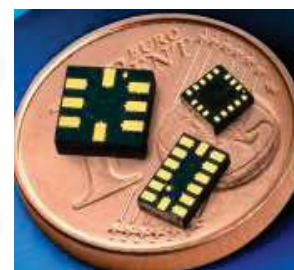


微機電運動感測器原理與應用

李炯毅

資深技術行銷工程師

意法半導體



STMicroelectronics

摘要



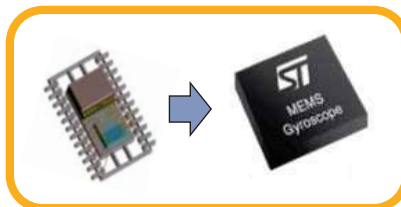
- 微機電技術與現有產品
- 微機電運動感測器原理
- 未來可能之創新應用
- iNEMO™ 慣性量測模組

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何謂微機電(MEMS)?



- MEMS = Micro-Electro-Mechanical System
- 利用半導體製程製作出微結構, 並將微結構與讀取電路整合在一個封裝裡面
- 微機電感測器的特點:
 - 多樣化的感測媒介 – 可移動之結構
 - 可微小化 – 奈/微米等級
 - 可大量生產 – 同一晶圓多重功能
 - 高度整合 – 機械與電路

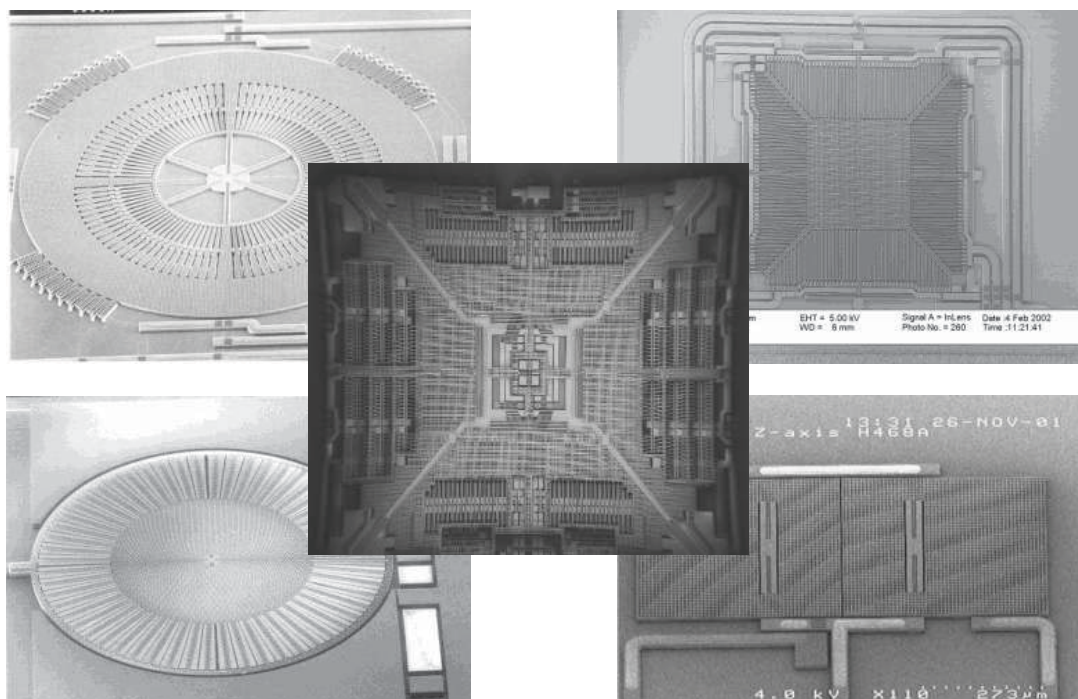


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ST 之微機電製程

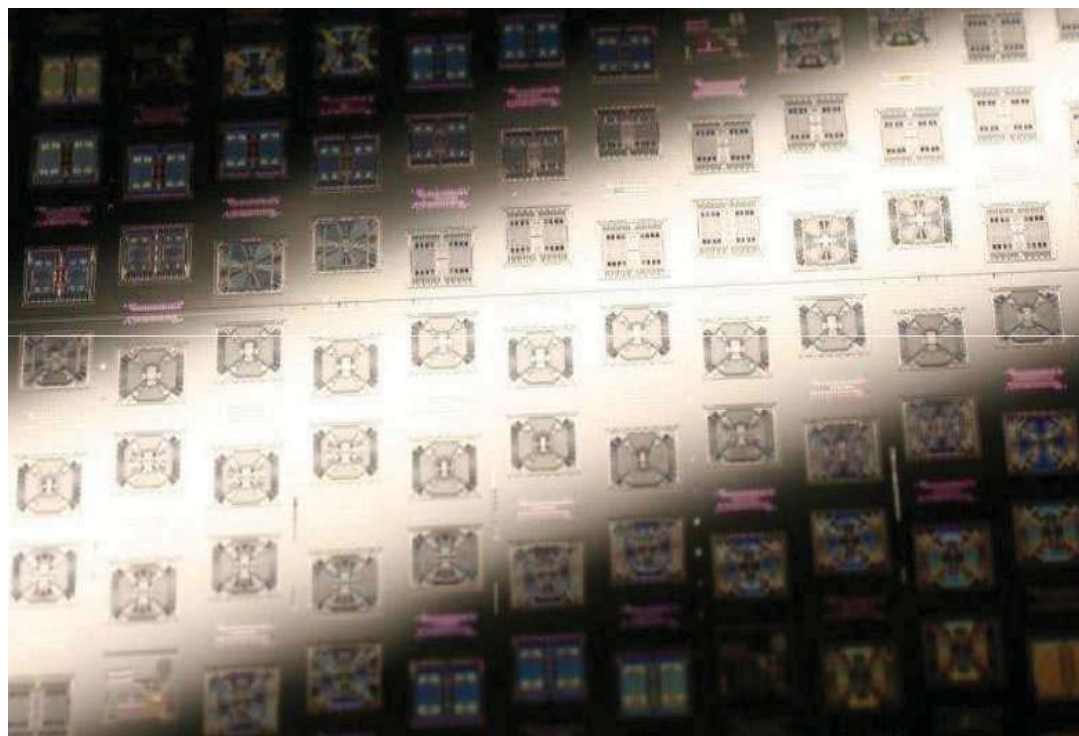


(THELMA: THick Epitaxial Layer for Microactuators and Accelerometers)



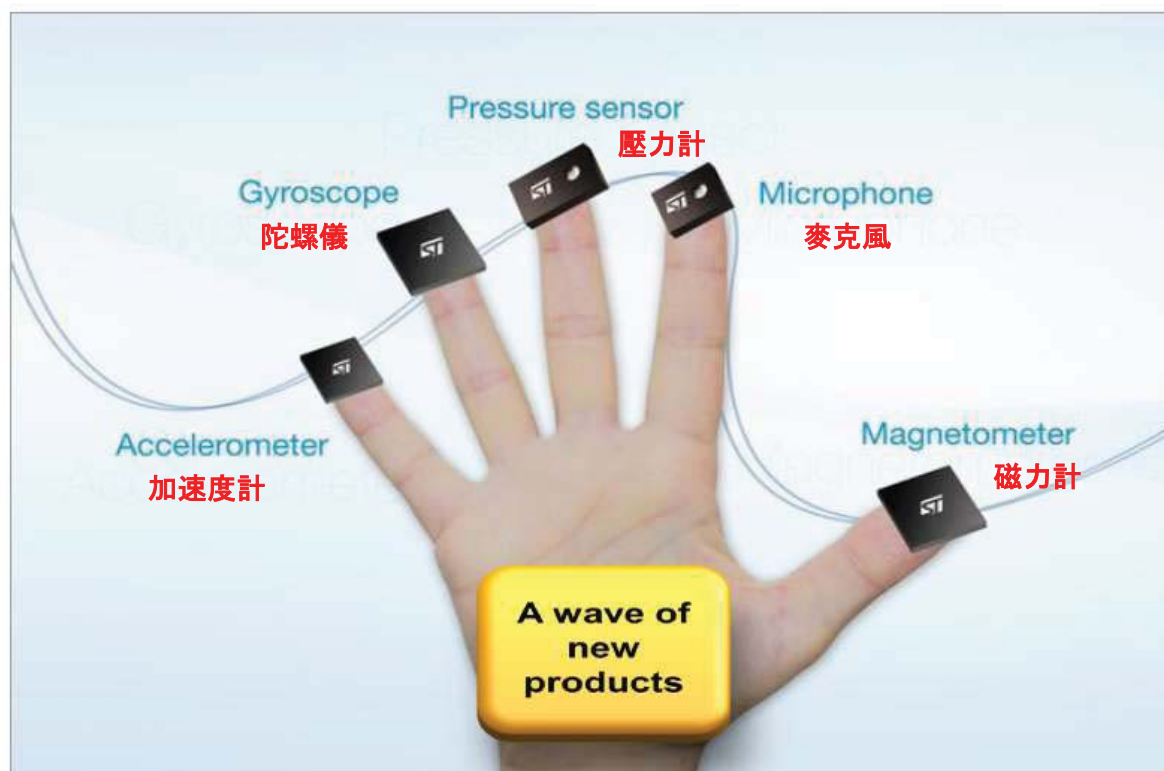
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THELMA可同時實現加速度計與陀螺儀之製作



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ST可提供之微機電感測器



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ST微機電產品已有之應用



- 2005:
We entered PCs
- 2006:
We entered Gaming
- 2007:
We entered Phones

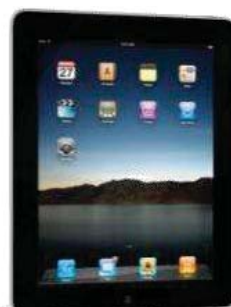


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ST微機電產品已有之應用



- 2008:
We entered Pockets
- 2009:
We entered Cameras
- 2010:



