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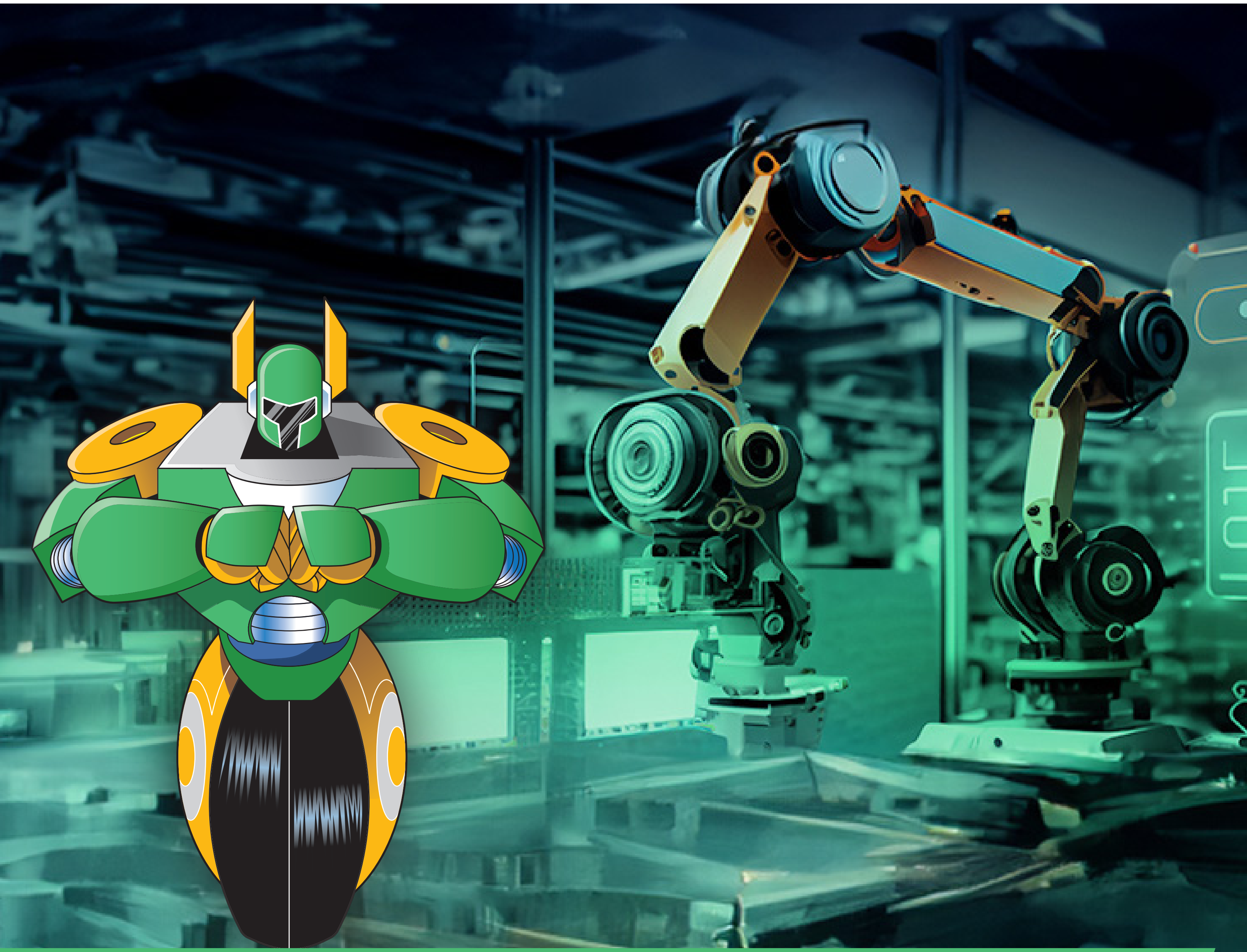


/INDUSTRIAL AUTOMATION: IOT AND SENSOR INNOVATIONS FOR PREDICTIVE MAINTENANCE

CONTENT

CONNECTED SENSORS AS A BASIS FOR HIGH EQUIPMENT AVAILABILITY

1. IOT IN INDUSTRY

Digitalisation and networking create new opportunities for automation in the manufacturing sector under the banner of Industry 4.0. Through the Industrial Internet of Things (IIoT), devices, machines, and equipment are now interconnected, capturing an enormous amount of machine-generated data. IoT technologies are used, among other things, to improve machine-to-machine (M2M) communication, thereby optimising workflows. Their use offers new possibilities to reduce downtime, enhance efficiency, make more informed decisions, and ultimately increase profit margins while reducing costs.

