CALIBRATION AND APPLICATION OF A PRESSURE MAPPING SENSOR

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Abstract − The paper presents the hardware and software for the calibration of a pressure mapping system and the application of the sensor in ballistocardiography recording for humans vital signs unobtrusive monitoring.

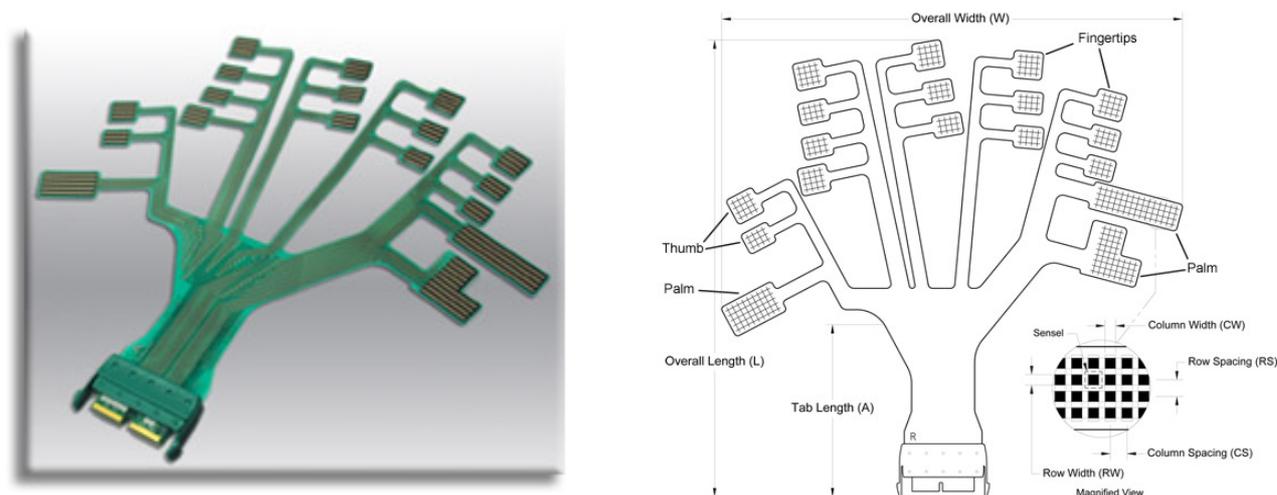**Keywords:** pressure mapping sensors, ballistocardiography, calibration

1. INTRODUCTION

Pressure mapping sensors are arrays of small size pressure sensors used in a variety of applications namely when the distribution of the force over a space region should be known. In some cases and applications, the information conveyed is related with the contact between two bodies and thus the name of tactile sensors for which they are known. Figure 1 shows a pressure mapping sensor based system used for ergonomics testing, to improved product design, in sports applications, and in robotics. The system uses a thin, high-resolution sensor that can be used directly on a hand or built into a glove. Each sensor has eighteen sensing regions. Each sensing region has multiple sensing elements (sensels) in a total of 349 [1].

Even in applications requiring essentially qualitative information (e.g. regions under higher and lower pressure), the calibration of pressure mapping sensing systems is fundamental to assure an adequate level of accuracy of the obtained data. Due to the constitution, size, number, and spatial position of the sensing elements of the sensors, the calibration requires special procedures based on dedicated hardware [2].

Vital signs unobtrusive monitoring on humans is an important research objective that implies the usage of different sensors. Some realization of the authors underlines the capabilities of electromechanical film sensors (EMFi) [3][4] embedded in daily used object as chairs and wheelchair to extract the cardiorespiratory activity using ballistocardiography (BCG) [5][6] [7]. BCG is a technique

