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White paper:
Sensors for Industrial IoT

Sensing technologies: Facilitating automation and control in IIoT applications

INTRODUCTION

Sensors and sensing systems have always been a critical element of industrial automation systems. Carefully selected, they ensure that temperature, pressure, position, vibration and other process data is accurately fed into control systems. The advent of next generation sensing technologies, along with ultra-low-power electronics, is enabling sensors to be placed in positions and locations that previously would not have been thought viable. In the context of the Industrial Internet of Things (IIoT), this provides significant extra insight into processes that can help improve quality or optimize maintenance schedules and logistics. Here we review some key sensing technology, where it is used, and the impact it is having as analog makes way for digital solutions.

THE EVOLUTION FROM ANALOG TO DIGITAL SENSING

Transducers and transmitters have formed the basis of physical parameter sensing in industrial control for decades. Transmitters based upon the 4 – 20mA current loop have been dominant in many industries. They can deliver their measurements accurately over long cable lengths, unlike voltage-based output transducers, and are less sensitive to induced noise. Their wiring is simple and the 4mA minimum output current ensures that faults, such as a broken cable or sensor, can be easily detected.

Despite this robustness, there are some limitations. The first is that the sensor electronics need to draw less than 4mA of current. Additional power-drawing sensor features, such as back-lit displays and output relay options, must be accommodated through the provision of a separate power supply. This often requires a move from 2-wire to 3-wire or 4-wire cabling. The second issue is that each cable laid can only accommodate a single process signal. This results in masses of cable being laid to handle many sensing signals. This brings further challenges related to ground loops should they not be properly isolated.

Digital technology has delivered a range of bus technologies suitable for industrial automation that allow many sensors to all be connected to a programmable logic controller (PLC) over a single length of cable. Solutions leveraging the robust controller area network CAN communication protocol, such as DeviceNet, can support up to 64 nodes on a single network. Furthermore, cable lengths can reach up to 500m. This approach not only allows sensors to deliver process data to the PLC, but the PLC to interrogate and configure the sensor too. The PLC could also reconfigure the sensor with differing ranges and limits for warnings, or even request manufacturer ID, date, serial number, and hours of usage. This may additionally form part of an IIoT-based maintenance checking solution.

For more information visit our TE Connectivity IIoT website at:
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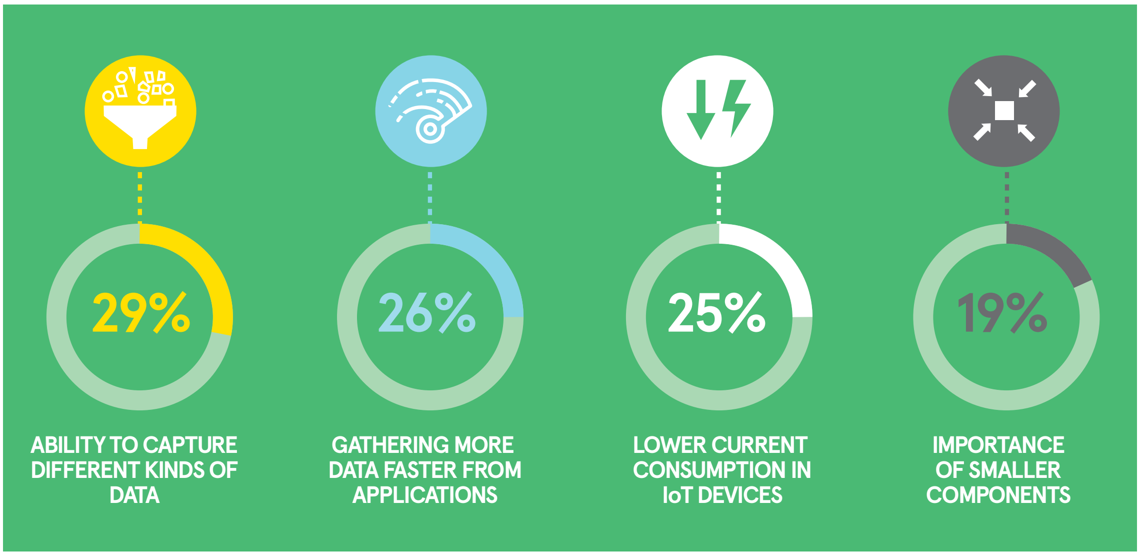
ARE INDUSTRIAL ENGINEERS' NEEDS FOR IIOT BEING MET?