Source: iFixit teardown report

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- 微機電技術與現有產品
- 微機電運動感測器原理
- 未來可能之創新應用
- iNEMO™ 慣性量測模組

9軸運動感測 : A+M+G

Accelerometer 加速度計 [m/sec²]

- Senses the linear acceleration.
- In **static** conditions, the projection of gravity on the three axes allow to compute tilt angles **可量測線性加速度或重力**

Magnetometer 磁力計 [Gauss]

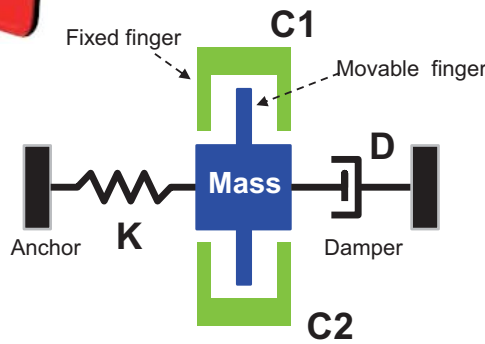
- Senses the magnetic field.
- In **static** conditions, the projection of geomagnetic field on the three axes allows to compute heading angle **可量測磁場**

Gyroscope 陀螺儀 [degree/sec]

- Measures the angular rate
- In **dynamic** conditions, the integration of the angular rate along the three axes allow to determine the 3D orientation **可量測角速度**

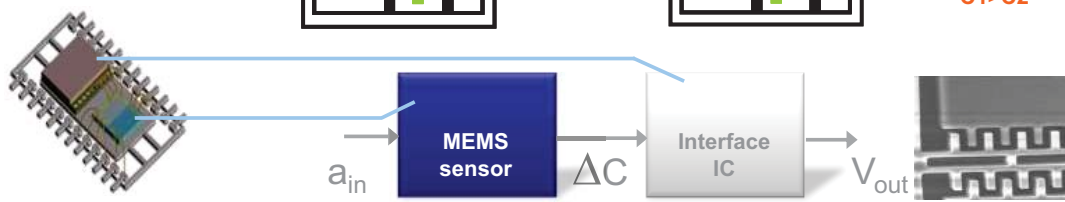
Accelerometers

線性加速度 ($a : m/sec^2$)



$$F = mx'' + dx' + Kx$$

~ 牛頓第二運動定律



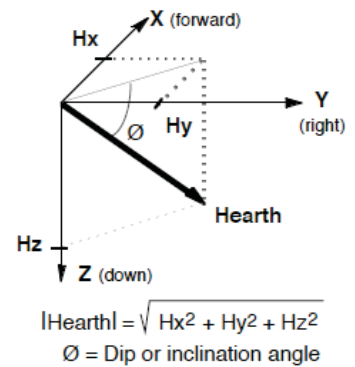
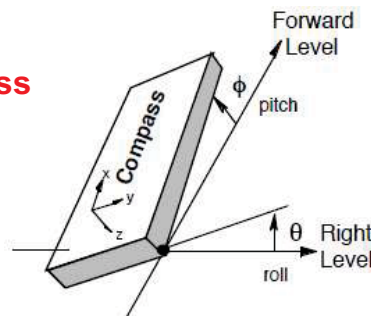
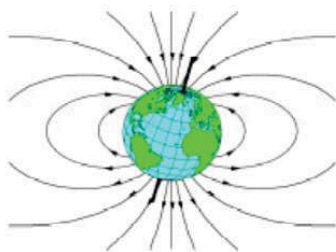
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Magnetometer

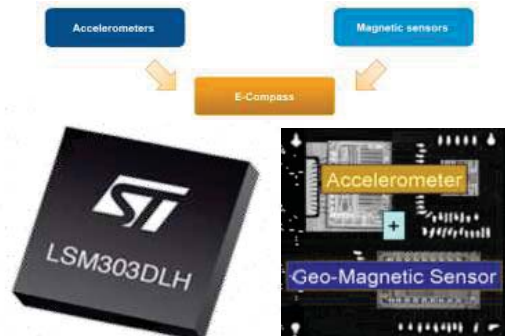
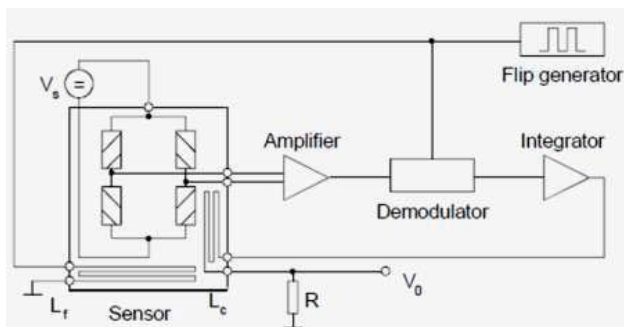
磁場 (Gauss)



地球磁場強度: 0.5 ~ 0.6 Gauss



利用非等向性磁阻組成惠斯頓電橋來感測磁場



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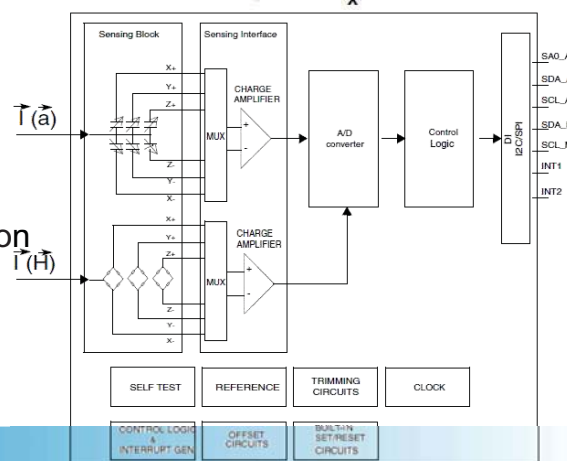
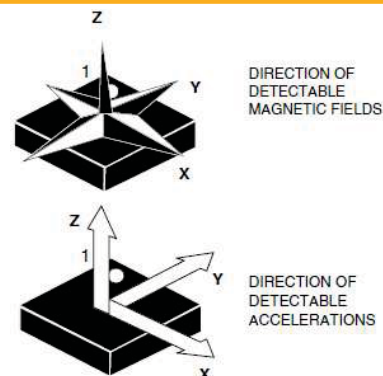
3axis Digital 1.3/8.1 gauss

電子指南針 (E-compass) – 元件特性



(LSM303DLH 電子指南針: 3軸加速度計 + 3軸磁力計)

- Analog supply voltage: 2.5 V to 3.3 V
- Digital supply voltage IOs: 1.8 V
- Power-down mode
- 3 magnetic field channels and 3 acceleration channels
- ± 1.3 to $\pm 8,1$ gauss magnetic field full-scale
- ± 2 g/ ± 4 g/ ± 8 g dynamically selectable fullscale
- 16-bit data out
- I2C serial interface
- 2 independent programmable interrupt generators for free-fall and motion detection
- Embedded self-test
- Accelerometer sleep-to-wakeup function
- 6D orientation detection



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電子指南針 (E-compass) – 重要規格



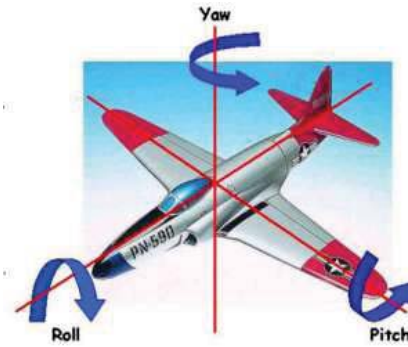
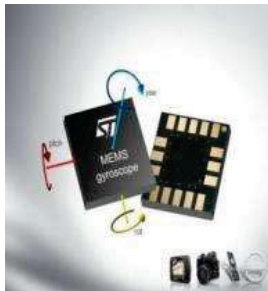
| Parameter | Typ. | Unit |
|---|------------|-------------------------------|
| Linear acceleration sensitivity (靈敏度) | 1 | Mg/digit |
| Linear acceleration sensitivity change vs. temperature (靈敏度vs. 溫度) | ± 0.01 | $\% / ^\circ \text{C}$ |
| Linear acceleration typical zero-g level offset (初始偏差量) | ± 20 | Mg |
| Linear acceleration zero-g level change vs. temperature (初始偏差量vs. 溫度) | ± 0.1 | $\text{mg} / ^\circ \text{C}$ |
| Magnetic gain setting (磁場感測靈敏度) | 430 | LSB/gauss |
| Magnetic cross-axis sensitivity (軸間干擾) | ± 1 | $\% \text{FS/gauss}$ |
| Magnetic resolution (磁場解析度) | 8 | mgauss |

- * $V_{dd} = 2.5 \text{ V}$, $T = 25 ^\circ \text{C}$ unless otherwise noted
- * Linear acceleration measurement range $\pm 2.0 \text{ g}$
- * Magnetic measurement range $\pm 4.0 \text{ gauss}$

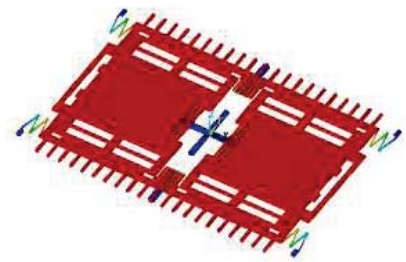
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Gyroscopes

角速度 (Ω : degree/sec)

