IOP Conf. Series: Materials Science and Engineering **254** (2017) 072008 doi:10.1088/1757-899X/254/7/072008

Smart wheelchair: integration of multiple sensors

H. E. Gassara[1], **S. Almuhamed**[1], **A. Moukadem**[2], **L. Schacher**[1], **A. Dieterlen**[2] **and D. Adolphe**[1]

[1]Laboratory of Textile Physics and Mechanics, LPMT - EA 4365 - UHA, University of Haute-Alsace, 11, rue Alfred WERNER, 68093 Mulhouse CEDEX, France

[2]Laboratory of Modelling, Intelligence, Process and Systems, MIPS – EA 2332 – UHA - University of Haute-Alsace, 4 rue des frères lumière, 68093 Mulhouse, France

Email: Laurence.schacher@uha.fr

Abstract. The aim of the present work is to develop a smart wheelchair by integrating multiple sensors for measuring user's physiological signals and subsequently transmitting and monitoring the treated signals to the user, a designated person or institution. Among other sensors, force, accelerometer, and temperature sensors are successfully integrated within both the backrest and the seat cushions of the wheelchair; while a pulse sensor is integrated within the armrest. The pulse sensor is connected to an amplification circuit board that is, in turn, placed within the armrest. The force and temperature sensors are integrated into a textile cover of the cushions by means of embroidery and sewing techniques. The signal from accelerometer is transmitted through Wi-Fi connection. The electrical connections needed for power supplying of sensors are made by embroidered conductive threads.

1. State-of-the-art

Many wearable health monitoring systems have become available in the markets [1]. These systems have the advantage of a nonstop real-time health monitoring throughout a long period. However, for a robust use, there are a number of challenges that must be overcome including cost of overall system, accuracy of the signal obtained, low power consumption, interconnection method and unobtrusive design [2]. In addition, wearable smart textiles are not conceivable for people with disabilities and seniors. The percentage of the seniors would increase 80% in 2050 comparing to their percentage in 2005 [3].

Therefore, another possible solution to monitor their health status is by developing a health monitoring system based on a smart wheelchair; since it is more adequate for such a numerous audience and a wheelchair does not need as much care (washing, drying, etc.) as wearable systems.

On the other hand, based on literature survey, very few projects can be found concerning the development of smart wheelchair such as Connected Wheelchair project by Intel® Technology [4] and Chech@flash project by Altran Stream Vision [5]. Therefore, the object of the present work is to develop a smart wheelchair based on a traditional one by integrating multiples sensors within its structure. Namely, the targeted sensors are pulse, force, accelerometer and temperature sensors, and the targeted integration structures are the armrest and the textile structures of both backrest and seat cushions.

2. Materials

The choose of a wheelchair is rather complicated and depends on many criteria, such as the user's pathology, morphology, his/her rate of evolution, his/her environment (at home, in the office, etc.),

IOP Conf. Series: Materials Science and Engineering **254** (2017) 072008 doi:10.1088/1757-899X/254/7/072008

user's daily activities (work or leisure), etc. [6]. Accordingly, there is not a "model" wheelchair. Thus, the wheelchair is selected according with economic and technical criteria. Among the wide spectrum of available wheelchairs, we chose NETTI 4U CED type [7]. It has a seat cushion of 45cm wide and is characterized by inclination angles of the seat and the backrest of 25° and 45°, respectively. The seat cushion is composed of three layers of foam with different densities. These layers are arranged in the order of the lowest to the highest density from the top to the bottom.

A plug-and-play optical pulse sensor type Amped [8] (Figure 1-A) and its compatible cardboard type Arduino UNO [9] are purchased from SparkFun, USA [10]. The pulse sensor has 3 mm thickness and its diameter is approximately 16 mm.

The force sensors used are of type FlexiForce A201 [11] (Figure 1-B) and purchased from Mescan, France [12]. They have dimensions of 0.302 mm thickness, 191 mm length and a sensing area of 9.53 mm diameter.

In order to trace the change in skin temperature, we use a miniaturized temperature sensor type Platinum SMD Flat Chip Temperature Sensor [13]. It is purchased from JUMO Gmbh & Co. KG, Germany [14], with dimensions of (L×W×H : 2×1.25×0.45) mm.

To continuously monitor heart rate without disturbing the patient, SCA11H [15] sensor was used (Figure 1-C). Its functioning is based on *Ballistocardiography* [16] by utilizing an ultra-low noise and narrow noise bandwidth SCA61T3D MEMS accelerometer and analog signal conditioning.

