Sensors as an alternative way for teaching Embedded Systems and Microelectronics

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Abstract – **This paper discusses an alternative way to implement a suitable engineering education program for teaching microelectronics by means of smart sensors and embedded systems using the different possibilities available in local facilities, to fabricate sensors and signal acquisition instrumentation. The aim of this program is to provide the necessary condition to apply solid state sensors and embedded systems in areas such as, but not restricted to, assistive technology and pervasive computation. To guarantee the viability of this proposal, it is structured with low capital investment for the integration in interdisciplinary projects in fields such as bio-medical engineering, electronics engineering, instrumentation and computer science. Most smart microelectronics transducers consist of substrate electronics that implements the drive and control functions with one or more additional specialized layers of material to produce the transducer function. As described, the development of sensors system is an interdisciplinary task which requires the detailed knowledge of experts from completely different fields. In general, computer scientists, electrical and electronic engineers, physicists, biochemists, biologists, or medical engineers may be involved.**

Keywords: Sensor Networks, Embedded Devices, Wireless Communication, Smart Sensors, pervasive computation, IEEE1451.

INTRODUCTION

The study of materials and processes used in integrated circuit manufacturing, applied to transducers, has become particularly relevant lately. Additionally, the rapid growth of communication technologies and processors capabilities have brought new challenges and opportunities to the engineering science [1-2].

To prepare undergraduate students to face these challenges, increasing their ability to handle the shelf electronic devices, proposed two courses are proposed. One (PSI2662) viewing to design embedded systems and the other (PSI2222) to practice basic electronic systems [3].

The aim of the PSI 2662 is to provide students with the practical knowledge necessary to work in a modern science or engineering setting design on embedded electronic systems: Sensors and Actuators.

The course is designed to provide a practical - hands on - introduction to electronics with a focus on measurement and signals, integrating demonstrations with laboratory examples and lectures on the following subjects:

1.- Classification of integrated sensors following physical properties detecting: Optical sensors, thermal sensors, magnetic sensors, piezoelectric and chemical sensors. 2.- Optoelectronic properties of materials. 3.- Thermoelectric properties of materials. 4.- Magnetoelectric properties of materials. 5.- Piezoelectric properties of materials. 6.- Chemical sensors. 7.- Instrumentation and signal conditioning circuits. 8.- Embedded electronic systems. 9.- Smart Instrumentation: Network sensors and Plug and Play sensors. 10.- Biomimetic systems: Olfaction systems; Neuro-electronic systems; Computational vision.

The second course, PSI 2222 Practice of electrical and electronics systems is offered in the second-year of electrical engineering. It is organized to present the fresh student with a first approach to real electrical circuits by the implementation of a complete and functional project.

This paper illustrates the result archived in the PSI2662 and PSI2222, trough the development of some projects that allowed introducing concepts related with sensors, actuators and electronic instrumentation normally present in embedded systems for a broad range of distributed applications. The idea was to motivate students to look for solutions for different suggested problems, and to establish the conditions that ease the learning process. At the end of the courses, students are expected to have the ability to recognize and understand transducers characteristics, capabilities, and the technologies used to collect, process and transmit information and commands.

As a result of the set of conditions introduced in the two courses described before, the next four main projects were developed:

electronic nose, sensors network architecture, electric energy quality real-time analyzer with web interface and a bioelectric signal sampler interface like an electromyography to be applied as integration tools for handicapped students in the mainstream school system (BRINCARE)

E-NOSE

The electronic nose was designed by means of a gas sensor array which is used to quantify breath alcohol grade as shown in Figure 1. The core of this application was an inflammable gas tin dioxide film sensor, associated to an analog-to-digital converter and a simple digital signal processing routine, developed in an 8-bit microcontroller. The students, at the end of developing phases, achieved a functional prototype able to identify the alcohol vapor concentration, mixed with the user's breath and distinguished with accuracy of up to three levels of alcoholization. This project was a successful teaching experience, using a typical application to concentrate the students' attention, to introduce subjects related with mixed signal circuit principles and digital signal processing.

FIGURE 1.
DSP UNIT AND TEST CHAMBER WITH $\mathbf{S_NO_2}$ SENSORS.

As an advanced version of the breath alcohol checker, this system aimed to be portable, easy-to-use, reliable, avoiding the long and expensive chemical and analytical laboratorial tests normally used to verify the quality of a sample.