1.1. RAPID GROWTH

It is therefore not surprising that, according to a survey by Ubisense, a leading provider of real-time location systems, by 2023, 62 percent of the surveyed companies had already integrated IoT technologies into their manufacturing or assembly processes. For 2024, market analysts at Mordor Intelligence estimate the industrial IoT market to be worth \$114.68 billion. By 2028, it is expected to nearly quintuple to \$503.07 billion. This corresponds to an average annual growth rate of 34.41 percent.

1.2. IIOT COMPARED TO IOT

Even though the fundamental technologies and ideas are the same, IIoT differs significantly from IoT.

Firstly, the Industrial IoT is more complex: in a factory, far more devices and systems are interconnected compared to, for example, a smart home. The sensors used are more precise and continuously capture a multitude of data from manufacturing machines and equipment. These data are encrypted and transferred to a dedicated data centre or specialised cloud platforms, where they are analysed and prepared for the respective applications.

IoT devices in industrial environments also need to be significantly more robust than those in the consumer sector. Sensors and communication modules must reliably operate at extremely low or high temperatures and be resistant to shocks and contaminants.

Often, the points where IIoT devices are placed in industrial plants are difficult to access (such as pipelines or large chemical plants). Therefore, they need to operate autonomously for long periods, ideally being maintenance-free. This also means that if a connection to the power grid is not feasible, energy is supplied via long-lasting batteries or energy harvesting, and the energy consumption of the devices is kept as low as possible.

It is also important to consider the differing typical lifespans of IoT and IIoT applications: while IoT devices in the consumer sector are used for only a few years (according to the market research institute Mafo, German consumers, for example, buy a new smartphone every two to three years), industrial plants can be in operation for decades. This means IIoT systems need to be capable of updates and compatible with older equipment.

Furthermore, the requirements for security and reliability are much higher for IIoT than for IoT. If a smart home's roller shutter control does not respond to sunlight, it is annoying but usually does not cause damage. It is different with IIoT: if a connected device fails here, it can bring the entire production to a halt, causing immense damage and costs. Accordingly, the requirements for cybersecurity are also high – it must be ensured that unauthorised persons cannot access or manipulate data.

2. KEY APPLICATIONS: CONDITION-BASED MONITORING AND PREDICTIVE MAINTENANCE

Avoiding unplanned downtimes is not only a crucial criterion concerning the reliability of IIoT components but also one of the key applications of IIoT.

Even today, maintenance in many businesses is a reactive measure: action is only taken when the machine has already failed or is producing defective products due to a malfunction. During troubleshooting and repair, not only the individual machine but also the upstream and downstream processes often come to a halt. A poor maintenance strategy can reduce the overall production capacity of a facility by 5 to 20 percent. The costs for one hour of downtime can quickly amount to several thousand euros – in the automotive industry, they can even reach millions. According to research by IoT Analytics, the costs of unplanned downtimes average around $125,000 per hour. It is therefore not surprising that reducing or even avoiding unplanned downtimes is one of the most frequently cited use cases for IIoT. By interconnecting industrial equipment and other applications, real-time data on the condition and performance of individual machines and the entire production system can be obtained.

2.1. CONDITION-BASED MONITORING

Condition monitoring is a maintenance strategy in which the condition parameters of equipment are measured in real time using IIoT tools. By capturing parameters such as vibration levels, temperature, or oil quality, machine faults can be detected early – before a machine failure occurs – and repairs can be carried out more quickly. With deep insights into the condition of equipment, maintenance activities, inventory needs, and budget can be better planned.

Condition monitoring offers several advantages:

- Reduced downtime: Damage and malfunctions in machines are detected early. This allows the maintenance team to intervene and carry out repairs before a failure occurs.

- Lower maintenance Costs: Maintenance work is only performed when it is truly necessary, reducing labour costs as well as the cost of spare parts. - Longer Lifespan: Well maintained equipment lasts longer and experiences fewer malfunctions.

- Improved safety: Damage to machines and equipment can pose a safety risk to employees. Additionally, failures can damage other equipment in the vicinity.

- Higher productivity: The operating times of the equipment are increased.

An important point is that equipment can be easily monitored through IIoT even in hard-to-reach locations. Maintenance technicians receive regular updates on the mechanical condition of a machine without needing to be on-site themselves.

2.2. PREDICTIVE MAINTENANCE

By capturing sensor data in condition-based monitoring and applying advanced analytical tools and processes, such as machine learning (ML), predictive maintenance can identify patterns and trends indicating upcoming issues or maintenance needs. For instance, replacement parts can be installed before the original part fails. Maintenance intervals can be planned based on the actual needs using condition monitoring data, rather than adhering to general guidelines that often significantly deviate from actual operating conditions and wear states. This allows for demand-oriented planning of service and maintenance actions to optimise equipment effectiveness.

