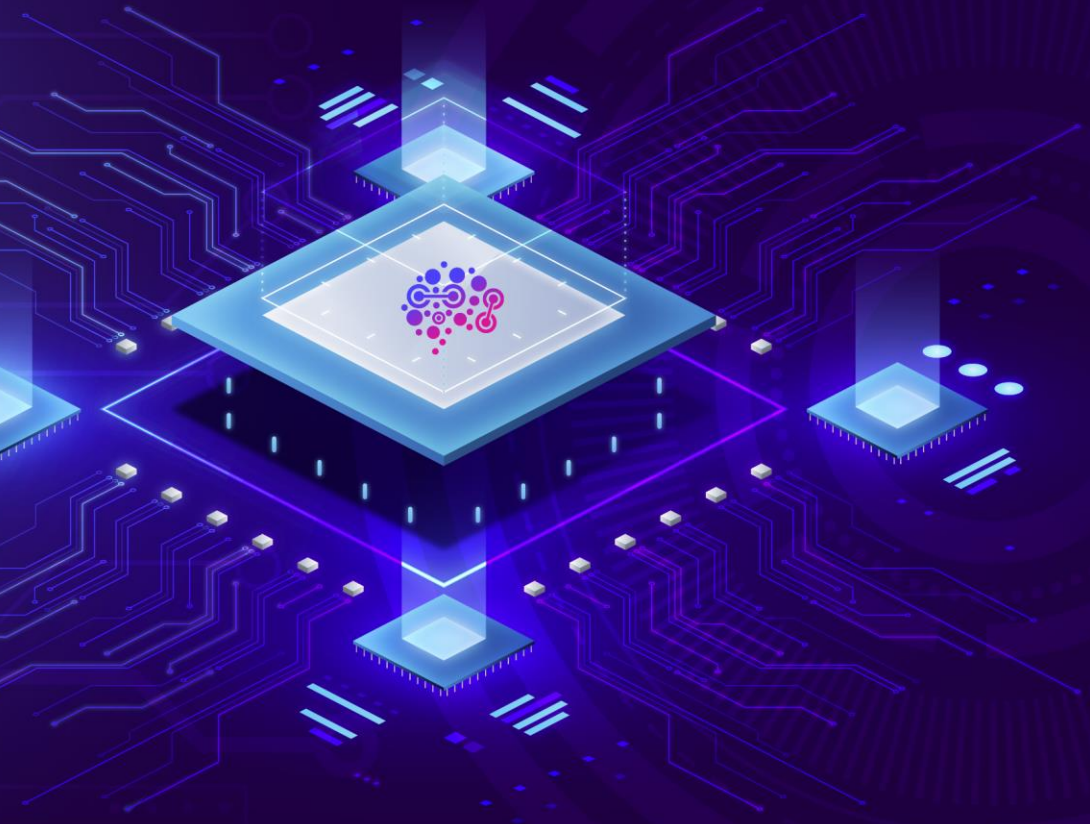
EDGE AI

European Conference on ED
Technologies and Application



Advancing en
technologies a
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17-19 October 2023, Athe

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European Conference on EDGE AI Technologies and Applications - EEAI

Energy Efficient Deep-Edge Computing through Hardware Machine Learning

Marcello Coppola, STMicroelectronics, FR

17-19 October 2023 Athens, Greece

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Chapter 1 Introduction

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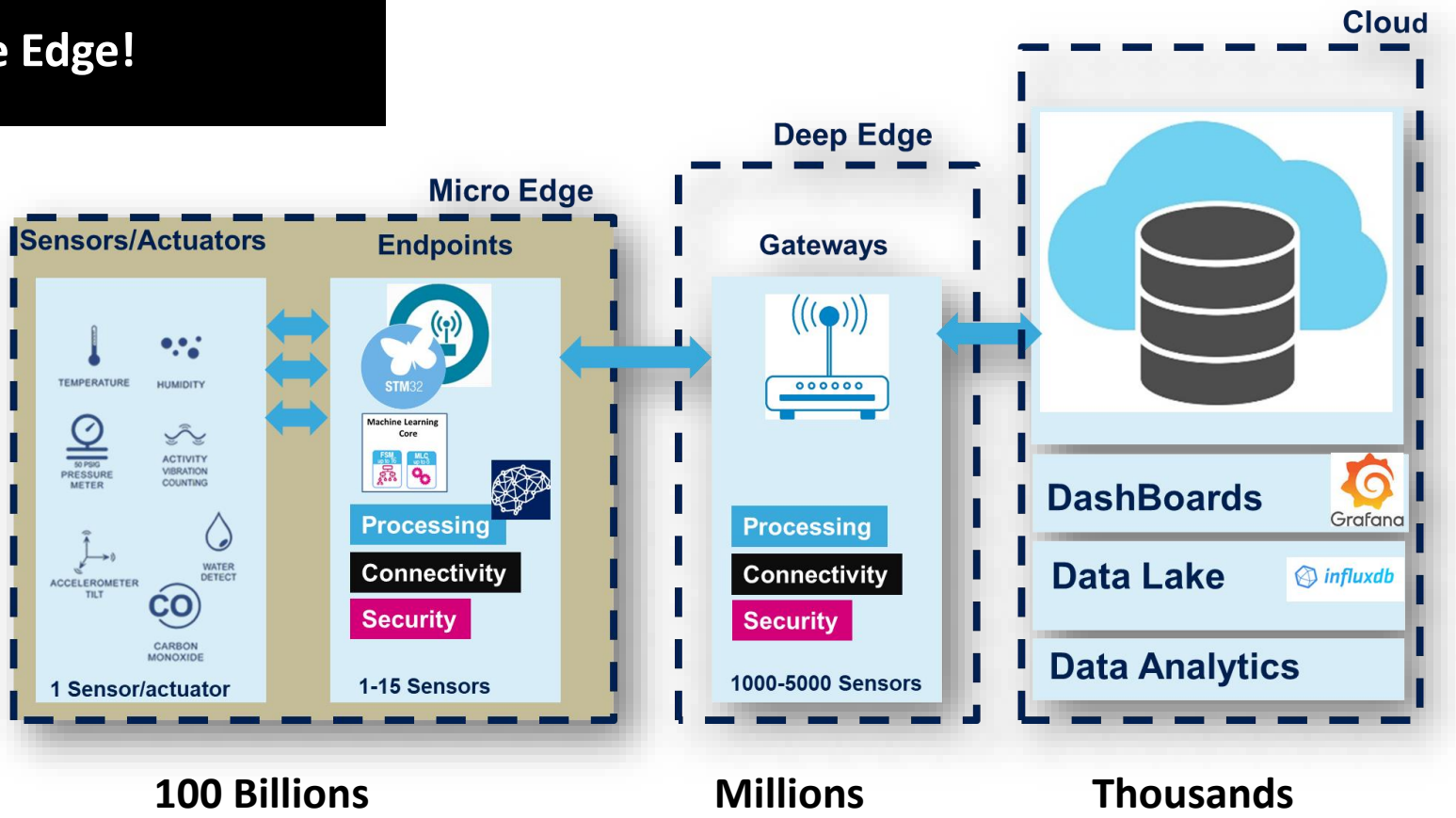
Distributed Artificial Intelligence approach

