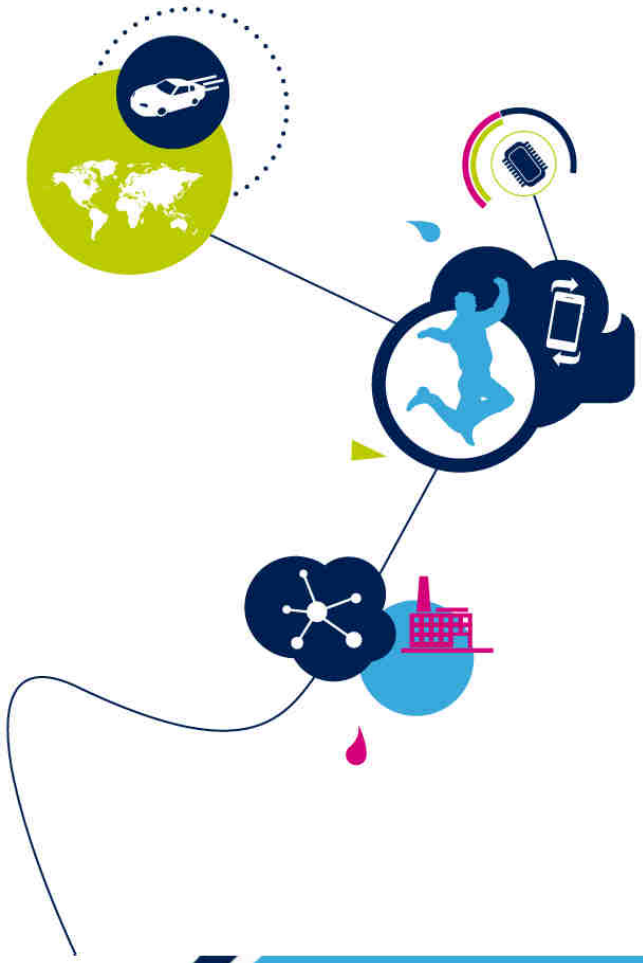
Predictive Maintenance: Use of Advanced Sensors in Smart Industry Applications

Ernesto Manuel CANTONE

AME IoT Marketing



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Technology Tour 2019

Minneapolis, MN | October 24

What is “Smart Industry”?

- Industry 1.0: Mechanization, Steam Power
- Industry 2.0: Mass Production, Assembly Line, Electrical Energy
- Industry 3.0: Automation, Computers and Electronics
- Industry 4.0: Cyber Physical Systems, IoT, Networks

Smart Industry
Scope and Goals

More efficient operation

Less waste

Producing more **efficiently** and in more e**nvironmentally friendly** manner

Responding to demand with more **flexibly** and with more **customization**

Local, mass customized production

Safer working environments

Evolved man-machine cooperation

With a better and safer **human experience**

Collecting and using manufacturing and supply chain **data** better

Big data & Cloud computing

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Predictive Maintenance

A Smart Industry hot topic

Maintenance is a set of actions to keep a machine working properly

Preventive Maintenance

Scheduled maintenance tasks based on a time schedule – don't care of the actual status of the equipment

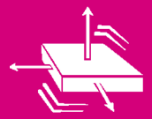
Advantages

- Simple to plan

Drawbacks

- Maintenance may happen too late (or too early)
- Maintenance may not be necessary

Condition Based Maintenance



Maintenance is based on the estimated conditions of the machine, typically monitored through inspection or sensors

Advantages

- Maintenance only takes place when necessary

Drawbacks

- Maintenance only after machine begins to show signs of failure

Predictive Maintenance

Maintenance actions predicted in advance based on monitoring combined with a dynamic predictive model for failure analysis

Advantages

- Maintenance optimized for machine life and production efficiency

Drawbacks

- Requires complex overall system

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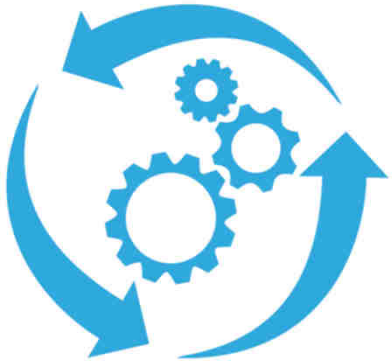
Predictive Maintenance Architecture



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Architecture for Predictive Maintenance

Low power / Scalable / Secure / Real-time

Sensing – Processing – Connectivity

Analytics

Monitoring

- Sensors to detect anomalies
- Communication at factory level
- Processing (e.g. FFT analysis in vibration monitoring)
- Secure communication outside the factory
- Remote monitoring from the Cloud

Predictive algorithms

- Analytical models limited to representing linear characteristics
- Machine learning techniques based on classification methods

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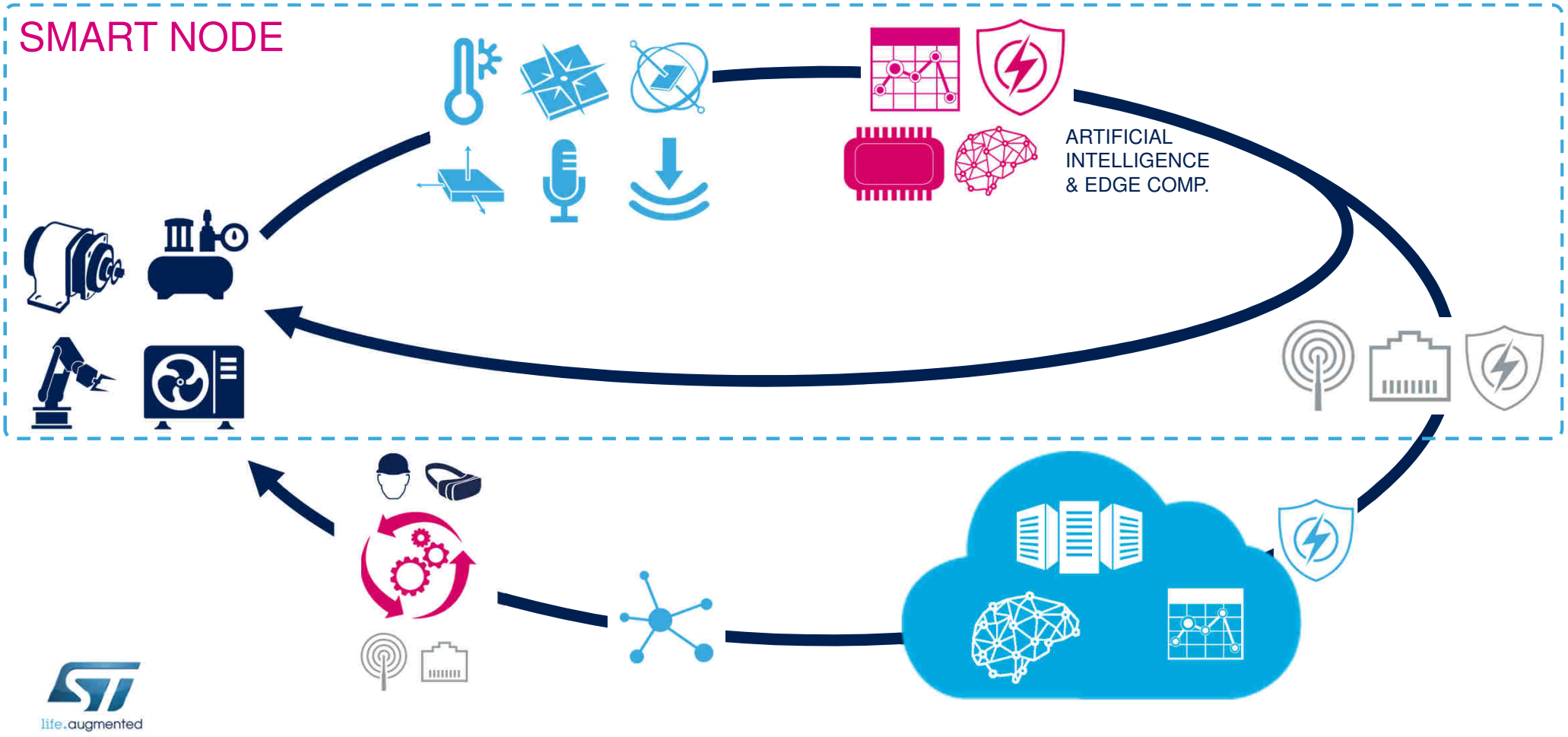
Smart Industry: Trends and Enablers