Predictive maintenance saves costs and time by enabling targeted deployment of service technicians, spare parts, and logistics. Since critical unplanned failures in equipment usually occur several times a year, an investment in predictive maintenance generally pays off very quickly.

3. SENSORS FOR CONDITION MONITORING

A prerequisite for the realisation of condition-based monitoring and predictive maintenance is the collection of the widest possible variety of data on the operating states of machines and equipment. For this purpose, they are equipped with additional IoT sensors that monitor various parameters.

Typical sensor solutions for use in rotating systems (motors, pumps, gearboxes, turbines, etc.) are exemplified below:

3.1. VIBRATION

Vibration diagnostics are the most important variable for monitoring and detecting potential problems in rotating machines. They enable the detection of machine damage at a very early stage.

Vibrations in machines can have various causes: the most common include worn or damaged bearings, imbalances due to bent parts or dirt deposits, misalignment in the drive train, or assembly errors. Vibrations typically occur with a main direction perpendicular to the axis of rotation. Measurement parameters for capturing vibrations include displacement in micrometres (µm), velocity in millimetres per second (mm/s), or acceleration in metres per second squared (m/s^2).

By continuously monitoring these parameters, vibrations are measured continuously. Changes in vibrations indicate misalignment, wear, or impending failures. Vibration thresholds are defined, above which condition-based monitoring triggers an alarm.

When selecting a suitable sensor for vibration measurements, various criteria should be considered to ensure the most informative measurements possible:

- Wide frequency response
- Measurement resolution and dynamic range
- Long-term stability with minimal drift
- Operating temperature range
- Housing options and ease of installation
- Signal output

Typically, two different types of sensors are used:

3.1.1. Piezoelectric accelerometers

Piezoelectric (PE) accelerometers contain a piezoelectric sensing element with a crystalline atomic structure that generates an electric charge when subjected to a force resulting in deformation. These sensors are active transducers, meaning they do not require a power supply to generate the electrical signal. PE sensors also contain no moving parts that can wear out. The sensing element responds immediately to events, making piezoelectric sensors ideal for highly dynamic measurements. The output signal, which is proportional to acceleration, can be electronically integrated to convert it into signals proportional to vibration velocity and displacement.

Most piezoelectric sensors are based on lead zirconate titanate ceramics (PZT). PZT crystals are ideal for condition monitoring applications because they offer a wide temperature range, a large dynamic range, and a broad frequency bandwidth (usable up to >20 kHz). The sensors can also operate at extreme temperatures, though they are limited by high output impedance, which requires low-noise cables and charge amplifiers for signal processing.

3.1.2. Variable capacitance sensors

Variable capacitance (VC) sensors derive acceleration measurements from a change in capacitance of a mass that moves between two parallel capacitor plates. The change in capacitance is directly proportional to the applied acceleration. VC sensors are typically made from silicon wafers and realised as MEMS (Micro-Electro-Mechanical Systems) chips. The very small changes in capacitance are converted into an output voltage using a microchip. This conversion process often results in a poorer signal-to-noise ratio and a limited dynamic range. However, they are smaller and lighter than piezoelectric accelerometers. Capacitive MEMS accelerometers are particularly used in performance-oriented applications.

3.2. SOUND

It is also possible to identify anomalies in the operation of a machine or component by capturing its sound emissions. Based on the analysis of sound emissions and their frequency spectra in both the audible and ultrasonic ranges, conclusions can be drawn about the condition of the monitored machines and potential problems can be detected early.

3.2.1. Measurement of audible sound

In the measurement of audible sound, microphone arrays are used today, among other tools. These arrays are placed at a certain distance from the equipment and can simultaneously monitor various processes, machines, or components. From the audio data, different parameters can be derived, such as sound pressure levels (dB) or frequencies. An analysis of deviations compared to fault-free operation can then identify anomalies and disturbances. However, this method is only partially suitable for condition-based monitoring, as it requires a massive amount of data storage and is expensive compared to other solutions available on the market.

3.2.2. Ultrasound sensors

It is different with the measurement of ultrasound emissions from a machine or component.

There are two main types of ultrasound sensors: air ultrasound sensors and structure-borne ultrasound sensors. Air ultrasound sensors are used to detect leaks in pressure and vacuum systems, steam traps, valves, etc. They operate with a microphone. Structure-borne ultrasound sensors, on the other hand, are used to detect bearing faults, lubrication issues, etc. These sensors use either a piezo element or a MEMS sensor.

