Data Collection Capabilities of a New Non-Invasive Monitoring System for Patients with Advanced Multiple Sclerosis

Diego E. Arias[1], Esteban J. Pino, D.Sc.[1], Pablo Aqueveque, D.Sc.[1], Dorothy W. Curtis, M.Sc.[2]
[1]Department of Electrical Engineering, Universidad de Concepción, Concepción, Chile;
[2]Computer Science and Artificial Intelligence Laboratory, MIT, Cambridge, MA

Abstract

This paper reports on a data collection study in a clinical environment to evaluate a new non-invasive monitoring system for people with advanced Multiple Sclerosis (MS) who use powered wheelchairs. The proposed system can acquire respiration and heart activity from ballistocardiogram (BCG) signals, seat and back pressure changes, wheelchair tilt angle, ambient temperature and relative humidity. The data was collected at The Boston Home (TBH), a specialized care residence for adults with advanced MS. The collected data will be used to design algorithms to generate alarms and recommendations for residents and caregivers. These alarms and recommendations will be related to vital signs, low mobility problems and heat exposure. We present different cases where it is possible to illustrate the type of information acquired by our system and the possible alarms we will generate.

Introduction

According to the World Health Organization, about 10% of the global population has disabilities and 10% of them need a wheelchair to move independently [1]. Depending on the cause of the disability, these patients may be affected in their physical and cognitive skills, requiring continuous nursing care and assistance in performing daily activities. In most cases, family members take the responsibility for supporting and caring for them at home. The alternative is moving to nursing homes or assisted living facilities with specialized personnel. Bringing new tools to family and/or caregivers for improving the care of these patients is essential for increasing their quality of life.

Monitoring technologies such as assistive devices can be useful to support caregivers' work and to provide an extra safety level for patients. Vital signs, patient activity and ambient conditions are useful to describe patient's health status and to detect risks conditions. However, the challenge is to capture this information in an unobtrusive way, with a minimal impact on patients' daily life. Conventional sensors such as skin electrodes can cause dermatitis during prolonged use, producing discomfort [2]. Also, respiration belts can be difficult to wear and uncomfortable for impaired patients. To this end, new ways of collecting physiological information have to be found.

This project proposes a non-invasive monitoring system to provide alerts to patients and to support caregivers working in assisted living facilities or in homecare environment [3]. In particular, we focus on people with advanced Multiple Sclerosis (MS) who use powered wheelchairs. The proposed system deals with some of the main issues in advanced MS: fatigue, heat sensitivity and low mobility. The hardware and software is designed based on research and professional advice.

MS is a neurodegenerative disease produced by autoimmune attacks that destroy the myelin sheath around the axons slowing or blocking the communication between the neurons. Usually, these attacks focus on the optic nerves, periventricular white matter, brain stem, cerebellum, and spinal cord white matter [4], producing a variety of symptoms affecting different body areas. Currently, MS has no cure and its cause is unknown. Around the world, 2.5 million of people are affected. In the United States, MS patients vary between 250,000 and 350,000. There are four typical forms of MS: relapsing remitting (RRMS), primary progressive (PPMS), secondary progressive (SPMS) and benign MS [5]. PPMS and SPMS are the most disabling courses of the disease, characterized by severe physical disability and cognitive impairment affecting considerably the quality of life.

Fatigue is one of the most disabling symptoms in MS patients [6]. It occurs in 53% to 90% of the cases. This symptom limits the physical and mental activity of the patient during daily life. MS patients also are very sensitive to heat, which exacerbates fatigue among other symptoms [7]. During the summer, outdoors activities can be dangerous if the necessary precautions are not taken. Deaths have been reported in situations like sunbathing [8] and hot baths [9] without any supervision.

Due to the progression of the disease, around 50% of MS patients will be wheelchair-bound within 25 years from onset. It is well known that all wheelchair users who spend long hours sitting are prone develop pressure ulcers. Additionally, MS patients can present other symptoms that increase the risk for developing pressure ulcers such as sensory impairment, decreased vascular reactivity and incontinence. The best method to avoid these ulcers is keeping active, but this is not an easy task for patients with advanced MS. Even so, there are some assistive devices to prevent pressure ulcers such as the pressure relief cushion and the tilt-in-space system.

