THE USE OF IEEE P1451.3 SMART SENSORS IN A DATA ACQUISITION NETWORK

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ABSTRACT

This paper describes the use of an IEEE p1451.3 Smart Sensor bus as part of a network centric data acquisition system. IEEE p1451.3 provides for synchronized data acquisition from a number of transducers on a bus. The standard provides for Transducer Electronic Data Sheets (TEDS) that the manufacturer can use to describe the function and capabilities of the sensor module. The standard also provides for TEDS where the user can store information relevant to a particular application. The information in these TEDS can be used to generate much of the information that is required to be able to process the data during or after a test. The use of this information to configure and operate a Network Based Data Acquisition is described.

KEY WORDS

Networks, Data Acquisition, Transducer Electronic Data Sheet, Meta-data

INTRODUCTION

This paper is not intended to be a dissertation on how you should use IEEE p1451.3 sensors in a system but it is a description of some of the possibilities. Some of these ideas may not work in your system at all and others may be considered undesirable for one reason or another, but they are the features that are available in the standard. You will need to choose the set of features that you want to use and build your system around them. That also means that the parts that you buy need to support the feature set that you want. Many of the features of the standard are optional and a given manufacturer may or may not choose to implement them. This is typical of the introduction of a new standard and it leaves it to the marketplace to decide just what is the optimum feature set. That may take a few years.

This paper is going to make some assumptions about how you operate and build on those assumptions to describe the available features of a system using IEEE p1451.3 sensors. The first assumption is that you are using an IRIG 106 chapter 4 compatible PCM system. It further assumes that this system has many programmable features and that you have a computer based system that you use to configure and manage this system. When the data arrives at the ground processing system either by a removable media, probably magnetic tape, or telemetry the ground data processing system uses information from the configuration and management system to decide how to decommutate and process the data. This information about the data is called Meta-data and it is critical to the data processing system to have up to date Meta-data about the data stream that it is currently processing. Another aspect of this type of system is that the Meta-data is usually defined before a test and cannot be changed during the course of a test.

THE SYSTEM CONCEPT

Figure 1 is a block diagram of a system containing a number or IEEE p1451.3 transducer modules known as Transducer Bus Interface Modules or TBIMs. The sensor may be included in the TBIM or it may be external. The Transducer Bus, that is simply labeled Bus in the figure, connects these TBIMs together and to a bus controller. The bus has a linear rather than a star topology. Included in the unit containing the bus controller is the network interface. This device is referred to in the standard as a Network Capable Application Processor or NCAP. In a normal system there will be many NCAPs each with its own bus on a network. The data recorder, telemetry system and any other devices are connected to the network to allow access to all of the sensors in the system.