Leverage billions of devices at the Edge!



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AI is everywhere, however the AI that matters to your products is enabled by a different category of Software and Hardware

Ultra-low latency
Real-time applications

01
10

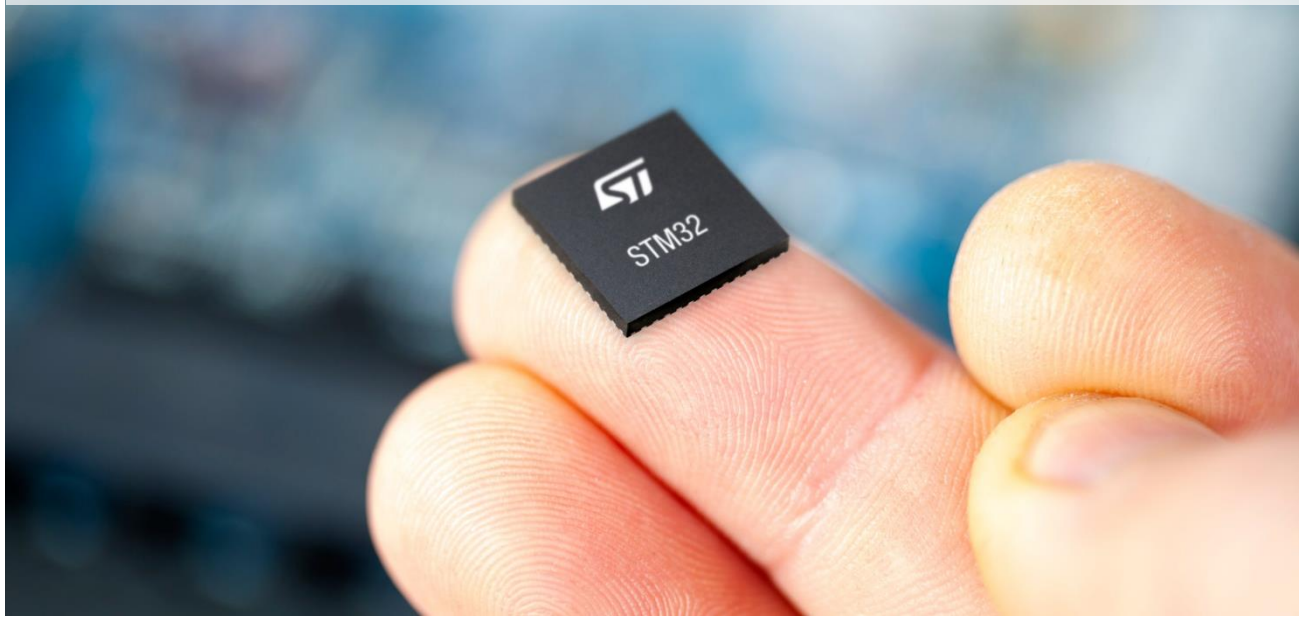
Reduced data transmission
Generate meaningful information

Enhanced privacy and security
No data sharing in the cloud

Sustainable on energy
Low data, Low power

Lower cost of inference to enable a new class of operations

This enables AI for devices



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Chapter 2 Related Works

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Use Cases

Industrial

In the industrial landscape, IoT technology ushers in a new era of efficiency and predictive maintenance. Sensors and big data processing monitor manufacturing processes in real-time, swiftly detecting abnormalities. Distributed sensor networks combined with AI algorithms anticipate issues and trigger timely machine shutdowns, enhancing productivity and reducing downtime.

Healthcare and Well-Being

In the IoT healthcare domain, advanced technologies converge as AI and wearable sensors collect real-time health data, enabling early anomaly detection. Edge computing optimizes sensor efficiency, extending device battery life. This promises personalized, data-driven healthcare at individuals' fingertips.

Animal activity recognition and precision farming

In the realm of animal activity recognition and precision farming, the integration of smart devices with embedded machine learning techniques revolutionizes agriculture. These devices play a pivotal role in crop management, livestock farming, and animal health. However, challenges persist, particularly in managing the limited battery life of ultra-wideband (UWB) nodes, which currently restrict their commercial application.