There are a few projects on monitoring devices for MS patients. Yu et al. [10] proposed a wireless system to monitor physiological data to study fatigue problems in MS. Their system was tested on patients in early stages of the disease, with an expanded disability status scale (EDSS) ≤ 5.5, where a wheelchair is not necessary. Also it requires the use of ECG and EMG electrodes which produce discomfort during long-term monitoring, unsuitable for patients with impaired mobility. Results show that their system is able to discriminate fatigued MS patients from healthy controls using heart rate variability. Some projects focus on monitoring systems for patients in wheelchairs. One approach is monitoring physiological data unobtrusively. Postolache et al.[11] and Han et al.[12] monitored heart and respiratory activity from ballistocardiogram (BCG). BCG is produced by the movement of the human body when blood is ejected from the heart. Results show that their system can collect physiological data when the wheelchair is not moving. However, both systems were not tested in a clinical environment, during daily activities. Another approach is to monitor pressure relief to avoid pressure ulcers. Yang et al. [13] proposed a monitoring system using pressure sensors around the ischial tuberosities to study pressure relieving patterns in manual wheelchairs. Ding et al. [14] used accelerometers to capture tilt usage in powered wheelchairs equipped with the tilt-in-space system. Combining monitoring physiological data and pressure relief patterns provides more complete information about the patient's health while using the wheelchair.

In this paper, we report the main findings in 246 hours of collected data in an actual clinical environment using our implemented system. We present different cases to illustrate the type of information acquired by our system and the possible alarms we will generate.

Materials and methods

1. Non-invasive monitoring system

Figure 1 shows an overview of the system. It consists of an assortment of sensors deployed on a wheelchair to monitor physiological data, patient activity and ambient conditions. To facilitate system acceptance, the key is to minimize the impact in patient's daily life. To this end, the selected sensors are able to capture all the information in a non-invasive way avoiding discomfort to patient. Accordingly, the following sensors were selected:

- Electromechanical Films (EMFi): An EMFi is a very sensitive sensor that can measure small pressure variations. Two EMFi (model L-3030 manufactured by EMFIT Ltd) are deployed on a wheelchair to measure BCG and respiration signals. Using this information, heart and respiratory rate can be calculated. One sensor is placed on the seat ($EMFi_S$) and another on the backrest ($EMFi_B$). Once the patient sits on the wheelchair, the system starts to collect respiration and heart activity without requiring any sensors on the skin, which is the main advantage over conventional ECG.

- Force sensing resistor (FSR): An FSR sensor consists on a polymer thick film which reduces its resistance when a force is applied in its surface. Nine small FSR sensors (model FSR 406 manufactured by Interlink Inc.), are deployed on the wheelchair to detect prolonged pressure over the buttock and back area. 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.

- Accelerometer: A 3-axis accelerometer (ADXL335 chip) is attached to the wheelchair to determine the usage of the tilt-in-space system based on the static component of acceleration and to detect subject movements and wheelchair vibrations during driving based on dynamic acceleration.

- Ambient conditions: An ambient sensor (SHT15 chip) allows us to measure temperature and relative humidity during outdoor activities to avoid heat exposure. Using this information it is possible to calculate the dew point which has been described as a possible indicator of the symptoms exacerbation produced by heat [15]. High dew point values can increase the probability of the symptoms worsening.

