A Summary the IEEE-1451 Family of Transducer Interface Standards

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Introduction

The IEEE-NIST 1451 family of standards is a set of open standards that define interfaces for sensors and actuators to communicate with processors. In fact, this family of standards is much more than a set of specifications associating connector pin positions with various signals. These standards contain a wealth of information and guidelines about connecting sensors and actuators to networks. The problem of developing a universal set of interface standards that will accommodate all sensors, actuators, communication needs, networks, and processor requirements is a very big task – in fact, it may be too big. The efforts by the IEEE standards committees and the U.S. government's National Institute of Standards and Technology must be praised as an important step in the direction of creating open standards for connecting sensors and actuators to the networks of the future. But, there is a long way to go before we reach the goal of a universal transducer-to-network interface standard.

Why Do We Need Standards

In fact, many of the great technological advancements anticipated for the future are predicted to need wide-ranging arrays of network-connected sensors and actuators. As networking technology advances along with the expansion of our worldwide connection infrastructure, the demand will continue to grow for enhanced sensor networking capabilities. Of course these demands will be accompanied by requirements for more features, more bandwidth and lower costs. Widely adapted, open standards can help bring about these goals – greater deployments of networked smart sensors at reduced costs.

Upon reflection, when considering the existing technology base of sensors, actuators, networks, processors and applications, it soon becomes apparent that it may not be possible to develop a single "standard" that satisfies the needs of all. When we consider the combinations that a universal transducer interface standard must satisfy given the range and scope of applications, sensors, actuators, network technologies, and processors, we rapidly recognize the problem. In fact, the IEEE-1451 family of standards attempts to accommodate a large segment of this "technology space". This family of transducer interface standards has grown from two to five members but still cannot be all things to all technologies.

Of course, without standards these issues rapidly become much worse. The precise number of standards used in industrial applications to connect sensors to controllers is difficult to identify, since different vertical industry segments and (often) different geographic regions tend to focus on different network standards. However, some researchers have counted in excess of 40 different network solutions. Although many have common hardware or software ancestors, the differences between these 40+ networks is great enough to prevent one device, designed for one type of network, from "talking" to a controller designed for a different type of network. The unmanageable nature of this problem rapidly becomes apparent when the perspective of the sensor manufacturer is considered. Which networks should be supported for which sensor products? Even for a reduced set of these networks, the costs can become prohibitive. For example, the engineering development resources required to develop network-specific, smart sensor solutions for 5 different sensor product families compatible with 5 different network solutions could convince the sensor manufacturer not to develop any network enabled, smart sensors. Unfortunately, this type of divided marketplace reduces technical advances. Instead of focusing development resources on adding new features or reducing manufacturing costs for the existing network interfaces, resources need to be allocated to re-inventing the network interface electronics for each supported network.

To further exacerbate the problem, as technology evolves, markets focus shifts from one area to another. The demand for additional feature support in a "universal" sensor interface standard will also evolve. For example, although Marconi invented the radio in 1901, it wasn't until 100 years later in 2001 that we discovered we needed Bluetooth , IEEE 802.11 and other "wireless" (read wireless as two-way radio) technologies to become connected in our increasingly complex workplaces and homes. The development of a "wireless" smart sensor interface standard is currently being explored by a new IEEE P1451.5 working group committee.

The 1451 Family of Transducer Interfaces

Accepting the limitations created by the diverse technologies associated with sensors, actuators, networks and processors, the IEEE 1451 family of sensors can be viewed as the cumulative efforts of several experts highly experienced in the area of networking sensors. With this approach, the IEEE 1451 series becomes a reference set containing valuable guidelines, practical rules, and insights into technical problems and possible solutions associated with networking sensors and actuators. A brief summary of some of the features of these standards is illustrated in Figure 1.

Key Features for IEEE 1451.1

This standard provides a common object model for the components of a "smart transducer" and the "networks" connecting these smart transducers to the rest of the world.. This software construct enables developers to implement a single set of 1451.2 smart transducers that can then operate with multiple network specific Network Capable Applications Processors – NCAPs such that each NCAP operates with a different type of network. This standard defines network-independent models for communications between the network and the smart transducer (such as a 1451.2 smart transducers) and also defines a model for implementing network-independent functions for a specific application. This standard also includes uniform models for representing physical data, event data, time, and memory management.

The key element of this standard is to provide the high-level software rules to develop multi-network compatible smart transducers. If a 1451.2 application is developed for a single type of network NCAP and the NCAP will primarily be used with the 1451.2 model, the material in 1451.1 may not be needed.

