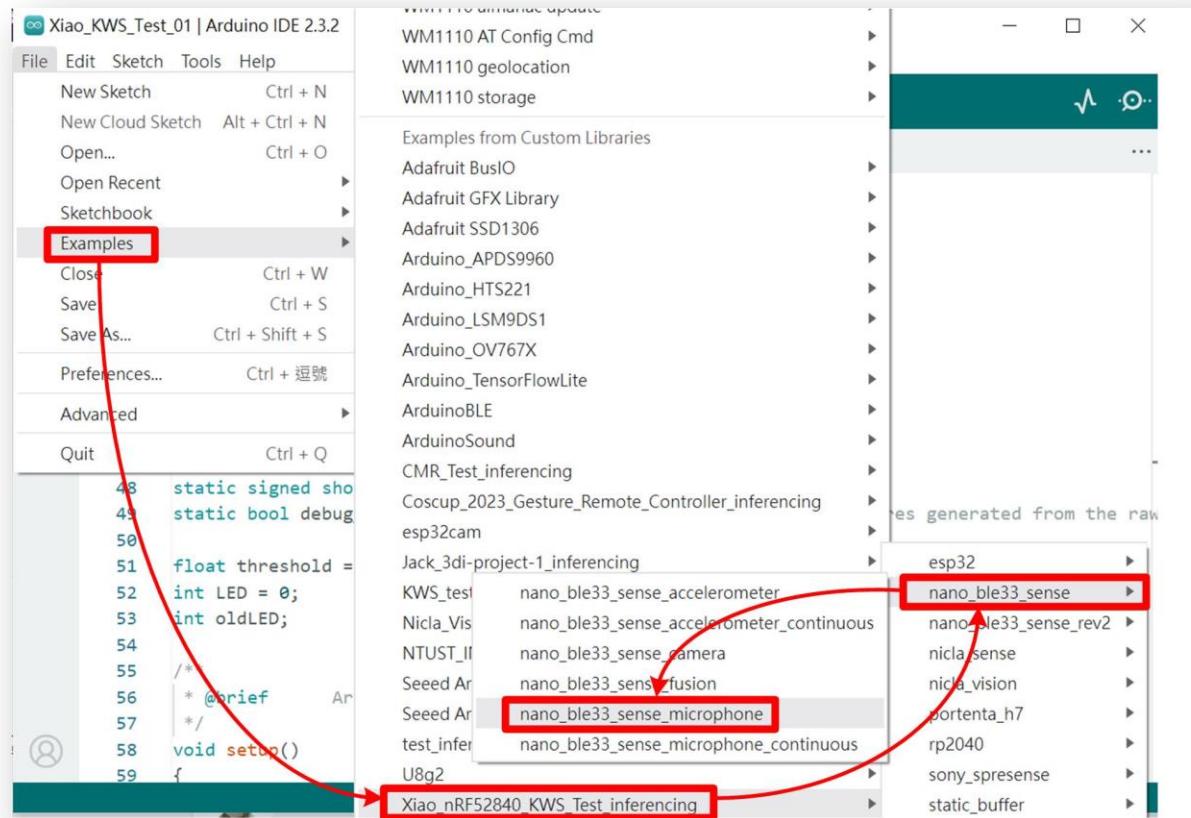
Job completed

以 **Arduino 函式庫(*.zip)** 方式輸出
預設檔名為「ei-專案名稱-arduino-版本序號.zip」

導入 Arduino 函式庫並進行推論測試

新增函式庫 Sketch > Include Library > Add .ZIP Library ...

新增範例 File > Examples > ei-專案名稱_inferencing > nano_ble33_sense > nano_ble33_sense_microphone (原始範例輸出結果從 COM 輸出文字串)