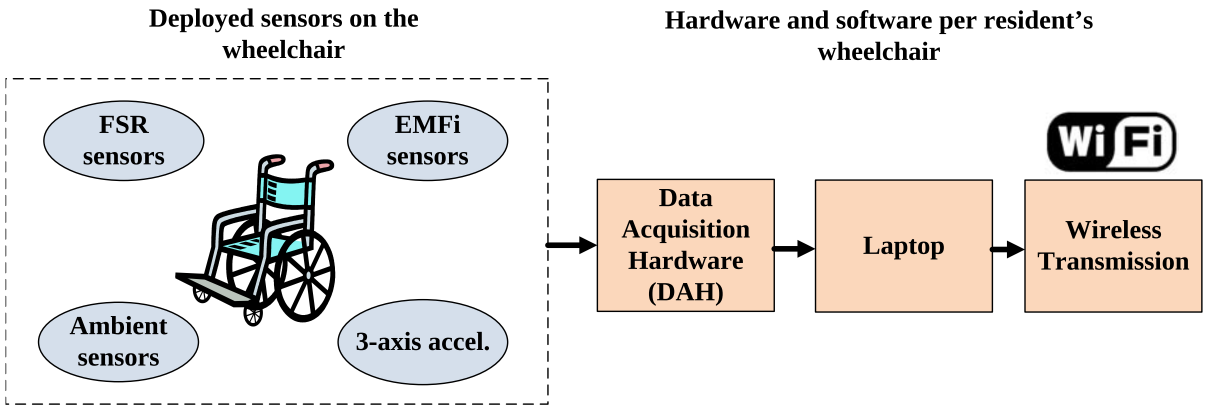

Figure 1. System overview.

All information captured by the sensors is sent to a data acquisition hardware (DAH). The DAH contains conditioning circuits for FSR and EMFi signals, a microcontroller to acquire, sort and pack the data and a serial transmission stage. The DAH transmits the data to a small laptop mounted in the wheelchair for storage and further processing. A Python script reads the raw data and writes it to a PostgreSQL database. The laptop will be used to generate alarms and patient recommendations in a stand-alone configuration and to send the data, through a Wi-Fi connection, to a centralized monitoring station for caregivers' alarms in the final version of this project.

The system is powered using the existing 24 V wheelchair batteries. The power used by the system is minimal and does not affect the wheelchair's performance.

The implemented system is shown in Figure 2 and Figure 3. Figure 2 shows the deployed sensors on the wheelchair. FSR_S and $EMFi_S$ are installed under a pressure relief cushion and FSR_B and $EMFi_B$ are installed inside a foam for support, which is covered with a pillow case. Power supply, DAH and the small laptop are mounted in a wheelchair bag as shown in Figure 3.

Figure 2. Deployed sensors on the wheelchair.

Figure 3. Power supply, DAH and the laptop are mounted on a wheelchair bag.

2. Participants

Participants were volunteers from The Boston Home (TBH), a specialized care residence for people with advanced MS and other neurological diseases. The inclusion criteria are related with their diagnosis and the type of wheelchair used. The participants should be diagnosed with a progressive form of MS. Also, they should be full-time wheelchair users and their wheelchairs should be electric-powered, equipped with the tilt-in-space system and a pressure relief cushion as methods to relieve pressure.

3. Study Protocol

The prototypes are deployed on the wheelchairs before the subjects start using them. Prior to data collection, the participants are asked if the sensors deployed on the wheelchair's backrest and/or seat produce discomfort. Then, the prototypes start to collect data continuously during the whole time spent on the wheelchair. As the data collection was performed in a nursing home, researchers contact the nursing staff in case of any problems.

To validate the information obtained from BCG signals, once a day the subjects are asked to use a Nonin® pulse oximeter to acquire the heart rate and the SpO_2 level. This sensor is used during short periods of time to minimize discomfort to the subjects. Figure 4 shows one of the participants during the validation stage using the pulse oximeter. During this validation, the volunteers are also requested to tilt their wheelchairs to validate the accelerometer information. This protocol was approved by The MIT Committee on the Use of Humans as Experimental Subjects (COUHES).

Figure 4. One of the volunteers using the pulse oximeter during the validation process.

Results

The study was conducted during two weeks at TBH. Six eligible TBH residents consented to participate in this study: 4 women and 2 men whose ages range between 39 and 73 years. Five of them are diagnosed with SPMS and only one is diagnosed with PPMS. The mean duration of the disease was 24 years. The EDSS varies between 7.5 and 8.5, indicating a high level of disability.

On average, each subject was monitored 6.5 days and 6.3 hours per day. In total, 246.5 hours were recorded, totaling 3.1 GB of data.

Only one of the participants refused to use the pulse oximeter during the validation process. In two opportunities, Subject 5 was asked to check heart rate and SpO_2 but she refused because she felt upset. However, no subjects experienced any discomfort during the study while using the system. Four cases that illustrate the potential of the system were observed from this preliminary study:

Case 1: Pressure relief using tilt-in-space and time spend on the wheelchair.