Key Features for IEEE 1451.2

The IEEE/NIST standard IEEE 1451.2 provides a complete means of creating a networked, smart transducer. Although this standard does not include the conversion of analog signals to digital information, it does include provisions for signal conditioning, error correction, calibration and much more. The standard describes in detail the software and hardware connection between the smart transducer and the Network Capable Application Processor (NCAP) but it does not include any discussion about the interaction between the NCAP and the network. If the signals between the NCAP and the smart transducer are compliant with the guidelines of the IEEE 1451.2 standard, then the NCAP is acceptable. This provides for the Network Independent feature. This standard includes a complete set of definitions and explanations for eight types of Transducer Electronic Data Sheets – TEDS. These TEDS includes a Channel TEDS, a Meta TEDS, a Channel ID TEDS, a Meta ID TEDS, a Calibration TEDS, a Calibration ID TEDS, an application specific user TEDS, and industry expansion for future TEDS. Only the Meta TEDS and at least one Channel TEDS are required and can be implemented in less than 300 bytes. The other TEDS may be implemented if these features are needed. The "Channel TEDS" refer to the details of one specific transducer signal channel including data units, acquisition delays, type of signal and other related information. The "Meta TEDS" refers to global information related to the entire unit. The "Calibration TEDS" provide a complete error correction and data calibration capability.

Key Features for IEEE P1451.3

As of this writing, this standard has not yet been finalized and so the "P" prefix indicates "Preliminary" standard. This standard has many similarities to the IEEE 1451.2 standard but this standard provides for many transducers to be connected as different nodes on a "multi-drop network" using a common set of connection wires. To accomplish this feature, a time synchronization approach controlled by the Transducer Bus Interface Module, this standard multiplexes digital data signals on a common transmission medium. This IEEE P1451.3 standards committee has recently proposed the use of XML (Extensible Markup Language) to provide for a flexible set of TEDS fields including many of the TEDS described in the IEEE 1451.2 standard and other TEDS needed to accomplish the goals of IEEE P1453 including transducer frequency characteristics.

Key Features for IEEE P1451.4

As of this writing, this standard also has not yet been finalized and approved so it also has a "P" prefix for "Preliminary" standard. A key feature of this standard is to provide for analog and digital signals sharing the same set of wires in a Mixed Mode Interface. This standard focuses on the front end of the smart transducer model and provides for a low-cost, memory lean, TEDS model. It also enables the use of existing cabling to send analog sensor signals from remote transducers. The IEEE P1451.4 primarily specifies the interactions between the transducer and the data acquisition module and does not get into the network connection. It does provide for a very low memory TEDS as well as the capability to expand the TEDS to utilize greater memory resources and provide more information between the transducer and the rest of the system.

Key Features for IEEE 1451.2 and PIEEE 1451.4

A tabular listing of similar features for the two of the IEEE standards, IEEE 1451.2 and IEEE P1451.4 has been prepared and is shown in Table I below. These standards are substantially different in many regards since they focus on solving different parts of the transducer interface problem. The IEEE 1451.2 standard assumes that the user is presented with a digital representation of transducer data and focuses on defining and describing the functional blocks between the "digital transducer data" and the "network processor". Although not yet in final form, the IEEE P1451.4 standard focuses on adding digital intelligence to the connection between mixed-mode (analog and digital) transducers and generic data acquisition modules. In addition to describing several ways to implement mixed mode connections, the IEEE P1451.4 defines a condensed (Basic) Transducer Electronic Data Sheet (TEDS) feature. The IEEE 1451.2 standard defines and describes the interactive control and hardware connection between transducers and a general, network-capable, application processor. The IEEE P1451.4 does not define the up-stream communications between the Data Acquisition Module and a Network Capable Application Processor but describes and defines the use of (existing) two, three, and multi-wire connections between mixed mode transducers and up-stream data acquisition/ data processing components. While IEEE 1451.2 defines an extensive set of stand-alone TEDS to accommodate a wide range of common transducer concerns, IEEE 1451.4 defines a compact, cost-sensitive implementation of smart transducer TEDS with minimal use of memory. IEEE P1451.4 describes techniques to expand these condensed TEDS in up-stream, computing-resource-rich, environments. The IEEE 1451.4 standard outlines protocols for extending and customizing TEDS beyond the Basic TEDS. The following chart is not a "pro" and "con" type of feature comparison but a listing of attributes in approximately similar categories.

Conclusion

In conjunction with the U.S. National Institute of Standards and Technology (NIST) and the Institute of Electrical and Electronic Engineers (IEEE), several organizations and individuals are dedicating long hours of low recognition, hard work to create the future. Their goals are to create the standards that will assist in making a reality the visions of a highly connected world. A world that utilizes connected sensors and actuators to improve everything from healthcare to security.