The basis of this project was, again, the tin dioxide sensor, included in array of sensors slightly doped and tuned to be sensitive to the different compounds presented in the combustible sample.

A pre-trained artificial neural network embedded in an 8-bit microcontroller received as digital inputs of the acquired information the pre-calibrated semiconductor temperature sensor and the capacitive moisture sensor from six combustible gas tin dioxide sensors array.

This project used the same concepts as a breath alcohol checker by using gas sensors, but adding a temperature and a capacitive moisture sensor as shown in Figure 2.

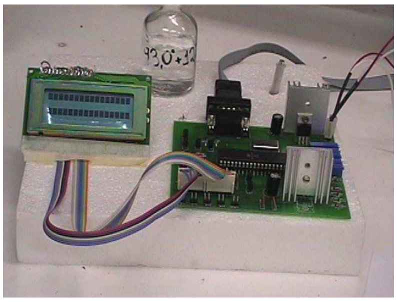

FIGURE 2.
SENSOR SYSTEM.

SENSOR NETWORK ARCHITECTURE

A major problem with sensor networking applications is network configuration management. This is especially troublesome with mobile systems and wireless networks. The network host must know which sensors are connected, which sensors are within range of a wireless communications link, and when new sensors are added to the network. In most systems, a form of network configuration table is manually created and maintained in the host system.

As the network changes, it is difficult to keep the configuration table synchronized with the actual network configuration. The concept of plug-and-play sensors addresses these problems by defining [4]:

- an architecture with a standardized electrical interface to the network, allowing a wide variety of sensor types to be used inn the same network and
- a self-identification protocol, allowing the network to dynamically configure and describe itself.

The IEEE 1451 standard allows transducers to identify and to describe themselves to the network, facilitating automatic system configuration. In that way, transducers communicate information such as manufacturer name, identification number, type of device, serial number, as well as calibration data, and other sensors attributes. Once this information is read, the network knows how fast it can communicate with the transducer, how many channels it has, and how is its data format. The network also knows what physical units are being measured, and how to convert the raw readings into corrected SI units.

On the other hand, the technological advantages of the wireless communication had led a lot of advantages, reducing wire space, weigh and cost; and improving the efficiency of some systems that use them.

The plug-and-play network sensor architecture combines the ubiquity of Internet, with the advantages of wireless communications and the interface facilities given by the IEEE 1451 standard.

The combination between transducers (sensors and actuators), communication technologies and energy efficient computation, is a very attractive solution for a broad range of distributed applications. However, with the multitude of protocols specifications and transducer interfaces, a certain degree of confusion and uncertainty has arisen about which network(s) to support, and how to establish a link with the transducer [2]. In addition, the increased use of a large number of transducers has also created the need for keeping track of them and their associated manufacturer data [3]. These concerns were the motivation of the measurement and control industry, lead by the IEEE and the NIST, which propounds to migrate from proprietary hardware and software platforms, in favor of open and standardized approaches. The idea is not to choose one specific network architecture, because each one has its own purpose, but to establish conditions that facilitate the recognition of transducers characteristics and capabilities, and their communication. In that way, they have created some physical interfaces for data interconnection, a common set of commands, and a self-described data sheet format, all together in the IEEE 1451 family standards.

The IEEE 1451 is a family of Smart Transducer Interface Standards that describes a set of open, common, network-independent communication interfaces for connecting transducers (sensors or actuators) to microprocessors, instrumentation systems, and control/field networks [5]. Currently, there are three approved and three proposed (P) members of the IEEE 1451 family of standards in addition to 1451.0. Each standard provides a set of specific physical interfaces and features for transducer interfacing. They are organized in:

- IEEE P1451.0: Defines the Transducer Electronic Data Sheet (TEDS), which is a memory device attached to the transducer, which stores its identification, calibration, correction data, measurement range, manufacture-related information, etc. This device is considered to be the key feature of all standards. It also defines a set of common commands and operations, through which any sensor or actuator can be accessed in the 1451 based wired and wireless network. The functionality is independent of the physical layer of the communication between the transducer and the network node, called Network Capable Application Processor (NCAP). This makes it much easier to add other proposed 1451.X physical layers to the family as technology advances in the future.