In a recent survey of industrial engineers, undertaken by TE Connectivity (TE), it was identified that sensor development is not keeping pace with the needs of engineers, especially with respect to IIoT integration and the future roll-out of 5G communication1. A full 29% highlighted that they were looking for solutions that enabled them to capture different kinds of data; 26% wanted that data faster; and 25% were looking for lower power consumption (Figure 1). Existing IIoT solutions are not considered to be robust enough from a hardware perspective, while challenges remain in finding the right hardware offering the necessary connectivity. Finally, IIoT development is, in the majority of cases, still starting with the hardware, and not the software.



▲ Figure 1: Industrial engineers cite the ability to capture different types of data as a key area of concern for future sensor selection, along with data volume and sensor power consumption.

WILL DIGITAL SENSING SOLUTIONS RESOLVE THESE CHALLENGES?

The move to digital sensing is delivering exceptionally low power draws thanks to miniaturization of silicon devices. This has also brought new sensing approaches based upon Micro-ElectroMechanical systems (MEMs), tiny components mere micrometers in dimension that are etched into silicon. Their low inertia and precision construction provide magnitudes of improvement in measurement accuracy over traditional analog alternatives.

The move to digital sensing is also benefiting the number of industrial applications utilizing autonomous guided vehicles (AGV). Warehouses are utilizing wheeled robots to collect supermarket orders, with each sharing data and receiving instructions wirelessly. Some manufacturing facilities are also moving to more adaptive production environments, meaning that fixed cabling is not an option. This is also the case in the semiconductor industry where complex manufacturing processes can no longer be efficiently completed with a "conveyor belt" approach. Instead, AGVs collect silicon wafers from one processing station and deliver it to the next, sometimes multiple times, roaming around the fabrication facility. Digital sensors naturally integrate themselves into these IIoT digital wireless networks.

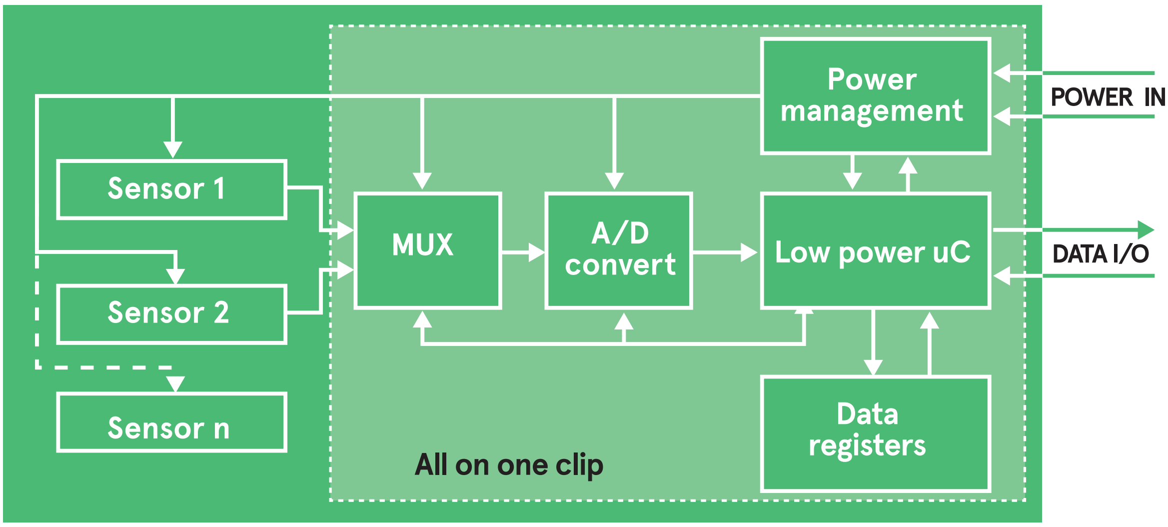
DEFINING SENSORS FOR MY IIOT APPLICATION

Sensor selection starts with defining the physical parameter to be measured. The challenge, however, is often ascertaining the range of the measurement required and determining the response time required. For process parameters such as temperature, pressure and humidity, this is a relatively straight-forward activity, although rate of parameter change is sometimes problematic to accommodate. Flow measurement, angle, vibration and torque can be more challenging, especially for very low and very high values or rates of change.

