ABSTRACT
Home TeleCare proved to reduce mortality rate and hospitalizations costs for various groups of chronic patients. In this context, the aim of the work now reported is to develop a dual channel smart sensor embedded in a wheelchair to provide information on the health status of patients with chronic diseases by measuring photopletysmography and skin conductivity. Elements of the embedded system design, software implementation and some results for an established voluntary group are included in the paper.

KEY WORDS
Optical fibers, embedded system, wireless communication, advanced data processing

1. Introduction

The disease profile of the world is changing at an astonishingly fast rate, especially in low and middle income countries. Nearly 60% of all deaths are now caused by chronic diseases, being the leading cause of death the cardiovascular disease (heart disease and stroke are responsible for 30% of all deaths) associated with daily stress [1]. Aware of the rising costs and burden of chronic diseases, many countries are taking a comprehensive approach to reduce them. One of solution is Home TeleCare that proved to reduce mortality rate and hospitalizations costs for various groups of chronic patients [2,3,4].

Heart signal, blood pressure signal, pulse oximetry, respiratory and electro dermal response are frequently used in hospital and clinical centers environment to better characterize physiological and pathological states and to adequately describe the full pathway response to the stressor. The analysis of heart rate variability (HRV) in frequency and time-frequency domain provides insight into the autonomic nervous system outflow to the heart in various real-life conditions [5]. Moreover, the evaluation of autonomic nervous system (ANS) can be used both for diagnosis and outcome prediction of different chronic diseases [6,7] and as a marker of emotion regulation, behavioral predisposition and of certain aspects of psychological adjustment [8]. Therefore, it is worth work in developing non-invasive and non-obtrusive devices that may monitor cardiovascular signals, respiratory signal and skin response to various changes in psychophysiological state of the persons in home.

In this work we present implementation of the smart sensors embedded on a wheelchair’s arm based on bifurcated optical fiber bundle and skin conductivity sensors that can unobtrusively monitor heart rate, HRV, electro dermal response and autonomic nervous system balance. The advantages of fiber optic sensors, which include low power consumption, high immunity to electromagnetic interference, high sensitivity, wide bandwidth and environmental ruggedness, ability to be passive, lightweight, and very small size are suitable for sensing and measurement devices in Home TeleCare context. The implemented system is based on a microcontroller that communicates through Bluetooth with a PDA used as an advanced data processing (wavelet transform analysis of heart signal) and HMI.

2. System Description - Hardware

The system, which includes a dual channel smart sensor expressed by photopleysmography (PPG) and skin conductivity (SKC) sensing units, assures vital signs monitoring of the wheelchair user. Fig. 1 shows the wheelchair including the embedded sensors, the PPG and SKC conditioning circuit blocks and the acquisition processing and Bluetooth communication unit. This unit delivers the information from the sensors to a laptop PC with Bluetooth communication capability.

2.1 PPG sensing channel

The PPG sensing channel uses a bifurcated optical fiber bundle whose two arms conduct the excitation IR (λ=940nm) beam from the IR LED (L8957) to the user placed on the wheelchair arm and the reflected beam to the optical detector TSL260R from Taos TSL260R. The TSL260R is a high-sensitivity low-noise light-to-voltage optical converter that combines a photodiode and a transimpedance amplifier on a single monolithic CMOS integrated circuit. The output voltage is directly proportional to light intensity (irradiance) on the photodiode.

The irradiance responsivity is 0.042 V/(W/cm²) for λ = 940 nm. The devices have improved offset voltage stability, low power consumption and accept single power
supply (5V) that is provided by a DC-DC converter included in the system conditioning circuit.

The BFB together with the IR optical devices are the main part of the photoplethysmography sensor implemented using a reflective architecture. The distance between the BFB head and the finger surface placed on the wheelchair arm is a critical quantity that plays a strong influence on the IR beam detection system sensitivity [9]. A study concerning the reflected and measured optical power and the distance between the finger surface and BFB head was carried out and the result is presented in Fig. 2.