- IEEE 1451.1: Defines the Network Capable Application Processor (NCAP) Information Model in a neutral descriptive language, biasing a network independent standard. It includes the definition of all application level access to network resources and transducer hardware. It also defines the Smart Transducer Object Model, which encompasses a set of classes, attributes, methods and behaviors that provide a concise description of a transducer and the network to which it may connect.

- IEEE 1451.2: Defines the communication between a NCAP and a TEDS for a point to point wired serial configuration. Here TEDS are integrated with a Smart Transducer Interface Module (STIM).

- IEEE 1451.3: Defines a transducer-to-NCAP interface and TEDS for multi-drop transducers using a distributed communications architecture. It allowed many transducers to be arrayed as nodes, on a multi-drop transducer network, sharing a common pair of wires.

- IEEE 1451.4: Defines a mixed interface for analog and digital transducers. It introduces a two-wire memory, and model for the TEDS.

- IEEE 1451.5: Currently under development. It defines the communication protocol for the interface between the NCAP and TEDS. For the physical interface, it considers standards such as 802.11 (WiFi), 802.15.1 (Bluetooth), 802.15.4 (ZigBee).

- IEEE 1451.6: Defines the interface between a TEDS and a NCAP using the high speed CANopen network. It also defines the mapping of the TEDS to the CANopen dictionary entries as well as communication messages, process data, configuration parameter, and diagnosis information.

The main hardware elements of this project include the Smart Transducer Interface Module (STIM), the Network Capable Application Processor (NCAP), the PHYsical interface (PHY) data connection between the STIM and the NCAP (including wireless connections), and the external network, as shown in Figure 3. The main difference between the 1451 family members is the PHY data connection; that is, different 1451 family members specify different types of data connections between the STIM and the NCAP [4]. Figure 1 illustrates a simplified model of the IEEE 1451 hardware and their communication relation.

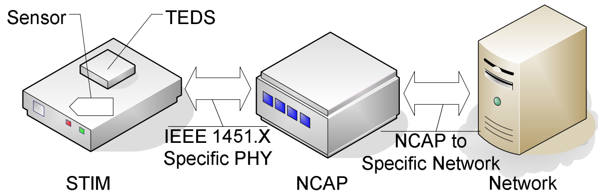

FIGURE 3.
HARDWARE ELEMENTS OF IEEE 1451 SCOPE.

The Smart Transducer Interface Module (STIM) contains the TEDS, the logic to implement the transducer interface, the transducer(s) and any signal conversion or signal conditioning. Once power is applied to the STIM, it makes the TEDS information available to the NCAP. That information can be used by the NCAP to determine how fast it can communicate with the STIM, how many channels the STIM has, and the data format of each channel. It can then send information to the STIM, or ask the sensor to perform a reading or get information about readings from the sensor.

The PHY represents the physical data connection between the STIM and the NCAP. Through this mean, data and commands are interchanged. Each member of the IEEE 1451 family uses different physical layer.

The Network Capable Application Processor (NCAP) is essentially a two-port gateway between the external network and the IEEE 1451 elements. The connection with the network is not specified, so that it can be used an deployed for any network type.

The essential software elements of this approach include the Transducer Electronic Data Sheets (TEDS), STIM embedded software that communicates with the NCAP, NCAP embedded software that communicates with the STIM and the external network.

A Transducer Electronic Data Sheet (TEDS) is a set of electronic data in a standardized format stored in a memory chip that is attached to a transducer, therefore allowing the transducer to identify and describe itself to the network, thereby easing automatic system configuration.

In its basic form, the STIM software must have the necessary methods to respond to every request made by the NCAP and initiate certain service requests. It can also include a set of communication, data conversion, and signal processing algorithms.

The NCAP software is divided in two. The first part dedicated to manage all communication with the STIMs, and the other one for communicating with an external network. The IEEE 1451.1 standard provides some of the communication functions with an external network; other aspects of this communication are beyond the scope of the standard.

The ZigBee standard developed by the ZigBee Alliance, it is the name of a suite of high level communication protocols, based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). It was created to address sensing and control applications that require low data rates and low power consumption. Compared with other wireless communication standards, it is cheaper, extends the battery life, and is less complex. Other key features are: mesh and start network topologies, cost effectiveness, and no line of sight worries [5].

