33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Building Smart Sensor Nodes according to IEEE 1451.3 Standard

Murilo N. J. da Costa, Olegario C. S. Neto, José O. Ferreira, Adson F. da Rocha and Talles M. G. de A. Barbosa, Member, IEEE.

Abstract—**A Body Sensor Network (BSN) application requires many software and hardware adaptations to support correctly data exchanges between different sensor node architectures. However, these customizations demand extra time, cost and components. This paper introduces a simple development process in order to customize off-the-shelf BSN sensor nodes according to Transducer Bus Interface Modules (TBIM) standard. IEEE 1451.3 offers technical solutions for interfacing multiple and physically separated transducer allowing self-identification, self-configuration, plug and play and hot swapping capabilities. These are important requirements relating to most BSN applications.**

I. INTRODUCTION

BODY Sensor Network (BSN) applications demands different adaptability levels since sensor nodes should be customized according to the applications requirements [13]. Besides, high quality of service (QoS) related to the communications services is demanded. A BSN is a distributed system composed by cooperative workers called sensor nodes.

Developing sensor nodes for BSN applications is an expensive and time consuming task. Thus, certain component customizations should be necessary in order to support changes in application requirements. In this scenario IEEE 1451 standard offers a standard framework for guidelining system developments in an open, common, network independent manner.

Since BSN applications have inner distributed characteristics IEEE 1451.3 offer technical solutions for interfacing multiple and physically separated transducers. A single transducer bus allows time synchronization and data exchanges. IEEE 1451.3 facilitates the network design and future modifications by means a platform independent framework.

An IEEE 1451 application is presented on [11]. Authors evaluate ADuC812 micro converter from Analog Devices to prototype an environmental temperature monitor. Most significant results are concerning in Transducer Electronic Data Sheets (TEDS) implementation, such as memory usage reports. Table I reports memory occupation to accommodate one Meta TEDS and two TransducerChannel TEDS.

TABLE I
TEDS IMPLEMENTATION MEMORY USAGE

Original Code: 2 Channel TEDS, 1 Meta TEDS		
ADuC812 Resource:	**Used:**	**Available:**
256 Byte RAM	178 bytes	78 bytes
640 Byte data Flash/EE	268 bytes	372 bytes
8 kByte program Flash/EE	5,534 bytes	2,657 bytes

A smart sensor network proposed on [4] illustrates IEEE 1451.0 and IEEE 1451.2 sub patterns applications in order to achieve interoperability between interfaces such as RS232, UART and USB. Communication protocol architecture was implemented according to IEEE 1451.0 in order to improve network layer abstraction. Main components where built according to IEEE 1451.2 reducing network components usage.

This paper proposes a BSN bottom-up development process based on IEEE 1451.3. As a case study an EKG sensor node was developed. Preliminary results show benefits in customizing BSN sensor nodes according to Transducer Bus Interface Module (TBIM) specification.

II. THE IEEE 1451.3 STANDARD

The main purpose of IEEE 1451.3 standard is providing a common, open interface for communicating physically separated transducers allowing time synchronization. Sensor communication interfaces customization is a time-consuming and expensive task [6]. The standard provides a minimum implementation to allow multi-drop system development.

The IEEE 1451.3 introduces both concepts Transducer Bus Interface Module (TBIM) and Transducer Bus Controller (TBC). A TBIM is a transducer interface module (TIM) adaptation for multi-drop system requirements, it contains a bus interface, signal conditioning and conversion circuitry. This module may range from a single sensor to an array of sensors. A TBC is both hardware and software in the Network Capable Application Processor (NCAP) that provides interface to transducer bus. The transducer bus provides communication between NCAP and one or more TBIM.

CommunicationChannels are mandatory for TBC module used for data transmission over TBIM and TBC by means transducer bus. The synchronization signal is optional, and

Murilo N. J. da Costa, Olegario C. S. Neto, José O. Ferreira and Talles M. G. de A. Barbosa are with the Department of Computing, Pontifical Catholic University of Goiás, Goiânia, GO 74605-110 Brazil (phone: +55-62-39461381, email: murilo.nunes.jose@gmail.com, olegarioneto@gmail.com, jolimpiof@gmail.com, talles.ucg@gmail).

Adson F. da Rocha is with Faculty UnB Gama, University of Brasília, Brasília, DF 70910-900 Brazil (phone: +55-61-33072328, e-mail: adson@ unb.br).

978-1-4244-4122-8/11/$26.00 ©2011 IEEE

should be sent from TBC to all TBIM connected on the same transducer bus.

Each TBIM may have at least one TransducerChannels which is usually composed by one transducer and all signal conditioning components associated with that transducer.

A block of data is used to store TBIM specifications description, called TEDS. TEDS must be stored on nonvolatile memory, because characteristics (configurations) of sensor nodes inner should be preserved even if an eventual shut down occurs.