Brief Biography for James Wiczer

James Wiczer is the President of Sensor Synergy, Inc in Buffalo Grove, IL. Sensor Synergy develops custom and semi-custom software and hardware interfaces for sensors and actuators used in industrial automation and control applications. Prior to Sensor Synergy, Wiczer was the manager of the Microsensors R&D Dept. and before that he was manager of the Robotics and Automation Dept. - both at Sandia National Laboratories in Albuquerque, New Mexico. James received his PhD in Electrical Engineering from the University of Illinois in 1977 and has worked at Sandia National Labs between 1977 - 1994. Wiczer's activities at Sandia have included: sensor program development; research and development of sensors for automation and process control applications using ultrasonic, optical and capacitance phenomena; and the design and development of specialized optical detectors for adverse environments. Wiczer has published over 40 articles on his research and development work and has been awarded five patents on microimpedance imaging sensors and fluid quality sensors. Additional patents on networking sensors are pending. He is a member of the IEEE, Tau Beta Pi, and HKN.

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.

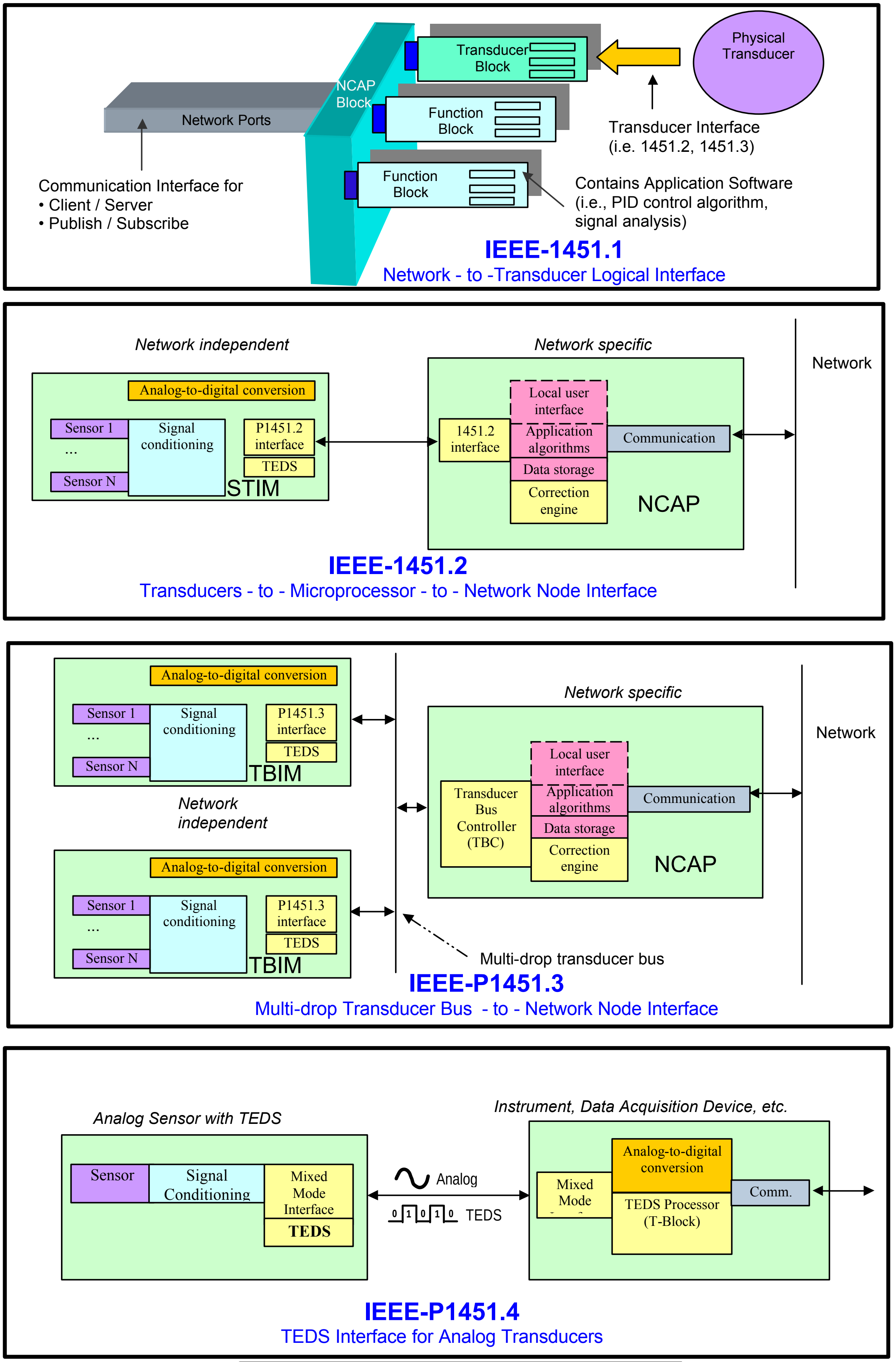
[3] For additional information about these standards, visit the IEEE 1451 web site at http://ieee1451.nist.gov.

