Static and dynamic inclinometers for Industrial IoT applications

Inclinometer Working Principle

Static Inclinometer: IIS2ICLX

Dynamic Inclinometer: ISM330DHCX

Machine Learning Core

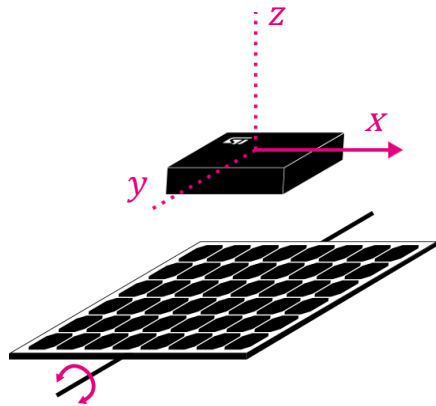life.augmented

Tilt measurement with an accelerometer

- Tilt measurement with an accelerometer is based on **projection of the Gravity vector** on its sensing axes

- An accelerometer does **not** measure **only the gravitational acceleration**, but any acceleration caused for example by:
  - Constant acceleration of the device
  - Centripetal acceleration due to a rotation of the device
  - Vibrations, for example due to a running machine or engine nearby

- Such accelerations **cannot be easily differentiated** from gravitational acceleration and can introduce measurement errors

- Therefore, accurate results require **static or quasi-static conditions**
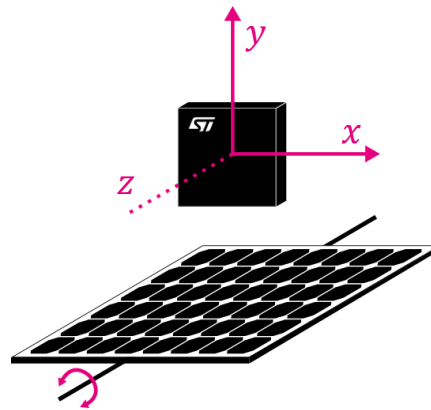
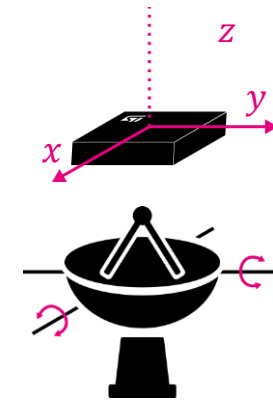**Inclinometer application examples** with possible sensor placements:

1. Tilt sensing of a solar panel that is rotated around a single axis

2. Dual-axis tilt sensing of an antenna

1-axis inclinometer

2-axis inclinometer
vertical placement

2-axis inclinometer
horizontal placement

Static inclinometers in industrial applications

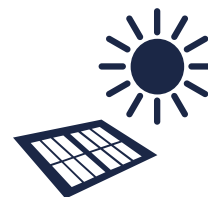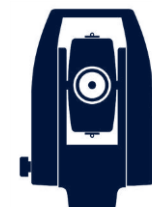| Antenna Leveling	Robotics and IIoT	Inclinometers for industrial vehicles	Equipment Installation & monitoring	Leveling Instruments	Structural Health Monitoring
Antenna pointing, platform leveling and stabilization	Robotics and Industrial automation	High accuracy inclinometers for industrial vehicles, forklift, construction machines	Installation and monitoring of equipment, tracker for solar panels	Precise leveling instruments	Building and infrastructure condition monitoring (inclination and low frequency vibration)

High-accuracy, high-resolution, low-power, 2-axis digital inclinometer with embedded Machine Learning Core
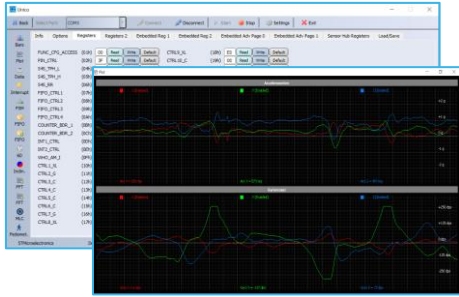
- **2-axis**, digital inclinometer, low power
- Top notch performance: **resolution**, **accuracy**, **stability** over temperature and time
  - Accuracy better than 0.5° over full temp. range and over time
- **Programmable Bandwidth** (-3dB) up to 260Hz
- **Ultra-low noise** (15 μg/√Hz)
- **Offset** change vs Temp <0.075 mg/°C
- Programmable **Machine Learning Core** & **Finite State Machine** to integrate AI algorithms and reduce power consumption at system level