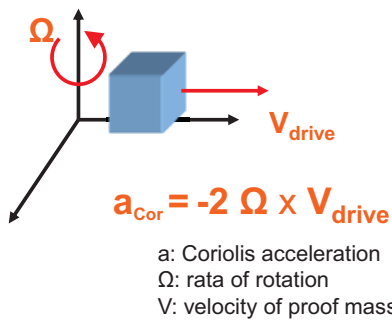
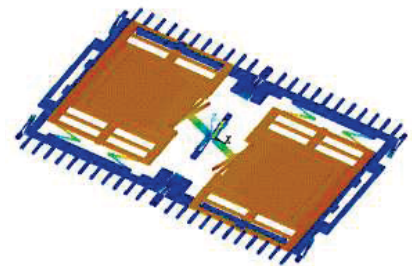
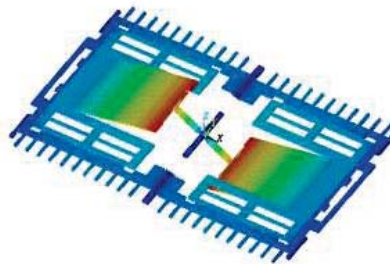


Drive mode



Roll mode

Yaw mode



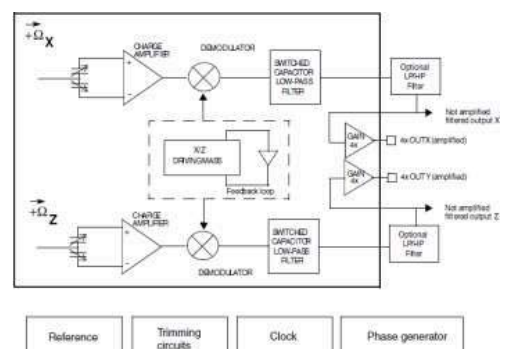
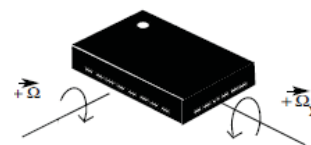
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陀螺儀 (Gyroscopes) – 元件特性



(LPR430AL: dual-axis pitch and roll ± 300 dps analog gyroscope)

- 2.7 V to 3.6 V single-supply operation
- Wide operating temperature range (-40 ° C to +85 ° C)
- High stability over temperature
- Analog absolute angular-rate outputs
- Two separate outputs for each axis (1x and 4x amplified)
- Integrated low-pass filters
- Low power consumption
- Embedded power-down
- Embedded self-test
- Sleep mode



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陀螺儀 (Gyroscopes) – 重要規格



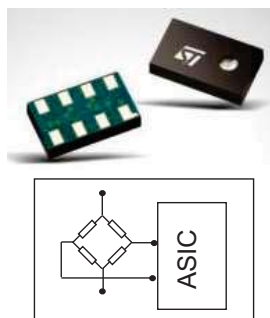
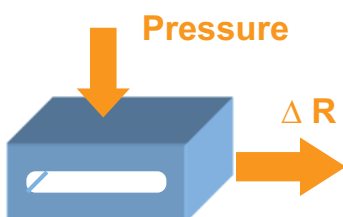
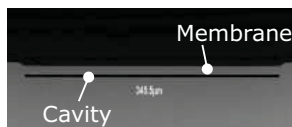
| Parameter | Typ. | Unit |
|--|-------------------------------|-------------------------|
| Measurement range (量測範圍) | ± 1200 (not amplified) | dps |
| Sensitivity (靈敏度) | 0.83 | mV/dps |
| Sensitivity change vs. temperature (靈敏度 vs. 溫度) | 0.07 | %/ $^{\circ}$ C |
| Zero-rate level (初始點電壓) | 1.5 | V |
| Zero-rate level change vs. temperature (初始點 vs. 溫度) | 0.05 | dps/ $^{\circ}$ C |
| Non linearity (線性度) | ± 1 | % FS |
| Bandwidth (頻寬) | 140 | Hz |
| Rate noise density (雜訊) | 0.018 | dps/ $\sqrt{\text{Hz}}$ |

* $V_{dd} = 3 \text{ V}$, $T = 25^{\circ} \text{ C}$ unless otherwise noted

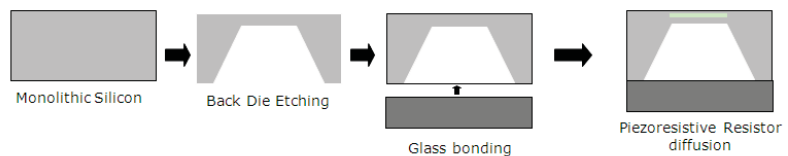
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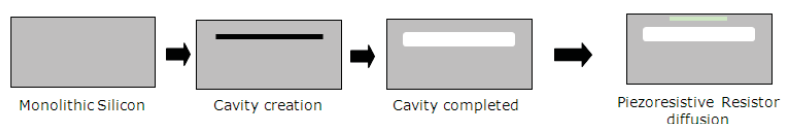
Pressure Sensor (mbar)



Typical Competitor technology



ST Pressure Sensor technology



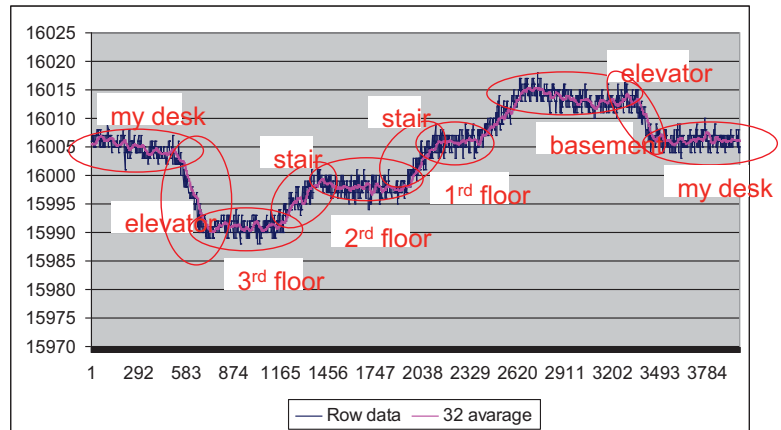
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- The relationship between the units is:
1 atm = 14.7 psi = 76 cm.Hg = 29.92 in.Hg = 1.01325 bar = 1013.25 mbar
- The atmospheric pressure vs. altitude can be expressed as Equation

$$P = P_0 \left(1 - \frac{\text{Altitude}}{44330} \right)^{5.255}$$

where:

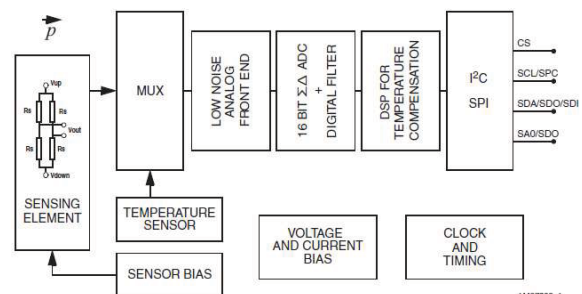
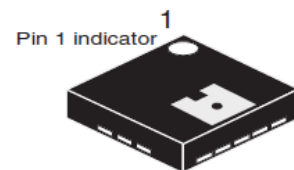
P = the air pressure at the altitude in the unit of mbar
 P_0 = the standard atmosphere, 1013.25 mbar
 Altitude = the height above sea level in meters



壓力計(Pressure Sensor) – 元件特性

(LPS001DL: 300 - 1100 mbar absolute digital output barometer)

- Piezoresistive pressure sensor
- Very low power consumption
- 300 -1100 mbar absolute pressure range
- 0.1 mbar resolution
- Embedded offset and span temperature compensation
- Embedded 16-bit ADC
- SPI and I2C interfaces
- Supply voltage: 2.2 V to 3.6 V
- 1.8 V compatible IOs
- High shock survivability (10000 g)



AM07299v1

壓力計(Pressure Sensor) – 重要規格

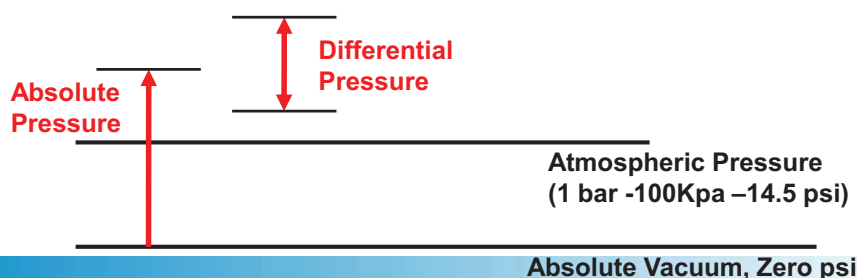


| Parameter | Typ. | Unit |
|---|--|----------|
| Operating pressure range (壓力範圍) | 300 -1100 | mbar |
| Resolution in normal Mode (解析度) | 0.1 (P=1013 mbar; T=25° C) | mbar |
| Accuracy (準確度) | ± 20 (P=300 to 1100 mbar; T=25° C) | mbar |
| Accuracy over temperature range (準確度vs.溫度) | ± 1.5 (P=1013 mbar; T=25° C to 60° C) | mbar |
| Pressure sensitivity (壓力靈敏度) | 16 | LSb/mbar |