Object detection, or the detection of bubbles in tubes, can also be quite a complex task. The composition of the materials in use, their opaqueness, the distance to the object, its size, and the environmental conditions all need to be considered. Visual systems may require a regular air purge in order to keep them operational in dusty conditions.

Many of us would prefer to use a finished, off-the-shelf, sensor, benefitting a standard mechanical housing, tested ingress protection (IP) levels, and the predefined integration of the desired industrial-grade signalling or network implementation. However, some industrial sensing applications may require the development of a custom sensor from the ground up. Here, not only do the sensing parameters need to be well defined but, also how the sensor will be mounted inside its housing. Thankfully, today's packaging technology allows sensor assemblies to be created that aren't much larger than the sensing element embedded inside them. This makes it possible to ensure that the sensing area is close to the physical parameter being measured, such as the temperature of a heating vessel.

In many cases, multiple sensing technologies can be embedded inside a single device (Figure 2). An accurate silicon-based temperature sensor is often embedded alongside the main sensor. With short pathways and highly integrated electronics, such devices are protected against induced and emitted noise sources, while emitting little themselves. Conversion of analog signals into appropriate digital values, along with power management and configuration functions, can be embedded in a single chip and can reside in the same package as the sensor itself. Non-volatile memory may allow the configuration settings to be retained, even after the power is turned off.



▲ Figure 2: Highly integrated solutions 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.

Most component-level digital sensors share their measurements and provide configuration capability digitally via a board-level interfacing technology such as SPI or I2C. The data transfer rate and the available bandwidth, especially when connecting several sensors to the same bus, needs to be factored in, too. The microcontroller unit (MCU) selected as part of this design must also be capable of supporting the number of interfaces required, while being powerful enough to execute any pre-processing algorithms, such as fast-Fourier transform filters, in conjunction with the industrial networking protocol stack required to communicate back to the PLC selected.

HOW DO I SELECT A TEMPERATURE SENSOR FOR MY IIOT APPLICATION?

Despite being a seemingly simple and well understood parameter to measure, electronic determination of temperature beyond the simplest application requirements can be quite challenging. The temperature range, rate of change, point of measurement (contact or contactless), and environmental factors such as moisture and vibration need to be taken into consideration.

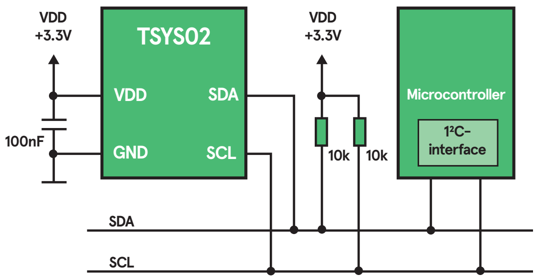
Simple analog measurement of temperature ranges from -80°C to 300°C can be accommodated by NTC (negative temperature coefficient) thermistors. In combination with a Wheatstone bridge and amplifier, such sensors can provide high accuracy, are reliable, and offer long-term stability, especially those in hermetically sealed glass. This makes them ideal for monitoring locations that are difficult to access. Fast changing temperatures can be accommodated with the Series I NTC thermistors offering a response time of <15 seconds. Packaging ranges from custom probe assemblies to leaded glass bead and surface mount chips (Figure 3). Combined with a suitable MCU and software, the sensor could be easily integrated into an IIoT application.

▲ Figure 3: A range of NTC thermistors suitable for -80°C to +300°C temperature measurement.

The health of motors and generators can be challenging to ascertain without stripping them down. Localized rotor overheating in synchronous motors, known as hot spots or black marks, can be detected with an RTD (resistance temperature detector) sensor **(Figure 4)**. Devices such as the 300 Series RTD Sensor Assemblies are rectangular, flat, laminated RTD-based sensor assemblies that can be inserted between the coils in the stator and are commonly known as "Stator Sticks". Packaged in fiberglass with PTFE leads, they can operate at temperatures of up to 180°C and have a dielectric strength of up to 3kV. These types of assemblies are ideal for integration into IIoT-based preventative maintenance systems.

▲ Figure 4: Stator Sticks are RTD thermistors used for health monitoring of motors and generators.

