Smart Interfaces for Sensors

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Introduction:

It seems that virtually every technical paper which describes a new technology to "make the world a better place", includes the term "smart" to refer to some aspect of this new technology. The technical literature is filled with smart capacitors, smart resistors, smart rectifiers, smart op-amps, smart memory, smart circuits, smart cards, smart systems, smart networks, smart partners, smart opinions, smart business, smart anything, smart everything and, yes, smart sensors. At the risk of speaking heresy, it seems that "smart" sensors may not always be a desirable goal. One of the issues with "smart sensors" is that, in some cases, it may not make economic sense to design, fabricate, and field smart sensors. Simply put, it may not always be smart to integrate "smart" enabling electronics to sensor components. Maybe what we really need are "smart" interfaces.

Analyze Successes and Failures

Despite the occasional appearance of arguing against smart sensors, on the contrary, this paper will argue for smart sensors technology. An objective analysis of the strengths and weaknesses of smart sensor technology will reveal strategies for successful implementation of smart sensors. At the risk of being obvious, we need to focus on exploiting this technology's strengths and avoiding the weaknesses. To create a "win-win" situation for customers and vendors, it is important to understand past problems and recognized strengths - sometimes an analysis of a failure can be more valuable than the review of a success.

Another requirement for successful smart sensor implementation is customer focus. Smart sensor approaches solely motivated by the goal of implementing "smart" technologies are destined to failure. Most likely, successful implementations of smart sensor technology (or at least some elements of this technology) will be the result of satisfying a customer's pressing need, not convincing a customer to try something new because it's new.

IEEE 1451 Background

During the past 15 years, several different - usually incompatible, and often proprietary - industrial buses have been promoted and implemented in industrial environments worldwide. In response to this growing "Tower of *e*-Babel", some industry and government leaders perceived a need to create standards to accommodate the future needs for networking and allow manufacturers the opportunity to take advantage of economies of scale.

Although we believe that it does not always make sense to tightly integrate intelligence providing electronics to sensing elements, in some cases arguments for this type of tight integration are compelling. In these situations, sensor manufacturers are confronted with issues about which physical bus and communications protocol their smart sensor should be compatible with. In general, it is not economically feasible to build multiple smart sensors systems – one for each of the currently popular network buses. A short list of frequently used networking bus technologies might include Profibus, Fieldbus, DeviceNet, Interbus, CAN bus, Modbus, Ethernet, and related electronic interfaces might include requirements for USB, RS-232, 4-20 mA, IEEE-488 and others.

Recognizing this problem, industry and government leaders from the IEEE (Institute of Electrical and Electronics Engineers), NIST (U.S. National Institute of Standards and Technology), the U.S. Department of Energy Laboratories, instrumentation manufacturers, sensor manufacturers and other interested organizations got to together and created the IEEE 1451 family of standards. Their goal was to sort out the network issues without putting unrealistic burdens on sensor manufacturers or network interface equipment makers. In short, the IEEE 1451 committee was assigned the straightforward task of making order out of the chaos of the competing network world without putting onerous burdens on any one segment of the industry. The committee would replace the growing tower of *e*-Babel with a coherent, planned, expandable networking strategy. [1]

The IEEE-1451.2 was the first standard to be finalized. [2] Its mission was to separate the network issues from the transducer issues. This was accomplished with four concepts: the Smart Transducer Interface Module (STIM), the Network Capable Applications Processor (NCAP), the Transducer Independent Interface (TII), and the most important element of this strategy the Transducer Electronic Data Sheet (TEDS). The STIM handled the sensor and actuator low-level interface stuff and formatted data communication messages between the NCAP and STIM in a standardized digital manner. The NCAP handled the network interface and also managed the TII dedicated interface port to the STIM. It can be argued that the TEDS was the crown jewel of this strategy in that it provided for self-identification of the connected sensor or actuator in a very general manner. Depending on how many of the TEDS fields are implemented, TEDS information can provide great detail about how to read data from the transducer and help identify which transducer is being viewed. The "how to read data" section of the TEDS can quantify such items as calibration factors, units of measure, read/write set-up time, warm-up time, and signal range limits to name a few. The TEDS fields containing identifying information can include various data such as the manufacturer's name, STIM version number, date of manufacture, serial number and other related information. The TEDS (Transducer Electronic Data Sheet) can also contain information about how to access sensor signal correction factors to minimize the effects of sensor non-linearities.

This segmented approach to "Smart Sensors" was created by the IEEE 1451 committee to minimize the impact of this potentially complex new standard on sensor and actuator manufacturers.

For example, with this approach, there could be a Profibus NCAP, an Ethernet NCAP, a CAN bus NCAP and a single IEEE 1451.2 Type K thermocouple. This smart thermocouple could then be attached to several different types of NCAPs – as long as there was an IEEE 1451.2 NCAP available for each of the desired networks. Continuing this scenario, sensor manufacturers would develop and produce Type K thermocouples tightly coupled to electronic components performing STIM functions and storing TEDS data. Any one of the three NCAPs could be connected directly to this IEEE 1451.2 sensor and function - immediately. The advantage of this approach is that the thermocouple manufacturer would not need to worry about which industrial bus their sensor was supporting, it would support all of the buses for which an IEEE-1451 NCAP exists.