	General Dimensions			Sensing Area Dimensions									
	Overall	Overall	Tab	Matrix	Matrix	Columns			Rows			Total	Resolution
	Length	Width	Length	Width	Height		Pitch			Pitch		No.of	
Model	L	W	A	MW	MH	CW	CS	Qty.	RW	RS	Qty.	Sensels	Sensel Density
US	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)		(in.)	(in.)			(sensel per sq. in.)
4256E	13.02	12.99	4.91	Various	Various	0.100	0.158	36	0.100	0.158	23	349	40.3
Metric	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		(mm)	(mm)			(sensel per sq. cm)
4256E	330.7	329.9	124.7	Various	Various	2.5	4.0	36	2.5	4.0	23	349	6.2

Fig. 1. Pressure mapping sensor with 18 active regions that can be individually placed on a hand (Courtesy of Tekscan, Inc.)

used to measures small movements of the body, imparted by the ballistic forces (recoil and impact) associated with cardiac contraction and ejection of blood and with the deceleration of blood flow through the large vessels informing about the overall performance of the circulatory system. After different implementations the challenge is to improve the quality of BCG wave used to extract accurate heart rate and respiration rate studying the relations between the pressure distributions caused by human body seat in a wheelchair and the BCG waves obtained with EMFi sensors as part of a BCG measuring system embedded in a wheelchair. The pressure distribution for different wheelchair users can be measured using a pressure mapping sensor. The paper presents and describes the hardware and procedure to calibrate such a sensor and results concerning the analyses of BCG wave acquired for different subjects and for a known seat and back pressure distribution and contact area on the people resting on a wheelchair are also included in the final version of the paper.

2. SENSOR CALIBRATION

The sensor used for ballistocardiography measurement is model 5530 from Tekscan (Fig. 2). The sensor is a 471.4 mm width and 471.4 mm height matrix of 1024 sensing elements (sensels) whose sensitive is 2.16 cm^2

A calibrator based on a programmable vacuum pump was developed for calibration in order to assure sort time calibration during ballistocardiography measurement sessions. The system, whose hardware block diagram is shown in Fig. 2, includes also a software component that assures the automatic calibration for different values of the negative pressure obtained through the usage of a vacuum pump UN811KVP from KNF Lab. The pressure values on the vacuum bag, where the sensor map under calibration is introduced and sealed are measured using a differential pressure sensor (26PCAFA6D from Honeywell) mounted on the vacuum line. The differential pressure sensor characterized by 0-760mmHg measurement range presents a Wheatstone bridge configuration, the output signal being amplified using an instrumentation amplifier (INA118). The amplified signal is applied to the analogue input of a NI USB-6008 multifunction board (m-DAQ) that assures
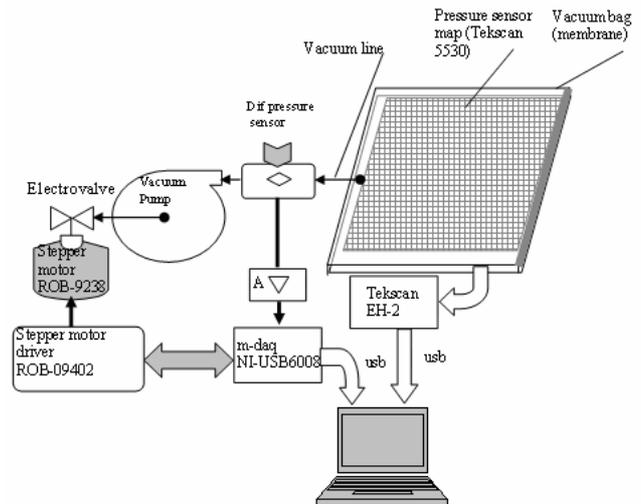

Fig.2. Pressure mapping sensor calibrator – hardware component

digital control of 2-phase stepper motor (ROB-09238) through the ROB-09402 driver included in the system. The stepper motor axis is mechanical coupled to the vacuum pump bleed valve that permits the automatic adjustments of negative pressures values in the -20mmHg to -160mmHg range.

Good results for statistical quantities calculation associated with image analysis provided by the Conformat Clinical system (Tekscan) for the position of ballistocardiography sensors embedded on a wheelchair requires errors less than 2% of the measuring range. The calibrator implemented allows such level of confidence.