MEMS microphones are particularly appealing due to their low cost. They detect sound waves in the frequency range of 20 kHz to 100 kHz, which is exactly the range where many disturbances cause noise.

The monitoring of ultrasound emissions can be used to detect a variety of machine faults and defects:

- Early stage bearing defects
- Lubrication issues, both over- and under-lubrication
- Leak detection in pressure and vacuum systems
- Detection of Leaks in steam traps, valves, seals, and gaskets
- Corona discharge, arcing, and creeping currents in electrical systems
- Predictive Maintenance of equipment with low rotational speeds (up to 1 RPM)

For rotating components, the last point is a significant advantage of ultrasound measurement: at low rotational speeds (less than ~600 RPM), the amplitude of vibrations is so low that an accelerometer must have a very high sensitivity of at least 500 mV/g (before amplification) or better. Additionally, at low rotational speeds and the associated low fault frequencies, noise occurs, making the measurement of accelerations difficult. Accelerometers that provide accurate measurements in these conditions are significantly more expensive than ultrasound sensors, which can easily capture emissions even at slow speeds.

Therefore, it is sensible to use ultrasound sensors in combination with vibration analysis for monitoring slow-moving components to gain a more comprehensive understanding of the condition of the equipment.

When selecting an ultrasound sensor, the following points should be considered:

- Signal-to-Noise Ratio (SNR)
- Sensitivity
- Frequency range
- Resonant frequency

3.3. TEMPERATURE

Another important technique in condition-based monitoring is thermal analysis. The range of temperature sensors used for this purpose includes simple thermocouples that measure the temperature at a defined point, infrared sensors, and infrared cameras that can capture the thermal image of a larger area.

3.3.1. Thermocouples

A thermocouple converts heat into electrical energy. It consists of two wires made of different metals, joined at one end. At the other end, the thermocouple wires are connected to a measuring device. When one side is heated, a current flows in this thermoelectric circuit. The resulting voltage (thermoelectric voltage) is a function of the temperature at the junction between the two metals. Thermocouples are available in various combinations of metals, each with its own temperature range.

3.3.2. Infrared cameras

According to Planck's law, any object with a temperature above absolute zero emits infrared radiation, the amount of which increases with temperature. Infrared cameras can capture this radiation and convert it into a colour map. Each colour in the image represents a different temperature. This allows for a very visual representation of the surface temperatures of machines and equipment.

Temperature anomalies can be detected, which may indicate excessive friction, poor heat dissipation, electrical malfunctions, or other problems. An advantage of temperature monitoring with infrared cameras is the non-contact and rapid monitoring of large areas of equipment.

3.4. HUMIDITY

Humidity is not only an important environmental parameter but can also provide insights for condition-based monitoring. Various types of humidity sensors are available on the market, each with its own advantages and disadvantages.

Fundamentally, there are four types of sensors used for humidity measurement:

3.4.1. Capacitive humidity sensors

Capacitive humidity sensors are among the most commonly used types. Their operation is based on measuring changes in the dielectric constant of a material in response to changes in air humidity. The dielectric constant describes the ability of a material to store electrical energy in an electric field. Capacitive humidity sensors consist of two electrodes, one of which is coated with a hygroscopic material that absorbs water vapour from the air. The absorption of water vapour leads to a change in the dielectric constant between the two electrodes, which is measured by the sensor.

3.4.2. Resistive humidity sensors

Resistive humidity sensors measure changes in the electrical resistance of a material in response to changes in air humidity. The most common type of resistive humidity sensors is the polymer-based sensor, which consists of a conductive polymer film that changes its resistance when exposed to water vapour. The expansion of the polymer film occurs proportionally to the amount of water vapour in the air and results in a change in resistance, which can be used as a measure of humidity.

3.4.3. Thermal conductivity humidity sensors

Thermal conductivity humidity sensors measure the thermal conductivity of a gas mixture in relation to changes in humidity. They consist of a heated sensing element and a temperature sensor that measures the temperature difference between the two. When the sensing element absorbs water vapour, its thermal conductivity decreases, leading to a temperature change that the temperature sensor can detect. This temperature change is proportional to the amount of water vapour in the air and can be used to determine the humidity level.

3.4.4. Psychrometric humidity sensors

Psychrometric humidity sensors, also known as dew point mirror sensors, allow the measurement of the temperature at which water vapour condenses on a surface. They consist of a cooled mirror on which dew or frost forms at a certain temperature. The temperature at which this condensation occurs is a function of the relative humidity of the air surrounding the mirror.

