

防疫大作戰！使用 Pi + FLIR Lepton 相機 + Python 自製熱像儀

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2020/09/06 @PyCon Taiwan 2020

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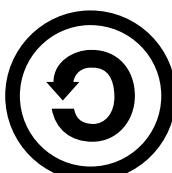
姓名標示 — 非商業性 — 相同方式分享



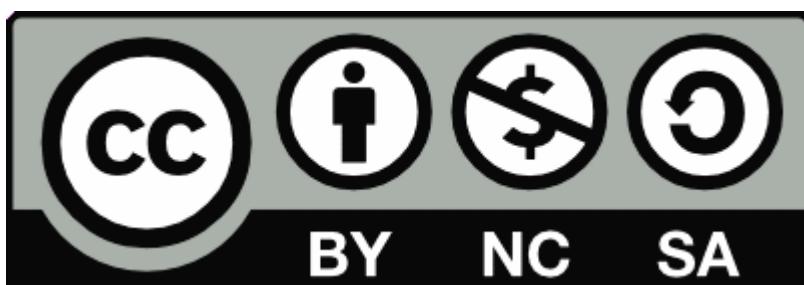
姓名標示 — 你必須給予 適當表彰、提供指向本授權條款的連結，以及 指出（本作品的原始版本）是否已被變更。你可以任何合理方式為前述表彰，但不得以任何方式暗示授權人為你或你的使用方式背書。



非商業性 — 你不得將本素材進行商業目的之使用。



相同方式分享 — 若你重混、轉換本素材，或依本素材建立新素材，你必須依本素材的授權條款來散布你的貢獻物。



關於我們

- Raspberry Pi 官方經銷商



- 專注 Raspberry Pi 應用與推廣，舉辦社群活動



學習路徑

 Pi選購指南

 Pi設定安裝



Linux系統管理



Python程式設計

I/O硬體控制

GPIO學習套件 初

感測器學習套件
(基礎/進階) 中

空氣盒子套件
(PiM25) 初

Win10開發套件 初

智慧開關套件 初

Linux Driver
學習套件 進

更多詳細資料

<https://www.raspberrypi.com.tw/26335/tutorial-learning-path-v1/>

無線/IoT

RFID/NFC
門禁系統 初

LoRa IoT
閘道器套件 初

生理資訊
監控IoT(藍牙) 初

毫米波人流/熱點監控
(mmWave) 初

相機/影像處理

特色相機改裝套件 初

寵物小車套件 初

自控機器手臂套件 中

小鴨車套件
(Duckietown) 進

人工智慧

驢車套件
(DonkeyCar) 初

AIY Vision Kit 中

Intel神經運算棒 中

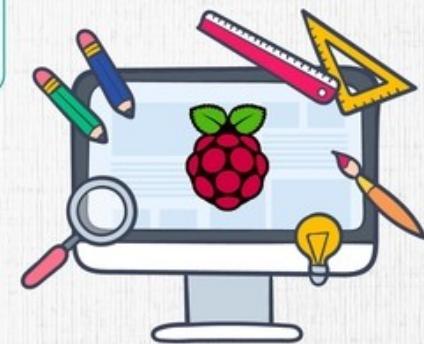
Google Coral
USB加速器 中

語音/訊號處理

智慧音箱套件 初

AIY Voice Kit 初

熱相機套件



初 開始課程

中 中階課程

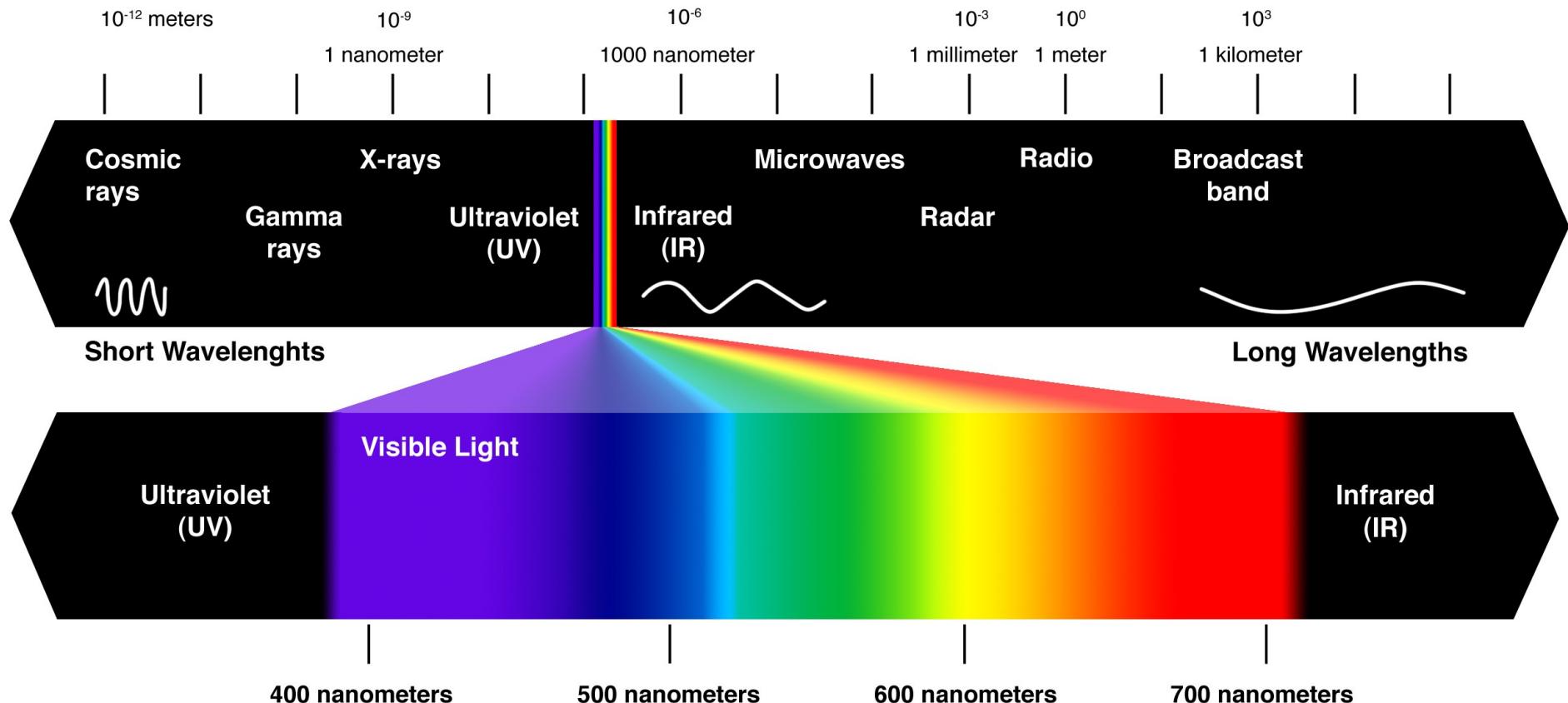
進 進階課程

大綱

- 光影像的限制與挑戰
- 熱影像技術介紹
- FusionPi 使用的軟體和硬體
- 如何應用機器學習讓 FusionPi 更聰明
- 未來專案方向

國中理化

- 問：樹葉為什麼看起來是綠色的？
- 答：因為樹葉吸收了大部分可見光，只反射綠色光



可見光相機已經充斥在你我周遭



<https://www.youtube.com/watch?v=aElkA0Jy0Xg>

但可見光會受到天候或是光線影響



(a)



(b)



(c)



(d)

紅外線讓我們重新認識這個世界



2019 到 2020 最大的改變

2019: 沒出息的廢物



2020: 優良公民



2020 生活日常



<https://news.ltn.com.tw/news/life/paper/1364790>

2020 生活日常



<https://www.ftvnews.com.tw/news/detail/2020327L05M1>

為什麼需要紅外線影像？

- 我們需要外部的光源來讓我們”看到”
- 紅外線影像讓我們對溫度有”第六感”



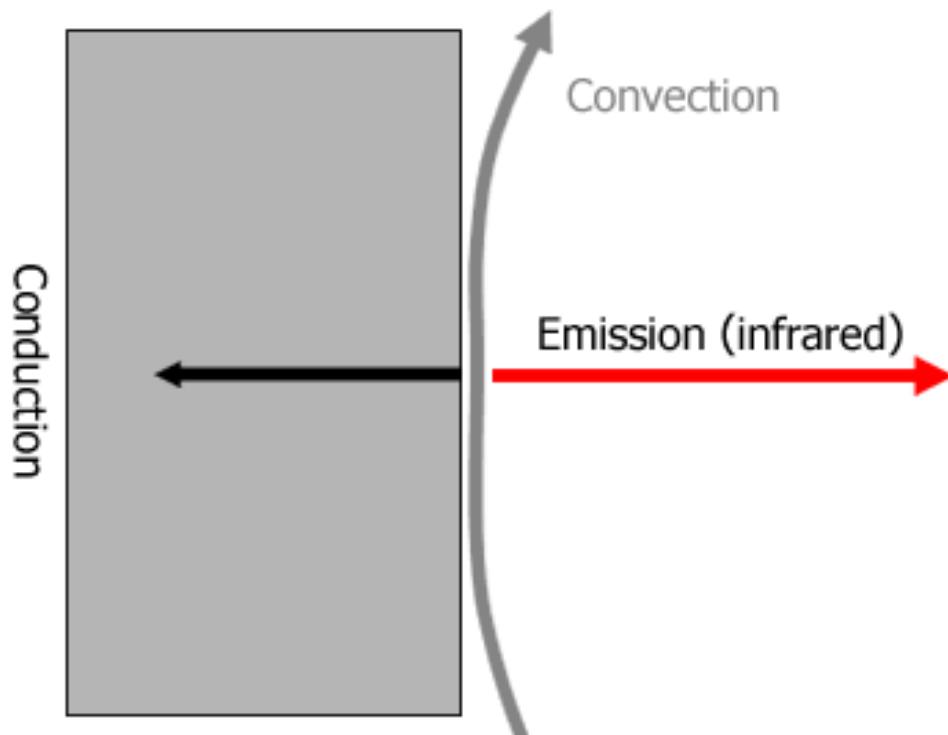
可見光影像受霧霾影響

紅外線影像不受天候或光線影響

紅外線測溫原理

熱傳遞方法

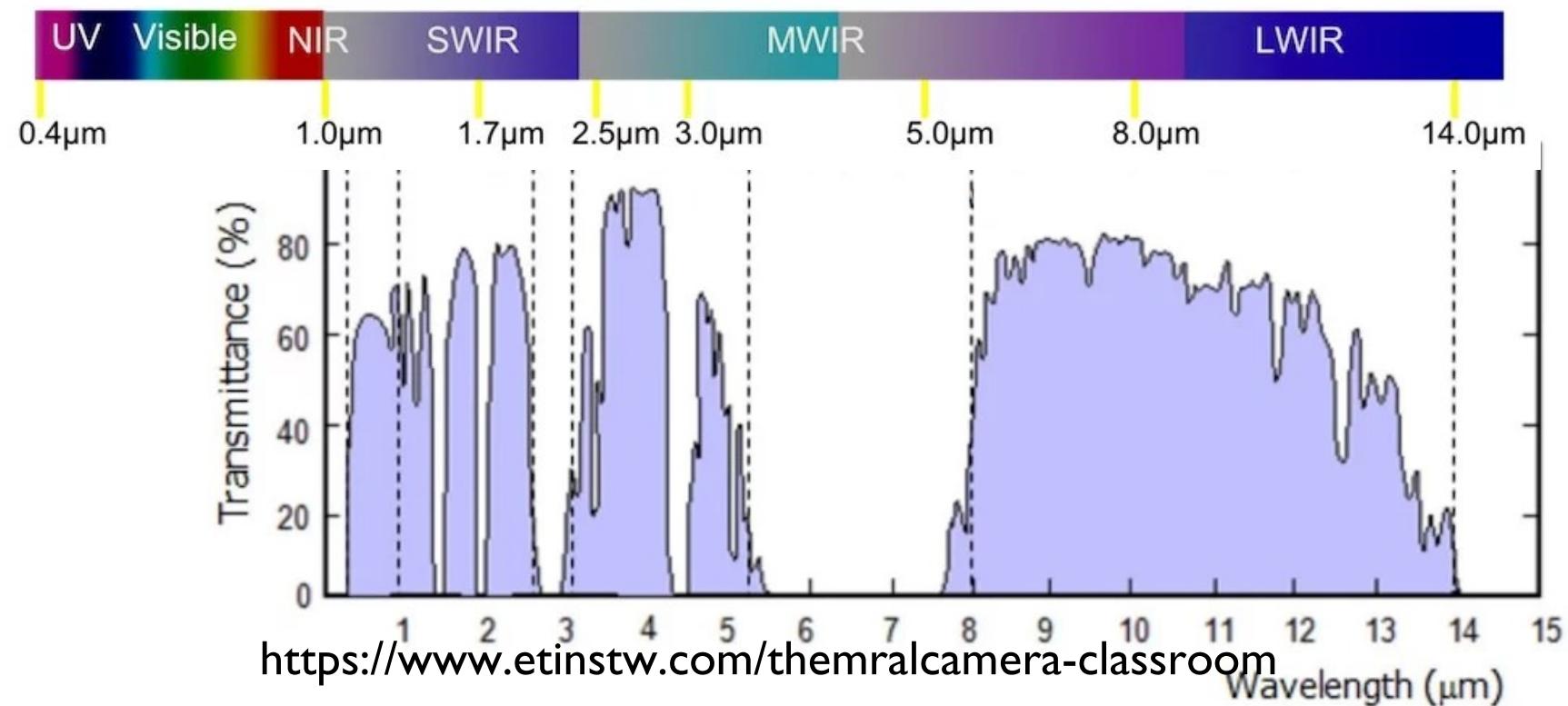
- 對流 (Convection): 經由流體傳遞
- 傳導 (Conduction): 經由固體傳遞
- 輻射 (Emission): 不須經過介質傳遞



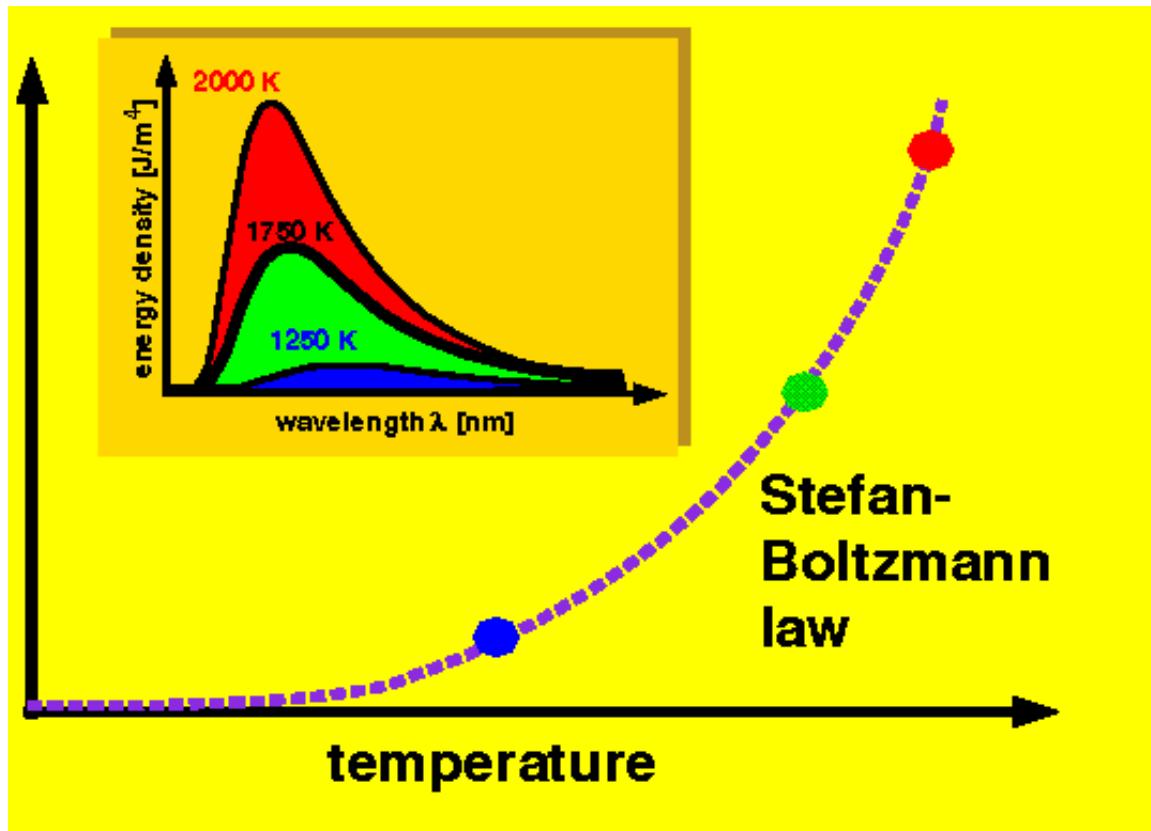
紅外線輻射 (Radiometric Infrared)