Using this approach, sensor manufacturers could make their sensor products "smart" by complying with the TEDS and TII interface standards and not be concerned with any of the network issues. Their "smart sensor" products would automatically be compatible with any network as long as an IEEE 1451 NCAP was available for the network of interest. Ideally, the user would just plug the desired NCAP into the smart sensor's TII interface connector and the user would create an instant, automatic smart sensor.

Unfortunately, things have not exactly worked out the way they were planned. Although the IEEE 1451 committee did a great job of developing some important and useful concepts for transducer interfacing to networks, sometimes "hot", market driven technologies (Ethernet) moves forward without waiting for the standards to catch-up.

The concepts from the IEEE 1451.2 standard are very general and can be used to interface many different types of sensors and actuators. The TEDS was particularly well planned and identified a useful set of data fields well suited for self-identifying transducers.

But the availability of commercial, off-the-shelf NCAP products to support the network interface part of the standard has been disappointing. The only NCAP widely advertised and generally distributed was removed from the market in less than one year after its introduction. Agilent Technologies, the manufacturer of this NCAP, sent a notice to all NCAP owners essentially explaining that sales did not justify continued marketing of their NCAP line of products. No other NCAPs have been generally announced or made available for sale.

Although the lack of NCAP products has slowed the intended, segmented implementation of IEEE 1451.2, other implementations of this technology are encouraging. There is significant, on-going development work on other aspects of this standard 1451.3 and 1451.4. In addition, there have been other approaches to 1451.2 in which the key technology features have been implemented in a manner slightly different from the original plan. Later in this paper we will describe Sensor Synergy's approach to implementing the IEEE 1451 smart sensor technology.

When It's Not Smart to Make a Sensor Smart

As noted earlier, there are some sensor technologies in which it does not make sense to tightly integrate smart electronics to sensing elements. Economic and technical feasibility issues need to be included in decisions about making a sensor into a smart sensor - smart sensors may not always be a desirable goal. A key issue with "smart sensors" is that it may not always make economic sense to design, fabricate, and field smart sensors. It must be determined that a specific sensing technology is amenable to higher levels of microelectronic integration in a cost-effective manner and the intended application (market) warrants the smart sensing technology.

Often sensor technologies work their magic by exploiting some obscure aspect of the laws of physics to provide an easily measurable indicator of a change of state, change in chemical composition, change in physical attribute, or variation in some other physical world parameter. The fabrication of these sensor technologies is sometimes inconsistent with fabrication technologies required to integrate microelectronic-based, "smart" capabilities.

Examples of "Economically-Challenged" Smart Sensors

Consider the example of a silicon, micromachined, diaphragm-type, pressure transducer integrated with analog signal processing circuits and digital interfacing circuits. Although this example was designed and fabricated before the IEEE 1451.2 standard was released, it is possible to make approximate comparisons in terms of the IEEE 1451 standard. It may be possible to correlate the signal processing circuits and analog interface circuits with many of the STIM functions. We can also loosely compare the digital interface circuits with many of the same functions found in the NCAP.

As the development effort on this project matured, the manufacturer learned that the integration of these system elements onto a single silicon chip created unanticipated problems. The cost of the package that provided exposure to environmental gas pressure changes and also provided the necessary number of microcontroller driven electrical interconnections was prohibitively high for the intended application. In addition, the exposure to the outside environment (essential for a pressure sensor) had the potential for a negative impact on the reliability of the companion microcontroller digital circuits. [3]

Beyond packaging costs and reliability issues, the cost of development to merge two, somewhat incompatible, technologies can also make the resulting devices prohibitively expensively.

In another example of a difficult smart sensor development, consider the Smart Hydrogen Sensor technology developed at Sandia National Laboratories. [4] Scientists and development engineers at Sandia implemented a silicon-based Smart Hydrogen Sensor with many of the same functional circuit blocks used in the IEEE 1451 - STIM and NCAP elements. Sandia researchers needed to solve difficult materials compatibility issues associated with integrating hydrogen sensor technology with silicon analog and digital circuits technology. It was found that some of the metals required to fabricate the hydrogen sensor elements within the smart hydrogen sensor were fundamentally incompatible with integrated circuit processing technology. Although the technical problems were eventually overcome with clever processing techniques, the additional processing and engineering costs of the solution may make the smart hydrogen sensor prohibitively expensive to manufacture.

However the basic sensor chip with heaters and temperature sensors along with the hydrogen sensing devices is now a commercial product. All of the signal processing, temperature control signals and networking is performed off chip in various packages. This approach has satisfied the technical needs for the current customers.

The separation of the sensing element from the network and signal processing electronics had some additional advantages by providing greater flexibility for hydrogen sensor applications in certain extreme environments. In this example, the separation between smart circuits and the basic sensor element is made possible by applying temperature control techniques to the hydrogen-sensing element. In operation, the sensor can be considered as a simple resistive circuit element, which further simplifies the remote electronic interface to the sensing element.