Referring to the excitation optical power control, a LED current driver (CD) was designed and implemented. The main blocks of the CD are the voltage to current converter (V/Iconv) and an active low pass filter (LPF) characterized by a cut-off frequency fc=1Hz. The LPF performs the conversion of the PWM signal delivered by the PWMA port output into a control voltage (Vc) applied to the V/Iconv, which assures the appropriate excitation current for the IR LED. An experimental approach concerning the dependence between the delivered optical power and the PWM duty cycle (DC[%]) control was carried out.

Referring to the detection part of the PPG sensing channel conditioning circuit, it consists of a non-inverter amplification scheme followed by a band pass filter (BPF). The BPF usage is related to the baseline wandering and 50Hz perturbation removal. In the present application, a 3pole active filter that uses ¼ TLC2274 low noise, rail-to-rail operational amplifier and a RC circuit materialize the imposed frequency characteristics f1=0.1Hz, f2=25Hz.

2.2 SKC sensing channel

The skin conductivity sensing is based on metallic electrodes that are mounted on the wheelchair arm and in contact with the subject’s skin. Tests to select the optimal placement of the skin conductivity electrodes and the type of electrodes to use to obtain a high sensitivity for the SKC measurement channel were performed. Nickel-plated discs and o-rings proved to be the best solution. Special attention was granted to the contact resistance between the wheelchair’s user skin and the electrodes. A good SKC signal response was obtained for the utilization of the EEG contact gel cream, but even without the gel the SKC measurement channel response was strong enough to detect user’s stress.

To design the SKC conditioning circuit a preliminary study on human skin conductance was performed. Thus, considering that human skin conductance values are supposedly only linear when voltages applied are below 0.5V, a voltage divider was set up to obtain a 0.5V reference voltage (Vref) using the +5V voltage provided by the isolated dual output DC/DC converter (CD Technologies NMH1205D) connected to the 12V system battery.

The utilization of electrodes, whose electrical model is a resistor, creates the possibility to obtain the information about the skin conductivity variation as the voltage output of a non-inverting amplifier configuration whose gain is controlled through a switching module (SW mod). The SW module uses a 4-channel analog multiplexer/demultiplexer (CD4052BC) controlled by a microcontroller (PIC18F452) using a set of digital output lines associated with digital port PORTB (Fig. 3).
Based on SW mod, which includes a set of high precision resistors and is microcontroller controlled, different skin conductance levels can be measured (e.g. 0-4.5μS and 0-36μS).

The output signal of the above presented SCK conditioning scheme is characterized by high level of 50Hz interference, which requires the utilization of a low pass filter (LPF_{SKC}) with a f_{c_{SKC}}=10Hz. This value is high enough to permit the visualization of the SKC variation under stressor application (e.g. high intensity sound stressor, hot/cold stressor). After filtering using a 1 pole active filter based on ½ TLC2274, the filtered signal V_{SKC} is applied to the analog input of the microcontroller that performs the SCK voltage acquisition task.

2.3 Embedded control, processing and data communication

The “brain” of the “smart” wheelchair is a PIC18F452 microcontroller that performs the following tasks: conditioning circuit control, acquisition of the plethysmography and skin conductivity signals, primary processing, such as heart rate estimation and voltage to skin conductivity conversion, and data transmission of the processed data to the PDA (Fig.4). PIC18F452 microcontroller main characteristics are: up to 10 MIPS, 32kbytes FLASH memory, 256bytes RAM memory, 256bytes EPROM memory, 2 capture/compare/PWM functions (one was used to the current driver control), 8 channels of 10-bit Analog-to-Digital (A/D) converter (2 channels were used to acquire the V_{PPG} and V_{SKC}) and Universal Asynchronous Receiver Transmitter (USART) (used for data transmission to the PDA).

Referring to the Bluetooth communication between the microcontroller and the advanced processing data mobile device (PDA2700), a Bluetooth-serial adapter was used. It connects to a RS232 serial port making it a Bluetooth Class 1 wireless connection capable of transmitting the data primary processed at the microcontroller level up at 100 meters.