The FSR sensors and the accelerometer capture pressure changes and the wheelchair tilt respectively. Combining both sensors it is possible to extract useful information for clinicians about how wheelchair patients are managing pressure during the day. No pressure changes or tilt absence during a long period of time should be reported to the nursing staff or patient to avoid pressure ulcers. Figure 5 shows several pressure changes during a full day record measured from Subject 1. It is possible to observe how pressure over the seat is transferred to the back when the subject tilts (T) the wheelchair, as she performs pressure relief (PR). From pressure signals it is also possible to calculate the hours that the residents spend using their wheelchairs. In Figure 5, Subject 1 spends 6:41 hours on the wheelchair.

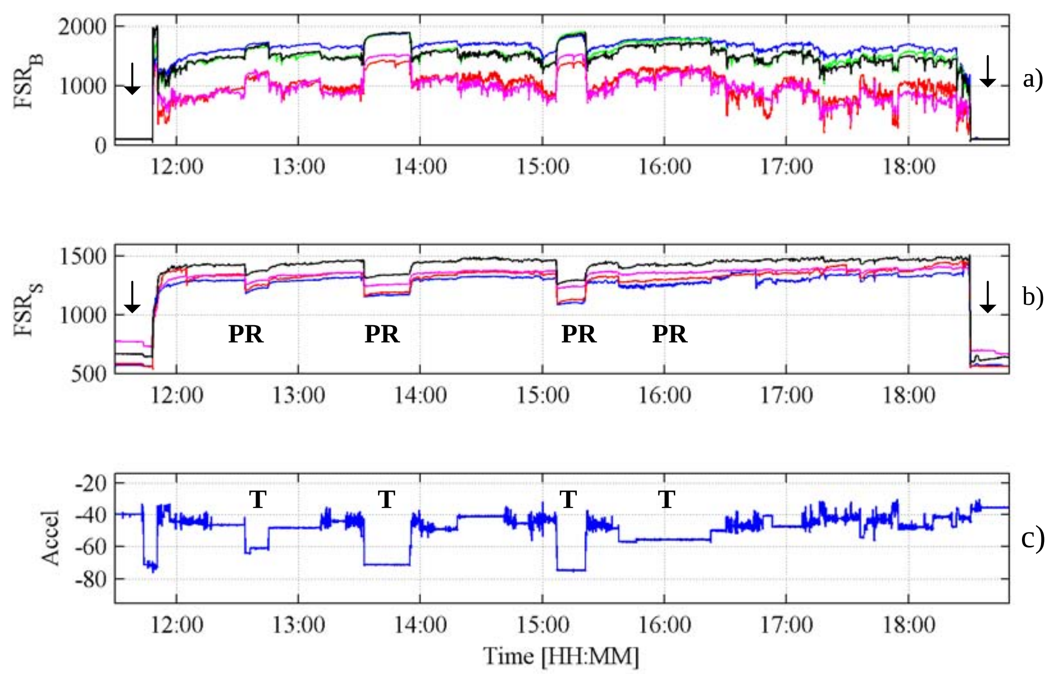

Figure 5. Pressure changes during a full day record and tilting (T) episodes that produce seat pressure relief (PR). a) FSR on backrest, b) FSR sensor on seat and c) angle obtained from accelerometer. Black arrows on the FSR sensors mark the beginning and end of the wheelchair occupancy.

Case 2: Vital signs during activity and resting periods.

The system collects data continuously during subject's daily life. For this reason, the data could be affected by noise mainly due to subject movements and wheelchair vibration during driving. It is possible to distinguish when the wheelchair is moving and when it is stopped by checking the accelerometer data. For example, Figure 6 shows Subject 1 while she was resting with the wheelchair tilted backward (before 15:15:30 hours). In this period, it is possible distinguish respiration and heart activity on the raw $EMFI_B$ signal. However, when she tilts the wheelchair forward and she starts to drive (after 15:15:30 hours), signals become noisy. On the other hand, Figure 7 shows Subject 2 while she is watching TV in his room. In this case, signals are not noisy and, it is possible to process the raw signal to show respiration and BCG signals.

