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Advances in textile technologies for unobtrusive monitoring of vital parameters and movements.

Abstract—**Recent research and development activity is described in the field of textile-based wearable systems for personalized health care. Sensorized shirts for vital signs monitoring and wearable systems for gesture and posture recognition are specifically illustrated, resulting from the EU funded project My Heart.**

I. INTRODUCTION

SMART wearable health systems have the capability of supporting the extension/expansion of health services outside the domain of classical healthcare establishments, and monitoring patients over extended periods of time. New promising research recently emerged from the miniaturization of electronics and informatics, making possible the integration of multiple, smart functions into textiles [1].

Smart fabrics are conceived as innovative and high knowledge content garments, integrating sensing, actuation, electronic, and power functions. Due to their multifunctional interactivity, enabled by wearable devices, e-textiles are considered relevant promoters of a higher quality of life and progress in biomedicine, as well as in several health-focused disciplines, such as biomonitoring, rehabilitation, telemedicine, teleassistance, ergonomics and sport medicine[2].

European research has put forth a significant effort through the IST (Information Society Technologies) R&D programme of the European Commission, enabling the establishment of a dedicated, competitive research community able to provide innovative wearable health solutions for better disease management, disease prevention and health promotion.

MyHeart (www.hitech-projects.com/euprojects/myheart/) is a public research project funded by the European Commission in the 6th framework programme dealing with the prevention and early diagnosis of cardiovascular diseases. The project is a major research initiative by Philips and more than 30 other industrial and academic partners. The idea behind MyHeart is to apply continuous or periodic monitoring of vital signs, in order to gain knowledge about a person's health status. To achieve this, MyHeart integrates functional clothes with on-body sensors (textile and non-textile) and electronics into *intelligent biomedical clothes*. These are capable of acquiring, processing and evaluating physiological data. This paper reports about conception, design, implementation and preliminary testing of the different textile interface developed by WorkPackage 2 (WP2) of MyHeart to support application concepts activities.

II. TEXTILE INTERFACE IN THE FRAME OF MY HEART

WP2 is responsible for the production of a series of garments for use during the day, at night and also during sporting activities. These garments are required to provide to both the user and the medical practitioner, where appropriate, output information on the users state of health and mindset via embedded technology. Intelligent biomedical clothes are based on conductive and piezoresistive fabric developed to work as textile sensors, i.e. working as transducers of vital signs to electrical signals to be sent to a unit of microprocessors.

Garments expected are made of an integrated system collecting: standard clothing for support goal; sensors and connections made of yarns; non textile sensors; cable, micro-processing unit and other electronic devices (headphones, microphones, etc).

From the textile point of view, different yarns and material are used to realise the textile interface:

Ground yarn for the base of the clothing:

The ground yarn has to be elastic, light, comfortable, breathable and antibacterial since the garment may be required to be worn over a 12 hour period and also during sporting activities.

As an initial choice we are using the Meryl® Skinlife fibre produced by Nylstar. This fibre has permanent bacteriostatic properties, which means that it maintains a natural balance on the skin, regardless of activity level.

Conductive yarn for the electrodes:

In the last few years several yarns and fibres made of pure metals or with a combination of textile and metallic fibres have appeared on the textile market. Such yarns and fibres fall into two main categories: silver plated polyamide fibres and staple spun stainless steel yarns and stainless steel continuous filaments. To realise the second skin of the intelligent biomedical clothes, WP2 opted for **BEKINOX®**

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VS, a stretch-broken sliver of 100% stainless steel fibres produced by Bekintex1.

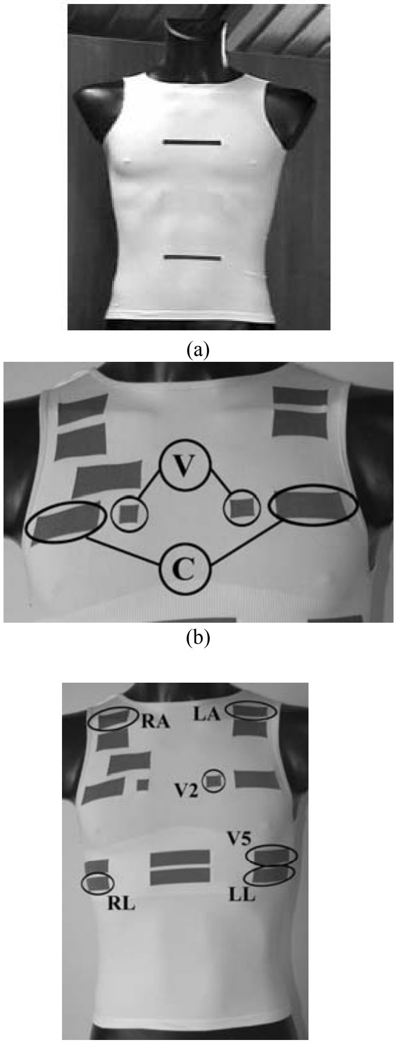
Piezoresistive yarn to monitor respiration signal:

To detect the body respiration movement, fabric sensors are knitted from piezoresistive yarns. A piezoresistive yarn is a conductive yarn combined with an elastic yarn, its electrical resistance changes with respect to the strain. To realise the piezoresistive sensors a carbon loaded polymer (a polyamide yarn with a carbon shell - Belltron 9R1 from Kanebo) has been used.

