Smart Sensor Architecture for Vital Signs for Monitoring of Wheelchair' Users

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Abstract:

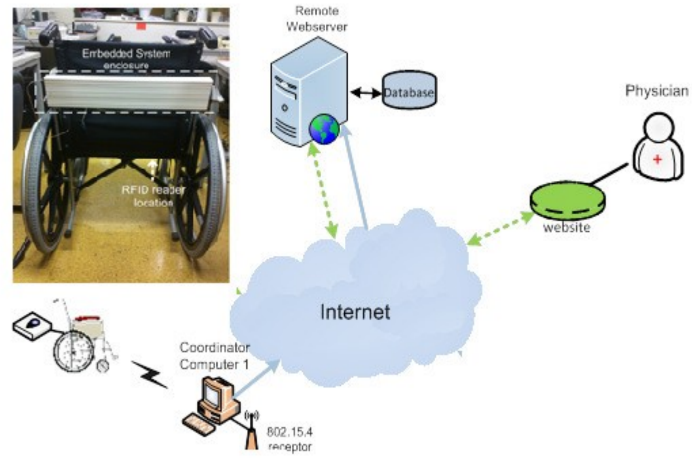
The development of a smart sensor architecture for health status monitoring and daily motor activity of wheelchair users is considered. Modularity of solution and compatibility of the architecture with IEEE1451 standard for smart sensors were part of the requirements. Thus the work presents a microcontroller-based platform compatible with IEEE 1451.4 standard for vital signs and motor activity assessment of wheelchair users. The identification of the wheelchair user is done using the LF RFID technology through a RFID reader connected to the platform. The signals from unobtrusive sensors embedded in the wheelchair characterized by plug and-play and auto-identification capabilities are acquired and primary processed at the platform level and transmitted using IEEE802.15.4 wireless communication protocol to a server application implemented in a host PC.

I. Introduction:

In the last years the necessity to reduce the hospitalization costs and to allow proactive and preventative care led to a set of developments in the field of home health monitoring. Such systems, denominated vital signs monitors, usually include blood pressure, heart rate, oxygen saturation, and temperature measurement [1]. The data from the monitors are sent to a clinical server allowing for early identification of clinical needs, adjustments to the treatment plan and medications, reducing emergency room visits and unplanned hospitalizations. The complexity of this kind of systems, especially the measurement procedure that imply the active participation of the users, conducts to undesired induced stress when no clinical staff is present or, even worst, when the patient avoids using of the vital signs monitor. In these conditions, unobtrusive embedded vital signs monitors associated with daily used objects represent interesting alternative solutions [2]. Our group has been developing a set of smart objects for vital signs and motor activity assessment of elderly people or related to rehabilitation and mobility assessment, as part of different prototypes of smart wheelchairs [3] [4] and smart walkers [5] [6]. In all developed prototypes, the hardware component of the smart objects can be characterized by the existence of different biomedical sensors, inertial sensors, force sensors and specific conditioning circuits. To assure modular and flexible solutions the vital signs and motor activity sensors can be assembled in plug-and-play modules containing the appropriate conditioning circuits, the sensor information in electronic format and a standard bus for data communication in a standard format. Several solutions regarding "plug-andplay" smart sensors are reported as prototypes or as commercial solutions [7][8][9]. This paper presents the design of a microcontroller platform allowing simplified replacement of vital signs and motor activity smart sensors based on the IEEE 1451.4 standard.

II. SMART SENSOR SYSTEM ARQUITECTURE

The main component of the smart sensor system based on IEEE 1451 standard is a microcontroller platform compatible with IEEE 1451.4, allowing acquisition of both analog and digital data from biomedical and inertial smart sensors embedded in the wheelchair (Figure 1). A connection board including connectors for a set of 8 sensors and a circuit to control the smart sensors network is included in the system. IEEE 1451.4 standard for smart sensors defines a mechanism for adding self-describing behavior to the traditional transducers characterized by analog output signals [10] [11], as is the case of the biomedical sensors used for vital signs and for motor activity monitoring of wheelchair users. Smart sensor identification is based on the use of an EEPROM memory that stores the IEEE 1451.4 Basic TEDS (Transducer Electronic Data Sheet) information [8]. This memory is attached to the transducer (e.g. photoplethysmography transducer) and the information stored in the memory is transmitted to the microcontroller through a 1-wire interface multi-drop bus. According to IEEE 1451.4 Class 2 architecture (considered in the present implementation), the analog signals are acquired by the ADC of the microcontroller after conditioning performed at the CCi level. The communication between the microcontroller platform and the host PC is performed using IEEE 802.15.4 wireless communication for a remote PC or RS232-to-USB based wired communication when the host PC is mounted on the wheelchair



The smart sensing part is accomplished by a network of smart sensors (IEEE 1451.4)[6] that are embedded in a wheelchair, thus creating the concept of a smart wheelchair. The smart sensors are connected to an embedded platform based on microcontroller (MCU) that performs the signal
acquisition associated with the measurement channels and primary signal processing (e.g. digital filtering). The MCU data can be wireless transmitted to a PC (coordinator) which runs a graphical user interface (GUI) application responsible of managing the wireless network of smart wheelchairs and store the data locally or remotely in a database. The remote database and web server application assure saved data visualization using a common browser.

