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A Physical Laboratory for Smart Transducers Education

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Abstract – In this paper, the development of a physical laboratory for practical activities in the field of smart transducers is presented. The themes of the laboratory works are close related to the curricula of the Smart Transducers course and are focused on the functionality and the structure of the most used type of smart transducers, the transmission and processing of acquired data. The paper will highlight that by carefully choosing the hardware and the software components, the cost of the implementation can be kept low without scarifying the educational purposes.

Keywords: sensors, actuators, smart transducers, educational tool.

I.. INTRODUCTION

Many universities are now offering courses and laboratory works in the field of sensors/actuators, in order to improve the knowledge of the graduates in the field. However, teaching students on sensorics in a laboratory, or training technical staff, may be a difficult task. Different approaches to this problem has been used in order to overcome some difficulties that arise.

The Virtual Laboratory is the simplest solution with some other advantages: easy of access for technical community, no constrains on the topics to be studied, users could teach themselves by selecting their particular route of their interest, etc. [1]. The main drawback of virtual laboratory is the limited level of education, no practical experience being offered to the users.

Distance Access Laboratory is another educational tool, used for acquiring practical skills in different areas of techniques [2] [3]. Now the users can access the lab experiments from anywhere at any time and follow them at their own peace. Distance Access Laboratory solution allow the users to be much closer to the physical phenomena for an affordable cost of the investment.

The conventional laboratory works, in despite of their disadvantages: limited number of participants at a time, no remote access, high level of investment, are the most effective educational tool when the practical skills are a primary goal.

In this paper, the problem of the implementation of a physical laboratory will be approached. This laboratory has only educational purposes, and is entirely devoted to practical activities with undergraduates students in the field of sensors and actuators.

There are different strategies of teaching sensorics, depending of the personal experience of teaching staff, the existing curriculum of the branch of electronic engineering and the most important targeted audience, who are, here, the students.

In some cases, the educational interests are focused on sensor technologies, sensor structure and sensing effects [1]; in other cases, the general structure and applications of sensors/actuators in different areas of industry are studied (industrial measurement, fields of automatic, robotics ,etc.). It is important to point out that in the first case, it is quite difficult or even impossible to implement laboratory works on that topics.

In the present paper, the new approach of teaching sensors/actuators is to include in the planned educational material all important aspects necessary to a graduate, to successful integrate of a transducer into applications in a networked environment. According to this strategy, the following steps are necessary in order to develop low cost/high efficiency laboratory works on sensors/actuators:

- Starting from the schematic structure of a smart transducer (ST), we will establish first the most important aspects covered by Smart Transducer course;
- Based upon the content of the course, the topics of the laboratory works will be developed then;
- In the next step, the necessary hardware and software resources will be chosen, in order to meet all requirements of the task and to keep down the cost;
- Finally, laboratory works for each type of ST have to be developed.

In this way, a good balance between the cost of the implementation and the educational efficiency of the laboratory works can be obtained.

Please observe that we have used in the above the term "Smart Transducer". This is a general term introduced by IEEE1451 Standard; *"transducer"*

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includes both sensors and actuators. A Smart Transducer is *"A transducer that provides functions beyond those necessary for generating a correct representation of a sensed or controlled quantity. This functionality typically simplifies the integration of the transducer into applications in a networked environment"*. A Smart Sensor is *"A sensor version of a smart transducer"* [4].

We highlighted the above mentioned terms because they are important entities in IEEE1451 Standard, and the proposed content of sensors/actuators course and the corresponding laboratory works will be developed around this standard.

II. PLANNED EDUCATIONAL MATERIAL

The IEEE1451 is a family of standards for connecting ST (sensors and actuators) to networks. These standards will enable network-capable but network-independent "plug-and-play" transducers for use in embedded products, distributed data acquisition and control systems, and networked controllers.

The key elements of a ST, according to the IEEE1451 Standard, are depicted in Fig.1 [4] [5].

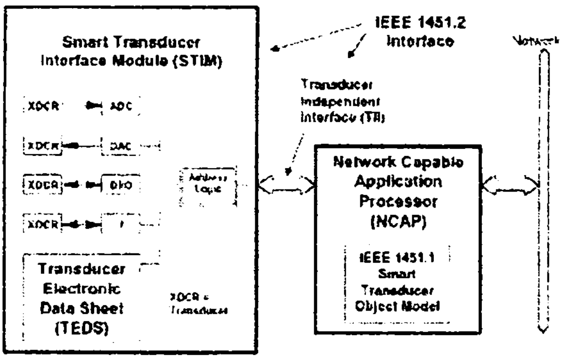

Fig.1. Schematic diagram of an IEEE1451 ST

A ST includes a Smart Transducer Interface Module (STIM) and a Network Capable Application Processor (NCAP). The field break between STIM and NCAP is a standardized Transducer-Independent Interface (TII).

Note that the transducers themselves are considered part of the STIM. Actually, in order to provide the critical self-identification features (stored in a Transducer Electronic Data Sheet - TEDS), the transducers must be inseparable from the STIM block during normal use. A STIM includes also, signal conditioning and conversion circuitry, a TEDS, and necessary logic circuits to implement the digital interface and protocols to communicate with a NCAP.