Fig. 3. SKC sensing channel block diagram (DIV – 1/10 divider, V_{ref}-reference voltage V_{SKC} skin conductivity output voltage, SwichS-res – switching scheme with resistors, PORTB-microcontroller digital port)

Fig. 4. Microcontroller PIC18F452 based smart sensor block diagram (L/Vconv – light to voltage conversion, AN0, AN1 – analog inputs, PORTB – digital output port, PWMA – pulse width modulation analog output, RS232- serial communication interface)

However, the particular utilization of the PDA, which is a Bluetooth Class 2 device, conducts to an effective range of only 10m (Class 2 range). This range is nonetheless sufficient when the PDA is the HMI used by the wheelchair user.

3. System Description - Software

The system software components include the embedded microcontroller software developed in the Microchip C Compiler and the PDA embedded software developed in LabVIEW Mobile.

The MICROCHIP MCC-18 compiler was used to permit writing the controller code in C language. The code for the controller contains the settings for timers, ADC operation and interrupts. Additionally, the embedded software has the code that uses timer capability to measure inter-beat values and also to program the USART module.

The PDA embedded software has the main following blocks: Bluetooth communication, advanced data processing, and automatic alarm when the user health condition is critic.

Taking into account that the serial adapter connected to the USART of the microcontroller permits paired communication with any other Bluetooth device that supports Bluetooth SPP (Serial Port Profile), the
implemented communication software was developed using VISA functions for serial communication (e.g. VISA Open, VISA Write, VISA Read, VISA Close). Using the write function, the microcontroller is interrogated about the latest values of the calculated heart rate (HR) obtained after photoplethysmography primary processing at the microcontroller level. The time intervals between two successive data readings can be programmed through the software implemented at the PDA level and are normally expressed by values between 60s and 300s. The time intervals between heart beats are also received by the PDA software and processed to obtain the heart rate variability.

The information on autonomic nervous system balance is obtained by wavelet analysis of heart rate variability and from electro dermal changes [10,11]. Discrete wavelet processing of beat-to-beat signal using Db12 mother wavelet gives also information on respiratory rate [12].

An important part of the developed software refers to the graphical user interface (GUI). Thus, the PDA display is used to plot heart rate changes, skin conductivity changes associated with stress situations and also presents some metrics associated with autonomic nervous system assessment expressed by high frequency component (HF) - associated with parasympathetic outflow to the heart -, the low frequency component (LF) of pulse signal and electrodermal changes associated with sympathetic drive to the heart and peripheral circulation, and index of LF/HF associated autonomic nervous system balance.

4. Results and Discussion

Beat-to beat signal obtained using bifurcated fiber optic sensor implementation and changes in SKC sensors were compared with beat-to beat interval and electrodermal response obtained by a PowerLab instrument in 5 healthy patients. The area under the ROC (receiver operating characteristic) curve is used to discriminate the sensibility of the implemented system versus the data obtained using gold standard in physiological measurements – the PowerLab instrument.

Regarding the measured signals different tests were carried out. Some results are presented in Fig. 5 and Fig. 6.

4.1 PPG signal obtained after signal conditioning for no stressor case

4.2 SKC signal obtained after signal conditioning for patient under stressor

The implemented primary processing at the microcontroller level assures accurate heart rate estimation (less than 1%) and beat-to-beat measurement using the microcontroller timer capabilities. Referring to SKC measurement, the obtained relative errors are less than 2% for the measurement range.

5. Conclusion

The smart sensor embedded on a wheelchair can be used in HomeTeleCare settings and are characterized by good accuracy and sensitivity for non-invasive monitoring of beat-to-beat changes, skin conductivity and autonomic nervous system outflow to the heart and peripheral circulation. The designed and implemented system is characterized by high noise immunity, auto-scaling, primary processing and wireless data communication capabilities and include a user friendly interfaces embedded on a PDA.

The main limitation of the system is represented by artifacts associated with wheelchair motion that requires advanced signal processing for artifacts removal.

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References