IEEE 1451.3 specifies mandatory TEDS, which must be implemented to achieve compliance. They are the Meta TEDS and TransducerChannel TEDS. Meta TEDS describes all TBIM characteristics, such as operational timeout, self-test time, number and type of TransducerChannel. A TransducerChannel TEDS should have specific details in order to operate appropriately e.g. physical unit measured, data conversion information and transducer calibration.

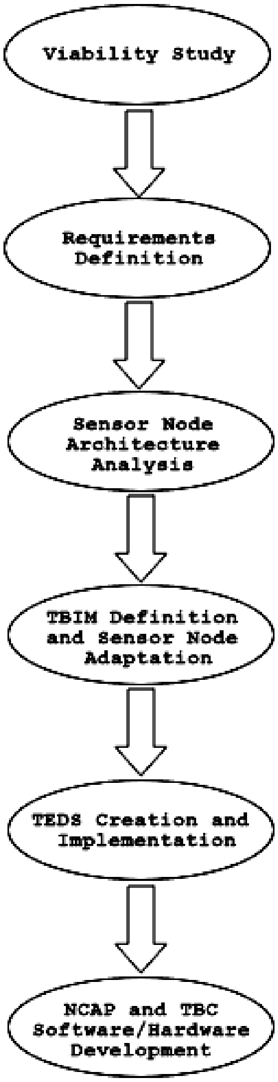


Fig. 1. BSN development process to meet IEEE 1451.3 standard specifications.

III. BUILDING SENSOR NODES FOR BODY SENSOR NETWORK APPLICATIONS

A. BSN Development Process Specification

A development pattern could be noticed in [9] - [11]. Each work displays a common set of steps used to achieve smart sensor based system development. Based on this observation and IEEE 1451.3 standard, a development process was proposed. It is shown in Fig.1.

A preliminary viability study is essential to detect additional cost and time. It provides information about availability of procedures and components for smooth application development. For example, if a method for data analysis is available, it may be necessary to spend more time and resources on developing this method.

Requirements definition is the most important part of systems development. Since it creates a solid foundation for application development it delimitates scope and avoids unnecessary work, material and time spend on development.

A sensor node architecture analysis should be done, since a BSN sensor node adaptation is required. Sensor node analysis will evaluate if necessary component and customization to be done. For example, if a sensor node lacks nonvolatile memory a TBIM can't be developed, since it lacks compliance with IEEE 1451.3 specifications.

TBIM definition and sensor node adaptation integrates application requirements and architecture analysis. Fig. 2 shows the sensor node adaptation to TBIM architecture.

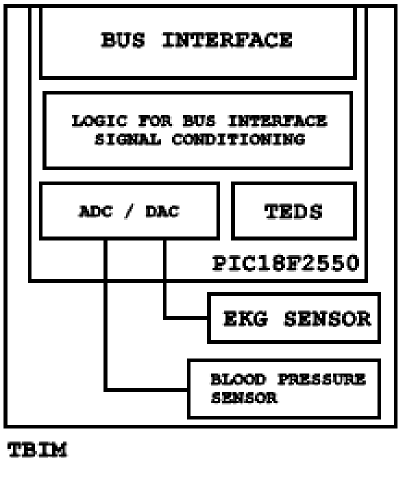


Fig. 2. Block diagram representing adapted BSN sensor node according to IEEE 1451.3 TBIM specifications.

After TBIM architecture definition TEDS may be created. TEDS describes each sensor nodes, its internal variables should be different according to TBIM's structure and components. The application requirements will determine which kinds of TEDS should be used besides the required ones.

The last phase focuses on building NCAP and TBC components, NCAP structure and main characteristics are described on [5].

B. Case Study: An EKG Sensor Node

As case study an already developed electrocardiogram (EKG) sensor node was used. Since is an already developed sensor node it can be adapted to standard and it is proven to be feasible according to [13]. In this paper we are mainly focused in customization aspects according to IEEE 1451.

Sensor networks require that connected sensor nodes may communicate with each other. To accomplish this requirement all TBIM must receive a network address. This 8-bit address is called TBIM alias, each TransducerChannel inside this TBIM receives a TransducerChannel number, which is an 8-bit address. The transducer bus uses a 16-bit address to send commands for specific TBIM or TransducerChannel within the network as shown in Table II.

TABLE II
CLASSES OF ADDRESSES

Address class	TBIM Alias	TransducerChannel number
Global	Zero	Zero
AddressGroup	Zero	Non-zero
TBIM	Non-zero	Zero
TransducerChannel	Non-zero	Non-zero
TBC address	255	Zero

Table II displays five possible address classes, each address class honors a particular set of commands as specified in [6].