Other several critical elements are also defined [6]: the various formats for TEDS, the transducer functional type (sensor, actuator, buffered sensor, event sensor, etc.), and a general-purpose calibration and correction engine.

Communication between the STIM and NCAP is via a TII. The TII is build around synchronous serial communications, based on the SPI (Serial Peripheral Interface) protocol. The NCAP usually initiates a measurements or action by means of triggering the STIM, and the STIM responds with an acknowledgement once the requested function is completed.

After this short review of the most important elements of the IEEE1451 Standard, we are capable now to develop a curricula for a Smart Transducer course. The planned material could be highlighted from the following six important aspects that are the six main chapters of this course.

- Smart Transducer Structure and Caracteristics: Smart Transducer Interface Module (STIM), Network Capable Application processor (NCAP), Transducer Independent Interface (TII), Electronic Data Sheet (EDS), signal conditioning circuitry, A/D and D/A converters, digital processors;
- Distance Access of Smart Transducers: wired and wireless busses (Radio Frequency, Mobile Phone and Infrared support), Internet access;
- Sensor Technologies: semiconductor technologies, polymer films, thin and thick-films, Microelectromechanical Systems (MEMS) technology;
- Sensors (sensing effect, sensor structures, characteristics):force/moment, visual, tactile, ultrasonic, global positioning system (GPS), biosensors;
- Actuators and micro actuators;
- Application of Smart Transducers: industrial applications, robotics including mobile and personal robots, biomedical applications.

Please observe that not all of the above questions are directly related to the Smart Transducer course (for example A/D and D/A conversions, digital processors) but all these knowledge are necessary in order to successfully implement a smart transducer application.

Having in mind the proposed curricula, we are proposing the following list of subjects for Smart Transducers laboratory works:

- Implementation of a ST (implementation of STIM, including TEDS;
- Implementations of a NCAP (TII only);
- Implementation of a NCAP (the bus side): wired buses (RS-232, RS-485 and Ethernet buses) and wireless (Radio Frequency, Mobile Phone and Infrared support);
- Force/Moment ST;
- Visual ST;
- Tactile ST;
- Ultrasonic ST;
- Global Positioning System (GPS);
- Experiments with muscle wires.

For actual implementation of the laboratory works, we have to choose now appropriate ardware an software resources. The most convenient solution for STIM implementation is to use highly integrated circuits, containing on the same chip signal conditioning circuitry, A/D and D/A converters, digital I/O, and some control logic(a microcontroller core with memory resources and some peripherals). Moreover, in some cases (ultrasonic, tactile ST) a high speed A/D converter is needed, while in other cases (force/moment transducer) high resolution converters are necessary. The most recommended circuits, which meet these requirements, are the family of microconvert^rs d^v^l^p^d ^nd manufactured by Analog Devices [6]. These circuits have been design according to the philosophy "system on chip" and ready to be used for STIM implementation [7].

The software applications are an important task in the development process of the laboratory works. In order to successfully complete this step, appropriate software development tools have to be used.

In universities, MATLAB and LabVIEW are the most preferred software tools for simulations, data acquisition and control, data analysis and data presentation. LabVIEW, a graphical programming language, is a easy to use and a very efficiently tool, especially when a Graphical User Interface (GUI) have to be developed; on the other hand, MATLAB is recommended for process simulation and data presentation.

In our application, where each laboratory work has its own GUI, we will prefer to use LabVIEW for software development.

The whole system includes, as hardware resources, a number of modules, each of them having a well defined functionalit . U to date, the following modules have been developed, build around microconverters from Analog Devices:

- STIM mod··l⁻ fo⁻ ᶠast p⁻ocesses (12 bit resolution and a sampling rate of 400 KSPS);
- STIM module for industrial processes (24 bit sigma-delta converter and 1.37 KSPS);
- NCAP module with RS-232 interface;
- NCAP module with RS-485 interface;
- NCAP module with Mobile Phone interface.

Other NCAP modules (having ETHERNET, Radio Frequency and Infrared support) are under development.

The STIM and NCAP modules are designed to be capable to interconnect each other and with sensors/actuators. As an example, the top view of STIM module for fast processes is presented in Fig.2. In some cases (ultrasonic smart transducer, experiments with muscle wires) additional circuits, for signal conditioning, are placed nearby sensors/actuators.

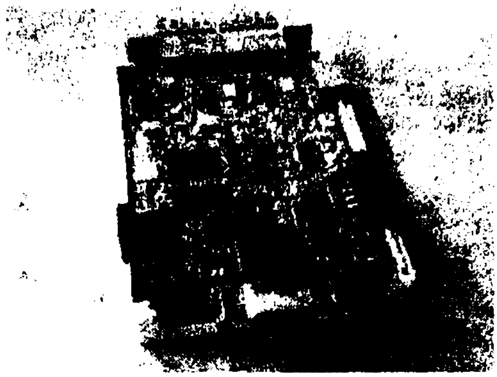

Fig.2. A top view of the STIM module for fast processes.