* Vdd = 2.5 V, T = 25 ° C unless otherwise noted



Absolute pressure Sensor
– One inlet hole



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Absolute Vacuum, Zero psi

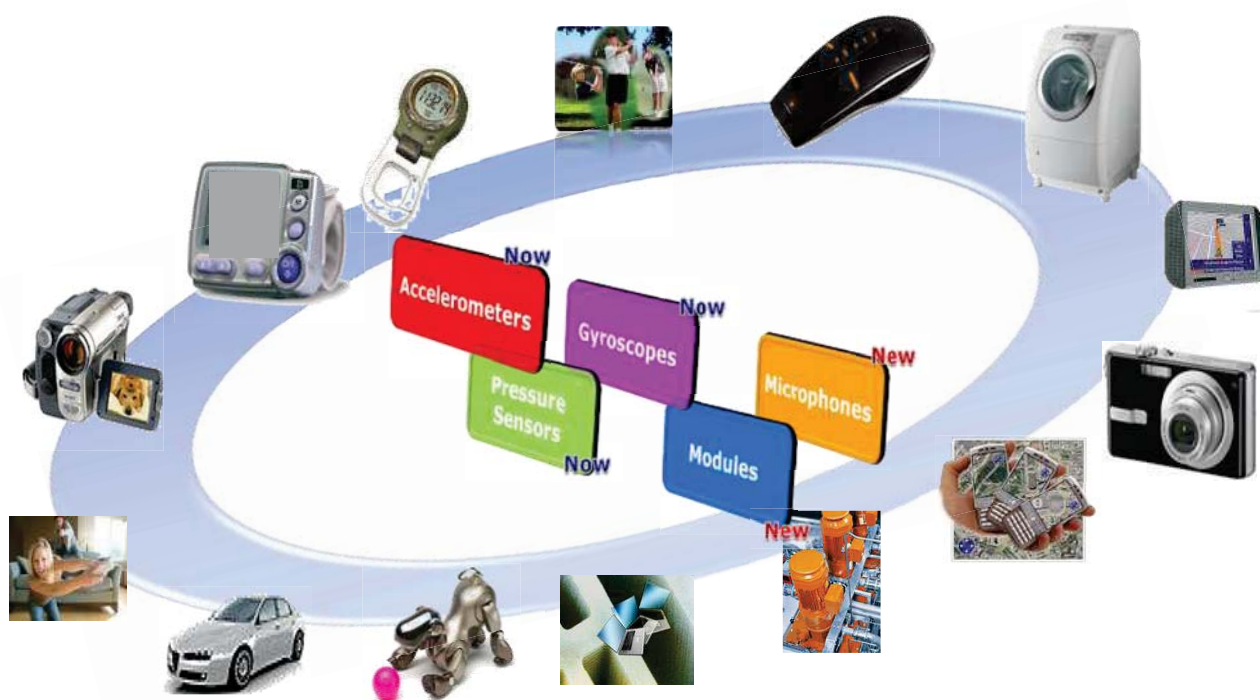
摘要



- 微機電技術與現有產品
- 微機電運動感測器原理
- 未來可能之創新應用
- iNEMO™ 慣性量測模組

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微機電運動感測器可能的應用



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微機電運動感測器可能的創新應用(1)







| APPLICATION | | CURRENT MEMS | NEW MEMS | FUNCTION |
|------------------------------|--|----------------------------------|------------------------------|---|
| 遊戲機 體感遙控器 | | A加速度計 G陀螺儀 M磁感應器 (電子羅盤) | M磁感應器 (電子羅盤) P壓力計(高度計) | A + G 提供高精度的三度空間運動追蹤與動作判別控制 加強了搖桿與選單介面與網路電視上瀏覽網頁的功能. M 提供了固定參考位置與絕對方位標示的可行性 可以免除舊有光學參考座標的需求. P 則提供了絕對高度的參考以強化三度空間的精確性 |
| 智慧型手機 平板電腦 個人可攜式 產品 | | A加速度計 G陀螺儀 M磁感應器 (電子羅盤) | P壓力計(高度計) | 除了提供簡單的遊戲控制與螢幕自動旋轉的 A, G + M 開啓了精確的三度空間定位 以提供高級遊戲運用在地諮詢服務 虛擬實境 慣性導航運動感知人機介面控制 及相機光學防手振功能 此外 P 則提供了室內樓層與高度的標示 |
| 數位像機 錄影機 | | G陀螺儀 | A加速度計 M磁感應器 (電子羅盤) | G 提供了手震的資訊 以供光學元件作為影像穩定系統 (OIS), 而 A 則提供了精確的地平線資訊 及自動影像翻轉, M 則提供了絕對方位東南西北的方向以供進一步的影像處理 |

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* Magnetometer needs Accelerometer for inclination compensation. A+M is called e-compass in ST

微機電運動感測器可能的創新應用(2)



| APPLICATION | CURRENT MEMS | NEW MEMS | FUNCTION |
|--|--------------------|------------------------------------|---|
| 筆記性電腦  | A加速度計 | M磁感應器 (電子羅盤) | A 能偵測撞擊與自由落摔狀況 暫時地停止硬碟讀寫磁頭的運作以保護碟片防止刮傷. M 則可以提供水平方向的螢幕相對位置以提供畫面自動旋轉 |
| 健康管理 與 戶外運動產品  | A加速度計 P壓力計(高度計) | G陀螺儀 M磁感應器 (電子羅盤) | A 可作為計步器功能 P 提供了絕對高度資訊 G + M 則提供了三度空間中的運動與姿態判別 紀錄高爾夫球揮杆 球拍與手軸 手臂 與腿部的相對運動姿態 |
| 玩具 機器人運用  | G陀螺儀 | A加速度計 M磁感應器 (電子羅盤) P壓力計(高度計) | G 提供伺服馬達轉速資訊 以提供校正補償 作為提升穩定性與精確度的依據. A + M + P 則提供了三度空間的位置資訊 |
| 家電產品  | A加速度計 | | A 提供洗碗機 冰箱 洗衣機的震動資訊以調整馬達轉速與水量控制 |

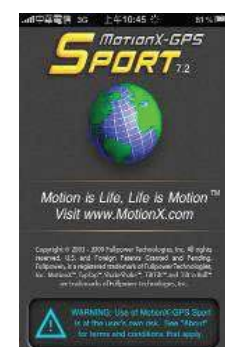
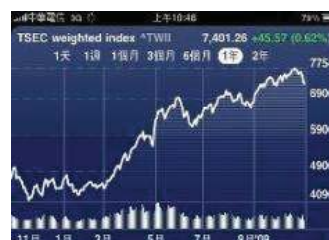
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* Magnetometer needs Accelerometer for inclination compensation. A+M is called e-compass in ST

智慧手機可能的創新應用



各種感測器已內建在智慧手機中
開放式軟體開發平台加速各種應用的發展



Pictures are used as example of application

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Star Walk

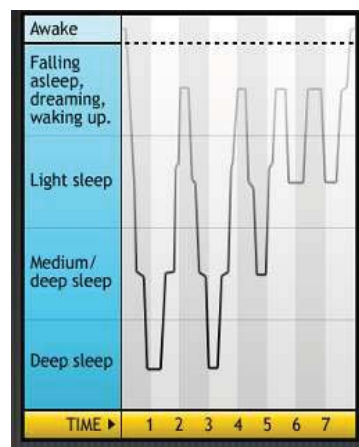


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Sleep Cycle



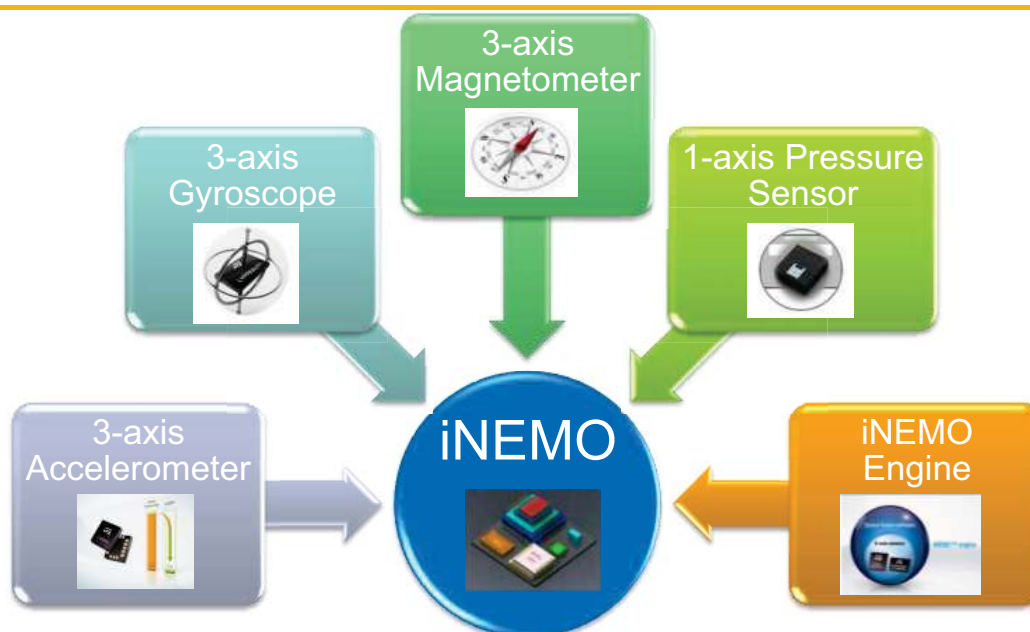
Depending on your bed and mattress you might find better placements. Do not place your phone under a pillow or mattress as it can become warm when charging.



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- 微機電技術與現有產品
- 微機電運動感測器原理
- 未來可能之創新應用
- **iNEMO™ 慣性量測模組**

iNEMO™ 模組可提供ST所有的感測器功能



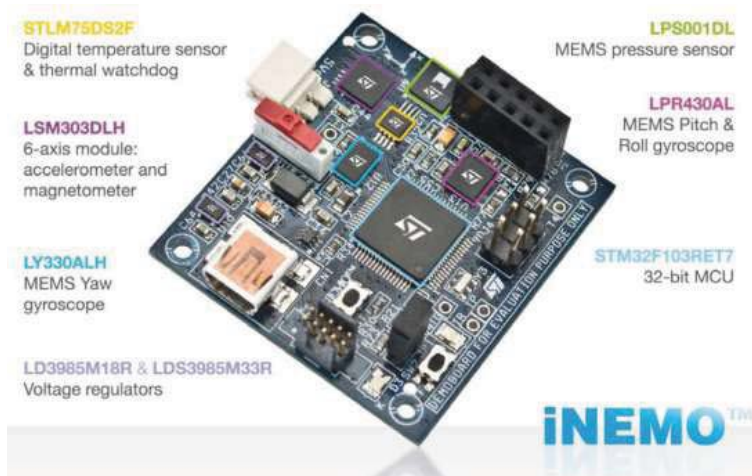
10 Degrees of Freedom

10 Degrees of Freedom



Smart sensor: combination of sensors, data processing and information transmission

- GUI for sensor output display
- Firmware library
- Advanced sensor fusion algorithm



THANK YOU!