- Extended operating temperature range: from **-40 to +105 °C**
- No Calibration required – ST is testing and calibrating at Final Test
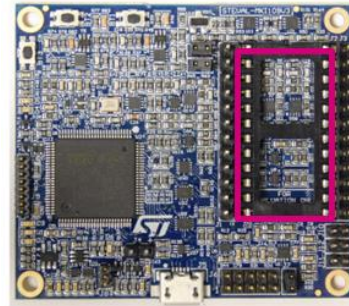- **ST Advantage: Accuracy, Resolution, High Stability & Repeatability**
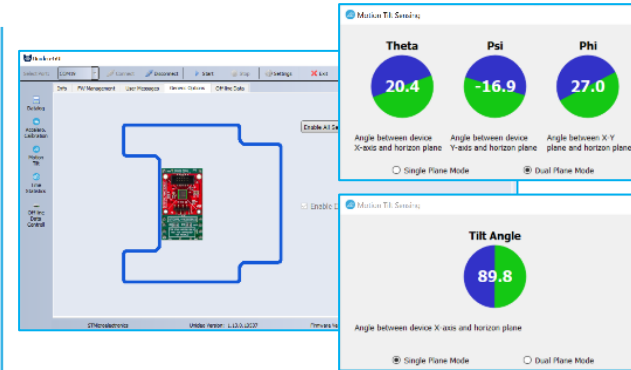
Ceramic Cavity
LGA 5x5x1.7 16L

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Development tools for the IIS2ICLX

PC Application
Unico-GUI

Professional MEMS motherboard
STEVAL-MKI109V3

DIL24 adapter board
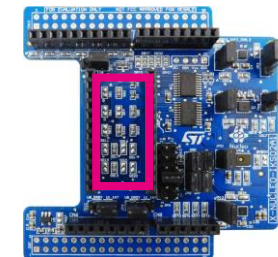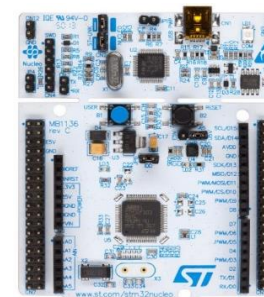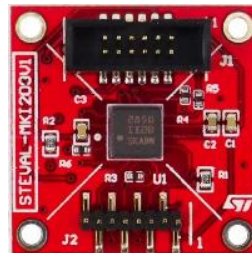STEVAL-MKI209V1K (IIS2ICLX)

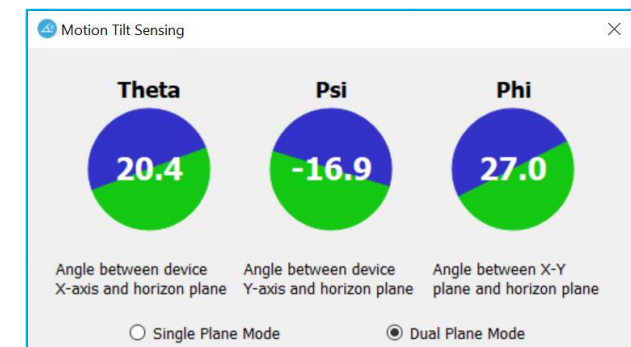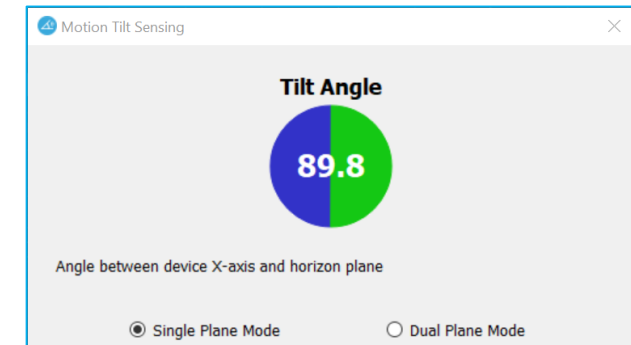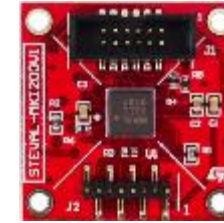**PC Application and Software package**
Unicleo-GUI
X-CUBE-MEMS1