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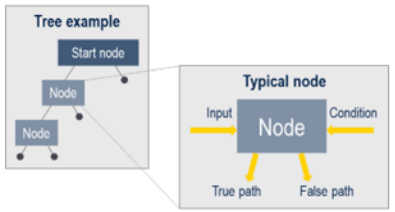
The MicroEdge Architecture
AI at the Edge of the Edge

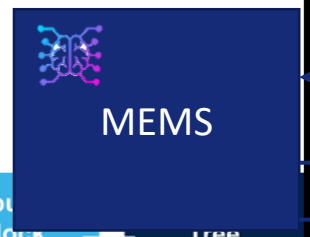
STM32WL
World's first LoRa SoC

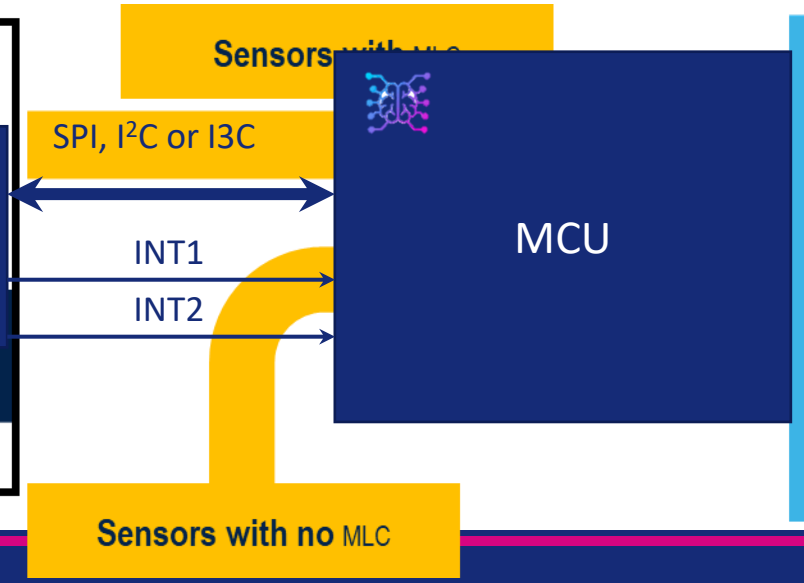
LoRa®
(G)FSK (G)MSK
BPSK$_{TX}$

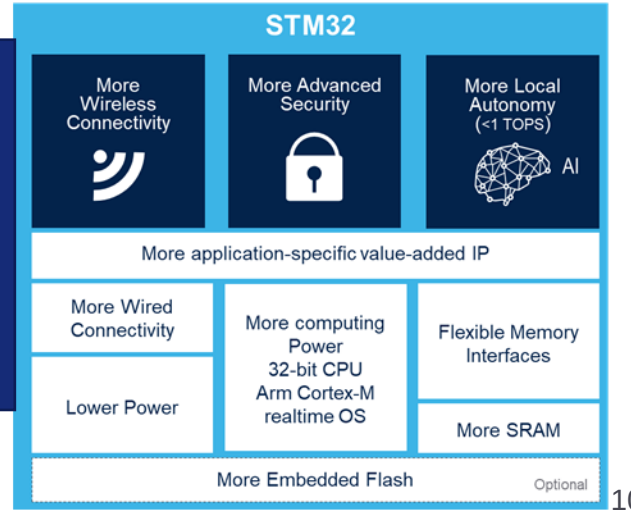
Sensors with **Machine Learning Core**

run predefined AI algorithm (decision tree)









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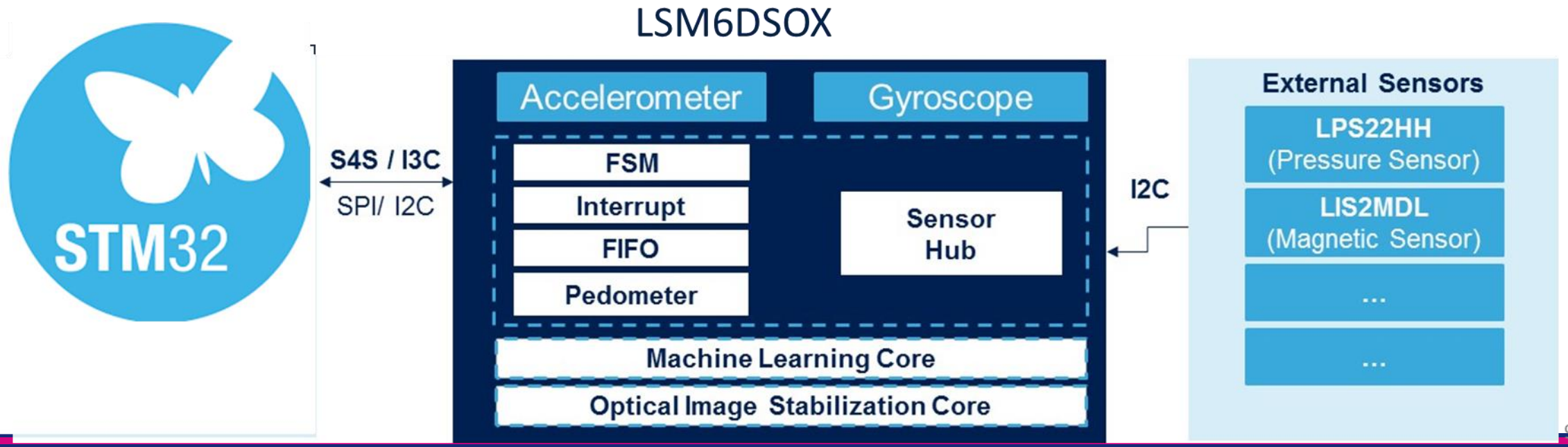
From low power sensor to low power system

- LSM6DSOX = Best in class 6axis IMU Power Consumption (0.55 mA combo mode HP)
- >1 to 100 times energy saving by running Machine Learning on Sensor HW (vs. MCU)
- Simplified and Lean System Concept based on 2 mainstreams:
  - Configurable power mode and high speed communication
  - Flexible HW solution running accurate algorithms