- 純對溫度超過 (-273°C) 的所有物體都會發出紅外線輻射
- 輻射傳播不需介質，不受白天晚上、煙霧、下雨等影響
- 紅外線輻射能量由物體的溫度和發射決定
 - 從 $0.76\mu\text{m}$ (紅光邊緣) 到 $1000\mu\text{m}$ (微波範圍起點)
- SWIR: $0.9-1.7\mu\text{m}$
 - 短波紅外線，適用於戶外夜間拍攝
- MWIR: $3-5\mu\text{m}$
 - 中長波紅外線，適用遠端監測，常用在低溫熱像檢測
- LWIR: $8-14\mu\text{m}$
 - 長波紅外線，適用多塵有霧環境，常用在室溫熱像檢測

紅外線波長



Stefan-Boltzmann law



$$P = e\sigma AT^4$$

Power radiated (Watts)

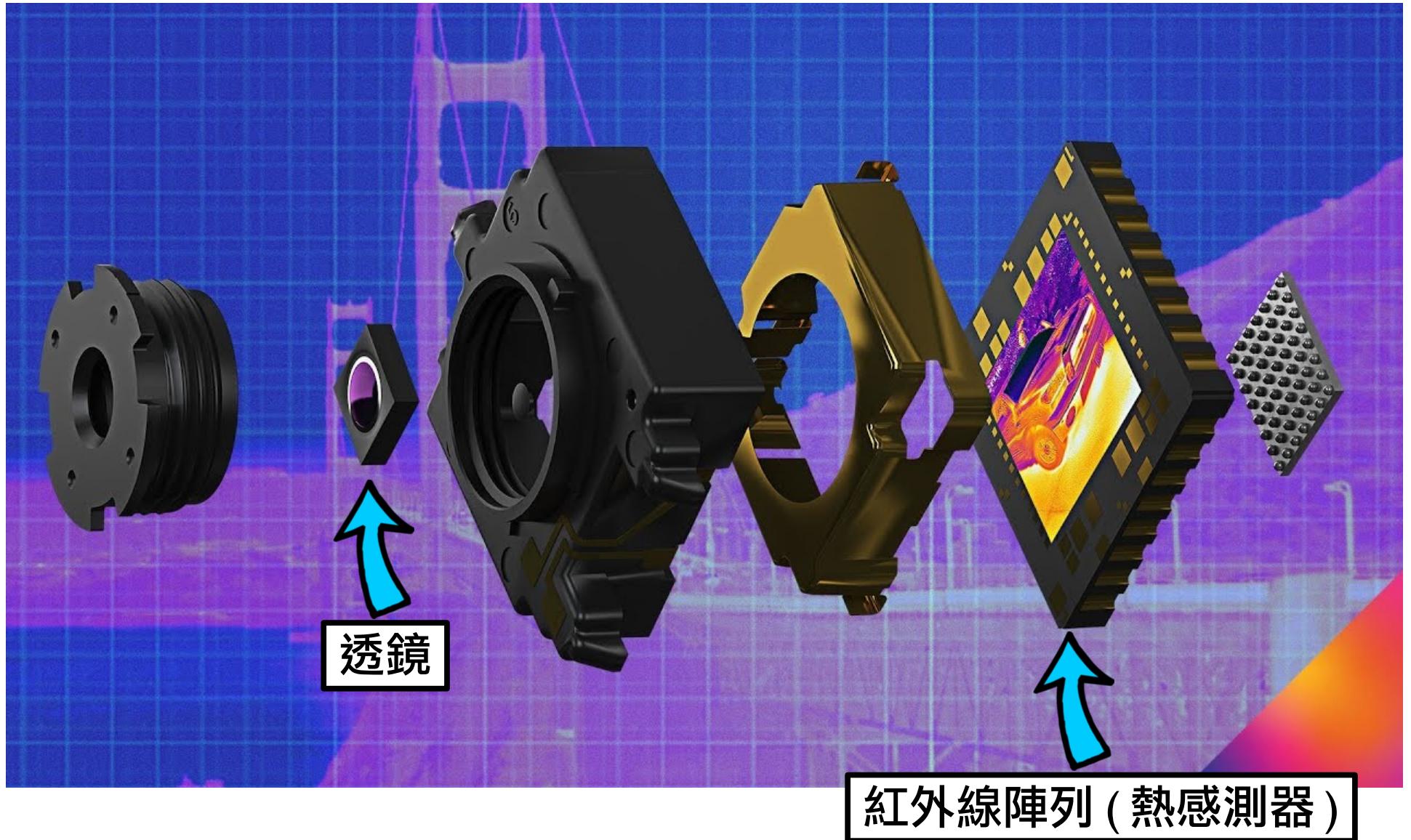
emissivity (no units)

Surface area (m^2)

Stefan-Boltzmann constant $5.67 \times 10^{-8} W m^{-2} K^{-4}$

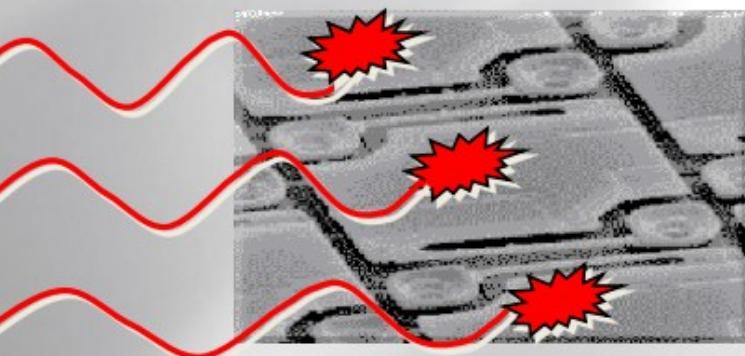
Temperature (Kelvins)

熱相機組成



熱影像顯示原理

How IR Cameras Work



Photons Impact and
HEAT the Detector Element.



Stefan - Boltzmann Law

$$E = \varepsilon\sigma T^4$$



Advanced Calculations

Temperature Values are calculated



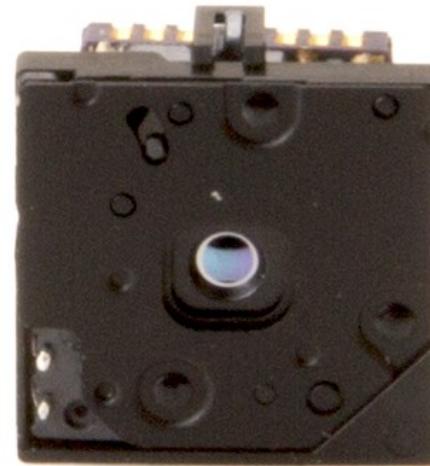
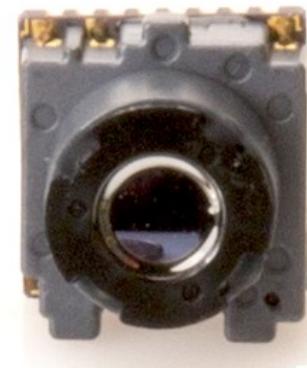
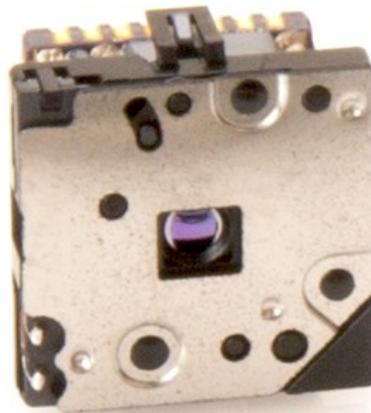
22	39	44	96	98	77
23	13	35	55	78	75
77	65	45	44	34	25
56	76	90	12	34	67
85	45	77	89	44	23
25	48	13	46	75	89

Colorized based on Temp Value



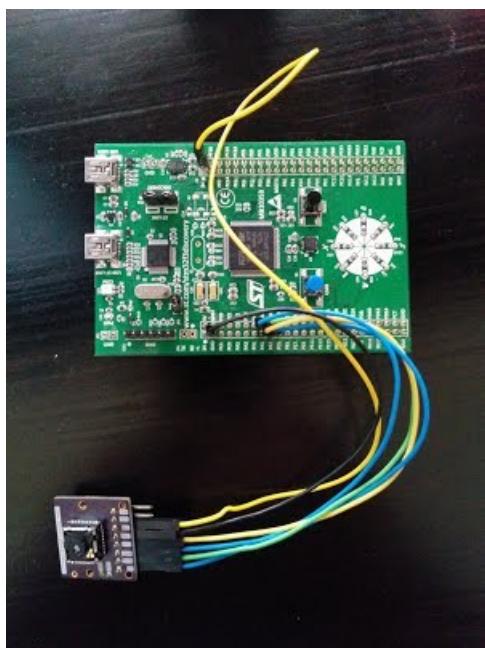
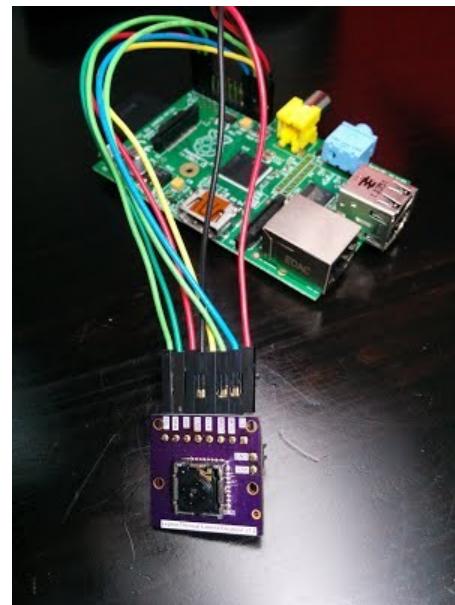
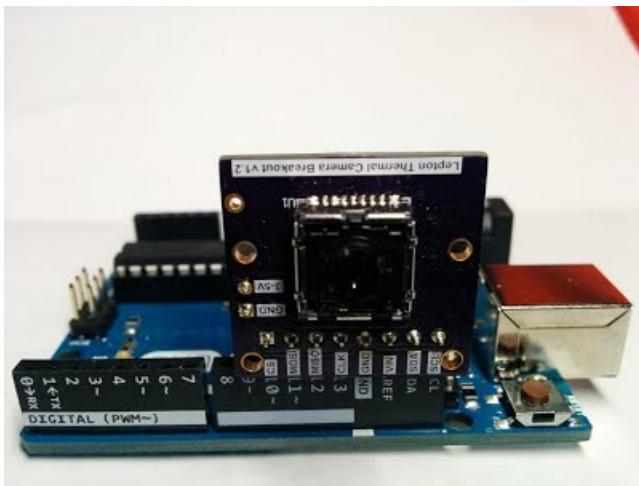
熱紅外線相機介紹

Lepton LWIR Micro Thermal Camera Module



<https://www.flir.com/products/lepton/>

適用多種平台

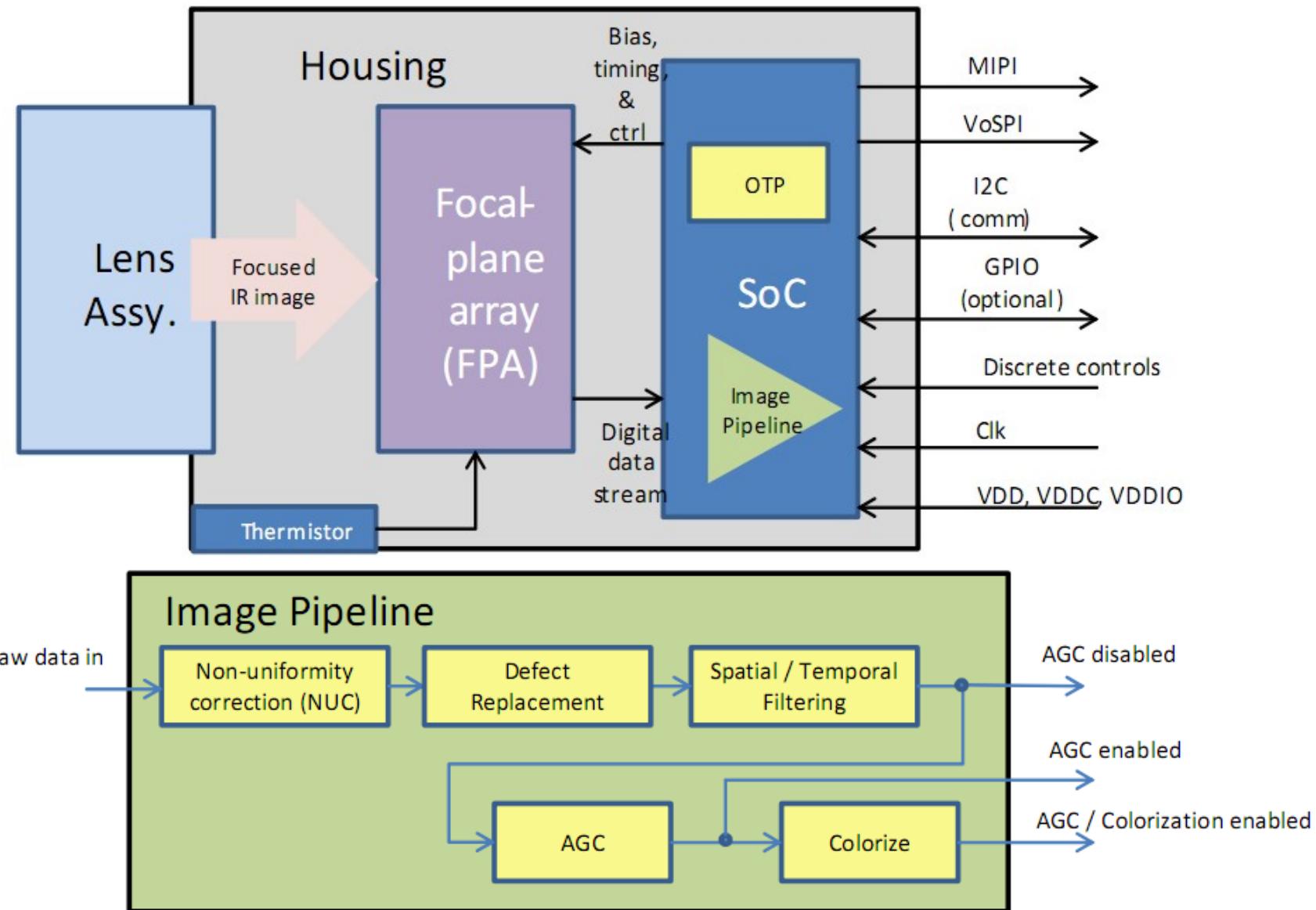


FLIR Lepton 2.x 規格

	FLIR Lepton 2.0	FLIR Lepton 2.5 with Radiometric
Resolution(H x V)	80x60	80x60
Spectral range	8μm to 14 μm	8μm to 14 μm
Horizontal FOV	51	50
Thermal sensitivity	< 50 mK(0.05 C)	< 50 mK(0.05 C)
Frame rate	8.7 Hz	8.7 Hz
Control interface	I2C	I2C
Video interface	SPI	SPI
Promised time to image	< 0.5 sec	< 1.2 sec
Radiometric accuracy		High gain: Greater of ±5 C or 5% Low gain: Greater of ±10 C or
Radiometry	14-bit pixel value	14-bit pixel value, Kelvin

