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Monitoring Technology for Wheelchair Users with Advanced Multiple Sclerosis

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***Abstract*— This paper presents a non–invasive assistive device for people with advanced Multiple Sclerosis (MS) who use electric power wheelchairs (EPW). The proposed system can acquire respiration and heart activity from ballistocardiogram (BCG), seat and back pressure distribution, wheelchair tilt angle and ambient temperature and relative humidity. The sensors collect information related to the main issues of MS patients: fatigue, heat sensitivity and low mobility. Preliminary results show the signals as the wheelchair is moving, stopped and tilting. The system is able to capture sufficient relevant information to provide suggestions and alarms in a future stage. The system will be tested at The Boston Home, a specialized residence for adults with advanced MS.**

I. INTRODUCTION

In most cases, people with motor disabilities use wheelchairs to move independently. Depending on the neurodegenerative disease, the percentage of wheelchair users varies. For instance, 86% of people with Cerebral Palsy (CP) use wheelchairs. In Amyotrophic Lateral Sclerosis (ALS), the percentage of wheelchair users is between 46% and 80% and for Multiple Sclerosis (MS) is 69% [1]. These patients may require special assistance. Usually, they need help from other people, either family members or specialized caregivers, to perform daily activities. However, this should not be at the expense of quality of life.

Patient monitoring technologies are useful to provide an extra level of safety. Also, they can provide objective information about patient health status and alarms in case of emergency. However, the main challenge is to acquire this information in a non–invasive way, minimizing the impact in patient's daily life. Currently, conventional sensors such as respiration belts and skin electrodes produce discomfort in impaired people, which can produce sores and irritation [2].

We present a new unobtrusive assistive device to encourage patient independence and comfort by helping caregivers improve patient care and supervision, increasing quality of life. This project focuses particularly on people with advanced MS who use electric power wheelchairs (EPW). The proposed system deals with some of the main issues in advanced MS: fatigue, heat sensitivity and low mobility.

MS is a chronic and progressive disease that results in the demyelinization of the central nervous system. Around the world, 2.5 million people are affected. Symptoms are diverse but generally patients suffer from fatigue, ataxia, spasticity and tremor [3]. Fatigue is the most common and disabling symptom. It occurs in 53% to 90% of the cases. Fatigue limits the performance during daily activities due to the lack of energy [4]. MS patients also get easily overheated. Heat exposure exacerbates MS symptoms such as fatigue. A simple activity like going outside in the summer could be dangerous if the necessary precautions are not taken. For instance, deaths have been reported in situations like sunbathing [5] and hot baths [6].

Some problems are common to all wheelchair users. EPW facilitate independent transport and help reduce fatigue, however, sitting in a wheelchair can add to low mobility problems by increasing the probability of pressure ulcers (PU). In addition, MS patients can present symptoms that increase the risk to develop PU such as sensory impairment, decreased vascular reactivity and incontinence [7]. To prevent them, some EPW are equipped with a tilting system and a pressure relief cushion to change contact points and reduce the pressure between the user and their wheelchair.

There are few projects reported about monitoring systems for people with MS. Yu et al. proposed a wireless monitoring system to study fatigue problems in MS [8]. However, their system is designed for people in early stages of the disease, where a wheelchair is not used. Also, it requires the use of ECG and EMG electrodes which produce discomfort during long-term monitoring. Postolache et al. [9] and Han et al. [10] worked on monitoring systems for wheelchairs using Electromechanical Film. Both are able to obtain heart rate and respiration rate processing the acquired signal with good results. In [10], this is complemented with standard ECG to obtain heart rate.

Our system proposes a multi–sensor, non–invasive monitoring system to provide alerts to patients and to support caregivers working in nursing homes [11]. The system is based on a battery of sensors to capture respiration and heart activity, pressure distribution and ambient conditions. Although the system addresses primarily the main issues present in advanced MS patients, it is also applicable to other neurodegenerative diseases. In this paper, we present the implemented system and preliminary experimental results obtained from subjects using an EPW.

II. SYSTEM DESCRIPTION

An overview of the proposed system is presented in Fig. 1. Several non–invasive sensors are deployed on an

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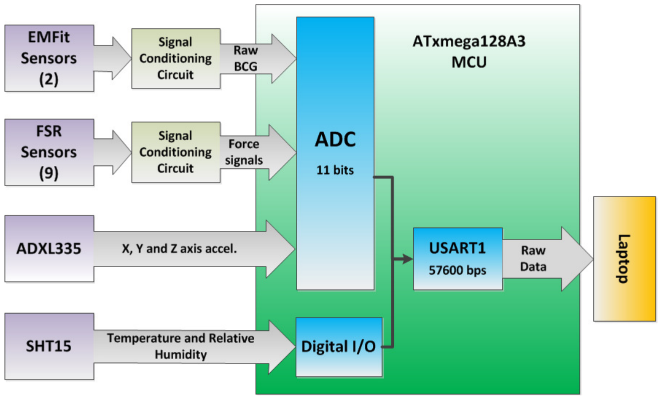

Fig. 1. System overview. The main components are: non–invasive sensors, signal conditioning circuits, microcontroller and laptop.