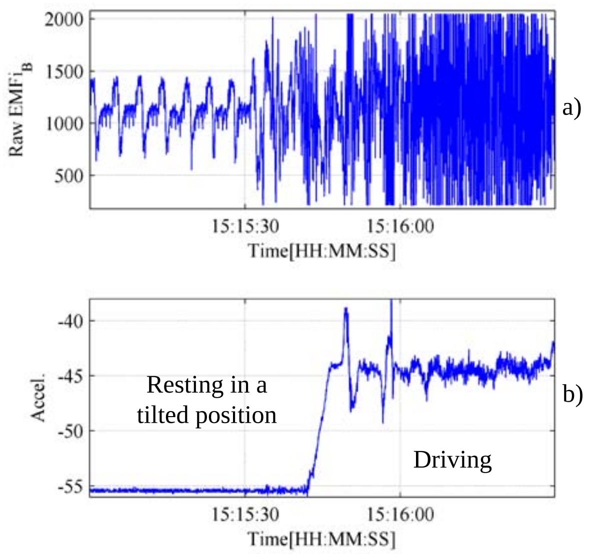

Figure 6. Subject 1 as the EPW stops (resting) and moves (activity). a) $EMFi_B$ and b) accelerometer.

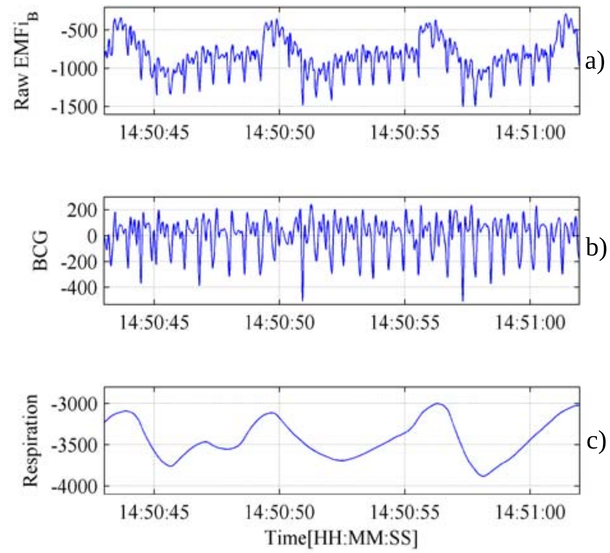

Figure 7. Segment of data captured from Subject 2 while resting, watching TV. Processing a) raw $EMFi_B$, it is possible to obtain b) BCG c) and respiration signal.

Case 3: Apnea

The FSR_B and EMFi sensors are able to capture respiration signals. This information allows estimation of respiratory rate trends to assess vital signs as well as the observation of respiratory abnormalities such as apneas. During the data collection, it is usual to observe the residents resting in their wheelchair or taking a nap. For instance, Figure 8 shows an EMFi record where is possible to recognize an 18 second apnea while Subject 3 is taking a nap. Figure 9 shows the same apnea captured by FSR_B sensors. In this case, four out of five sensors are able to capture respiration signals.

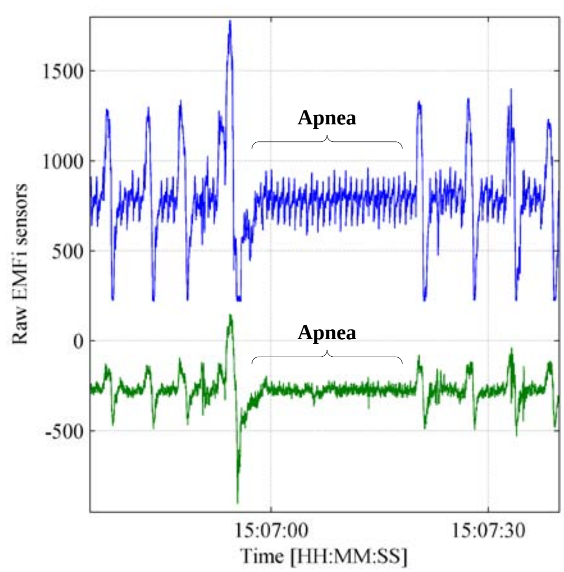

Figure 8. Apnea detected in EMFi sensors.