There are three different types of ZigBee devices, illustrated in the Figure 4 [6]:

- Coordinator (ZC): The most capable device, the coordinator forms the root of the network tree and might bridge other networks. There is exactly one ZigBee coordinator in each network. It is able to store information about the network, including acting as the repository for security keys.
- Router (ZR): Routers can act as an intermediate router, passing data from other devices.
- End Device (ZED): Contains just enough functionality to talk to its parent node (either the coordinator or a router); it cannot relay data from other devices. It requires the least amount of memory, and therefore can be less expensive to manufacture than a ZR or ZC.

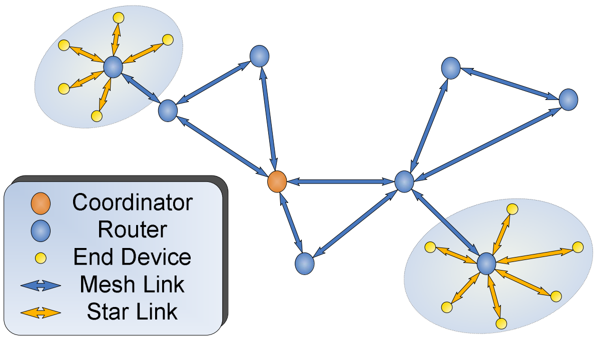

FIGURE 4.
ZIGBEE NETWORK MODEL

The architecture presented in this project uses the IEEE 1451 family standards, specifically the 1451.0, 1451.1, and 1451.5, to provide a platform for wireless sensor network development, remotely controlled through an Internet channel. Figure 5 shows a general scheme of the proposed architecture, the main components of which are: the web server, the database, the remote users, the NCAPs nodes and the wireless STIM sensors nodes.

The project evolution was divided in four principal stages. The first one dedicated to develop all Internet network subjects, including the webservice, database and client software; then the hardware of the NCAP and STIM nodes was specified, built and tested; this was followed by the definition of the application layers and nodes software programming; finally, all parts were combined and depurated, to jointly execute the remote configuration, monitoring and command of wireless node transducers.

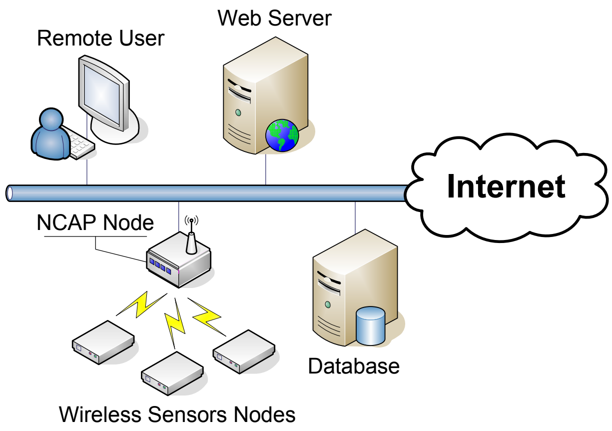

FIGURE 5.
WIRELESS SENSORS ARCHITECTURE WITH INTERNET CONNECTION.

In [7] an UML representation of the common object model and interface specification for network smart transducers are depicted; they are specified in the IEEE 1451.1 standard. Based on this model, a set of methods for communication with the NCAP nodes was structured, which supports the following tasks:

- Discovering a new NCAP node and managing its information.
- Requesting access to transducers data and properties.
- Initialing transducers management task and responding NCAP service request.
- Request TEDS information.

The web server supports interoperable machine to machine interaction over the Internet, though it is possible to access any NCAP node that is on the net, and its associated transducers.

When a NCAP node is plugged into the Internet, it sends a message to the web server informing its presence, the number of its associated STIM nodes, the transducer channels, etc. This information is gathered and packaged into the data base. A remote client program can access this information to configure its interface with the transducers. Through this, the user can manage the transducers data and configure a sensing or control function.

All data to be exchanged are formatted with XML tags. The encoded message responds to a XML-RPC scheme, through which are passed the parameters of the methods that a NCAP must execute [8].

The Network Capable Application Processor is the gateway between the network and the STIM nodes. In this case, the network was associated with a wired Ethernet link to the Internet, managed by a Rabbit 2000 microcontroller attached to the RCM2200 development board. In this board, a modified version of the XML-RPC version from [9] was implemented, with all the procedures that can be executed by a remote client, through the web server. The RCM2200 board was also programmed to exchange messages with the ZigBee development board, using a RS232 link.

