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eTECH JOURNAL

ISSUE 12

FEEL THE **FUTURE**

DESIGNING SMART WIRELESS SENSORS

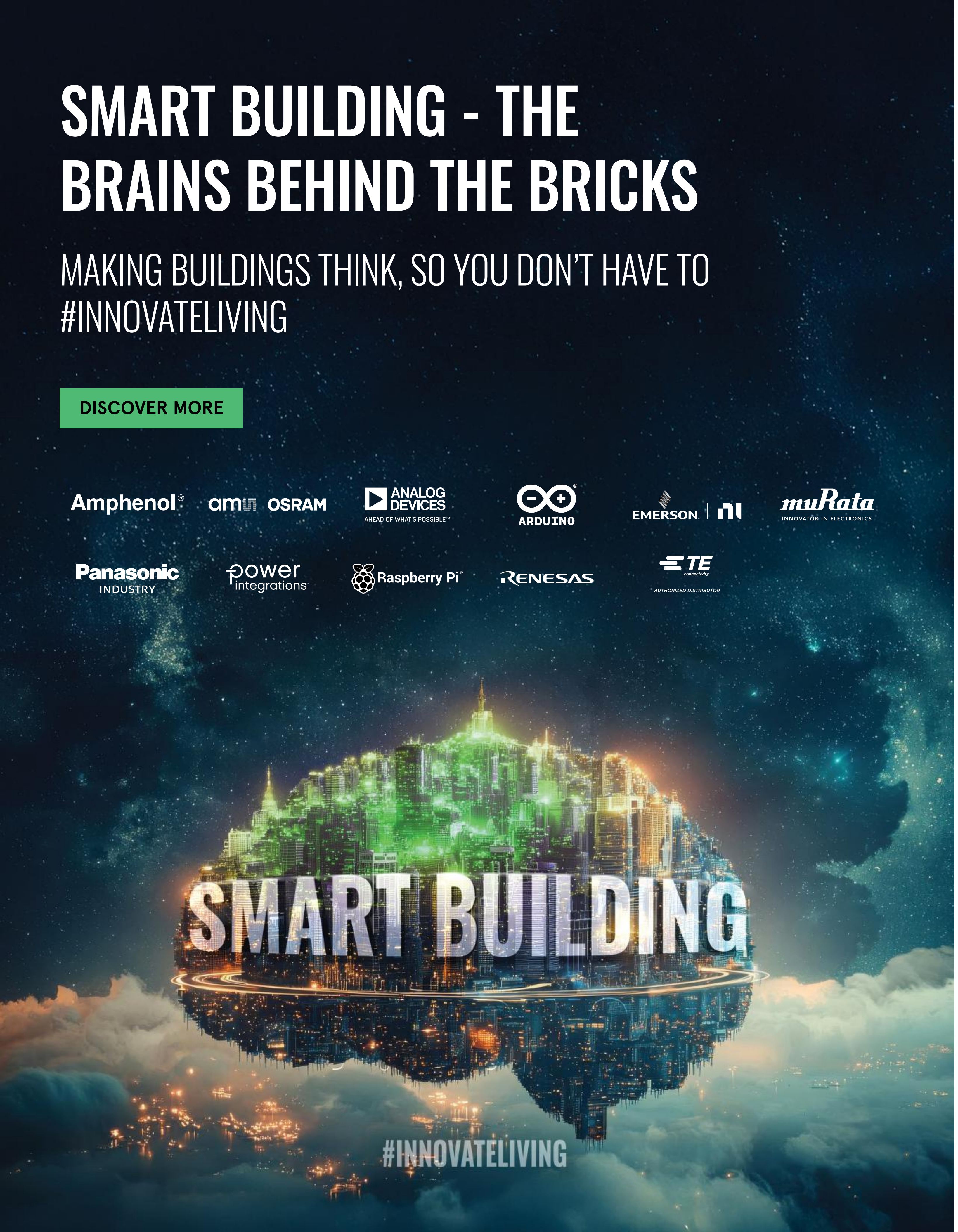
+

THE MEMS REVOLUTION

WHICH SMART SENSOR?

MEMS FOR PREDICTIVE MAINTENANCE

HARSH INDUSTRIAL ENVIRONMENTS



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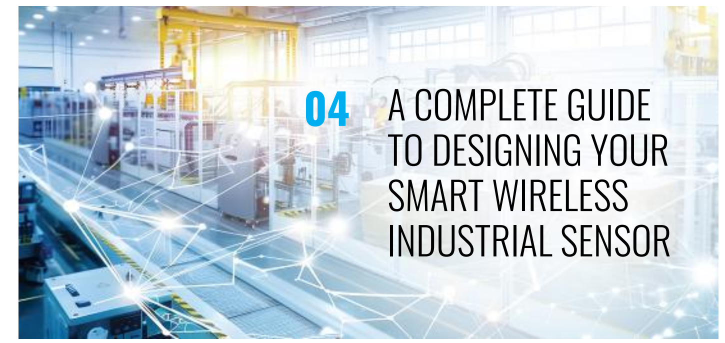

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Editor-in-chief: Cliff Ortmeyer, Managing Editor: Ankur Tomar

WELCOME

Today's industrial landscape is evolving faster than ever, and smart sensing technology lies at the heart of this transformation. From streamlining predictive maintenance to enabling wireless connectivity in the most rugged environments, sensors continue to drive innovation in the Internet of Things (IoT) and Industry 4.0 applications.

As factories become smarter and systems more autonomous, the demand for intelligent, reliable, and robust sensors grows. Designing sensors that can not only communicate wirelessly but also withstand extreme conditions requires a blend of innovation, precision engineering, and deep application knowledge. Whether it's MEMS-based vibration sensing for early fault detection or wireless modules for remote monitoring, modern industrial sensors are being pushed to new limits.

In this edition of the e-TechJournal, we explore what it takes to build the next generation of smart industrial sensors. Get a complete guide to designing your own wireless sensor solution, learn how MEMS technology is revolutionising the future of IoT, and dive deep into designing for predictive maintenance with vibration sensors. Plus, find out what makes sensors for harsh industrial environments not just durable – but essential.

We hope this issue inspires your next industrial design challenge.

Cliff Ortmeyer Editor, eTech Journal
Email: editor-TJ@element14.com

A COMPLETE GUIDE TO DESIGNING YOUR **SMART WIRELESS INDUSTRIAL SENSOR**

Richard Anslow, Senior Manager

This article provides an overview of wireless standards and assesses the suitability of Bluetooth® Low Energy (BLE), SmartMesh (6LoWPAN over IEEE 802.15.4e), and Thread/Zigbee (6LoWPAN over IEEE 802.15.4) for use in industrial harsh RF environments.

Comparative metrics are provided, including power consumption, reliability, security, and total cost of ownership. SmartMesh time synchronization results in low power, and SmartMesh and BLE channel hopping result in higher reliability. A case study for SmartMesh concludes with 99.999996% reliability.

Analog Devices' BLE and SmartMesh wireless condition monitoring sensors are presented, including a new wireless sensor with edge artificial intelligence (AI), which increases battery life for constrained edge sensor nodes.

INTRODUCTION

The market for smart sensors for motor driven systems is expected to more than double in sales volume between 2022 and 2024 (growing to $906M USD).1 Within smart sensors, wireless and portable devices are expected to be the primary growth drivers. Monitoring industrial machines using wireless environmental sensors (temperature, vibration) has one clear goal: to detect when the equipment being monitored deviates from healthy operation.

For industrial wireless sensor applications, low power consumption, reliability, and security are consistently ranked as the most important requirements. Other requirements include low total cost of ownership (minimal gateways, maintenance), short range communication, and a protocol capable of mesh formation for factory environments that include lots of metallic obstacles (meshing networks help to mitigate possible signal path shielding and reflections).

INDUSTRIAL APPLICATIONS AND WIRELESS STANDARDS REQUIREMENTS

Figure 1 provides an overview of wireless standards, and Table 1 ranks selected wireless standards against key industrial requirements. It's clear that BLE and SmartMesh (6LoWPAN over IEEE 802.15.4e) offer the best combination of low power consumption, reliability, and security for industrial applications. Thread and Zigbee offer low power and secure mesh implementations but score lower on reliability.

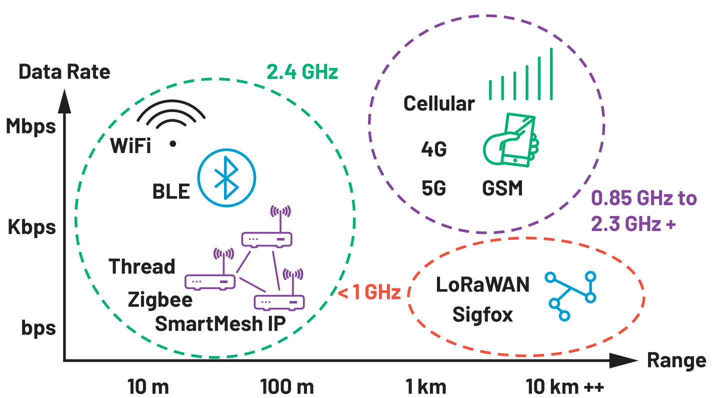


Figure 1 – Survey of wireless standards.

Standard	Range	Power Consumption	Reliability	Robustness	Total Cost of Ownership	Mesh Capable	Security
Wifi (802.111 b, g)	100 m	High	Low	Low	High	Yes	Yes, WPA
BLE	20 m to 100 m	Low/medium	Medium/high	Low	Medium	Yes	Yes, AES
Zigbee, Thread (6LoWPAN over IEEE 802.15.4)	20 m to 200 m	Low/medium	Low	Low	Medium	Yes	Yes, AES
SmartMesh (6LoWPAN over IEEE 802.15.4e)	20 m to 200 m	Low	High	High	Low	Yes	Yes, AES
LoRaWAN	500 m to 300 m	Medium to low power nodes, high power gateways	Low	Low	High	No -- Star Topology	Yes, AES

Table 1 – Mapping Wireless Standards to Industrial Application Requirements.

Feature	Zigbee, Thread (6LoWPAN over IEEE 802.15.4)	SmartMesh (6LoWPAN over IEEE 802.15.4e)	BLE Mesh
Radio frequency	2.4 GHz	2.4 GHz	2.4 GHz
Data rate	250 kbps	250 kbps	1 Mbps, 2 Mbps
Range	20 m to 200 m	20 m to 200 m	20 m to 150 m
Application throughput	< 0.1 Mbps	< 0.1 Mbps	< 0.2 Mbps
Network topology	Mesh, Star	Mesh, Star	Mesh, Star
Security	AES encryption	AES encryption	AES encryption
Power	Line powered routing nodes	Routing nodes require only average 50 µA	Line powered routing nodes
Total cost of ownership	$$ to $	$	$$ to $
Time synchronized channel hopping	✕	✓	✕
Robustness (channel allocation)	✕ Single channel comms	✓	✕
Reliability (channel hopping)	✕ Single channel comms	✓	✓
Standards (interoperability)	Yes	Proprietary	Yes

Table 2 – Key Wireless Standards and Performance for Industrial Applications

This article will focus on SmartMesh and BLE mesh as the most suitable wireless standards for industrial condition monitoring sensors.

ANALOG DEVICES WIRELESS CONDITION MONITORING SENSORS

Table 3 provides an overview of Analog Devices' Voyager 3 Wireless Vibration Monitoring Platform and next-generation wireless condition monitoring sensors. Voyager 3 uses a SmartMesh module (LTP5901-IPC). An AI enabled vibration sensor (still in development) uses a BLE microcontroller (MAX32666). Both sensors include temperature and battery state of health (SOH) sensors. The Voyager 3 and AI version sensors use ADI MEMS accelerometers (ADXL356, ADXL359) to measure vibration amplitude and frequency for industrial equipment. Increasing vibration amplitudes and frequencies are identified using FFT spectra, which can indicate faults such as motor imbalance, misalignment, and damaged bearings.

Figure 2 provides an overview of a typical operation for Voyager 3 and the AI enabled vibration sensors. Like many industrial sensors, the duty cycle is 1%; most of the time the sensor is in a low power mode. The sensor wakes up periodically for bulk data gathering (or in a high vibration amplitude shock event) or to send the user a status update. The user is typically notified with a flag to state that the monitored machine is in good health, and the user is given the opportunity to gather more data.

Parameter	Voyager 3	Next-Generation Sensor
Wireless standard	SmartMesh	BLE
Ultra low power edge AI	No	Yes
Temperature sensor	Yes	Yes
MEMS accelerometer	Yes (triaxial 1 kHz)	Yes (triaxial 8 kHz)
Battery SOH monitoring	Yes	Yes

