The Technical Evolution of Sensors

Diverse Sensors for Diverse Applications

By Daniele Valanzuolo

Sensor technology used to rely upon ingenuity in advancing existing mechanical measurement techniques. However, over the past two decades, sensor manufacturers have increasingly drawn upon new and innovative measurement principles. The result has been an exciting array of highly integrated, affordable sensors suited to wired and wireless applications.

The development of innovative sensors that closely match rapidly changing market needs is an exciting, sometimes difficult, challenge. The breakneck uptake in wearables, coupled with smartphones, has delivered tiny sensors of increasing accuracy with low current draw. Such sensors also support digitalization demands in other sectors, such as the Internet of Things (IoT). The focus on delivering safer vehicles and autonomous driving has placed emphasis on radar and Lidar technology. Finally, improved sensing technologies in the medical space have supported efforts to improve personal health by capturing and analyzing patient data. Many of these sensors are increasingly integrated into Wireless Sensor Networks (WSN).

At the beginning of the decade just passed, there was much discussion regarding Micro Electro Mechanical Systems (MEMS), an ambitious technology capable of blending the best of silicon design with mechanical skill. A whole new miniature world was to be invented and opened to advanced experimentation. Now, after a decade, what seems innovative has become the bread and butter of everyday life. With MEMS technology in inertia sensors of smartphones and strain gauges of industrial machines, it has become a technology found in almost every device in daily use.

Is the MEMS Sector Saturated?

While MEMS has undoubtedly soared as a sensor technology, it is certainly not at the end of its capabilities. One reason for its continuing popularity, and continued use, is its reliability and ability to adapt to any context. Continued innovation has delivered reductions in both size and cost, but there is still a long way to go. Moreover, the consolidation that has been achieved in this technology will only lead to its broader use in applications it has not yet tackled. Yes, we may consider discussing its obsolescence in 2030. However, for now, it remains one of the core technologies on which many companies are investing serious technical and economic resources.

For example, in 2019 STMicroelectronics announced the development of water-resistant MEMS pressure sensors with high stability, accuracy, as well as chemical compatibility required in industrial applications with its LPS33HW. And there remain MEMS challenges to be resolved. These include optimizing the technology's manufacturing processes, developing new, increasingly integrated sensors, solving calibration problems, and energy consumption, to name a few. Therefore, it is no coincidence that MEMS sensors innovations are still included in the general market trend charts of the major manufacturers and distributors of electronic components, especially in the consumer and automotive sectors.

From the Microscopic World to the Nano

If almost everything in the microscopic world seems accomplished, why not go a step further to the nano-level? New research is examining nanometric and organic materials to solve the challenges of extreme miniaturization. With it comes the promise of sensors of greater sensitivity, selectivity of measuring range, and stability. One of the applications that encompass all these challenges is the field of medicine by using nano-FET sensors. These nanometric sensors can integrate into cells, providing an intracellular measurement with highly localized detection of a living cells' state, and possible relationships with tumor or other cells. With a nearly one-dimensional semiconductor nanostructure, they exploit sensitivity to the presence of electric fields to detect the charges of molecules.

In addition to nano-FETs, the nanometric field covers all materials with at least one dimension smaller than 100 nm. Compared to conventional sensors, nanomaterials are characterized by a higher surface area or volume ratio. They promise improved optical, mechanical, electrical, structural, and magnetic performance. A range of applications could potentially benefit from these technologies, such as:

- Detection of chemical composition in gases — This helps improve the quality of products used in chemical processes that must fulfill quality standards or perform pollution monitoring.
- Improved detection of standard physical parameters — These are often at a localized level, such as temperature, flow, and pressure.
- Plant biology monitoring — Typically used to monitor the environment in agricultural applications and other sectors.

Optical Fiber

Optical fiber has seen a surge in development interest in the past decade. Such sensors offer unique characteristics such as geometric versatility, high sensitivity, immunity to electrical noise, electrical insulation, temperature. Furthermore, they are typically highly suited for use in environments where corrosive or stress-inducing agents are present. In general, these sensors fall into two main categories: amplitude sensors or interferometers (phase sensors).

Amplitude sensors are sensitive to physical variation through interaction with the fiber, resulting in modulation of light intensity in the fiber or, potentially, through devices connected to it. This measurement technique's simplicity makes them highly suited for use under challenging environmental conditions, despite their low cost. Interferometers, however, place their reliance on high levels of precision and must deliver their performance based upon geometric versatility. Such techniques can achieve almost theoretical levels of sensitivity to measure tiny variations. Despite the significant progress made with fiber technology, it still has much development scope in terms of application, noise reduction, and coating optimization.

