Predictive Maintenance: Use of Advanced Sensors in Smart Industry Applications

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AME IoT Marketing
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
Big data & Cloud computing

Local, mass customized production

Producing more **efficiently** and in more **environmentally friendly** manner

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

Safer working environments

More efficient operation

Less waste

With a better and safer **human experience**

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

Evolved man-machine cooperation

Big data & Cloud computing
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
Predictive Maintenance Architecture
Architecture for Predictive Maintenance

Low power / Scalable / Secure / Real-time

Sensing – Processing – Connectivity

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

Analytics

Predictive algorithms
- Analytical models limited to representing linear characteristics
- Machine learning techniques based on classification methods
Smart Industry: Trends and Enablers

SMART NODE

ARTIFICIAL INTELLIGENCE & EDGE COMP.
Smart Industry: Trends and Enablers

SMART NODE

SMART SENSORS

ARTIFICIAL INTELLIGENCE & EDGE COMP.
Sensors Technologies and Predictive Maintenance
Monitoring of an Industrial Motor

Typical Use Case

Any parameters deviation is an indicator of potential failure

Mechanical vibration
- Displacement
- Speed
- Acceleration
- Acoustic noise
- Angular speed
- Torque

Thermal
- Winding temperature
- Bearing temperature

Electromagnetic
- Current
- Voltage
- Electrostatic discharge
- Magnetic flux – internal
- Magnetic flux – external
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.
Accelerometer and Microphone
Distinctive sensors for Predictive Maintenance

The curve slope depends on the life-cycle of the equipment.

- **Ultrasound**
- **Vibration**
- **Power**
- **Noise**
- **Heat**
- **Smoke**

Time:
- minutes
- days
- weeks
- months

Machine conditions:
- Conditions start to change

Failure
Standard Audio vs Ultrasound

**Standard Audio Bandwidth**

Audible noise (CbM, Preventive Maintenance)

**Ultrasound**

Predictive Maintenance

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.
Predictive Maintenance

ST enables new approaches with a distributed architecture

- Connectivity/Bandwidth Requirements
  - Connectivity
  - Sensing & Actuating
  - Processing
  - Security
  - Sensor Data
  - Actions

Edge

1 Sensor

100 Sensors

10,000 Sensors

Sensor / Cloud communication

Processing Requirements

Connectivity/Bandwidth Requirements
ST Enablers: Products and Solutions
## Complete Ecosystem Offering by ST

<table>
<thead>
<tr>
<th>All building blocks for IoT devices</th>
<th>Lower barriers for developers getting started</th>
<th>Lower barriers from prototyping to first product</th>
<th>Enable product &amp; service commercialization</th>
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</thead>
<tbody>
<tr>
<td>Microcontrollers</td>
<td>Stackable boards &amp; modular SW</td>
<td>Pre-integrated software for vertical applications</td>
<td>Integration of Cloud Provider SDKs</td>
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<td>Secure solutions</td>
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<tr>
<td>Sensors &amp; actuators</td>
<td>STM32 Nucleo Development &amp; Expansion boards</td>
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<tr>
<td>Connectivity solutions</td>
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<tr>
<td>Power management</td>
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<tr>
<td>Motor control</td>
<td>Form-factor boards</td>
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<tr>
<td>Analog components</td>
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</tbody>
</table>

**Development ecosystem**

- Discovery Kit IoT Node
- SensorTile.box
- NFC Dynamic Tag
- BlueTile
- SensorTile

**Integration of Cloud Provider SDKs**

- Smart Things
- Smart Home & City
- Smart Industry

**Partner Program and ST community**

- Life augmented
- ST Community
- Educational Platforms
Microcontrollers and Microprocessors
Today - STM32 portfolio positioning

15 product series / More than 50 product lines

High-performance MCUs:
- Cortex®-M0+
- Cortex®-M0
- Cortex®-M3
- Cortex®-M4
- Cortex®-M33
- Cortex®-M7
- Dual Cortex®-M7 & Cortex®-M4
- Dual Cortex®-A7 & Cortex®-M4

Mainstream MCUs:
- Cortex®-M0+
- Cortex®-M0
- Cortex®-M3
- Cortex®-M4
- Cortex®-M33
- Cortex®-M7
- Dual Cortex®-M7 & Cortex®-M4
- Dual Cortex®-A7 & Cortex®-M4

Ultra-low-power MCUs:
- Cortex®-M0+
- Cortex®-M0
- Cortex®-M3
- Cortex®-M4
- Cortex®-M33
- Cortex®-M7
- Dual Cortex®-M7 & Cortex®-M4
- Dual Cortex®-A7 & Cortex®-M4