(A) (B) (C)

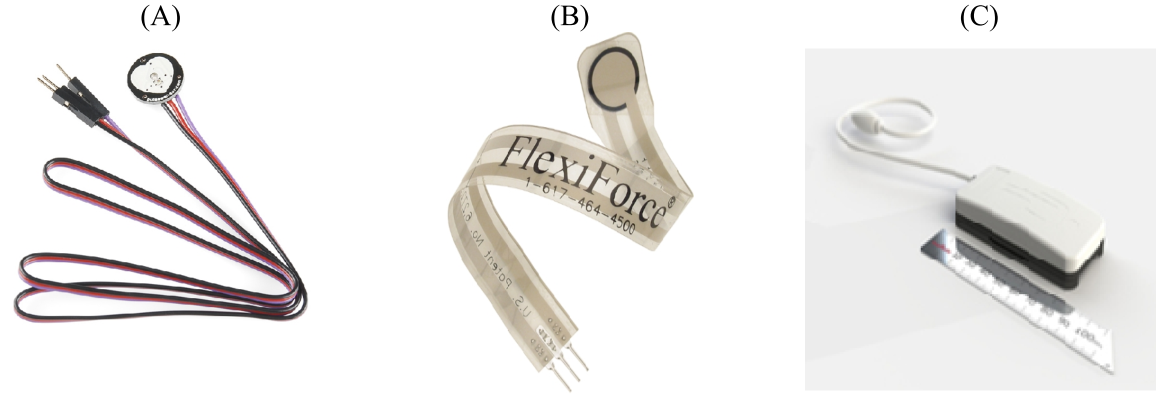

Figure 1. Optical pulse sensor (A), FlexiForce A201 sensor (B), and SCA11H Sensor (C)

3. Methods

A prototype of wooden armrest covered with polyurethane foam is fabricated within which the pulse sensor and the amplification cardboard are entirely integrated. The prototype has dimensions of (420×80×38) mm, as shown in (Figure 3). This prototype is composed of three wooden layers whose thicknesses are 5, 18 and 5mm respectively. A hole is made through the thickness of the top layer for positioning the head of the sensor onto the upper layer. The amplification cardboard is located in the middle layer; while the base layer is perforated for cooling purpose.

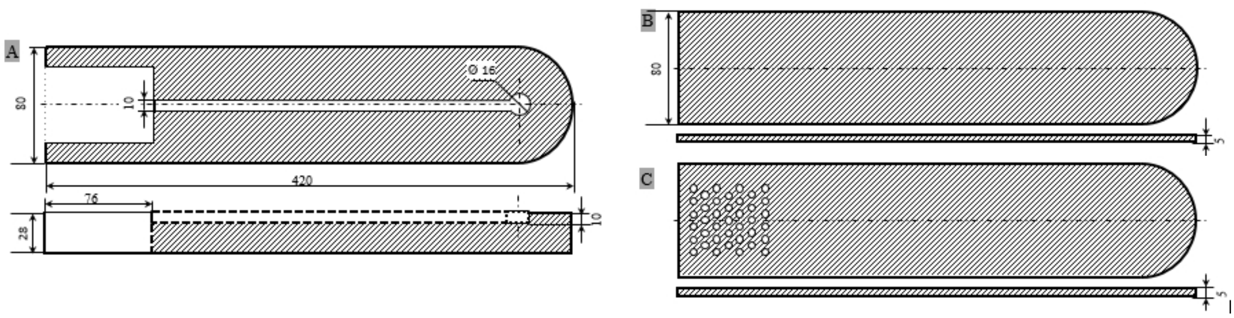

Figure 2. Profiles of the three components of the wooden armrest prototype

The three layers are then assembled and covered by a thin layer of polyurethane foam whose thickness was of 20mm, to provide more comfort to the user. Finally, a suitable textile cover is prepared. This cover is composed of a front part made of Lycra/Polyester warp knitted fabric. Figure 3 reveals the components of the armrest prototype and its final appearance after being mounted on the wheelchair.