3D Sensors

With video cameras a ubiquitous piece of technology in today's world, we rarely consider how their 2D renderings remove a dimension of our 3D world. Sensors that capture this third dimension have been growing in capability since their introduction in combination with gaming consoles. Unlike regular cameras, 3D sensors additionally acquire and store depth information whose architectures can be classified 3D as follows (**Figure 1**):

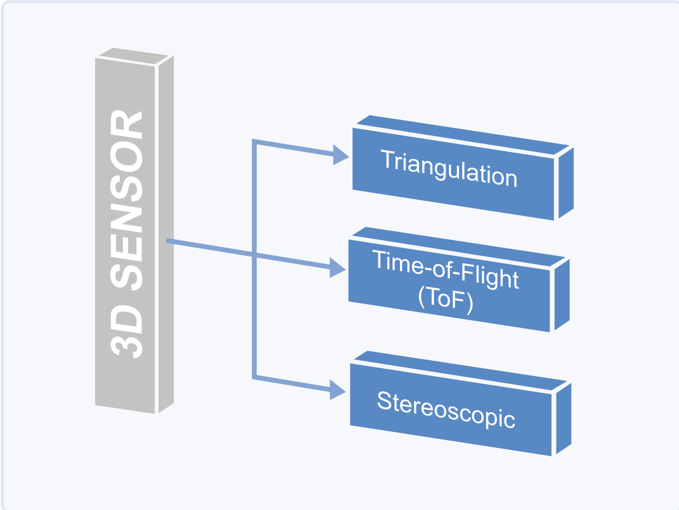

Figure 1: 3D sensor categories.

- Sensors that use light sources to illuminate the object (such as a laser), acquiring the data with standard 2D sensors. Depth measurements are calculated using triangulation algorithms and exploiting the distortion of the reflected light.
- Time-of-Flight (ToF) sensors that estimate the depth of the environment from the time delay between light emission and its detection (the time of flight of the illuminating beam).
- Stereoscopic vision through two offset chambers, replicating human sight.

3D sensors are widely used in applications as diverse as autonomous driving, the surveillance sector, and object detection in industrial manufacturing. There are, however, a range of challenges concerning the robustness of such sensors. These include disturbances due to other light sources or day/night acquisitions, temperature range, which influences time-of-flight behavior in the fluid within which the light moves, and surface variations, changing how light rays are reflected.

Waterproof Sensors

Exploration of our seas has been accompanied by both cutting-edge and mature sensing technology. With the growing focus on environmental issues, sensors that can help the study of climate change, pollution, and sustainability are of growing interest. These must be water-resistant and capable of operating at the high pressures present in the depths of the ocean. Scientific teams are also proposing developing sensor networks at the bottom of the sea. Such ideas face a range of challenges that start with the exchange of data underwater. Thus far, acoustic technologies have been developed with obvious limitations in bandwidth, multi-path phenomena, and limited speed that impacts latency.

Additionally, the issue of powering such sensor networks remains an open issue. But which sensors can find application at the bottom of the sea? Today's range of cheap sensors can measure traditional parameters, such as pressure, temperature, or brightness, in such systems. However, this branch of measurement also needs specialized sensors to assess water turbidity, sonar for viewing objects on the seabed, CO_2 sensors, and fluorometers, to name a few.

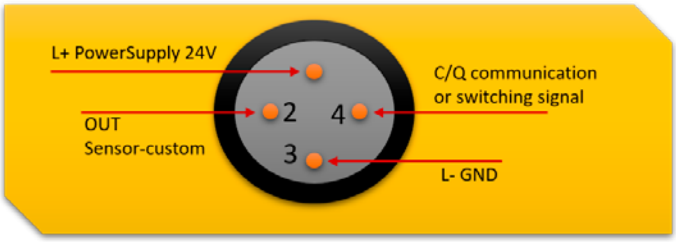

Figure 2: IO-Link standard.

The IO-Link Standard

Of course, all the sensors in the world are of no use unless their measurements can be collected for analysis. While wireless is increasingly the de facto for IoT networks, it is the wired IO-Link that stands out in the field of industrial applications. Today, almost all manufacturers offer smart sensors equipped with this bidirectional communication bus. Its popularity stems from its support of classic I/O, meaning sensor power supply and signal proportional to the measured quantity, and I/O-Link, where a master device, usually a PLC, intelligently interrogates the available sensors. The standard connector and pinout are shown in **Figure 2**.

IO-Link overcomes the issues commonly associated with analog sensing, such as signal disturbance and EMC compatibility. This digital technology also enables much simpler cabling installations. Its backward compatibility ensures IO-Link sensors can still be used in existing equipment while also being ready to support complex Industry 4.0 installations. Additionally, it also supports actuators in addition to sensors that provide further economic benefits.