EPW to monitor physiological state, subject activity and ambient conditions. Data from sensors are integrated into a microcontroller unit (MCU) which then packs and sends them to a laptop where information is stored in a database for further analysis.

A. Non–invasive Sensors

Our goal is to provide support during daily living activities, unobtrusively. The sensors selected are able to provide physiological and activity information related to the main issues of MS patients, in a non–invasive way.

1) Electromechanical Films (EMFi): An EMFi sensor consists of a film structured with flat voids separated by a thin layer of polyolefin material, able to measure small pressure variations in a large 290x300 mm surface. Two EMFi are deployed on wheelchair to measure ballistocardiogram (BCG) and respiration signals. One sensor is placed on the seat ($EMFi_S$) and another on the backrest ($EMFi_B$).

2) Force sensing resistor (FSR): An FSR sensor is a polymer thick film which reduces its resistance when a force is applied in its surface. Nine small 44x38 mm FSR sensors are deployed on the EPW to measure prolonged pressure on the skin and patient movements with better spatial resolution than EMFi. Four sensors are put on the seat (FSR_S) and five on the backrest (FSR_B). FSR_B can also capture respiration activity based on thoraco-abdominal movement.

3) Accelerometer: The ADXL335 is a 3-axis accelerometer with $\pm$3g measurement range and analog output data. It is used to measure wheelchair tilt based on the static acceleration of gravity and detect wheelchair crashes based on dynamic acceleration.

4) Temperature and Humidity: The SHT15 measures ambient conditions during outdoor and indoor activities. This information will be used to avoid dangerous heat exposure. This sensor integrates ambient temperature (Ta) and relative humidity (RH) in one chip. Its digital output data are sent using a proprietary communication protocol to the MCU.

B. Data Acquisition Hardware

The Data Acquisition Hardware (DAH) captures the data from the different sensors and routes them to a laptop for storage and further processing. The DAH includes conditioning circuits for FSR and EMFi signals, an MCU to acquire, sort and pack the data and a serial transmission stage to the laptop computer.

1) FSR and EMFi signal conditioning: Both sensors require analog conditioning circuits for signal transduction, amplification and filtering before the analog to digital converter (ADC). The conditioning circuit for EMFi was based on [12]. It consists of a charge amplifier followed by a second order Sallen-Key low pass filter with a cut off frequency of 30 Hz. The circuit has calibration potentiometers to modify offset, gain and sensor sensitivity. For FSR, the conditioning circuit consists of a current to voltage amplifier followed by another 30 Hz low pass filter. The amplifier for FSR_B is sensitive enough to capture respiration signals.

2) Microcontroller stage: The information acquired by the sensors is sent into an ATxmega128A3 MCU running at 12 Mhz. The main tasks of the MCU are sampling the signals from the ADC, establishing the SHT15 communication protocol and sending all the information to a laptop for further processing and storage. Each analog signal is sampled at 100 Hz using 11 bits of resolution. Ambient data from SHT15 sensor is read digitally using a two-wire serial protocol. Ta and RH are sampled at 0.1 Hz and their resolutions are 12 bits and 8 bits respectively.

3) Data transmission: Each sensor datum transferred to the laptop has 24 bits: 12 bits of data and 12 bits to identify the source of the data. There are 16 identifiers, one for each measured variable. The MCU sends the data to a laptop installed on a subject's wheelchair via serial communication at 57.6 Kbps. The devices are connected to each other by a RS–232 / USB adapter.

C. Laptop Stage

The acquired data is stored and processed in a small laptop mounted in the EPW. A Python script reads the raw data sent by the MCU through the serial port and writes it to a postgreSQL data base. Another script unpacks the data according to the identifiers. The laptop will be used to generate alarms and patient recommendations in a stand-alone configuration and to send the data to a nursing station for caregivers alarms in the final version of this project.

D. Power Supply

The system is powered using 24 V wheelchair batteries. A custom–made power supply circuit with multiple outputs supplies power to the hardware components: 20V / 1.5A for the laptop and $\pm$ 5 V / 150 mA for MCU and DAH.