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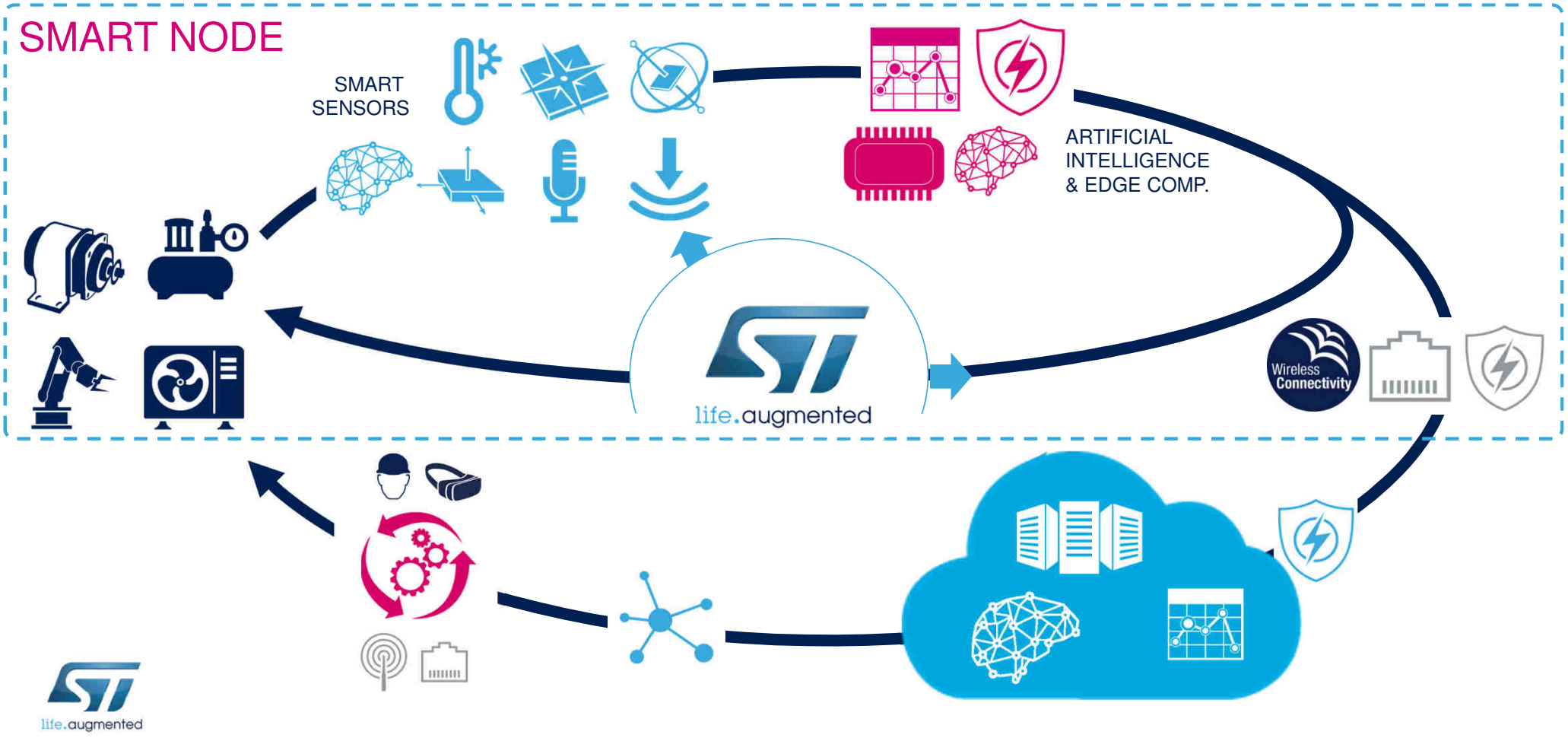
Smart Industry: Trends and Enablers



Sensors Technologies and Predictive Maintenance

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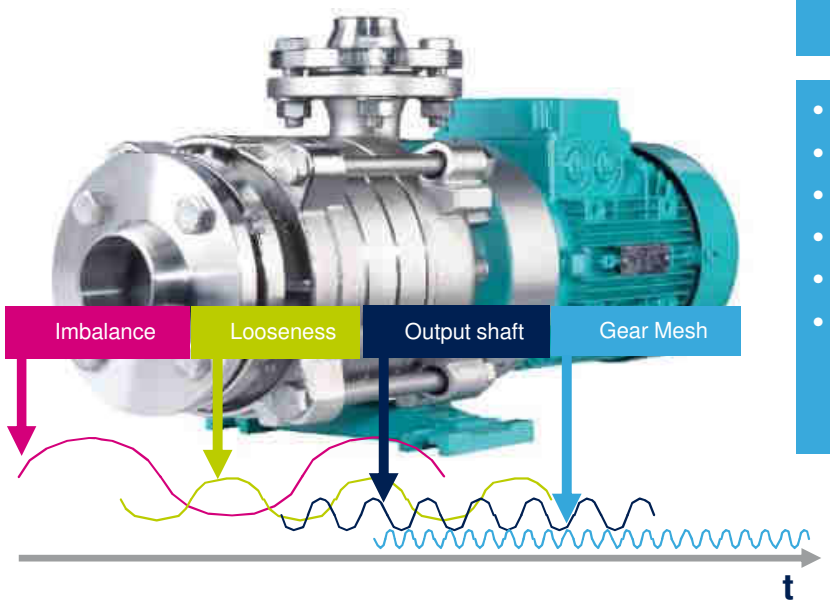
Monitoring of an Industrial Motor

Typical Use Case

Any parameters deviation is an indicator of potential failure



Mechanical vibration	Thermal	Electromagnetic
• Displacement • Speed • Acceleration • Acoustic noise • Angular speed • Torque	• Winding temperature • Bearing temperature	• Current • Voltage • Electrostatic discharge • Magnetic flux – internal • Magnetic flux – external

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Monitoring and Predictive Maintenance

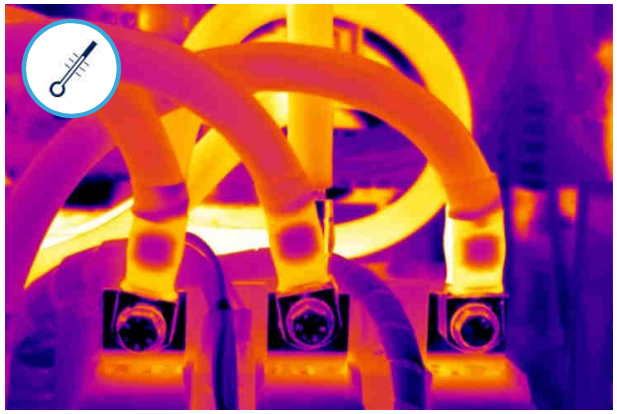
Use of Environmental Sensors

Key components for process and quality control in industrial applications

Pressure measurements **for "air management" systems**, which monitor the performance indicators and the different stages of the air compressors connected to the compressed-air supply grid

Humidity sensors are adopted in **HVAC systems** to control water vapor level or to help in regulating parameters such as air temperature and blowing speed

Measuring **operating temperatures** is crucial for detecting losses or improperly terminated electrical connections, overloading, defective contacts, phase imbalances and other electrical issues