A. Sensing modules

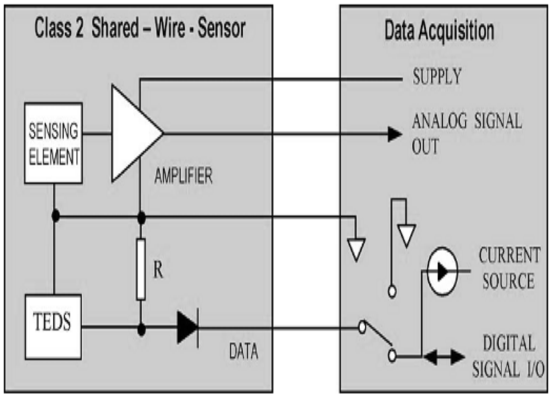
The cardiac activity and the stress status assessment of the wheelchair user are performed by three smart sensors associated with PPG, BCG and skin conductance sensing sensors. The motor activity of the wheelchair occupant is provided by a MEMS accelerometer, while the indoor/outdoor air conditions (very important for a wheelchair user with cardio respiratory chronical diseases) is retrieved with temperature and relative humidity sensors characterized by analog voltage output. A photoplethysmography (PPG) sensor is used to detect blood volume changes in the micro-vascular bed of tissue. Two red-infrared optical emitters (680nm, 940nm) and a broadband optical detector materialize the PPG sensor. The ballistocardiogram reflects the mechanical activity of the heart and is one of the oldest non-invasive methods for cardiac evaluation. It is based on sensing structures associated with different natural frequencies and damping that bring information about cardiac output. To acquire the BCG signal, an electromechanical film (EMFi) was used. This sensor generates a charge variation applied to a charge amplifier that provides a voltage associated with the applied dynamic forces. Skin conductance sensing is performed by two electrodes placed on the user's skin, in which one of them is connected to a non-inverting amplifier configuration.

B. Embedded sensing and processing unit

The wheelchair's acquisition and processing embedded platform system can be interpreted as an IEEE 1451 Network Capable Application Processor (NCAP). It is based on a ARM microcontroller. Two external modules are connected to the MCU: the Xbee 802.15.4 module and an FTDI chip. The XBee module transmits and receives data available in the 802.15.4 wireless network of smart wheelchairs, while the FTDI allows communication through USB for a single wheelchair. UART2interfaces with an RFID reader for user identification. The SPI2 peripheral is used for the SD Card writing and reading. To acquire data from the connected sensors, the ADC samples eight channel at 1 kS/s rate which is enough for the sampled analog signals. When the ADC is enabled, a 16-bit timer is used to generate an interruption with a period of 1 ms. A 11.1 V DC lithium-polymer battery with 1500 mAh capacity powers the embedded system. An input power source connector is connected to two low dropout regulators (LDOs), which permit to use 9 to 15V and providing 3.3V and 5V to the system. The MCU operates at a voltage of 3.3V, while 5V are used for powering the RFID reader and analog sensors (physiological, inertial and environmental sensors). In order to assure high flexibility of the implemented distributed architecture associated with the wheelchair, the IEEE 1451.4 standard for smart sensors was considered taking into account that it defines a mechanism for adding selfdescribing behavior to the transducers with analog interface that are actually embedded in the wheelchair and assure physiological, inertial and environment measurements in the present application. The standard establishes the concept of a transducer that has both digital and analog interface, i.e, a Mixed Mode Interface (MMI). The analog interface is responsible for transmitting the signal which reflects the quantity sensed by the sensor. Furthermore, the digital interface provides communication with an embedded memory within the transducer in order to read the IEEE 1451.4 TEDS.

IEEE 1451.4 Sensor Interface Module (SIM):

All the transducers were designed to fulfill the IEEE 1451.4 Mixed Mode Interface (MMI) Class 2 specifications having two separate connections for analog and digital signals. The use of Class 2 was considered taking into account that the Class 1 requires switching between the analog and digital signals, which means higher complexity and reduced reliability for the system. Each sensor interface module is attached to an analog sensor embedded in the wheelchair (e.g. EMFi ballistocardiography sensor) materializing a node of the wheelchair smart sensor network. Figure 3 shows an example of an IEEE 1451.4 MMI Class 2 smart sensor interface.



As can be observed in Figure 4, the IEEE 1451.4 SIM provides voltage supply for each analog biomedical sensor and a connection for the analog output of the sensor. The SIM also contains the 1-wire EEPROM to store digital information expressed in Basic TEDS format. The SIM board was designed to allow the use of two different types of 1-wire EEPROM: DS24B33 or DS28E04-100. However, only one should be soldered to the board. The DS24B33 memory is just a memory capable of storing 1kbytes of digital information. Besides having also 1kbytes of memory, the DS28E04-100 EEPROM has also two PIO pins that can control external circuitry that exists in the BSn or CCn. This could be very useful, for example, if one should want to control switches, multiplexers or other type of circuit that can be digitally controlled. In the current implementation.

CONCLUSION

The design and implementation of a microcontroller platform for IEEE 1451.4 standard for smart sensors as part of a smart wheelchair prototype showing how play-and-plug vital signs sensors can be achieved is described in the paper. An extended description of the designed, implemented, and tested architecture, which includes up to eight measurement channels that access analog and digital information through 1-wire protocol assures high modularity and extensibility, was made. Additionally, smart biomed LabVIEW software, including graphical user interface adapted to the user type, was presented. The tests performed with the system highlight the benefits of the implementation of the IEEE 1451.4 standard.

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