E. Implemented System

Fig. 2 shows the implemented system set up on an EPW. Power supply, DAH and the small laptop are put in a wheelchair bag. Fig. 3 and Fig. 4 show the deployed sensors. FSR_S and $EMFi_S$ are used under a standard pressure relief cushion. FSR_B and $EMFi_B$ are installed either in a pillow or a foam for support, depending on the subject's preference.

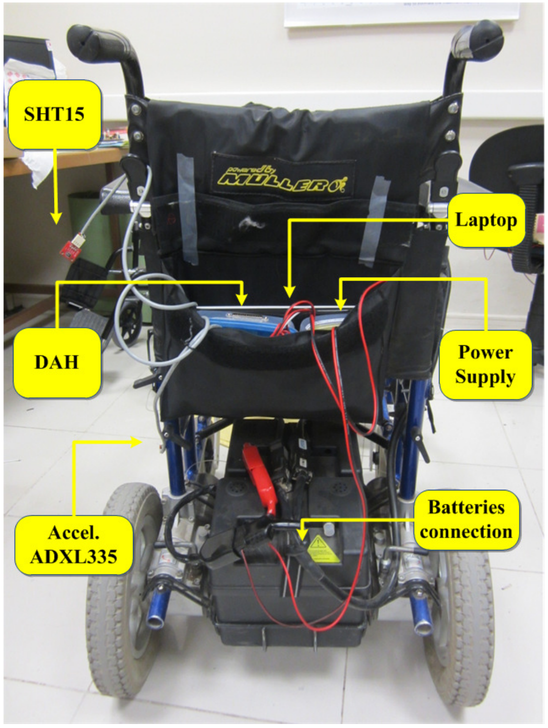

Fig. 2. Monitoring system mounted on an EPW. DAH, power supply and laptop are set up on wheelchair back.

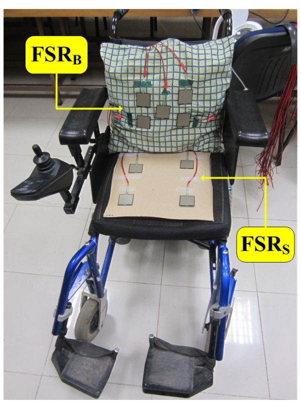

Fig. 3. Seat and back FSR.

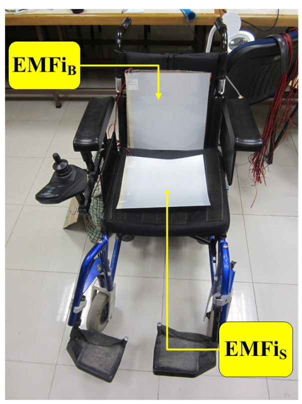

Fig. 4. Seat and back EMFi.

III. RESULTS

The system was tested with volunteers using an EPW in the laboratory. To participate in this preliminary test, the volunteers were required to sign an informed consent. First, subjects were asked to rest in their EPW to acquire signals with low movement noise. Then, subjects were asked to move their wheelchairs around the laboratory stopping as they please, as if performing daily activities. Finally, subjects were requested to tilt their EPW for a few minutes and then return to the original position. After the test, volunteers were asked about the comfort of the system.

Raw BCG signals obtained during the test are shown in Fig. 5. $EMFi_B$ and $EMFi_S$ can measure BCG when the wheelchair is not moving (after 21:53). In both cases, noisy signals are captured when the wheelchair is moving, due to vibration and subject movement. Respiration and mechanical heart activity are shown in Fig. 6. Both signals were extracted from the raw BCG using different IIR filters. With these signals it is possible to calculate heart and respiration rate.

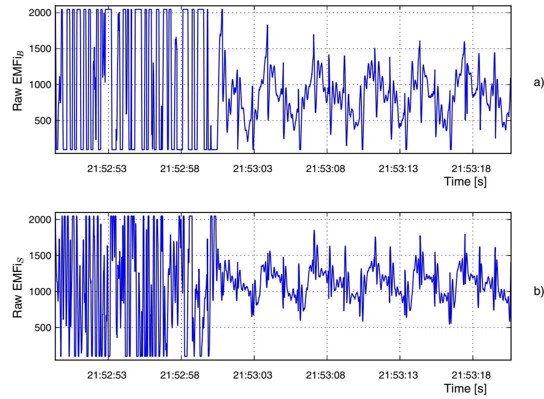

Fig. 5. Raw BCG signals. Wheelchair stops moving at 21:53. (a) Raw $EMFi_B$ (b) Raw $EMFi_S$.