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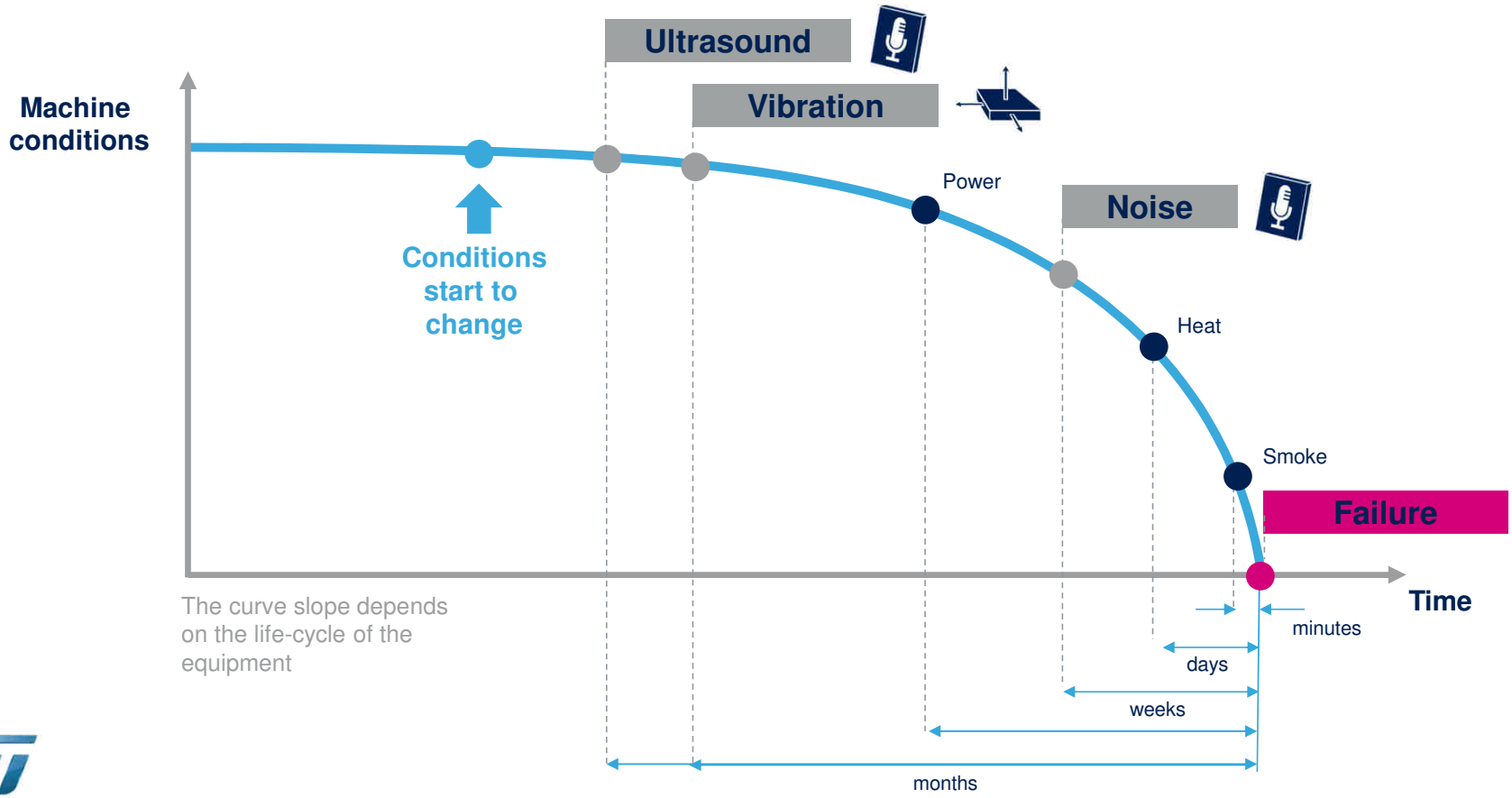
Accelerometer and Microphone

Distinctive sensors for Predictive Maintenance



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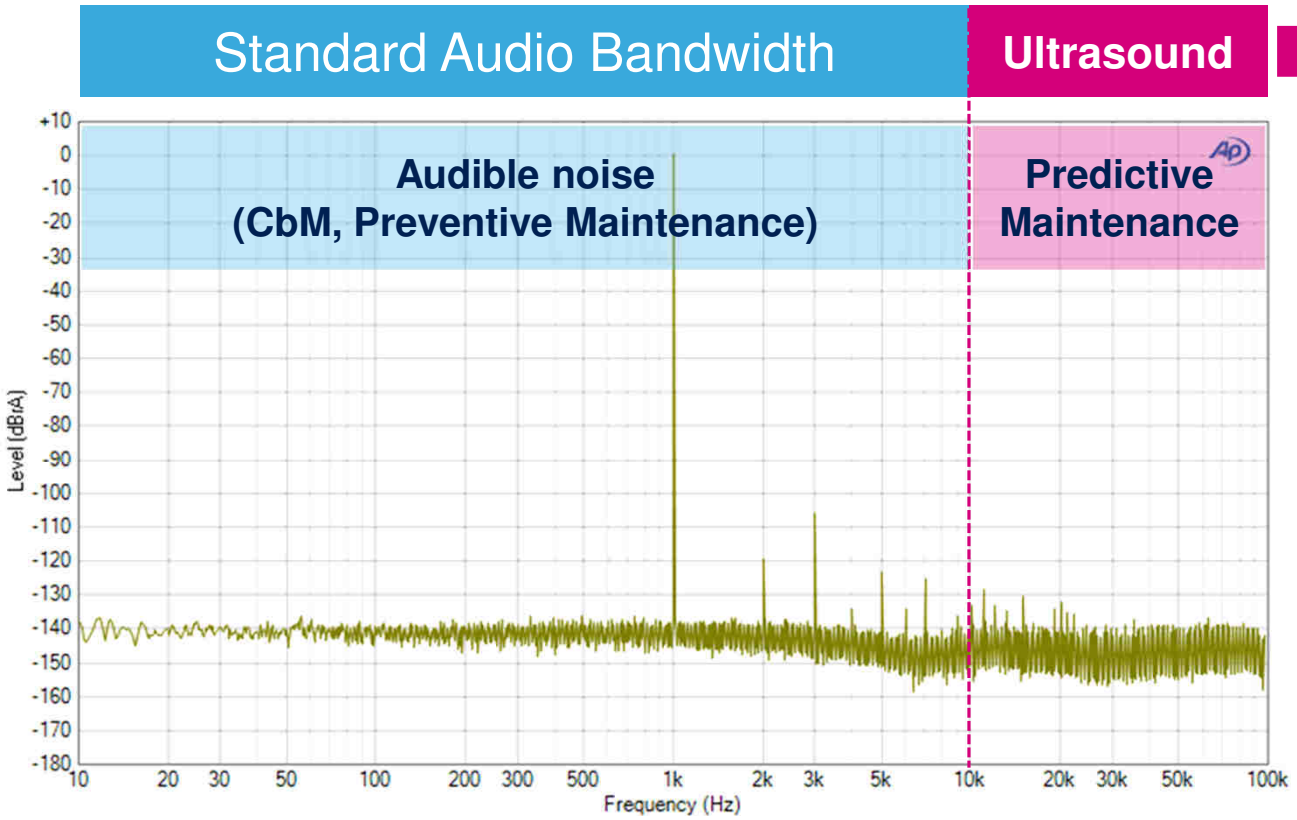
Standard Audio vs Ultrasound



Post processing analysis
Ultrasound frequencies
to **detect** and **classify** leaks

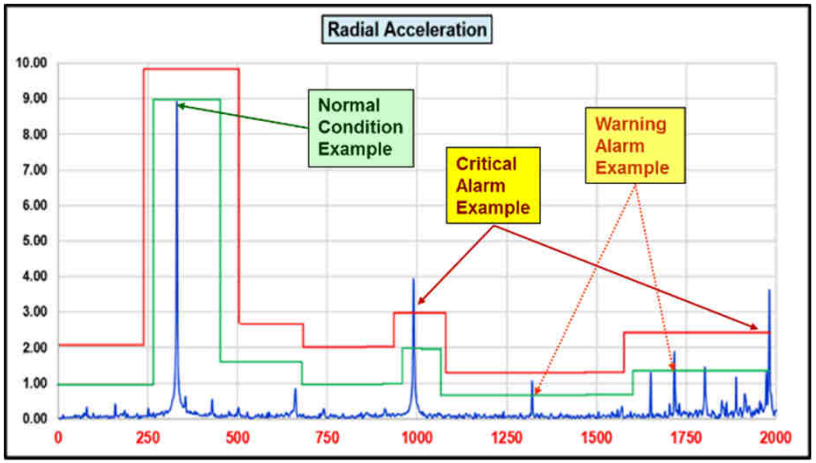
Most common maintenance applications

- Air Leak Detection of compressed air equipment
- Vibration monitor
- Compressor Valve Inspections
- Acoustic Lubrication
- Heat Exchanger and Condenser Leaks
- Hydraulic Systems
- Pump Cavitation

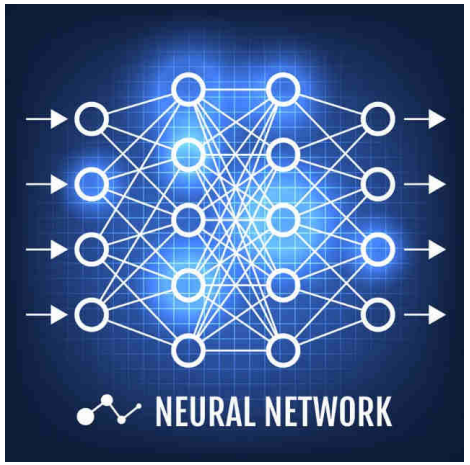
Embedded Analytics
From FFT to AI

While FFT are widely used, Deep Learning and AI can enable new scenarios

- **Embedded FFT** analysis on the sensor can **isolate vibration**
- **Alarm** can be set according to specific threshold to detect potential defects



- **AI** improves the data analysis (vs FFT) hence the capabilities of failure prediction
- AI models, resulting of a “learning process” can be distilled down into a **Neural Network hosted into MCUs** or even down to new generation of smart sensors.