The feature enhancements of smaller size and lower weight associated with highly integrated smart sensors may not be of interest to users due to the added costs and manufacturing difficulties for the networked smart hydrogen sensor. However, it is possible that future users may require smaller size and lighter weight for microrobotics, space applications, or other low-volume and low-weight applications.

Deployment Costs

Another cost factor that needs to be considered is the implementation costs. In addition to the difficulty of integrating microelectronics to sensors, many sensor components are used in highly constrained applications that could not exploit the beneficial features of smart sensors - even if it were available at no additional cost. Depending on the details of the application, the added cost of smart-sensor software interfaces, software compatibility issues, and other software field maintenance issues may make it infeasible to consider smart sensor technologies.

Even if there is zero cost (free) associated with acquiring the smart sensor, some applications may not be suitable for smart sensor technologies. From the perspective of the real-world sensor user, the added cost, interface complexity, and associated decreased reliability for a smart sensor over the plain unenhanced (dumb) sensor, may not be wise in all applications.

For some applications, "not-smart" or "dumb" sensors are smart to use. It just may not be smart to integrate "smart" enabling electronics to all sensor components. In some cases, "smart" interfaces may provide the desired networking features without imposing the technical compatibility and cost requirements on the sensor fabrication technology.

Where Do We Draw the Line?

Since the industry appears to be focusing its future efforts on Ethernet networks, there may no longer be a great need for compatibility with several types of networks and therefore no need for several types of NCAPs. The strategy for implementing smart sensor technology may radically change if one considers only one type of network interface and one type of NCAP – an Ethernet NCAP.

If one considers a simplified view of the IEEE-1451 segmented sequence of logical blocks as Transducer - STIM - NCAP, then the issue may become "where do we draw the line?" Do we follow the scenario described above with the thermocouple example and make smart sensor units that integrate the STIM and TEDS functionality into the sensor product?

Or do we make adaptable smart interfaces that combine the functionality of the NCAP and STIM into a single sensor interface? The second approach can be used with many types of unenhanced sensor products.

Sensor Synergy's strategy has been to combine the NCAP and STIM into an adaptable smart transducer interface and provide the most useful features of the IEEE 1451.2 to both end-users and transducer manufacturers in a cost effective manner. This approach addresses the reality of an Ethernet dominated network environment without requiring sensor manufacturers to re-work their product offerings by tightly integrating microelectronic-based intelligence into their sensors.

A Smart and Adaptable Interface

There seems to be a paradox in which smart sensors may be desirable from the perspective of remote-access, network interface features yet the economic and technical barriers may make smart sensors undesirable. The solution to this paradox may be the use of "smart and adaptable" sensor interfaces. There are many applications in which the features of smart-sensor technologies would be highly beneficial. However, instead of trying to get sensor component manufacturers to provide "smart" versions of each sensor in their catalog, consider the use of smart and adaptable sensor interface units. These smart interfaces would enable the use of one's favorite, existing sensor component in applications that require "smart", networked sensors.

Smart Interfaces for Unenhanced Sensors

As an example of applying this adaptable smart interface technology, consider the need to make a specially coated quartz crystal microbalance sensor into a smart sensor. This sensor technology is based on monitoring the frequency of oscillation of a crystalline quartz resonator. To fabricate the sensor, Sandia National Laboratories researchers deposit specially designed chemically absorbing polymer layers on the surface of crystalline quartz resonator disks. In operation, the thin polymer film selectively absorbs chemical contaminants from the resonator's environment. As the film absorbs more or less of the target chemical, the mass and stiffness of the film change. The frequency of oscillation and the resonator's damping factors change as the film changes. Careful calibration and numerical transformations of the frequency shift, damping voltage, and temperature can result in an exceptional sensitive chemical contaminant sensor. [5]

Due to the mechanical isolation requirements for the 2.5 cm resonator disk, the severe environments for the intended application, the discrete nature of the radio frequency drive circuits [6], and small number of specialized sensors [7] ultimately required for this market segment, a tightly integrated smart sensor solution was not considered feasible. However, Sensor Synergy's adaptable smart interface seemed well suited for this application.

This smart, adaptable sensor interface approach provided the desired form factor features, met the physical constraints of the sensor's environment, and cost goals of the program.

The target application required remote sensor reading via http protocol with physically remote client computers utilizing "browser" programs to access the data. In addition, this smart sensing application required three near-simultaneous sensor readings to derive valid contamination sensor data. Separate measurements for frequency change, temperature, and damping voltage were all made within a 1 second trigger window and reported to each connected browsers.

The completed solution included the ability to customize the displayed "web" page and to modify certain fields in the TEDS sensor data sheet. The interface also included an actuator signal for future use of controlled contaminant sources for remote re-calibration. A version of this system has run continuously for seven months without difficulty.

Conclusions

We have described some real-world examples of smart sensor technologies that suffered from significant economic and technical feasibility challenges. We have also described a real-world example of a smart interface applied to an unenhanced sensor to create a functioning smart sensor unit. The smart interface provided the key features of the IEEE 1451.2 for an application that was able to benefit from smart, networked sensor data. The use of the smart interface avoided the economic and technical challenges of a more tightly integrated approach.

References

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