Standard	IEEE 1451.2	IEEE 1451.4
Title **SMART TRANSDUCER INTERFACE FOR SENSORS AND ACTUATORS …**	**Transducer to Microprocessor Communication Protocols and TEDS Formats**	**Mixed-mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats**
Scope	Enable Plug and Play at the Transducer Level, Enable and Simplify the Creation of Networked Smart Transducers, Facilitate the Support of Multiple Networks	A mixed-mode interface for analog transducers with analog and digital operating modes and a Descriptive Language Encoded Electronic Data Sheet
What is Included	Hardware Interface between Smart Transducer Interface Module and Network Capable Application Processor (Network Interface Unit), Stand-Alone Text-based, Transducer Electronic Data Sheet (TEDS) with Data Formats, Various Read and Write Logic Functions to Access the Digital Transducer Data and TEDS	Mixed-Mode Interface (MMI) Transducer Interface and a T-Block Decoded. Transducer Electronic Data Sheet (TEDS). A Description Language which is a scripted and tagged language to describe the Transducer.
What is Not Included in the standard	No Signal (Analog to Digital) Conversion Covered, No Signal Conditioning - Transducer Data is Assumed to be Digital and Beyond the Scope of this Standard. No Network Specific Requirements	NCAP Hardware Interface is not Specified but uses the Dallas One Wire protocol. Read & Write Logic Functions to Access TEDS from Network Level not Specified. The digital interface is not part of TEDS templates.
Main Technical Strengths	Complete End-To-End Specifications From Digital Transducer Data To Network Processor	Low-Cost limited, Smart Transducer Support for Legacy Transducer Installations allows for Mixed Analog and Digital Transducer Signals.
Key Hardware Strengths	Includes Complete Electrical Interface for Network Capable Application Processor. Revision Includes Flexible, Low-Cost Implementation of TEDS to NCAP Network Interface	Inexpensive Implementation of Limited Basic TEDS Capabilities, Support for Two-Wire and Multi-Wire Analog and Digital Transducer Interface
Key Hardware Issues	10 Wire Interface in Original 1451.2 Standard is Non-Standard Electrical Interface although this can be implemented with relatively low effort.	Limited TEDS Memory Forces the Need for Multiple T-Blocks to Expand TEDS into Meaningful Data Sheet
Key Software Strengths	Extensive Support for TEDS including Global TEDS, Channel TEDS, Calibration TEDS, ID TEDS, End-	Description Language Is A Scripted And Tagged Language for flexible, customized expansion.

	User Specific TEDS, and Extension TEDS for Additional Capabilities	
Key Software Issues	Extensive Capabilities Also Create Significant Learning Curve for Developers. Additional tools and explanatory texts will make it easier to use this standard	May Need to Maintain Many T-Block Software Objects to Decode TEDS from Different 1451.4 Transducers
User Appeal Features	Existing Approved Standard Provides a Complete, Clearly Defined, Non-Proprietary Solution for Putting Transducer Data on Multiple Types of Networks with Special Features to Accommodate Needs of Sensors and Actuators	Add Low-Cost Smarts To Transducers. Make A Bridge Between The Legacy Transducers And The Networked Transducers
Developer Appeal Features	Complete and Available, End-to-End Solutions, Ready to Use to Put Transducer Data on Networks	Inexpensive Solution to Adding TEDS Intelligence to Transducers. Accommodates Legacy Transducer Wiring and Supports Analog and Digital Signals
Possible Target Applications/ Markets	High-End Industrial Monitoring and Control Applications. Other Monitoring Applications which Value Plug and Play and Stand-Alone Extensive TEDS	Lower Cost, Higher Volume Monitoring and Control Applications Networked through PCs or Other Shared NCAP. Applications that may Require Some Intelligence in Sensor but Limited Network Requirements
Sensor vendor appeal	Although more complex to implement, provides standardized tool to correct for various "real world" sensor limitations such as intrinsic non-linearities and unit-to-unit calibration variations .	Attractive to sensor vendors despite limited information in Basic TEDS. Smart sensor is created by adding Dallas/Maxim One Wire interface and a small memory chip.
Data acquisition vendors appeal	Provides potentially low total-solution cost, end-to-end solution to get sensor data on network although requires close teaming with sensor manufacturers.	Attractive to data acquisition vendors since this standard can leverage technology from existing PC-based products. Allows vendors to maintain ownership of the signal conditioning products and added software to parse the TEDS and perform correction engine functionality.
Smart sensor vendor appeal	Attractive to vendors that want to provide smart sensors with a digital interface. Digital interfaces and very flexible TEDS allowed innovation on smart sensor features. It is also	This is a step towards smarter sensors by providing self-identification.

	possible to embed the correction engine into the STIM and output corrected transducer readings in engineering units and in floating point format. Changing to a common physical interface should make this approach more popular.	

Figure 1. IEEE 1451 Family of Transducer Interface Standards



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