For more information, please contact

chiung.lee@st.com or visit

www.st.com

iNEMO V2.2 軟硬體介紹

ST G.C MEMS Support Team

陳建成

意法半導體 應用工程師

morris.st@st.com

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大綱

- 課程目標
- iNEMO Suite 2.2 是什麼?
- 軟體套件安裝過程
- 軟體套件使用方法
- 如何更新韌體
- 如何開發
- 參考文件

- 快速地 概略地了解 iNEMO v2.2
- 快速地 了解iNEMO的硬體架構
- 快速地 了解iNEMO的軟體架構
- 如何安裝及使用軟體套件
- 如何更新韌體
- 介紹API使用以便開發應用軟體

- 課程目標
- **iNEMO V2.2 是什麼?**
- 軟體套件安裝過程
- 軟體套件使用方法
- 如何更新韌體
- 如何開發
- 參考文件

- 第二代的iNEMO模組系列
 - 包含accelerometers, gyroscopes, magnetometers, pressure, temperature這五種感應器
 - 呈現 ST 10-DOF (degrees of freedom) 平台
 - 可應用於多種應用人機介面及機器人。
- 新增加的功能
 - 感應器的暫存器設定
 - 整合韌體更新
 - 新版軟體套件 1.6.4
 - 支援新暫存器的設定
 - 客製化指令

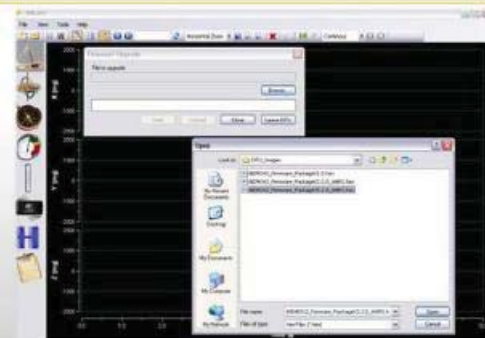
Smart Sensor Setting

- Output (Data, AHRS, Freq.)
- Accelerometer
- Magnetometer
- Gyroscope
- Pressure
- Temperature



Device Firmware Upgrading (DFU)

- Integrated Firmware Upgrading without board disconnection

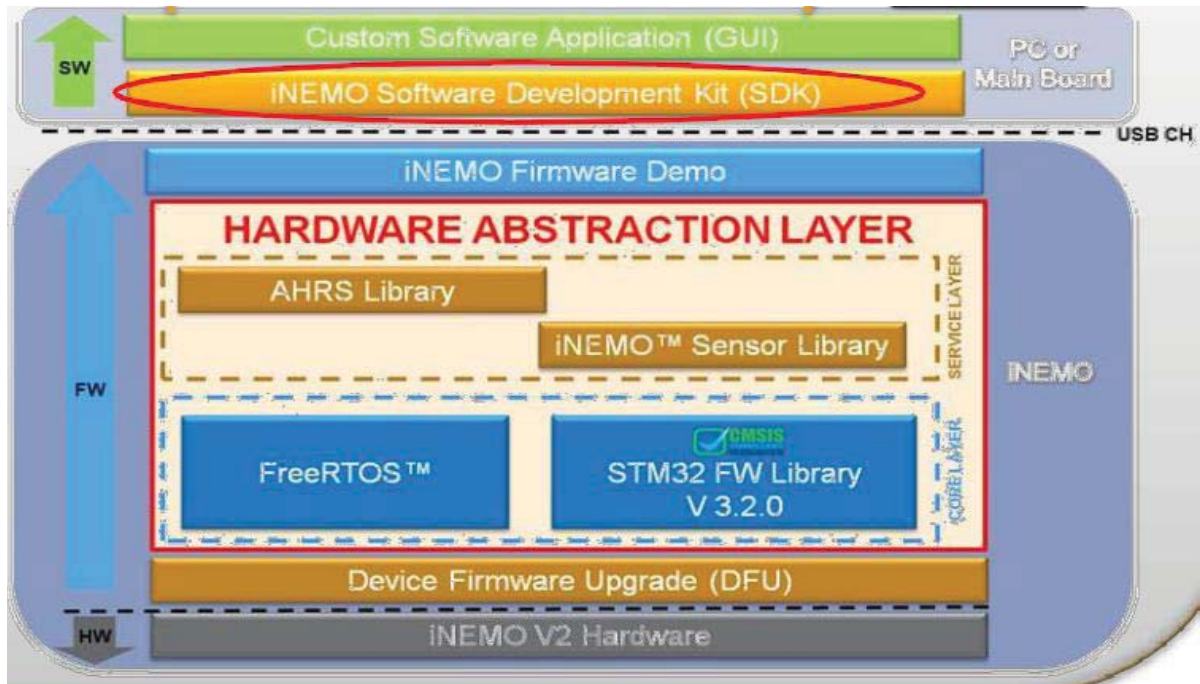


DFU @: C:\Program Files\STMicroelectronics\iNEMO Suite\Firmware\DFU_Images\...

iNEMO V2.2 是什麼 (3/7)



軟體架構



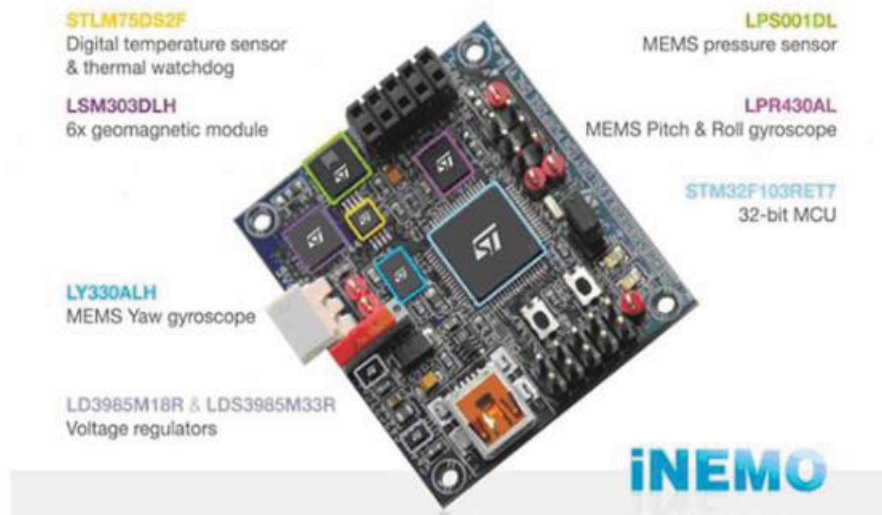
STMicroelectronics

7

iNEMO V2.2 是什麼 (4/7)