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Chapter 3 Platform and Methodology

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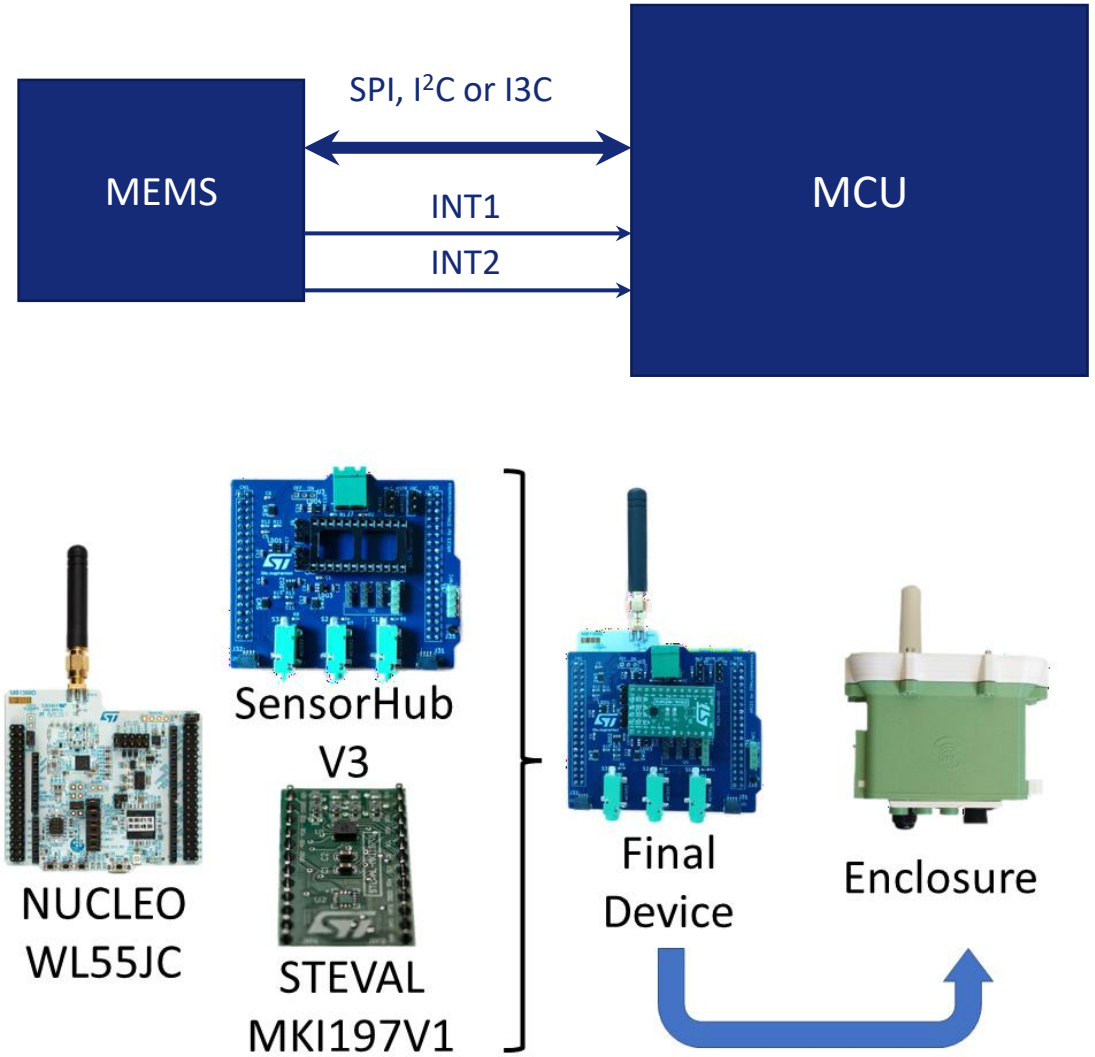
Devices

- **Nucleo WL55JC:**
  - Radio Transceiver Integration: It incorporates a sub-GHz radio transceiver within its microcontroller, enabling wireless data communication in scientific research and IoT applications.
  - The integrated ST-LINK/V2-1 debugger facilitates real-time debugging and program development for precise scientific experimentation.
  - The board's expansion options enable researchers to adapt and customize the platform for specific scientific experiments and data acquisition purposes.
- **SensorHub v3:**
  - The SensorHub v3 was designed and developed by STMicroelectronics, collaboratively with ISCA Lab .
  - It has multiple connectors, including Grove-I2C Hub, Stemma QT, SJ-3524-SMT-TR-GR Jack 3.5mm, 2.54 NFC antenna pin, Buchanan 7744 and most importantly, a DIL24 Socket.
- **Steval MKI197V1:**
  - Equipped with diverse sensors, enabling data acquisition in scientific experiments, including environmental and motion parameters.
  - Designed for seamless interfacing with STMicroelectronics microcontrollers, facilitating precise sensor control and data analysis for scientific research.
  - Offers expandable features via headers, facilitating integration of additional scientific sensors and peripherals for tailored experimentation.
  - Supported by extensive software libraries, streamlining data processing and analysis in scientific investigations.
- **Enclosure:**
  - The enclosure was developed and produced by the members of the ISCA Lab of the Hellenic Mediterranean University specifically for the Nucleo WL55JC MCU.