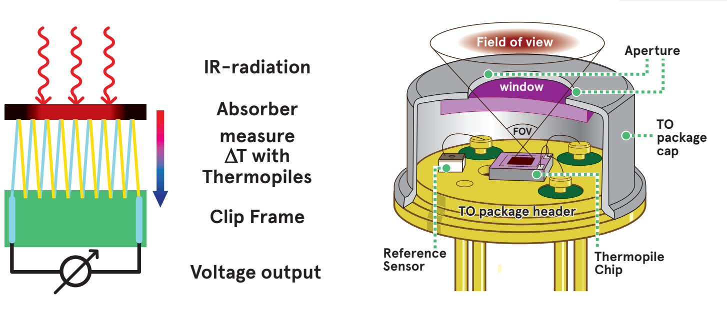
Highly integrated digital sensors can, under some circumstances, provide an alternative to NTC and RTD-based sensors. Available in tiny packages, down to 2.5 x 2.5 mm, their low thermal mass facilitates a fast response time. This makes them ideal in heating and cooling systems and other industrial control applications. Being silicon-based devices, their upper operating temperature is limited to about +125°C. Integrating a digital temperature sensor such as the TSYS02 is exceptionally simple. Two devices pins are reserved for power and ground.
Two other pins provide the digital interface to the host MCU, in this case over an I2C interface, which requires just one data line (SDA) and one clock line (SCL) (Figure 5).



▲ Figure 5: The TSYS02 temperature sensor is simple to integrate with the I2C interface of a host MCU.

Thermopile sensors are non-contact temperature sensors that utilize the fact that all objects transmit infrared energy in direct proportion to their absolute temperature (Figure 6). Typically packaged in an industry standard round metal package, the silicon window at the top of the sensor is pointed towards the object being measured. The silicon window provides protection against ingress while additionally filtering out sunlight that would otherwise influence the temperature measurement of the object.

Optimal measurements are achieved when the surface to be measured is entirely in the field-of-view of the sensor (Figure 6). The TSD305 is a digital thermopile sensor and provides an I2C output to an MCU. Providing a measurement accuracy of up to ±1°C, the device can be operated across a -10°C to +85°C temperature range and measures object temperatures from 0°C up to 300°C.

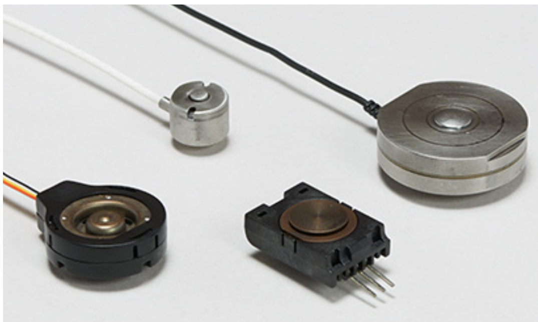


▲ Figure 6: The composition of a thermopile detector is shown (left) along with the anatomy of the full sensor (right).

WHAT OPTIONS ARE AVAILABLE FOR MEASURING FORCE?

Force sensors provide a measurement for compression, tension, or a combination of the two. Within industrial environments they provide feedback on the loading of cranes, pressure within the end-effectors of robots, or the volume of material in vats and storage vessels. Measuring force ranges from 4.5N up to 1000kN making them suitable for a wide range of applications.

TE Connectivity's FC23 is a robust, highly reliable compression load cell sensor that can be easily integrated with a PLC or an MCU to share its data in an IIoT application (Figure 7). Measuring direct forces of up to 8,890N, it is not susceptible to the lead-die fatigue of comparable designs. Proprietary Microfused™ technology, a micromachined silicon piezoresistive strain gauge fused with high temperature glass to a high temperature stainless steel substrate, eliminates the use of age-sensitive epoxies. This ensures that long-term span and zero stability are achieved. Provided in a 31.75mm diameter and 9.2mm thick package, three different output signal types are offered. Two provide a differential signal direct from the strain gauge, while the third integrates a signal amplifier to deliver a single-ended amplified output. With an output range of up to 4.2V, the load cell can be easily coupled with the analog-to-digital converter (ADC) of an MCU.



▲ Figure 7: The FC23 is a robust load cell for measuring forces of up to 10000Nm, offering an amplified output signal.