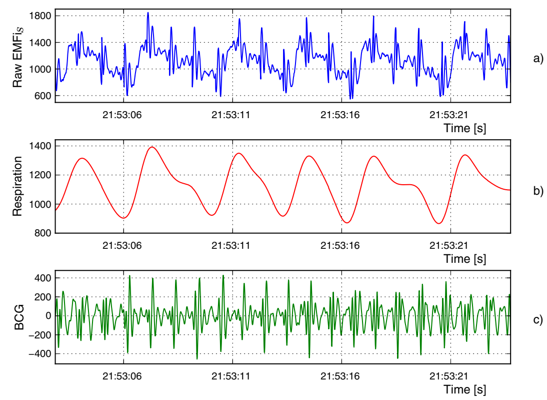

Fig. 6. Raw $EMFi_S$ (a) and the extracted respiration (b) and BCG (c) signals.

Pressure and accelerometer signals obtained during the test are shown in Fig. 7. Combining information from both sensors, it is possible to detect pressure relief during wheelchair tilting. Maximum pressure is measured on the seat in the normal position. When the subject tilts the wheelchair, the maximum pressure moves to the back. Fig. 8 shows that FSR_B can also detect respiration in at least one of the five sensors.

Ambient data were also captured successfully. Since the tests were conducted indoors, Ta and RH measured is 23.3 °C and 60.2% respectively, on average. No subject experienced any discomfort while using the system.

IV. DISCUSSION AND FUTURE WORK

The proposed system allows the capture of physiological data without causing discomfort to the patient. The system is set up on a wheelchair by deploying sensors in a pillow and under a pressure relief cushion to avoid direct contact.

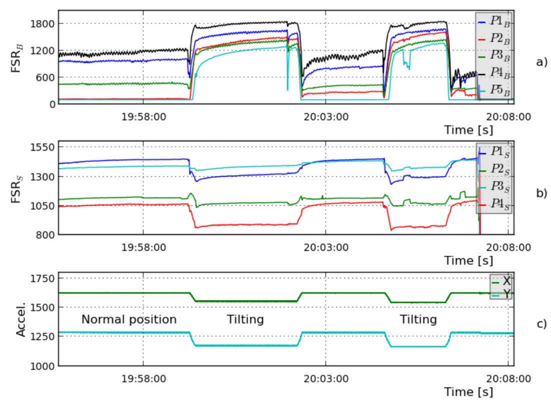

Fig. 7. Pressure signals during wheelchair tilt. (a) FSR_B. (b) FSR_S. (c) Acceleration in X and Y axis.

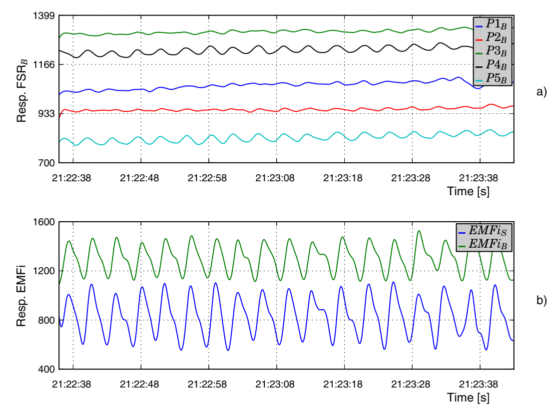

Fig. 8. Respiration signals obtained from FSR_B (a) and EMFi sensors (b).

This way, patient stress is kept to a minimum, and the system can be used to capture relevant information during long-term monitoring.

Data collected from these preliminary tests show that it is possible to capture respiration signals with the FSR_B and the EMFi sensors. Five FSR_B sensors and two EMFi provide redundant ways to measure respiration activity.

Although we confirmed that the electric motor does not interfere with the signals, wheelchair vibration and patient movement do. The most affected signal is BCG from EMFi, due to its high sensitivity. However, as we observed in actual MS patients and as expected, EPW activity is short, representing a small percentage of the total time in the wheelchair. When stopped, EMFi sensors show BCG with clear peaks corresponding to heart rate. Using respiration rate and heart rate from these signals, we expect to have an indication of patient stress and fatigue. This estimation does not need to be in real time, as both are slow changing conditions.

Pressure sensors and accelerometer data can be used to evaluate how often a patient relieves pressure by tilting. This information is relevant for caregiver supervision. When this action does not occur frequently, wheelchair users develop PU. Ta and RH combined with vital signs will be especially useful during summer, to avoid overheating problems.

The next step, which started in February 2013, is deployment at The Boston Home, a specialized care residence for adults with advanced MS. During a month, eight prototypes will collect data for sensor evaluation and algorithm development. All tests were approved by The MIT Committee on the Use of Humans as Experimental Subjects. Future work will focus on the development of algorithms to generate alarms and recommendations for patients and caregivers based in data collected.

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