Sensor node main requirements are defined according to [13, pp. 31-38]. The sensor node architecture was composed of a microcontroller with an Analog-to-Digital converter (ADC), store capacity (memory), and serial communication interface (USART – Universal Synchronous Asynchronous Receiver Transmitter). The communication interface used was RS-232 using a bootloader program for USB (Universal Serial Bus) usage; for wireless communication radio transmitter were used. Fig. 3 displays hardware implementation of an EKG sensor node.

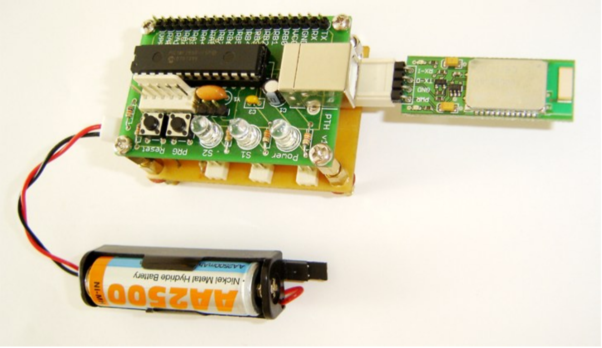


Fig. 3. EKG sensor node hardware implementation using PIC18F2550.

For TEDS implementation the 256 bytes EEPROM data memory was used. Each TEDS has specific fields that must be filled, the TLV (Type, Length, Value) format is used. TEDS fields have a field type number, which identifies the field utility. Each field has a data length that defines octet quantity a value can have. The value is the information itself. All values must be converted into binary, and then converted into hex.

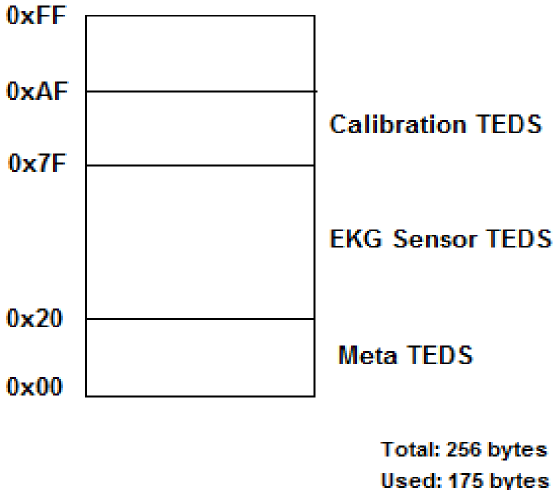
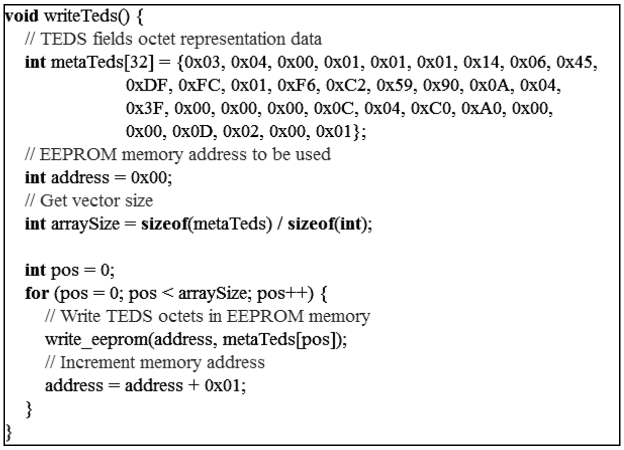


Fig. 4. Memory map describing PIC18F2550 EEPROM data memory usage.

As an example implementation, Meta TEDS operational time-out field will be used. This field type is 10 converting into binary yields 1010 which is 0x0A into hex. Its length is 4 octets which yield 0100 binary and 0x04 into hex. Supposing a 0,5 seconds operational time-out for this EKG TBIM. This field must be represented as 32 bit floating point number resulting into 00111111 00000000 00000000 0000 0000 binary, converting to hex yields 3F 00 00 00. Finally, adding the field type and length following the final TLV octet pattern of 0A 04 3F 00 00 00.



```
void writeTeds() {
  // TEDS fields octet representation data
  int metaTeds[32] = {0x03, 0x04, 0x00, 0x01, 0x01, 0x01, 0x14, 0x06, 0x45,
                      0xDF, 0xFC, 0x01, 0xF6, 0xC2, 0x59, 0x90, 0x0A, 0x04,
                      0x3F, 0x00, 0x00, 0x00, 0x0C, 0x04, 0xC0, 0xA0, 0x00,
                      0x00, 0x0D, 0x02, 0x00, 0x01};
  // EEPROM memory address to be used
  int address = 0x00;
  // Get vector size
  int arraySize = sizeof(metaTeds) / sizeof(int);

  int pos = 0;
  for (pos = 0; pos < arraySize; pos++) {
    // Write TEDS octets in EEPROM memory
    write_eeprom(address, metaTeds[pos]);
    // Increment memory address
    address = address + 0x01;
  }
}
```

Fig. 5. C implementation of Meta TEDS data storage using EEPROM memory.

