Smart Sensor Standards and the USB Model

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Abstract:

Discussions and announcements about smart sensor standards have been appearing in the technical press, at various technical conferences, and at trade shows with increasing regularity during the past five years. Significant progress has been made but there seems to be more to do. This paper will compare and contrast some aspects of the IEEE 1451 family of smart sensor interfaces with the Universal Serial Bus (USB). Although USB is not a competing technology, there are some analogies that may be useful in refining some members of the 1451 smart sensor interface family. Recommendations for making IEEE 1451 easier to implement, less complex to use, and less cost to develop are included.

Introduction:

Although a large amount of overview information about smart sensor standards has appeared in the technical press, at various technical conferences, and at trade shows, the widespread availability and implementation of smart sensor standards has been elusive. To be sure much progress has been made in making the sensor industry and sensor users aware of these standards but there still seems to be much more to do. While smart sensor standards have moved forward at a gradual pace, other standards, such as USB seem to have exploded into the market place during the same time period. Although USB and IEEE 1451 are not competing technologies and solve different problems, they have some interesting similarities and differences. The following brief discussion comparing USB with the 1451 family of standards may be useful in understanding the key strategies necessary to develop a widely accepted interface standard.

The IEEE 1451 Family of Smart Sensor Interface Standards

The effort to create the IEEE 1451 smart sensor interface standard formally began in September 1993. This group was established to develop a communication interface standard for smart sensors and was launched as a joint activity by the Institute of Electrical and Electronic Engineers (IEEE) and the U.S. National Institute of Standards and Technology (NIST). This effort was chartered with the mission of resolving some very specific technical issues associated with interfacing smart sensors to digital communication networks. Part of the motivation for this effort was a response to the wide variety of proprietary industrial sensor and actuator interface bus technologies. The IEEE 1451 effort was designed to be network neutral in which many of the features between a digital representation of the sensor signal and the network capable application processor (NCAP) would be specified but the network details would not be specified. In this way, with the appropriate network specific NCAP, many different types of networks could be supported with the same 1451

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smart transducer (sensor or actuator) interface module STIM.

Before IEEE 1451, users applying smart sensor technologies were confronted with a large set of complicated smart sensor implementation issues, especially when trying to implement the same type of sensor devices on different industrial networks. To those involved with applying sensor technology, the need for a common, open standard was apparent.

The goal of the 1451 Working Group was to reduce the complexity and cost of interfacing smart sensor to higher-level controllers while exploiting the features of the rapidly evolving microprocessor based smart sensors. A plug and play like interface was developed to satisfy the needs of a broad set of sensor devices and applications. The 1451 also tried to meet the needs of actuators in addition to sensors and generally used the broader term transducer to refer to either a sensor or an actuator. A myriad of trade-off decisions had to be made in order to accommodate the broad variety of sensors currently in use, anticipate the types of smart sensors that would soon be in the marketplace, and create a generally usable interface standard. As the development work on a smart sensor interface standard progressed, it became clear that a single, workable standard would not be able to satisfy all of the goals established by the originators of this effort.

Additional smart sensor standard working groups evolved as the needs for different categories of sensor interfacing requirements surfaced. Today, within the IEEE 1451, there is a family of six smart sensor interface standard efforts either completed or under development attempting to deliver on the original vision of the earlier smart sensor interface visionaries. These IEEE smart sensor interface efforts are referenced with the family number –1451, followed by a dot suffix, .x. The current family[1,2,3] includes IEEE P1451.0, 1451.1, 1451.2, 1451.3, 1451.4, and P1451.5. IEEE 1451.2 was officially published[1] in September 1998. The IEEE has a policy of reviewing standards every five years to determine if changes are required; the IEEE Std 1451.2-1997 is currently in the process of being revised and updated.

As will be noted below, there are many similarities and some differences between the IEEE 1451 efforts and the Universal Serial Bus, a current standard often used for interfacing computer peripherals to computers.