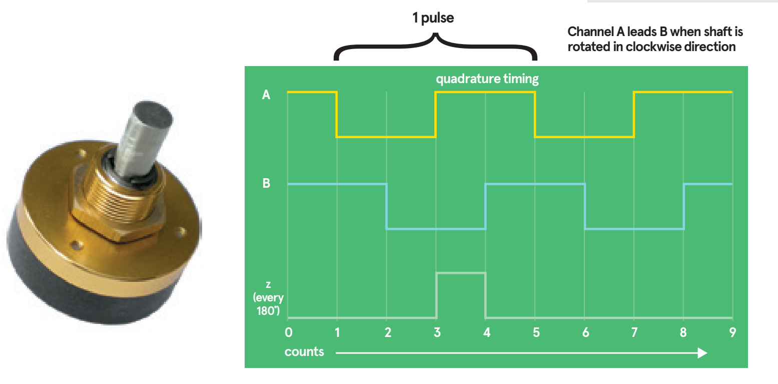
WHEN REPORTING POSITION OR ROTATION TO IIOT SYSTEMS, WHAT SENSING OPTIONS ARE AVAILABLE?

Industrial automation applications that process materials, feed granulates and move materials require accurate feedback on position, torque and tilt. Continuous monitoring of such parameters and their analysis can be integrated into an IIoT solution, with feedback on progressive performance loss or even failure being automatically highlighted to operators. Just like the other sensing technologies discussed, these measurement parameters can be integrated into digital systems in a range of different ways.

Measuring tilt angle is essential in applications where materials are being moved from one location to another. This includes mobile and stationary lifting equipment and can also apply to robotic arms and AGVs too. The D-Series of inclinometers are high-accuracy, dual axis devices with a measurement range of ±5° to ±30° (Figure 8). Temperature compensation is automatically managed, while measurements are also linearized by the integrated MCU. A 4 – 20mA current loop or a pulse-width modulated (PWM) output option is available. However, for easy integration into digital systems, both RS-232 and CANopen are supported. RS-232 allows for measurement updates of up to 16 times per second while CANopen offers data rates of up to 1MBaud. For CANopen, the D-Series sensor can be one of 127 devices on a single bus.

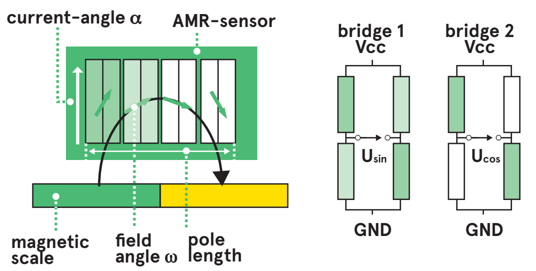
▲ Figure 8: The D-Series of inclinometers provides simple digital integration via both RS-232 or CANopen interfaces.

Rotational position of shafts can be determined using rotary encoders. These come in a variety of form factors and output options. The ED-19 and ED-20 are quadrature output magnetic encoders suitable for medium duty applications (Figure 9). Providing up to 400 counts per revolution, and an index pulse every 180° on the ED-20, they are ideal for monitoring the speed and rotational direction of pumps, position of XY stages, and the position of valves. With an IP52 rating, they are protected against dust ingress and dripping water. The versions featuring ball bearings offer a life of 30 million revolutions at operation speeds of up to 3000 RPM.



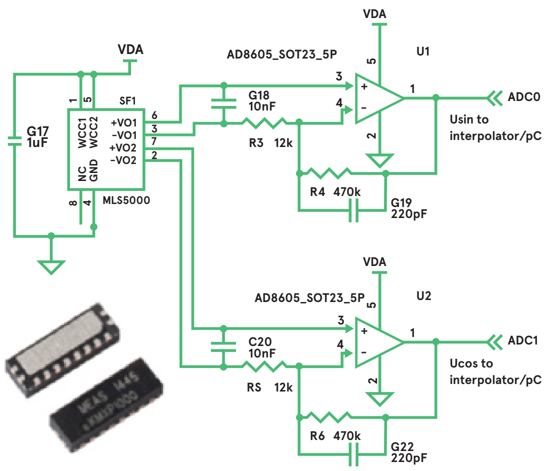
▲ Figure 9: The ED-20 Series rotary encoders provide a quadrature output together with a 180° index pulse.

Accurate linear position measurement can be challenging to achieve accurately, especially in hazardous environments or locations that are subjected to moisture and dust. Contactless approaches using magnets are ideal in such situations and are becoming more advanced. The latest sensors make use of magnetoresistance, a property of material discovered by Lord Kelvin in 1857, whereby the resistance of a material changes value according to the magnetic field applied to it. This measurement approach has been integrated into the KMXP Series of sensors, enabling industrial engineers to achieve accuracies of 10-50µm at a measuring distance of between 1 – 5mm. Magnetic scales, a steel-backed elastomer strip filled with ferrite particles, are applied to the object to be monitored. These typically come in widths of 10mm on rolls of 50m or more in length.