Wireless MCUs:
- Cortex®-M0+
- Cortex®-M0
- Cortex®-M3
- Cortex®-M4
- Cortex®-M33
- Cortex®-M7
- Dual Cortex®-M7 & Cortex®-M4
- Dual Cortex®-A7 & Cortex®-M4

More than 40,000 customers

Note: Cortex-M0+ Radio Co-processor
STM32 Rolling Longevity Commitment

Longevity commitment is renewed every year

- 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

Starting January 1st 2019 ➔ Until 2029
STM32 Artificial Intelligence
Neural Networks for STM32

STM32Cube.AI SW tool allows our customers to innovate...

Off-the-shelf tools

Pre-trained Neural Network Model from major framework

ST SW tools

Optimized Neural Network code automatically generated for STM32

ST AI solution

Trained model inference

... bringing AI into the STM32 Portfolio
Sensors
A Broad Sensor Portfolio

**Market leading #1 in the Consumer MEMS segment**

- Motion sensors 40% share (#1)
- Pressure sensors 31% share (#2)

**New sensors portfolio for Industrial applications**

- Smart Things

**Broader sensors portfolio addressing Personal Electronics, Industrial & Automotive**

- Smart Industry

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

- MIPI I3C -- High Performance Interface & Scalable solution

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

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

IMU = Inertial Measurement Unit

IHS Motion Sensors Market Share Report 2017
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

Motion Sensors and more
Humidity and temperature sensors as enablers for in-situ calibration

- **Motion sensors**
  - Accelerometers, gyroscopes, 6-axis IMUs, magnetometers

- **Temperature sensors**
  - Analog and digital contact temperature sensors

- **Humidity sensors**
  - Combo humidity and temperature sensors

- **Pressure sensors**
  - Water proof solutions

- **MEMS microphones**
  - Analog, digital, top and bottom port solutions
# Motion MEMS Sensors for Smart Industry

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Description</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IIS3DWB</strong></td>
<td>Vibration Sensor - Ultra Wide Bandwidth</td>
<td>LGA-14 2.5x3 mm</td>
</tr>
<tr>
<td></td>
<td>COMING SOON!</td>
<td></td>
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<tr>
<td><strong>IIS3DHHC/IIS2ICLH</strong></td>
<td>Inclinometer - High Resolution, Ultra Low Power</td>
<td>LGA-16 5x5 mm</td>
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<tr>
<td></td>
<td>Inclinometer – Digital Output</td>
<td></td>
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<tr>
<td></td>
<td>High Accuracy (&lt;0.5° over Temp. and Time)</td>
<td>ES NOW</td>
</tr>
<tr>
<td><strong>IIS2DH/IIS2DLPC</strong></td>
<td>Accelerometer - Wide Bandwidth, Ultra low-power</td>
<td>LGA-12 2x2 mm</td>
</tr>
<tr>
<td></td>
<td>3D Accelerometer – Digital Output</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wide Bandwidth (up to 2.3 kHz)</td>
<td></td>
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<tr>
<td></td>
<td>Ultra Low Power – Ultra Compact</td>
<td></td>
</tr>
<tr>
<td><strong>IIS2MDC</strong></td>
<td>Magnetometer Low-Noise, Low Power</td>
<td>LGA-12 2x2 mm</td>
</tr>
<tr>
<td></td>
<td>3D Magnetometer – Digital Output</td>
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<tr>
<td></td>
<td>AMR Technology - up to 50 Gauss Full Scale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ultra Low Noise, Low Power</td>
<td></td>
</tr>
</tbody>
</table>

(*) Contact Sales for availability
<table>
<thead>
<tr>
<th>Sensor Code</th>
<th>Sensor Description</th>
<th>Specification</th>
</tr>
</thead>
</table>
| ISM330DLC   | Combo accelerometer & Gyroscope  
Wide Bandwidth  | 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  | 3D accelerometer with full scale up 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  | 3D Accelerometer – Digital Output  
3D Magnetometer – Digital Output  
±2/±4/±8/±16 g selectable acceleration full scales  
Up to ±50 gauss magnetic dynamic range |
Environmental Sensors for Smart Industry