DIL24 adapter board
STEVAL-MKI209V1K (IIS2ICLX)

STM32 NUCLEO & Industrial Sensor expansion board
e.g., NUCLE-F401RE
X-NUCLEO-IKS02A1

UNICO

STM32 Nucleo

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Tilt Measurement Library for IIS2ICLX MotionTL2

- **MotionTL2** is a dedicated library for 2-axis accelerometers that provides real-time information about tilt angles of the user device in single or dual plane mode

- The MotionTL2 sensor fusion library features:
    - Calculation of angles according to the desired mode
    - Configuration of knobs to mitigate vibration noise

- The MotionTL2 library is part of the **X-CUBE-MEMS1** software package
    - Sample implementation is available for the STEVAL-MKI209V1K (DIL24 adapter board with the IIS2ICLX)
    - The implementation utilizes also MotionAC2 for calibration

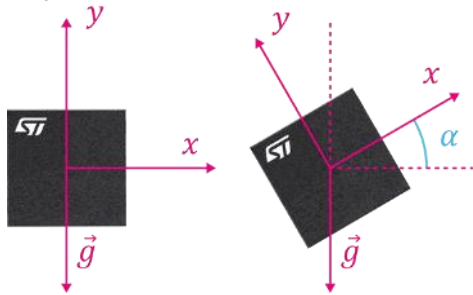- Available for ARM Cortex-M0+, M3, M4 and M7 architectures

- User Manual: UM2775

Tilt Angle

89.8

Angle between device X-axis and horizon plane

◉ Single Plane Mode   ○ Dual Plane Mode

Theta   **Psi**   **Phi**

20.4   -16.9   27.0

Angle between device X-axis and horizon plane   Angle between device Y-axis and horizon plane   Angle between X-Y plane and horizon plane

○ Single Plane Mode   ◉ Dual Plane Mode
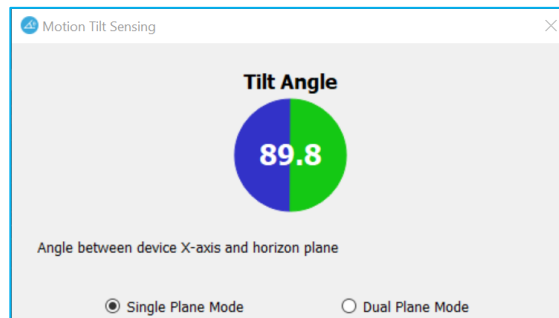
Single plane mode

- Single plane mode provides the angle of X axis with respect the horizontal plane

- The reference position is when the **X axis is in horizontal plane and Y axis is pointing up** (towards the sky)
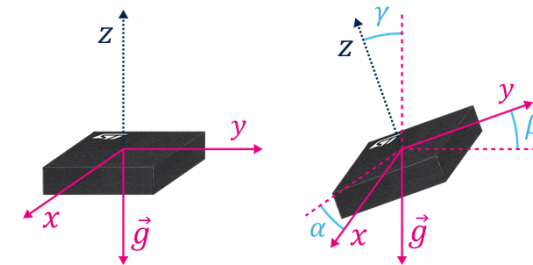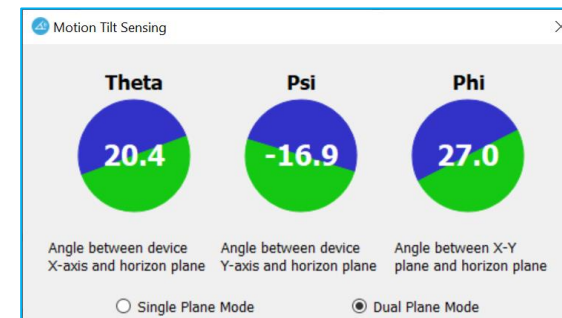