Table 3 – ADI Wireless Industrial Sensor Prototypes

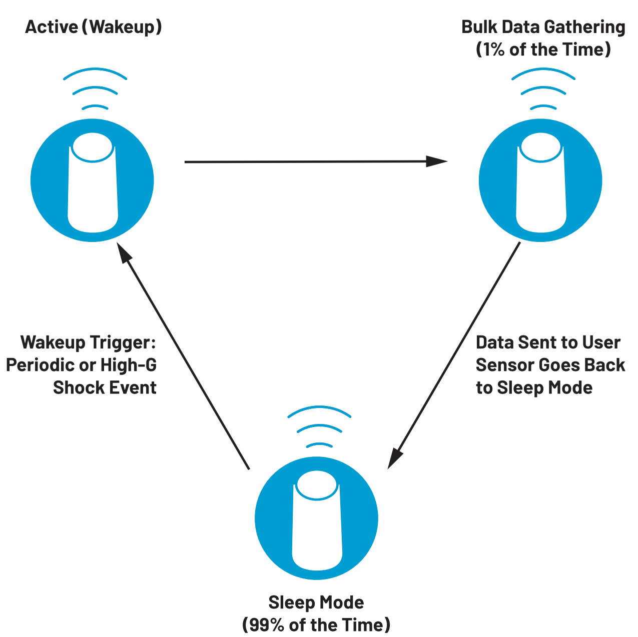
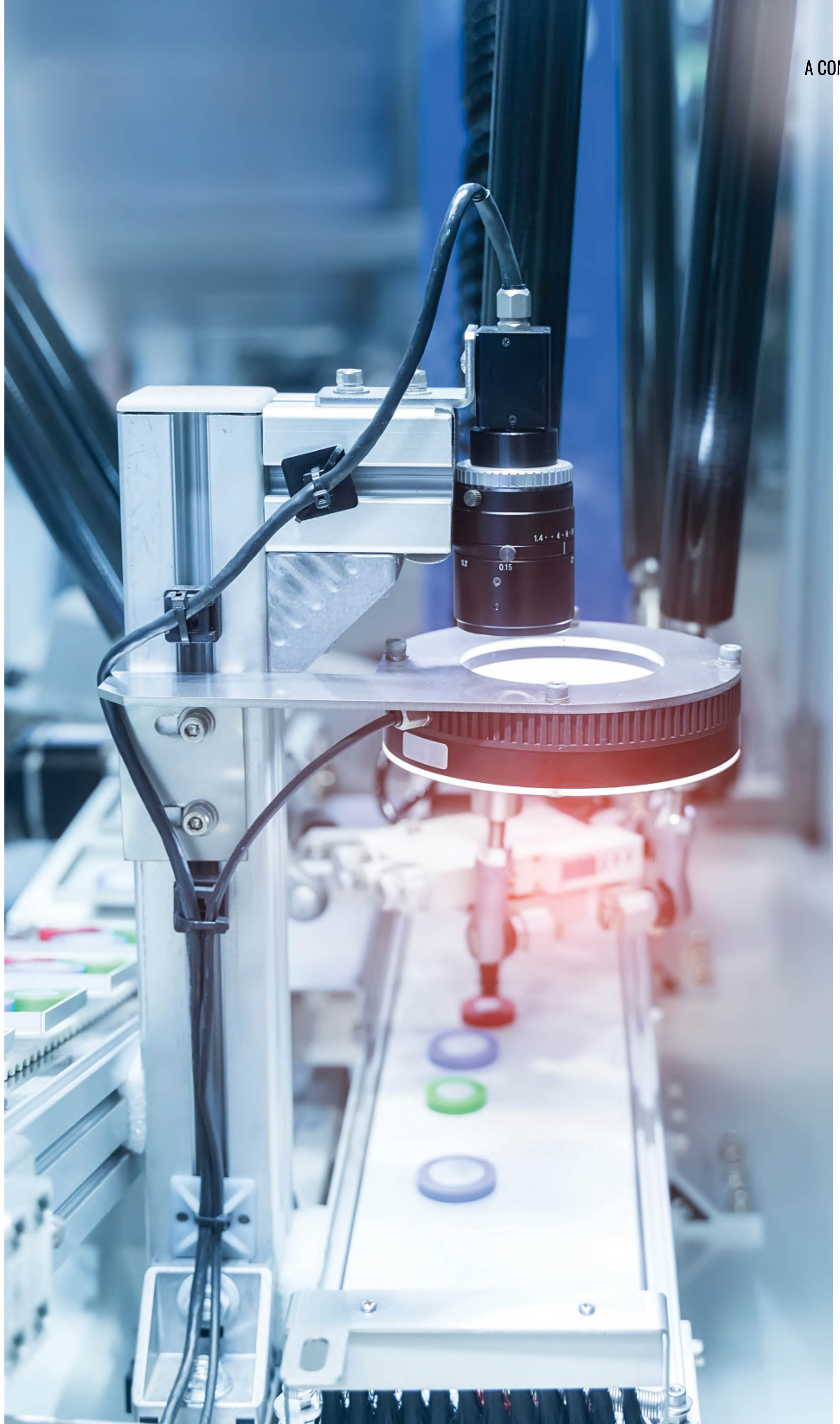


Figure 2 – An industrial wireless sensor typical operation.



SECURITY

SmartMesh IP networks have several layers of security, which can be categorized as confidentiality, integrity, and authenticity. A summary of SmartMesh security is provided in Figure 3. Confidentiality is achieved with AES-128-bit encryption end to end, even if there are multiple mesh nodes in the network. Data transmitted is protected by message authentication codes (message integrity check, or MIC) to ensure that it has not been tampered with. This protects against man in the middle (MITM) attacks, as shown in Figure 3. Multiple device authentication levels are possible, which prevents unauthorized sensors from being added to the system.

Devices operating with versions 4.0 and 4.1 of the BLE standard are security vulnerable, however, versions 4.2 and above include enhanced security (as described in Figure 3). ADI's MAX32666 is compliant to the BLE standard 5.0. This version introduces the P-256 Elliptic Curve Diffie-Hellman key exchange for pairing. In this protocol, the public keys of the two devices are used to establish a shared secret between the two devices, called the long-term key (LTK). This shared secret is used for authentication and generation of keys to encrypt all communication, protecting against MITM attacks.

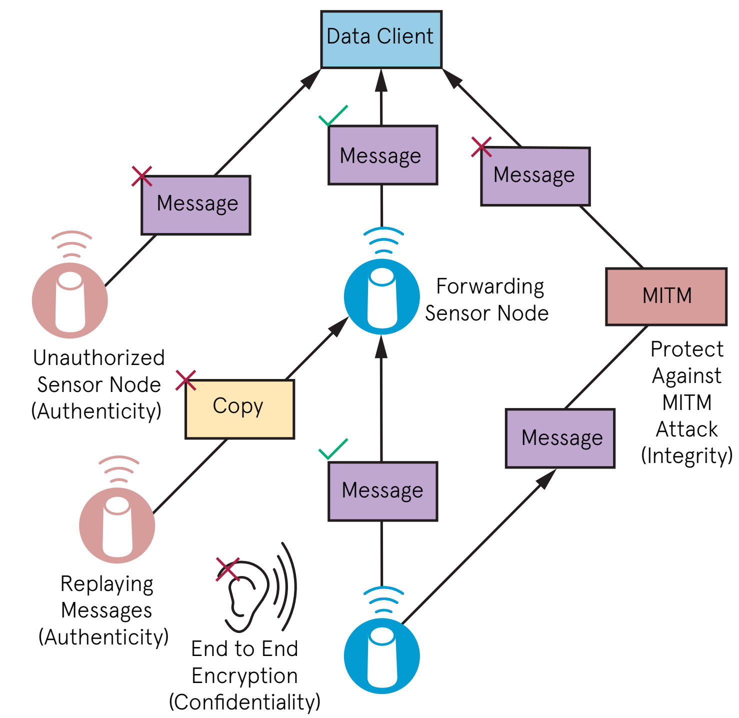


Figure 3 – Security implementation for BLE and SmartMesh networks.

LOW POWER CONSUMPTION

The sensors described in Table 3 operate on a 1% duty cycle, with Voyager 3 maximum payload of 90 bytes, and the AI version maximum payload of 510 bytes. Figure 4 (adapted from Shahzad and Oelmann3) shows that for 500 bytes to 1000 bytes, BLE consumes less energy compared to Zigbee and Wi-Fi. BLE is thus a good match for the AI enabled use case. SmartMesh provides ultra low power consumption, especially for payloads of 90 bytes or less (as used in the Voyager 3 sensor). The SmartMesh energy consumption is estimated using the SmartMesh Power and Performance Estimator tool available on the website. The SmartMesh power estimator tool accuracy has been experimentally verified 87% to 99% accurate depending on whether a sensor is a routing or leaf node.

In addition to radio transmit power consumption, one must consider the total system power budget and total cost of ownership. As described in Table 2, BLE and Zigbee both operate using a single gateway. However, both also require line power for routing nodes. This increases the power budget and total cost of system ownership. In contrast, SmartMesh routing nodes only require on average 50 µA of current, and an entire network can operate using a single gateway. SmartMesh is clearly a more energy efficient implementation.

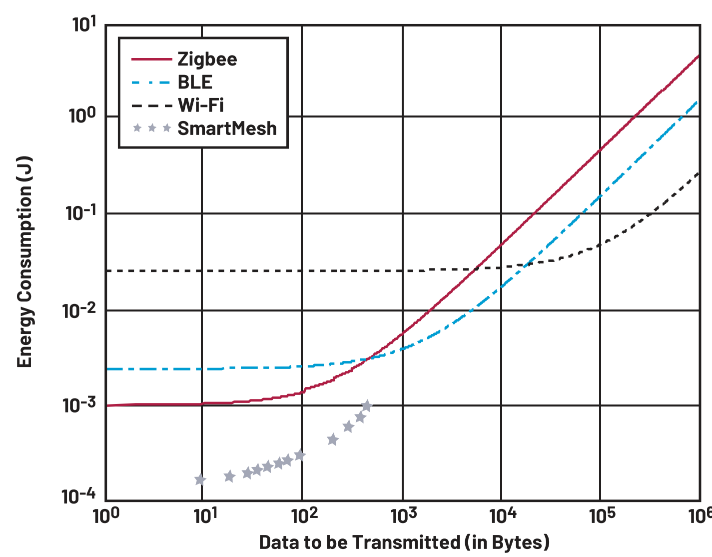


Figure 4 – Data transmitted (radio transceiver PHY) and energy consumption (adapted from Shahzad and Oelmann).

RELIABILITY AND ROBUSTNESS

As mentioned previously, SmartMesh uses TSCH, which has the following characteristics:

- All nodes in a network are synchronized.
- Communication is orchestrated by a communication schedule.
- Time synchronization results in low power.
- Channel hopping results in high reliability.
- The scheduled nature of communication brings a high level of determinism.

The synchronization accuracy is less than 15 µs across the entire network. This extremely high level of synchronization results in extremely low power. On average 50 µA current draw, and 1.4 µA greater than 99% of the time.

Table 4 provides some key application challenges and how SmartMesh and BLE mesh meet these challenges.

SmartMesh performs better for dense networks with large numbers of nodes. Both BLE and SmartMesh perform well in dynamic industrial environments.

The reliability of SmartMesh was tested in ADI's wafer fab facility.5 This is a harsh RF environment, with dense metal and concrete. Thirty-two wireless sensor nodes were distributed in a mesh network, with four hops between the furthest sensor node to the gateway. Four data packets were sent every 30 seconds from each sensor node. Over a time period of 83 days 26,137,382 packets were sent from the sensors, with 26,137,381 packets received, resulting in 99.999996% reliability.

Challenge	Problem	SmartMesh	Bluetooth Mesh
Robust communications in densely formatted networks	Nodes interfere with each other, slowing down network	Efficient channel allocation eliminates collisions	Relies on collisions that slow down network
Long battery life when sensors mounted in shielded locations	Requires power efficient edge node connections to meet battery lifetime specs	Battery-powered routing nodes establish close range connection to edge nodes	Line-powered routing nodes establish close range connections to edge nodes
Reliable connections in dynamic industrial environments	Movement of equipment or opening/closing of doors cause multipath reflections	Employs channel hopping to avoid reception nulls	Employs channel hopping to avoid reception nulls
Reliable communications in congested radio bands	Interferers restrict data traffic bandwidth on the network	Channel hopping to avoid interferers and efficient bandwidth allocation maintains traffic	Designed for small networks and suffers from network flooding

Table 4 – Key Challenges for Wireless Networks in Industrial Application and BLE/SmartMesh Performance

ARTIFICIAL INTELLIGENCE AT THE EDGE

The next-generation wireless sensor includes the MAX78000 microcontroller with AI hardware accelerator. This AI hardware accelerator minimizes data movement and leverages parallelism for optimal energy use and throughput.

Wireless industrial sensors currently available on the market typically operate on very low duty cycles. The user sets the sensor sleep duration, after which the sensor wakes up and measures temperature and vibration, and then sends the data over the radio back to the user's data aggregator. Commercially available sensors typically quote a 5-year battery life, based on one data capture every 24 hours, or one data capture every 4 hours. The next-generation sensor will operate in a similar fashion but take advantage of Edge AI anomaly detection to limit the use of the radio. When the sensor wakes up and measures data, the data is only sent back to the user if a vibration anomaly is detected. In this way the battery life can be increased by at least 20%.

For AI model training the sensor collects healthy data for the machine, which is then sent over the air to the user for AI model development. Using the MAX78000 tools the AI model is synthesized into C code, and then sent back to the wireless sensor and placed in memory. When the code is deployed the wireless sensor wakes up at predefined intervals, or in a high-g shock event. Data is gathered and an FFT is generated. From the FFT, the MAX78000 makes an inference based on this data. If no anomaly is detected the sensor goes back to sleep. If an anomaly is detected the user is notified. The user can then request FFT or raw time domain data for the measured anomaly, which can be used for fault classification.

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ABOUT THE AUTHOR

Richard Anslow is a senior manager working in the field of software systems design engineering within the Industrial Automation Business Unit at Analog Devices. His areas of expertise are condition-based monitoring, motor control, and industrial communication design. He received his B.Eng. and M.Eng. degrees from the University of Limerick, Limerick, Ireland. Recently, he completed a postgraduate program in AI and ML with Purdue University.

CONCLUSION

This article provides an overview of wireless standards and assesses the suitability of BLE, SmartMesh (6LoWPAN over IEEE 802.15.4e), and Thread/Zigbee (IEEE 802.15.4) for use in industrial harsh RF environments. SmartMesh has superior reliability and low power operation compared to BLE and Thread/Zigbee. BLE can operate more reliably and at lower power compared to Zigbee and Thread for networks requiring 500 bytes to 1000 bytes of data transmission. Microcontrollers with embedded AI hardware accelerators provide a path to better decision-making and longer battery life for wireless sensor nodes.

For comprehensive product insights and cutting-edge innovations in Smart Wireless Industrial Sensor.

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THE MEMS REVOLUTION:

POWERING THE FUTURE OF IOT & INDUSTRIAL INNOVATION

Author: Farnell Technical Marketing Team

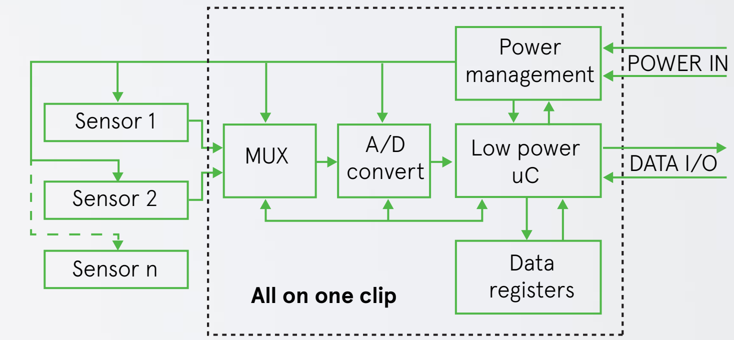
Let's talk about the MEMS sensors–those tiny, often unseen devices quietly revolutionizing how we interact with technology and the world around us. For engineers, knowing the capabilities and advancements in MEMS is a must to stay ahead of the wave.

