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# Smart sensors fulfilling the promise of the IoT

The Internet of Things (IoT) is all about making life simpler and more exciting for consumers by interconnecting the world around them. But how can this promise of the IoT be fulfilled?

In the world of IoT, microelectromechanical systems (MEMS) sensors form the backbone of the interface between the user and the multitudes of devices that surround us, such as smartphones, wearables, robots and drones. However, making devices able to sense and be connected is simply not enough to realize the grand promise of the IoT. The fact remains, that IoT will only be successful if it follows a user-centric approach, i.e. by solving real-life everyday challenges, making life simpler, enhancing ease of use. Furthermore, ubiquitous sensing of everything on all manner of devices in an ever-increasing number of complex environments poses definite and growing challenges for sensor providers. These challenges as well as the possible solutions to overcome them are discussed below from a sensor vendor's perspective.

**Three-pronged challenge for smart sensors in the IoT**
When we consider today's smart sensor modules, which contain certain processing capabilities integrated with the raw sensors, it boils down to three key challenges:

The first challenge is the technology itself. Vendors are pushed to leverage their core MEMS and system know-how to achieve the almost impossible. There are physical constraints challenging the engineer, package sizes cannot shrink forever, whilst demands for lower power and higher performance continue to rise incessantly. Vendors are also forced to embed more and more intelligence and awareness into these systems. To achieve this aim, technology will need to be leveraged across multiple product platforms.

The second challenge results from the industry's broad fragmentation. Today, the bulk of revenue booked from MEMS sensors comes from the smartphone segment – there are more than a billion smartphones sold each year with each containing at least one MEMS sensor. Here, the smartphone OEMs set the specifications and the vendors such as Bosch Sensortec define their MEMS sensors accordingly.

But the IoT world is very different, characterized by a highly fragmented structure of competing technological platforms. The demands placed on the sensor subsystem comprising of the sensors, microcontrollers and actuators vary widely across the IoT space. Vendors such as Bosch Sensortec thus need to create cross-platform solutions integrating hardware and software, and provide application-specific software. By leveraging software and expert application know-how, vendors help their customers to solve specific issues without having to tailor a custom hardware solution for each and every individual application.

The final challenge is geometrically expanding complexity. IoT systems are inherently complex, and OEMs often require turnkey solutions or reference designs; supplying just components is no longer enough. Market-leading vendors meet these requirements head on with integrated smart sensor solutions, which greatly reduce complexity by incorporating increasingly more system processing power into single modular devices. And since no one company can provide an all-encompassing complete solution, suppliers must also closely co-operate and form partnerships with third parties, for example in creating reference designs.

**IoT sensor information hierarchy**
The IoT information structure comprises of several levels, which, for a typical application, can be ranked in the following order of increasing information usefulness:

<u>Sensor information hierarchy</u>
1. Raw data
2. Motion detection
3. Activity monitoring
4. Context awareness
5. Intent prediction

Although raw data may be filtered, compensated and corrected, in most cases there are definite limits to what a user can do with it. At the subsequent level, by identifying patterns and applying algorithms, data can be interpreted to provide motion detection information. Then, by adding in additional sensor functions, such as altitude detection through barometric pressure measurement, we go up another level to assign inferred activity monitoring information. Context awareness of the device in the modern ubiquitous computing environment encompasses adding further elements such as interaction with other devices, adapting to ambient noise and light conditions, network status, etc. Finally, this leads to more sophisticated tasks, such as predictive decision-making based on weighted evaluation of context and behavioral patterns over time.

At this point, it becomes very interesting to correlate the methods by which a sensor system processes data with the function of the human brain. The human brain has two primary systems by which data is processed: the cognitive and the limbic. The cognitive level can be compared to cloud computing – high processing power and large memory, but with reoccurring delays and latencies. In contrast, the limbic system is primordial, reactive and reflexive – corresponding to local processing in a sensor system, i.e. edge computing.