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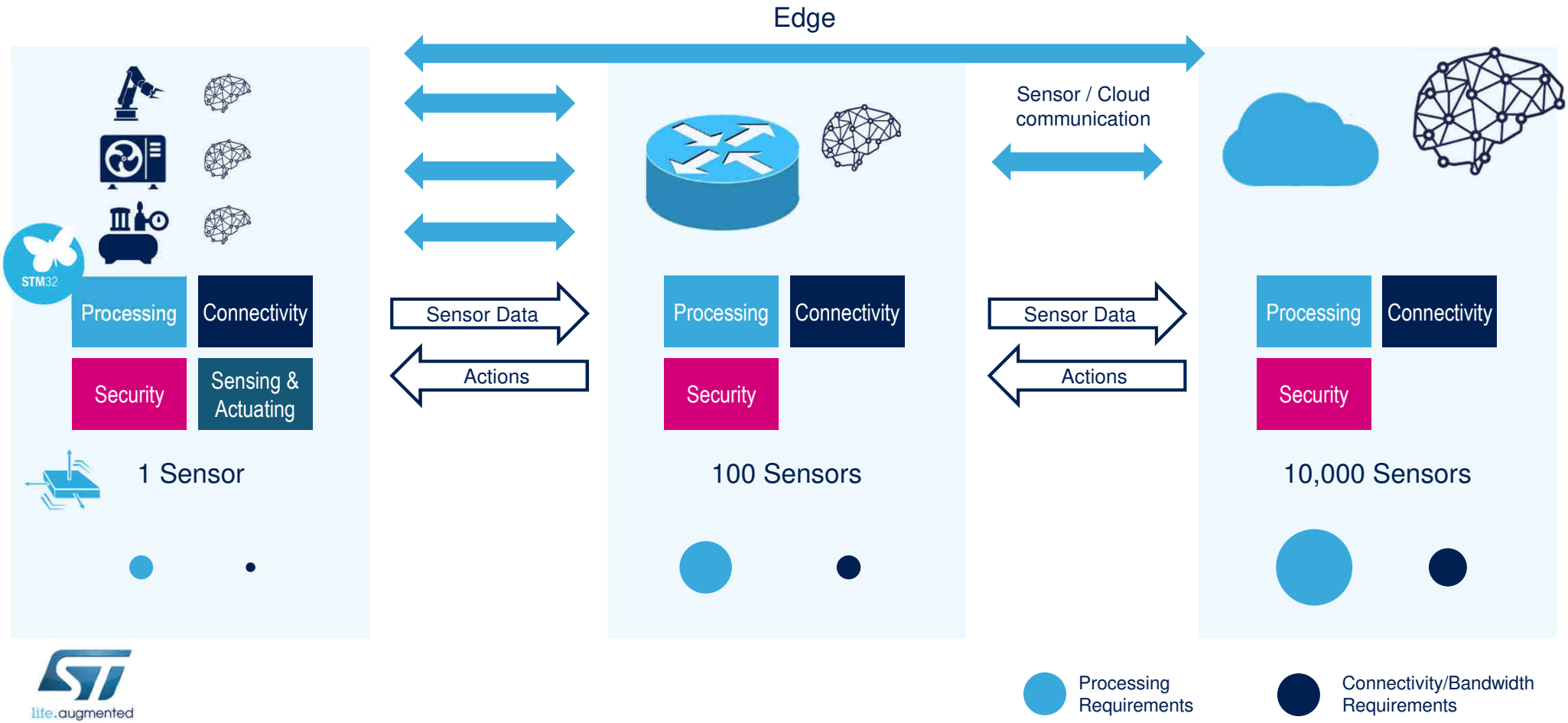
Predictive Maintenance

ST enables new approaches with a distributed architecture



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ST Enablers: Products and Solutions

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Complete Ecosystem Offering by ST

All building blocks for IoT devices	Lower barriers for developers getting started	Lower barriers from prototyping to first product	Enable product & service commercialization

Microcontrollers

Secure solutions

Sensors & actuators

Connectivity solutions

Power management

Motor control

Analog components

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Stackable boards & modular SW

STM32 Nucleo Development & Expansion boards

Form-factor boards

Discovery Kit IoT Node

SensorTile.box

NFC Dynamic Tag Sensor Node

BlueTile

SensorTile

Pre-integrated software for vertical applications

Smart Things

Smart Home & City

Smart Industry

Development ecosystem

Code generators

Prototyping software

IDE

Development environments

Artificial Intelligence toolbox

Debug solutions

Simulation and analysis tools

On-line design tools

Integration of Cloud Provider SDKs

aws

Microsoft Azure

Google Cloud

IBM

Partner Program and ST community

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Partner Program

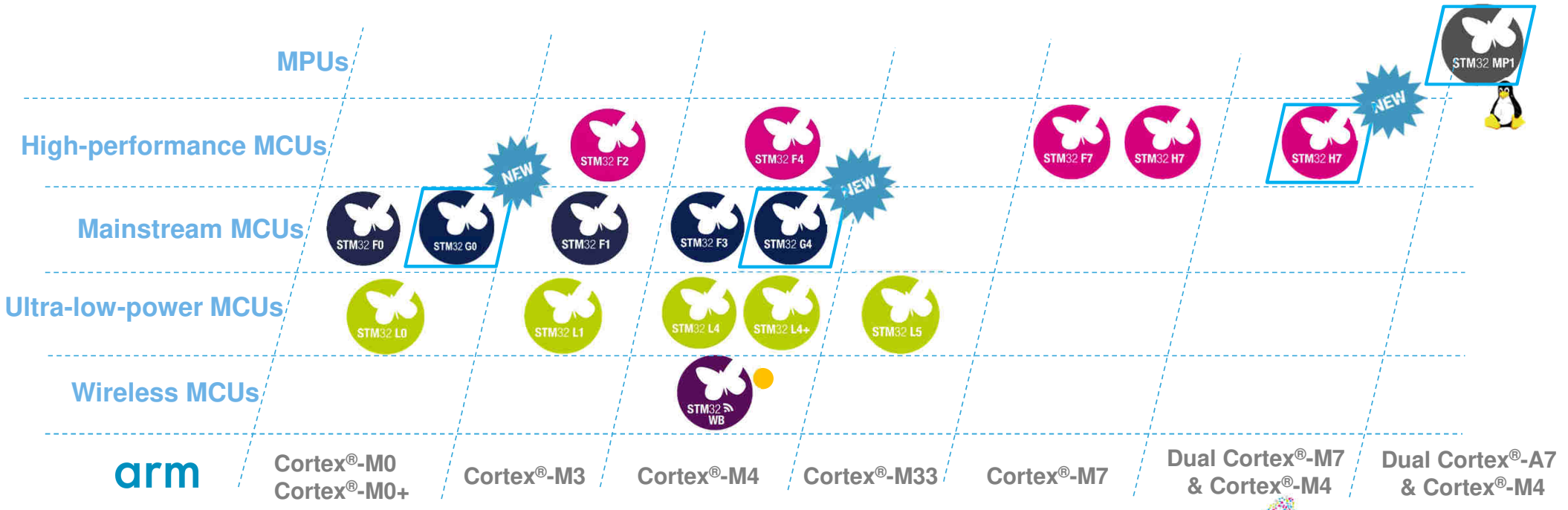
ST Community

Educational Platforms

Microcontrollers and Microprocessors

Today - STM32 portfolio positioning

15 product series / More than 50 product lines



Note ● : Cortex-M0+ Radio Co-processor

More than
40,000 customers

STM32 Rolling Longevity Commitment

Longevity commitment is renewed every year

starting January 1st 2019
➔ Until 2029

• **STM32F1**	(launched in **2007**)	**22 years** of commitment
• **STM32L1**	(launched in **2009**)	**20 years** of commitment
• **STM32F2**	(launched in **2010**)	**19 years** of commitment
• **STM32F4**	(launched in **2011**)	**18 years** of commitment
• **STM32F0**	(launched in **2012**)	**17 years** of commitment
• **STM32F3**	(launched in **2012**)	**17 years** of commitment
• **STM32L0**	(launched in **2013**)	**16 years** of commitment
• **STM32F7**	(launched in **2014**)	**15 years** of commitment
• **STM32L4**	(launched in **2015**)	**14 years** of commitment
• **STM32L4+**	(launched in **2016**)	**13 years** of commitment
• **STM32H7**	(launched in **2016**)	**13 years** of commitment
• **STM32WB**	(launched in **2018**)	**11 years** of commitment
• **STM32G0**	(launched in **2018**)	**11 years** of commitment