Embedded end-node platform used in this work

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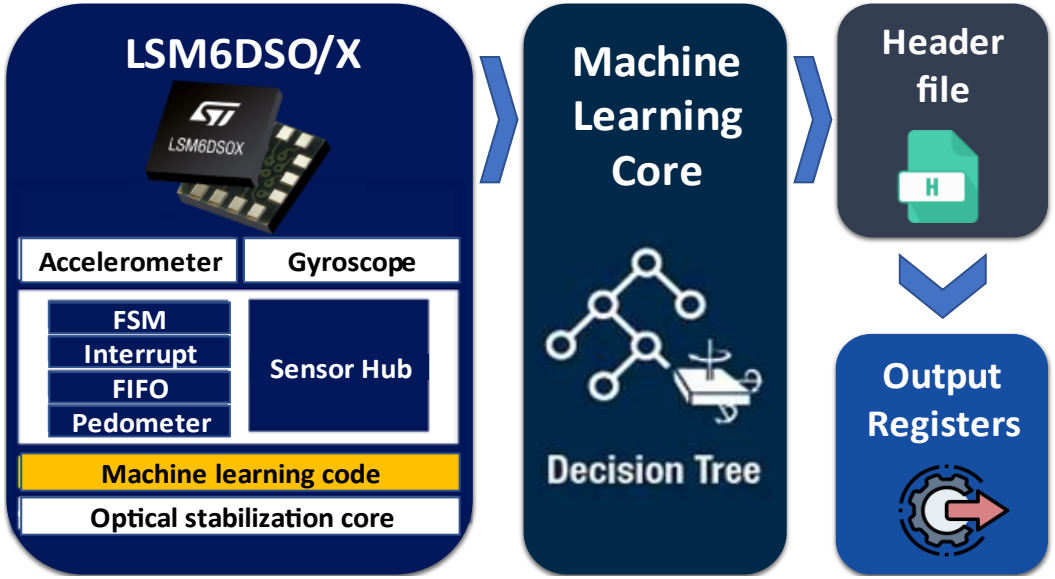
Methodology



Machine learning embedded processing in LSM6DSOX and dataflow generation

- **MLC Efficiency:** The LSM6DSOX features a Machine Learning Core (MLC) for algorithm execution within the sensor, reducing power consumption.
- **Multi-Tree Classification:** The MLC identifies data patterns, supporting up to eight decision trees running simultaneously, each independently configured.
- **Customizable FSMs:** The system-in-package (SIP) sensor allows programming of up to sixteen Finite State Machines (FSMs) for motion detection and gesture recognition.
- **Decision Trees:** Decision trees consist of configurable nodes evaluated using "if-then-else" conditions, defining classification criteria.
- **WEKA Toolchain:** Decision trees are generated using the Waikato Environment for Knowledge Analysis (WEKA) toolchain, converted to header files for firmware inclusion.
- **Data Logging:** Data logs with diverse movements and ample samples are essential for accurate model training.
- **Custom Firmware:** A custom firmware facilitates sensor I/O, data logging, and decision-tree configuration through the Unicleo-GUI toolchain.
- **Offline Mode:** Due to limited NUCLEO microcontroller support, Unico-GUI operates in custom, offline mode.
- **Serial Terminal Access:** The firmware provides access to Machine Learning Core results through the serial terminal.

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Chapter 4 *Falling Detection Implementation*

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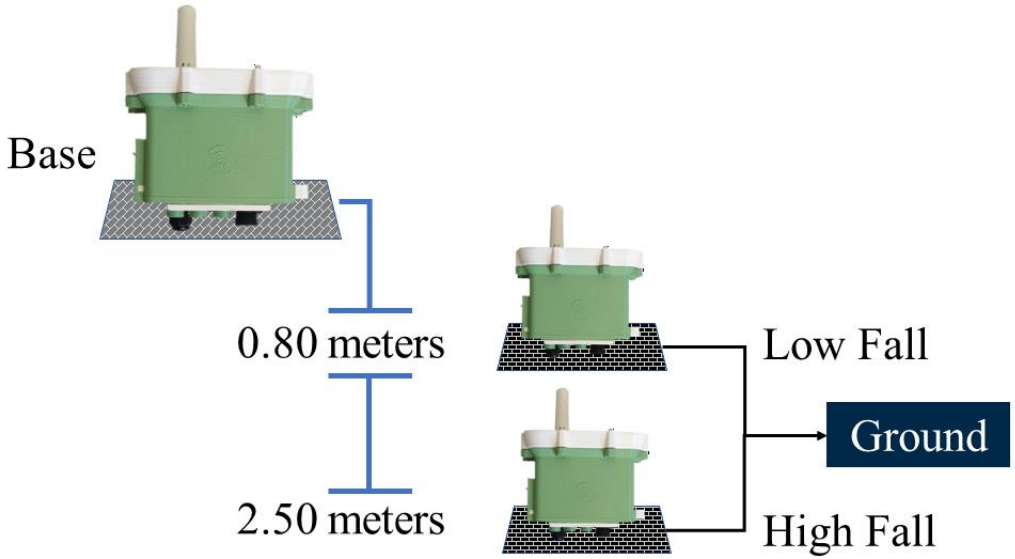
Experimental Platform Setup

Experimental setup for collecting data from the embedded device (NUCLEO-STM32WL55JC and LSM6DSOX)



- **Experimental Setup**:
  - The experiment entails an enclosure situated 2.50 meters above the ground with a system node inside. The system relies on sensors like an accelerometer and a gyroscope to gather crucial data.
- **Data Collection and Precision**:
  - Data precision is high in the controlled testing environment but necessitates real-world validation.
  - The accelerometer detects sudden speed changes, while the gyroscope tracks shifts in the enclosure's orientation concerning its resting state.
- **Falling Detection**:
  - The system distinguishes between various fall scenarios:
    - **Low Fall**: Occurs when the enclosure drops approximately 0.80 meters and lands on a soft surface, resulting in an output register value of 04.
    - **High Fall**: Initiated by a drop from roughly 2.50 meters, yielding an output value of 08.
    - **High Fall and Bounce**: Resembles a High Fall but extends until the rubber rope reaches its maximum extension, causing an oscillatory rebound phase.
  - These classifications depend on gyroscope-derived position alterations and the enclosure's velocity during the descent, with greater falls corresponding to higher velocities.