The 13192DSK ZigBee development board has a Freescale MC9S08GT60 microcontroller that was programmed to accept commands from the RCM2200 board, to send and receive messages from the STIM nodes [10-13].

Once a new STIM node is discovered, the 13192DSK board assigns it a channel, and transmits the TEDS main information to the RCM2200. The last one grabs the TEDS data and stores it in its memory, and sends them to the web server when required.
Figure 4 shows an illustrative schema of the NCAP node, its ports and its internal communication.

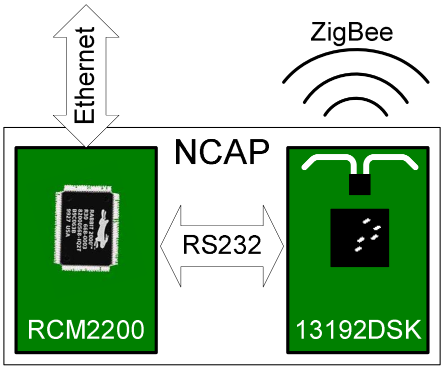

FIGURE 6.
NCAP NODE.

The Smart Transducer Interface Modules were implemented with the 13192DSK board. The MC9S08GT60 microcontroller was programmed to reserve a space of memory to store the TEDS information. Some digital (LEDs and switches) and analog (accelerometer and temperature sensor) were used to validate the architecture.
Once the STIM is powered, it sends a message to the NCAP, reporting its activation. When the NCAP receives this activation signal, it assigns a channel for the STIM and requests information from the TEDS, to configure the communication. When required by the remote client, the STIM executes a measurement and control method.

ELECTRIC ENERGY QUALITY REAL-TIME ANALYZER WITH WEB INTERFACE

This is a graduation project, award-winner and proposes real-time measuring of waveform parameter in a tri-phase high voltage bus. All the energy quality indicators are calculated in real-time and compared with the ideally predicted parameter by using a powerful DSP processor.
At this point, many solutions, from isolation of a high voltage bus, analog filter and fast conversion A/D to mathematical procedures to predict the future waveform, are applied, associated to a high velocity digital signal processing and a suitable programming of all the firmware to develop a device able to measure and classify even the fastest quality fault event and store all data locally.
As a final course project it has an embedded internet web server to supply the user all the information and make it accessible from any part in the world by using an ordinary computer connected to internet as shown in Figure 7. The different elements included in the systems are shown in Figure 8.
This kind of interface is important since it is part of a new movement of industrial equipment makers in adopting internet solutions as a standard.