Those steps should be done for each of the TEDS fields. Fig. 4 displays the memory map for TEDS implementation using PIC18F2550 256 bytes EEPROM data memory, it includes one Meta TEDS, one TransducerChannel TEDS for EKG sensor and one Calibration TEDS totaling 175 bytes memory usage. Fig. 5 shows an example implementation code of Meta TEDS resulting into 32 bytes of data. TEDS field types, lengths and data types are specified on IEEE1451.3 standard [6].

IV. CONCLUSION

This paper describes a BSN sensor node customization process. It facilitates to build smart sensors according to IEEE 1451.3. Besides, Meta TEDS technological aspects are presented in order to accommodate BSN.

IEEE 1451.3 proposes complete distributed system architecture for accommodating BSN smart sensor. Each module has its own characteristics and responsibilities. With minimal sensor node customization it is possible to achieve certain benefits. For example, customization involving TEDS implementation supported by nonvolatile memory enables sensor node self-identification, and communication channels for data transmission and synchronization signal.

Sending commands to specific components is possible by addressing each TransducerChannel associated with TBIM, and each TBIM associated with TBC. Consequently, modules communication becomes less burdensome, since transducer bus may send information directly to an addressed component.

TEDS can provide essential information concerning sensor nodes proper functioning. Therefore, sensor node self-identification is possible. A full description about sensor node characteristics can be retrieved from TEDS data block within a TBIM. Consequently, this sensor node can be incorporated on network without impacting its operation, since information needed for sensor node adaptation is available.

IEEE 1451.3 offers a promising solution for accommodating BSN systems constraints, since it proposes a multi-drop distributed system approach. This solution involves connecting many TBIM (sensor nodes) to a single bus (transducer bus) which is controlled by a TBC (bus manager) that sends data synchronization signals in order to acquire data with greater accuracy and consistency.

Future works will concern in TBC development investigation, since both software and hardware are involved. A promising possibility lie in IEEE 1451.0 sub pattern. By definition it includes a set of independent API which basic functions are required to control and manage smart sensors systems.

ACKNOWLEDGEMENT

This study was supported in part by Microchip's Academic Program (AP-0280) at Pontifical Catholic University of Goiás.

REFERENCES

[1] A. Juvva et al., "Demonstration of the plug and play of smart sensor nodes", IEEE Sensors Applications Symp. (SAS), Limerick, 2010, p.265-268.

[2] A. R. Al-Ali et al., "Wireless Smart Sensors Networks Overview", 2nd IFIP Int. Conf. on Wireless and Optical Communications Networks, 2005, p. 536-540.

[3] E. Y. Song and K. B, Lee, "Wireless Sensor Network Based on IEEE 1451.0 and IEEE 1451.5-802.11", The 8th Int. Conf. on Electronic Measurement and Instruments, 2007, p. 4-7 to 4-11.

[4] E. Y. Song and K. B. Lee, "Sensor Network based on IEEE 1451.0 and IEEE p1451.2-RS232", Instrumentation and Measurement Technology Conf. Proc., 2008, p. 1728-1733.

[5] IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats, IEEE Std1451.0TM-2007.

[6] IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multi-drop Systems, IEEE Std1451.3TM-2003.

[7] J. Schmalzel et al., "Architecture for Intelligent Systems Based on Smart Sensors", IEEE Trans. on Instrumentation and Measurement, vol. 54, no. 4, p. 1612-1616, Aug. 2005.

[8] L. Zhaochun et al., "Design of smart temperature sensor based on IEEE 1451.2 standard", Int. Forum on Information Technology and Applications, 2009, p. 312-314.

[9] M. A. Laguna et al., "Mobile health monitoring and smart sensors: a product line approach", Proc. of the Euro American Conf. on Telematics and Information Systems: New Opportunities to increase Digital Citizenship, 2009, article no. 8.

[10] N. Kularatna and B. H. Sudantha, "An Environmental Air Pollution Monitoring System Based on the IEEE 1451 Standard for Low Cost Requirements", IEEE Sensors J., vol. 8, no. 4, pp. 415-422, Apr. 2008.

[11] P. Conway et al., "IEEE 1451.2: An Interpretation and Example Implementation", Instrumentation and Measurement Technology Conf., vol. 2, pp. 535-540, Aug. 2000.

[12] S. Gumudavelli et al., "A network management approach for implementing the smart sensor plug and play", IEEE Sensors Applications Symposium (SAS), Limerick, 2010, p.261-264.

[13] T. M. G. de A. Barbosa, "Uma Arquitetura de Sensores do Corpo Humano", Doctoral Thesis, Dept. Elect. Eng., UnB, Brasilia, Brazil, 2008.