3. RESULTS AND DISCUSSION

In order to obtain a quantitative information about the forces excited by the body on the wheelchair' seat and backrest and to establish a relation between the distribution of this forces and the quality of the BCG signals obtained from the EMFi sensors mounted on the wheelchair seat, pressure mapping sensor calibrating is needed. Based on the implemented calibration procedure, and analysing the images obtained from the Tekscan Conformat Clinical
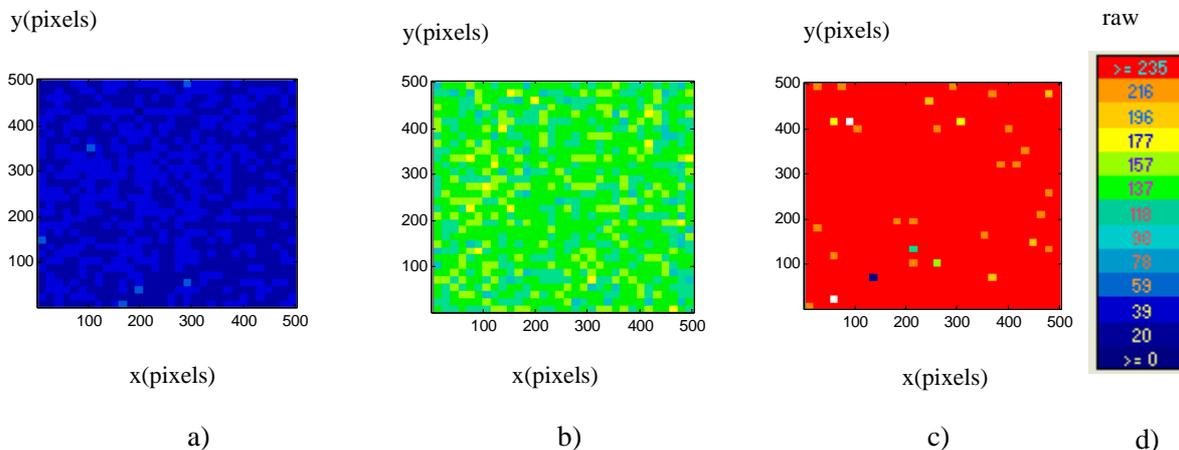

Fig.3. The distribution of the pressure on the 5530 level for different imposed calibration pressures

software, the calibration curves for each pixel of Tekscan 5530 sensor was carried out. The calibration curves express the evolution of the mean (μ_p), and standard deviation (σ_p) associated with pixel intensity distribution for gray images obtained after the conversion of the RGB images provided by the Tekscan software (Fig.3). In Fig. 3 are presented the distributed of the pressure sensed by the 32x32 sensels of the Tekscan 5530 obtained for -20mmHg (Fig. 3.a), -80mmHg (Fig. 3.b) and -160mmHg (Fig. 3.c). The colour scale associated with the measured pressures is presented in Fig. 3.d, and analysing the obtained figure can be concluded that the 5530' sensels present different sensitivities. In these conditions, the usage of statistical parameters, such as mean and standard deviation, to express the value of the applied pressure on the whole sensor surface represents a good option.

Using the implemented automatic calibration system, a set of pressures was applied on the mapping sensor surface. The evolution of mean and standard deviation are presented in Fig. 4.
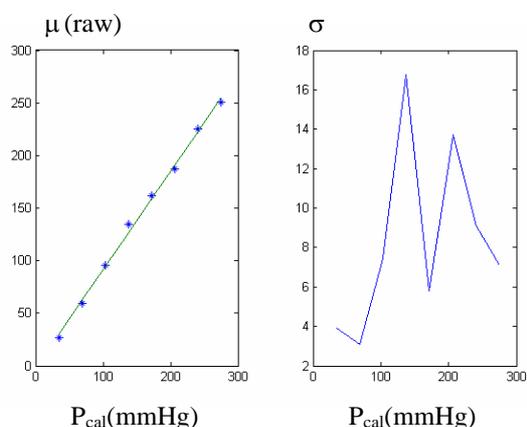