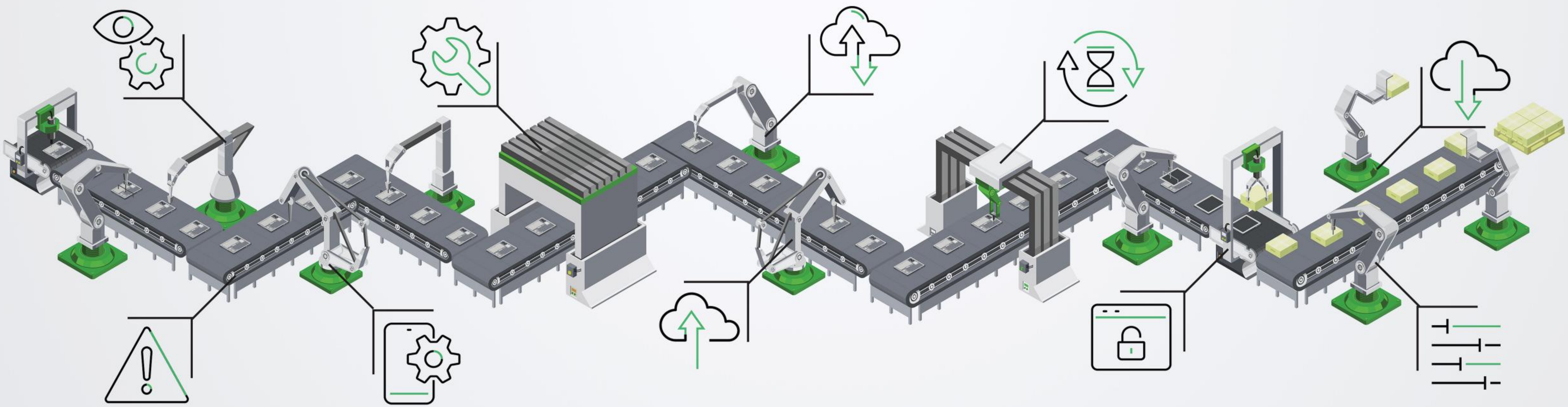
THE RISE OF MEMS: A PARADIGM SHIFT

Until recently, sensors relying on physical phenomena such as pressure, motion, and magnetic field variations were cumbersome, expensive to procure, and power-consuming. Along came MEMS, which manufactures sensors directly onto silicon using processes developed for integrated circuits. This was their big break: MEMS Sensors are now:

- **Miniaturized**: Significantly smaller, allowing for integration into even the most compact devices.
- **Low-Power**: Consuming minimal power, extending battery life and enabling wireless applications.
- **Cost-Effective**: Mass production techniques make them affordable for a vast array of applications.
- **Rugged**: Durable and reliable in harsh environments.

These attributes have made MEMS indispensable for IoT and Industrial IoT (IIoT). Here is an example of highly integrated solutions that convert analog sensor signals to digital value, can process data using a low-power MCU, and may even support several sensor types in a single package.





MEMS IN IOT: CONNECTING THE WORLD

In the world of the Internet of Things, MEMS sensors form the backbone for connected devices and real-time monitoring. Their advancements are driving growth in several key applications:

- **Smart Homes and Cities**: MEMS sensors enable automation, environmental monitoring, and efficient resource management. For example, MEMS pressure sensors can monitor HVAC systems, while environmental MEMS sensors can track air quality or humidity in real time.
- **Wearables**: Accelerometers, gyroscopes, and pressure sensors make motion, health metrics tracking, and intuitive user interfaces possible. Suppliers like NXP have recently started integrating advanced fusion algorithms into MEMS sensors, enabling wearables to provide enhanced accuracy in fitness tracking and biometrics.
- **Logistics and Tracking**: MEMS sensors are utilized in asset tracking, real-time location monitoring, and goods condition tracking. Infineon and Honeywell MEMS accelerometers have been quite efficient in vibration, shock, and tilt monitoring for sensitive shipments.
- **Smart Agriculture**: In IoT for agriculture, MEMS sensors monitor soil conditions and moisture levels and enable automated irrigation.

IIOT: REVOLUTIONIZING INDUSTRY

The use of MEMS sensors are profoundly affecting the Industrial IoT, especially in predictive maintenance, operational efficiency, and industrial automation.

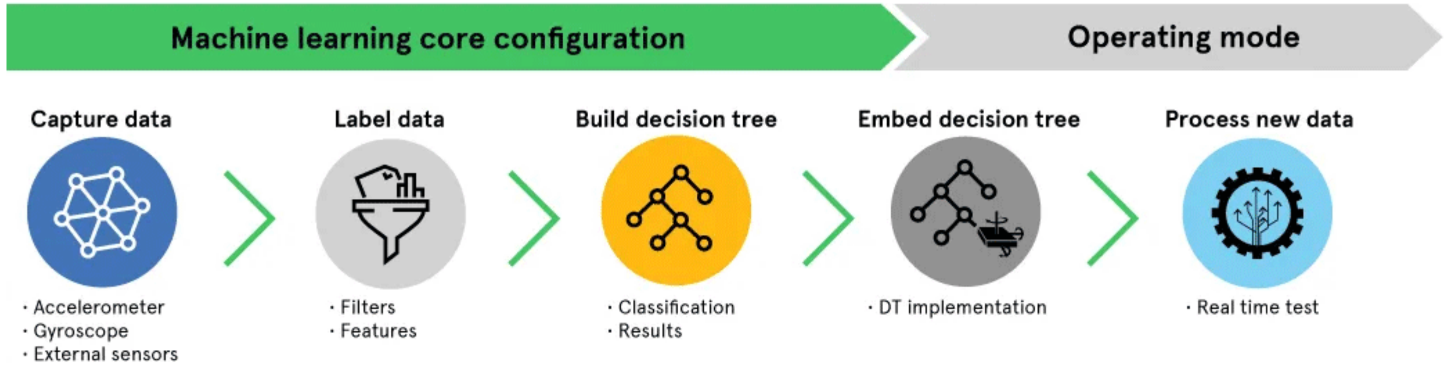
- **Condition-Based Monitoring**: MEMS accelerometers replace Traditional piezoelectric sensors due to their size reduction, low power consumption, and integrability. Such sensors can detect low level vibrations and higher-frequency oscillations, representing early-stage mechanical faults. Besides, Analog Devices' ADXL1002 includes high bandwidth and low noise features, making it appropriate for enhanced vibration analysis in predictive maintenance applications.
- **Wireless Condition Monitoring**: Development in low-power MEMS accelerometers is now beginning to displace wired setups by wireless systems in CbM applications. Panasonic's Grid-EYE infrared array sensors enable wireless monitoring in industrial environments via mesh networks by complementing with a MEMS accelerometer. The wireless platforms of Analog Devices-Voyager and STMicroelectronics MEMS based nodes allow deployment at lower cost with much higher scalability for brownfield sites.
- **Vibration Analysis**: Sub-1mG rms noise levels from MEMS accelerometers by Xsens and Honeywell can now detect minute vibrations that serve as an early signal of mechanical degradation. These sensors provide wide bandwidth and multi-axis detection for more detailed insights into machine health.
- **Industrial Automation**: Robotics, manufacturing equipment, and energy management systems use MEMS to an increasing degree for precise measurement and control. Infineon's XENSIV™ MEMS sensors are used for high-precision positioning in automated guided vehicles and robotic arms.

TECHNOLOGY ADVANCEMENTS: UNLOCKING NEW CAPABILITIES

INTEGRATION OF AI AND MACHINE LEARNING

Artificial intelligence and machine learning are transforming MEMS sensor capabilities. Traditionally, a regular MEMS sensor amplifies, digitises, and makes the signal available to a host processor. The software running on the host will decide what the measurements mean. The engineers would need to write the code to evaluate the measurements and resolve them into actions, such as changes in direction or speed of travel. However, MEMS sensors equipped with a machine learning core, that evaluation is carried out on the device. Instead of sending separate measurements, the core evaluates all the data into actions or activities.

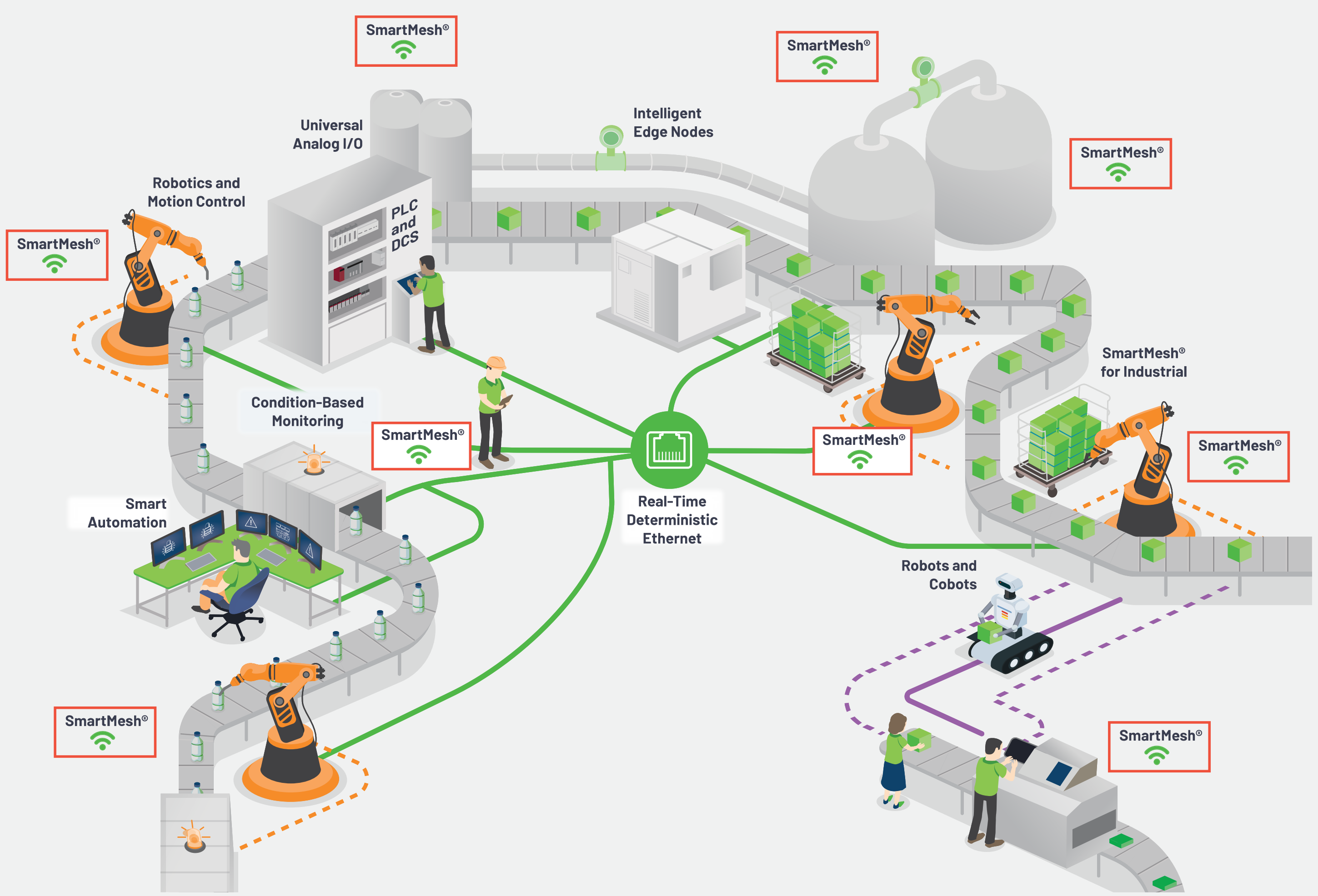
- **Edge Processing:** MEMS sensors with integrated ML cores (e.g., STMicro's MLC-enabled sensors) allow data processing directly at the sensor level, reducing latency and power consumption.
- **Predictive Analytics**: MEMS sensors powered by ML algorithms detect subtle anomalies that indicate potential failures, enabling proactive maintenance.
- **Adaptive Sensing**: AI-enhanced MEMS sensors adjust to dynamic environments, improving accuracy in changing conditions.



ENERGY HARVESTING AND WIRELESS INTEGRATION

Energy harvesting techniques are extending the utility of MEMS sensors in remote and wireless applications:

- **Piezoelectric MEMS**: Sensors that harness vibrational energy to power themselves are being developed for IoT nodes in hard-to-access locations.
- **Wireless Mesh Networks**: Platforms like Analog Devices' SmartMesh IP use MEMS sensors to build robust, low-power wireless networks for industrial monitoring.



WHAT DOES THIS MEAN FOR ENGINEERS?

As technical application engineers, you are the drivers of this MEMS-powered revolution. Here's how to stay ahead:

- Stay Updated: Regularly explore the latest MEMS products and application notes from leading suppliers like Analog Devices, Infineon, NXP, Panasonic, STMicroelectronics, and Honeywell.
- Leverage Development Kits: Use evaluation boards from suppliers to test and optimize sensor performance in your designs.
- Embrace AI and ML: Integrate edge AI and predictive analytics into your MEMS applications to unlock smarter systems.
- Experiment with Wireless Solutions: Explore MEMS-enabled wireless platforms to reduce complexity and enable flexible deployments.

MEMS sensors have evolved from essential components into sophisticated, high-performance powerhouses, changing the rules of the game. With recent breakthroughs in AI-driven edge processing, seamless wireless integration, and energy harvesting technologies, the potential seems almost limitless. For engineers, it's time to push beyond limits, innovate relentlessly, and explore the uncharted possibilities that MEMS can unlock in shaping a smarter, more connected world.