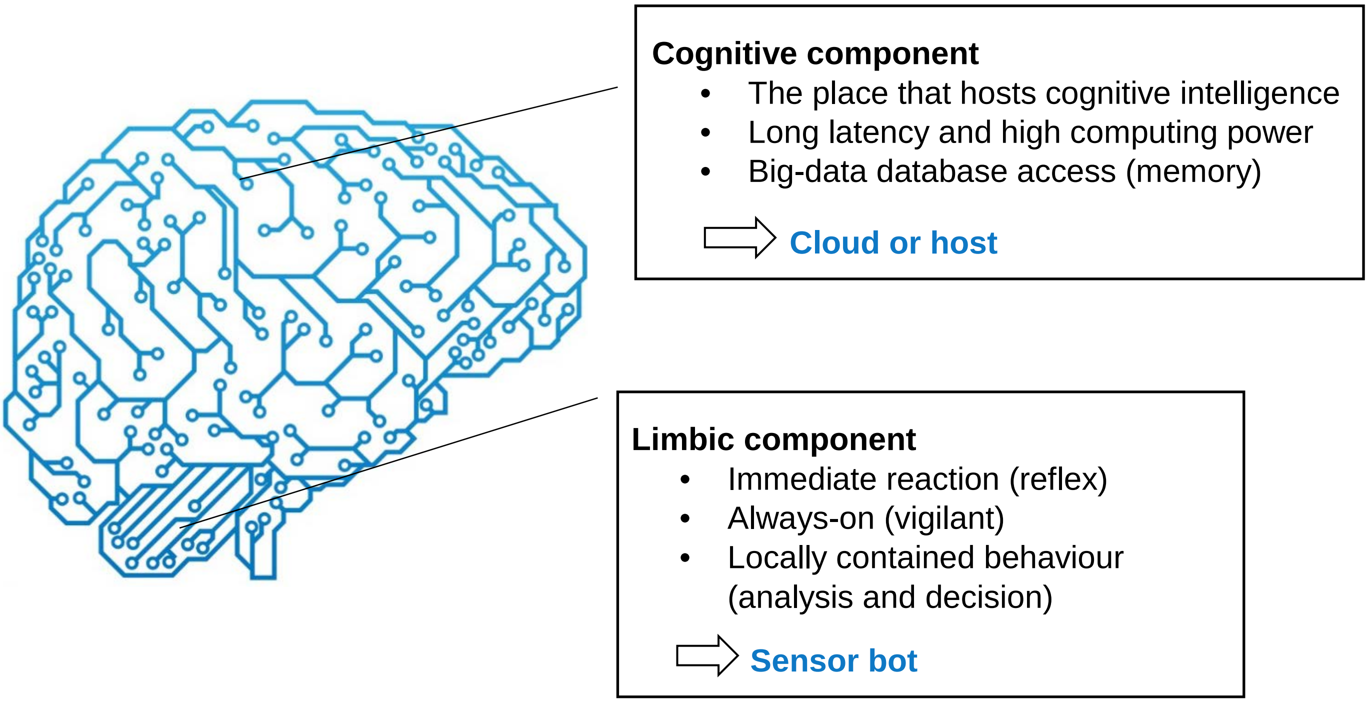


*Figure 1: Description of the differences between cognitive and limbic systems, correlating to the human brain's processing of sensory data (Picture source: [Krisdog]/Depositphotos.com; Bosch Sensortec).*

Referencing back to the topic of IoT, the sensor information hierarchy becomes crucial in determining which measured data is important and which is not. If data is not actionable, it is essentially useless, making the vast amounts of data present in most applications superfluous.

Counter intuitively, it is often more efficient to simply leave a sensor on permanently, waiting to identify useful information, e.g. an accelerometer in a step counter application. Our sensor system must intelligently determine which data is worth transferring to the cloud and thereby efficiently utilize the available bandwidth and power. The key is for local on-sensor processing to discard most of this superfluous data autonomously and thus save valuable system driver capacities.

**IoT system drivers**

In IoT sensor applications, we can identify several key system drivers that influence system and component design:

- Low power consumption is crucial in certain applications, for example small or portable devices. Here, an autonomous sensor processor paired with a sensing element ("Sensor bot") is helpful for edge processing, for determining when to transmit to the cloud, thereby cutting down the resource costs of data transmission.

- **Low latency** has significant importance in situations where we need to transmit large volumes of data with minimal delay. For example, in virtual reality (VR) images need to be sent in real time speed in order to keep up with the dynamic motion of the user's head.

- A **high data sampling rate** may be required for rapid system activity learning applications, e.g. in predictive maintenance on vibrating machinery, the sensor must sample at a sufficiently high rate in order to capture all the relevant data leading to the equipment failure.