SSR=1:122 => 可以在 1.22m 測量 1cm 物體

System Architecture + Video Pipeline



Software Development Kit(SDK)

<https://github.com/groupgets/LeptonModule>

master		LeptonModule / software /	Go to file	Add file ▾
	matthewnavarro	fixed readme text	0395494	on Dec 21, 2019
..				
	STM32F3Discovery_ChibiOS	Reorganizing files		5 years ago
	ThermalView	Reorganizing files		5 years ago
	arduino_i2c	Reorganizing files		5 years ago
	beagleboneblack_video	More updates for consistency and ease of building		5 years ago
	edison_capture	Reorganizing files		5 years ago
	flirpi	flirpi/fblept: add possibility to choose spidev at runtime		3 years ago
	raspberrypi_capture	More updates for consistency and ease of building		5 years ago
	raspberrypi_libs/leptonSDKEmb32PUB	Update Makefile		7 months ago
	raspberrypi_qt	More Makefile updates		5 years ago
	raspberrypi_video	fixed readme text		7 months ago
	stm32nucleo_401re	More renaming and duplicate removal		5 years ago
	v4l2lepton	v4l2lepton: fixes documentation now that runtime arguments are possible		3 years ago

<https://github.com/groupgets/LeptonModule>

使用 Raspberry Pi + FLIR Lepton 自製熱像儀

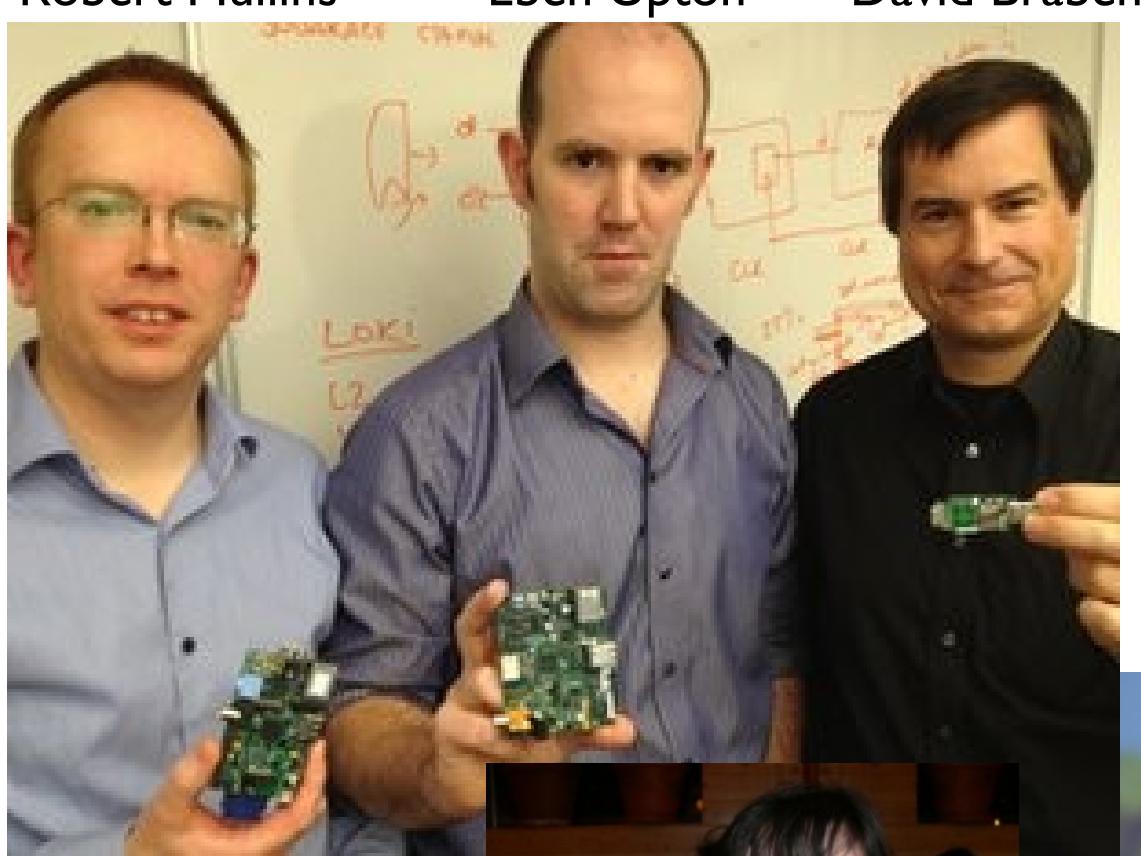
Raspberry Pi 是什麼？

- 信用卡大小般的電腦



<http://www.flickr.com/photos/fotero/7697063016/>

Robert Mullins



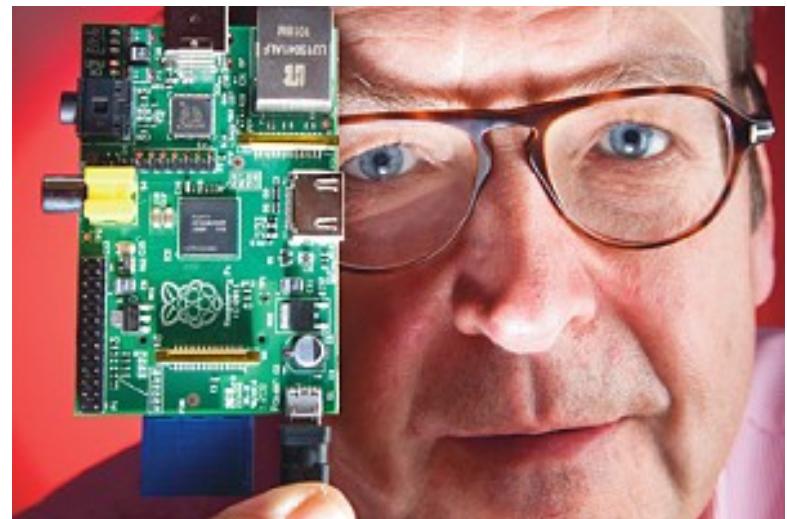
Eben Upton



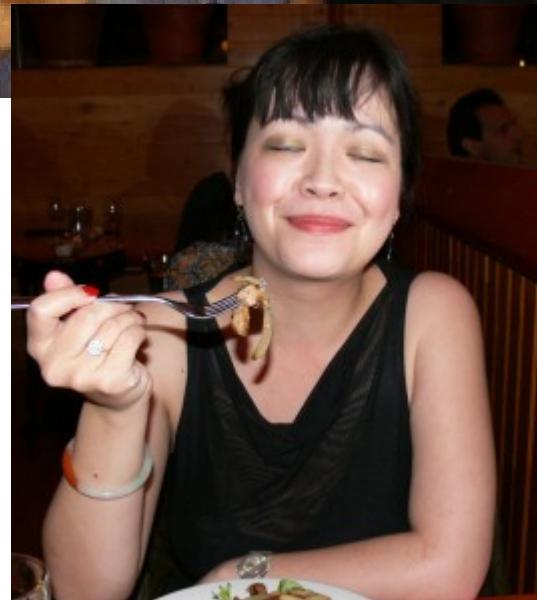
Alan Mycroft

David Braben

A criação do Raspberry Pi - com Pete Lomas - Palco Principal - Campus Party Brasil - 01/02/2013 - Foto: Flávia de Quadros/indicefoto