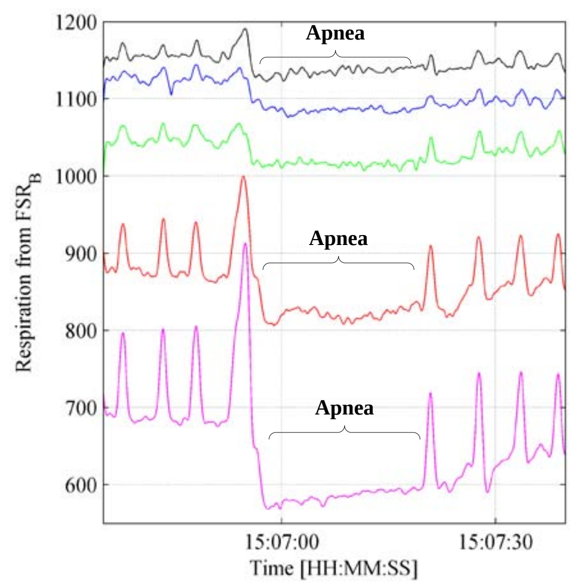

Figure 9. Apnea detected in FSR sensors.

Case 4: Subject 4 does not contact the backrest sensors.

To obtain information from backrest sensors, the users need to support their back on the wheelchair backrest. However, depending on the muscle strength and the disability level, some patients can drive without leaning into the backrest. Subject 4 uses the wheelchair in a posture where most of the time she does not touch the foam with sensors, rendering it impossible to detect respirations and BCG signals from the backrest sensors. Figure 10 shows that the FSR_B sensors are not pressed while FSR_S are, indicating the resident is actually using the wheelchair. In this case, Figure 11 shows that the signal acquired only from $EMFi_S$ is able to capture respiration and heart activity signals.

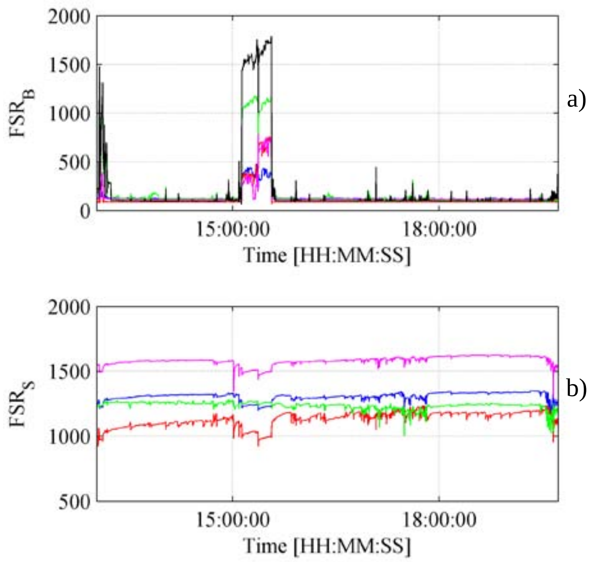

Figure 10. Most of the time, Subject 4 does not touch backrest sensors. Only seat sensors are pressed.

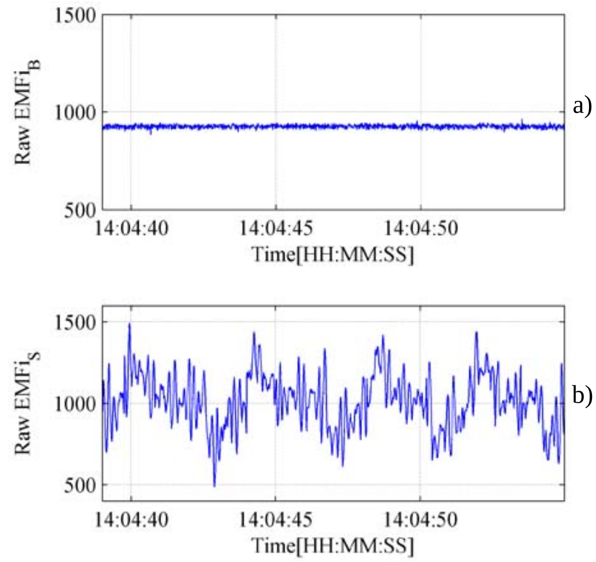

Figure 11. BCG and respiration signals can only be detected by the $EMFi_S$

Ambient data consists only of indoors measurements because the data collection was done during winter season. For this reason, no residents were exposed to high temperatures.

Discussion

The data collection in an actual clinical environment shows that the proposed system allows capturing physiological data without causing discomfort to the patient. The system is set up on a wheelchair by deploying sensors in a piece of foam and under a pressure relief cushion to avoid direct contact. This way, patient stress is kept to a minimum, and the system can be used to capture relevant information during long-term monitoring. The collected data reflect signals during patients' daily lives.