硬體架構



STMicroelectronics

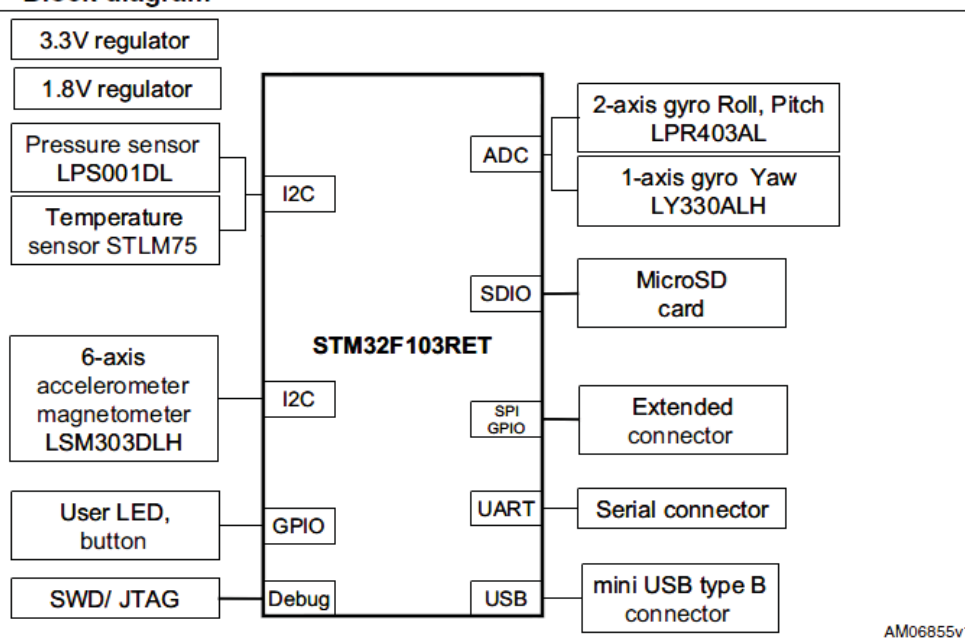
8

■ 硬體元件

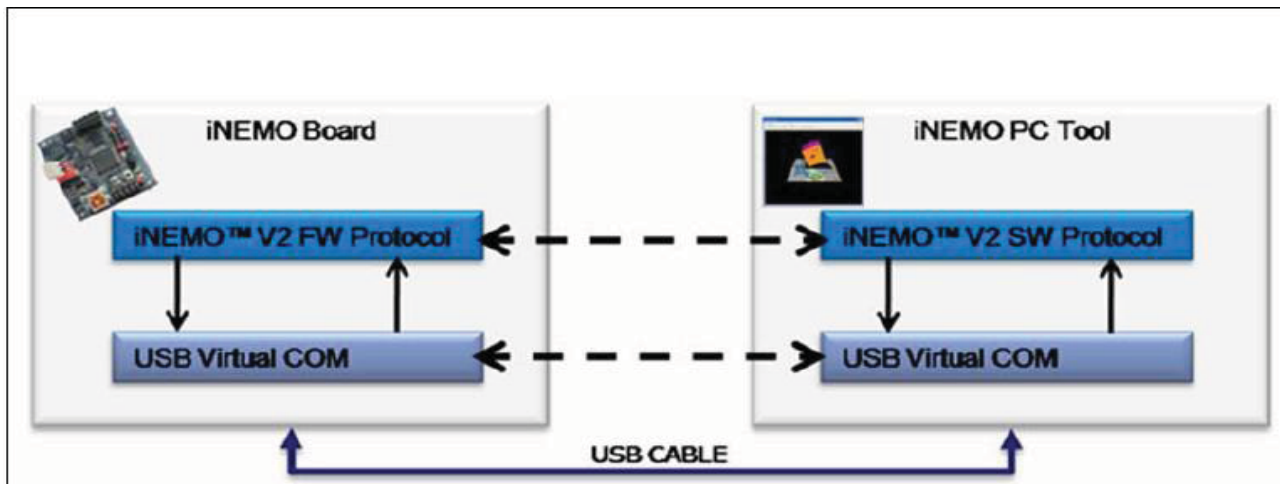
- Two power supply options: external power connector and USB connector
- STM32F103RET: low power high performance 32-bit microcontroller powered by ARM® Cortex™-M3
- LPR430AL: 2-axis gyro (roll, pitch) selectable full-scale 300-1200 dps (degrees per second), analog output, optional HP (high-pass) and LP (low-pass) filters
- LY330ALH: 1-axis gyro (Yaw) 300 dps full-scale, analog output, optional HP (high pass) and LP (low pass) filters
- LSM303DLH: 6-axis geomagnetic module, $\pm 2g/\pm 4g/\pm 8g$ linear acceleration full-scale, magnetic field configurable full-scale ± 1.3 to ± 8.1 gauss, I²C digital output
- LPS001DL: pressure sensor 300-1100 mbar absolute full-scale, I²C digital output, barometer
- STLM75: temperature sensor, -55 °C to +125 °C range, I²C digital interface
- Extended connector for wireless connectivity
- MicroSD card slot
- COM connector with RTS and CTS on TTL signals
- USB 2.0 full speed connection
- Reset button
- User LED and button

■ MCU 控制圖

Figure 2. Block diagram






- 溝通方式



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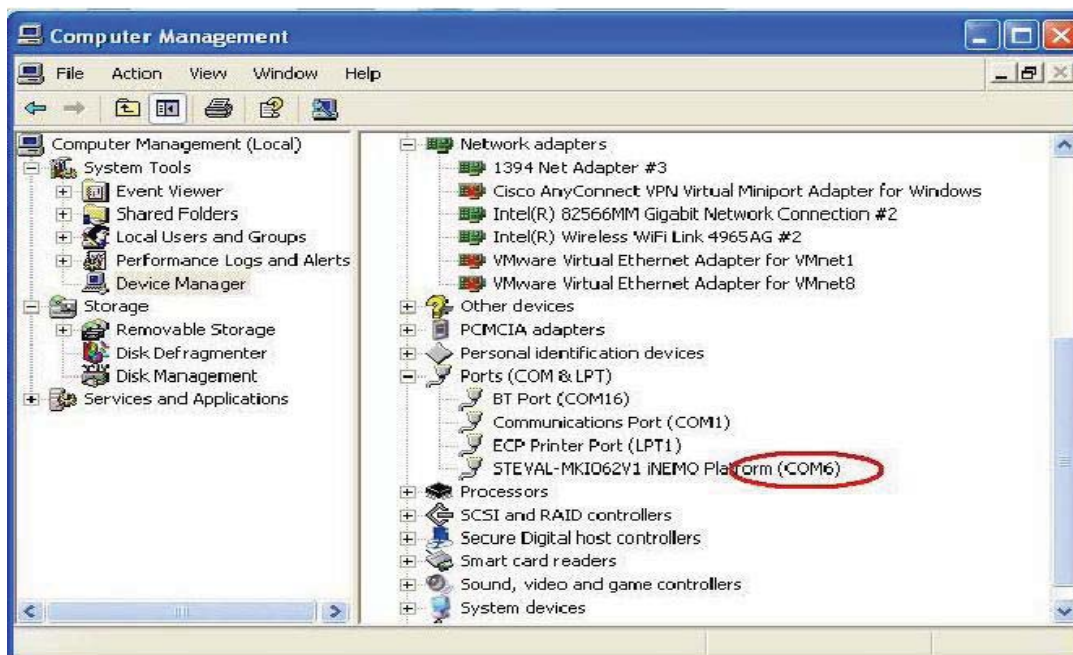
- 課程目標
- iNEMO V2.2 是什麼?
- 軟體套件安裝過程
- 軟體套件使用方法
- 如何更新韌體
- 如何開發
- 參考文件

- 系統需求
 - Microsoft Windows XP® Service Pack 2, or higher
 - Microsoft.NET Framework 2.0 (or higher)
- 步驟1. 下載軟體套件
 - <http://www.st.com/internet/evalboard/product/250367.jsp> -> Design support
 - 軟體套件如下

| SW FUNCTIONS | | |
|--|---------|---------|
| Description | Version | Size |
|  Dfuse | 3.0.1 | 16034KB |
|  SDK setup | 2.2.0 | 3756KB |
|  iNEMO GUI and firmware | 2.2.0 | 30150KB |

- 步驟2. 安裝下載的三個套件
- 步驟3. 連接目標板及開發電腦
- 步驟3-1. 安裝驅動程式 方法一
 - 選擇 install the software automatically
- 步驟3-2. 安裝驅動程式 方法二
 - 選擇 install from a list or specific location
 - 驅動程式所在地
 - C:\Program Files\STMicroelectronics\iNEMO Suite\ driver inemo