In this way, we can easily implement the hardware resources for all of the above mentioned laboratory works, using only a limited number of modules. This strategy keeps down the cost of the whole system without sacrificing the educational content.

III. EXAMPLE OF LABORATORY WORK

In order to evaluate the efficiency of the proposed strategy, in this chapter will be presented, as an example, a laboratory work on a Smart Transducer Implementation. Actually, the purpose of the practical activity is to study the structure, behavior and some characteristics of the hardware/software components included in a ST. A force/moment sensor will be connected to the input of the STIM for demonstration. The structure of the smart sensor is depicted in Fig. 3.

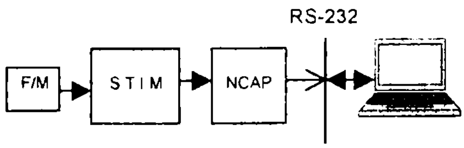

Fig. 3. The schematic diagram of the Force/Moment Smart Transducer.

It includes the well-known elements: a force/moment sensor connected to a STIM and a NCAP. A host computer controls the activity of the system and processes the acquired data. For the purpose of simplicity, NCAP is interconnected to the host computer using a simple RS-232 bus.

As we already known, STIM element is build around a microconverter chip (ADuC824) developed by Analog Devices. The schematic diagram of this circuit is presented in more detalied in [8].

This highly integrated circuit incorporates all provisions necessary for a STIM implementation: conditioning circuitry, two independent 24 bit sigma-delta A/D converters with on-chip digital filtering, a data flash memory for TEDS implementation and a 8052 compatible microcontroller system. It has been proved that STIM equipped with ADuC824 microconverter chip is simple, low cost and has excellent performances, being the most appropiate solution in this application.

In the present laboratory work NCAP play a minor roll, because STIM can be actually directly connected to the serial interface of the personal computer (UART within microconverter should be used for this purpose). However, NCAP has been included in the structure of the smart sensor in order to maintain the compatibility with IEEE1451 Standard and to allow the students t.. experiment .he TII betwe..n S.IM a... NCAP.

NCAP is implemented on a 8052 microcontroller system, having a RS-232 compatible serial interface, which allow the interconnection with the host computer.

Some digital I/O lines of Port 0 are used for TII implementation, as is represented in Fig. 4. The corresponding lines from the STIM belong to the

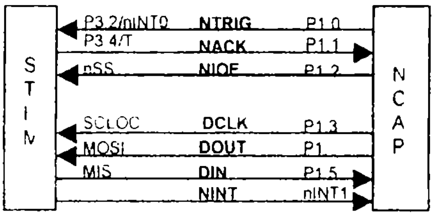

Fig. 4. The STIM and NCAP connections

Serial SPI interface. NINT is the only TII signal line that the STIM is permitted to assert at will. The other STIM outputs are not really under the full control of the STIM. NTRIG is used by the NCAP to control the timing of when the new data is taken (or is act upon in the case of an actuator). The NCAP is the SPI communications master and always controls data clock DCLK. Other than that, the NCAP controls all communications and all message exchanges are originated by NCAP. A more detailed presentation of the handshaking between STIM and NCAP, which has been used to implement here the communication protocol, is given in [7].

The software resources of the laboratory work includes the following main components:

- a small foot print real time operating system (RTOS) and some software applications, resident on the NCAP system;
- software applications for data acquisition and process control, resident on the STIM;
- software application running on the host computer, which controls the functionality of the whole system; at the same time, this application assure the man-machine interface, using an appropriate GUI.

The software applications can be easily accessed by the students in order to change/improve them. The programs loaded on STIM and NCAP are developed in assembling and C languages respectively. The Keil uVision2 IDE development tool has been used for this purpose. The RS-232 serial interface, included on both STIM and NCAP, allow in a simple manner to load the modified/improved versions of the software applications, using appropriate loaders.

The GUI is a very flexible application, which allow the user to send control strings to the NCAP and to visualize the acquired data. The analogical signals are presented on a waveform graph while the digital I/O signals are displayed on array of LEDs.

A snapshot of the developed GUI is shown in Fig. 5.

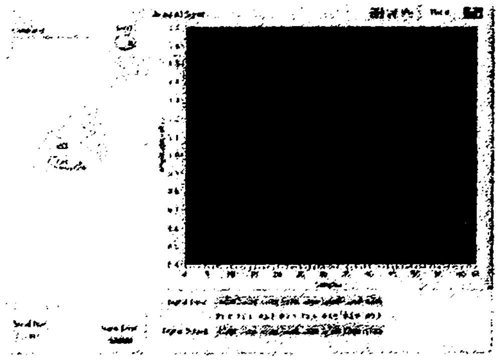

Fig. 5. A snapshot of the GUI implemented on the host computer.

V. CONCLUSIONS

In the present paper, a topics for Smart Transducers laboratory works has been proposed, centered around the latest standard in the field, IEEE1451 Standard. It has been proved that by using appropriate hardware and software resources, an important number of laboratory works, with a high educational content, can be developed, while the cost is kept down. The proposed educational laboratory will significantly improve the knowledge of graduates on the new era of "plug-and-play" transducers.

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