- **Manual Reset Capability**:
  - A noteworthy feature is the system's capacity to discern when the device is manually returned to its initial idle position at the base.
  - In such instances, the Machine Learning Classifier (MLC) output register returns to a value of 01, signifying the device's transition to an idle state.
  - This functionality aids in post-fall analysis and system control by enabling the decision tree algorithm to distinguish between post-fall conditions and the device's restoration to its resting state.

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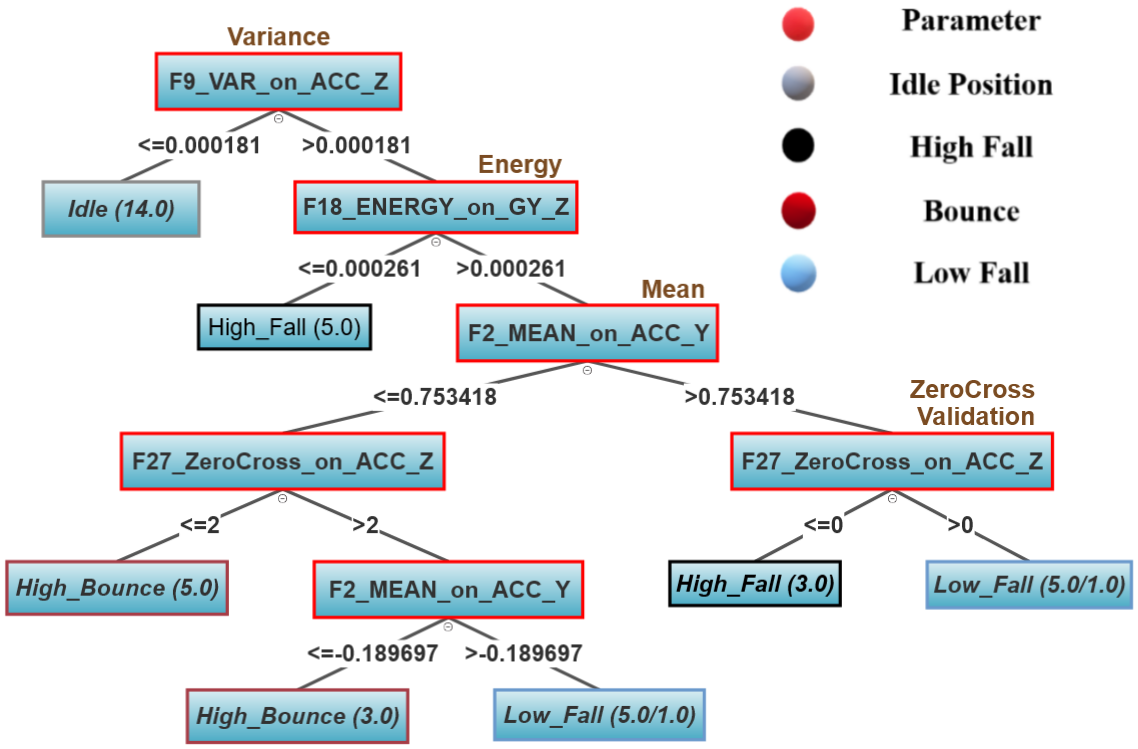
Decision Tree



Falling Detection Algorithm's Decision-Tree

• **System Operation:** The system predicts device position and calculates movement using LSM6DSOX accelerometer and gyroscope data from the STEVAL-MKI197V1 adapter.

• **Decision Tree Creation:** The Decision Tree was created using Unico-GUI and WEKA toolchains, combining separately logged data into a single file.

• **Activity Descriptions:** Activities include Idle (device inactivity), Low Fall (fall from ~0.80 meters), High Fall (fall from ~2.50 meters), and High Fall and Bounce (fall from ~2.50 meters with bouncing).

• **Feature Selection:** The Falling Detection Algorithm's Decision Tree features include variance, energy, mean, and zero-crossing, user-selectable via Unico-GUI.

• **WEKA Pre-processing:** WEKA's pre-process filter reduces dataset attributes from 31 to 8 for faster processing. The J48 algorithm serves as a classifier within the "WrapperSubsetEval" evaluator, employing cross-validation.

• **AdaBoostM1 Classifier:** AdaBoostM1, a meta-estimator, fits classifiers on the dataset to enhance accuracy. The system achieved an accuracy of 91.6859%, an error margin of 8.31%, and an average F1 score of 0.914.

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Chapter 5 Energy Consumption

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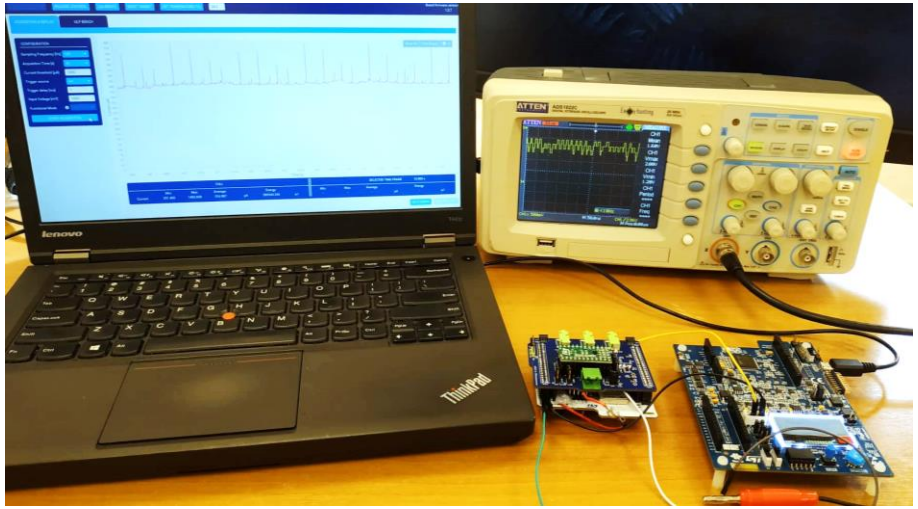
Setup and Measurements