3.4.5. Applications and selection

The applications of humidity sensors in condition-based monitoring are diverse: they are used, for example, to detect corrosion on or inside metal pipes or on field-level control cabinets. Humidity sensors can also measure water dissolved in hydraulic or lubricating oils. Even small amounts of water in the oils can significantly impair their quality: acids can form, leading to corrosion in the equipment or system. Moreover, the properties of the oil can deteriorate significantly, such as a rapid decrease in temperature resistance or load-bearing capacity. In general, oil ages excessively quickly under the influence of water.

When selecting suitable humidity sensors, the following aspects should be considered:

- Accuracy of the humidity probe (at least ±2% relative humidity (RH))
- Required humidity range
- Long-term stability
- Response time
- Environmental conditions (temperature and humidity range of the application, exposure to chemicals or other contaminants)
- Calibration effort
- Compatibility with measurement system/data logger

4. FROM SENSOR MODULE TO SYSTEM

In addition to the modules for capturing measurement data, IIoT sensors require additional functionalities or components to enable condition monitoring or predictive maintenance:

MCU: A microcontroller converts the measurements from the sensor module into a digital signal. During this process, the signal undergoes an initial stage of preprocessing, including error correction, filtering, and self-monitoring using the MCU.

Communication interface: The pre-processed data is then transmitted to a controller or central data storage. Communication can occur over wired or wireless networks using data transmission protocols such as MQTT, CoAP, or HTTP.

Power supply: The sensor module, MCU, and communication interface require power. This can be provided by the mains supply, typically using switch-mode power supplies that convert the mains input voltage to a 24V DC output. A more flexible option is an off-grid power supply, such as batteries or energy harvesting modules.

In addition to the sensor system itself, condition monitoring applications require a central location where the data from the various IoT sensors converge and are stored. This can be in-house servers or cloud-based platforms. Centralised storage acts as the "Source of Truth" – the single source for all operational data of equipment and machinery. This source is then accessed by condition monitoring or predictive maintenance software to identify trends, patterns, and anomalies that could indicate potential failures.

5. OVERARCHING SENSOR TRENDS

Regardless of the sensor type and the measurements being captured, various technological trends currently shape the development of IIoT sensors.

5.1. WIRELESS CONNECTIVITY

For condition-based monitoring, the necessary sensors can be implemented both wired and wirelessly. The decision between the two solutions depends on factors such as the specific application, the plant layout, and the desired level of flexibility and convenience.

Wired systems offer stable and reliable data transmission, especially in industrial environments. However, wired networking can be complex and costly depending on the plant layout. Laying cables can be particularly challenging during the retrofitting of existing facilities.

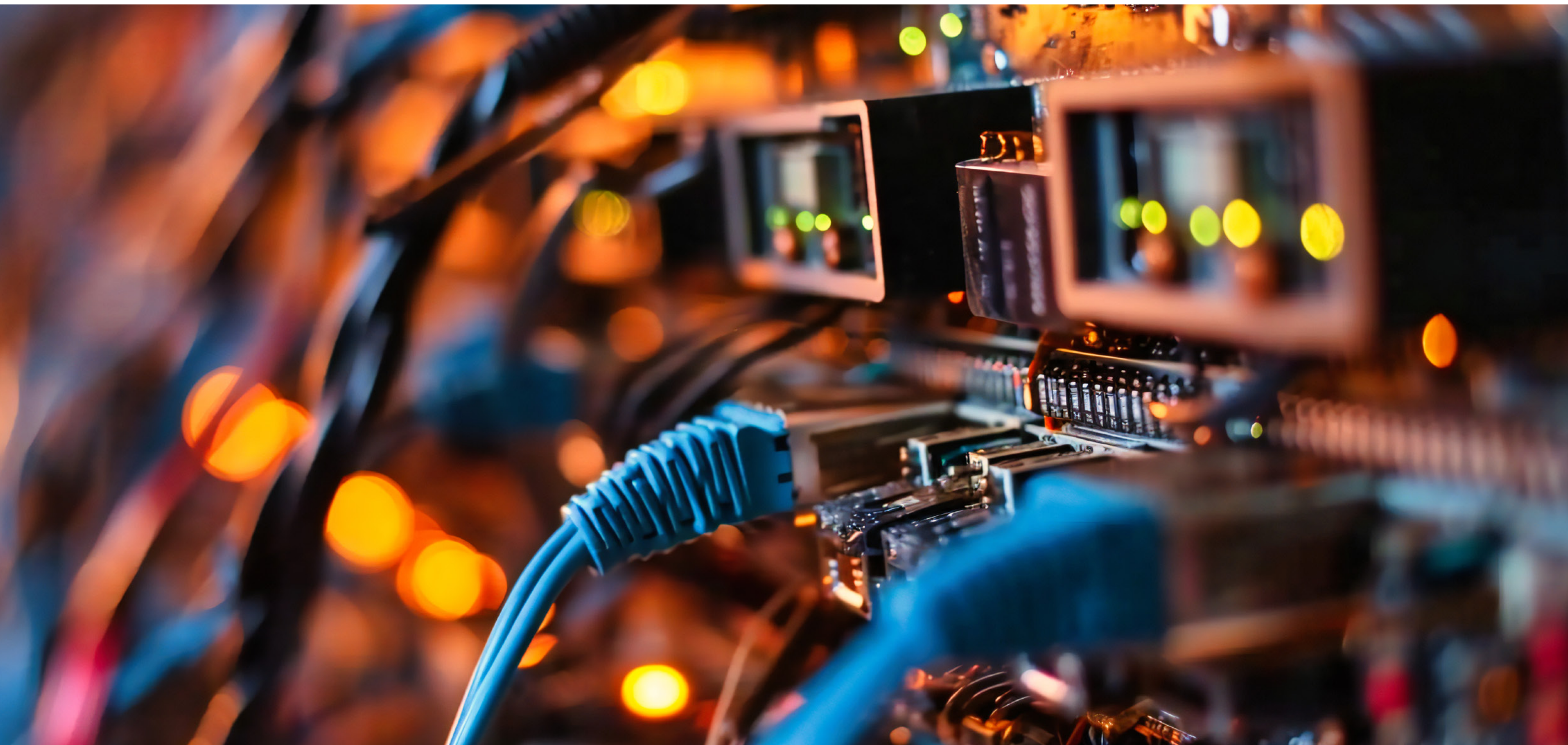
With the advent of specialised wireless protocols for use in IIoT sensor networks, there is a trend towards wireless sensors. They offer great flexibility in sensor placement, easy expansion, and adaptability to changing requirements. Installation is also significantly easier and faster than with wired systems.