- **Ease of integration** varies widely and OEMs often have very different expectations of how much time and engineering resources they are prepared to invest into interpreting sensor data. To simplify sensor integration into their applications, many companies require increasingly intelligent sensors that provide a certain degree of data processing embedded inside the sensor with a vendor-provided software solution to match. For example, in robotics the OEMs will focus on the motion of the robot itself, preferring not to deal with raw sensor data at all.

- **Edge computing** is analogous to the above-mentioned limbic system. Sometimes we require processing performance on the edge, and often this goes hand-in-hand with both the low power and ease of integration prerequisites.

- Since the cost of memory in a sensor module is much higher, **cloud storage** presents a viable alternative to local storage and processing. The issue is that on the one hand, we do not want to transmit copious amounts of unnecessary data, but on the other hand we are constrained by the sensor's physical storage capacity. Therefore, we must implement on-sensor intelligence and make sure the sensor discards the majority of unnecessary data and prevents flooding its memory capacity.

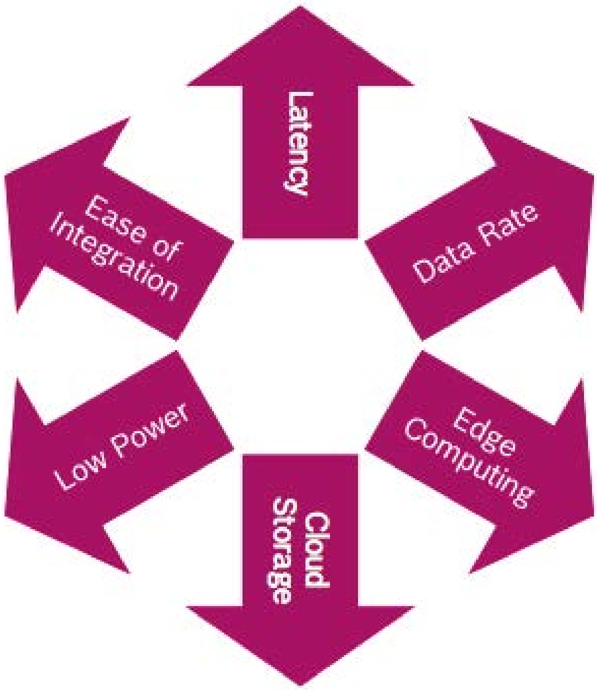


*Figure 2: There are six forces influencing and constraining the IoT system and component design (picture source: Bosch Sensortec).*

**Example applications**
To illustrate the above points, let's consider a few examples. Firstly, a wearable application such as a step counter needs to be always-on, with a battery that is as small as possible. The key factor here is low power consumption, which can be achieved by integrating the step counting functionality directly within the sensor itself. This saves battery power by not waking up the wearable's main processor unless it is absolutely necessary.

To further save resources, the wearable must not transmit all the step counting data to the host, which makes this into a typical example of an edge computing application. With power consumption being the primary consideration, an ultra-low power solution such as the BHA250 or BHI160 is an ideal choice.

Another example is the trend of rapid prototyping, which is increasingly common even in large corporations for market validation of use cases. Rapid prototyping is typically performed on development platforms such as Arduino, Raspberry Pi or other similar open-source systems, where components including sensors are combined to validate a concept.

To maximize ease of integration, this type of application requires relatively sophisticated software to be provided by the sensor vendor. Development times need to be as short as possible, and OEMs need to explore system design even with limited sensor knowledge. Having the sensors available on a number of platforms, such as Arduino and Raspberry Pi, greatly simplifies its integration.

**Conclusion**

For a successful IoT application, it is crucial to work with a competent sensor vendor that understands this highly complex IoT environment. Such a partner should provide a wide portfolio of high performance sensors and propose just the right solution for your application. No less important is quality, local support and strong partnerships with third parties who can provide reference designs and system-level expertise.

IoT requires in-depth understanding of the multitudes of applications and the ability to meet various sensor and processing requirements – low power, ease of integration, data rate, latency, etc. Only by understanding the interrelationships between these different factors, can you design innovative and successful products for the rapidly growing IoT market that make life simpler for the users and thereby fulfill the promise of the IoT.

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