▲ Figure 10: The principle function of the sensor delivers a sine and cosine signal in relation to the movement of the magnetic scale.

The KMXP Series relies on several anisotropic magnetoresistors (AMR), arranged in a Wheatstone bridge configuration, integrated into tiny DFN packages of 6 x 2 x 0.8mm in size. Connection pads are limited to just three sides, leaving the fourth side to be placed at the edge of a printed-circuit board (PCB). This enables simple installation perpendicular and close to the magnetic scale in use. These can be easily integrated with an ADC or an MCU together with suitable amplification circuitry. In software, the position is then determined based upon the sine and cosine signals measured (Figures 10 and 11).



▲ Figure 11: The KMXP Series of AMR position sensors (left) deliver an analog output that can be processed by a suitable MCU after amplification (right).

HOW DO I INTEGRATE PRESSURE SENSING INTO MY IIOT APPLICATION?

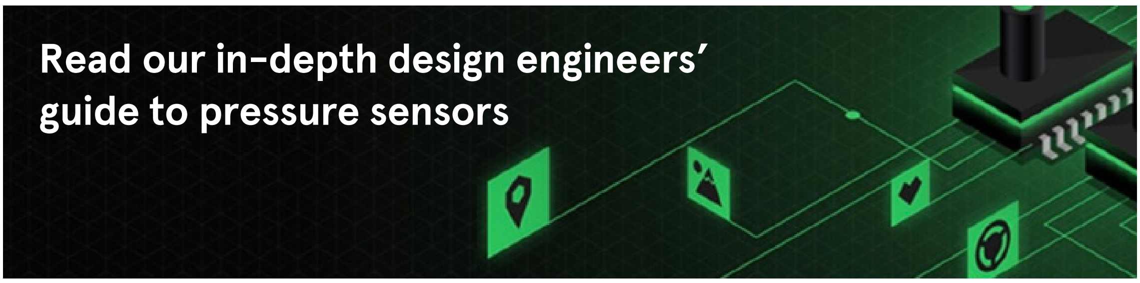
As with previous sensors, pressure can be integrated into IIoT applications in a variety of ways. The digitalization of sensors also enables engineers to benefit from a range of features that were not available in their analog predecessors. Often, when maintaining production and processing facilities, it would be advantageous to know the value a sensor is measuring when standing in front of it, and not just when back at a central control panel.

The IP67 rated, weatherproof M5800 pressure transducer uses a pressure port that is machined from a single piece of material, and integrates a piezo-resistive strain gauge for measuring gauge or compound pressure (Figure 12). Available in a variety of pressure port configurations, the sensor features a 310° rotatable 4-digit display that provides pressure measurements in PSI, KPSI and BAR. Available in ranges from 0 – 50 PSI to 0 – 15k PSI, it is ideal for food and beverage equipment and monitoring pumps and compressors, and is available in either a 4 – 20mA output or a range of voltage outputs.

▶ Figure 12: The M5800 pressure transducer includes a rotatable display for local output of measurement values.

The U5600 and M5600 pressure transducers deliver their measurements via a Bluetooth 4.0 compliant wireless interface, common in all handheld devices and laptops (Figure 13). Measurements can be viewed on smartphones and tablets utilizing apps available for both Android and iOs devices. Versions are available using gauge, sealed, absolute and compound pressure, with pressure ranges from 0 – 5 PSI up to 0 – 15K PSI being supported. Using a CR2050 battery, operation for up to 2 years can be expected, with values being output every 5 seconds. The devices are weatherproof up to IP66 and IP67, while the supporting app provides a battery level warning at 2.5V. Because these sensors are self-powered they can be utilized in locations where no other power is available or on mobile equipment.

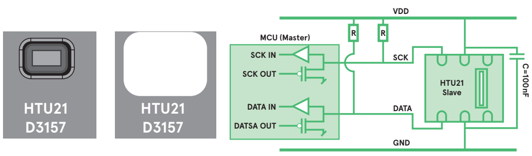
▲ Figure 13: Pressure values can be shared wirelessly, using Bluetooth, with sensors such as the M5600 and U5600.