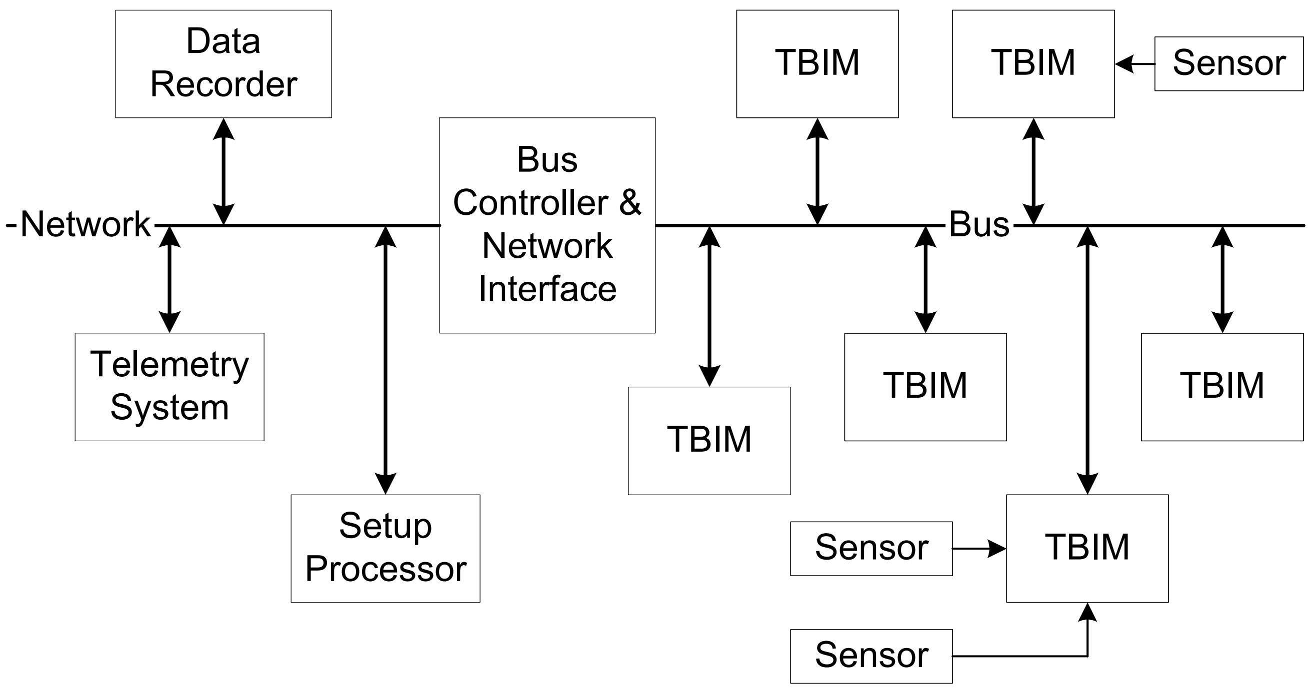

Figure 1 The System Concept

There are three separate signals available on the bus. The most obvious one is the data packets. The second signal is a synchronization clock running at two MHz. The final one is dc power. All of these signals share a common twisted shielded pair of wires. There are two ways in which the bus can be operated, command/response or streaming. For command/response operation the bus controller issues a trigger to one or more TBIMs on the bus that causes them to acquire one or more samples of data. After enough time has elapsed for the data to be acquired the bus controller issues a read data command to each TBIM that was triggered and reads back the data. This works well and is simple to understand but is not very bandwidth efficient. In the streaming mode of operation, time is divided into epochs. As shown in Figure 2, each epoch contains an isochronous interval and an asynchronous interval. The isochronous interval is further subdivided into 200 μsecond time slots. When the bus controller sets up each sensor, it assigns it a number of contiguous time slots in which to transmit its data. Then the bus controller issues a single trigger to the TBIM causing it to acquire a set of data samples and transmit them to the bus controller during its time slot. After that initial trigger the TBIM will acquire and transmit a set of data samples in each epoch without intervention of the bus controller. This streaming mode of operation requires the use of the two MHz synchronization clock to keep all TBIMs running synchronously. The asynchronous interval may be used to acquire data in the command response mode or to manage the bus.

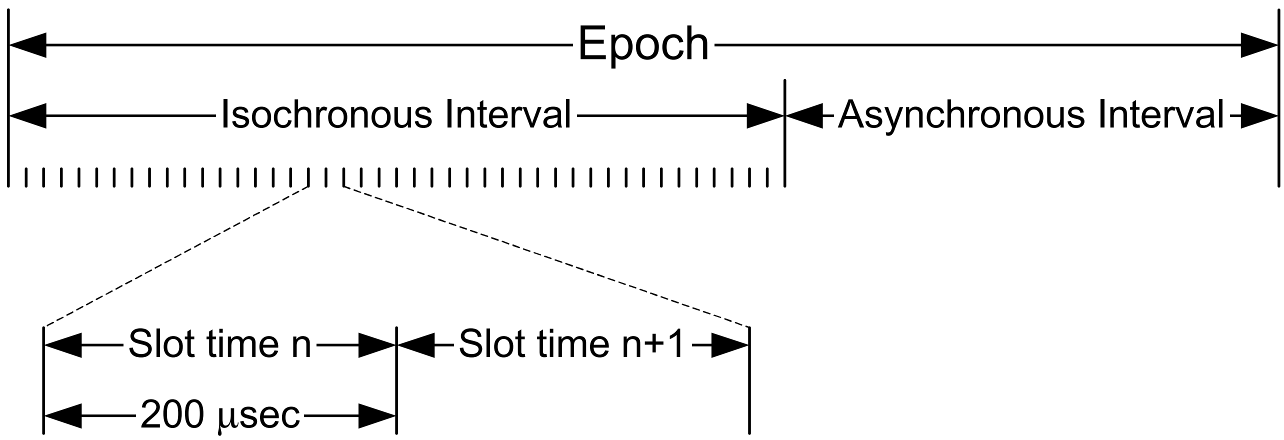

Figure 2 Bus Timing During Streaming Operation

An IEEE p1451.3 sensor is intended to be used in a packet based data acquisition system rather than a conventional PCM system. One of the big impacts that this has is that the transmission overhead on the transducer bus consumes all of your bandwidth if you try to transmit a lot of one-word packets. This makes it desirable to collect several samples of data from each sensor and to transmit them in a single packet to preserve bandwidth. Yes, this does mean that there is some latency in the data. We have not found any way to avoid it in a packet-based system. However, the latency can be managed and kept within bounds. The epoch defined above determines the maximum latency when operating in the streaming mode. The standard allows the epoch to be up to 250 milliseconds long. In the command/response mode of operation, the number of individual data samples acquired on each trigger and the sample rate determines the latency. The bus controller can increase the latency if it waits too long to read the data.