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STM32 Artificial Intelligence

Neural Networks for STM32

STM32Cube.AI SW tool allows our customers to innovate…

Off-the-shelf tools

ConvNetJS
Deep Learning in your browser

Lasagne

Caffe

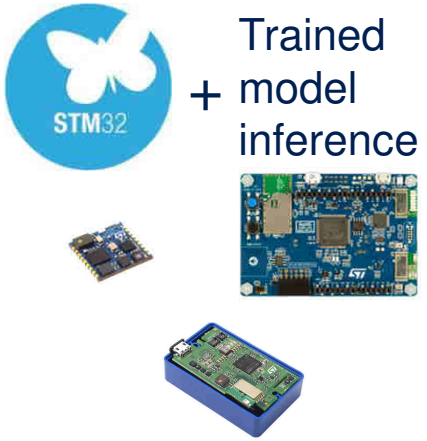
Pre-trained Neural Network Model from major framework

ST SW tools

STM32 Cube.AI

Optimized Neural Network code automatically generated for STM32

ST AI solution



... bringing AI into the STM32 Portfolio

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Sensors

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A Broad Sensor Portfolio

ST Sensors Shipped 17 BILLION

Market leading #1 in the Consumer MEMS segment

Motion sensors **40% share** (#1)

Pressure sensors **31% share** (#2)

Smart Things

IHS Motion Sensors Market Share Report 2017

New sensors portfolio for **Industrial applications**

LONGEVITY 10 YEARS COMMITMENT

Smart Industry

Broadest sensors portfolio addressing Personal Electronics, Industrial & Automotive

a unique sensor portfolio

Smart Industry | Smart Home & City Smart Things | Smart Driving

Subscribe to the MEMS and Sensors Newsletter

High stability IMU for **Always ON** applications, finite state machine, w/ I3C Interface

iNEMO

MIPI I3C -- High Performance Interface & Scalable solution

mipi alliance

IMU = Inertial Measurement Unit

Unique Pressure Sensors portfolio: Dust and **Water resistant** packages

Complete system solutions and official Partners for **fast go-to-market**

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10-Year Product Longevity

Benefits

- 10-YEAR LONGEVITY FROM PRODUCT INTRODUCTION DATE
- DESIGN AND MANUFACTURING FOR HIGHER ROBUSTNESS & PERFORMANCES
- CALIBRATION & TESTING FOR HIGHER ACCURACY & QUALITY
- EXTENDED TEMPERATURE RANGE AND ENDURANCE TO SHOCK AND VIBRATION

Growing Product Family

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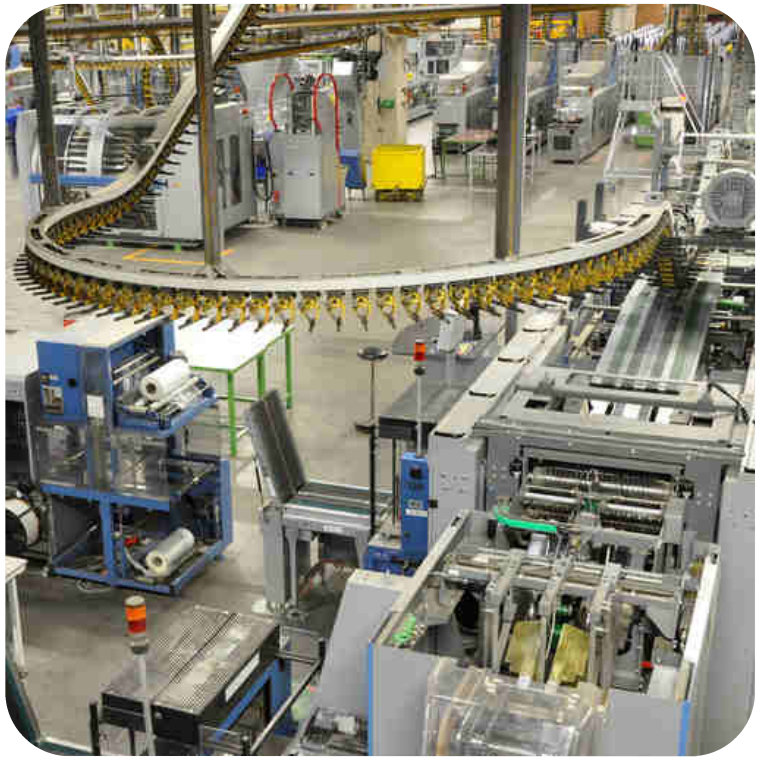
https://www.st.com/content/st_com/en/about/quality-and-reliability/product-longevity.html

Motion Sensors and more

Humidity and temperature sensors as enablers for in-situ calibration

Motion, Vibration, Angle measurement	**Motion sensors** Accelerometers, gyroscopes, 6-axis IMUs, magnetometers
Temperature Monitoring and calibration	**Temperature sensors** Analog and digital contact temperature sensors
Environmental Humidity Monitoring	**Humidity sensors** Combo humidity and temperature sensors
Environmental Pressure Monitoring	**Pressure sensors** Water proof solutions
Acoustic Monitoring	**MEMS microphones** Analog, digital, top and bottom port solutions



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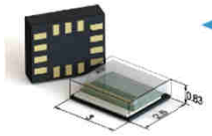
Motion MEMS Sensors for Smart Industry

IIS3DWB*
Vibration Sensor - Ultra Wide Bandwidth



LGA-14 2.5x3 mm ES NOW

- 3D Vibration Sensor – 16g Full Scale
- Digital Output
- Ultra Wide Bandwidth (to 5 kHz)
- Ultra Low Noise
- Up to 105°C Operating Temp

IIS3DHHC/IIS2ICLH*
Inclinometer
High Resolution, Ultra Low Power

LGA-16 5x5 mm

- Inclinometer – Digital Output
- High Accuracy (<0.5° over Temp. and Time)
- Ultra Low Current consumption: 400 uA

IIS2DH/IIS2DLPC
Accelerometer - Wide Bandwidth, Ultra-low-power

LGA-12 2x2 mm

- 3D Accelerometer – Digital Output
- Wide Bandwidth (up to 2.3 kHz)
- Ultra Low Power – Ultra Compact

IIS2MDC
Magnetometer Low-Noise, Low Power

LGA-12 2x2 mm

- 3D Magnetometer – Digital Output
- AMR Technology - up to 50 Gauss Full Scale
- Ultra Low Noise, Low Power

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(*)Contact Sales for availability

Motion MEMS Sensors for Smart Industry

ISM330DLC

Combo accelerometer & Gyroscope
Wide Bandwidth

LGA-14 2.5x3 mm

- 3D accelerometer with full scale up to ±16g
- 3D gyroscope with full scale up to ±2000 dps
- Accelerometer with Wide Bandwidth (up to 3 kHz)
- Ultra Low Power and Smart Features

ISM330DHCX

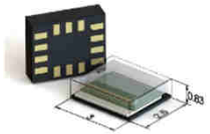
Combo accelerometer & Gyroscope
Wide Bandwidth

LGA-14 2.5x3 mm

- 3D accelerometer with full scale upt to ±16g
- 3D gyroscope with full scale up to ±4000 dps
- Accelerometer with Wide Bandwidth (up to 3 kHz)
- Ultra Low Power and Machine Learning Core

ISM303DAC

E-Compass
Combo Accelerometer and Magnetometer



LGA-12 2x2 mm

- 3D Accelerometer – Digital Output
- 3D Magnetometer – Digital Output
- ±2/±4/±8/±16 g selectable acceleration full scales
- Up to ±50 gauss magnetic dynamic range