Wireless Sensor Networks

In recent years, WSN have acquired significant attention due to their applicability in a wide range of market segments (**Figure 3**). Studies into the capabilities of WSN are ongoing due to the vast range of use cases. Much of this is focused on energy consumption and communication, such as the impact of the atmosphere on communication reliability. Depending on the task tackled, physical dimension and weight are also of significant interest.

Given the vast areas that WSN can cover, they find wide application in environmental monitoring (both terrestrial and marine) and tracking the health status of wild or farmed animals. Many of the existing challenges relate to maintaining wireless communication in the absence of one or more nodes and guaranteeing an adequate quality of service (QoS).

The Challenges of the Future

Sensors are an essential element of the new digital era, finding wide application from professional sectors, such as industrial, electro-medical, and environmental applications, to the leisure, wearable, autonomous driving, and gaming sectors. In fact, the use of sensors can be seen as technology's contribution to a better world, with diagnostic applications in the electromedical or environmental fields, in disaster prevention, and optimized manufacturing.

There is a significant ongoing research effort to deliver innovative solutions that can adapt to diverse sensing needs. We are working on ever smaller and more specific sensors but simultaneously need to deploy them to cover ever larger areas, and operate them under extreme conditions, such as underwater and in the presence of contaminants and aggressive chemicals.

The challenges are also to make them less power-hungry and as cheap as possible to integrate them where needed, from the electronic objects we use, to the cars we drive, to the clothes we wear. The fact is that sensors will continue to integrate into our daily lives, contributing to our health and safety, and driving improvements in our environment.

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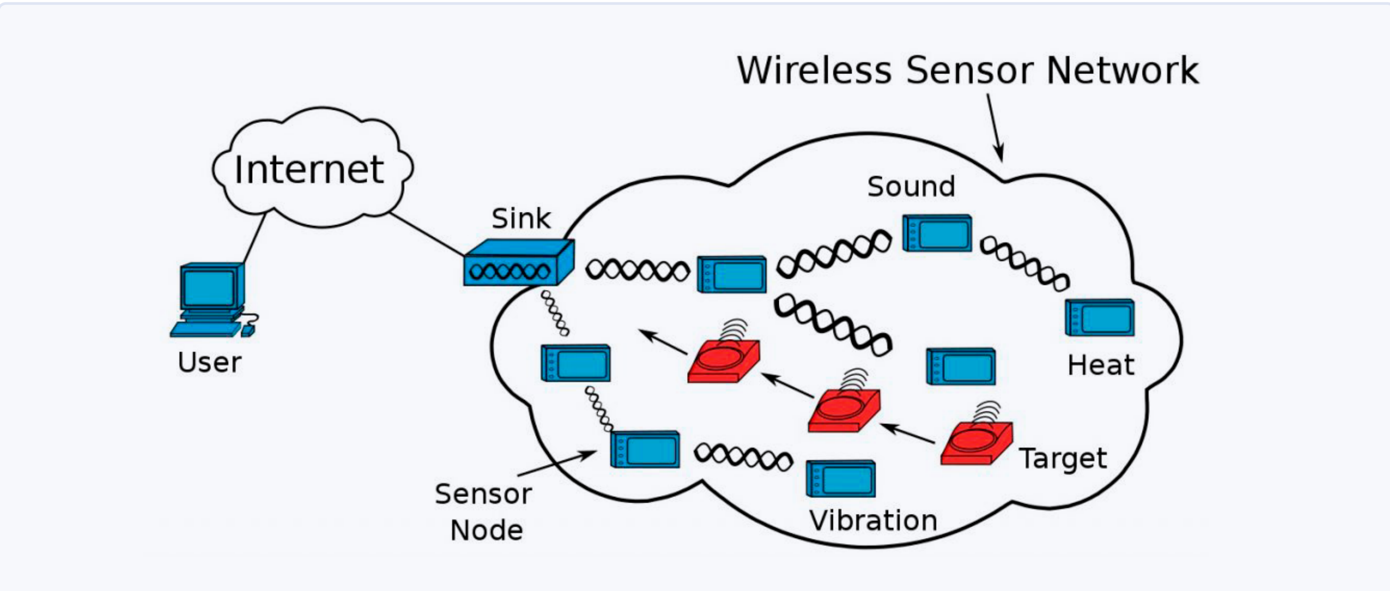

Figure 3: Representation of a sensor network. (Source: https://en.wikipedia.org/wiki/File:Wireless_Sensor_Network_General_Structure.svg)