In either mode of operation it is possible to accurately time stamp the data samples in the bus controller. This does not eliminate the latency but it allows the data processing system to accurately time align the data for processing purposes. The time stamp must be applied in the bus controller in order to minimize the problems associated with the variable latency associated with transmitting the data over a commercial computer type network.

DATA FORMAT

IEEE 1451 assumes that all data is in eight bit bytes or octets when transmitted over the bus. With that as a limitation, a single data sample can require from one bit to 2,040 bits. There are seven different data models that can be used as listed in Table 1. There are N-octet Integers that may require up to eight octets and Long Integers that may contain up to 255. Long Integers will not be supported in most systems. N-Octet Fractions and Long Fractions are similar to the integer formats. With the integer formats the least significant bit of the data is in the least significant bit of the word and any unused bits, which occupy the most significant bit positions, are set to zero. In the fractional representations the radix point is assumed to be between the two most significant bits of the word and any unused bits, which must be set to zero, are in the least significant bits of the word. The data can also be in a bit sequence for things like a bank of switches, single or double precision IEEE 754 floating point or in a Time-of-Day format. For a given transducer, the data model, the number of octets required and the number of significant bits in the word are given in the Transducer Electronic Data Sheet or TEDS. Depending on several factors there may be more than one sample acquired by a single trigger or during a single epoch. The collections of samples are called data sets. A data set may contain from one to 65,535 samples of the data.

Table 1 Data Models

Data Model	Constraint on data model length
N-octet integer (unsigned)	0≤N≤8
Long integer (unsigned)	9≤N≤255
N-octet fraction (unsigned)	0≤N≤8
Long fraction (unsigned)	9≤N≤255
Single precision real	N=4
Double precision real	N=8
Bit sequence	1
Time of day	N=8

Another feature of the TBIM is that the manufacturer may choose to combine the output of several sensors into a single packet for transmission. This is accomplished by defining what is called a TransducerChannel proxy. A proxy has an address and can be read but it does not respond to many setup commands and does not have TEDS. There are two ways that the data from the sensors making up a proxy can be arranged as shown in Figure 3. If all data sets are the same length they can be interleaved otherwise they are arranged in blocks with the block of data from each sensor being appended together to form a larger block.

SETTING UP THE MEASUREMENT

The META-Data required to set up the TBIM can come from a variety of sources and will depend upon just what features a manufacturer decides to build into the TBIM. For example, a TBIM could be built that contained a 10 g accelerometer. In this example, the TBIM becomes a self-contained unit. The sensor, signal conditioning and the A/D conversion are all built into the TBIM and are set up by the manufacturer. The user can simply plug it in and use it. This is considerably different from the usual process of setting up the signal conditioning to get the best resolution from the A/D converter and matching that to the sensor. If you wanted to use this 10 g accelerometer in an 8 g application you would have the choice of deciding to accept the 20 % decrease in resolution or changing the set up of the TBIM. Assuming that the manufacturer has implemented the commands that are required to do the set up, you would send the unit into the Calibration lab and they would return an 8 g accelerometer. The sensor, signal conditioner and A/D converter would all be covered by the same calibration. Most of the META-Data required for setup can be built into the TBIM and never seen by the user. However, there are two pieces of setup data that the user must supply. The first is the sample rate for the sensor. The sample rate can be fixed at the time of manufacture but that would be unusual in a vehicular instrumentation environment. There are provisions in the standard for a small non-volatile memory called the End User Application Specific TEDS that allows the user to store this type of information in the TBIM either in the lab or on the vehicle. The other piece of information that only the user can supply is the measurement title. The measurement title is not required to operate the transducer but it is convenient when using the installed TBIM. The Commissioning TEDS is a small non-volatile memory that is provided for this function. This same discussion could also apply if the transducer and the TBIM can both be sent into the Calibration Lab and calibrated as a pair.