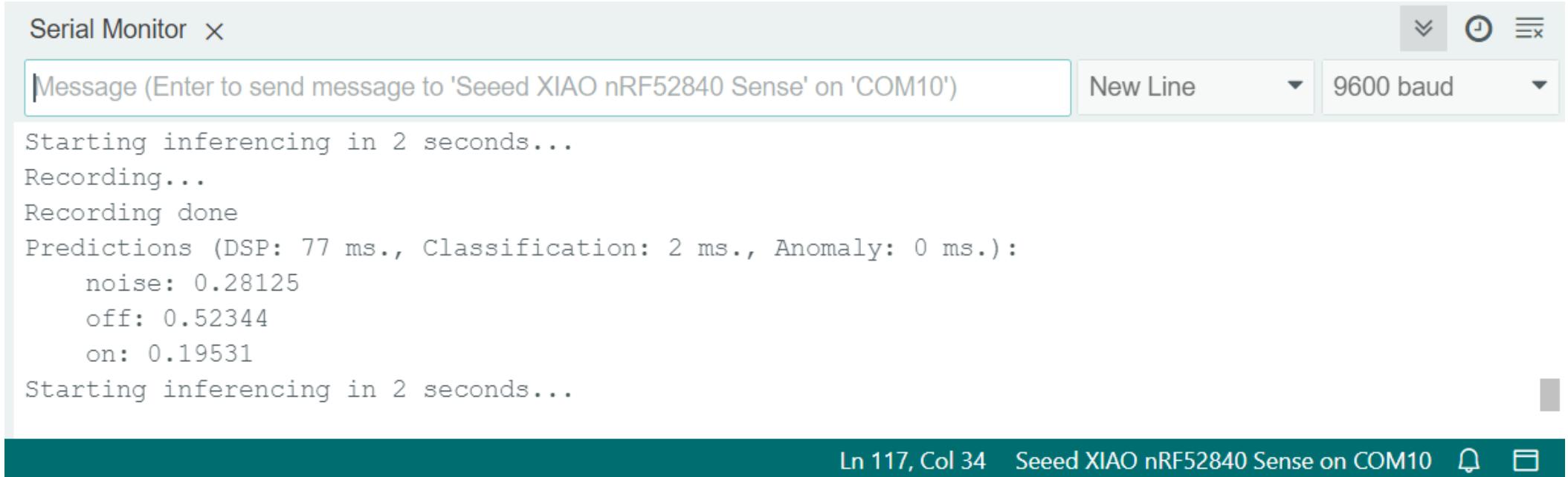
```

51 float threshold = 0.50;
52 int LED = 0;
53 int oldLED;

117 //lets light up some LEDs
118 if (result.classification[ix].value > threshold) {
119 //now let's see what label were in
120 switch (ix) {
121 case 0: LED = 11; break; // RED LED
122 case 1: LED = 12; break; // BLUE LED
123 case 2: LED = 13; break; // GREEN LED
124 default: LED = 0;
125 }
126 //in Sense, LOW will light up the LED
127 if (LED != 0) {
128   digitalWrite (oldLED, HIGH); //if we enter a wo
129   digitalWrite (LED, LOW);
130   oldLED = LED;
131 }
132 else //turn off LED
133   digitalWrite (oldLED, HIGH);
134 }
```

新增程式碼 (Low Code)
可調整觸發門檻
可指定辨完成亮滅LED

測試結果 (No Code型式)



A screenshot of a Serial Monitor window titled "Serial Monitor". The window shows a message input field containing "Message (Enter to send message to 'Seeed XIAO nRF52840 Sense' on 'COM10')". Below the input field, the text area displays the following output:

```
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 77 ms., Classification: 2 ms., Anomaly: 0 ms.):
  noise: 0.28125
  off: 0.52344
  on: 0.19531
Starting inferencing in 2 seconds...
```

The status bar at the bottom indicates "Ln 117, Col 34 Seeed XIAO nRF52840 Sense on COM10" along with a bell icon and a close button.

- 推論結果，包括前處理(DSP)、分類及異常時間 (ms)
- 將三個標籤的置信度顯示出來，1.0為完全正確，0.0為完全不正確，可設置門檻值來限制置信度不高之答案。
- **No Code型式**，範例程式直接編譯上傳，不需改寫任何程式，輸出結果由 COM 接收文字串。

控制 LED 點滅 (Low Code 型式)

- 新增第 51-53 列，定義推論門檻值及 LED 目前及上一個狀態變數。117-134 列，指定當特定分類置信度高於門檻值時點滅對應的 LED。
- 預設推論時間間隔 2000ms，可自行調整第 86 列程式 **delay(n);**，n 為時間間隔。

```

47 static inference_t inference;
48 static signed short sampleBuffer[2048];
49 static bool debug_nn = false; // Set this to true to see e.
50
51 float threshold = 0.50; // 分類置信度門檻值
52 int LED = 0; // 目前 LED 顯示狀態
53 int oldLED; // 上一次 LED 顯示狀態

82 void loop()
83 {
84     ei_printf("Starting inferencing in 2 seconds...\n");
85
86     delay(1000); // 調整二次取樣推論間隔時間 (ms)
  
```

```

114     for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++)
115         ei_printf("    %s: %.5f\n", result.classification[i]
116
117         //lets light up some LEDs
118         if (result.classification[ix].value > threshold) {
119             //now let's see what label were in
120             switch (ix) {
121                 case 0: LED = 11; break; // RED LED
122                 case 1: LED = 12; break; // BLUE LED
123                 case 2: LED = 13; break; // GREEN LED
124                 default: LED = 0;
125             }
126             //in Sense, LOW will light up the LED
127             if (LED != 0) {
128                 digitalWrite (oldLED, HIGH); //if we enter a wo
129                 digitalWrite (LED, LOW);
130                 oldLED = LED;
131             }
132             else //turn off LED
133                 digitalWrite (oldLED, HIGH);
134         }
135     }
  
```

參考文獻

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- Seeed, Learn TinyML using Wio Terminal and Arduino IDE #2 Audio Scene Recognition and Mobile Notifications

<https://www.seeedstudio.com/blog/2021/02/03/learn-tinyml-using-wio-terminal-and-arduino-ide-2-audio-scene-recognition-and-mobile-notifications/>

沒有最邊



只有更邊



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開 源 : <https://github.com/OmniXRI>

YOUTUBE 直播 : <https://www.youtube.com/@omnidri1784streams>