LPS22HH
Pressure Sensor – High Accuracy – Compact Size

LPS33W/LPS27HHW
Pressure Sensor – Water Resistant

HTS221
Humidity and Temp Sensor – High Accuracy

STTS751
Digital Temperature Sensor

LM235 – STLM20
Analog Temperature Sensor

STTS22H*
Digital Temperature Sensor – High Accuracy

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

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

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

Accuracy ±1.0 °C ; Programmable resolution
Accuracy ±1.0 °C ; Op. Temp up to 150 °C
High Accuracy:
  • Temperature: ±0.2 deg
Low Power

(*)Contact Sales for availability
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 dB SPL)

**MP23DB01HP**
Digital Bottom Port Microphone
3.35x2.5x0.98 mm
Bottom Port Microphone
Multi mode PDM Output
Wide Dynamic Range (AOP up to 137 dB SPL)
Hi SNR 65.5 dB

**IMP34DT05**
Digital Top Port Microphone
3x4x1 mm
Top Port Microphone
Digital Output
Wide dynamic range (AOP up to 122 dB SPL)
-26 dBFS ± 3 dB sensitivity

(*) Contact Sales for availability
When frequency matters

**Type of Defect / Wear**
- Unbalance
- Losses
- Misalignment
- Roller Bearings
- Gear Cavitation
- Bearings
- Gear Box
- Lubrication
- Fan Bearings
- Venting Occlusion
- Cooling failure

**Frequency Bands**
- 2Khz
- 5Khz
- 10Khz
- >50Khz

**Devices**
- IIS3DWB
- ISM330DLC
- IMP34DT05
- IIS2DH
- MP23ABS1

**Analysis Methods**
- Sound analysis (10-10KHz)
- Ultrasound analysis
Connectivity
Connectivity Options

Match the needs of Industrial Environments

**Wired Connectivity**

- P2p, Industrial Fieldbus, Industrial Ethernet

- IO-Link
- CANopen
- PROFINET
- EtherCAT
- Sercos
- Ethernet/IP

- And more ..

**Wireless Connectivity**

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

- Bluetooth
- WiFi
- Sub 1GHz
- LoRa
- sigfox
- LTE
- LoWPAN

Any Industrial protocol for any STM32
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
From Sensor to Fieldbus

Predictive maintenance kit with sensors and IO-Link capability

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

**Wired**
- L6362A IO-Link communication transceiver device IC

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

*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

---

**Equipment Use cases**
- Motors
- Environment
- STM32F469AI

**Connectivity**
- Optimized form factor for industrial M12 connector

**Processing**
- Embedded algorithm for sensors data analysis, detecting anomalies
- Logging of worst working condition events

---

**STEVAL-BFA001V1B**
STEVAL-IDP004V1
Applications with 2+ nodes to be monitored

Adapter RS485 / USB
Optional USB

Axel spectrum

Axel Peak

Speed RMS

P, T, H parameters

STEVAL-BFA001V1B

Download the condition monitoring_iol
fw from the STSW-BFA001V1 Demonstrations folder
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.
- **FP-CLD-AWS1**
  - Companion AWS-based web dashboard

- **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).

- **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

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

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

Alpha engagements
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 DS1SM, 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
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
2019: Predictive Maintenance Node to Cloud

Ultrasound, Vibration, Environmental sensing

IoT hardware boards

Predictive Maintenance Kit

Serial

STM32MP1

AWS IoT Greengrass

Wi-Fi/Ethernet

Wi-Fi

Amazon FreeRTOS

IoT Discovery Kit Node

AWS IoT Core

AWS Lambda

Amazon S3

Amazon DynamoDB

Amazon API Gateway

Amazon Cognito

AWS Shield

AWS WAF
Platform Evolution

Ultrasound, Vibration, Environmental sensing

IoT hardware boards

Predictive Maintenance Kit

STM32MP1

Serial

AWS IoT Greengrass

Wi-Fi/Ethernet

STWIN

Amazon FreeRTOS

AWS IoT Core

AWS Lambda

Amazon S3

Amazon DynamoDB

Amazon API Gateway

Amazon Cognito

AWS Shield

AWS WAF
Predictive Maintenance Solutions

Value Proposition

Smart Sensor Nodes: different connectivity and UI to evaluate specific products
- Evaluation
  FP-IND-PREDMNT1

PoC
- STEVAL-BFA001V1B

Full feature evaluation: Equipment/Asset Retrofitting
- HW Available
- SW available
- BLE Data log with APP
- Same SW Library shared with same features: Vibration and Sound Analysis

Understanding Needs

Field Test: Predictive Maintenance Platform
- Edge and Cloud: e2e
- Gateway SDK available on GitHub
- Dashboard on st.com available end of September 2019
- Cloud dashboard Data Log

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