Fig. 4. The evolution of the mean and standard deviation for the pressure distribution images obtained, when uniform external pressure is applied, multiplied by the vacuum based calibrator constant (cal=1.72)

Using the experimental values (Pcal, raw), marked in the figure by '*', the linear approximation of the calibration curve was calculated to express the global sensitivity and the nonlinearity of the pressure mapping sensor. The obtained values were 0.93 raw/mmHg for sensitivity and 2.09% for non-linearity of the response.

Considering the aim of the work, and after pressure mapping calibration using the designed and implemented system, several tests were done using both the EMFi sensor and the Conformat sensor fixed on the wheelchair seat and wheelchair backrest. In Fig. 5 are presented the pressure distribution map and the ballystocardiography signal when both sensors are fixed on the seat.

The ballystocradiography shown in Fig.5 is expressed in normalized values and was obtained after filtering using a Bessel 20th order low pas filter implemented on the software component.

Additionally, a study concerning the BCG signal evolution obtained from the EMFi sensor mounted on the wheelchair back and the corresponding pressure distribution was carried out. Some results are presented in Fig. 6.

The forces that assure the preloading of the EMFi sensor are lower than the previous case that conducts to smaller values for BCG signal (the normalization factor is the same for BCGfilt_back and BCGfilt_seat acquired signals). At the same time can be highlighted the influence of the respiration movements when the EMFI sensors is mounted on the wheelchair' backrest.

4. CONCLUSION

Pressure mapping sensing systems provides important insight into both static and dynamic pressure events. Like all measuring systems, they require calibration to output data with the required accuracy. The number of sensing elements to calibrate requires hardware that can implement an automated calibration procedure. Sensing elements size and spatial distribution require ad-hoc hardware solutions. The calibrating system proposed verifies both conditions and is particularly suited for continuous monitoring of the metrology performance of pressure mapping sensors that are subject to continuous operation and thus tend to change their characteristics with time.
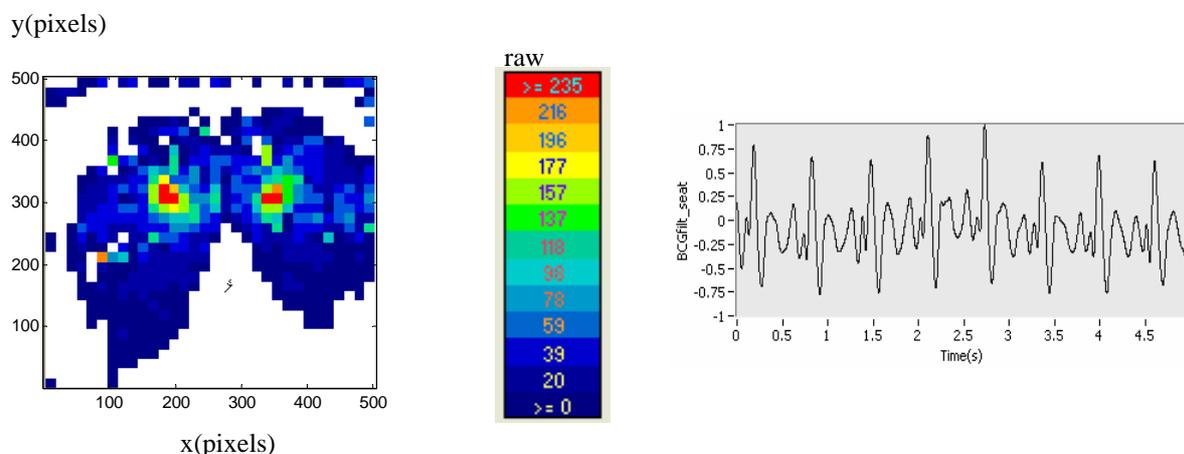