Universal Serial Bus

USB, the acronym for Universal Serial Bus, refers to a connectivity standard that enables various types of computer peripherals to be connected to a computer with a small amount of effort or specialized knowledge. USB[4], initiated in 1993 by a consortium of large computer system companies including Compaq, Digital Equipment Corporation, NEC and Microsoft, was launched to provide a simpler way to interface computer peripherals to computers. Before USB, interfacing a computer peripheral such as a printer, optical scanner, communications modem, or auxiliary drive, was frequently a difficult task requiring mechanical skills, specialized computer knowledge, separate specialized interface hardware cards and special software drivers. Due to the variety of computers, peripherals, and software, attaching a peripheral to a personal computer system could be a difficult task for the most skilled computer professionals -- and an impossible mission for individuals with less detailed computer knowledge. The USB effort was motivated by the need to eliminate these interfacing hurdles while making computer peripheral technology available and usable to a broader audience.

In many ways analogous to the IEEE 1451 smart sensor interface standards, the USB effort was attempting to solve difficult technical interface issues for existing and future computer peripheral technology while making the solution easier to use than prior interfacing solutions. Prior to USB, there was a wide range of technical solutions used

to interface computer peripherals to computers. Some of these solutions included the use of special interface electronics hardware in the form of printed wiring boards that plugged into the computer's chassis, serial cables, parallel cables, and various SCSI (Small Computer System Interface) cables and cards. Generally, the user needed special software, special hardware and specialized interface knowledge to complete the interface.

By 1996, the USB 1 (Low-Speed USB Mode - 1.5 Mbps) specification was released, in September of 1998, USB 1.1 (Full Speed USB mode - 12 Mbps) was released, and in April of 2000, USB 2.0 (High-Speed USB mode – 480 Mbps) was completed.

For comparison purposes, USB 1.1 interfaces can transfer approximately 10 times more data than a standard personal computer parallel port and approximately 200 times more data than a 56Kbaud serial port. USB 2.0 can provide up to 40 times greater information transfer than USB 1.1.

In general, a user with very limited computer technology skills can connect peripherals to a computer using USB. Usually, the user does not need to open the computer case to install special hardware, does not need to install special software drivers, and does not need to utilize specialized information to complete the interface connection. The USB interface in concert with a USB aware computer operating systems (including Windows 98, Windows ME, Windows NT, Windows 2000, Mac OS 9, Mac OS 10, and Linux) provide all of the software needed to automatically interface the peripheral through the USB connection. USB supports "plug and play" and "hot-swap" features.

USB - It's the Market Size and Size Does Matter

Approximately 400 million USB enabled devices were shipped in 2002. Predictions about future markets size for USB are interesting and, like all projections, include some uncertainty. However, some market analysts project that over 850 million units with USB enabled interfaces will be sold in 2007. If the passage of time shows these predictions to be correct, the USB interface world will have experienced a compound annual growth rate in excess of 18% during the 2003 to 2007 time period.

Several large integrated circuit manufacturers currently sell USB interface devices in which a single device will perform a complete set of the necessary USB hardware and software interface functions. In some instances, these devices can perform all necessary USB interface tasks for less than one-dollar per device.

Comparing USB with IEEE 1451

The explosive growth as observed with the USB effort from its launch in 1993 has not been shared by the IEEE 1451 family of standards also launched in 1993. Aside from the main distinction of solving different problems, there are some other differences and similarities that are worth exploring.

USB and IEEE 1451 Similarities:

- Both USB and IEEE-1451 specify the details of how data shall be transferred between two nodes.
- Both USB and IEEE-1451 accommodate a wide range of complex device/peripheral data and format this into a standard digital data stream.
- Both USB and IEEE-1451 exploiting the special features of connecting smart transducers or smart computer peripherals.
- Both USB and IEEE-1451 provide self-identifying information in respond to requests from the connected system as to what type of device is connected.