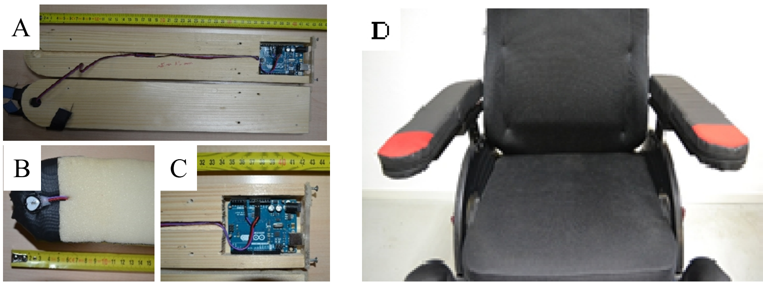

Figure 3. Novel connected armrest

For adequate body pressure measurement using minimum number of individual force sensors, optimum positioning of the force sensors was required. We firstly acquired pressure cartographies of both the seat and the backrest cushions and by using XSENSOR pressure imaging system [17] of the Centre of Rehabilitation of Mulhouse (Alsace, France) and several volunteers of different weight and shape (male and female). The cartographies are acquired in relation to the inclination angle between the backrest and the seat. An especially made angle protractor (Figure 4) measures this angle. The principle of this protractor is based on measuring the distance between two laser points projected on a horizontal plan from two laser pointers; one is always vertical since it is fixed on a free rotating disk, and the other one is fixed on the rotation axis and inclines with the backrest.

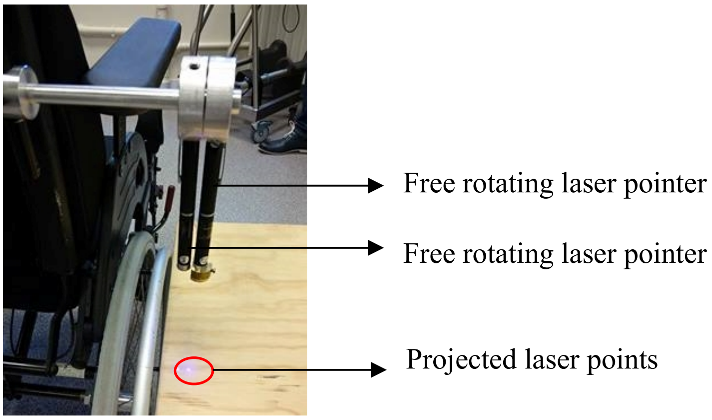

Figure 4. Prepared angle protractor

The acquired cartographies (Figure 5) are treated by Photoshop software to segment the pressure values into three levels: < 40mmHg, 40-70mmHg and > 70mmHg for the seat and < 25mmHg, 25-35mmHg and > 35mmHg for the backrest (Figure 5-B). Such segmentation, recommended by the medical team from Centre of Rehabilitation, will help identifying the pressure range of each sensor and the calibration of the corresponding amplification circuit, accordingly.

(A) (B)

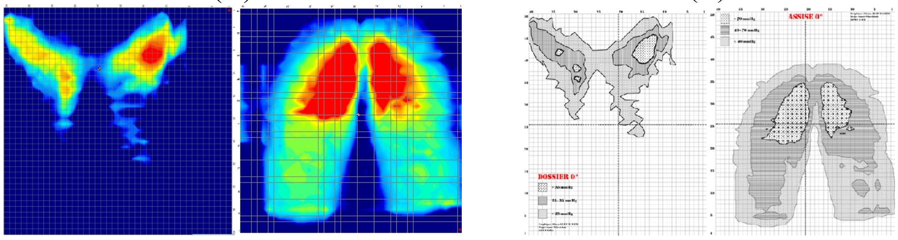

Figure 5. Acquired (A) and treated (B) pressure cartographies of the seat and the backrest, respectively

Accordingly, the position of each force sensor is identified where one force sensor is positioned in each pressure zone except those that are less than 25 and 40mmHg for the seat and the backrest, respectively. In total, four force sensors are integrated into the seat textile cover and other four sensors are integrated into the backrest cover.

Temperature sensors are integrated following the same procedure of force sensors, where a temperature sensor is placed just in front of each pressure sensor (Figure 6-C).

All the force and temperature sensors are connected to a designed circuit via embroidery means by using a conductive filament [18] (Figure 6-A and 6-B).