Range: [-180°, +180°]

Dual plane mode

- This mode provides angles between the horizontal plane, X-axis (α) and Y-axis (β), and angle between vertical axis and gravity vector (γ)

- The reference position is when the **X and Y axis are in the horizontal plane**

Range: [-90°, +90°]

Dynamic inclinometers in industrial applications

Industrial Vehicles	Robotics	Autonomous Vehicles	Equipment Installation & monitoring
Inclinometers for industrial vehicles. Mining, cranes	Robotics	Inclinometers for autonomous vehicles	Antenna pointing and stabilization, platform leveling and stabilization

Best-in-class accuracy 6-axis IMU with Machine Learning Core

High Accuracy, Stability and linearity over temperature and time

- Gyro Offset vs T ±0.005 dps/°C (typ)
- Gyro Bias Instability 3°/hr (typ)
- Rate Noise Density 5 mdps/√Hz (typ)
- Axel Noise Density 60 µg/√Hz (typ) – ODR up to 6.6kHz

Programmability & digital features

- Programmable Machine Learning Core & Finite State Machines to integrate AI algorithms
- 9 kB Embedded FIFO
- Sensor Hub

Configurability

- Angular rate range: from ±125dps up to ±4000 dps
- Axel Full Scale: from ±2g up to ±16g
- Low power and high performance modes

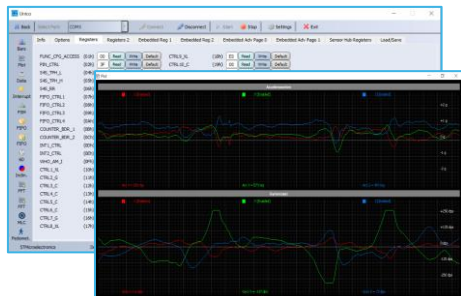### Extended operating temperature range from -40 to +105 °C
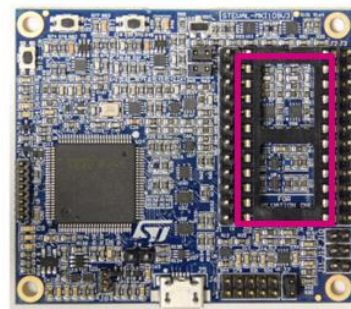
ISM330DHCX

LGA 14L
2.5x3x0.86 mm

Development tools for the ISM330DHCX

PC Application
Unico-GUI

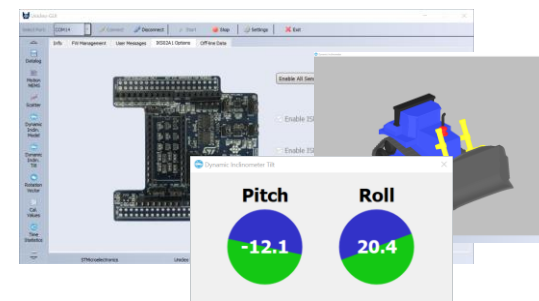**Professional MEMS motherboard**
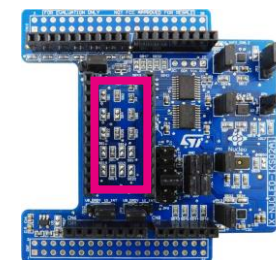STEVAL-MKI109V3