USB and IEEE 1451 Contrasts:

- USB is focused on connecting a wide range of computer peripherals to computers running USB aware operating systems; IEEE 1451 is focused on connecting a wide range of sensors and actuators to a wide range of computer networks, electronic instruments, computers, and other intelligent digital interfaces.

- USB is primarily focused on bi-directional transfer of digital data between peripherals and computers; IEEE 1451 is focused on the bi-directional transfer of sensor and actuator information between transducers and a wide range of digital electronic clients. The sensor information may need additional signal conversion and signal processing to extract the necessary information; the sensor data may also need signal compensation and correction algorithms applied before transmitting the data through the NCAP. The sensor and actuator data may need to be synchronized with special trigger signals operating in several different modes. The IEEE 1451 interface may need to satisfy special legacy wiring concerns.

- USB has a very strict concept of host and slave / functional endpoint; IEEE 1451 attempts to implement a more flexible architecture allowing the 1451 transducer-STIM-NCAP to function either as a server, a client, or in a peer to peer mode –depending on the NCAP implementation.

- USB has a strict set of requirements on the host operating system software to identify new USB plug and play devices; IEEE 1451 has no specific requirements on an NCAP-digital electronic system connection.

- USB has a strict physical cable and connector specification; IEEE 1451 does not specify connectors or cables but tries to accommodate various legacy connectors and cables.

- USB standard includes a strict set of configuration data describing the computer peripheral and the interface; IEEE 1451 includes a flexible set of required and optional Transducer Electronic Data Sheets allowing for the inclusion of various types of information associated with smart transducers and smart sensor data acquisition interface.

- USB is generally intended to apply to computer peripherals that intrinsically provide digital information; IEEE 1451 is generally intended to apply to sensors and actuators – many of these sensors and actuators intrinsically operate with analog information.

Differences

In addition to the technical differences described above, the acceptance and success in the marketplace between these two standards has been radically different. Some of the reasons for these differences are explored below in greater detail but can be summarized with the following six issues: 1) Cost, 2) Trend Setting Proponents, 3) Complexity, 4) Market Size, 5) Entrenched Legacy Solutions, 6) User Perspective. These issues are not all strictly independent of each other. As frequently happens in the real-world, some aspect of each issue listed here may be related to some of the other listed issues. For example, with enough analysis, almost every issue can be related to costs. But these six issues also have a unique aspect to consider.

Costs

Many real world solutions are highly sensitive to cost issues. It is interesting to note that the USB

interface is often compared with another functionally similar interface generally referred to as FireWire (IEEE 1394). Prior to USB 2.0, the competing FireWire technology has enjoyed a higher throughput of data but involves the use of proprietary technology with a significantly higher implementation cost than a similar USB device. For comparison purposes, an auxiliary external disk drive may cost $20 per unit more when using FireWire[5] when compared to a similar drive using USB. In the consumer world, a $20 price difference on a $150 unit can be very significant. To further validate this issue, it should be noted that during 2002, there were approximately 60 million FireWire enabled devices sold while during the same period there were 400 million USB enabled devices sold.

The cost of implementing 1451.x family members is related to the specific application selected, the features set included in the implementation, the complexity/ options included in the implementation, and the anticipated market size.

Another aspect of the cost issue is the relative value of the components being connected. If the goal is to connect a $150 auxiliary disk drive to a $1000 computer system, a $10 - $20 interface solution may be readily acceptable to system designers. However, if a $20 thermocouple is to be connected to a $100 furnace controller, the same $10 - $20 interface solution may not be as readily acceptable. For this case, the acceptance will need to be determined by other factors including the value of the information, the availability of alternative solutions, and the negative aspects of each interface solution.

The cost of implementing a USB or IEEE-1451 solution will be related to the availability of infrastructure building block components. For example, there are several USB interface integrated circuits available from at least three very large integrated circuit (IC) manufacturers with costs below $2/each in quantity. From computer mice to external recordable compact disk drives, the demand for USB interface circuits is clear to many IC manufacturers. This justifies the IC manufacturer using substantial internal resources to design and build complex USB interface circuit solutions. As a result of these infrastructure investments, sophisticated USB building block components are available for relatively low costs. Currently, a similar availability for IEEE 1451 infrastructure circuits does not exist.