Setup for power-energy measurements of STM32WL55JC and LSM6DSOX sweeping all active and non-active/sleep modes of operation by using the Nucleo-LPM01A measurement board

Freq. (ODR)	Min (µA)	Max (µA)	Average (µA)	Energy (µJ)
Output Data Rate (ODR) STM32WL55JC1, accelerometer-gyroscope, MLC @1.8V				
104 Hz (High-Perf.)	1441	2778	2197.98	263691.684
12.5 (Low-Power)	664.6	2601	1321.914	237254.537
Output Data Rate (ODR) STM32WL55JC1, accelerometer-gyroscope @3.0V				
12.5 (Low-Power)	1452	3059	1863.218	558965.52
Output Data Rate (ODR) STM32WL55JC1, accelerometer-gyroscope with MLC @3.0V				
12.5 (Low-Power)	1150	3274	1868.161	560448.36

Power consumption of STM32WL55JC1 with LSM6DSOX including accelerometer-gyroscope sensors and MLC-based detection of free fall events for a time window of 100 secs and operating at 1.8V and 3.0V

Current and energy consumption of full system over a 10s operation period for different operation supply voltage

	High Power (System clock = 2 Mhz)			
Voltage	**Min (µA)**	**Max (µA)**	**Average (µA)**	**Energy (µJ)**
1.8V	1016	1448	1165.781	20984.058
2.4V	1241	1883	1464.377	35145.048
3.0V	1548	2316	1857.391	55777.44
3.3V	1803	2687	2186.841	72237.924
	Low Power (System clock < 2 Mhz)			
1.8V	774.5	1221	933.787	16824.976
2.4V	779.1	1559	1162.435	27898.44
3.0V	1345	2145	1660.641	49819.23
3.3V	1822	2772	2195.59	72526.938
	Sleep			
1.8V	440.7	659.9	463.725	8355.398
2.4V	527.9	781	548.165	13169.11
3.0V	891	1174	930.123	27931.581
3.3V	1363	1646	1401.988	46311.87
	Stop Mode 1			
1.8V	395.5	617.9	410.26	7392.067
2.4V	514.9	763.7	532.457	12791.736
3.0V	839.5	1093	858.418	25778.289
3.3V	1312	1559	1329.278	43866.174

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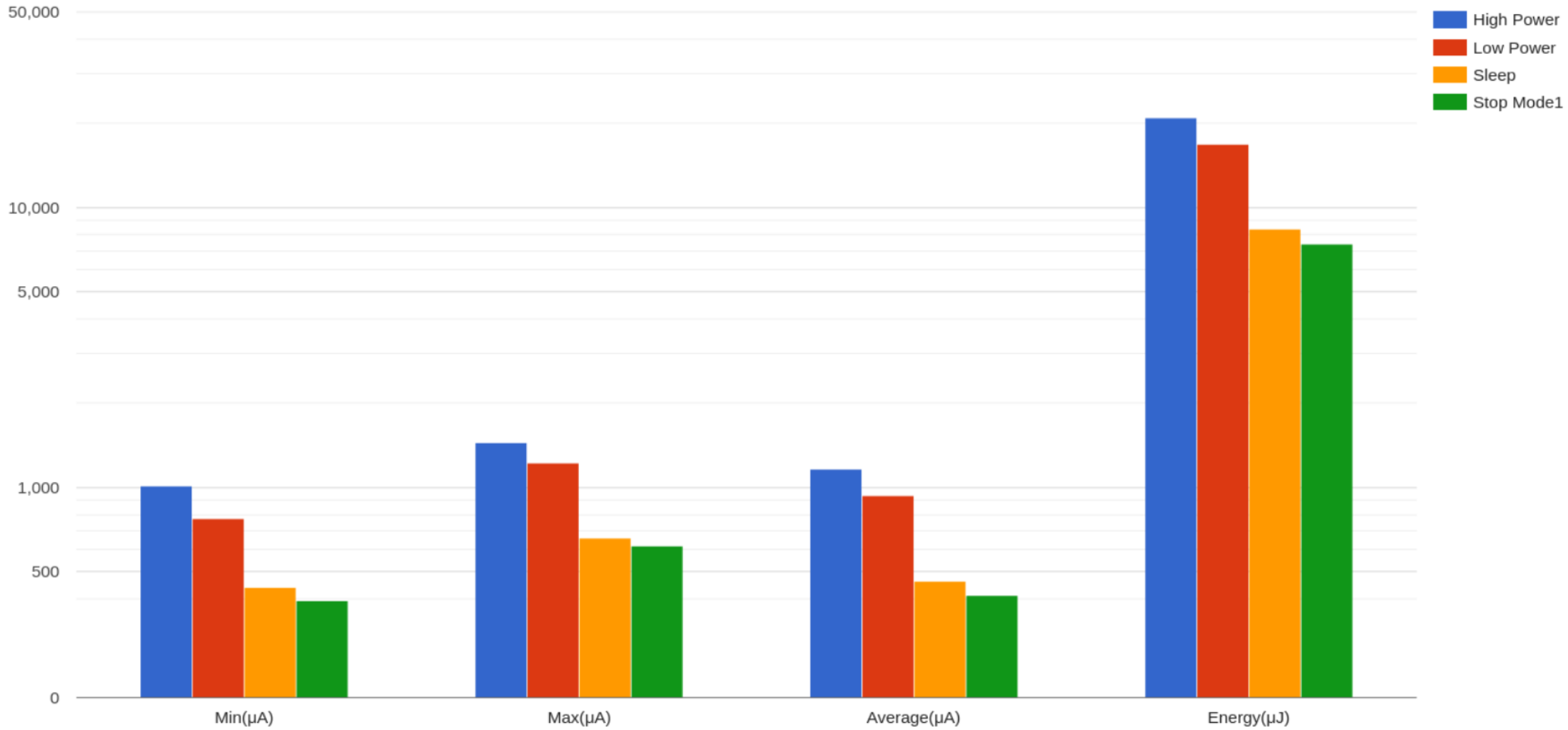
Extensive Energy Comparison