From the small number of volunteers in this preliminary study it is of note that even a simple 'non-invasive' pulse oximeter can produce discomfort in patients with advanced chronic diseases such MS. This is our motivation to continue research in contactless/ambient sensor systems.

The cases presented show the feasibility of implementing alarms that support daily activities in EPW patients. The implemented system is able to provide relevant information such as time on wheelchair, moving vs resting, ambient conditions, vital signs and pressure relief which are useful for guiding or warning patients and caregivers.

The next stage of the project will further analyze the collected data and design algorithms to generate useful alarms and recommendations. These alarms will be related to vital signs, low mobility problems and heat exposure. We will test the complete system at TBH during the summer. We expect this system to be useful for other EPW users and also easily adapted to other chronic disease requirements.

Acknowledgments

The authors would like to thank to the MISTI program at MIT and the Biomedical Engineering program at the Universidad de Concepción for the financial support. We also want to express our gratitude to Professor Seth Teller from MIT for his support and advice. Also to Don Fredette and The Boston Home for being so enthusiastic about this project.

References

1. World Health Organization. Guidelines on the Provision of Manual Wheelchairs in Less Resourced Settings. World Health Organization; 2008. p. 129.

2. Avenel-audran M, Goossens A, Zimerson E, Bruze M. Contact dermatitis from electrocardiograph-monitoring electrodes: role of p-tert-butylphenol-formaldehyde resin. Contact Dermatitis. Munksgaard International Publishers; 2003;48(2):108–11.

3. Pino E, Arias D, Aqueveque P, Curtis D. Assistive Devices for HealthCare: Multiple Sclerosis. AMIA 2012 Annual Symposium. 2012. p. 1899.

4. Noseworthy JH, Lucchinetti C, Rodriguez M, Weinshenker BG. Multiple Sclerosis. N Engl J Med. 2000;343(13):938–52.

5. World Health Organization. Neurological Disorders: Public Health Challenges. World Health Organization; 2006. p. 218.

6. Kos D, Kerckhofs E, Nagels G, D'hooghe MB, Ilsbroukx S. Origin of Fatigue in Multiple Sclerosis: Review of the Literature. Neurorehabil Neural Repair. 2007;22(1):91–100.

7. Marino FE. Heat reactions in multiple sclerosis: An overlooked paradigm in the study of comparative fatigue. Int J Hyperthermia. 2009;25(1):34–40.

8. Henke AF, Cohle SD, Cottingham SL. Fatal hyperthermia secondary to sunbathing in a patient with multiple sclerosis. Am J Forensic Med Pathol. 2000;21(3):204–6.

9. Kohlmeier RE, DiMaio VJ, Kagan-Hallet K. Fatal hyperthermia in hot baths in individuals with multiple sclerosis. Am J Forensic Med Pathol. 2000;21(3):201–3.

10. Yu F, Bilberg A, Dalgas U, Stenager E. Fatigued patients with multiple sclerosis can be discriminated from healthy controls by the recordings of a newly developed measurement system (FAMOS): a pilot study. Disabil Rehabil Assist Technol. 2013;8(1):77–83.

11. Postolache OA, Girao PMBS, Mendes J, Pinheiro EC, Postolache G. Physiological Parameters Measurement Based on Wheelchair Embedded Sensors and Advanced Signal Processing. IEEE Trans Instrum Meas. 2010 ;59(10):2564–74.

12. Han D-K, Kim J-M, Cha E-J, Lee T-S, Hong J-H. Wheelchair type biomedical system with event-recorder function. Engineering in Medicine and Biology Society, 2008 EMBS 2008 30th Annual International Conference of the IEEE. 2008. p. 1435–8.

13. Yang Y-S, Chang G-L, Hsu M-J, Chang J-J. Remote monitoring of sitting behaviors for community-dwelling manual wheelchair users with spinal cord injury. Spinal cord. 2009;47(1):67–71.

14. Ding D, Leister E. Usage of tilt-in-space, recline, and elevation seating functions in natural environment of wheelchair users. J Rehabil Res Dev. 2008;45(7):973–83.

15. Johnson R. Warm, sultry weather and multiple sclerosis. Weather. 2002;57(10):395–6.