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Environmental Sensors for Smart Industry

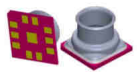
LPS22HH
Pressure Sensor – High Accuracy – Compact Size

HLGA-10L 2x2x0.76 mm

- Absolute Pressure Sensor
- 260 to 1260 hPa Range - Digital Output
- High Accuracy (±0.75 hPa)
- Low noise (0.75 Pa RMS)
- Ultra Compact full molded package

LPS33W/LPS27HHW
Pressure Sensor – Water Resistant

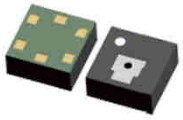
3.3x3.3x2.9 mm



2.7 x 2.7 x 1.7 mm

- Absolute Pressure Sensor
- 260 to 1260 hPa Range - Digital Output
- High Accuracy (±2.5 hPa / ±0.5 hPa)
- Low noise (0.8 Pa / 0.7 Pa)
- Water resistant up to 10 ATM

HTS221
Humidity and Temp Sensor – High Accuracy



HLGA-6 2x2x0.9 mm

- Humidity and Temperature Sensor
- Digital Output
- High Accuracy:
  - Humidity: ±3.5 %RH
  - Temperature: ±0.5 deg
- Low Power

STTS751
Digital Temperature Sensor

UDFN-6L or SOT23-6L

- Accuracy ±1.0 ºC ; Programmable resolution

LM235 – STLM20
Analog Temperature Sensor

TO92/SO8

- Accuracy ±1.0 °C ; Op. Temp up to 150 °C

STTS22H*
Digital Temperature Sensor – High Accuracy

UDFN-6L 2.0 x 2.0 x 0.5mm

COMING SOON!

- High Accuracy:
  - Temperature: ±0.2 deg
- Low Power

(*)Contact Sales for availability

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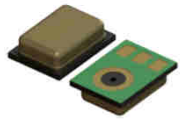
MEMS Microphones for Smart Industry

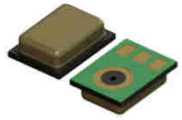
MP23ABS1
Analog Differential Microphone



3.35x2.5x0.98 mm

- Bottom Port Microphone
- Analog Differential Output
- Wide Acoustic Bandwidth (up to 80 kHz)
- Wide Dynamic Range (AOP up to 135 dBSPL)

MP23DB01HP*
Digital Bottom Port Microphone



3.35x2.5x0.98 mm

- Bottom Port Microphone
- Multi mode PDM Output
- Wide Dynamic Range (AOP up to 137 dBSPL)
- Hi SNR 65.5dB

IMP34DT05
Digital Top Port Microphone

3x4x1 mm

- Top Port Microphone
- Digital Output
- Wide dynamic range (AOP up to 122 dBSPL)
- -26dBFS ± 3 dB sensitivity

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(*)Contact Sales for availability

Accelerometer and Microphone

When frequency matters





Unbalance
Losses
Misalignment

Roller Bearings
Gearing
Cavitation

Bearings
Gear Box
Lubrication

Fan Bearings
Venting Occlusion
Cooling failure

Type of Defect / Wear

IIS3DWB

ISM330DLC

IMP34DT05

Sound analysis (10-10KHz)

Ultrasound analysis

IIS2DH

MP23ABS1

Bandwidth

2Khz

5Khz

10Khz

>50Khz

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Connectivity

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Connectivity Options

Match the needs of Industrial Environments

Wired Connectivity

P2p, Industrial Fieldbus, Industrial Ethernet

IO-Link
CANopen
PROFINET INDUSTRIAL ETHERNET
EtherCAT
sercos the automation bus
EtherNet/IP
ETHERNET POWERLINK

And more ..

Any Industrial protocol for any STM32

Wireless Connectivity

Retrofit, flexibility of technologies and protocols, interoperability with Ethernet and Cloud

Bluetooth SMART
Wi Fi
Sub 1GHz
LoRa
IEEE 802.15.4
sigfox
Lte
6LoWPAN

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Development Kits

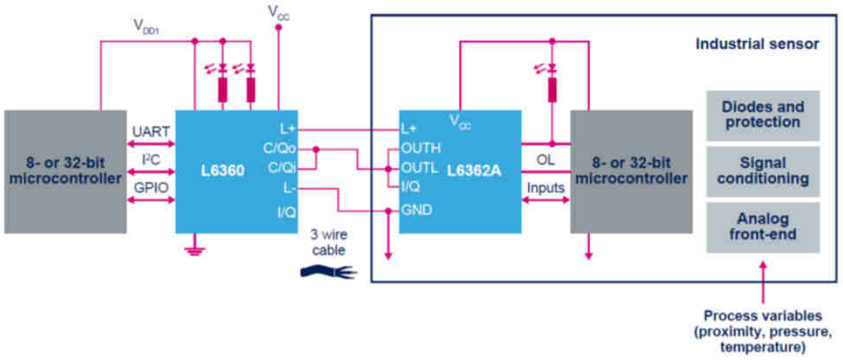
Wired Connectivity

IO-Link: from ICs to a wide offering of solutions

L6360

Single port Master PHY for IO-Link and SIO mode

- Supply voltage up to 32.5 V
- Up to 200 mW max. power dissipation
- Over-voltage (>36 V) and over-temperature protection
- ESD protection according IEC 61000-4-2
- Conform to IEC 61000-4-4, IEC 61000-4-5



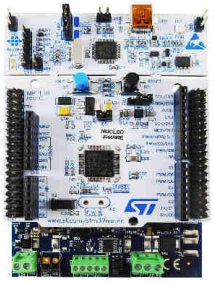
L6362A

Transceiver Device for IO-Link and SIO mode

- Configurable Output stage: High Side, Low Side, Push-Pull
- Reverse Polarity and Surge protections
- Up to 400 mA output Current with Overload and Cut-OFF protections
- 5 V or 3.3 V / 8 mA selectable linear regulator

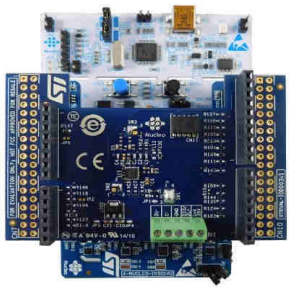
Visit st.com for the full list of IO-Link solutions

Based on **Master** L6360



The **P-NUCLEO-IOM01M1** is a STM32 Nucleo pack for IO-Link Master with IO-Link v1.1 PHY and stack

Based on **Device** L6362A



The **P-NUCLEO-IOD01A1** is a STM32 Nucleo pack for IO-Link Device fully compatible with IO-Link v1.1 PHY and stack

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From Sensor to Fieldbus

Predictive maintenance kit with sensors and IO-Link capability

Use cases

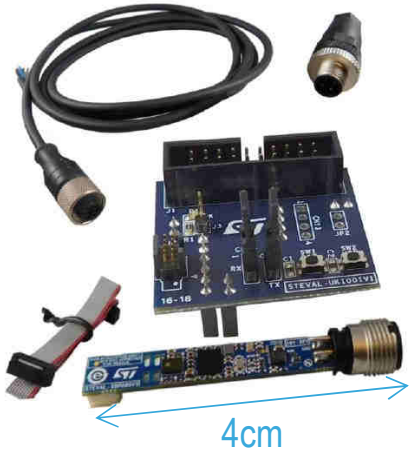
Motors

Equipment

Environment

AI ready

STEVAL-BFA001V1B



Sensing

Vibration and Environmental

- **ISM330DLC** 6-Axis digital MEMS axel + gyro (*)
- **MP34DT05-A** Microphone
- **LPS22HB** MEMS Pressure sensor
- **HTS221** Humidity & Temperature Sensors

Connectivity

Wired

- L6362A IO-Link communication transceiver device IC

Processing

Local Processing

- **STM32F469AI** 32-bit ARM Cortex-M4 microcontroller

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**ISM330DLC bandwidth is 3 kHz, coming soon replacement with IIS3DWB (5 kHz)*