Jack Lang



Liz



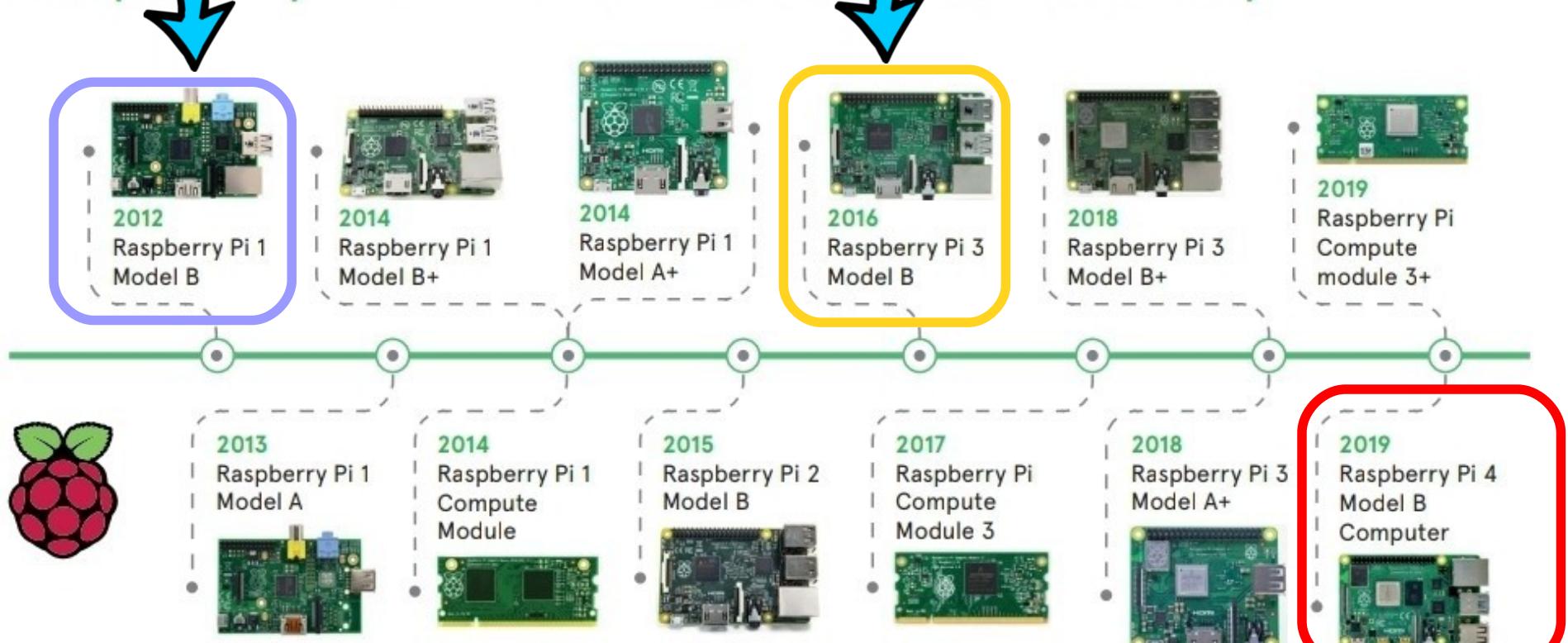
Pete Lomas

Raspberry Pi Family

最早量產

最穩定

Raspberry Pi - The Historical Journey



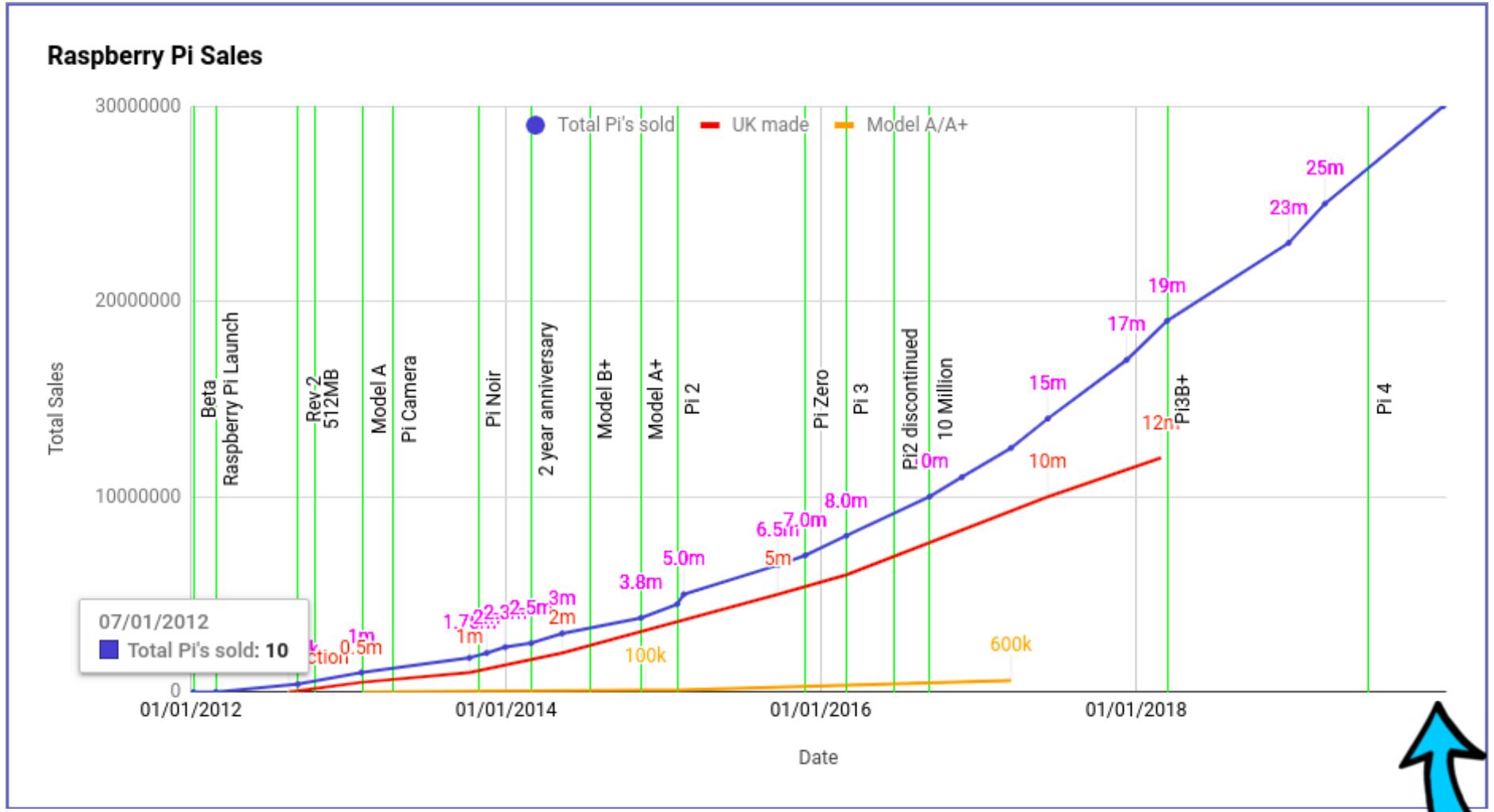
element*i4*

element*i4*
AN AVNET COMPANY

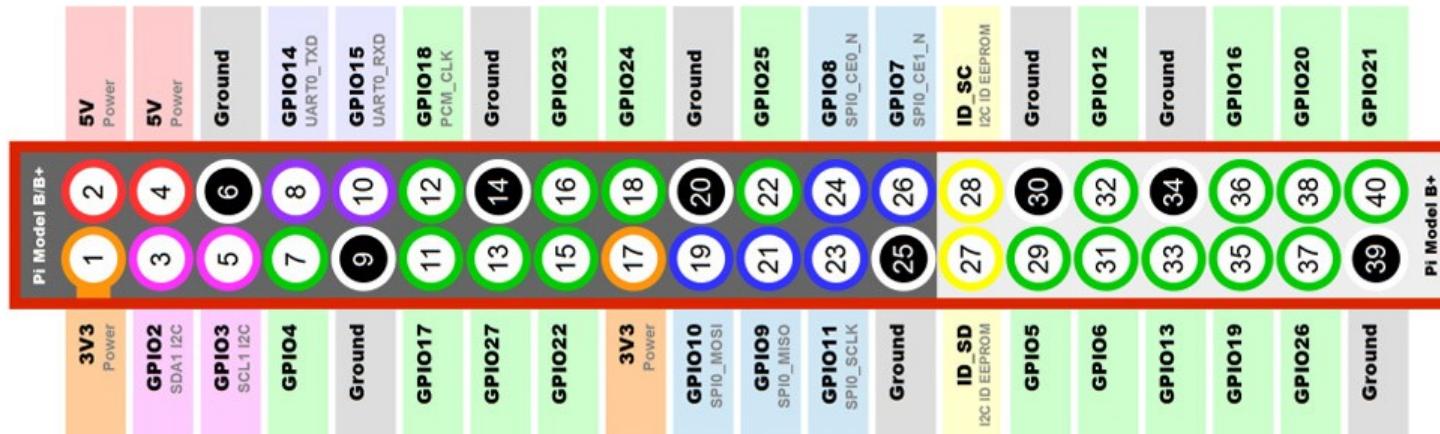
Newark
AN AVNET COMPANY

Farnell
AN AVNET COMPANY

累計銷售已經超過 3000 萬台



Pi 4B 硬體規格與特色



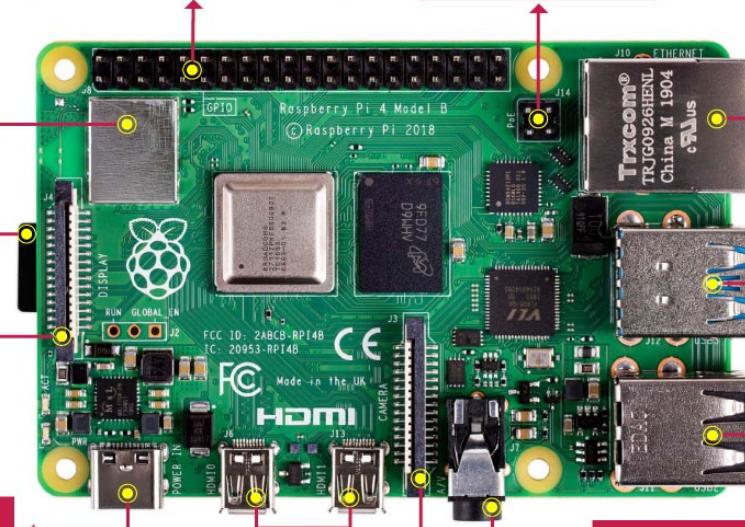
GPIO 控制腳位

內建 WiFi 和 BT

Micro SD Card Slot

2-lane MIPI DSI display port

USB-C Power Port 5V/3A



可接相機模組

FLIR Lepton 2.5 + Breakout Board v2.0



FLIR Lepton 2.5



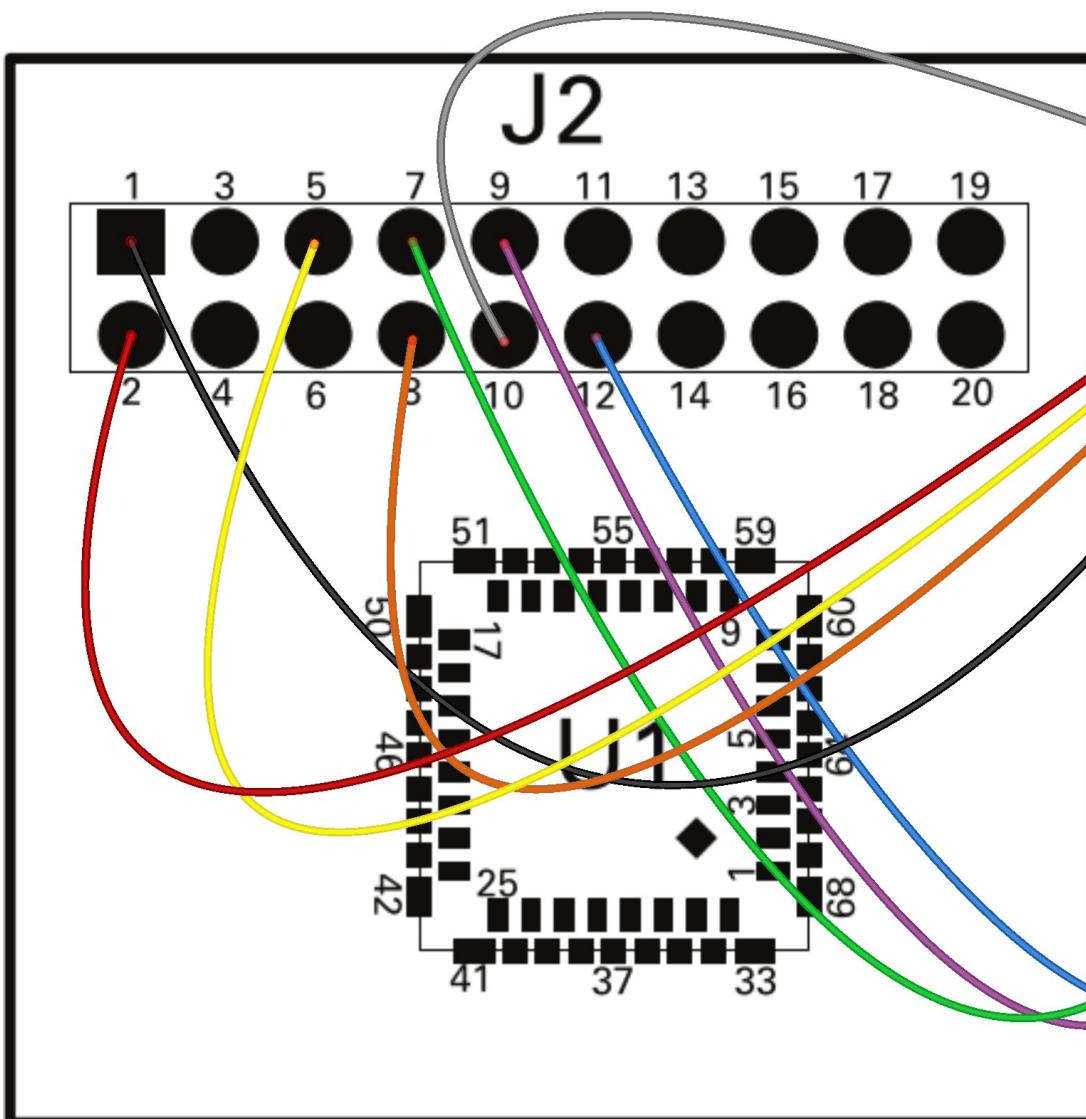
Breakout Board v2.0

Lepton

2	RPi	Pin1 (3.3V)
5		Pin3 (SDA)
8		Pin5 (SCL)
1		Pin9 (GND)

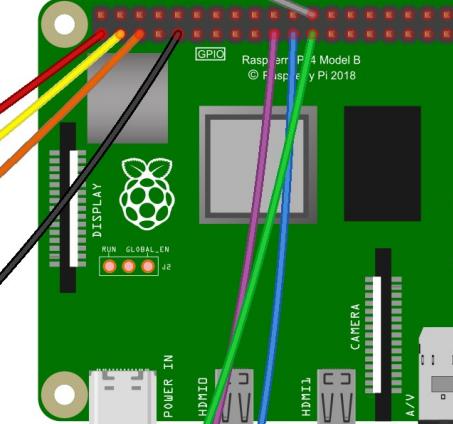
Lepton

7	RPi	Pin23 (SCLK)
9		Pin19 (MOSI)
12		Pin21 (MISO)
10		Pin24 (CE0)



RPi

7	RPi	Pin23 (SCLK)
9		Pin19 (MOSI)
12		Pin21 (MISO)
10		Pin24 (CE0)

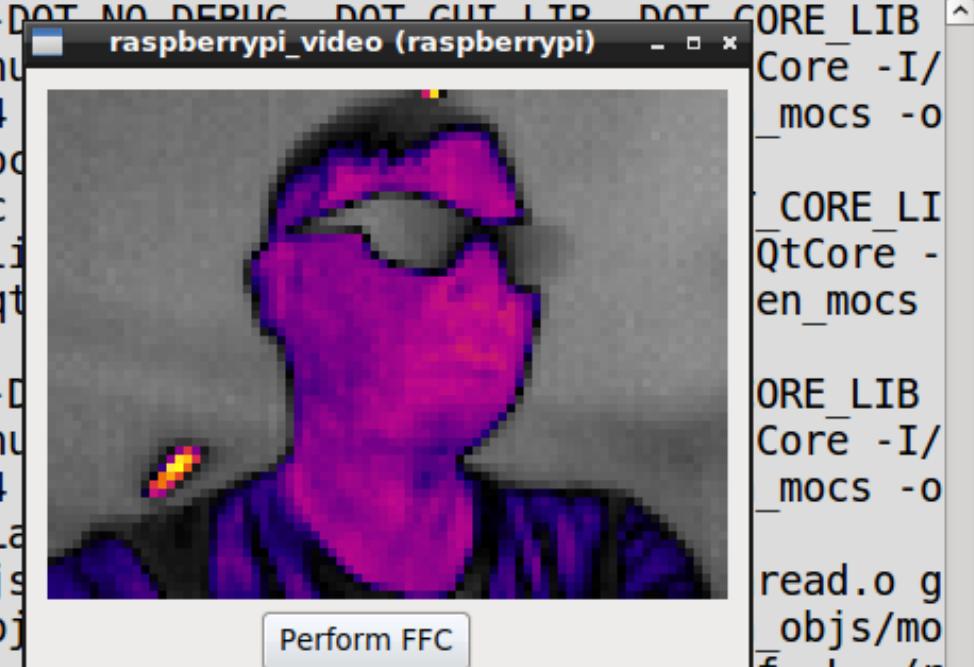


- \$ tree -L 2 LeptonModule

```
├── docs/
├── hardware/
└── software/
    ├── arduino_i2c/
    ├── beagleboneblack_video/
    ├── edison_capture/
    ├── flirpi/
    ├── raspberrypi_capture/(測試拍照功能)
    ├── raspberrypi_libs/(Lepton SDK)
    ├── raspberrypi_qt/
    ├── raspberrypi_video/(測試VoSPI功能)
    ├── STM32F3Discovery_ChibiOS/
    ├── stm32nucleo_401re/
    ├── ThermalView/
    └── v4l2lepton/(轉V4L2)
```

執行 raspberrypi_video

```
pi@raspberrypi: ~/LeptonModule/software/raspberrypi_video
File Edit Tabs Help
g++ -c -pipe -O2 -Wall -W -D REENTRANT -D QT_SHARED -I/usr/share/qt4/mkspecs/linux-gnueabihf/ /usr/include/qt4/QtGui -I/usr/include/qt4/ gen_objs/moc_LeptonThread.o gen_mocs/moc_LeptonThread.h g++ -c -pipe -O2 -Wall -W -D REENTRANT -D QT_SHARED -I/usr/share/qt4/mkspecs/linux-gnueabihf/ /usr/include/qt4/QtGui -I/usr/include/qt4/ MyLabel.h -o gen_mocs/moc_MyLabel.cpp g++ -c -pipe -O2 -Wall -W -D REENTRANT -D QT_SHARED -I/usr/share/qt4/mkspecs/linux-gnueabihf/ /usr/include/qt4/QtGui -I/usr/include/qt4/ gen_objs/moc_MyLabel.o gen_mocs/moc_MyLabel.h g++ -Wl,-O1 -o raspberrypi_video gen_objs/main.o gen_objs/MyLabel.o gen_objs/LeptonThread.o gen_objs/moc_MyLabel.o raspberrypi_libs/leptonSDKEmb32PUB/Debug -lLEPTON_SDK -lQtGui -lQtCore -lpthread
pi@raspberrypi:~/LeptonModule/software/raspberrypi_video $
pi@raspberrypi:~/LeptonModule/software/raspberrypi_video $ ls
gen_mocs          LeptonThread.cpp   MyLabel.cpp    raspberrypi_video      SPI.h
gen_objs          LeptonThread.h    MyLabel.h     raspberrypi_video.pro
Lepton_I2C.cpp    main.cpp        Palettes.cpp  README.md
Lepton_I2C.h      Makefile       Palettes.h    SPI.cpp
pi@raspberrypi:~/LeptonModule/software/raspberrypi_video $ ./raspberrypi_video
```



輻射溫度換算

影響 Radiometry 溫度量測的原因

解析度 (Resolution)

大氣影響 (Atmosphere)

反射率 (Reflectivity)

Thermal Imaging System

Atmospheric Effects

Infrared
Reflections

View
Angle

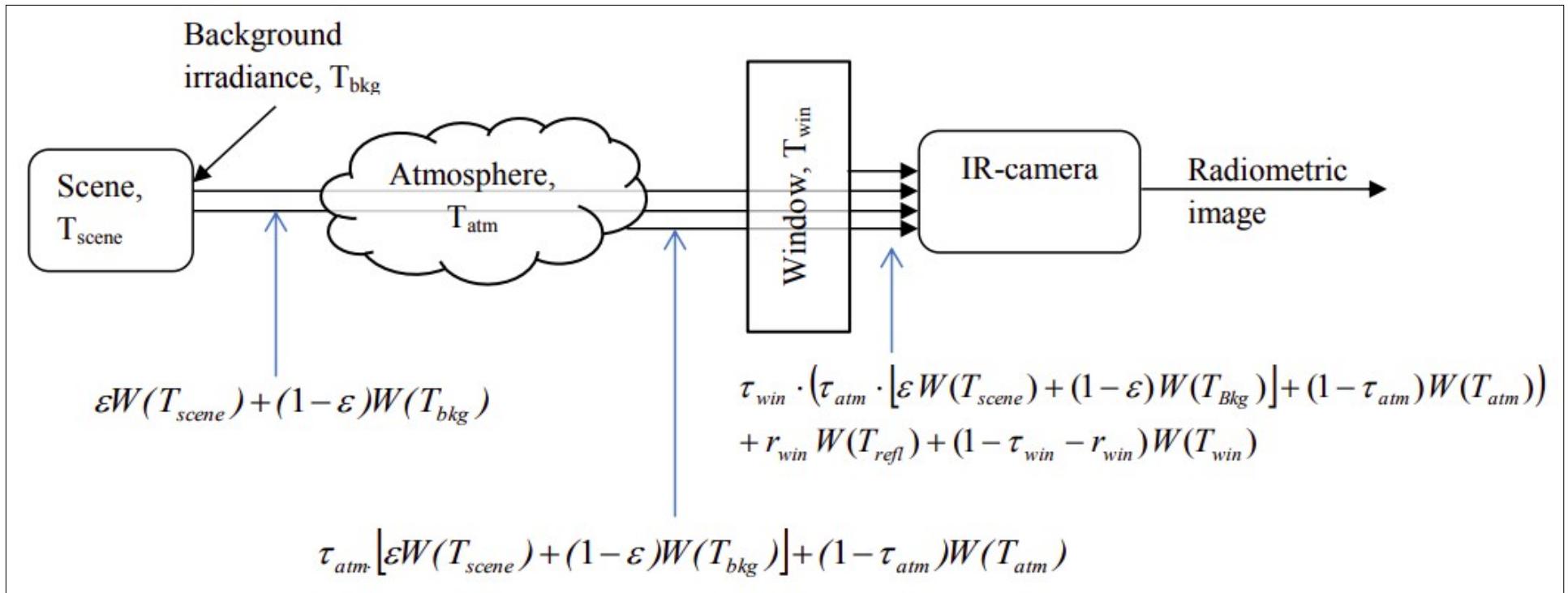
Surface
Conditions

Infrared Heat Source

Background Sky Temperature

發射率 (Emissivity)

溫度計算模型與公式



溫度計算模型

$$S = \tau_{win} \cdot (\tau_{atm} \cdot [\varepsilon W(T_{scene}) + (1 - \varepsilon)W(T_{bkg})] + (1 - \tau_{atm})W(T_{atm})) + r_{win} W(T_{refl}) + (1 - \tau_{win} - r_{win})W(T_{win})$$