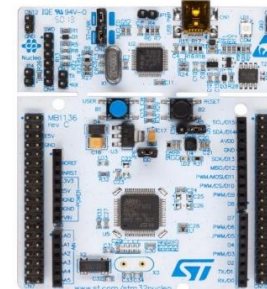**ISM330DHCX's DIL24 adapter boards**

STEVAL-MKI207V1

STEVAL-MKI210V1K

PC Application and Software package
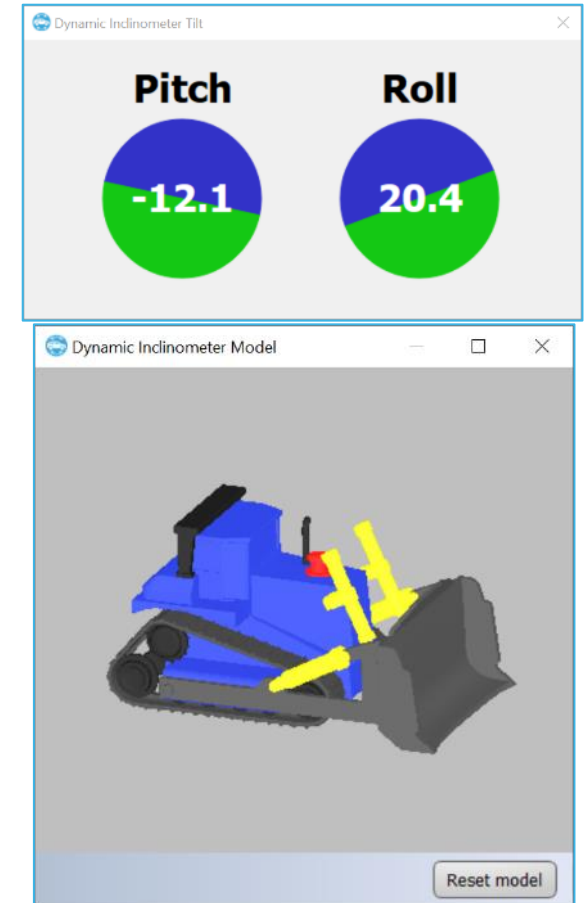Unicleo-GUI
X-CUBE-MEMS1

STM32 NUCLEO & Industrial Sensor expansion board
e.g., NUCLEO-F401RE
X-NUCLEO-IKS02A1

Dynamic Inclinometer Library for ISM330DHCX
MotionDI

- **MotionDI** is a library that provides real-time motion sensor fusion and tilt information - accurate estimation of device orientation even in presence of vibrations and motion using Kalman filtering

- The MotionDI sensor fusion library features:
  - Real-time 6-axis motion-sensor data fusion (accelerometer, gyroscope)
  - Computation of rotation vector, quaternions, gravity and linear acceleration data
  - Accelerometer and Gyroscope calibration

- Available for ARM Cortex-M3, M4 and M7 architectures

- Requires 6-axis IMU (ISM330DHCX)

- The MotionDI library is part of the X-CUBE-MEMS1 software package
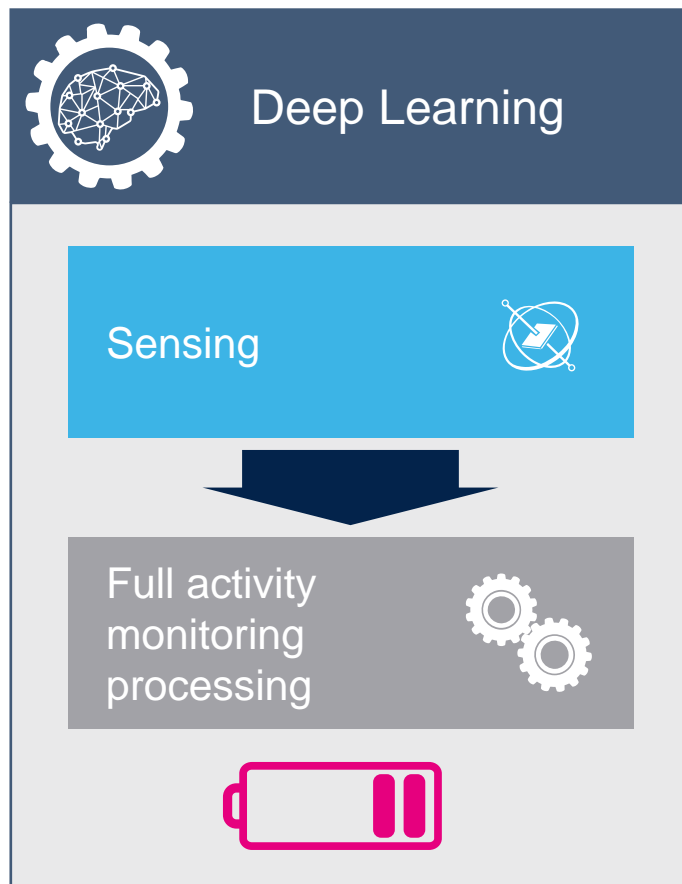 - An example implementation is available for following Nucleo boards:

