Important Considerations when Specifying IoT Sensors

White Paper

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Introduction

In the rapidly expanding realm of Internet-of-Things (IoT) technology, the role of electronic sensors is pivotal. These sensors are not just new introductions; they are also transforming, retrofitting, or replacing older sensor and monitoring technologies across various domains. This transformation spans a wide range of applications - from electrical and electronic ones to those that traditionally relied on mechanical, hydraulic, or pneumatic systems but are now moving towards electrical/electronic actuation and sensing.

This white paper serves as an essential guide to the diverse world of IoT sensor technologies. While it is not exhaustive, it provides detailed descriptions and insights into a significant array of IoT sensor technologies, including guidance on their usage and understanding their limitations. The paper acknowledges the vast diversity and the multitude of manufacturers in the field of IoT sensors. Although it's challenging to cover the entire breadth of IoT sensor technology, this paper is crafted to offer a solid foundation with key terms and essential descriptions. It aims to assist readers in their exploration and learning about IoT sensors, helping them navigate through this complex and evolving landscape.

Outside of the type of real-world information an IoT sensor is designed to capture, there are a myriad of other considerations around IoT sensors. There are many nuances of IoT sensor function that are important to know as these largely dictate the limitations of IoT sensors and the types of electronics necessary to convert, condition, store, stream, transfer, and/or transmit the data these sensors capture.

Sensor Type

There are two main types of sensor types, passive and active sensors. Passive sensors transduce energy without previously energizing the medium that leads to the transduction, in other words, passive sensors only capture outside energy, which must then be digitized and transmitted. Active IoT sensors use actively energized electronics and transducers to capture external data. For instance, a microphone is a passive transducer that generates electrical signals based on the acoustic energy (sound waves) that impact the microphone. An ultrasonic proximity sensor is an active sensor that emits ultrasonic pulses that reflect off surfaces and are then captured by an ultrasonic pickup. Passive sensor types usually require some time of signal conditioning, such as amplification and filtering, before being digitized for IoT applications. Many active sensors may also require signal conditioning and even amplification, but this depends on the electronics and any configuration/programmable settings that may be applicable.

Image of a passive inductive proximity sensor

Sensor Data Output

The signals captured from these transducers may be either current, voltage, power, phase, pulse length/duration, pulse period, pulse repetition interval, pulse duty cycle, frequency, DC offset, or other characteristics of electrical signals. Depending on the nature of the transducer, the signals captured could either be a single scalar set of data or could be two or more signals that convey vector or multidimensional information. A scalar signal only conveys the magnitude of the data, while a vector signal conveys both the magnitude and the phase of the data. This distinction can be critical for many applications.

The electrical signals generated by these transducers are typically analog signals that are then converted to digital signals in a variety of methods. Many modern electronic sensors include integrated digitization technology, namely analog-to-digital converters (ADCs). Hence, these sensors provide digital signal output which can be more readily stored, streamed, and/or transmitted for IoT use cases. Some IoT sensors are more sophisticated and also include signal conditioning, storage and even processing technologies, such as Digital Signal Processors (DSPs), field-programmable-gate-arrays (FPGAs), graphics-processing-units (GPUs), microprocessor units (MCUs), general purpose processors (GPPs). These electronics and circuits can provide deeper levels of processing, data analysis, and may even be used to select what information is sent and compress the information for more efficient data transmission.

Analog sensor data can be limited or continuously variable and exhibit resolution that is only limited by the sensitivity of the transducer, routing, interference susceptibility, and signal conditioning of the sensor circuit. Digital sensors on the other hand, output digital signals with a finite number of bits, and hence, resolution. Greater digital signal resolution requires more advanced electronics to process, store, transfer, convert, and transmit. In some cases, high resolution digital signals with high refresh rates may output a greater volume of data over time than the connectivity of the IoT sensor is able to handle.

Connectivity

IoT sensor connectivity is what drives the amount and extent of the data captured by the sensors that can then be transferred or transmitted outside of the sensor platform. IoT sensors can either be hardwired or wireless depending on the sophistication of the sensor. Some IoT sensors are just the transducer themselves, and only present discrete leads that are then connected to IoT platforms. Some IoT sensors are fully integrated modules that provide sensing and connectivity solutions in a single module. Still other IoT sensors are more complex platforms that often have several transducers and methods of selectively storing and/or transmitting the data captured by the transducers.

Conductive Connectivity

Analog transducer signals are typically either referenced to ground (single-ended) or differential (double-ended). A single-ended signal can be transferred to another circuit with a single lead as long as that circuit has the same ground reference. Differential analog signals require two differential leads and may not require a ground reference at all as the signals are self-referencing. Differential circuits present greater circuit complexity but also greater immunity to common-mode interference and other signal degrading factors.

The frequency of analog signals matters greatly as to how they are handled. Higher frequency analog signals are typically carried on transmission lines and waveguides to provide better signal integrity than traditional analog leads. High frequency digital signals may also be carried on RF interconnects, such as transmission lines and waveguides, as these interconnects also more efficiently carry high frequency electrical signals and may provide some natural shielding/interference immunity.