Notation	Description
S	Value of the 14-bit digital video in counts
ε	Emissivity of the scene.
τ_{win}	Transmission coefficient of the window
T_{win}	Window temperature
r_{win}	Window reflection
T_{refl}	Temperature reflected in the window
τ_{atm}	Transmission coefficient of the atmosphere between the scene and the camera
T_{atm}	Atmospheric temperature
T_{bkg}	Background temperature (reflected by the scene)
T_{scene}	Scene temperature
$W(T)$	Radiated flux (in units of counts) as function of the

溫度計算公式

<http://bit.ly/39hAr6U>

DEMO

pylepton_temp_colorbar.py

```
$ cd ~/thermal-pi/01-flir  
$ python3 pylepton_temp_colorbar.py
```

執行結果

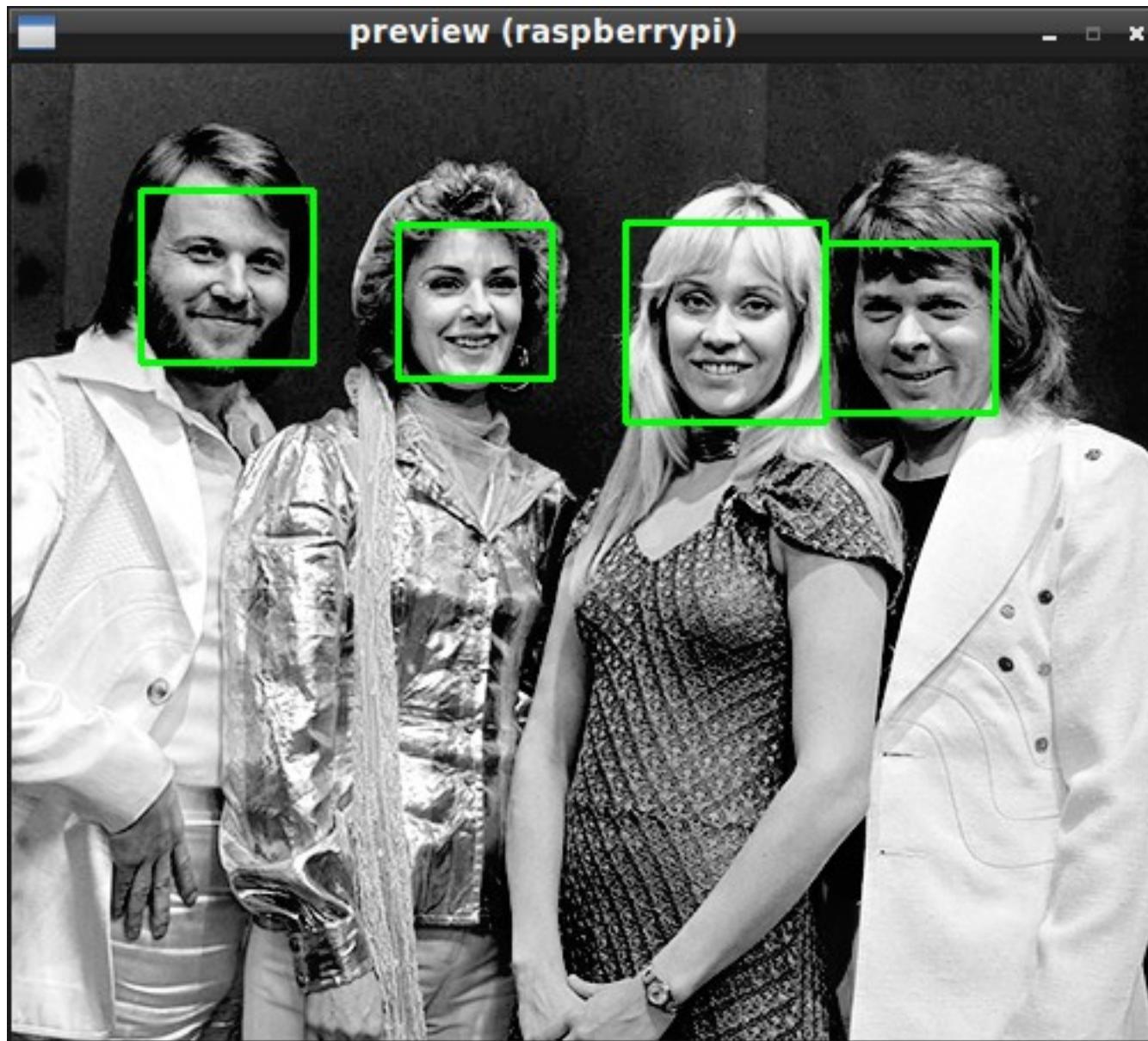
```
pi@raspberrypi: ~/thermal-pi/01-flir
File Edit Tabs Help
pi@raspberrypi:~/thermal-pi/01-flir $ python3 pylepton_temp_colorbar.py
[30549] 32.34
[30380] 30.65
[30361] 30.46
[30394] 30.79
[30328] 30.13
[30390] 30.75
[30785] 34.7
[30461] 31.46
[30361] 30.46
[30766] 34.51
[30766] 34.51
[30758] 34.43
[30764] 34.49
[30737] 34.22
[30735] 34.2
[30747] 34.32
[30749] 34.34
[30739] 34.24
[30749] 34.34
[30756] 34.41
image (raspberrypi)
```