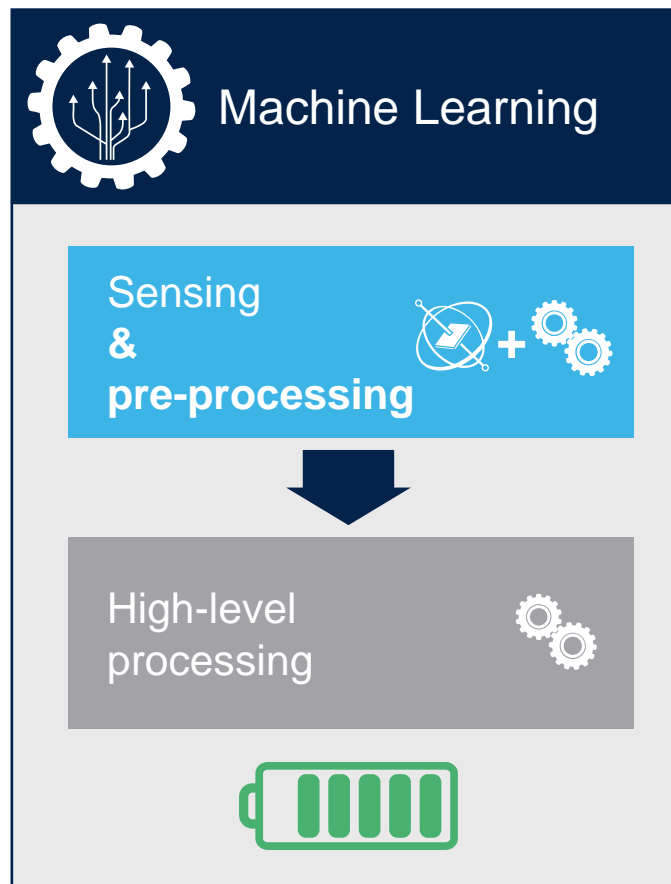| STM32 development board	MEMS & Sensors expansion board
NUCLEO-F401RE	X-NUCLEO-IKS01A2
NUCLEO-L476RG	X-NUCLEO-IKS01A3
NUCLEO-L152RE	X-NUCLEO-IKS02A1

From low power sensor to low power system

Machine Learning Core (MLC) for real edge computing enables high system flexibility

Deep Learning

Sensing

Full activity monitoring processing

Power optimization at system level

Machine Learning

Sensing & pre-processing

High-level processing

FSM up to 16

MLC up to 8

- Higher computation power
- Lower power consumption
- Cost optimized solution

This is the added value!

Machine Learning embedded in ST sensors

Classic machine learning

Unsupervised
- Dimension reduction
- Clustering
- Pattern search

Supervised
- Regression
- **Classification** — **Decision trees**
  - Naïve Bayes
  - SVM
  - k-NN
  - Logistic regression

MLC is an in-sensor engine embedded in the latest products:

- 6x IMUs
- Inclinometer

Tree example

Start node
Node
Node

Typical node

Input → **Node** ← Condition

True path   False path

Explore MLC resources and examples

- Machine Learning Core landing page is the reference product resources and ML introduction to users:

https://www.st.com/MLC

- Decision tree examples are available online at the dedicated **GitHub project for Machine Learning Core**

https://github.com/STMicroelectronics/STMems_Machine_Learning_Core

Our technology starts with You

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