Trend Setting Proponents

A consortium of very large computer industry leaders – Microsoft, Compaq, Digital Equipment Corporation, and NEC - initially introduced USB. These companies were able to publicize and promote technical solutions because of their size and influence. Although the promoted solution must also meet other criteria including functionality, cost, and availability, it may not necessarily be the best solution in all categories. For example, in raw data transfer capabilities, USB 1.1 is second to FireWire. However, USB has other redeeming qualities including the support of industry leaders and a cost advantage. These advantages have helped USB overcome concerns about maximum data transfer rate technical limitations to win a greater share of the market for computer peripheral interface units.

In trying to serve as an open standard for interfacing sensors and actuators to computer networks, the IEEE 1451 approach has not been strongly supported by a group of large commercial entities. In the data acquisition and industrial control area, proprietary solutions are frequently promoted for interfacing sensors and actuators to industrial computing and control networks. These proprietary solutions provide the product differentiation features essential to many corporate marketing strategies.

Although the IEEE 1451 family has used a network neutral approach with the NCAP concept, rapid and widespread implementation of IEEE 1451 solutions will require the efforts of large corporate proponents capable influencing the industry and building 1451 infrastructure devices. During the past year, a few large

corporate entities have openly supported some members of the IEEE 1451 family.

Complexity

USB and IEEE 1451 are both complex computer interfacing solutions. Since these standards perform different tasks, it is difficult to make direct comparisons of the relative complexity of each. However, from the list above, it is clear that the IEEE 1451 approach has targeted a broader set of goals with greater implementation flexibility. The goal of greater inclusion has come at the expense of simplicity. The most general IEEE 1451 solution appears to be significantly more complex than the USB solutions. This complexity effects the cost of implementation, the magnitude of learning curve barriers for developers and implementers, and technology selection attitudes.

Market Size

Market size is essential to determining how many resources a manufacturer is willing to dedicate to developing technology infrastructure for a new interface standard. It is estimated that there are more than 350 million personal computers capable of interfacing to USB peripherals; the market size for some of the IEEE 1451.x family solutions is considerably smaller. If the potential market size has 350 million potential users, corporate investments to develop technology solutions will be more plentiful than if the market size is more limited in upside potential. USB and IEEE-1451 both benefit from custom integrated circuit solutions but the USB infrastructure product will generally command more resources within a corporate investment strategy.

Entrenched Legacy Solutions

Consider a recently acquired handheld Personal Digital Assistant (PDA) that provides mobile e-mail, web browsing, cell phone communications, calendar functions, note-capture capabilities, and calculator functions. This device may include a USB interface to connect this mobile device to the user's desktop system. There may not be an alternate set of existing interface solutions that people generally use to interface their new PDA to their desktop system. For many new technology computer peripherals such as PDA's, there is no established legacy interface solution.

However, for sensor and actuator interfaces, there is a significant amount of technology developed to interface analog sensors to the digital world. These technologies may not exploit the features of smart sensors but they are familiar to the user and supporting components may be readily available for test and development.

User Perspective

For USB interface solutions, the prior solution were generally significantly more difficult to implement than the new USB approaches. Users find USB an empowering technology permitting relatively low-technology individuals to perform the integration of computer peripherals that formerly required the assistance of computer specialists. Users have generally considered USB solutions as an easier interface than alternate approaches.

For sensor and actuator interfaces, many users have extended experience with conventional simple hardware interface technology solutions. Although users may be more familiar with other hardware-only sensor and actuator interface solutions, the development of smart sensor and smart actuator technology will necessitate the use of smart interface solutions such as the IEEE 1451. Users may initially minimize their use of these newer solutions due to various factors including: risk adverse attitudes in highly competitive manufacturing environments, learning curve issues, perceived complexity issues, and the uncertainty of implementing new technology. All of these concerns are valid user issues and need to be considered as IEEE 1451 solutions become available in the marketplace.