Several wireless technologies are available for IIoT applications. Each has its advantages and disadvantages for condition-based monitoring, and each use case has its own requirements regarding latency, data throughput and volume, range, power consumption, and reliability. Another factor, also concerning cybersecurity, is the extent to which the sensor system needs to be future-proof and whether features such as over-the-air updates (OTA) are required.

Industrial wireless technology comparison table

Category	**WiFi**		**Cellular**			**Wide Area (LPWA)**	
Sub-category	802.11 a/b/g/n	802.11ac					
Distance	100 Meters	100 Meters	By service provider coverage			15 kilometers	5 kilometers
Data rate	2 x 2 300Mbps	2 x 2 73Gbps	60Kbps	1Mbps	LTE advanced Pro Cat. 16 1000Mbps (DL) / 150Mbps (UL)	50Kbps	50Kbps
Data Category	Data, voice and SD video	Data, voice, and HD video	Sensor data	Sensor data, voice, image	Data, voice, HD video	Sensor data	Sensor data
License free	Yes		No			Yes	
Security	Open system, shared key, legacy 8021X, WPA/WPA2, WPA-PSK (TKIP), WPA2-PSK(AES)		3GPP (128 to 256bits)	3GPP TS 33.401, 128 to 256bits	Based on 3GPP TS	AES-128bit	
Node	One-to-many		One-to-many			One-to-many	
Recommended application scenario	· Indoor and fixed range areas · Less signal interference · Supports medium data rate · Provides high scalability		· Ideal in complex area, has high signal penetration · High anti-interference capability · Low data transmission · Supports long distance transmission with low power consumption		· Data transmission without geographical constraint · Long distance transmission · Low signal interference · Supports ultra-high data rate transmission · Widely functional	· Self-configuration for easy deployment in widespread area · High anti-interference capability · Low data rate transmission · Supports long distance transmission with low power consumption	· Ultra-low power consumption, self-configuration · High anti-interference capability · Low data rate transmission · Supports long-distance transmission with low-power consumption

Source: advantech



5.2. ENERGY EFFICIENCY AND ENERGY HARVESTING

The increasing integration of wireless sensors also means that the sensors' power supply is independent of a power cable. In addition to using long-lasting, robust batteries, more and more sensors are utilising renewable energy sources such as solar energy or kinetic energy to power themselves. They "harvest" the necessary energy from their surroundings, hence these solutions are called "energy harvesting systems." This eliminates the need for battery changes, allowing the sensors to operate largely maintenance-free. This is particularly beneficial in remote or inaccessible locations, significantly reducing the lifecycle costs of sensor solutions.

The wireless power supply of the sensors also leads to changes in sensor design to achieve the highest possible energy efficiency. Sensors consume less energy if they have a small form factor and use increasingly smaller microcontrollers. Additionally, a better signal-to-noise ratio ensures that the sensor's power is used exclusively for capturing the actual signals, further reducing energy consumption.