FURTHER READ:

As technical application engineers, you are the drivers of this MEMS-powered revolution. Here's how to stay ahead:

- eTechJournal Publication: Industrial Sensors – SMART Sensing
- How to implement MEMS sensor for vibration and condition monitoring
- MEMS Sensors: A Deep Dive into Emerging Trends and Cutting-Edge Innovations
- Advanced ML for MEMS Sensors: Enhancing the Accuracy, Performance, and Power consumption
- How to design a MEMS Vibration Sensor for predictive maintenance
- How To Optimize Low-Power Operation for Sensor Applications
- Decoding Gas Sensors: Ultimate Guide to Cutting-Edge Gas Sensors Technologies
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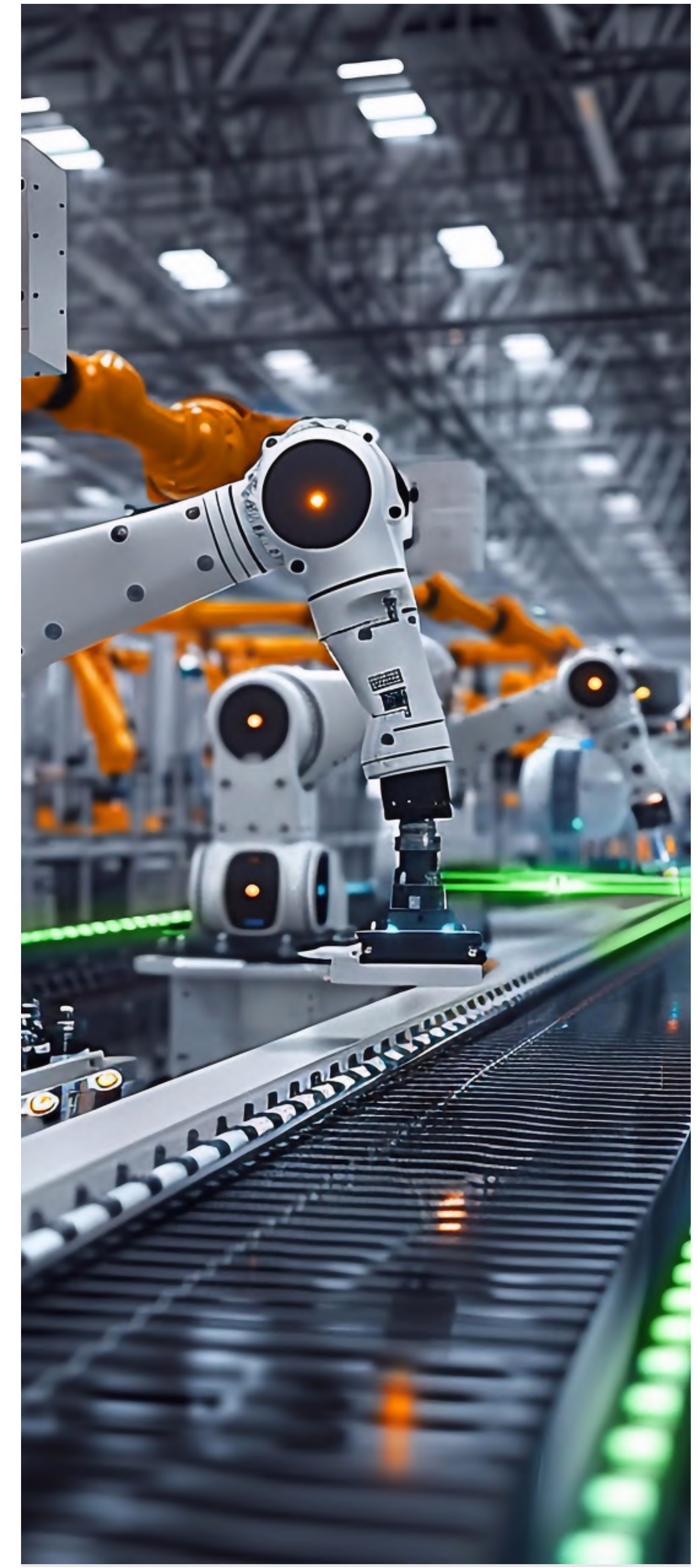


VISIT STMICROELECTRONICS

WHICH SMART SENSOR CAN I CHOOSE FOR MY APPLICATION?

This article describes embedded programmable features built-in in ST MEMS smart sensors, taking benefit of embedded features, Finite State Machine (FSM), Machine Learning Core (MLC), and Intelligent Sensor Processing Unit (ISPU), Adaptive Self Configuration (ASC) and Sensor Fusion Low Power (SFLP).

INTRODUCTION

ST MEMS motion sensors have two types of embedded features. All features mainly focus on running data processing in the sensor instead of the MCU. This results in a lower power consumption of the system. Embedded configurable features (for example, wake-up, free-fall, 4D/6D orientation) are present in most of our motion sensors. It is possible to adjust them mainly using threshold and duration. However, these features are only configurable, as the name suggests, and it is not possible to program a custom data processing. Recent ST MEMS motion sensors embed programmable features like Finite State Machine (FSM), machine learning core (MLC) or intelligent sensor processing unit (ISPU) to incorporate custom data processing into the sensor. Knowing this, we have 3 main approaches to run a custom embedded data processing based on sensor data described in the list and picture below:

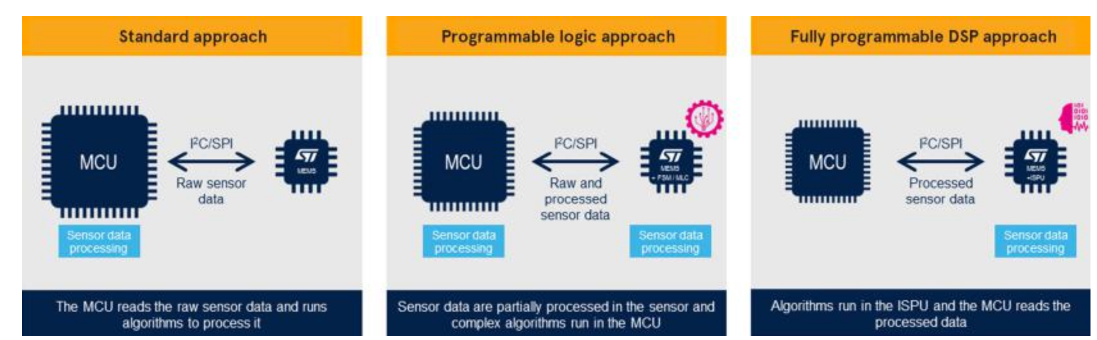
- Standard approach - MCU reads raw data provided by the sensor and desired processing is done inside the MCU,
- Programmable logic approach - targets the lowest power consumption on a specific processing model. MCU reads the model results and possibly raw data when an interrupt is triggered,
- Fully programmable DSP approach - any custom code (considering the computational and compiler limits) can be run inside the sensor and MCU reads processed data out of the sensor.

Generally, using programmable logic or fully programmable DSP approach brings the following advantages for the application:

- The power consumption of the embedded feature is distinctly lower than running the same feature inside the MCU
- Data reads from the sensor can be limited to events when interrupt is triggered → MCU can be in sleep mode the rest of the time
- Traffic on I²C/SPI bus between sensor and MCU is reduced
- Offloading the MCU - either processing time can be used for different purpose or a less expensive MCU can be used

Whatever approach selection, ST sensors propose smart features which generate fusion data (SFLP) based on accelerometer and gyroscope raw data and optimize the sensor setting (ASC).

In this article, we provide a brief introduction to smart features, including FSM and MLC (both utilizing a programmable logic approach), ISPU (employing a fully programmable DSP approach), as well as ASC and SFLP features.



FINITE STATE MACHINE (FSM)

A Finite State Machine is a behavioral model composed of finite number of states with specific transitions between states, which are similar to a flow chart able to process both internal and external data (if sensor hub is available). There are two types of states - Reset/Next Condition (RNC) and command (CMD). The RNC type of state is composed of two conditions, one to reset the state machine and one to continue the program flow. The detailed description of the RNC state is shown in the picture below. The first condition evaluated is reset. If the result is true, the state machine is reset, otherwise next condition is evaluated.

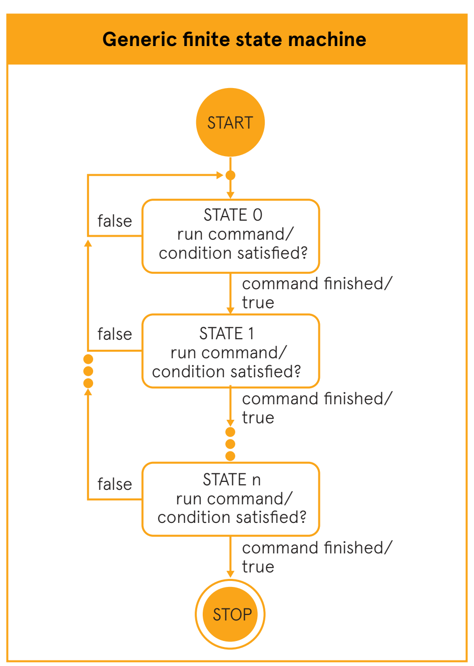
The flow continues to next state if the next condition was satisfied, otherwise the flow is paused until next sample arrives and the evaluation (both reset and next condition) is performed with a new sample. The examples of conditions for Reset/Next state types are: no operation, timers, comparison to thresholds, etc. The second type of state (CMD) executes a command to modify the program behavior in terms of flow control and output. The examples of commands are: stop execution, reset pointer set/reset, etc. An interrupt of FSM is generated when the end state is reached or when some specific command is performed.

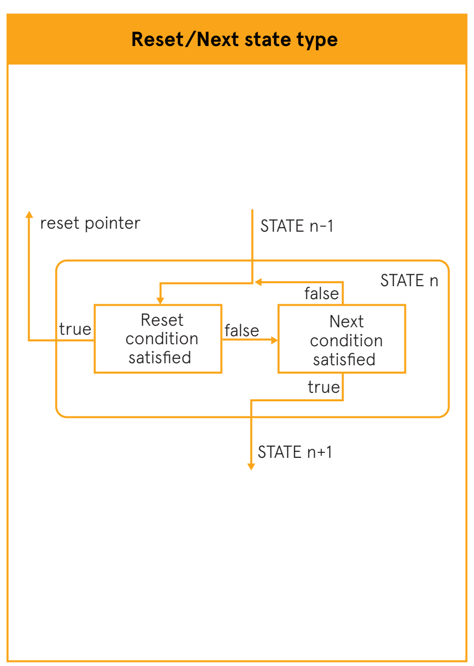
It is possible to run multiple state machines in parallel. In the picture below a simple wake-up example based on accelerometer data is shown.

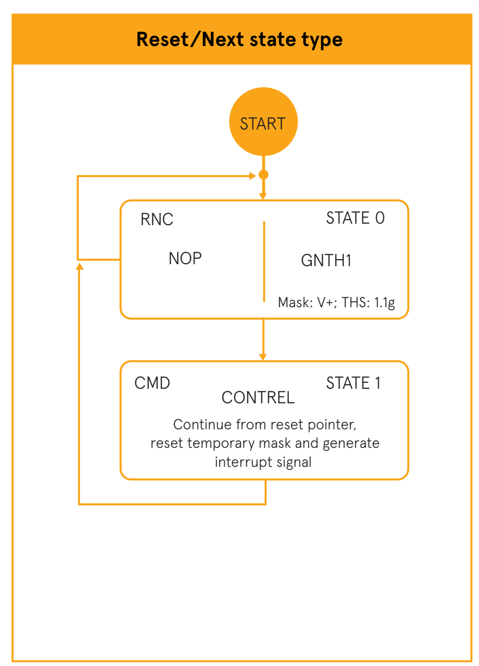
The Finite State Machine approach is most suitable for applications, where a user-defined gesture pattern needs to be recognized.

The latest ST sensors with FSM include an adaptive self-configuration (ASC). This means that the FSM interrupt can be used to trigger device setting changes (incl. ODR, FS, BW, power mode and FIFO), thus the MCU can be kept in sleep mode.

Find more information about Finite State Machine feature in ST's GitHub repository. This repository includes application and configuration examples. Application examples are available for various sensors and are ready to be uploaded into sensor and evaluated. The configuration examples are focused on providing information to configure and evaluate an own Finite State Machine using different tools provided by ST. The main software is MEMS Studio providing a dedicated tool to develop and evaluate FSM configurations.







SUPPORTED SENSORS

		FSM Finite State Machine	MLC Machine Learning Core	Sensor type	Description
Consumer	LSM6DSO	X		iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit): always-on 3-axis accelerometer and 3-axis gyroscope
Consumer	LSM6DSOX	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with embedded AI: always-on 3-axis accelerometer and 3-axis gyroscope
Consumer	LSM6DSO32	X		iNEMO-Inertial Modules	iNEMO inertial module: always-on 3D accelerometer and 3D gyroscope
Consumer	LSM6DSO32X	X	X	iNEMO-Inertial Modules	iNEMO inertial module: always-on 3D accelerometer and 3D gyroscope
Consumer	LSM6DSR	X		iNEMO-Inertial Modules	iNEMO Inertial Module: 3D Accelerometer and 3D Gyroscope
Consumer	LSM6DSRX	X	X	iNEMO-Inertial Modules	iNEMO Inertial Module with Machine Learning Core, Finite State Machine and Advanced Digital Functions for High Accuracy Applications.
Consumer	LSM6DSV	X		iNEMO-Inertial Modules	6-axis IMU with embedded sensor fusion, I3C, OIS/EIS for smart applications
Consumer	LSM6DSV16X	X	X	iNEMO-Inertial Modules	6-axis inertial measurement unit (IMU) with embedded AI and sensor fusion, Qvar for high-end applications
Consumer	LSM6DSV16B	X		iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with sensor fusion and hearable features for TWS
Consumer	LSM6DSV16BX	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with embedded sensor fusion, AI, Qvar and hearable features for TWS
Consumer	LSM6DSV32X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with 32 g accelerometer and embedded sensor fusion, AI, Qvar for high-end applications
Consumer	LIS2DUX12	X	X	Accelerometer	Ultralow-power 3-axis smart accelerometer with AI, antialiasing filter, and advanced digital features
Consumer	LIS2DUXS12	X	X	Accelerometer	Ultralow-power 3-axis smart accelerometer with Qvar, AI, antialiasing filter, and advanced digital features
Consumer	ST1VAFE6AX	X	X	Biosensor	Biosensor with vAFE (vertical analog front-end) for biopotential signals and 6-axis IMU (inertial measurement unit) with AI and sensor fusion
Consumer	ST1VAFE3BX	X	X	Biosensor	Biosensor with vAFE (vertical analog front-end) for biopotential signals and ultralow-power accelerometer with AI and antialiasing
Industrial	ISM330DHCX	X	X	iNEMO-Inertial Modules	iNEMO inertial module with Machine Learning Core, Finite State Machine with digital output for industrial applications.
Industrial	IIS2ICLX	X	X	Accelerometer	High-accuracy, High-resolution, Low-power, 2-axis Digital Inclinometer with Embedded Machine Learning Core
Industrial	ISM330BX	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with wide bandwidth, low-noise accelerometer, embedded AI and sensor fusion for industrial applications
Automotive	ASM330LHHX	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis automotive inertial measurement unit (IMU) with embedded machine learning core and dual operating modes
Automotive	ASM330LHHXG1	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis automotive inertial measurement unit (IMU) with embedded machine learning core and dual operating modes
Automotive	ASM330LHB	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis inertial measurement unit (IMU) for ASIL B automotive applications
Automotive	ASM330LHBG1	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis inertial measurement unit (IMU) with extended temperature range for ASIL B automotive applications

MACHINE LEARNING CORE (MLC)

The machine learning core is composed of a set of configurable parameters (also called features) and decision trees. A decision tree is represented as a binary tree composed from two types of nodes - inner nodes and leaves. Inner node of a decision tree is a node, which has child nodes. Since the decision tree inside the MLC is a binary tree, the number of children is two. Inner nodes represent a part of decision tree, where a statistical parameter automatically calculated from raw sensor data is compared to a threshold (if-then-else) in order to choose next path, which can be either a true or false path. A leaf node of decision tree is a node, which does not have any children nodes and contains one of user defined classes - result. A brief description of a decision tree with an Activity/Inactivity example using only accelerometer data can be seen in picture below.