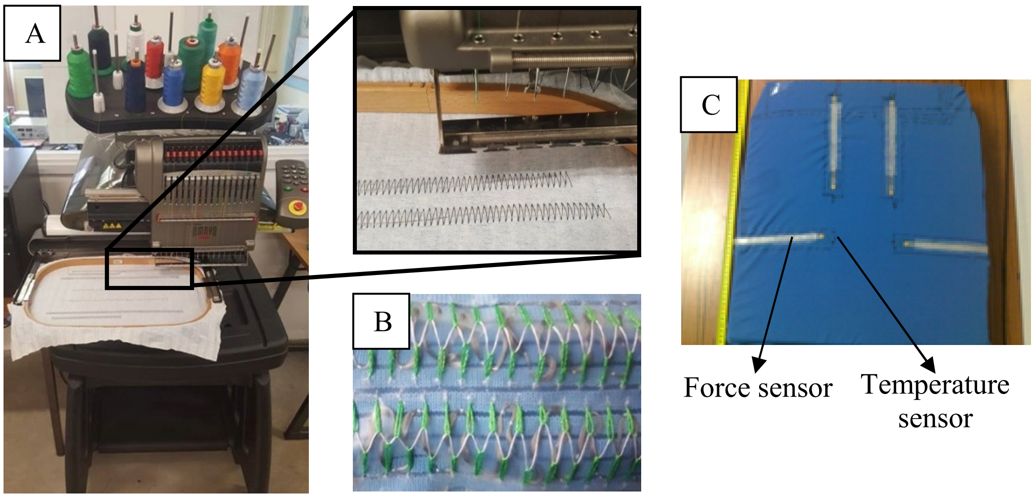

Figure 6. Embroidery machine (A), Conductive filament inserted by embroidery technique into the tissue (B) within the textile cover of the seat cushion (C).

By using a miniature high-resolution acceleration sensor, it is possible to measure the heart functioning more accurately and less annoyingly than with conventional electrocardiograms, with *Ballistocardiography*. When the person is leaning against his or her chair, the backrest begins to vibrate following the movement of the blood. The MEMS accelerometer picks up the signal, which is then transmitted to a microcontroller using a special algorithm via a Wi-Fi receiver for analog signal conditioning. This combination of accelerometer and software allows for embedded heart and respiration rate signal processing with 1Hz output rate.

4. Results

Depending on the weight and the morphology of the wheelchair user, the applied pressure over one force sensor is in the range up to 500g. All the integrated force sensors maintain the linearity between the output of card board; voltage, and the applied force with a very good accuracy (Figure -A).

(A) (B)

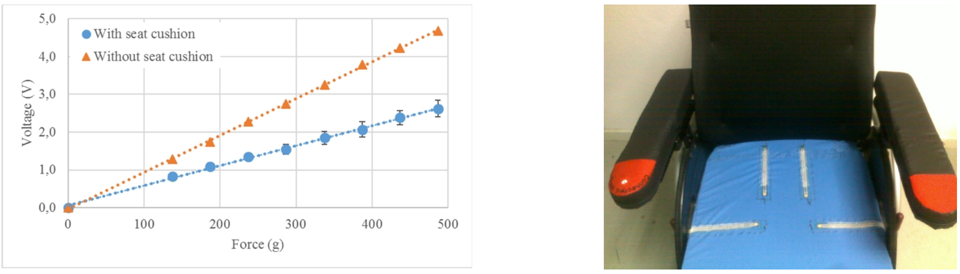

Figure 7. Calibration of an integrated force sensor (A) and connected seat cushion (B)

When the user touches the LED of the pulse sensor, his/her heart-rate is monitored on a PC or tablet screen like so in Figure 8.

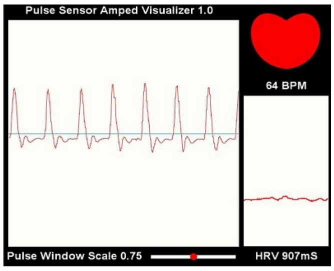

Figure 8. User's Heart-rate

Thanks to the ultra-sensitivity of the MEMS sensor, the return effect of pumping blood into the body by the heart was detected even through the backrest. SCA11H sensor provide thus vital sign information such as Heart Rate (HR), Heart Rate Variation (HRV), Relative Stroke Volume (SV), Respiration Rate (RR), and chair occupancy.

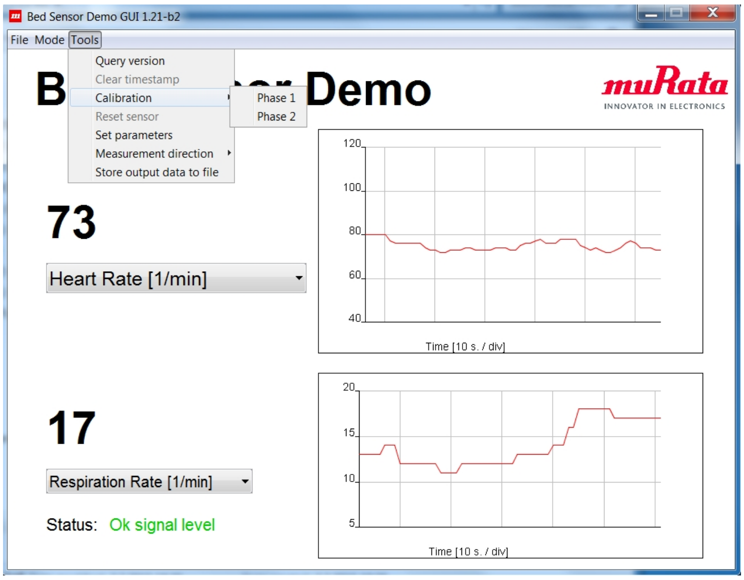

Figure 9. User's heart-rate and respiration rate extracted by MEMS accelerometer

All sensors are being connected via a specially designed conditioning card placed at the rear of the wheelchair. It is powered by a rechargeable battery, which is placed in the back of the chair.