The two main categories of digital signal interconnect are parallel and serial. Parallel digital signals require a distinct line or signal path for each bit of digital data. While serial digital interconnect uses a single line and a serial communication method to distinguish between the bits in the data stream. There are a wide range of digital signal interface types. Largely, the type of digital interface used depends on the specific application and downstream electronics. The most common digital interfaces (also often called digital hardware communication protocols or embedded system communication protocols) for IoT are as follows:

- Universal Serial Bus (USB)
- General-purpose input/output (GPIO)
- Digital GPIO with pulse width modulation (PWM) support

- Analog pins with connectivity to ADCs and digital-to-analog converters (DACs)
- I2C
- Serial Peripheral Interface (SPI)
- Transistor-to-transistor logic (TTL)
- Universal Asynchronous Receiver/Transmitter (UART)
- Universal synchronous and asynchronous receiver/transmitter (USART)
- RS-232
- RS-485
- Controller area network (CAN)
- One-wire
- PCI
- IEEE-488

Dust and Particulate Sensor Module with USB Interface

Some sensors also only communicate one of two states, such as on/off. These sensors may output as a PNP or NPN. As with bipolar-junction transistors (BJTs) the PNP output is a sourcing output while a NPN is a sinking output, meaning that contact/active state for NPN is tied to the negative supply, while NPN contact/active is tied to the positive supplies.

Wireless Connectivity

There are also a slew of wireless interfaces, protocols, and standards. Much like the digital interfaces, these communication technologies require both compatible hardware and software to enable communication. With the IoT wireless communication RF/wireless hardware is also needed, this includes RF transmitters, receivers, and antenna hardware. The following are a few of the most common wireless protocols and standards used with IoT:

Wireless Protocols & Standards

- Advanced Message Queuing Protocol (AMQP)
- Bluetooth and Bluetooth Low Energy (BLE)
- Cellular, Long-term evolution (LTE) 2G, 3G, 4G, 5G, and future 6G
- Constrained Application Protocol (CoAP)
- Data Distribution Service (DDS)
- Long range (LoRa) and LoRa wide area network (LoRaWAN)
- Lightweight machine-to-machine (LWM2M)
- Message Queueing Telemetry Transport (MQTT)
- Wi-Fi
- Extensible Messaging and Presence Protocol (XMPP)
- Zigbee
- Z-wave

- Thread
- Ethernet Internet Protocol (IP)
- Hypertext Transfer Protocol (HTTP)
- WebSocket
- Near-field communication (NFC)
- Sigfox
- Radio-frequency identification (RFID)
- OPC-UA

Power Source & Requirements

IoT Devices are powered in many ways, including small batteries and through energy harvesting methods. Depending on the type of IoT sensor, the power requirements for the sensor may be different. Passive IoT sensors may be the most power efficient depending on what signal conditioning may be necessary to digitize the signals. Active IoT sensors will have some type of power draw, so it may be necessary to limit the up time of certain active sensors if the IoT device hosting the sensors has power limitations. It may also be necessary to intermittently run the communication protocol, especially if it is a wireless protocol, to avoid using energy while an IoT device has little to report, or to allow for more efficient periodic reporting. This is why current sensors and other power monitoring devices are common on power constrained IoT devices and platforms, as to help ensure the device achieves the desired goals given certain power constraints.

Physical & Environmental Constraints

Other IoT sensor considerations have to do with the physical and environmental constraints of the IoT sensors, device/platform. Some IoT sensors may be extremely small and low weight, allowing for easy integration on PCBs or via compact interconnect. Some IoT sensors may be larger than the rest of the IoT devices, depending on the sensor type.

IoT sensors also differ in the types of environmental constraints they pose. Some IoT sensors are intrinsically very sensitive to the outside environment and either need to be exposed to it in order to sense or otherwise be protected to prevent the sensor from being damaged or presenting sensor readings. Some IoT sensors come packaged or encapsulated in such a way that the sensors are protected from external environmental factors within a specified margin.

Packaging is a critical consideration for IoT sensors, as eros in packaging or housing design can lead to degraded performance of IoT sensors or even inoperability. For instance, a relative humidity sensor module installed on an IoT platform with a plastic housing without any ventilation will likely not be effective at measuring the relative humidity outside of the enclosure as may be intended.

Reliability/Lifetime

All IoT sensors have a specified reliability/lifetime of operation. This can include a number of sensor reading cycles or may be for a length of time. The environment the IoT sensor is deployed in often impacts this specification. For instance, many IoT sensors are prone to accelerated aging at temperatures beyond a certain limit. Often the limiting factor in an IoT sensor's operational lifetime is the most fragile link in the IoT sensor design. This could be a switch, or a highly sensitive transducer that is damaged/degraded during sensing operations or atmospheric exposure.

Other IoT sensor reliability considerations could stem from the type of power source deployed with the IoT sensor. In the case of certain batteries, this could be the lifetime of the battery, which may be minutes to decades depending on the application, power use, and battery type.

Conclusion

IoT sensors stand as critical components in the modern technological ecosystem, bringing the physical world into the realm of digital data. However, the simple task of capturing real-world information is intricately laced with a multitude of considerations, from the type of sensor — passive or active — to the nuances of data output and connectivity. The evolution of sensors has given rise to advanced integration of various digital components, such as ADCs, DSPs, and MCUs, making it imperative to understand the complexities of their functionalities. Moreover, connectivity, both wired and wireless, has expanded the scope of sensor applications but has also introduced its own set of challenges. Yet, irrespective of their advancements, sensors remain bound by power, environmental, and reliability constraints.

As the IoT landscape continues to expand, a holistic understanding of these devices, from their basic operation to their limitations, becomes increasingly vital for innovators, developers, and users alike. Future advancements in IoT sensor technology will no doubt seek to address current challenges, pushing the boundaries of what is possible in the realm of interconnected devices.

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