The statistical parameters, which are compared against a threshold within inner nodes of a decision tree, are parameters selected by the user (for example, mean, variance, etc.) in defined time window from available sensor data - both internal and external data (if sensor hub is available).

The parameters selected by user are evaluated during decision tree training. After the training, only statistically relevant parameters are included in the final decision tree.

To use machine learning core capability, it is necessary to use supervised learning approach. This includes following steps described below:

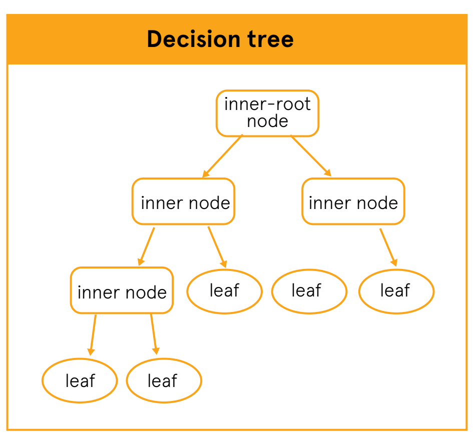
- Define the classes to be recognized, at the same time covering all possible options
- Log sufficient amount of training data for each class
- Choose different parameters for each class (this can be an iterative process as it is not guaranteed to find the most suitable parameters during the first iteration)
- Create the decision tree using relevant software tool
- Transform trained decision tree into configuration to be loaded into sensor

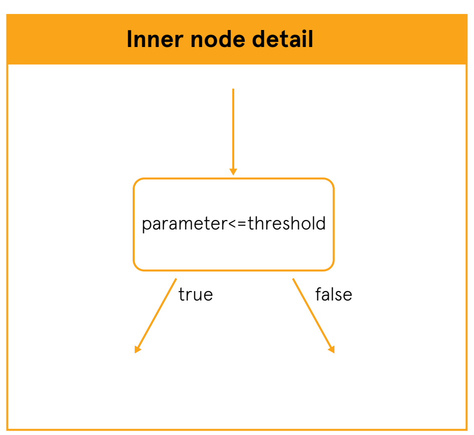
ST's MEMS software package MEMS Studio includes an MLC tool, which guides the user through the whole process of creating a decision tree - from labeling the data logs up to creating a configuration file for specific sensor.

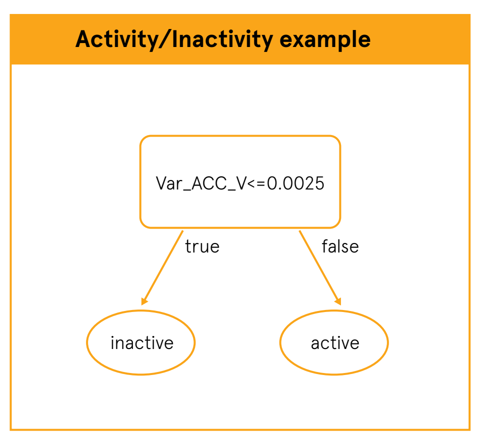
Suitable applications are the ones, which can be implemented by following an inductive approach, which involves searching patterns from observations.

This includes application as: activity recognition, fitness activity recognition, motion intensity detection, vibration intensity detection, carrying position recognition, context awareness, etc.

More information about MLC enabled sensors can be found at st.com/MLC, or ST's MLC GitHub repository. The MLC repository includes application examples ready to be evaluated for various sensors and configuration examples with different ST's hardware and software tools to guide you through a process of making a decision tree. The main software is MEMS Studio providing a dedicated tool to develop and evaluate MLC configurations.







SUPPORTED SENSORS

		FSM Finite State Machine	MLC Machine Learning Core	Sensor type	Description
Consumer	LSM6DSOX	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with embedded AI: always-on 3-axis accelerometer and 3-axis gyroscope
Consumer	LSM6DSO32X	X	X	iNEMO-Inertial Modules	iNEMO inertial module: always-on 3D accelerometer and 3D gyroscope
Consumer	LSM6DSRX	X	X	iNEMO-Inertial Modules	iNEMO Inertial Module with Machine Learning Core, Finite State Machine and Advanced Digital Functions for High Accuracy Applications.
Consumer	LSM6DSV16X	X	X	iNEMO-Inertial Modules	6-axis inertial measurement unit (IMU) with embedded AI and sensor fusion, Qvar for high-end applications
Consumer	LSM6DSV16BX	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with embedded sensor fusion, AI, Qvar and hearable features for TWS
Consumer	LSM6DSV32X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with 32 g accelerometer and embedded sensor fusion, AI, Qvar for high-end applications
Consumer	LIS2DUX12	X	X	Accelerometer	Ultralow-power 3-axis smart accelerometer with AI, antialiasing filter, and advanced digital features
Consumer	LIS2DUXS12	X	X	Accelerometer	Ultralow-power 3-axis smart accelerometer with Qvar, AI, antialiasing filter, and advanced digital features
Consumer	ST1VAFE6AX	X	X	Biosensor	Biosensor with vAFE (vertical analog front-end) for biopotential signals and 6-axis IMU (inertial measurement unit) with AI and sensor fusion
Consumer	ST1VAFE3BX	X	X	Biosensor	Biosensor with vAFE (vertical analog front-end) for biopotential signals and ultralow-power accelerometer with AI and antialiasing
Industrial	ISM330DHCX	X	X	iNEMO-Inertial Modules	iNEMO inertial module with Machine Learning Core, Finite State Machine with digital output for industrial applications.
Industrial	IIS2ICLX	X	X	Accelerometer	High-accuracy, High-resolution, Low-power, 2-axis Digital Inclinometer with Embedded Machine Learning Core
Industrial	ISM330BX	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with wide bandwidth, low-noise accelerometer, embedded AI and sensor fusion for industrial applications
Automotive	ASM330LHHX	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis automotive inertial measurement unit (IMU) with embedded machine learning core and dual operating modes
Automotive	ASM330LHHXG1	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis automotive inertial measurement unit (IMU) with embedded machine learning core and dual operating modes
Automotive	ASM330LHB	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis inertial measurement unit (IMU) for ASIL B automotive applications
Automotive	ASM330LHBG1	X	X	iNEMO-Inertial Modules	High-accuracy 6-axis inertial measurement unit (IMU) with extended temperature range for ASIL B automotive applications

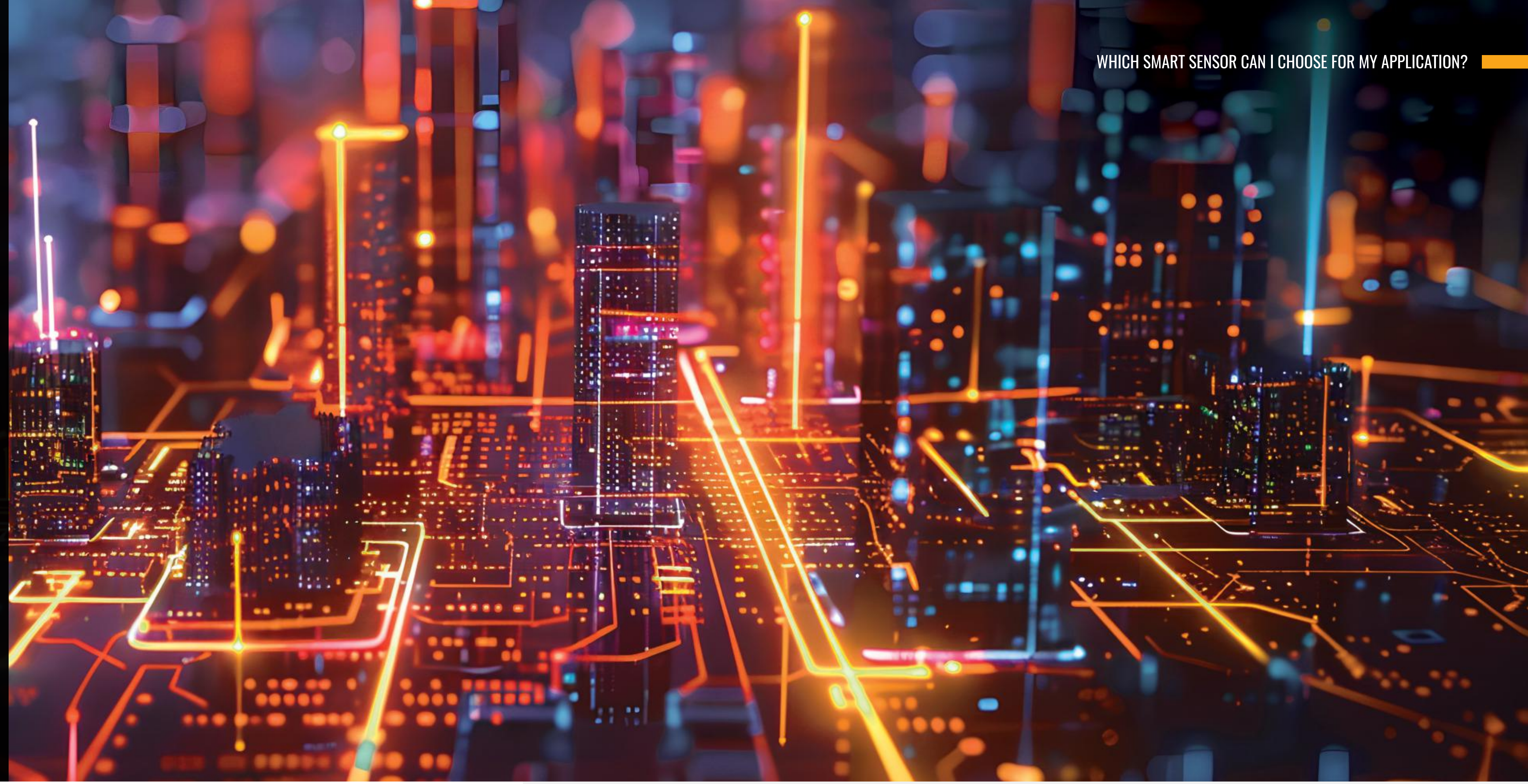
INTELLIGENT SENSOR PROCESSING UNIT (ISPU)

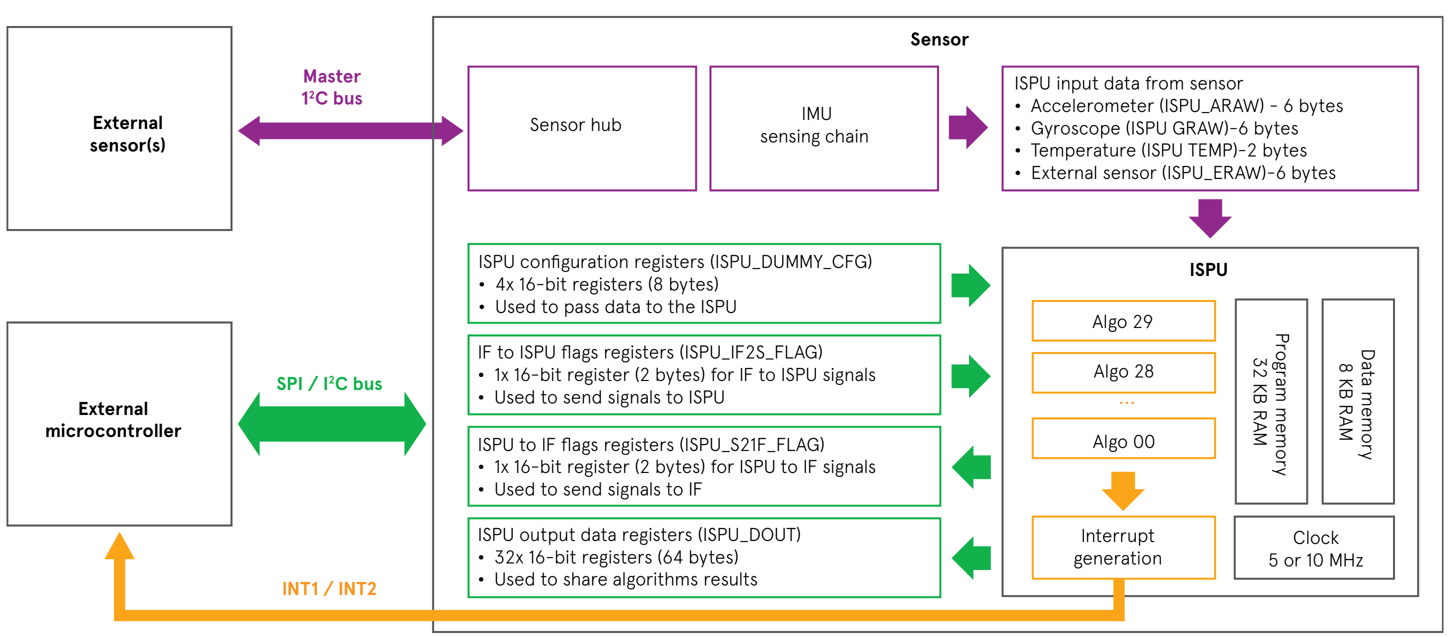
The ISPU is a compact, ultra-low-power and high-performance programmable core based on the STRED architecture, a proprietary architecture developed by STMicroelectronics. This core allows processing both internal (accelerometer, gyroscope and temperature) and external (connected through sensor hub to the sensor) data in up to 30 separate, user defined algorithms. The algorithms are executed each time a new set of data is sampled starting from algorithm 29 down to algorithm 0. The ISPU is supported by two separate RAMs - 32 KB for code and 8 KB for variable data and the clock can be set to run either at 5 or 10 MHz.

The picture below contains a scheme describing the processing of data and connection of sensor to microcontroller and external sensors.