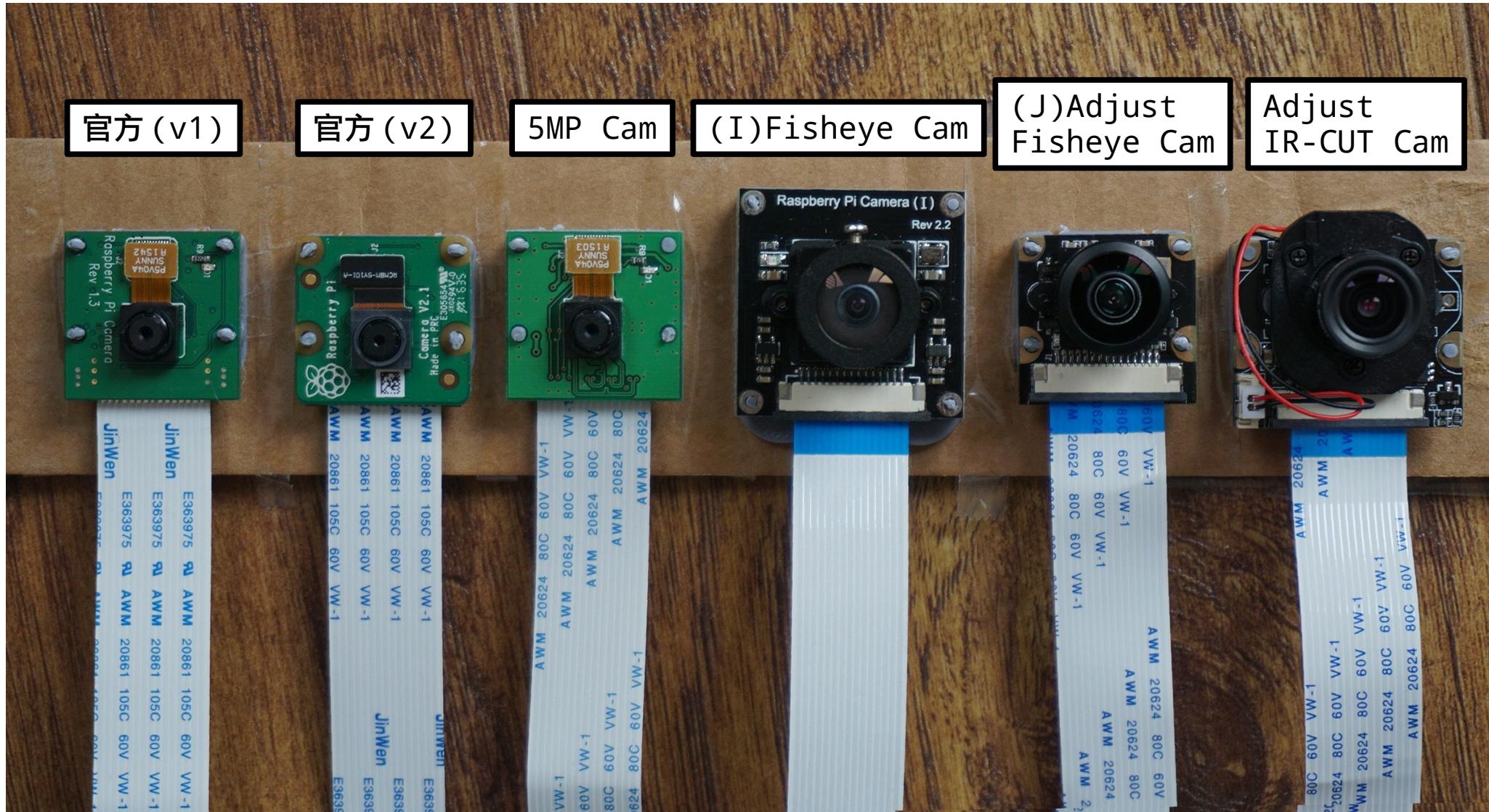
如何更智慧的測量？



先找到人臉再進行測溫



搭配 Raspberry Pi Camera



<http://www.semifluid.com/2017/01/23/raspberry-pi-camera-comparison/>

FusionPi

雙相機熱像儀專案

FusionPi 所需軟體



Keras



OpenCV



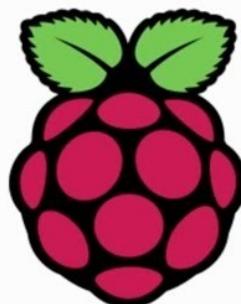
TensorFlow



NumPy

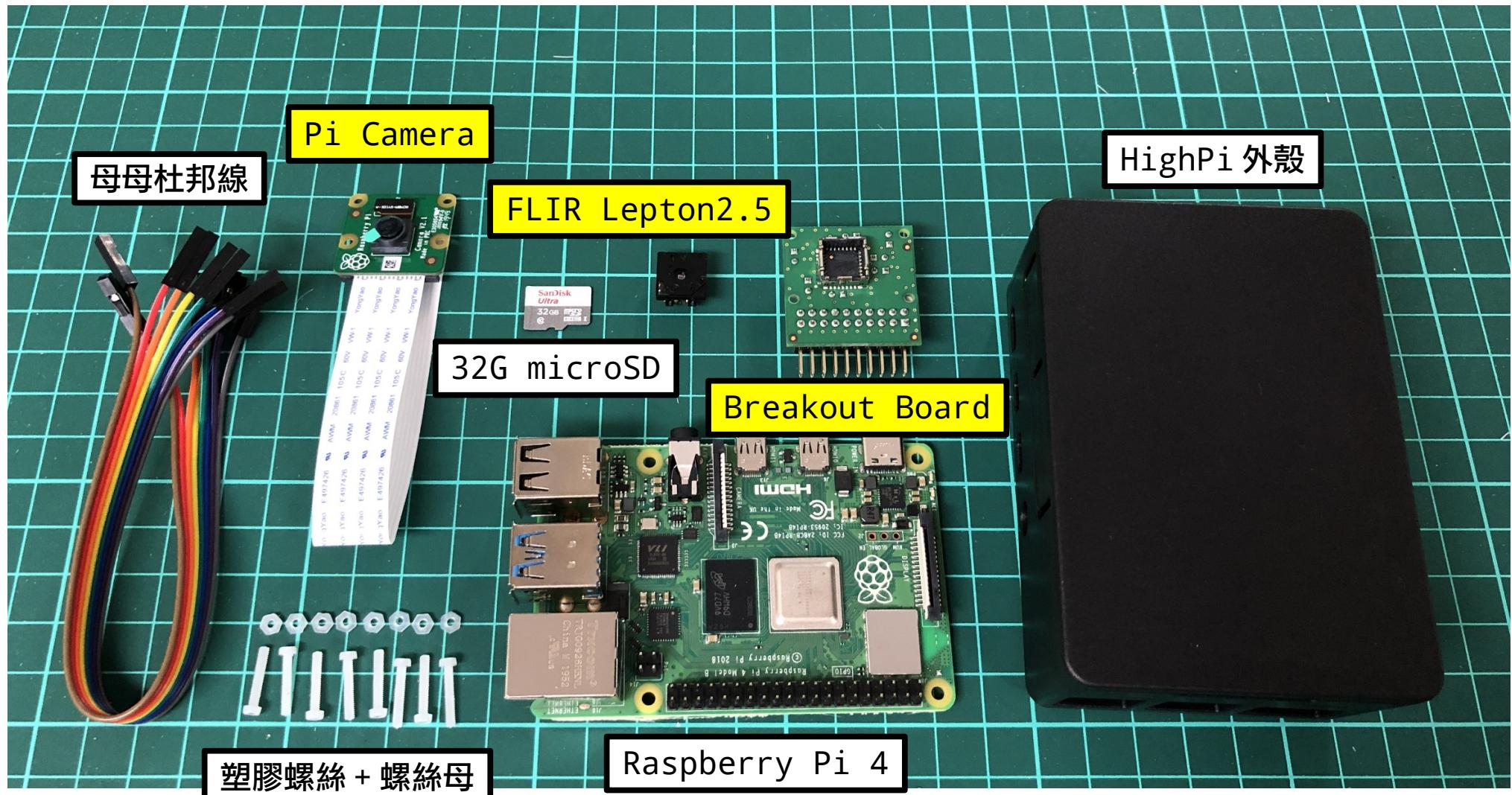


Flask

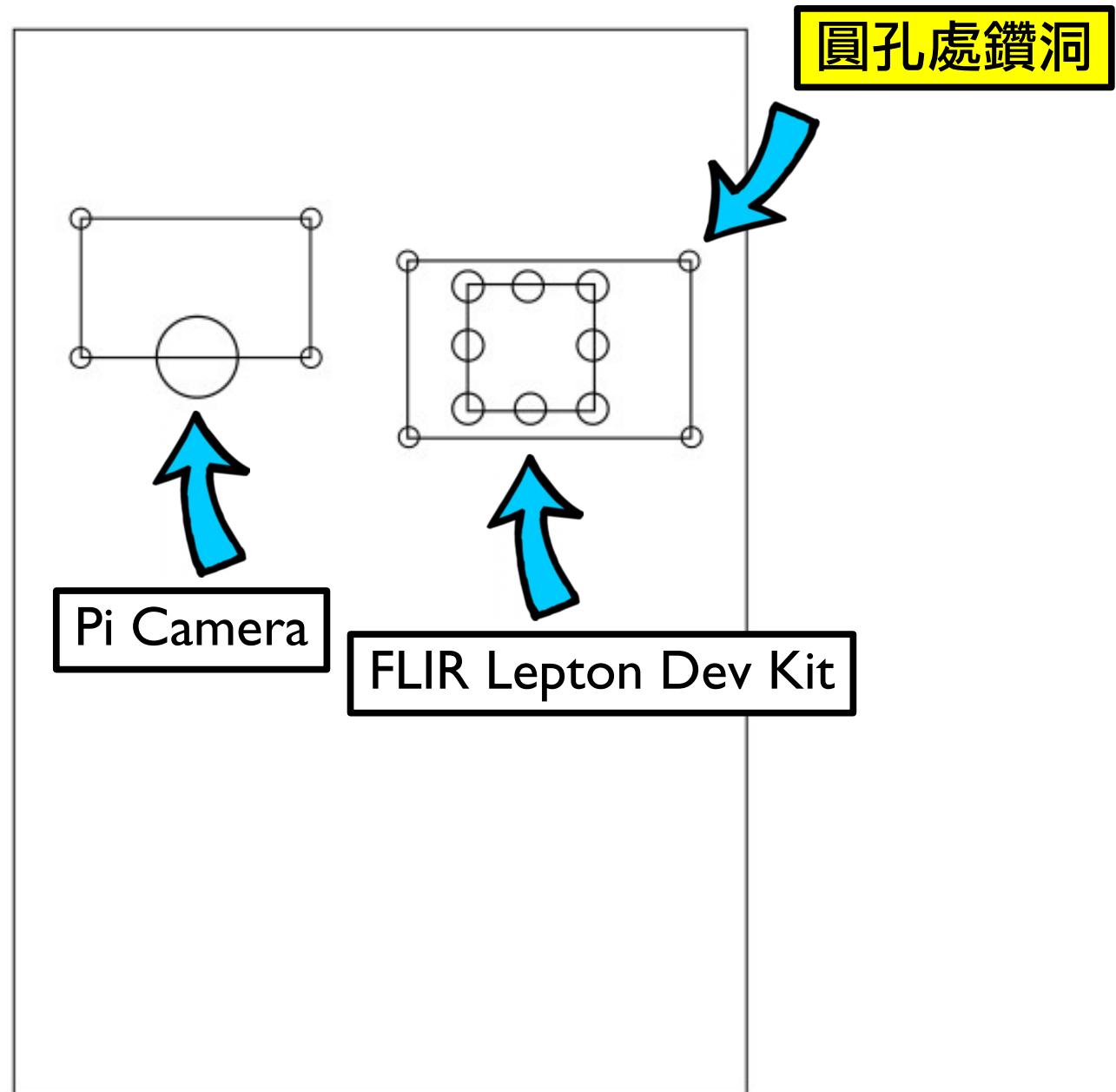


Raspberry Pi OS

FusionPi 所需硬體

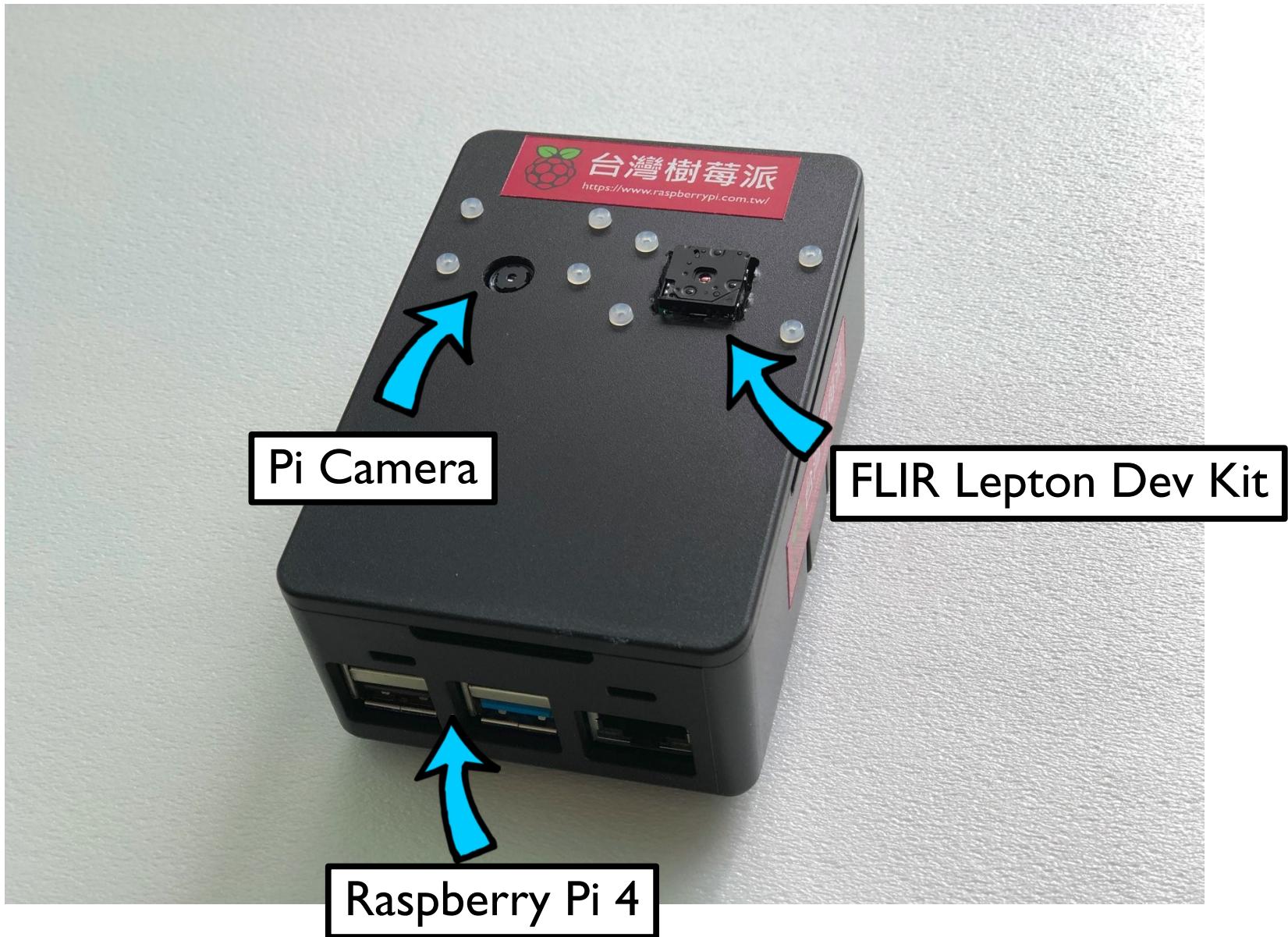


在 HighPi 上安裝雙相機

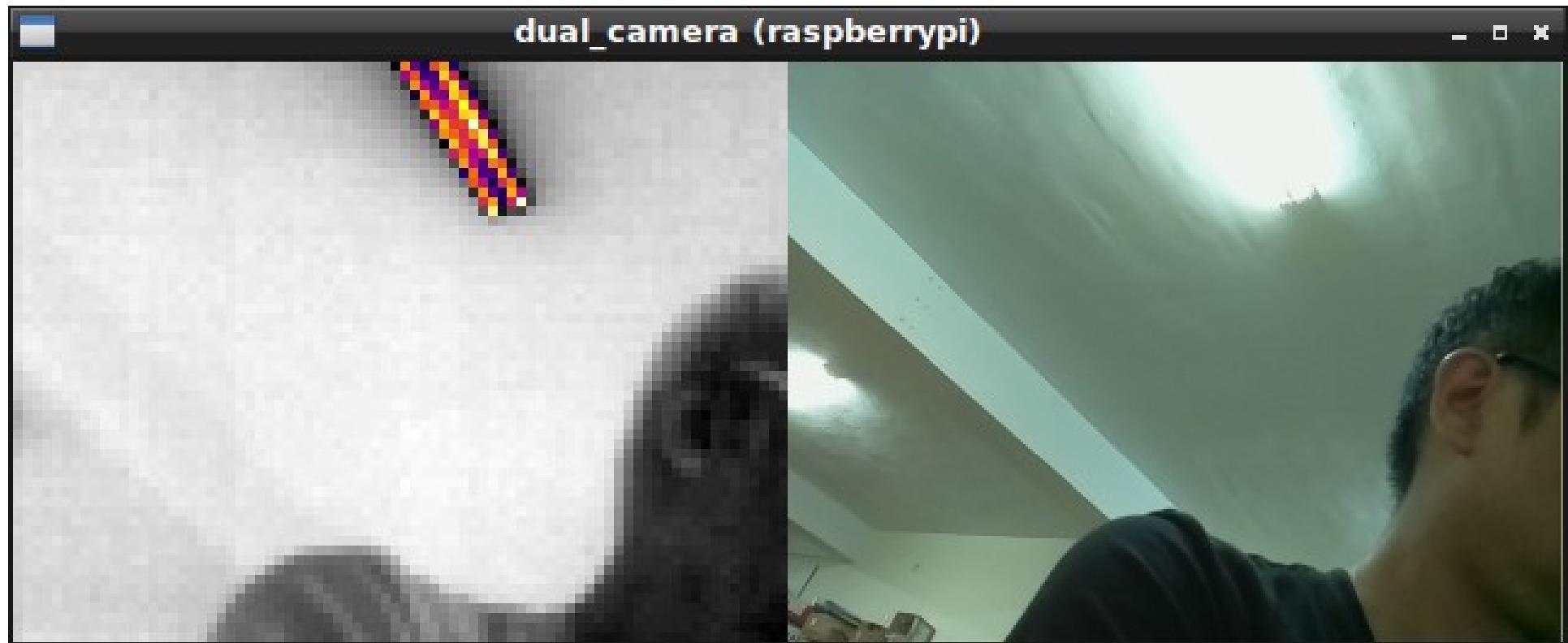




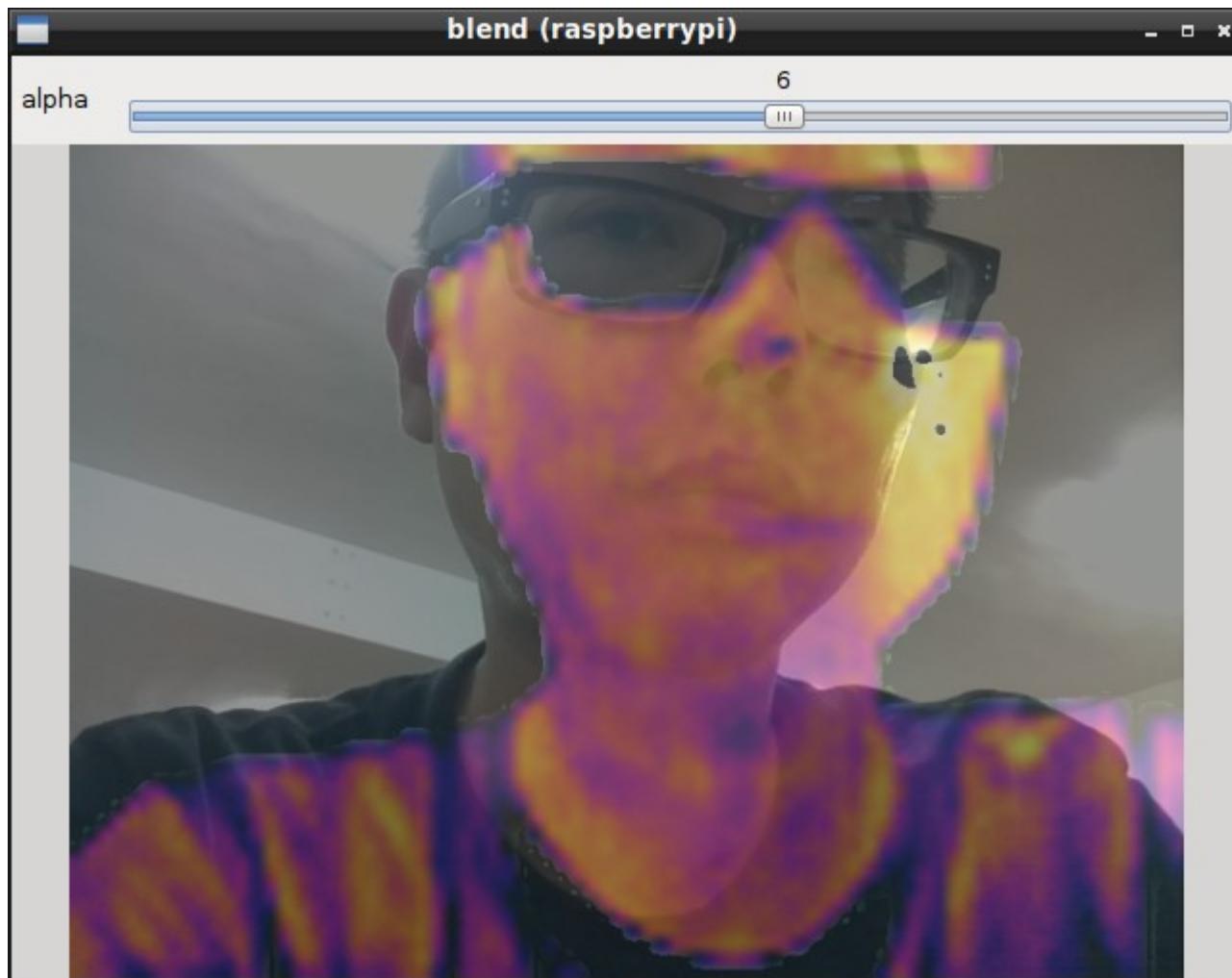
雙相機熱像儀雛型



將雙相機並排顯示



調整雙相機的 alpha 值



DEMO

dual_camera.py

```
$ cd ~/thermal-pi/02-calibration  
$ python3 dual_camera.py
```

雙相機校正

相機矩陣模型



Lens configuration (internal parameter)

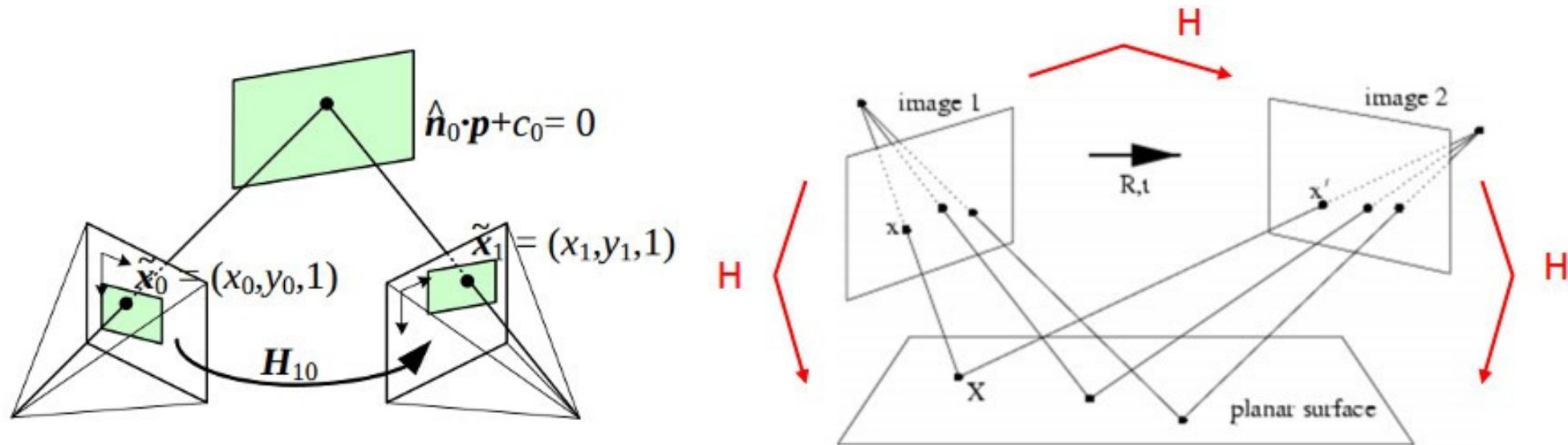
$$\begin{bmatrix} x \\ 1 \end{bmatrix} = L \left(K [R \ t] \begin{bmatrix} x \\ 1 \end{bmatrix} \right)$$

Spatial relationship between sensor and pinhole
(internal parameter)

Camera body configuration
(extrinsic parameter)

Homography(平面投影轉換 / 單應性)

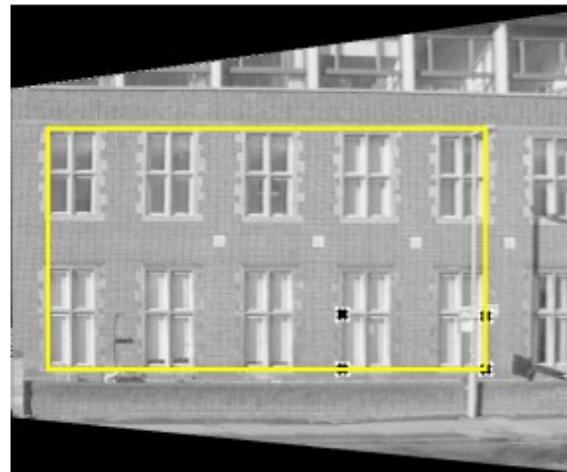
- Homography 描述了兩個平面間的變換關係，表示一個平面到另外一個平面的投影對映



$$s \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = H \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