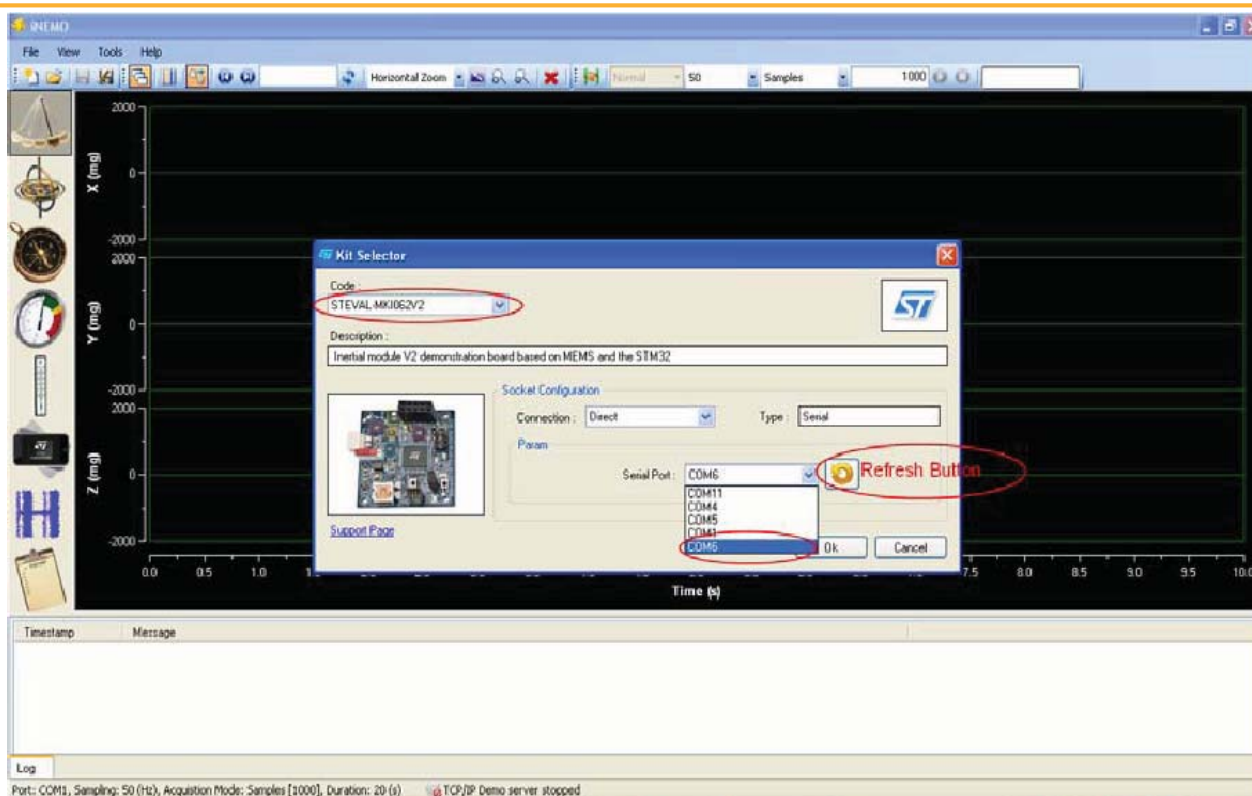
- 步驟4. 安裝成功後，確認裝置管理員，如下圖示



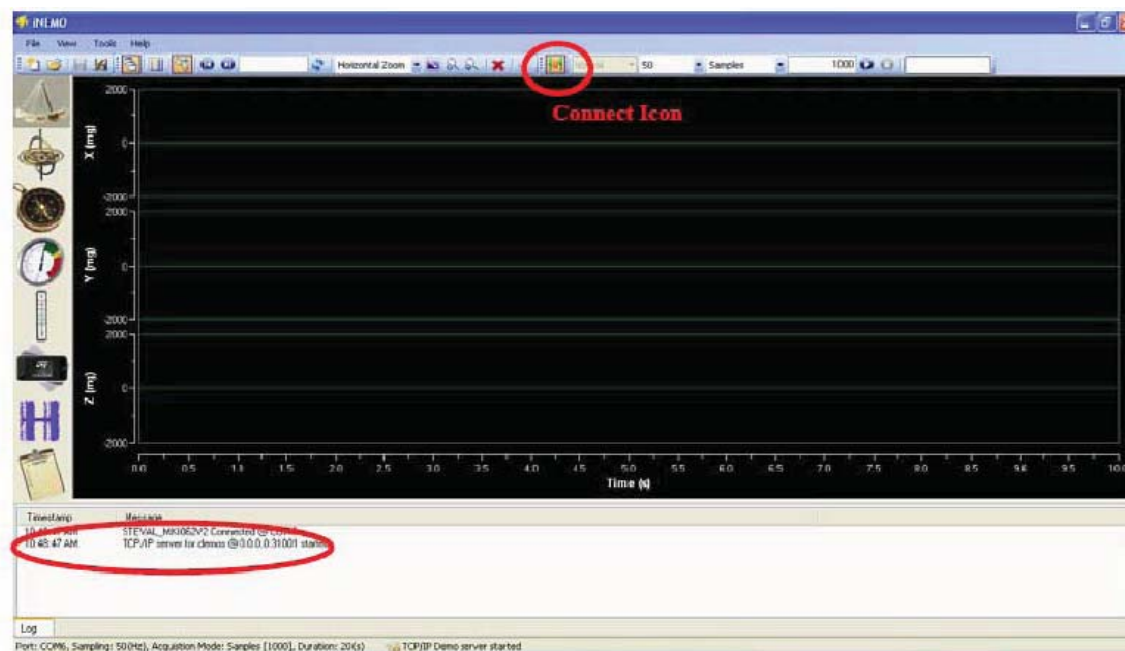
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- 步驟1. 開啟iNEMO Suite application
 - 使用 software development kit (SDK) 及 iNEMO2_SDK.dll (for STEVAL-MKI062V2) 所開發出來的一套軟體



- 步驟2. 連接iNEMO Suite application及實驗板

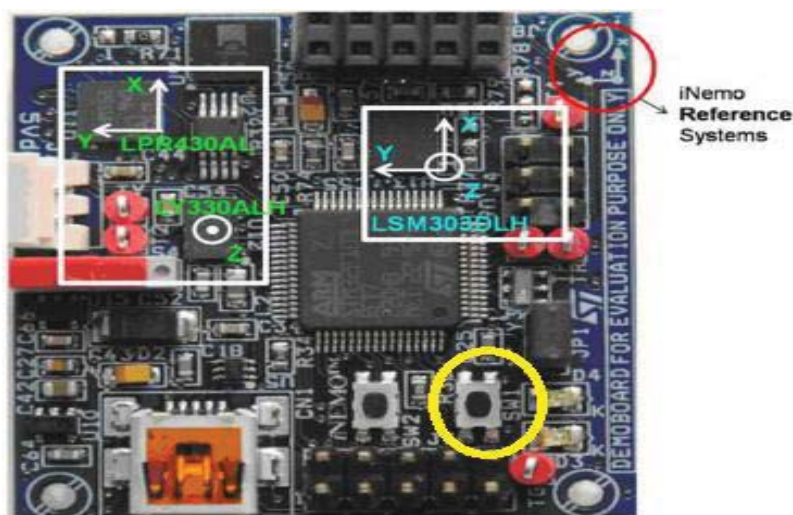


- 步驟4. 開啟3D Cube Demo,
- 採用實機操作方式，快速介紹以上各個功能

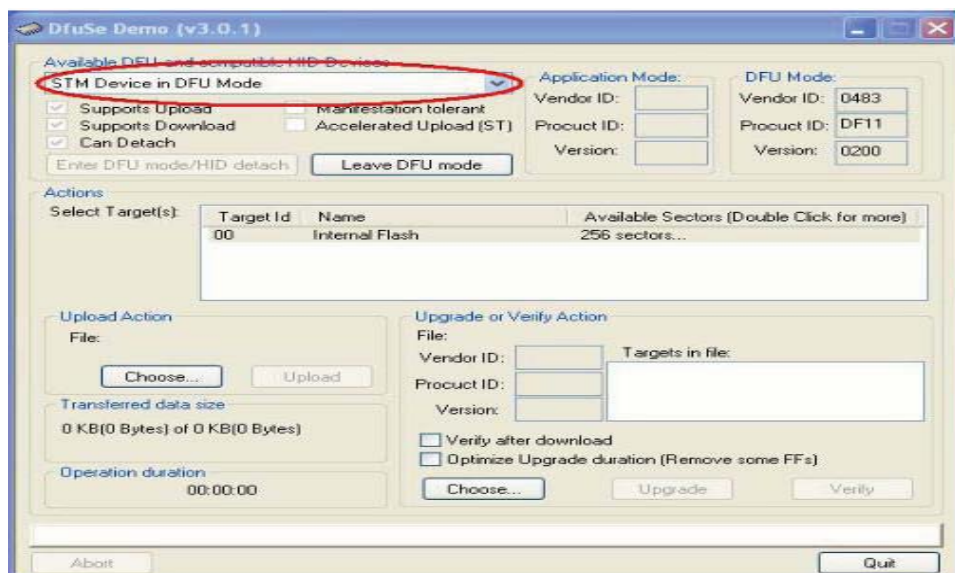
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如何更新韌體 (1/8)

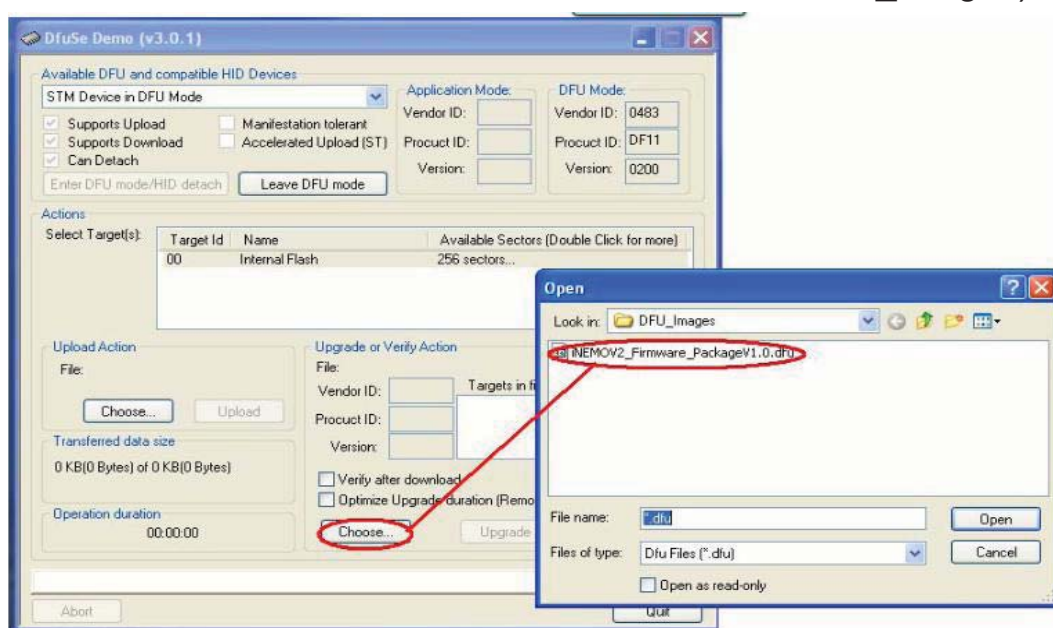
- 步驟1. 連接實驗板及開發電腦, 請先按住下方黃色按鍵



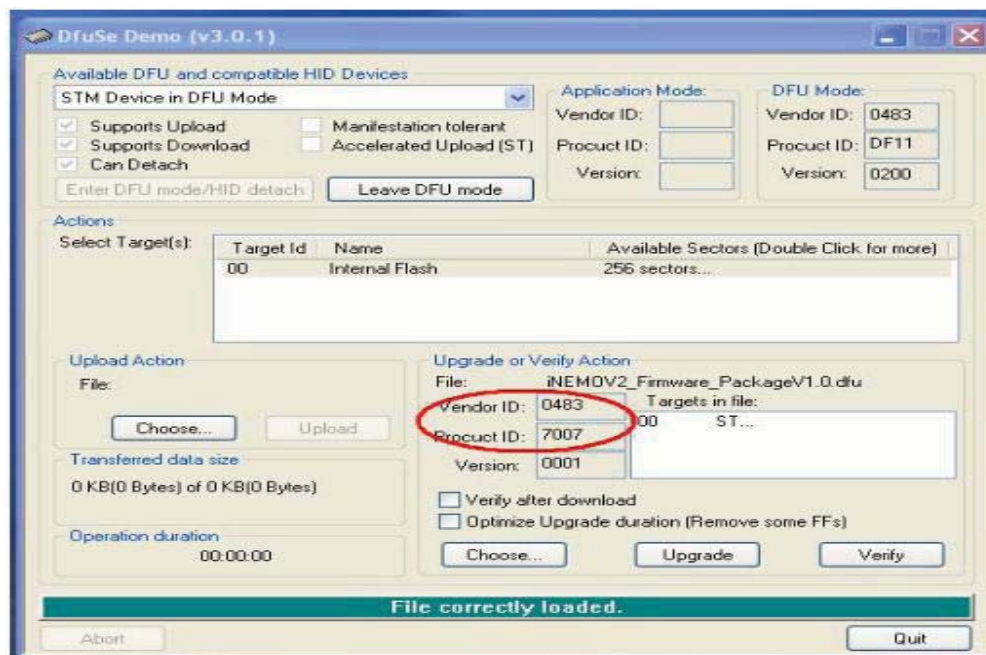
- 步驟2. 開啓DfuSe GUI :
 - 開始 -> 程式集 -> STMicroelectronics -> DfuSe -> DfuSe Demonstration”.



