SMART SENSORS... DEFINED AND REDEFINED

ROBUST GROWTH IS FORECAST FOR SENSORS THAT ADD FUNCTIONS TO INCREASE VALUE AND CAPABILITIES

By Roger H. Grace, President, Roger Grace Associates

Recent research has uncovered the first mention of the term…"smart sensor" in a 1986 article which appeared in Sensors and Actuators [1] and authored by industry sensors expert Joe Giachino. However, according to market research, sensors that appear to conform to the functionality requirement of smart sensors (or smart sensor-based systems) first emerged in the late 1960's at Honeywell's Solid State Engineering Group (SSEG) for an aerospace application.

Sensors expert Joe Giachino has defined a smart sensor in his article as…."smart sensors are those that include some logic functions and/or make some kind of decision". He continued…" A smart sensor must do one of the following:

- perform a logic function
- perform two-way communication
- make a decision.

In addition, he states that "it is not necessary for it to be integrated (monolithically) with these electronic functions."

The IEEE 1451.2 Standard states…"a smart sensor is one that provides functions beyond those necessary for generating a correct representation of a sensed or controlled quality. This function typically simplifies the integration of the transducer into applications in a networked environment."

Over 30 highly experienced (accumulated experience of over 750 years) sensor industry experts were surveyed for their definitions. The experts responded with answers that are classified according to functions (Figure 1):

- Level 0: Raw sensor i.e. with no added electronic functionalities
- Level 1: Level 0 plus trim resistors for gain and offset adjust
- Level 2: Level 1 plus signal conditioning including A/D conversion, filtering, amplification, temperature compensation…and typically referred to as a "sensor interface chip"
- Level 3: Level 2 plus microcontroller with embedded algorithms (security, sensor fusion, local processing)

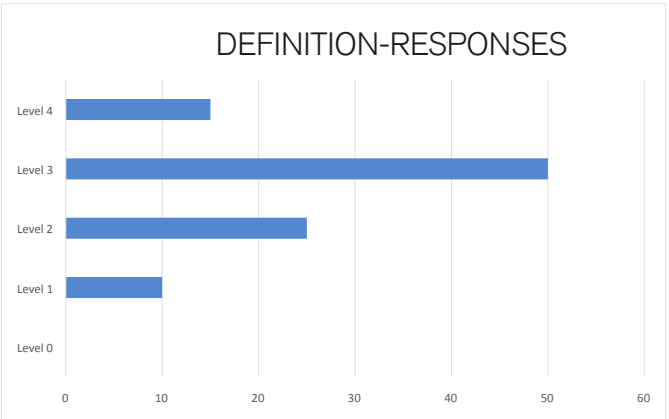

Figure 1. A recent market research project of over 30 interviewees has shown that there is a wide disparity in the definition of "smart sensor". The consensus shows that Level 2 and Level 3 constitute approximately 75 percent of the opinions. Credit: Roger Grace Associates

- Level 4: Level 3 plus communications

Approximately 50 percent of the respondents defined a smart sensor as described by level 3, with 25 percent selecting level 2. These decisions were primarily based on the minimum number of functionalities corresponding to this level.

Figure 2 shows what is referred to [2] as a sensor-based systems solution and it directly addresses the topic of the integration of these functionalities to create a product. It is interesting to note that a smart sensor has these functionalities inside of a package (which could be comprised of several chips stacked or layered out on a common substrate). However, when additional packaged electronic functionalities including a microprocessor are added to this in their own separate and different packages, this concept is referred to as a "smart sensor-based system".

MARKETS

Several market research firms have published market studies on the "smart sensor" market. One study, from Roger Grace and Associates, projects the total available market to grow from approximately $33 billion US in 2018 at a compound

annual growth rate of between 16-20 percent to 2024. Fifty percent of these smart sensors in 2018 are reported to be MEMS-based. As such, smart sensors are an important and fast-growing market. However, one must be aware of the definition of smart sensors that these researchers have adopted to truly understand these values.

BENEFITS OF SMART SENSORS

Based on the answers of the respondents to my market study, there are a significant number of benefits for both suppliers and users... and this is good news that both parties hold smart sensors as providing significant benefits and value.

From a user perspective:

- Reduces systems engineering efforts resulting in lower cost and faster time to market (and the supplier takes ownership of the complete solution)
- Higher reliability through reduction of interfaces between packages
- Smaller size... especially footprint which is key to many applications

From a supplier perspective:

- Enhanced value added
- Enhanced profit margin
- Enhanced product differentiation and product defensibility in the marketplace
- Increased yield due to auto/self-calibration

More good news here…these were just sampling of a much larger benefit analysis provided by the respondents and significant benefits were mutually shared, making for a favorable supplier/customer experience.

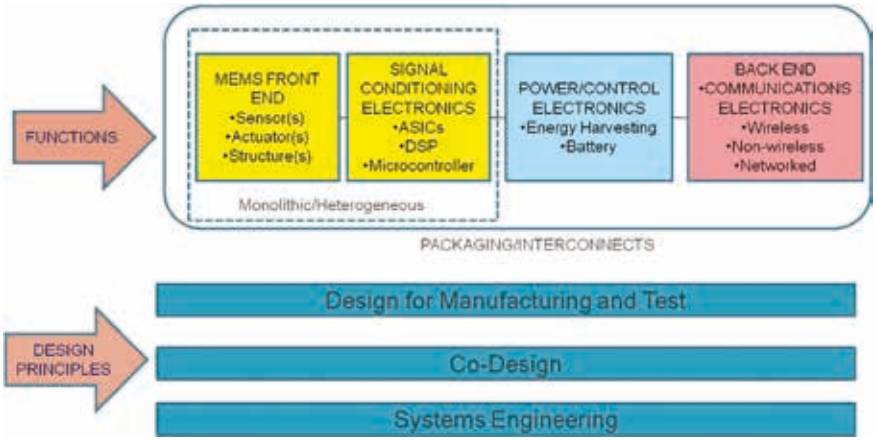

Figure 2. Smart sensors embrace a broad spectrum of electronic functionalities…beginning with signal conditioning through communications. Packaging, interconnects and integration strategies are key elements in successfully creating these systems. Credit: Roger Grace Associates