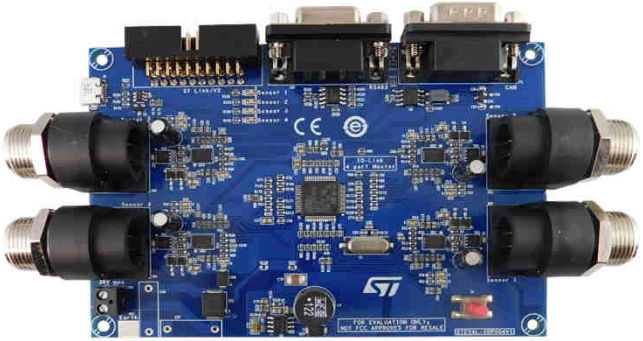
Main Features

- Optimized form factor for industrial M12 connector
- Embedded algorithm for sensors data analysis, detecting anomalies like unbalance, misalignment, or bad equipment condition
- Logging of worst working condition events

STEVAL-IDP004V1

Applications with 2+ nodes to be monitored

Adapter RS485 / USB
Optional USB



STEVAL-IDP004V1

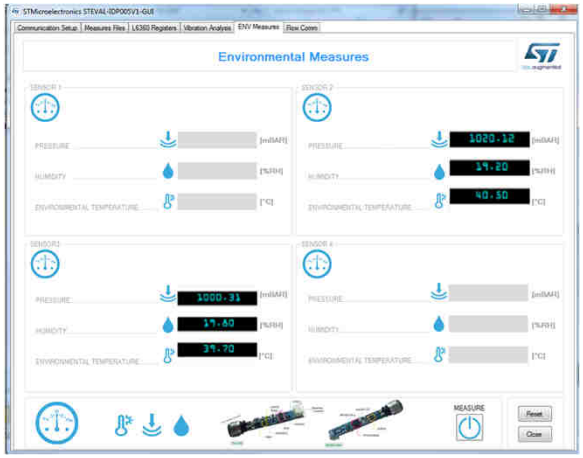
Also available the firmware package STSW-IO-LINK

Axel spectrum

Axel Peak

Speed RMS

P, T, H parameters



STEVAL-BFA001V1B

Download the *condition monitoring_iol* fw from the STSW-BFA001V1 Demonstration folder

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STM32 Cloud Connected IoT Nodes

- **X-CUBE-AWS**
  - Cloud Connector: libraries and application examples
- **FP-CLD-AWS1**
  - Companion AWS-based web dashboard
- **Amazon FreeRTOS**
  - STM32's port of the Amazon operating system for microcontrollers that makes small, low-power edge devices easy to program, deploy, secure, connect, and manage.


NUCLEO-H743ZI


B-L475E-IOT01A


32F413HDiscovery


32F769IDiscovery

- **X-CUBE-AZURE**
  - Cloud Connector: set of libraries and application examples
- **FP-CLD-AZURE1**
  - Companion Dashboard with full support for Azure device management primitives and sample implementation for firmware update over the air (FOTA).


NUCLEO-F429ZI


SensorTile.box


B-L475E-IOT01A


32F413HDiscovery


32F769IDiscovery

- **X-CUBE-WATSON**
  - Cloud Connector: libraries and application examples
  - IBM Quickstart and Registered Mode support.
- **FP-CLD-WATSON1**
  - Includes pre-integrated FFT algorithms for the processing of accelerometer


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B-L475E-IOT01A


32F413HDiscovery


32F769IDiscovery

- **X-CUBE-GCP**
  - Cloud Connector: set of libraries and application examples, MCU acting as end devices.


B-L475E-IOT01A


32F413HDiscovery


32F769IDiscovery

- **X-CUBE-CLD-GEN**
  - Cloud Connector: libraries and application examples

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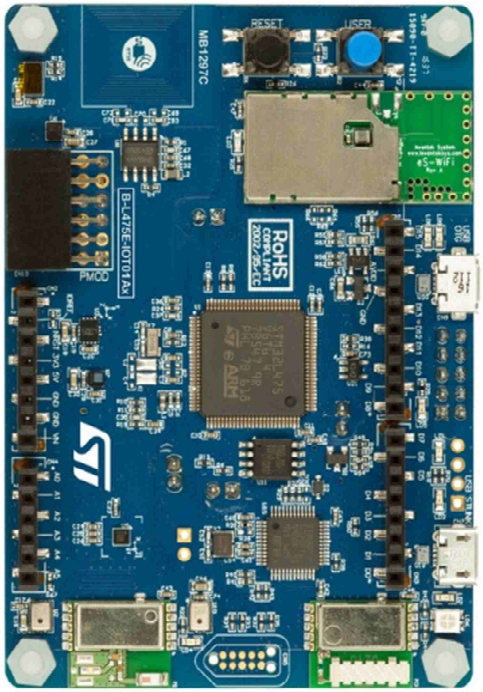
STM32L475 Discovery Kit IoT Node

B-L475E-IOT01A

Cloud Connectivity Out-of-the-Box



- Ultra-low-power STM32L475 Arm® Cortex®-M4, 1 Mbyte Flash memory, 128 Kbytes of SRAM
- Firmware example for IoT end node connected with Wi-Fi®
  - 802.11 b/g/n compliant Wi-Fi® module
- Low Power Communications
  - Bluetooth 4.1, Sub-GHz, Dynamic NFC Tag
- Multiway Sensing
  - 3D Accelerometer, 3D Gyroscope, 3D Magnetometer, Temperature/Humidity, Pressure, Time of Flight, Microphones

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Alpha engagements

STWIN SensorTile Wireless Industrial Node

STEVAL-STWINKT1

Use cases

Motors | Equipment | Environment

Sensing

Industrial grade sensors for
- Vibration analysis
- Sound Emission up to 80 kHz
- Environmental

Connectivity

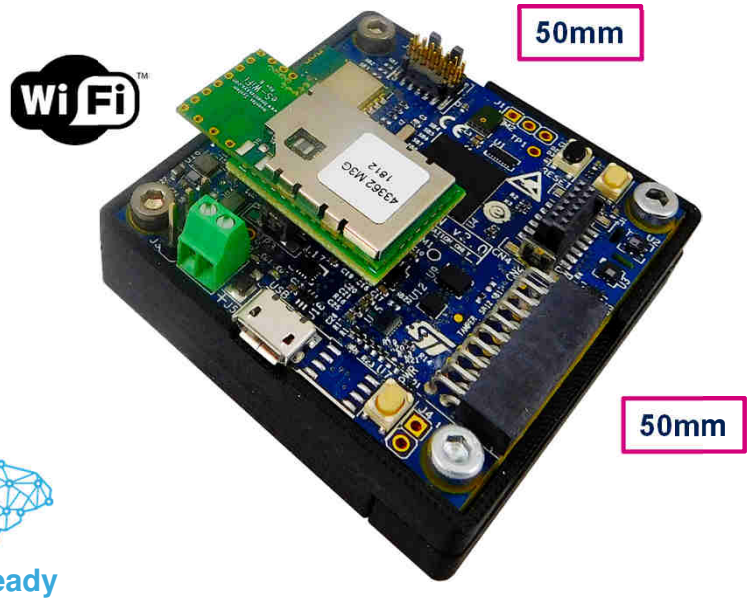
Embedded Wireless and Extension
- BLE, WiFi (Inventek)
- Modular expansion: LTE, LoRa, Industrial Ethernet

Processing

Local Processing & Security
- ARM® Cortex®-M4 STM32L4R9
- Secure Element STSAFE on request

Power

Power Management
- Li-Ion linear battery charger with load switches
- Miniaturized synchronous step down converter with high efficiency conversion



AI ready

LoRa®

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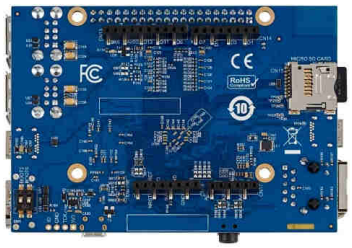
STM32MP157C MPU Discovery Kit

STM32MP157C-DK2

AWS IoT Greengrass v1.8.0 Certified



- STM32MP157 Arm®-based dual Cortex®-A7 32 bits + Cortex®-M4 32 bits MPU in TFBGA361 package
  - ST PMIC STPMIC1
  - 4-Gbit DDR3L, 16 bits, 533 MHz
  - 1-Gbps Ethernet (RGMII) compliant with IEEE-802.3ab
  - USB OTG HS
  - Audio codec
  - 4 user LEDs
  - Ethernet RJ454, USB Type-A, USB Type-C™, DRPMIPI DSI℠, HDMI®, headset jack including analog microphone input, micro SD™ card
  - GPIO expansion connector
    - Raspberry Pi® shields capability
    - ARDUINO® Uno V3 expansion connectors