5.3. AI @ EDGE

Another significant development in the field of IIoT sensors is the trend towards "smart sensors." These sensors are equipped with powerful computing capabilities, allowing them to process signals at least partially by themselves – for example, for data validation and interpretation, displaying results, or executing specific analysis applications. This transforms sensors into so-called edge devices. By processing data at the "edge" of the network, less data is transmitted, which minimises latency and avoids network bottlenecks.

The latest smart sensors are equipped with processors powerful enough to run AI applications. This enables faster decision-making and allows sensitive data to be processed without leaving the company or facility. Thus, anomalies can be identified, and warnings generated directly at the edge, i.e., within the sensor or machine, for condition-based monitoring.

6. USE CASE: CUSTOMISED IOT SENSORS FOR CONDITION MONITORING OF PUMPS

Many industrial facilities were designed and built before the rapid development of digitalisation and networking could be foreseen. However, such "brownfield" environments can still be upgraded to enable modern condition-based monitoring, similar to that in "greenfield" facilities. While various standard sensor solutions are already available today, they are usually expensive and do not necessarily provide the desired end-to-end solution (from the edge to the cloud).

6.1. GOAL: REDUCE ON-SITE VISITS BY THE MAINTENANCE TEAM

Avnet's IoT Team has demonstrated in a proof-of-concept that such IoT sensor solutions can be realised much more cost-effectively. The cooperation of partners with various expertise enables functional, customised, and seamless end-to-end solutions.

The project's goal was to create a condition monitoring solution for pumps in a remote pumping station for a global company in the water, waste, and energy management sector. The remote monitoring enabled by this IIoT solution ensures that maintenance technicians only need to visit the station if anomalies in the pump operation are detected. At the same time, downtime could be reduced. Overall, this significantly lowers operating costs, and the investment in the IIoT solution quickly pays off.

6.2. SETUP: COMBINING VARIOUS FUNCTIONAL MODULES

To achieve this, Avnet's IoT Team designed devices primarily equipped with accelerometers for vibration analysis. Additionally, humidity and temperature measurement were partially integrated.

The sensors were combined with a microcontroller featuring AI and machine learning capabilities, capable of performing initial analyses directly within the device. Through over-the-air updates (OTA) received from the backend cloud platform, the IIoT sensor system can be trained during the initial phase and later continuously improve its algorithms.

Communication is handled via a wireless module, including a suitable antenna solution. Depending on the requirement, this communication module can use Bluetooth Low Energy, WiFi, Ethernet, LoRaWAN, or NB-IoT to connect to a cloud gateway.

The communication between the cloud and the sensor is secured by state-of-the-art secure element technology. The hardware security module protects cryptographic processes and keys used for encrypting and decrypting data, as well as creating digital signatures and certificates.

The power supply module for all electronic components of the IIoT sensor also comes from our portfolio. The system is powered by batteries, making it independent of wiring and allowing flexible placement on the pumps.

Depending on the network, various gateway technologies can be used. In the project's initial phase, a third-party cloud platform was used; later, the solution operated on our own IoTConnect platform.

6.3. SUCCESS: ANOMALIES ARE INDEPENDENTLY DETECTED

With these custom-designed IIoT sensors for the application, it was demonstrated that the sensors could independently detect anomalies in the pump operation and "flag" them in real-time. This enables maintenance technicians to receive timely information on whether and when on-site maintenance is required – before a failure occurs.

The project also exemplifies how Avnet's IoT Team, as the project leader, can offer a comprehensive, end-to-end solution for IoT applications by involving appropriate partner companies. While Avnet's IoT Team was responsible for the hardware – from conception through component selection to construction – the embedded software, edge AI, machine learning algorithms, and backend cloud platform were provided by partners.