Fig. 5. The pressure distribution for a subject seated on the wheelchair and the ballistocardiography signal obtained from the EMFi sensor mounted on the wheelchair seat
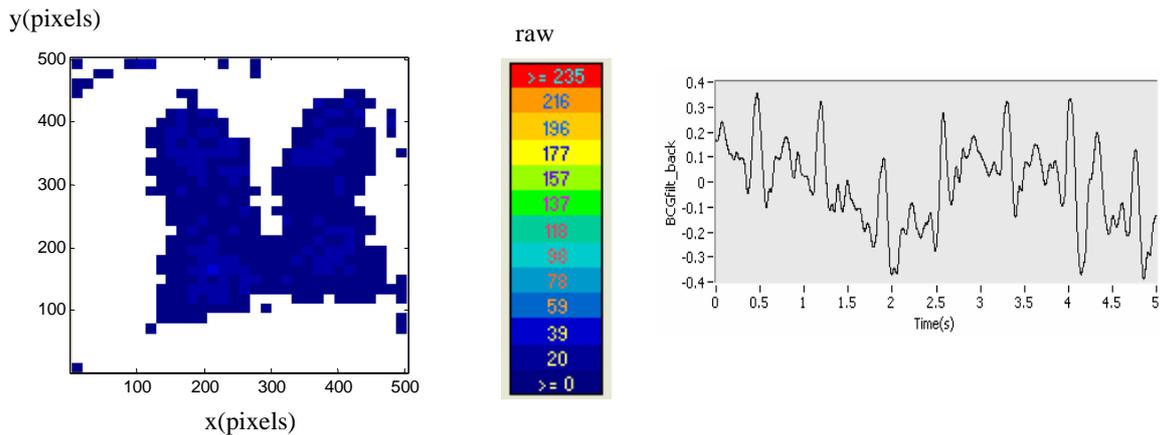
Fig. 6. The pressure distribution for a subject seated on the wheelchair and the ballistocardiography signal obtained from the EMFi sensor mounted on the wheelchair back

REFERENCES

[1] Tekscan, "4256 Map sensor - Grip – Hand grip and ergonomic studies", on-line at
http://www.tekscan.com/industrial/catalog/4256.html

[2] Jill M. Brimacombe, Carolyn Anglin, Antony J. Hodgson and David R.Wilson, "Validation Of Calibration Techniques For Tekscan Pressure Sensors", *Proc. of ISB XXth Congress - ASB 29th Annual Meeting July 31 - August 5*, Cleveland, Ohio, 2005

[3] M. Paajanen, J. Lekkala, K. Kirjavainen "ElectroMechanical Film_EMFi— a new multipurpose electret material", *Elsevier Sensors and Actuators*, No. 84, pp. 95–102, 2000

[4] M. Paajanen, H. Valimaki, Jukka Lekkala "Modelling the electromechanical film (EMFi)", *Elsevier Journal of Electrostatics*, No. 48, pp. 193-204, 2000.

[5] O. Postolache, P. Girão, G. Postolache, M. Dias Pereira, "Vital Signs Monitoring System Based on EMFi Sensors and Wavelet Analysis ", *Proc. IEEE Instrumentation and Measurement Technology Conf.*, Warsaw, Poland, Vol. I, pp. 3 - 7, May, 2007.

[6] O. Postolache, P. Girão, J M Joaquim; G. Postolache; "Unobtrusive Heart Rate and Respiratory Rate Monitor Embedded on a Wheelchair", *Proc. IEEE International Workshop on Medical Measurements and Applications*, Cetraro, Italy, Vol. 1, pp. 1 - 6, May, 2009.

[7] O. Postolache, P. Girão, J. Mendes, E. Pinheiro, G. Postolache "Physiological Parameters Measurement based on Embedded Sensors in a Wheelchair and Advanced Signal Processing", Accepted for publication in IEEE Instrumentation and Measurement, 2010.