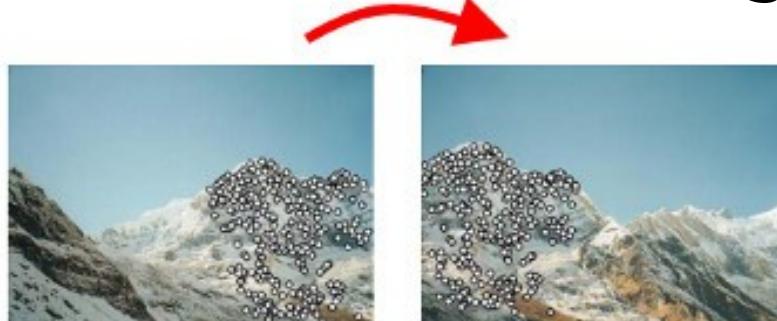
Homography 應用

- Perspective removal/correction(透視去除)



from Hartley & Zisserman

- Panorama stitching(全景拼接)

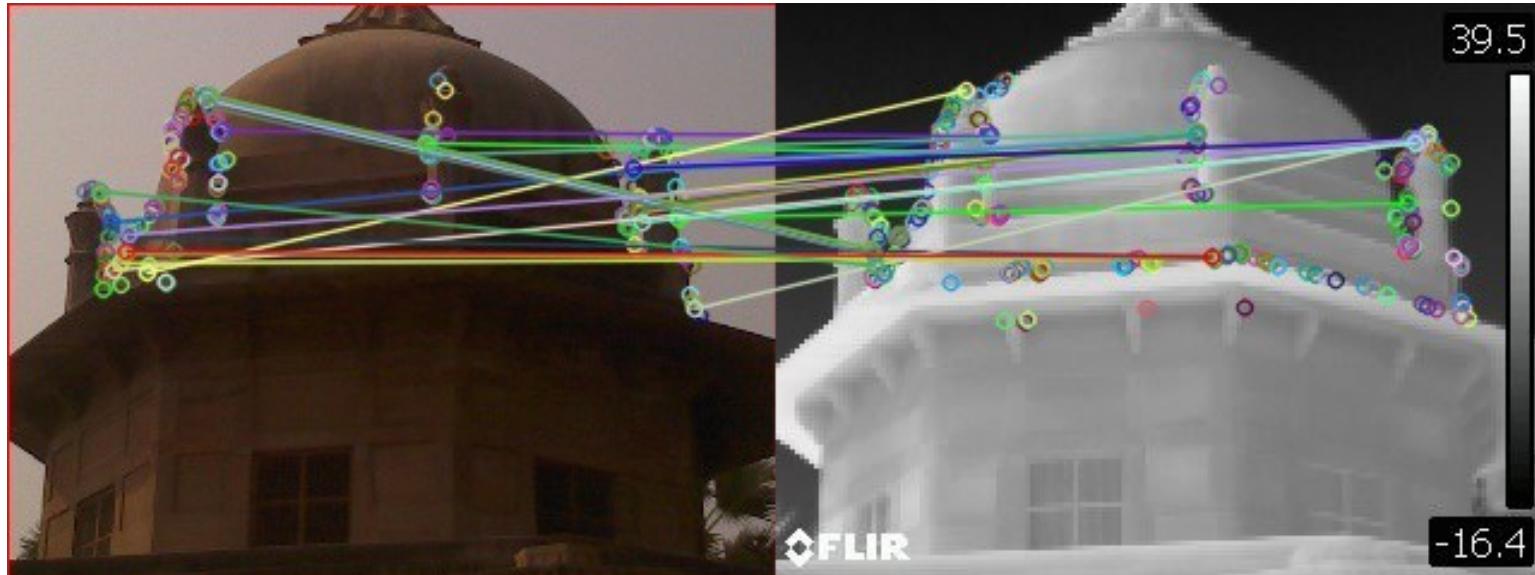


https://docs.opencv.org/3.4/d9/dab/tutorial_homography.html

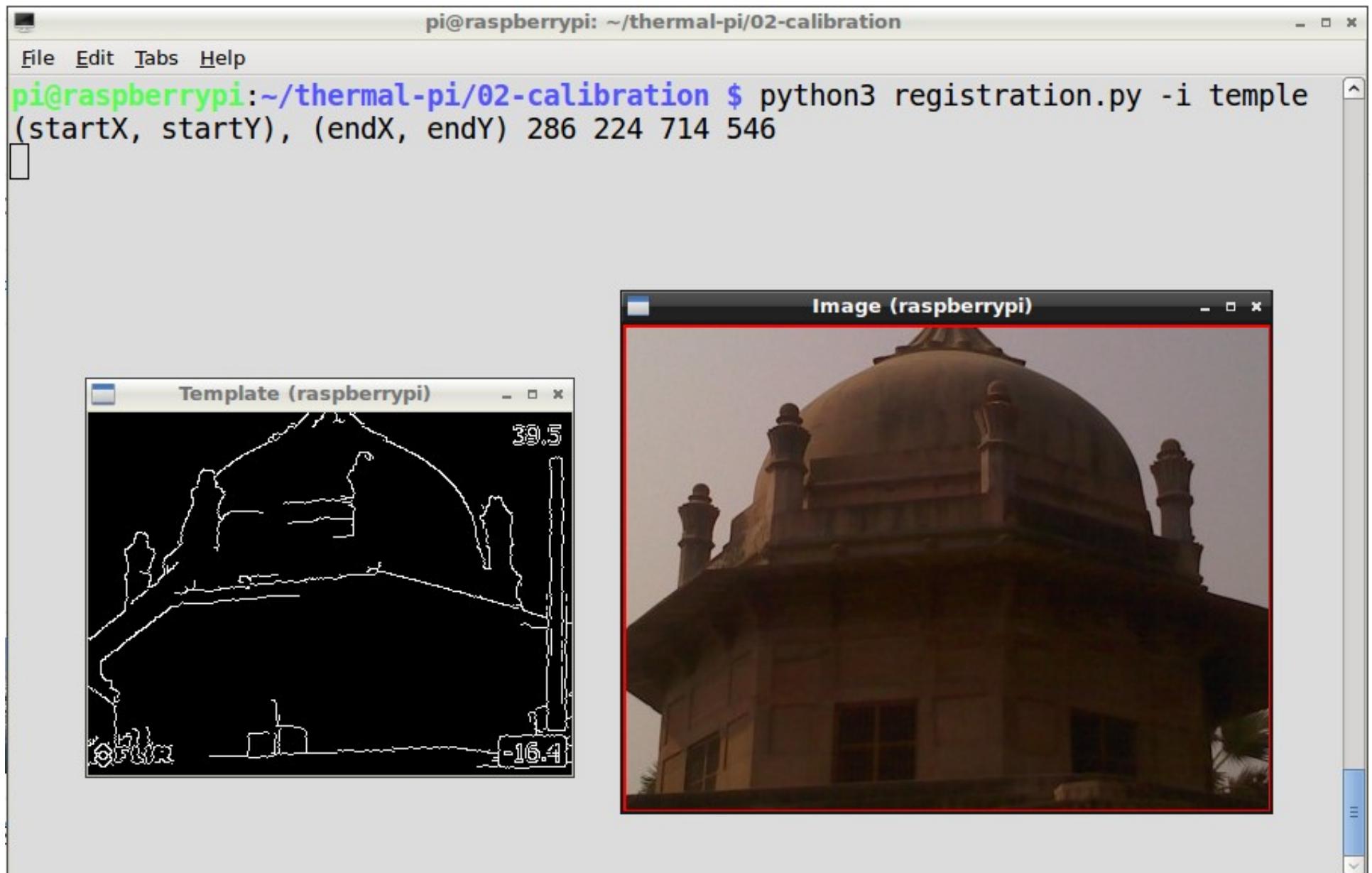
雙相機的座標系和視角都不同



- 利用多尺度樣板匹配 (multi-scale template match) 對雙相機做校正



執行結果



DEMO

calibrated_blend_camera.py

```
$ cd ~/thermal-pi/02-calibration  
$ python3 calibrated_blend_camera.py
```

自製雙相機熱像儀

- 先找出人臉，再算出人臉平均溫度（或最大溫度）



DEMO

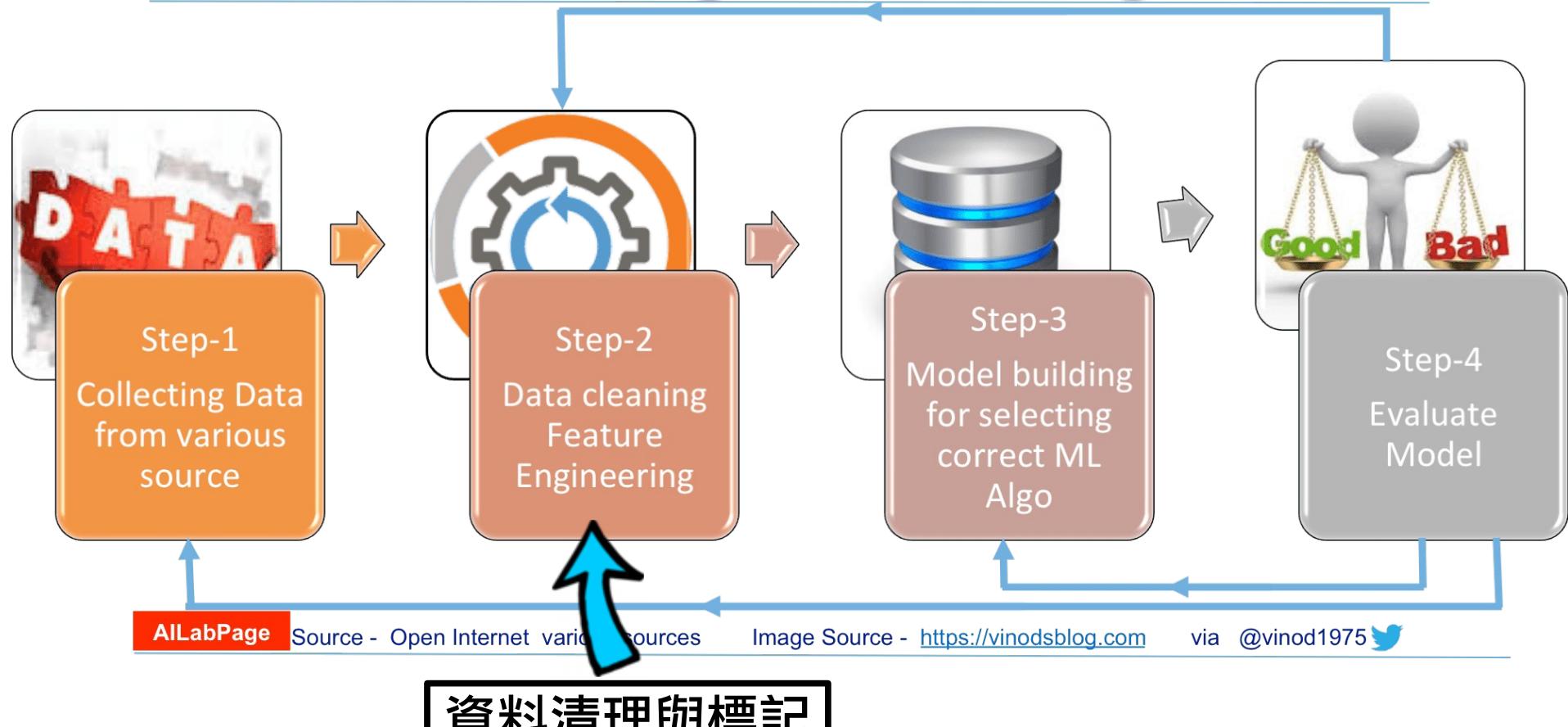
pylepton_fusion_pi.py

```
$ cd ~/thermal-pi/03-fusion  
$ python3 pylepton_fusion_pi.py
```

如何讓 FusionPi 更聰明？

使用機器學習做自動化辨識

Machine Learning Process at High Level



光學影像已經有大資料庫

ImageNet Dataset

IMAGENET

超過 1,500 萬張



Russakovsky, O., Deng, J., Su, H., Krause, J., Satheesh, S., Ma, S., ... & Fei-Fei, L. (2015). [Imagenet large scale visual recognition challenge](#). *arXiv preprint arXiv:1409.0575*. [\[web\]](#)

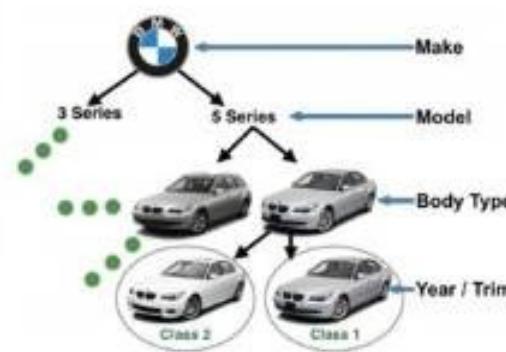
千萬等級和完整標記結構資料

Fine-Grained Recognition

IMAGENET



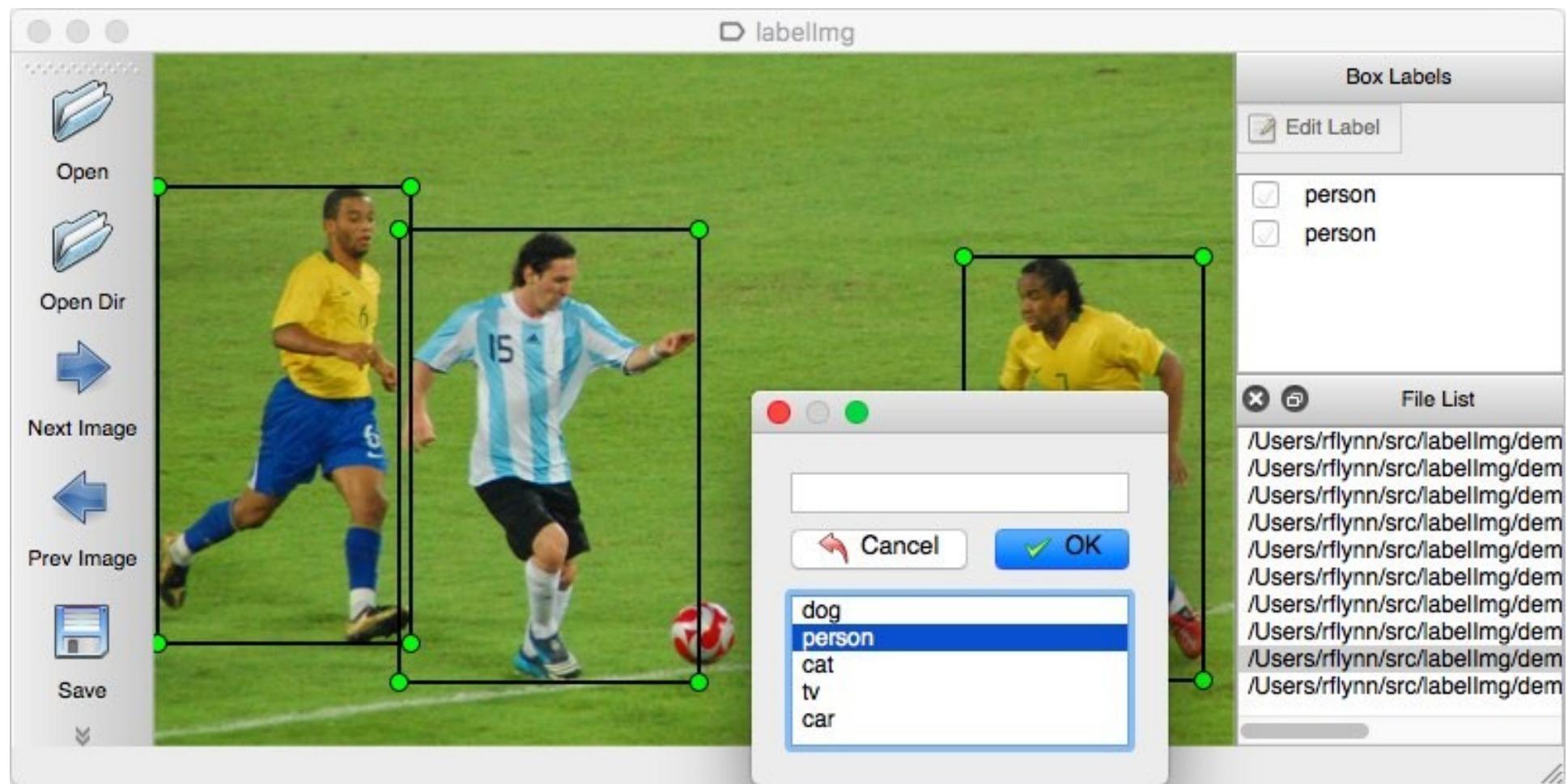
[Gebru, Krause, Deng, Fei-Fei, CHI 2017]