Conclusions

This comparison of USB with IEEE 1451 has revealed several major differences but also has shown some similarities. There are some important lessons to be learned from reviewing the market interactions of analogous technology solutions; however, it should also be noted that there are important differences in the target markets of these two technologies that may limit the validity of these lessons.

IEEE 1451 may benefit from a more limited, less inclusive goal. There are hundreds of major types of sensor categories that will benefit from the IEEE 1451 smart sensor interfacing technology. Unfortunately, while trying to be inclusive to accommodate the needs of as many of these types of sensors as possible, the 1451 efforts can inadvertently increase the complexity of 1451 implementations. This can result in an increase in implementation cost and a decrease in user-appeal.

It may be beneficial to narrow the scope of software interface options. For example, complexity and cost reductions could be achieved if a set of specific, predefined command and response interchanges were mandated to occur whenever a smart sensor interface is connected to a digital interface. The software infrastructure will cost less be easier to develop if the standard requires the use of a predefined sequence of software identification/discovery commands to be exchanged whenever a 1451 sensor is connected to an acceptable digital interface. Although this may limit the number and type of digital interfaces capable of interfacing with a 1451 system, it may enhance the overall appeal of the system. Unfortunately, this approach may effectively exclude certain types of semi-smart instruments from interfacing with an IEEE 1451 sensor; however, a tightly controlled discovery sequence will benefit most implementations. Fewer options make the system easier to implement and in some instances easier to use.

It may be useful to specify the physical connector used to interface the NCAP to the STIM in detail. This level of specificity may disqualify some applications from using a particular member of the 1451 family; there may be that other members of the 1451 family that will satisfy the physical connector needs restricting a particular application. The advantage of specifying a physical connector is that it is easier to create solutions which are known to be plug and play compatible. Once again, at the cost of losing some potential applications, a specified connector will reduce cost and complexity. With a specified standard connector, the user will not have to worry about connector compatibility – not an insurmountable concern but another factor that can impact a user's technology selection.

As a result of reviewing the USB approach to computer peripheral interfaces and extrapolating these lessons to the IEEE 1451 family of smart transducer interfaces, some general conclusions can be made.

- More options to provide greater inclusion may be detrimental to a standard's practical appeal – cost, ease of use, and perceived complexity.
- Sometimes clearly defined, basic features can be important user selection criteria – for example the specification of physical connectors.
- Simpler may be better – single no-choice hardware architectures may be easier and less costly to implement than approaches with multiple options.
- Wherever possible, provide options in software not hardware – support multiple sensors through software-defined features and not by permitting multiple types of hardware implementations.

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References:

[1] IEEE Std 1451.2-1997, "IEEE Standard for a Smart Transducer Interface for Sensors and Actuators – Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats", IEEE Instrumentation and Measurement Society, TC-9 Committee on Sensor Technology, Institute of Electrical and Electronics Engineers, New York, N.Y., Sept. 1998.

[2] IEEE Std 1451.1-1999, "IEEE Standard for a Smart Transducer Interface for Sensors and Actuators – Network Capable Application Processor (NCAP) Information Model", IEEE Instrumentation and Measurement Society, TC-9 Committee on Sensor Technology, Institute of Electrical and Electronics Engineers, New York, N.Y., Published April 2000.

[3] For additional information about these standards, visit the IEEE 1451 web site at http://ieee1451.nist.gov.

[4] Universal Serial Bus Specification, Revision 2.0, April 27, 2000 by Compaq, Hewlett-Packard, Intel, Lucent, Microsoft, NEC, and Philips. Available at www.usb.org/developers.

[5] Metz, Cade, "FireWire vs. USB 2.0", PC Magazine, February 25, 2003.

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