This card is designed to be able to monitor, control, and remotely send all the signals transmitted by different sensors installed, to an external treatment center (pc, tablet ...).

5. Conclusions and perspectives

The occupancy of a wheelchair can even exceed 50% for the majority of users [19]. This requires non-invasive integration of the sensors in order to keep the comfort level of the wheelchair [20]. This condition has been respected during the insertion of the force, temperature, and cardiac pulse sensors into the covering textile structure. Regarding SCA11H sensor, this one can be placed even at the back of the backrest or under the seat of the chair.
The medical team partner of the project validated the first results. Thanks to the developed prototype, it becomes possible to get complete set of data of the user in his/her daily activities. Rapid intervention in an emergency already knowing the history of physiological parameters of the patient may also be possible. The conducted project also highlights the potentially positive psychological effect for the patients who may feel much safer in such condition.

References

[1] M. Suh, “Wearable sensors for athletes,” in *Electronic Textiles, Smart Fabrics and Wearable Technology*, Tilak Dias, 2015, pp. 257–273.
[2] P. S. Kumar, S. Oh, H. Kwon, P. Rai, and V. K. Varadan, “Smart real-time cardiac diagnostic sensor systems for football players and soldiers under intense physical training,” presented at the Nanosensors, Biosensors, and Info-Tech Sensors and Systems, 2013, vol. **8691**, p. 869108.
[3] I. Robert-Bobée, “Projections de population pour la France métropolitaine à l’horizon 2050,” *INSEE PREMIÈRE*, Paris, Jul-2006.
[4] “Stephen Hawking Wheelchair – Intel® Technology Helping Others,” *www.intel.fr*. [Online]. Available: http://www.intel.com/content/www/fr/fr/internet-of-things/videos/dr-hawkings-connected-wheelchair-video.html. [Accessed: 29-Sep-2016].
[5] A. Martin, “Efficiency Evaluation of the Check@flash eHealth Solution,” in *EH 2014 Proceedings*, Lisbonne, Le Portugal, 2014.
[6] “Extraits de l’enquête INEUM (réalisée en 2006-2007 pour la CNSA) sur le marché français des fauteuils roulants.” Ineum Consulting, 2006.
[7] “NETTI 4U CED - netti-4u-ced.pdf.” .
[8] “PulseSensorAmpedGettingStartedGuide.pdf - 1562.405_en.pdf.” .
[9] “02 Intro to Arduino.pdf.” .
[10] D. Runberg, *The SparkFun Guide to Processing: Create Interactive Art with Code*. No Starch Press, 2015.
[11] “FlexiForce A201 Standard Force and Load Sensors - DatasheetA201.pdf.” .
[12] “Mescan, Révélateur de technologies | Capteurs et Systèmes de Mesure Innovants,” *Mescan*. [Online]. Available: http://www.mescan.com/. [Accessed: 15-Mar-2017].
[13] “ptsserie.pdf.” .
[14] “JUMO Thermoelement, Druckmessumformer oder Kompaktregler – Innovative Spitzenleistungen für Ihren Erfolg.” [Online]. Available: http://www.jumo.de/. [Accessed: 15-Mar-2017].
[15] “Product Specification 1323 Rev1 SCA11H Product Dat-780338.pdf.” .
[16] I. Starr and A. Noordergraaf, *Ballistocardiography in Cardiovascular Research: Physical Aspects of the Circulation in Health and Disease*. Lippincott, 1967.
[17] “X3 MedicalSeatSystem 02_11.pdf.” .
[18] P. Lennox-Kerr, “Current state of electrically conductive materials.” High Performance Textiles, 1990.

[19] “Habiletés motrices du blessé médullaire en fauteuil roulant manuel,” 09-Jan-2015. [Online]. Available: https://www.kineonline.fr/etudiants/memoires/habiletes-motrices-du-blesse-medullaire-en-fauteuil-roulant-manuel. [Accessed: 15-Mar-2017].
[20] “Non-invasive BCG monitoring for non-traditional settings - IEEE Xplore Document.” [Online]. Available: http://ieeexplore.ieee.org/abstract/document/7591795/?reload=true. [Accessed: 15-Mar-2017].