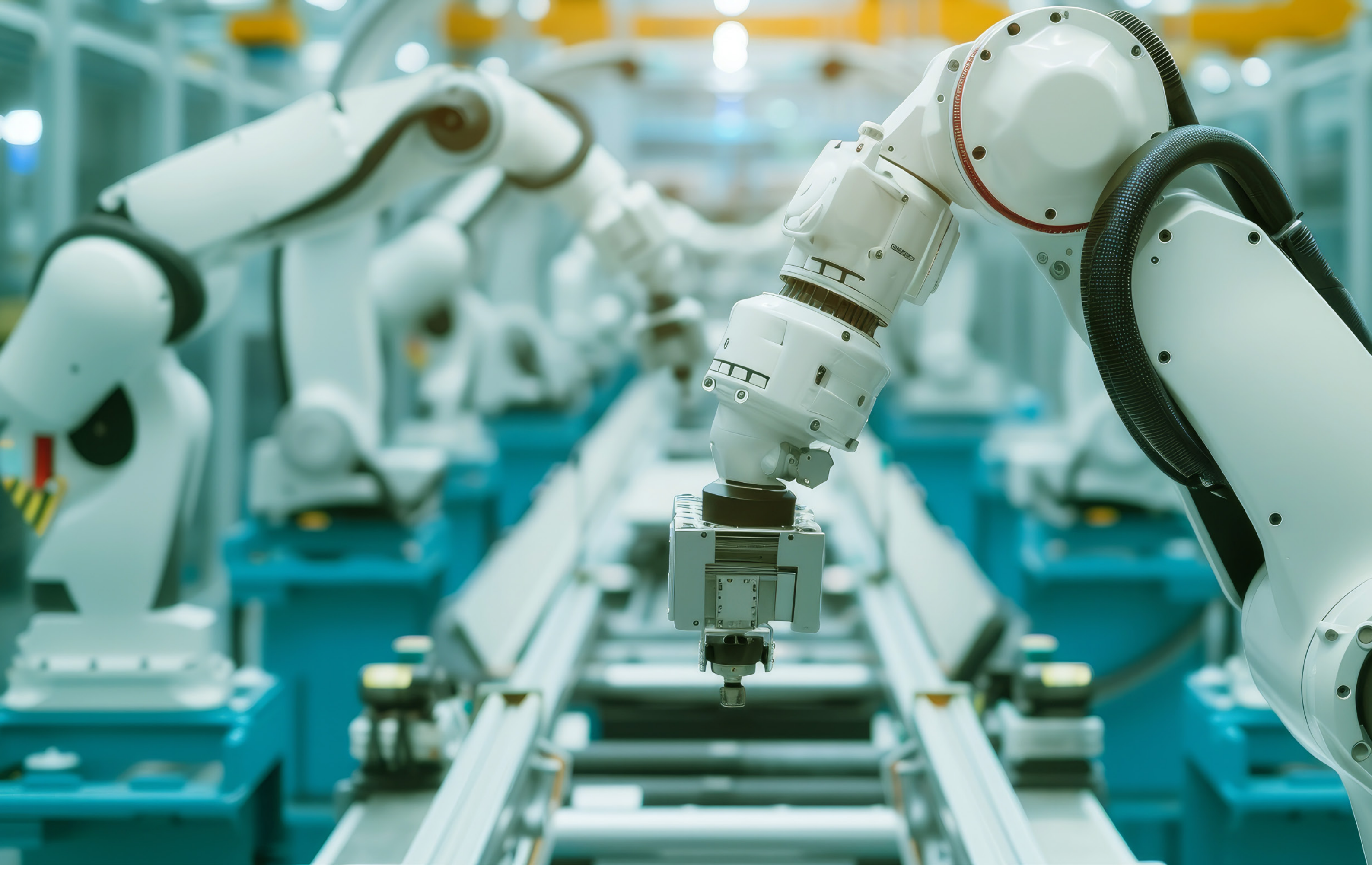
Developing such an IIoT sensor presented various technical challenges to the team. Key considerations included the form factor (i.e., a compact design), appropriate IP rating (protection against ingress), choice of battery technology, network communication, energy management, and OTA updates. Nonetheless, the proof-of-concept demonstrated that a custom-designed sensor could not only reliably fulfil the task but also be significantly more cost-effective than an off-the-shelf solution.

7. CONCLUSION

By integrating IoT technologies into the industrial environment, a comprehensively digitally networked production environment can be established. Industrial IoT thus enables a transition from conventional production methods to the Smart Factory. This increases efficiency and productivity, improves customer orientation, and enhances resilience to crises.

Condition-based monitoring is currently the most widespread IIoT application. Continuous monitoring of machines and equipment through IIoT sensors and the analysis of the captured data minimises downtime and prevents severe damage. Maintenance teams can be deployed more effectively, and spare parts can be ordered in time. Overall, condition-based monitoring and predictive maintenance increase production performance, availability, and the longevity of the machines. According to a McKinsey study, IIoT-supported predictive maintenance can reduce maintenance costs by up to 30%, downtime by up to 45%, and extend equipment lifespan by up to 20%.

The comprehensive collection of operational data in use also leads to a deeper understanding of the machine and its use by the customer. This opens up new possibilities for providing data-driven services, including pay-per-use solutions. Thanks to IIoT, new revenue streams for companies can be unlocked.



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THE INTERNET OF THINGS IN THE INDUSTRIAL ENVIRONMENT

Digitalisation and connectivity are forging new avenues for automation within the manufacturing industry under the banner of Industry 4.0.

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