Current and energy consumption of full system over a 10s operation period for different operation supply voltage

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Ultra-Low Power Operations

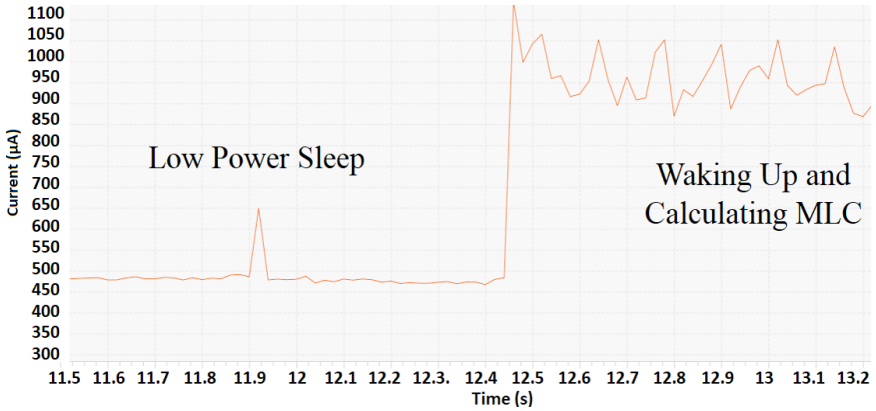

Figure 1

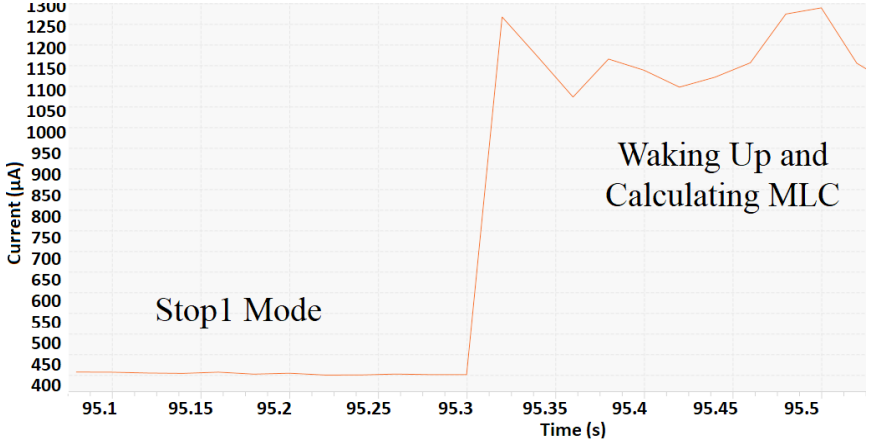

Figure 2

The figures 1 and 2 illustrate that the system response time after sleep mode is negligible and less than 1.5 ms, while when the system wakes up after stop1 mode, it is almost 22ms. The system power supply was set in 1.8V and an activity event

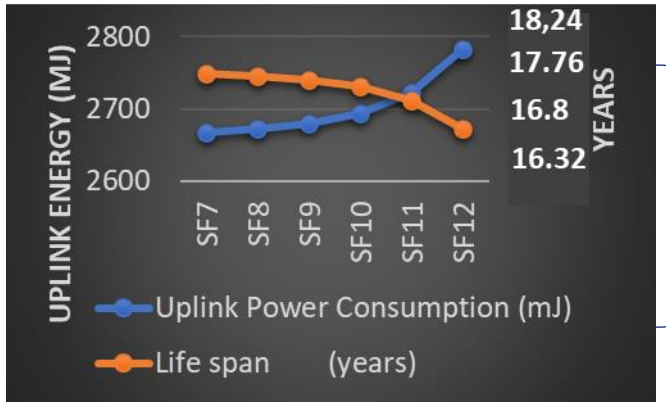

Figure shows, when we consider the stop mode1, we can achieve a life span of 17.5 years by using a single AA battery, under the assumption we send one uplink LoRa frame per 24 hours.

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Conclusions

- We have presented an original way to use Artificial Intelligence at the Edge
- We have presented the STEVAL-MKI197V1 combined to STM32 MCU
- Final considerations about power measurements have been provided with real case applications

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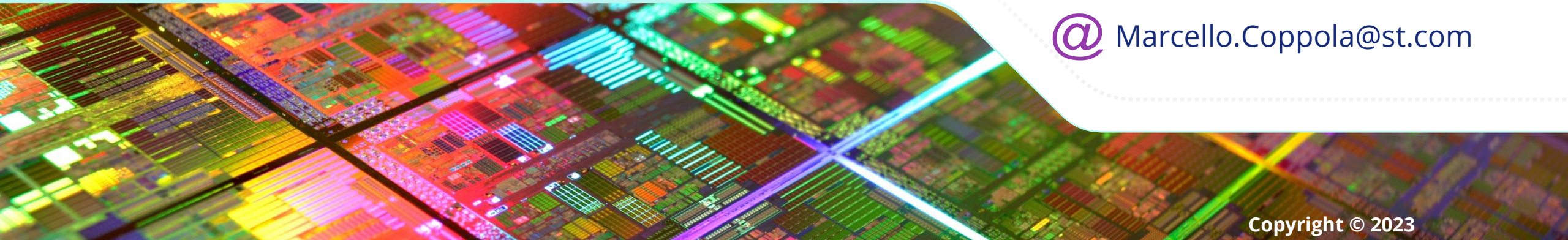
EDGE AI

Thank You

For your attention



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