The ISPU can run C language algorithms that can be compiled by ISPU toolchain, or anomaly detection library can be generated using NanoEdge AI Studio (offered for ISM330ISN). The X-CUBE-ISPU software package includes examples (including calibration algorithms, sensor fusion, wrist solutions, etc.) ready to be evaluated, a blank template project to be used for a new custom embedded feature, integration examples of anomaly detection projects and data log firmware to be used with MEMS Studio. X-CUBE-ISPU package is available at st.com or ST's GitHub page.

More information about ISPU sensor family can be found at st.com/ISPU.





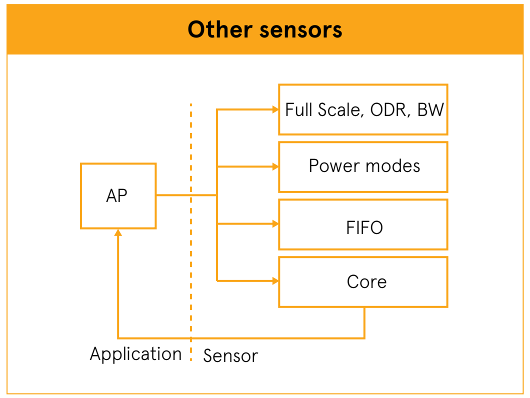
SUPPORTED SENSORS

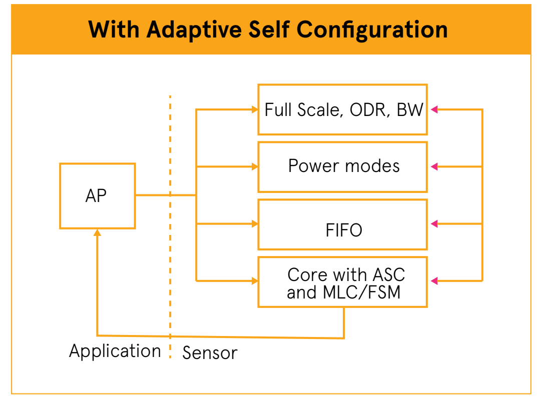
		ISPU Intelligent Sensor Processing Unit	Sensor type	Descritpion
Consumer	LSM6DSO16IS	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit): always-on 3-axis accelerometer and 3-axis gyroscope with ISPU (intelligent sensor processing unit)
Industrial	ISM330IS	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit): always-on 3-axis accelerometer and 3-axis gyroscope with ISPU - intelligent sensor processing unit
Industrial	ISM330ISN	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit): always-on 3-axis accelerometer and 3-axis gyroscope with ISPU - intelligent sensor processing unit (can execute the machine learning libraries)

ADAPTIVE SELF CONFIGURATION (ASC)

The ASC feature modifies Sensor setting automatically (such as ODR, Power Modes, etc.) based on the events detected by the FSM.
This enables sensor to always run in the optimized setting.

There is no MCU interaction intervention, no additional current consumption





SENSOR FUSION LOW POWER (SFLP)

The SFLP is a dedicated sensor fusion bloc, ultra-low-power and high-performance generating fusion data; SFLP is integrating data from accelerometer and gyroscope to produce more accurate, reliable, and comprehensive information:

- Game rotation vector, which provides a quaternion representing the attitude of the device
- Gravity vector, which provides a three-dimensional vector representing the direction of gravity
- Gyroscope bias, which provides a three-dimensional vector representing the gyroscope bias

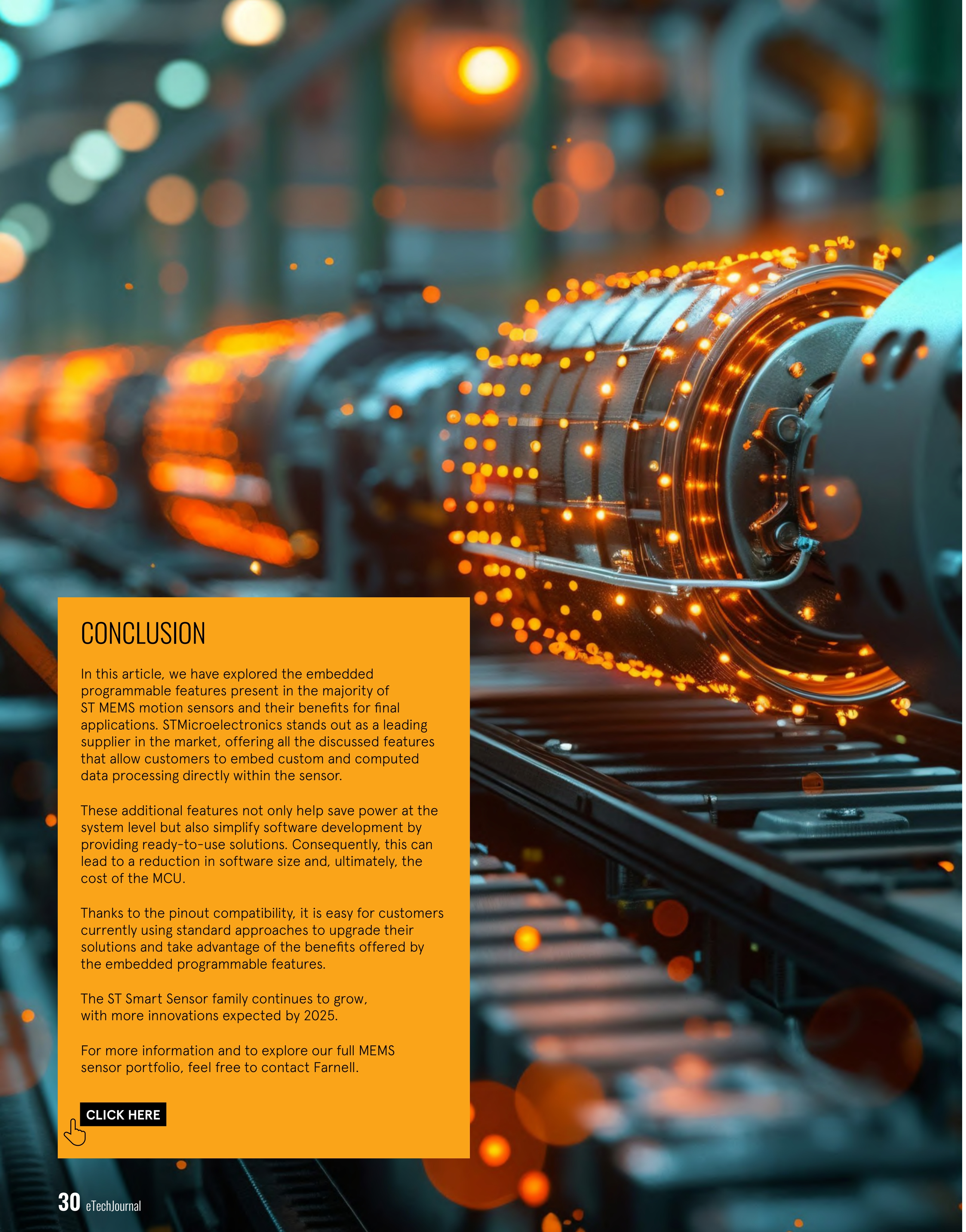
SFLP extra power: 30µA @120Hz in the edge with 50% power reduction vs. external MCU processing used as a reference.

SUPPORTED SENSORS

		FSM Finite State Machine	MLC Machine Learning Core	ASC Adaptive Self Configuration	Sensor type	Description
Consumer	LSM6DSV16X	X	X	X	iNEMO-Inertial Modules	6-axis inertial measurement unit (IMU) with embedded AI and sensor fusion, Qvar for high-end applications
Consumer	LSM6DSV16BX	X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with embedded sensor fusion, AI, Qvar and hearable features for TWS
Consumer	LSM6DSV32X	X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with 32 g accelerometer and embedded sensor fusion, AI, Qvar for high-end applications
Consumer	LIS2DUX12	X	X	X	Accelerometer	Ultralow-power 3-axis smart accelerometer with AI, antialiasing filter, and advanced digital features
Consumer	LIS2DUXS12	X	X	X	Accelerometer	Ultralow-power 3-axis smart accelerometer with Qvar, AI, antialiasing filter, and advanced digital features
Industrial	ISM330BX	X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with wide bandwidth, low-noise accelerometer, embedded AI and sensor fusion for industrial applications

SUPPORTED SENSORS

		FSM Finite State Machine	MLC Machine Learning Core	SFLP Sensor Fusion Low Power	Sensor type	Description
Consumer	LSM6DSV16X	X	X	X	iNEMO-Inertial Modules	6-axis inertial measurement unit (IMU) with embedded AI and sensor fusion, Qvar for high-end applications
Consumer	LSM6DSV16BX	X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with embedded sensor fusion, AI, Qvar and hearable features for TWS
Consumer	LSM6DSV32X	X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with 32 g accelerometer and embedded sensor fusion, AI, Qvar for high-end applications
Consumer	ST1VAFE6AX	X	X	X	Biosensor	Biosensor with vAFE (vertical analog front-end) for biopotential signals and 6-axis IMU (inertial measurement unit) with AI and sensor fusion
Industrial	ISM330BX	X	X	X	iNEMO-Inertial Modules	6-axis IMU (inertial measurement unit) with wide bandwidth, low-noise accelerometer, embedded AI and sensor fusion for industrial applications



CONCLUSION

In this article, we have explored the embedded programmable features present in the majority of ST MEMS motion sensors and their benefits for final applications. STMicroelectronics stands out as a leading supplier in the market, offering all the discussed features that allow customers to embed custom and computed data processing directly within the sensor.

These additional features not only help save power at the system level but also simplify software development by providing ready-to-use solutions. Consequently, this can lead to a reduction in software size and, ultimately, the cost of the MCU.

Thanks to the pinout compatibility, it is easy for customers currently using standard approaches to upgrade their solutions and take advantage of the benefits offered by the embedded programmable features.

The ST Smart Sensor family continues to grow, with more innovations expected by 2025.

For more information and to explore our full MEMS sensor portfolio, feel free to contact Farnell.

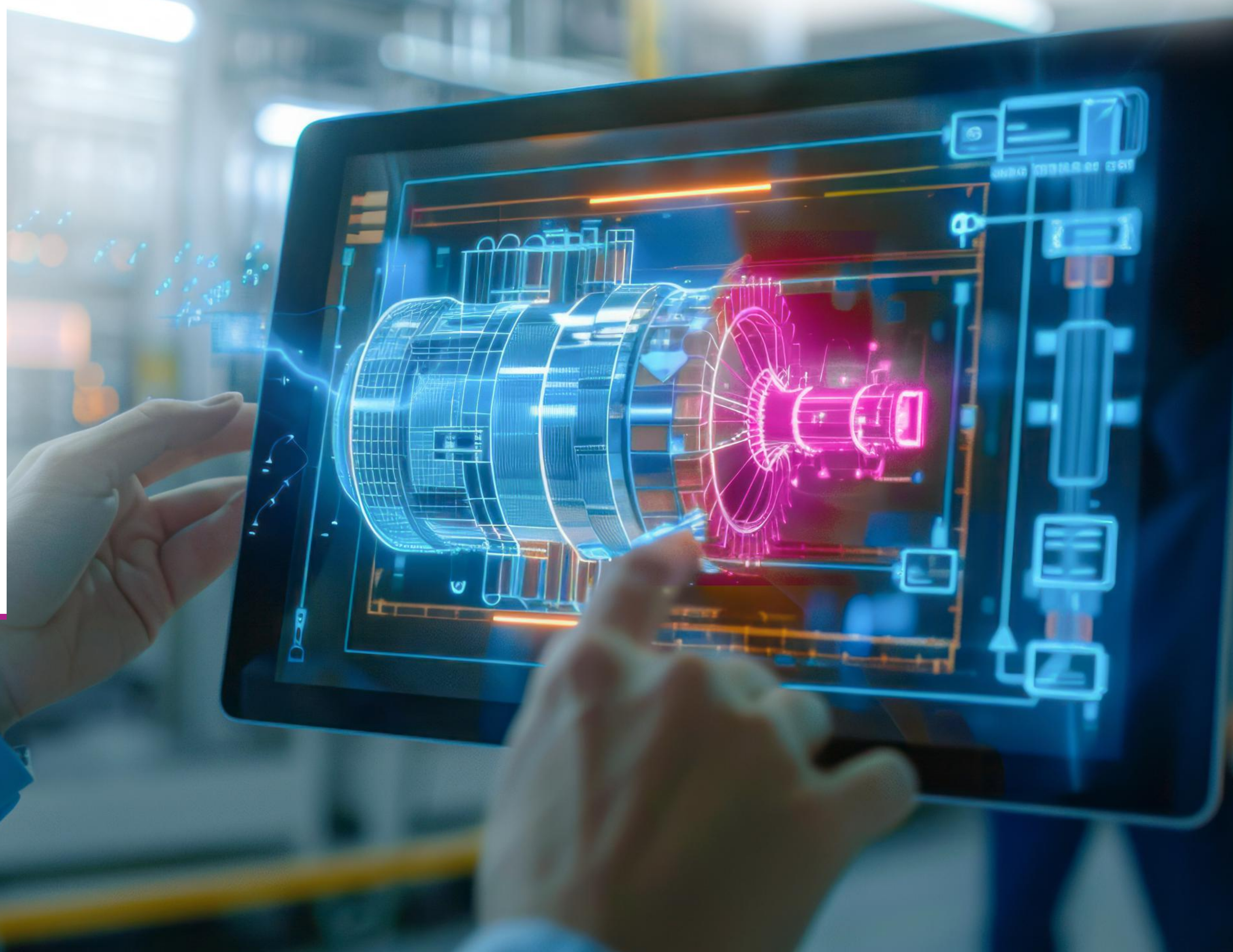
CLICK HERE

HOW TO DESIGN A MEMS VIBRATION SENSOR FOR PREDICTIVE MAINTENANCE

In the past, checking for problems and expert analysis took a lot of time and made maintenance expensive.

Modern sensors have transformed predictive maintenance by offering real-time monitoring and early fault detection, which is crucial for large-scale operations. These sensors work seamlessly with Computerized Maintenance Management Systems (CMMS), providing high accuracy, reliability, and robust real-time data processing.

To be effective, sensors must be durable under harsh conditions and have low power consumption. Key parameters for analyzing machine vibrations include output speed, turbulence, cavitation, and bearing elements. Proper sensor orientation is important. Single-axis sensors align with linear vibrations, while multi axis sensors detect vibrations in all directions but may have higher noise levels. This article explains the essential features sensors need for predictive maintenance in industrial environments.



FACTORS TO BE CONSIDERED WHEN DESIGNING SENSORS FOR PREDICTIVE MAINTENANCE

Several critical factors must be considered when designing sensors for predictive maintenance to ensure their effectiveness and reliability.