2567 classes
700k images

光汽車就有七十萬個影像

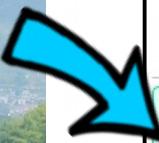
但需要大量的人工做標記



<https://github.com/tzutalin/labelImg>

FusionPi 使用智慧服務自動標記

1. 光影像資訊



2. 辨識人形和取得人形位置

PersonDetection 人形偵測

POST /Person/v0.1/DetectPerson 人形偵測

資料圖片輸入，將回傳人形偵測結果，包含每個人形的上下左右邊界。

Parameters

Name **Description** **Try it out**

X-API-KEY * required API金鑰，登入IOT大平台後，在[帳號資訊]底下[API金鑰管理]獲得，需先勾選使用的服務
string
(header)

Request body required `text/html;charset=utf-8`

1. **queryData** Base64人形圖片
輸入資料建議：輸入的影像長寬接近 608x608，人形遮蔽範圍小於50%，人形高度大於影像高度1/5，視角俯角小於60度
反應時間：偵測一張600KB圖片約1.8秒
精確度：在 COCO test-dev dataset 下 MAP (mean Average Precision) 48.1
狀態碼及說明 0: 執行驗證成功 1: 未提供Api Key 2: 身份驗證失敗 3: JSON無法剖析 4: JSON欄位錯誤 5: 測試圖片為空 6: 測試圖片解碼失敗 7: 其它錯誤

3. 標記顯示



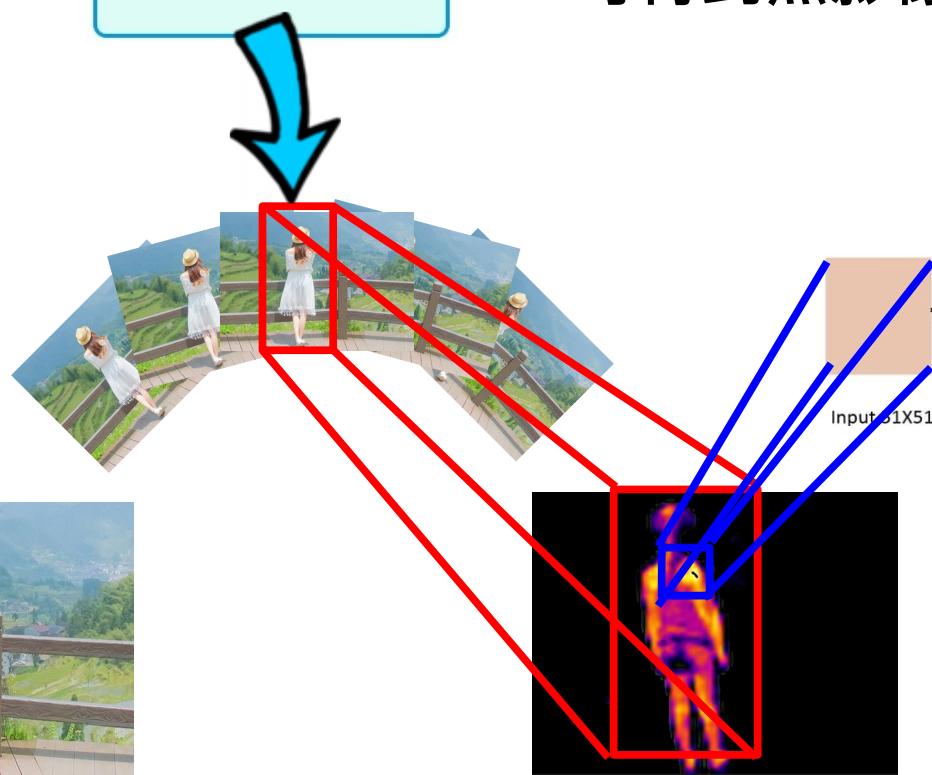
<https://iot.cht.com.tw/iot/developer/intelligence>

軟體系統架構

2. 人形偵測 API



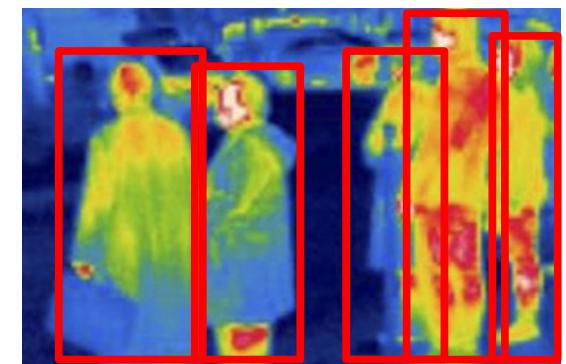
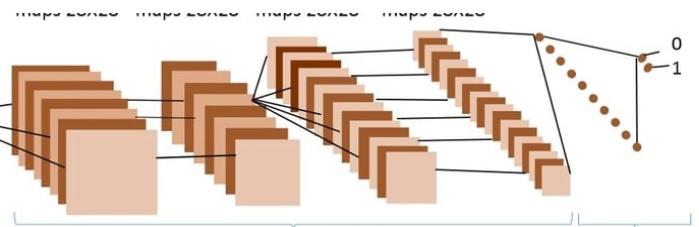
透過中華電信大平台的人形偵測 API，可將光影像資訊標記出人形和位置座標，再使用程式將該座標自動化對應到熱影像，取出特徵和建立深度學習模型後訓練，可得到熱影像人形偵測結果。



1. 光影像資訊

3. 熱影像自動標記

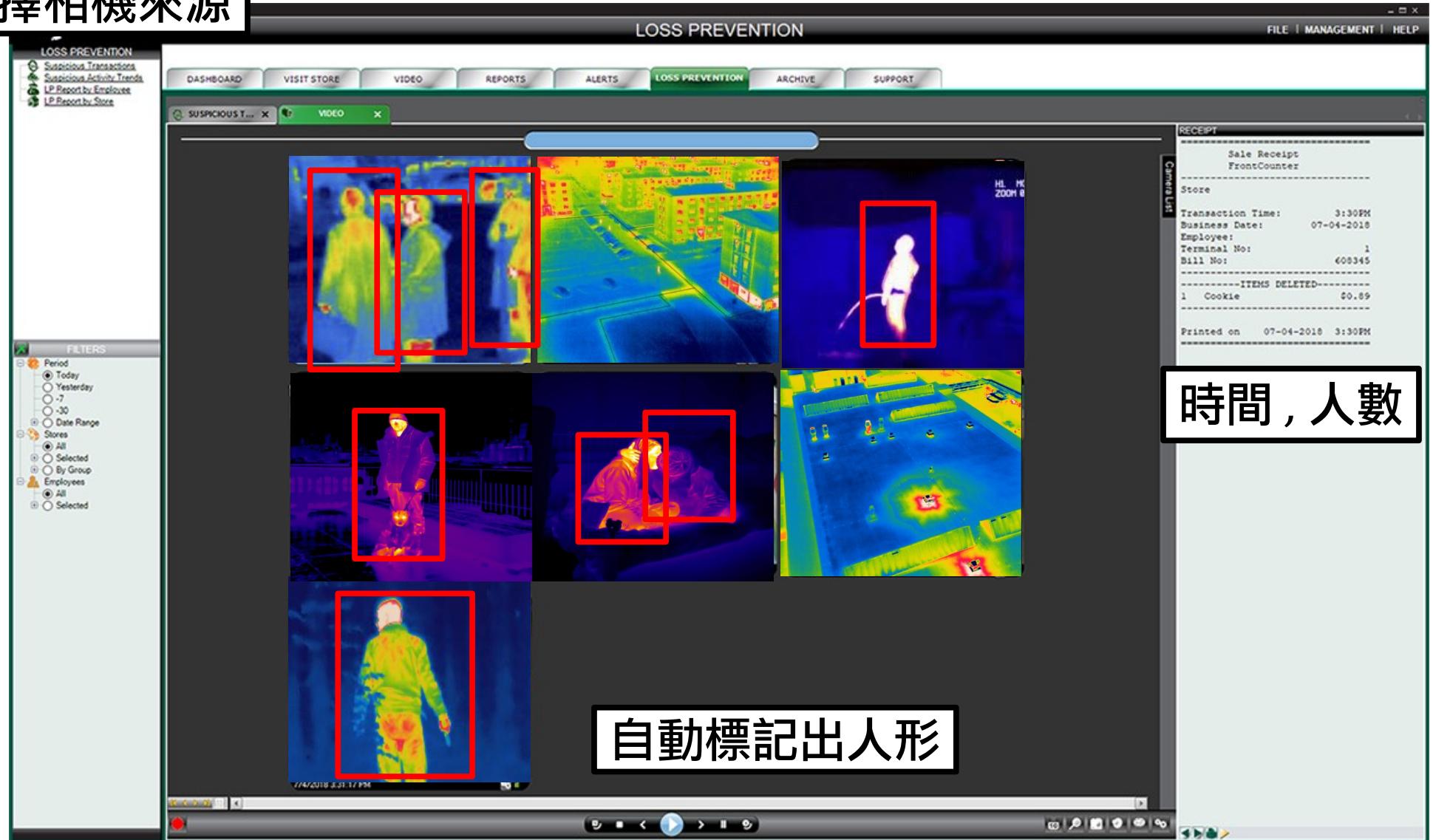
4. 特徵抽取和建模



5. 熱影像人形偵測

(預計)人機界面

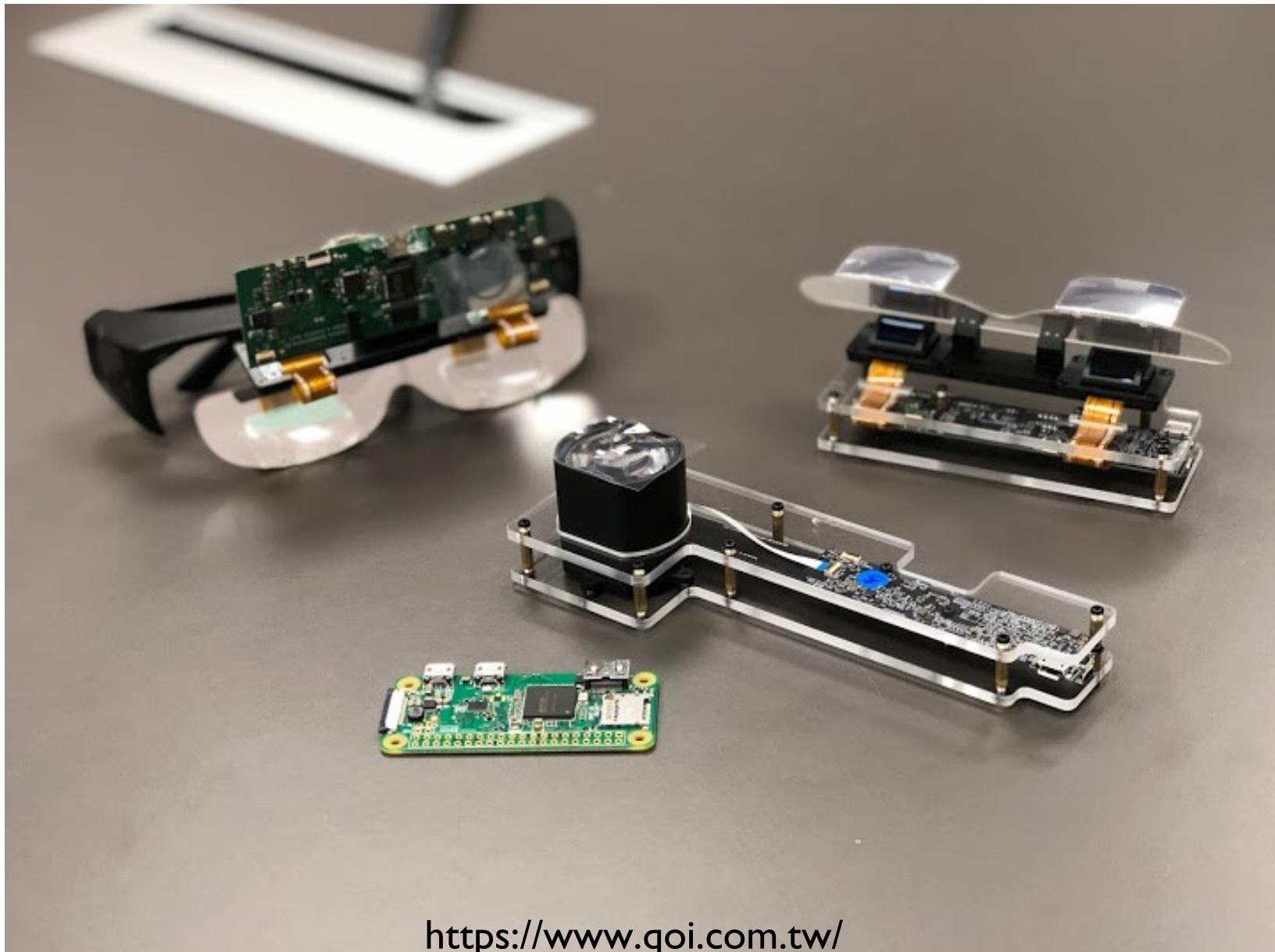
選擇相機來源



時間，人數

自動標記出人形

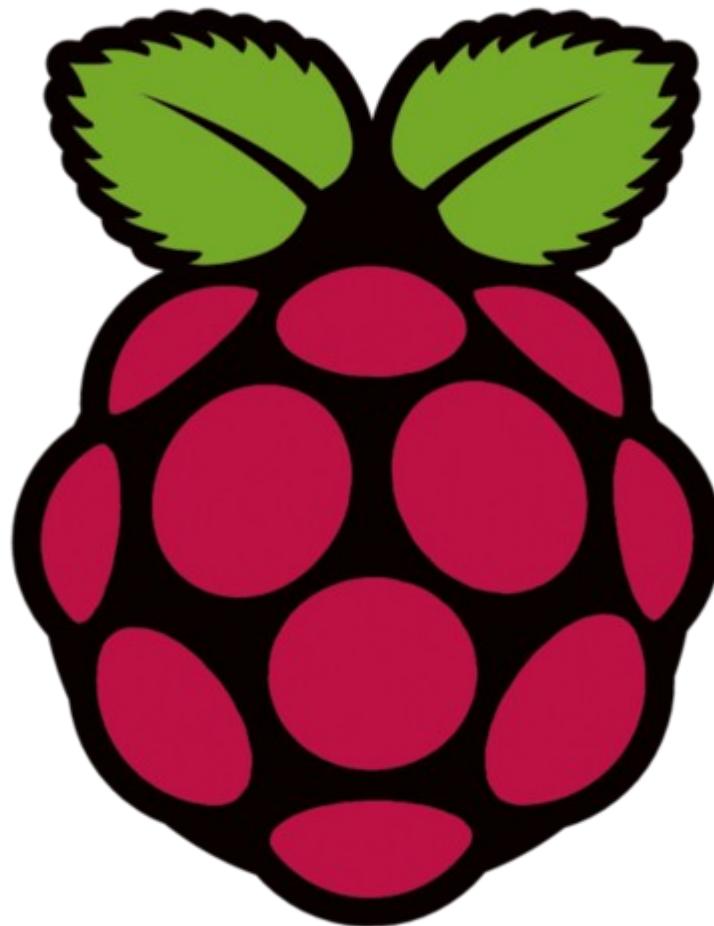
未來可結合微投影機



雙相機熱像儀 AR



Raspberry Pi Rocks the World



Thanks