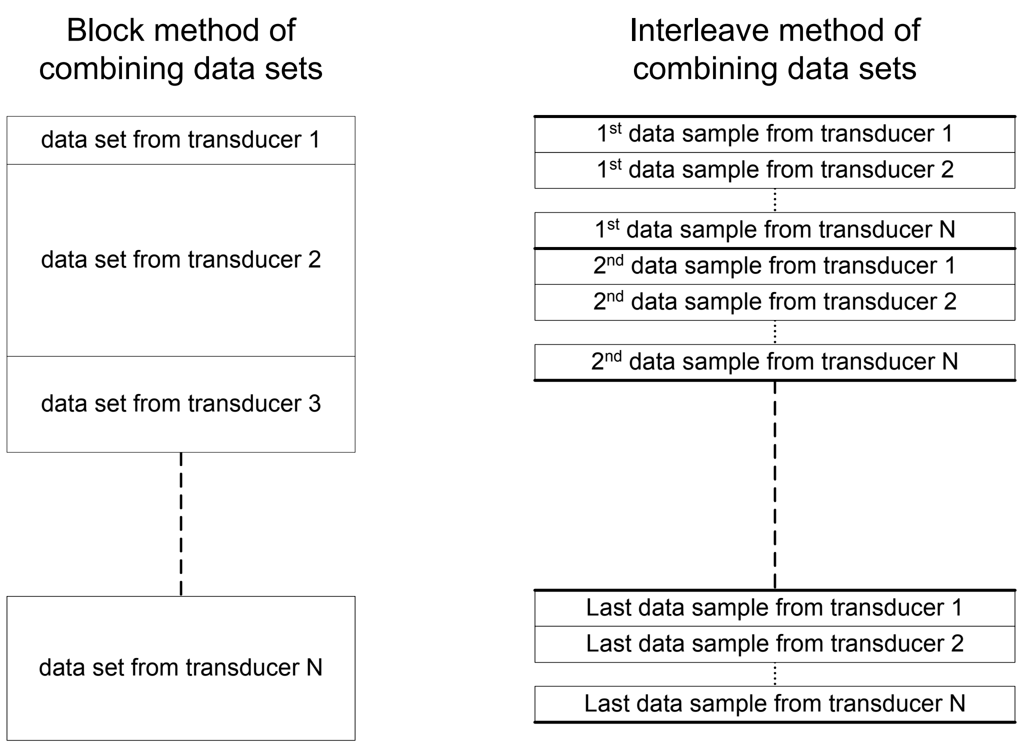

Figure 3 Combining Multiple Sensor outputs

There is also the other class of measurements where the Sensor and TBIM cannot be calibrated as a set. Structural strain gages and thermocouples are common examples of this type of measurements. For these types of measurements we need to consider a TBIM that is separate from the sensor and is calibrated separately from the sensor. Another way of looking at this is that the TBIM becomes a signal conditioner similar to the ones in use in present day systems. There are two different scenarios that we will consider in this paper. The first scenario is the traditional approach. We take the general-purpose signal conditioning that we have used in the past, integrate an A/D converter, if one is not already present, and add the bus interface. It works just like the device that we have used in the past and is just as expensive as it ever was. The approach at the other end of the cost spectrum is to use hardware that is not as costly but requires that it be set up for the measurement and calibrated for that specific application. An untrimmed analog ASIC will normally provide tolerances of around 20%. However, with a little bit of overkill in the A/D converter, i.e. higher resolution than absolutely required, this can be digitally compensated. The same mechanism that can digitally correct for component tolerances can also compensate for drifts caused by temperature. That mechanism is the Calibration TEDS and the correction method that it supports. In either case the setup for the TBIM is expected to be stored in non-volatile memory in the TBIM. Thus it can be done ahead of time in the laboratory and will retain the setup when installed on the vehicle. It can be changed on the vehicle if required.