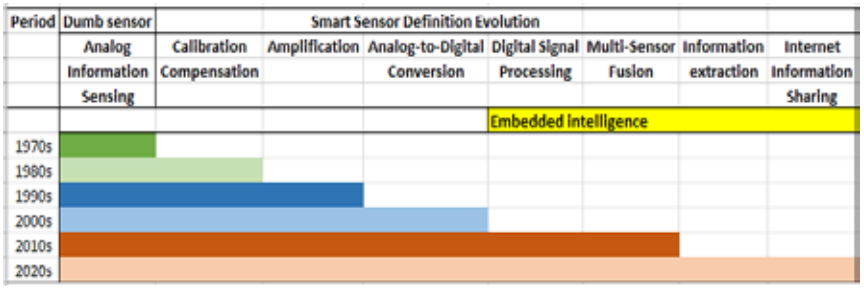

Figure 3. The evolution of the constituents of "smart sensors" has grown with the availability of low-cost mixed-signal electronics and especially application specific integrated circuits (ASICs). Credit: Dr. Janusz Bryzek, eXo Imaging Systems

EVOLUTION

Also of note is the evolution of the adoption of newer functionalities as time has progressed (Figure 3). The primary driving factor of this process is in the broad availability and the continuing low cost of IC functions. This is in addition to the necessary functionalities that users require to make more desirable and affordable products.

An example of level 1 was the piezoresistive pressure sensor introduced in the late 1970's by several companies including Foxboro ICT. Here, the pressure sensor was gain and offset calibrated by discrete resistors that were shipped along with the sensor in a plastic bag along with the printed resistor values.

The next step in developing a "smarter" sensor was to produce a laser-trimmed resistor that was mounted on the back to the TO-8 package that essentially did the same thing.

One of the earliest manifestations of the next level of smart sensor technology, especially from a monolithic integration of several functionalities, was the Analog Devices ADXLhi-g automotive accelerometer (Figure 4). Entering the market in 1991 and selling for $5.00 in large volumes, it was produced using a 5.0 micron biCMOS process. The device integrated a differential capacitor accelerometer and support circuits that included a synchronous demodulator, buffer amps, and self-test. Although this device is not considered smart, it is considered revolutionary because of the assemblage of several functionalities in addition to its being monolithic.

ASICS… TRUE ENABLERS OF SMART

The initial function requirement for a smart sensor is to transform a low-level sensor output signal and "condition" it such that it can become useable in a system. In the early years of sensor design, this was accomplished using discrete electronic components…e.g. passives, amplifiers etc. As demonstrated earlier with the ADI ADXL 50 airbag accelerometer, monolithic circuit functions became the norm.

With the popularity of application-specific integrated circuits (ASICs) over the past several decades, sensor designers have a new tool in their design toolkit. ASICs, whether custom or "off-the-shelf", can include all of the functions to create a smart sensor including the radio. Many sensor designs, especially those from smaller companies, that do not possess their own internal IC design groups, take the route of outsourcing their custom ASICs or sensor interface circuits. Companies including ZMD (now IDT) have developed a broad line of these standard sensor interface circuits that a designer can purchase off-the-shelf.

Figure 4. Analog Devices' ADXL 50 is a monolithically integrated capacitive accelerometer with electronic functionalities, including an oscillator, demodulator, pre-amp, buffer amp and passives. It was primarily used for supplemental restraint systems (airbag) deployment. Credit: Analog Devices

At the other end of the spectrum, many custom ASIC designer/developer organizations (e.g. Si-Ware Systems, En Silica) can meet the varying needs of designers whose needs cannot be fulfilled by standard parts. Interestingly, many companies have developed in-house ASIC capability to be able to maximize the uniqueness and IP confidentiality and resulting product differentiation of their designs through the "secret sauce" of the in-house designed ASIC.

CONCLUSIONS

Approximately 30 in-person interviews have recently been conducted with both suppliers and users of smart sensors and/or smart sensor-based systems. "Smart" can have many different and varied definitions based primarily on their functionalities. Referring back to Figure 1, somewhere between level 2 and level 3 is the most widely accepted definition. However, product designers should not be taken up with the appeal of the term "smart sensor"…but rather need to be divorced from the hype of the technology and listen to the "voice of the customer" and provide solutions that best meet customer's needs. They must adopt an application "pull" versus technology "push" strategy.

The bottom line is that products need to be more smart… a.k.a. more functional and possess more "bells and whistles" to be successful in today's marketplace. Simultaneously, they must be more reliable and have a lower bill-of-materials to reduce cost.

More in-depth information is available in the Understanding Smart Sensors by Randy Frank…available from Artech House [3].

In an upcoming article, we will address some of the more interesting "almost" smart sensor and smart sensor systems available on the market today.

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[1] J. Giachino, Smart Sensors, Sensors and Actuators, 10 (1986), pp.239-248
[2] R. Grace, Think Outside the Chip, Small Times, July 2008
[3] R. Frank Understanding Smart Sensors, Third Edition, Artech House, 2013, 367 pp.