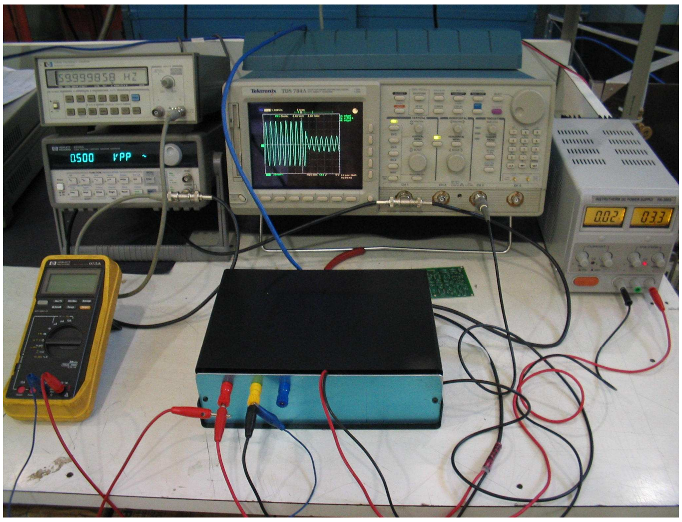

FIGURE 7.
QUALITY ENERGY ANALYZER

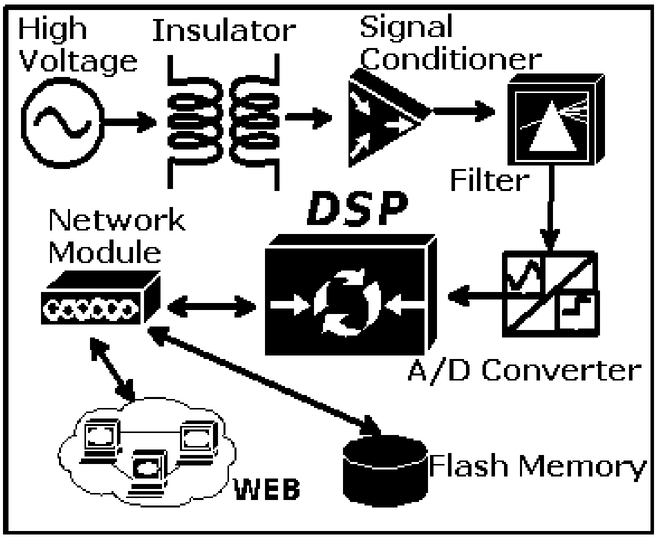

FIGURE 8.
ENERGY QUALITY ANALYZER HARDWARE BLOCK DIAGRAM.

BRINCARE PROJECT

The main idea of this project comes from a social inclusion problem that happens to people with neurophysiological disorders. A bioelectric signal sampler interface as an electromyography to be applied as integration tools of handicapped students in the mainstream school system was developed. Special children that carry neuromuscular dystrophies, and have difficulties in the relationship with other children, since the first friendship relation process is based on the integration of players in some kind of game.
After the giant revolution of computational power and the Internet, the electronic games have grown as an interesting means by which students can establish relationships using different interfaces that ease the communication of commands and let them interact, without worrying about their physical limitations.

This project works in the development of a socialization environment based on an electronic platform and an intelligent interface that captures signals and translates them into processed information. Thus, it suppresses the neuromuscular problem and lets the child act in the same way as children that have their neuromuscular system intact.
The proposal was a bioelectric signal sampler interface as an electromyography (EMG). The signals were captured on the skin surface with no kind of invasion using disposable electrodes as sensors. These signals were amplified, filtered and digitalized as shown in Figure 9.
A strong digital process of the captured signal commands are used to extract the voluntary information of the user, even if these signals are not coherent to be converted in a coordinated movement by the muscles and even if a very significant part of them are involuntary.
This project was developed for two years as subject to the discipline PSI 2222, introduction to electronics and electricity practices, and reached the complete functionality when presented by the students.

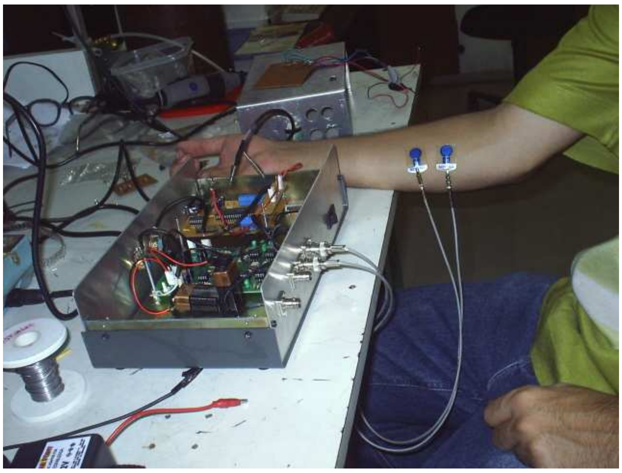

FIGURE 9.
ENERGY QUALITY ANALYZER HARDWARE BLOCK DIAGRAM.

CONCLUSIONS

The results presented in this work are related with two undergraduate courses for the development of projects on sensors, actuators and electronic instrumentation normally present in embedded systems for applications, such as breath alcohol checker, sensors network architecture, electric energy quality real-time analyzer with web interface and a bioelectric signal interface by means of an electromyography system to be applied as integration tools of handicapped students in the mainstream school system The idea was to motivate students to look for solutions of different suggested problems, and to establish the conditions that facilitate the learning process. At the end of the courses, students acquire the ability to recognize and understand transducers characteristics, capabilities, and the technologies used to collect, process and transmit information and commands.
This work presented a plug-and-play network sensor architecture, based on the IEEE 1451 standards. It implements self-described nodes that can be accessed from a remote location trough an Internet connection.
The web service software system has proved its effectiveness, interconnecting different platforms that exchange data over the Internet. This interoperability is due to the use of open standards such as XML and RPC. The plug-and-play network sensor architecture addresses a broad range of applications that demands flexibility, with a cost-effective solution.

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