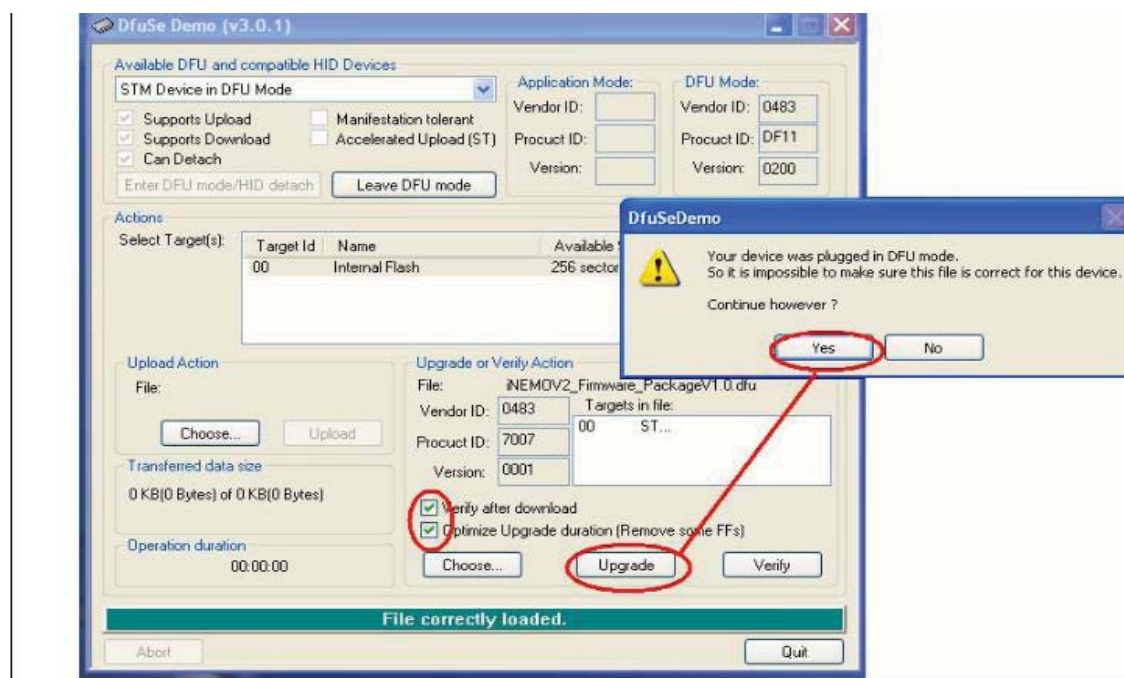
- 步驟3. 選取韌體檔案(C:\Program Files\STMicroelectronics\iNEMO Suite\Firmware\DFU_Images)



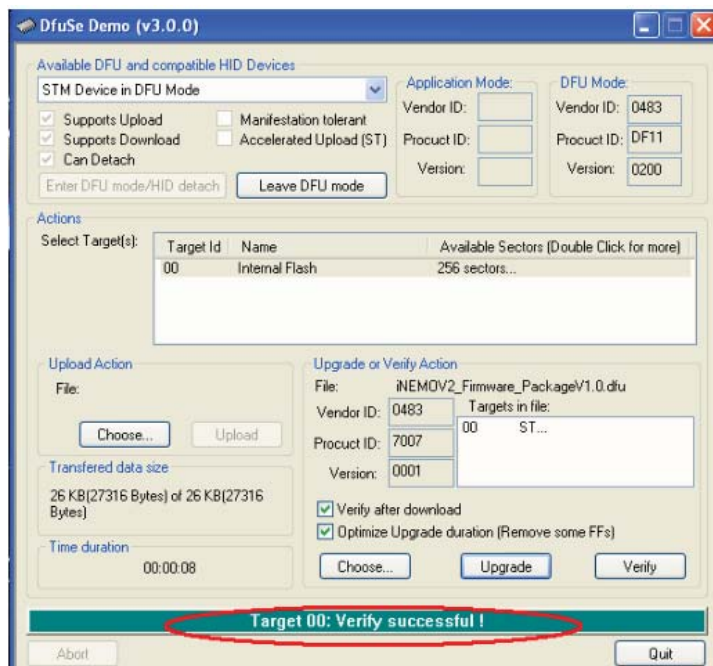
- 步驟4. 確認Vendor ID = 0483, Product ID = 7007



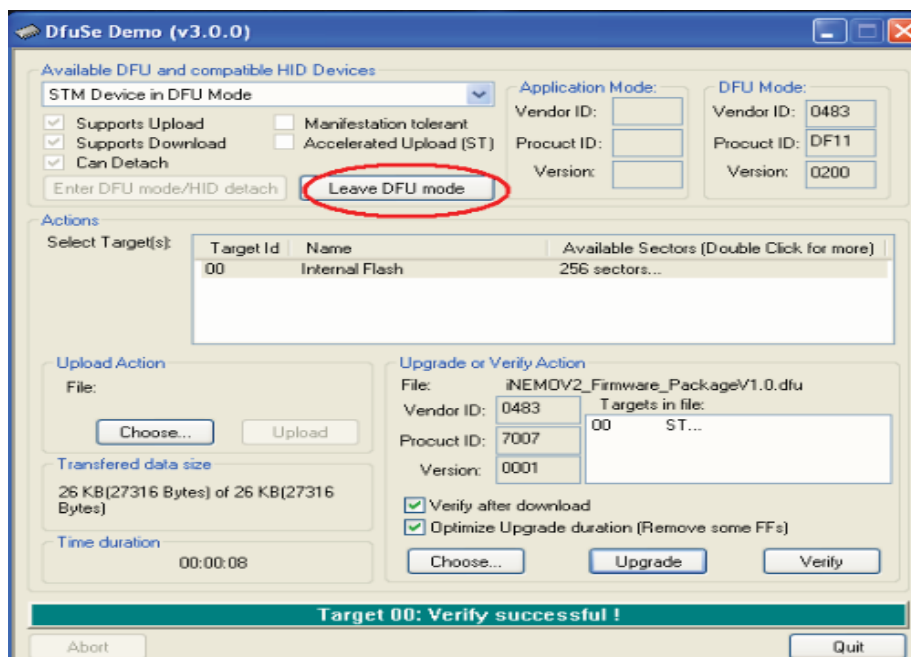
- 步驟5. 執行更新



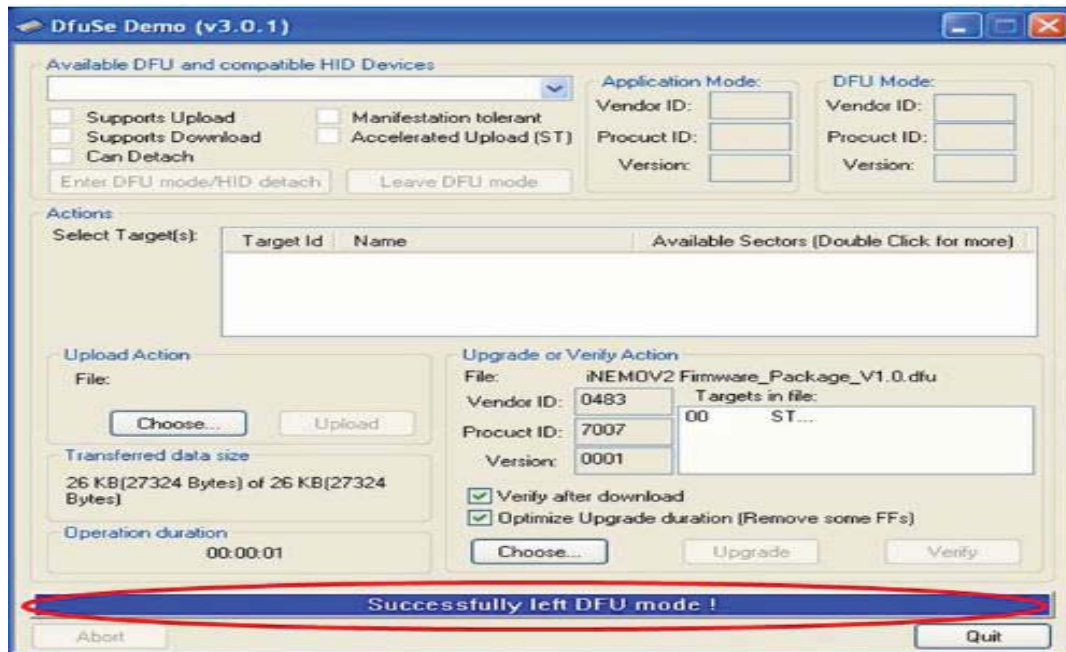
■ 步驟6. 確認是否更新完成



■ 步驟7. 離開DFU模式



- 步驟8. 確認成功離開DFU模式



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- 使用iNEMO SDK來開發客製化的軟體去使用實驗板
- 使用visual studio來搭配iNEMO SDK
- 主要的檔案
 - iNEMO2_SDK.h, INEMO2_SDK.lib, iNEMO2_SDK.dll
- 透過iNEMO2_SDK.h來使用目前有提供的API及資料結構
- For example
 - C:\Program Files\Stmicroelectronics\iNEMO v2 SDK\iNEMO2_SDK Client
 - iNEMO_SDK Client.cpp

- 從這個例子可以得知如何使用API及資料結構
 - 如何連接實驗板
 - 如何確認成功
 - 如何控制LED
 - 如何取得硬體版本
 - 如何取得感應器資料等等
- 更多的使用文件
 - C:\Program Files\STMicroelectronics\iNEMO Suite\iNEMO.chm
 - C:\Program Files\STMicroelectronics\iNEMO Suite\redistrib\iNEMO_SDK.chm

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- <http://www.st.com/internet/evalboard/product/250367.jsp>
- <http://www.st-inemo.com.tw/index.php?name=download>