SETTING UP THE ACQUISITION

In the IRIG 106 PCM systems in use today a great deal of effort is put into defining the major/minor frame format that is to be used to transmit and record the data. The use of IEEE p1451.3 sensors in a network based data acquisition system eliminates the need for the PCM structure. The frames used in the PCM system are replaced with packets and the structure of a packet may be completely different from the structure of the PCM frame. In the PCM frame individual samples of a measurement are assigned to positions in the frame. In the IEEE p1451.3 the data is transmitted from the TBIM to the bus controller in “data sets.” A data set is a number of samples of a given measurement collected into a structure and transmitted at one time. If TransducerChannel proxies are used a data set may include multiple samples from multiple sensors. These packets, as the bus controller receives them, may be small or large depending on the sample rate of the sensor and the allowable latency. To transmit the small packets over the network it is desirable that they be combined into larger packets to improve the overall bandwidth efficiency of the network. The Network Interface shown in Figure 1 can be used to accomplish this combination of the data packets. However, who determines how this is accomplished as well as when and where are open to debate. To most of us who have been doing this with ground based support systems for years the answer is obvious. It works so why change it? Well consider what else is happening in the industry. IRIG 106 Chapter 10 is a standard for Solid State data recorders. One of the features of this standard is that the META-Data that is needed to be able to interpret the recorded data is stored on the same media as the data. If that step can be taken why not generate the META-Data on the system as well? Much of the information required to define the structure of the packets that are to be placed on the network is available in the TEDS in each TBIM. The network interface could read the information from the TEDS, determine the structure to be transmitted across the network and send that information to the recorder and telemetry transmitter. It can be done on the ground just as well but doing it on the airplane using information from the TEDS means that there is less chance of a mix up about some characteristic of the data and that it can be changed during the test if needed. Today we normally do not make this kind of changes without stopping testing, getting access to the vehicle and making the changes. One reason for this is that we do not have access to the vehicle during a test so it is not physically possible but there is talk of changing that and allowing telemetry up links for other reasons so that reason could go away. The other, and more important reason is that the data processing is set up by the information that was developed on the ground and used to set up the vehicle and any unplanned changes could cause us to lose the ability to process the data. However, with the META-Data available on the recording media and generated on the vehicle, any change in the setup can also result in a change to the META-Data. It can become possible to go out to the test item or vehicle, load a list of parameters to be recorded into the system and have the system set itself up.

THE TIME PROBLEM

Another problem that must be faced by any network based data acquisition system is the problem of knowing when the sample is taken. In most vehicular instrumentation systems it is important that each parameter is sampled at a precise and repeatable interval. When trying to make comparisons between multiple parameters it is important to be able to determine the time or phase relationship between the parameters. The IEEE p1451.3 bus was designed to allow the time that a data sample was taken to be determined by the bus controller. Thus for data being acquired on one bus it is quite possible to determine the timing relationships. However, IEEE p1451.3 does not cover the data acquisition network so the same thing cannot be said about data acquired on different buses. The solution to this that is usually proposed is to provide a common time reference to the bus controllers and to time tag the data in the bus controller. If this is accomplished the lack of repeatable timing on the network is not a major issue.

There are two ways to accomplish this that have been proposed. One is referred to as "In-Band" meaning that the time is transmitted over the network and no additional wires are required to transmit time to the network interfaces. There has been a standard written around an in-band approach to this problem. That standard is IEEE Std 1588. If the network is simple, without switches and routers this approach works well and is simple. However when switches and routers are added to the network, the switches and routers must contain additional features for this approach to work and commercially available switches and routers do not have these features yet. Perhaps in the future the ruggedized switches and routers will have the added features. The other approach is referred to as "out of band" because it requires additional wires to be added to the system. With this approach a separate time signal such as IRIG G is transmitted to each network interface and that signal is used to generate a clock and time-of-day information. Either approach will work but there is no consensus within the industry as to which is the most desirable approach. Perhaps iNET should address this issue.

THE META-DATA

The META-Data that is required to be able to interpret the data can be generated on the system as was discussed above. However, the form that this information should take is not as clear. One possibility is to use the Telemetry Attributes Transfer Standard (TMATS) similar to what is defined in IRIG 106. This would require significant modification since the TMATS format is intended to describe a PCM format. The work currently being done to modify TMATS for the solid state recorder standard would be similar to what would be needed for a network based acquisition system. Another option is to consider the use of the eXtensible Markup Language (XML) to describe the data. The work would be the same as is required for TMATS but it would take a different form. Instead of a document defining the structure of the data either a Document Type Description (DTD) file or an XML Schema would be produced. The use of XML is not a panacea but it would give greater flexibility. XML files can be displayed using a browser and can be readily parsed to extract the needed information. They are extensible meaning that a new element can be included in a file and not cause problems for the system using the file. For example a new tag could be included in an XML file that was not described in the version of the Schema that someone is using. As long as the party trying to use the XML data did not require that information for processing it would not matter.

For a simple example, comments can be added this way. However, if a program needs the information to function, there needs to be an agreement on the DTD or Schema that is being used.

CONCLUSIONS

IEEE p1451.3 is a new standard for smart sensors for use in a network based data acquisition system. This standard describes the characteristics of the sensor module and provides TEDS to provide detailed information about the module. However, it does not describe how the overall acquisition system should work. There are still many questions to be answered about the system. Some of those questions relate to just how we want to use the tools that the standard provides. We can stick with tried and true methods or we can investigate possible new architectures and processes. We may be able to automate features that we now do by hand and thus achieve considerable cost reductions. This has been a somewhat non-technical description of some of the possibilities. Hopefully it has given you some ideas and will open up new approaches to old problems for you.