CAN I MEASURE MORE THAN PARAMETER WITHIN A SINGLE SENSOR?

Environmental conditions in vessels, operations facilities and storage units need not require several sensing solutions. Several sensing technologies can be combined into a single package – for example pressure and temperature or humidity and temperature. These combination sensors can provide additional benefits as they typically require less power than two separate sensors and can be lower cost too.

One example of such a combination sensor is the HTU21D that integrates both humidity and temperature sensing. The combination of temperature and humidity measurements can be used to provide an additional measurement known as dew point. The 3 x 3 x 0.9 mm DFN package enables compact sensor solutions to be developed, while the I2C interface can be connected directly with almost all MCUs. A version including an integrated PTFE membrane is also available that enables an IP67 rating with little impact on the sensor's response time. With an average current draw of just 15µA, the HTU21D would be ideal for battery-powered solutions.



▲ Figure 14: The HTU21 is also offered with a white PTFE filter (left) and integrates simply with a host MCU.

References

1. https://www.te.com/usa-en/industries/sensor-solutions/applications/iot-sensors.html

SUMMARY

With the miniaturization of sensor technology, the advancement of measurement techniques, and the reduction in power consumption, the available options for industrial engineers are expanding rapidly. The IIoT provides further impetus to measure additional parameters to acquire a broader picture of processes as well as gain deeper insight into the maintenance needs of plant and equipment. While analog sensors allow integration into IIoT through PLCs, a broad range of digital sensors are being developed that deliver exceptional results that can be integrated directly with MCUs, or attached directly to digital industrial networks. With some functions moving to mobile AGVs, wireless sensing technology is also growing in both range and capability.

SENSOR SELECTION FOR IIOT APPLICATIONS CHECK-LIST

- What range of measurement (min/max) is required at what accuracy?
- How much power is available at the location of measurement?
- Is wireless data transfer an option?
- Under what environmental conditions should the sensor function? Temperature, moisture, dust, vibration, etc.
- How much room is available? What mounting is required?
- How will the sensor be integrated into the IIoT solution? Which interfaces or networks need to be supported?

Knowing that sensor selection can be challenging, sensor specialists are available to provide advice and guidance, in conjunction with TE Connectivity, during the sensor selection process.

Contact our team in your local language at

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M5600 series pressure sensors

TE Connectivity's modular M5600 wireless pressure transducer is enclosed in a stainless steel and polycarbonate housing.

BUY NOW

TDS305 series digital thermopile sensors

TE Connectivity TSD305 series digital thermopile sensors include an infrared sensor and integrated signal conditioner. These thermopile sensors can directly interface with micro-controllers through an I2C interface.

MORE INFORMATION

DOG2 series position sensors

TE Connectivity's M5800 digital display transducer offers visualized pressure value readings for demanding , harsh applications. The 310° rotatable display enables easy viewing and on-demand adjustment.

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M5800 series digital display transducer

TE Connectivity's M5800 digital display transducer offers visualized pressure value readings for demanding, harsh applications. The 310° rotatable display enables easy viewing and on-demand adjustment.

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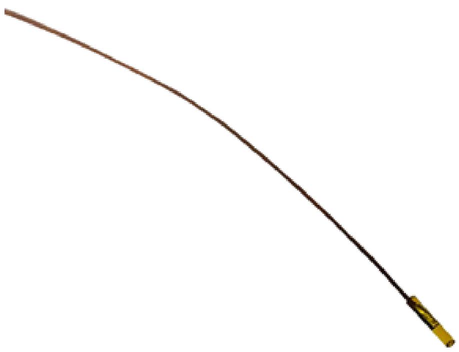
GA10K series temperature sensors

TE Connectivity GA10K NTC thermistors feature a zero power resistance of 10kohm at 25° and a fast response time.



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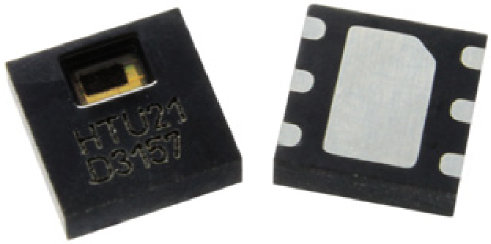
HTU2 series humidity sensors

The TE Connectivity HTU2 sensors series senses true relative humidity and temperature to provide excellent performance and value.



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