- High accuracy and reliability: Sensors must detect early signs of equipment failure with high accuracy and reliability.
- Robust data processing and integration: Robust real-time data processing capabilities are essential. Sensors should integrate seamlessly with existing maintenance systems to provide actionable insights.
- Durability and low power consumption: Durability in harsh conditions and low power consumption are also crucial for sustained operation.

WIDE FREQUENCY RESPONSE

A wide frequency response is essential for vibration sensors used in predictive maintenance. This allows the detection of a broad spectrum of vibration frequencies, which is vital for identifying various equipment faults. The key points include:

By addressing these factors, sensors can significantly enhance maintenance processes, improve efficiency, and ensure safety in large-scale operations.

MEASUREMENT RESOLUTION AND DYNAMIC RANGE

The measurement resolution of a vibration sensor depends on the amplitude of the output relative to the broadband noise of its onboard electronics. Sensors with superior signal output can detect more minor vibration levels in machinery, enabling earlier fault prediction compared to sensors with lower dynamic ranges. Environmental conditions, EMI/RFI interference, Data acquisition interface quality, and cable length influence measurement resolution and should be carefully considered during installation. To ensure reliable measurements, the output signal should be at least ten times higher than the sensor's noise level. This can be calculated using the following equation:

RESOLUTION (g's) = BROADBAND NOISE (V) / SENSOR SENSITIVITY (V/g) --- Eq 1

LONG-TERM STABILITY WITH MINIMUM DRIFT

Long-term drift refers to changes in a sensor's sensitivity and zero output measurements. Zero output drift is particularly relevant for MEMS sensors. Shifts in sensitivity or zero output can cause false alarms in monitoring applications. Stability is crucial for reliable monitoring, providing accurate data to detect subtle changes in vibration patterns that could indicate potential faults. Minimal drift reduces the need for frequent recalibration, lowering maintenance costs and minimizing downtime.

LOW NOISE

Low noise is essential for enhancing measurement accuracy and data reliability. Low-noise sensors minimize electrical and environmental interference, allowing for precise detection of subtle vibrations and early signs of equipment faults. This clarity improves the sensor's ability to distinguish between normal operational vibrations and potential issues, reducing the likelihood of false alarms and unnecessary maintenance actions. High-quality, low-noise data supports accurate predictive modelling and effective maintenance decisions, ensuring the sensor remains reliable and efficient.

OPERATING TEMPERATURE RANGE

The typical operating temperature of piezoelectric sensors is within -500C to 2000 °C, and Variable Capacitance MEMS vibration sensors typically operate within a temperature range of -40°C to +125°C, which is suitable for condition monitoring applications. However, charge mode piezoelectric sensors without onboard charge converter circuits are recommended for extreme requirements requiring higher temperature tolerance (exceeding +700°C). Piezoelectric sensors offer higher temperature limits with specialized materials, and variable capacitance sensors provide stability across a wide range of temperatures, making them versatile in various industrial and scientific applications.

PACKAGING OPTIONS

Sensors' size and mounting options are crucial when selecting a sensor for embedded predictive maintenance, especially for smaller machinery. While larger machinery often uses externally mounted TO-5 stud sensors, smaller machinery with compact bearings and shafts requires embedded or miniature sensors.

Variable Capacitance MEMS sensors are commonly available in SMT mount packages, which are ideal for high-volume PCB assembly. These sensors also come in tiny packages, offering flexibility in packaging options.

Piezoelectric (PE) sensors come in various configurations. SMT mount versions are available, like Variable Capacitance MEMS, although they are typically larger. Additionally, PE sensors are offered in rugged TO-5 can packages with stainless-steel housings, allowing direct mounting to bearing housings or embedded installations.

SENSOR OUTPUT OPTIONS

Selecting the right sensor output signal depends on the installation and application requirements. In most current predictive maintenance setups, an analog signal from the sensor is essential, allowing end users to monitor specific machinery parameters. The signal output, commonly driven by DAQ or PLC interfaces, typically uses analog outputs such as ±2V or ±5V. Alternatively, loop-powered 4-20mA sensors are frequently employed for installations needing long cable lengths.

Predictive maintenance (PdM) systems require high-performance sensors to ensure reliable asset operation. The performance of these sensors is linked to the importance of the asset rather than its cost. Motor vibration analysis (measuring peak, peak-to-peak, RMS) can detect issues like imbalance or misalignment. However, early-stage faults like bearing or gear defects need high-performance vibration sensors. These sensors should have low noise (<100 µg/√Hz) and wide bandwidth (>5 kHz) to detect these faults effectively. They must also be used with a high-performance signal chain, processing, transceivers, and post-processing systems.

AI-DRIVEN ANOMALY DETECTION FOR INDUSTRIAL HVAC SYSTEMS

Industrial HVAC systems are essential for maintaining comfortable and climate-controlled environments in office buildings, industrial facilities, and commercial living spaces. However, the complexity of modern equipment and compatibility issues with legacy systems can lead to costly failures and downtime, disrupting business operations and tenant satisfaction.

To address these challenges, Infineon, in collaboration with Klika Tech and AWS, has developed an advanced solution that leverages AI and TinyML at the edge. This solution integrates Infineon's high-precision XENSIV™ sensors, XMC™ microcontrollers, and OPTIGA™ Trust security solutions to monitor HVAC system performance in real time.

Working: The system continuously monitors HVAC systems using Infineon's XENSIV™ sensors, which collect real-time data. This data is processed by a TinyML model that immediately detects any anomalies, identifying potential issues as they occur. When an anomaly is detected, the system compiles the relevant sensor data and transmits it to a cloud-based AI solution.

The AI then analyzes the data, generating actionable insights and potential solutions. These insights empower businesses to proactively manage and address issues, effectively minimizing downtime and preventing costly failures.

KEY BENEFITS:

- **Preventative maintenance**: By identifying issues early, the system helps prevent unexpected failures, reducing the risk of operational disruptions.
- **Enhanced system performance**: Continuous monitoring ensures HVAC systems operate efficiently, maintaining optimal environmental conditions.
- **Seamless integration**: The solution is designed to work with both modern and legacy HVAC systems, providing a versatile and robust approach to anomaly detection.

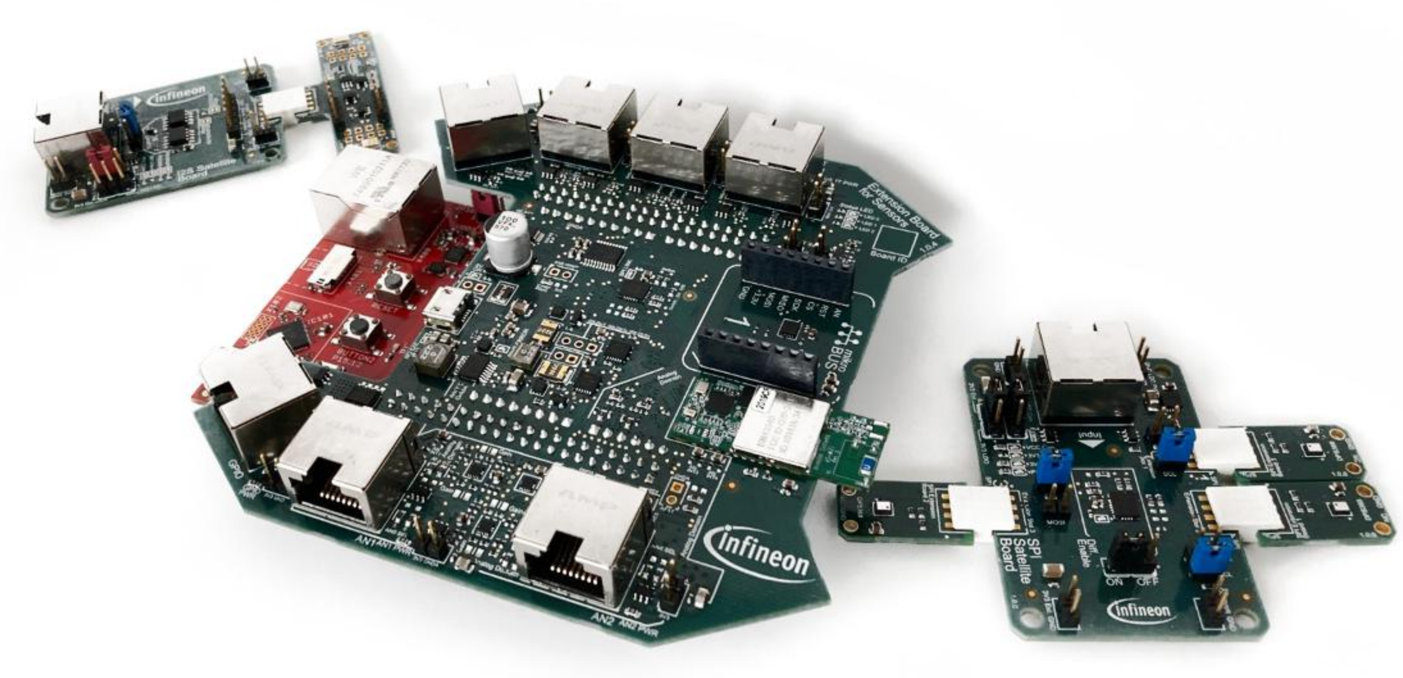
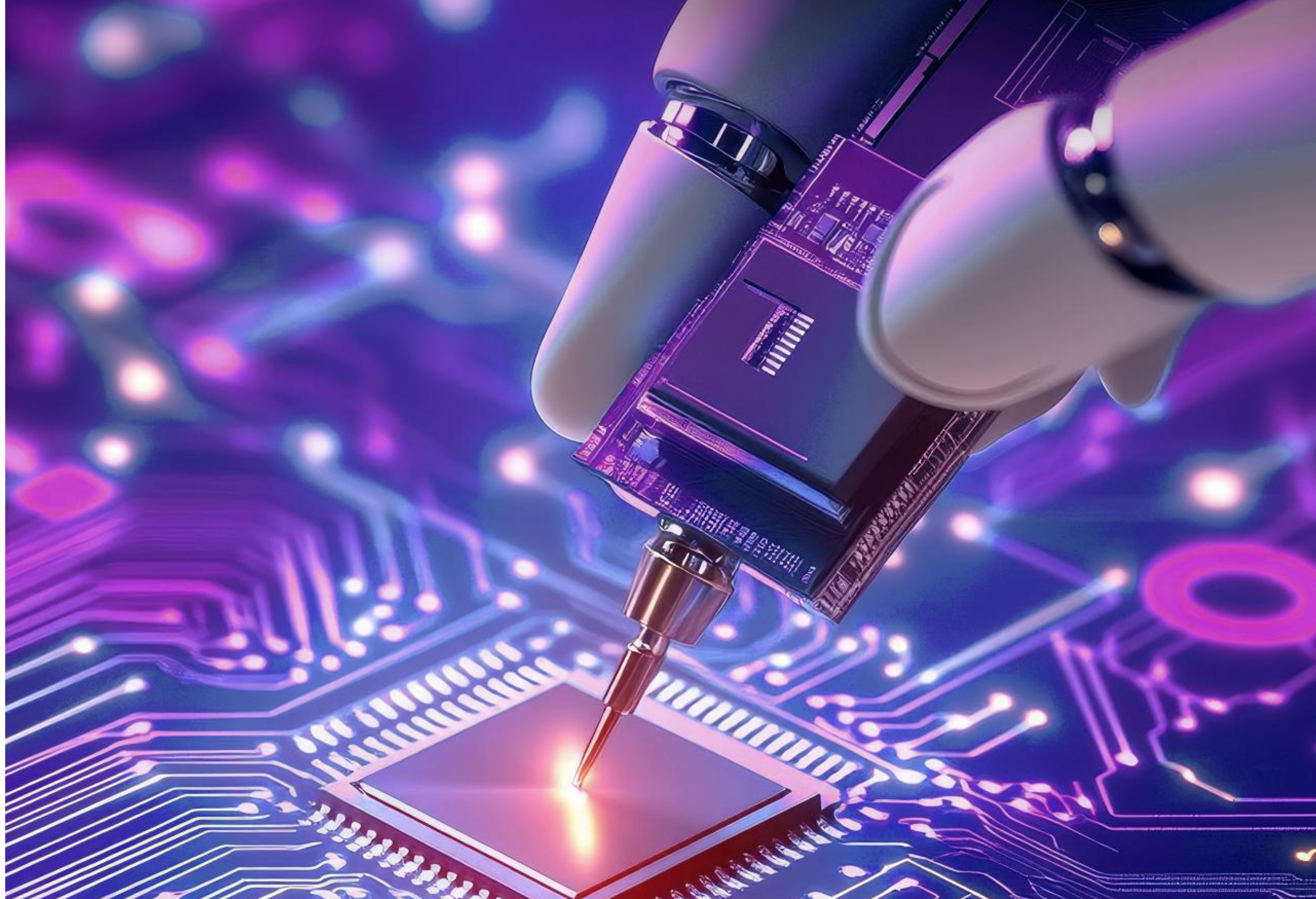


Figure 1 – XENSIV™ PdM Evaluation Kit (Source: infineon)



CONCLUSION

Modern predictive maintenance relies on advanced sensors to provide real-time monitoring and early fault detection, enhancing efficiency and safety in industrial operations. Key factors for effective sensors include wide frequency response, high measurement resolution, minimal long-term drift, and robust performance in harsh conditions. MEMS-based accelerometers are particularly advantageous due to their high resolution, low power consumption, and integration capabilities. These advancements in sensor technology streamline maintenance processes and improve operational reliability.

Head over to our website to discover the full range of sensor solutions tailored for extreme conditions or visit our Technical Resource Hub for in-depth technical insights, application notes, and product guides.

CLICK HERE

SENSORS FOR **HARSH INDUSTRIAL** ENVIRONMENTS

Sensors deployed in industrial environments must contend with a range of severe conditions that can impact their performance and reliability.

These conditions include exposure to moisture, high humidity, extreme temperatures, airborne particulates, electrostatic discharge (ESD), electromagnetic interference (EMI), vibrations, and physical impacts. Designing sensor systems for such harsh environments requires a comprehensive understanding of these challenges and their specific applications. For example, in the oil and gas sector, rotary encoders are essential for providing accurate feedback on machinery situated near wellbores, where the presence of flammable agents poses significant risks.

Similarly, sensors play a critical role in environments such as paint spray booths with volatile fumes, explosive dust conditions in grain silos, chemical, and explosives factories, and even cosmetic manufacturing facilities where fine powders are highly flammable.This article has sensors suitable for industrial applications. Effectively addressing these challenges is crucial for ensuring the robustness and reliability of sensor systems in demanding industrial settings.