Sensor to Cloud

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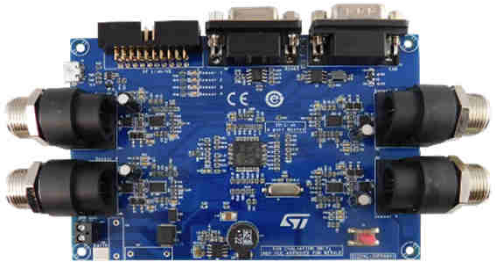
From Dev Kits to End to End solution

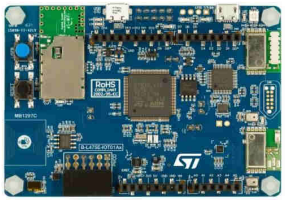
STEVAL-BFA001V1B
Stand Alone Sensor Node

STEVAL-IDP004V1
Expand your capabilities up to 4 Nodes



STM32MP157C-DK2
Discovery Kit

B-L475E-IOT01A
Discovery Kit IoT Node



STEVAL-STWINKT1
SensorTile Wireless Industrial Node

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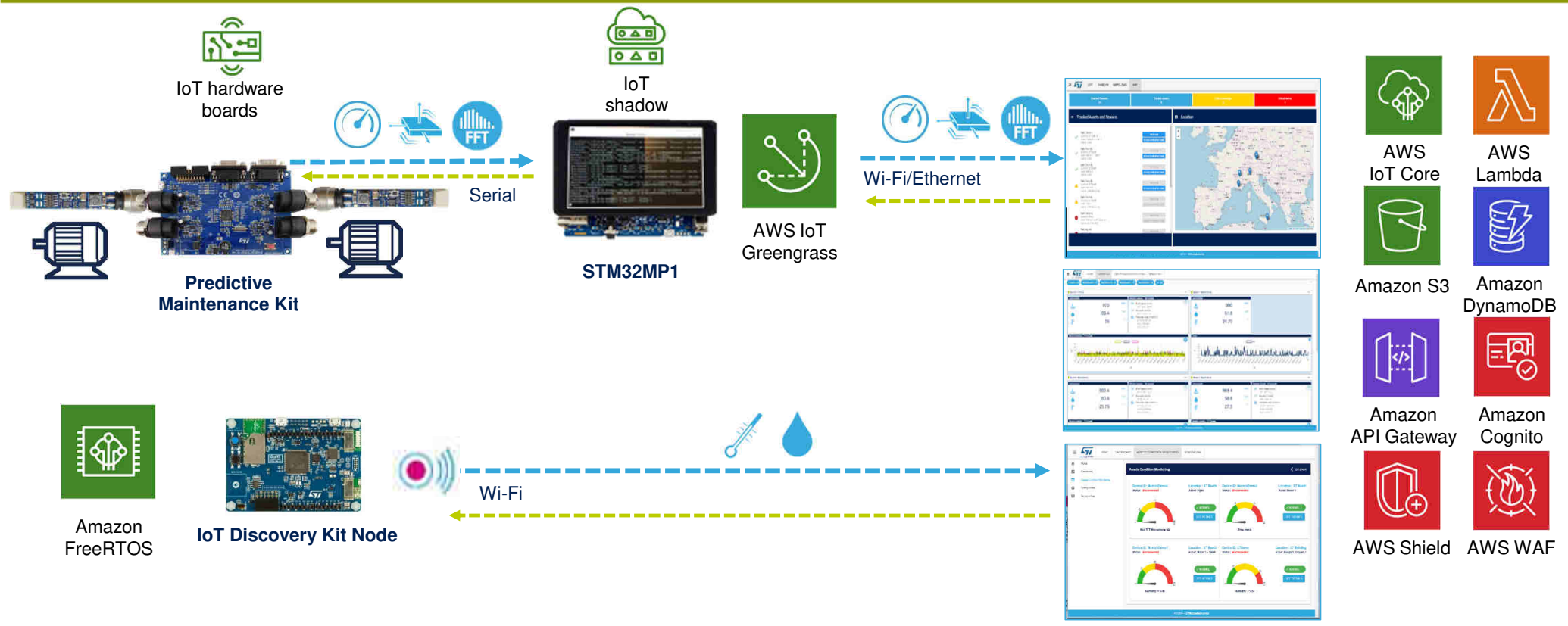
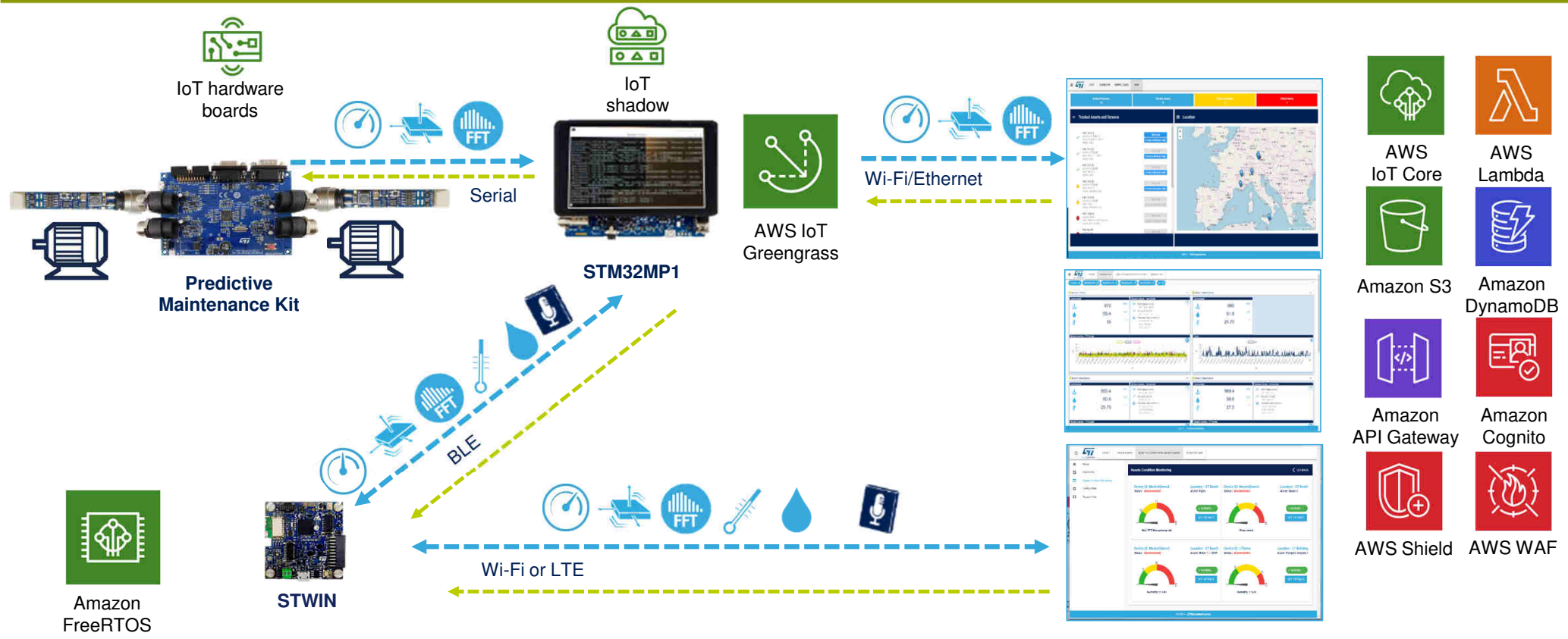
2019: Predictive Maintenance Node to Cloud

Ultrasound, Vibration, Environmental sensing



Platform Evolution

Ultrasound, Vibration, Environmental sensing



Predictive Maintenance Solutions

Value Proposition

Smart Sensor Nodes: different connectivity and UI to evaluate specific products

Edge and Cloud: e2e

Evaluation
FP-IND-PREDMNT1

PoC
STEVAL-BFA001V1B

Field Test: Predictive Maintenance Platform

Understanding Needs

Full feature evaluation: Equipment/Asset Retrofitting

Framework to ingest sensors data in the cloud and work on insight (analysis or ML)

Same SW Library shared with same features: Vibration and Sound Analysis

- HW Available
- SW available
- BLE Data log with APP

- STEVAL-BFA001V1B and STEVAL-IDP004 available
- STWIN available end of July 2019 (Alpha Engagements)
- PC Data log, GUI and DLL for Matlab
- BLE Data log with APP

- Gateway SDK available on GitHub
- Dashboard on st.com available end of September 2019
- Cloud dashboard Data Log

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