ASSESSING HARSH ENVIRONMENTS IN THE INDUSTRIAL SECTOR

It involves a comprehensive evaluation of various environmental factors that can impact equipment and operations. This includes measuring temperature extremes, humidity levels, dust and particulates, corrosive substances, vibrations, shocks, radiation, and pressure conditions. Ensuring material compatibility, adequate sealing, and the durability of equipment is crucial. Assessing the operational impact involves determining maintenance requirements, identifying potential failure modes, and evaluating operational efficiency. Implementing monitoring systems with sensors and IoT devices for real-time data analysis and alerts is essential. Regular inspections and testing, protective measures like coatings, insulation, and dust-proofing, and thorough employee training and safety protocols are critical. Compliance with regulatory standards like, IP65 offers protection against dust ingress (dust-tight) and low-pressure water jets from any direction, while IP66 enhances this with protection against powerful water jets.

IP67 provides complete dust protection and safeguards against immersion in water up to 1-meter depth for a limited time. For even more demanding conditions, IP68 offers full dust protection and continuous immersion in water under manufacturer-specified conditions. The IP69K rating is designed for environments requiring close-range, high-pressure, and high-temperature water jets, making it ideal for applications with rigorous cleaning procedures, and obtaining necessary certifications ensures adherence to industry norms. Utilizing tools such as environmental chambers, predictive maintenance kits, and software solutions for data analysis and reporting helps in maintaining operational efficiency and mitigating risks in harsh environments.

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IP67 provides complete dust protection and safeguards against immersion in water up to 1-meter depth for a limited time. For even more demanding conditions, IP68 offers full dust protection and continuous immersion in water under manufacturer-specified conditions. The IP69K rating is designed for environments requiring close-range, high-pressure, and high-temperature water jets, making it ideal for applications with rigorous cleaning procedures, and obtaining necessary certifications ensures adherence to industry norms. Utilizing tools such as environmental chambers, predictive maintenance kits, and software solutions for data analysis and reporting helps in maintaining operational efficiency and mitigating risks in harsh environments.

SELECTION OF APPROPRIATE SENSORS FOR HARSH INDUSTRIAL ENVIRONMENT

Sensors are vital in maintaining harsh environments by providing critical data for monitoring, controlling, and optimizing conditions. They help ensure safety, protect equipment, comply with regulations, and enhance operational efficiency. Industrial environments pose unique challenges, such as exposure to flammable gases, explosive dust, and extreme conditions. By leveraging sensor technology, industries can effectively manage challenging conditions and mitigate associated risks. Here are some types of sensors designed to withstand such harsh industrial conditions:

- Pressure sensors: Pressure sensors can be implemented to monitor the liquid level or gas pressure accurately in continuously varying applications. They are essential for industrial process control, HVAC systems, and industrial pumps and compressors. Their durability allows them to withstand severe media, such as contaminated water and mildly corrosive fluids, ensuring reliable performance. In industrial settings, pressure sensors provide precise process control and monitoring, optimizing pumps, compressors, and pneumatic and hydraulic systems. These sensors need to be built with durable materials such as stainless steel or titanium to withstand harsh conditions, including exposure to corrosive substances, high temperatures, and mechanical shocks. High IP (Ingress Protection) and NEMA (National Electrical Manufacturers Association) ratings ensure protection against dust, water, and other contaminants, making the sensors suitable for harsh industrial environments. Sensors should provide output signals (e.g., 4-20 mA, 0-10 V, digital interfaces like I2C or SPI) compatible with industrial control systems, ensuring easy integration into existing infrastructure.
- Vibration sensors: Each piece of equipment has a unique vibration signature for regular operation. Accelerometers monitor both the magnitude and frequency of equipment vibrations. An increase in the magnitude of vibration or the occurrence of vibrations at higher or different frequencies indicates a change in the equipment's vibration signature. Vibration sensors measure slight changes in vibration, ensuring efficient factory operations. Electromagnetic and radio-frequency interference (EMI/RFI) can be significant in industrial environments. Vibration should be shielded to prevent interference from affecting their performance. Sensors can be embedded within controls and equipment using board-mountable accelerometers or mounted externally with ruggedized and sealed plug-and-play or wireless accelerometers to be functional in a harsh environment.
- Temperature sensors: In harsh environments, temperature sensors monitor vital equipment components, such as stator windings and bearings, to detect signs of wear, overload, or potential failure. This early detection helps prevent premature equipment failure and reduces downtime. By maintaining optimal temperature levels, these sensors ensure reliable operation and extend equipment life. Non-contact sensors like infrared thermopiles are used for applications where physical contact with machinery is impractical, such as rotating equipment. Industrial temperature sensors must be capable of measuring across a broad range of temperatures, from extreme cold to very high heat, making them suitable for various applications like metal processing, chemical manufacturing, and power generation.
- Humidity sensors: When used alongside temperature sensors, humidity sensors play a key role in controlling industrial processes involving volatile substances like paints, solvents, and inks. Proper humidity control is essential for process efficiency and product quality. Industrial humidity sensors must be designed to resist condensation, which can occur in environments with high humidity and rapidly changing temperatures. This feature prevents sensor malfunction or degradation over time. Industrial humidity sensors often have a fast response time, allowing them to quickly adjust to changes in humidity levels, which is important in dynamic industrial processes.
- Position sensors: Position sensors are essential for maintaining safety and efficiency in harsh environments by providing accurate feedback for monitoring and controlling various types of industrial machinery, such as drilling equipment, CNC machines, industrial robotics, and automation systems. Anisotropic Magneto Resistive (AMR) position sensors are particularly effective in these conditions due to their accuracy and reliability and their insensitivity to temperature fluctuations and magnetic field changes. Additionally, other technologies like linear variable differential transformers (LVDTs), precision potentiometers, and cable extension sensors (e.g., string pots) are used to address specific position-sensing needs in industrial applications. These sensors ensure precise control and operation even in the most challenging and harsh environments.
- Fluid property sensors: In harsh industrial environments, fluid property sensors are essential for monitoring lubricants and oils used in equipment. They ensure effective lubrication, which is vital for efficient machine operation and equipment longevity. These sensors are housed in rugged packaging to cope with challenging conditions like dirt, vibration, and temperature swings, ensuring accurate, reliable data and long-term performance despite harsh exposures.

SENSOR REQUIREMENTS FOR HARSH ENVIRONMENTS

When designing sensor applications for harsh environments, engineers must carefully consider the specific conditions in which each sensor will operate. Effective design ensures that sensors can handle extreme temperatures, pressures, vibrations, and corrosive elements while providing accurate and reliable data. Here's a structured approach to selecting the right sensors for these challenging conditions:

Sensing requirements

- Objective: Identify what needs to be sensed—process parameters (temperature, pressure, flow), object presence, distance, or position.

Environmental conditions

- Suitability: Ensure the sensor is designed to withstand the unique environmental conditions of the application, such as high temperatures, corrosive substances, or extreme vibrations.

Measurement range

- Limits: Verify the sensor's measurement range and ensure it accommodates the expected target values.

Control interface

- Compatibility: Determine the type of controller interface and switching logic required for integration.

Resolution

- Granularity: Assess the sensor's resolution to ensure it meets the precision needs of the application.

Target composition

- Material: Consider the material composition of the substance being sensed (e.g., metal, plastic) to ensure compatibility.

Repeatability

- Consistency: Ensure the sensor consistently measures the same variable under identical conditions.

Form factor

- Space: Evaluate the physical space available and choose a sensor that fits the application's constraints.

Special requirements

- Additional Needs: Account for any specific requirements, such as protecting piezoelectric crystals in vibration transducers from excessive stress.

PACKAGING OF SENSORS FOR PROTECTION IN HARSH ENVIRONMENTS

In harsh environments, effective packaging and environmental isolation of sensors are crucial for ensuring their reliable performance. Proper packaging protects the sensor components from extreme conditions while maintaining connectivity to external systems. Sensors must be designed to withstand exposure to corrosive substances, high temperatures, and mechanical stresses while remaining in contact with the medium they measure. For example, miniaturized pressure sensors are engineered to endure aggressive environments, including exposure to strong oxidizers like halogens in automotive or medical applications and chlorine in wearables used in swimming pools or seawater. Without robust packaging, sensors risk corrosion and failure, impacting their functionality and reliability. Therefore, choosing the right materials and designs for packaging is essential to protect sensors from environmental damage and ensure accurate and long-lasting operation.

USE CASE OF IN-PIPE TEMPERATURE MEASUREMENT WITH OMEGA'S HANI HIGH ACCURACY, NON-INVASIVE CLAMP TEMPERATURE SENSOR

A stainless-steel pipe with flowing water was used, fitted with an immersion RTD probe and a surface RTD sensor, as shown in Figures 1 & 2, to set up an experiment. This experiment compares the performance of the HANI High-Accuracy, Non-Invasive Clamp Temperature Sensor with traditional temperature sensors.

- **Surface RTD sensor**: Shows lower temperature readings than the actual 39°C due to ambient temperature bias. It reacts slowly to temperature changes because it measures the pipe surface, which lags the fluid temperature.
- **Immersion RTD probe**: Provides accurate temperature readings with quick response times as it is directly immersed in the fluid (Figure 1).
- **HANI temperature sensor**: Which combines a surface RTD and a heat flux sensor with advanced heat conduction algorithms, was used, HANI sensor closely matched the actual water temperature, outperforming the surface RTD sensor. It also showed a quick response to temperature changes, comparable to invasive sensors, addressing the latency issues of traditional surface sensors (Figure 2).

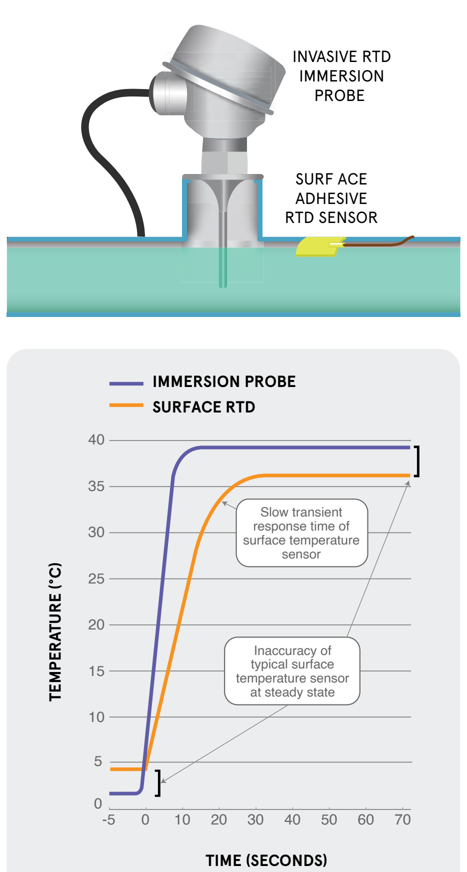

Figure 1 - Comparison of Temperature Readings During Fluid Transition: Immersion RTD Probe vs. Surface RTD Sensor (Source: Omega)

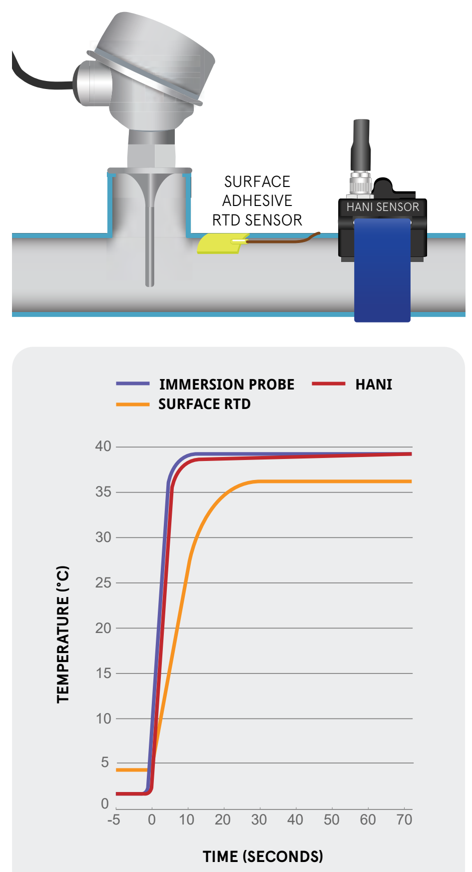

Figure 2 - Comparison of Temperature Readings During Fluid Transition: Surface RTD Sensor vs HANI High Accuracy, Non-Invasive Clamp Temperature Sensor (Source): Omega)

The HANI High Accuracy, Non-Invasive Clamp Temperature Sensor is specifically designed to thrive in harsh industrial environments due to its robust and user-friendly features. Its non-invasive design allows for easy installation on the exterior of pipes, eliminating the need for penetration or modifications that could introduce contamination or require complex procedures. This design prevents common issues such as media buildup and sensor wear, which are particularly problematic in harsh conditions where aggressive or abrasive substances are present.

The sensor's accuracy is maintained through its combination of surface temperature measurement and a Heat Flux Sensor, which accounts for heat loss and material properties, ensuring reliable readings even in challenging environments. The straightforward installation process, which can be completed by hand in seconds, minimizes downtime and operational disruption—critical in high-stakes industrial settings.

Furthermore, the sensor's durability is enhanced by its non-invasive nature, which reduces the risk of equipment wear and contamination. This makes it suitable for industries dealing with sensitive or abrasive media. Its versatile communication options, including 4-20 mA analog output, direct laptop connection, and LayerN cloud monitoring, support various industrial applications and facilitate easy integration into existing systems. Additionally, the pre-loaded thermal conductivity values for different materials ensure accurate measurements without the need for additional calibration, further simplifying its use in demanding environments. Overall, the HANI sensor's design features make it a reliable and cost-effective solution for industrial temperature measurement in harsh conditions.

CONCLUSION

Designing sensor systems for hazardous environments requires meticulous attention to durability and performance in extreme conditions. Advanced packaging protects these sensors from harsh elements, while compliance with functional safety standards guarantees reliability. Infineon's air pressure sensor exemplifies this approach, offering autonomous operation, low power consumption, and robust diagnostics for detecting thermal runaway events in electric vehicle battery packs. By leveraging such sophisticated sensors, industries can enhance safety, maintain operational efficiency, and extend the longevity of critical equipment in challenging environments.

Head over to our website to discover the full range of sensor solutions tailored for extreme conditions or visit our Technical Resource Hub for in-depth technical insights, application notes, and product guides.

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