III. TEXTILE SENSING INTERFACES FOR CARDIOPULMONARY SIGNS MONITORING

A. Materials and Methods

Both electrodes and piezoresistive fabric sensors are processed with Santoni seamless knitting machines using intarsia technique, see Fig.1.



(a)

(b)

(c)

Fig 1: Knitted system for the acquisition:
a) abdominal and thoracic respiratory activity by piezoresitive fabric sensors
b) position of the fabric electrodes for impedance pneumography
c) position of the electrodes used for ECG acquisition

Fabric piezoresistive sensors signals are acquired using a voltage divider to convert resistance to voltage, gathered by an acquisition card (National Instruments PCI 6036) with sampling rate of 1000 Hz. The performance of fabric piezoresistive sensors as plethysmographic sensors is compared with that of a respiratory effort transducer, model SSL5B contained in the BIOPAC® MP30 system, this transducer is sensitive to changes in thoracic or abdominal circumference that occur during the respiratory activity .

The Conductive Elastomer (CE) we used is realized by a silicon rubber and graphite mixture and it can be smeared on an elastic fabric substrate according to the shape and the desired dimensions for the sensors by using an adhesive mask. This technology provides both sensors and wiring by using the same elastic material and avoids the use of obtrusive metallic wires which may bound movements of the kinematic chain under study. The production process to obtain sensing substrate is reported in [3].

The CE sensor gauge factor is about 2.8 and the temperature coefficient ratio is $0.08K^{-1}$. Capacity effects showed by sensors are negligible up to 100MHz. Complexity arises in the dynamical characterization, because the material shows several non-linear peculiarities. Moreover, after a feedback linearization, sensors need to be regulated to be used in our applications. This matter is widely described in [4]. By using Lycra® based fabric as a substrate we have obtained a sensing material which allows us to manufacture garments capable of monitoring human movements. In particular, by designing the spreading mask according to the location of the joints we desire to monitor, we have obtained meaningful information from Upper Limb Kinetics Garments (ULKG), which detects the posture of wrist, elbow and shoulder. ULKG has been developed by using the presented technology and it is going to be used in post-stroke patients rehabilitation. The ULKG is integrated in a health care service which allows patients to continue the rehabilitation training at home without the help of physicians, after the intensive rehabilitation period. The ULKG acquires information on the joints of the upper limb by 20 sensors spread on a shirt, and allows the monitoring of shoulder, elbow and wrist joints. Fig.2 shows the ULKG prototype, where all sensors are represented by the segment series which compounds the bold track.

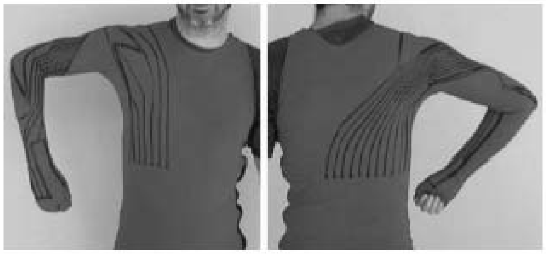


Fig. 2 ULKG prototype

Signals from electrodes, see Fig. 1c, were conditioned by using a device made by CSEM (www.csem.ch) able to gather five different ECG leads. ECG is sampled at 250Hz and transmitted by Bluetooth® or GPRS connection at 125 Hz.

Impedance pneumography methodology is used to monitor respiratory activity. In this case, four electrodes are placed on thoracic position, as shown in Fig.1b. The two external ones are used to inject a high frequency current (50 kHz) and the other ones to capture the voltage variation caused by thoracic impedance change. The impedance pneumography measurement is acquired by means of the same CSEM device. The respiratory signal is sampled at 16 Hz.

To improve the electrical signal quality in dynamic conditions, the electrodes have been wet.

B. Results

Fabric sensors improve comfort and wearability of health care device. Using these sensors is possible to obtain signals and performances comparable to gold standards. This system is able to acquire simultaneously five ECG leads as depicted in Fig.1c. The quality of such signals, an example is reported in Fig.3, allows an accurate analysis of possible cardiovascular diseases. A more accurate analysis of system performances has been reported on previous publication [5],[6].

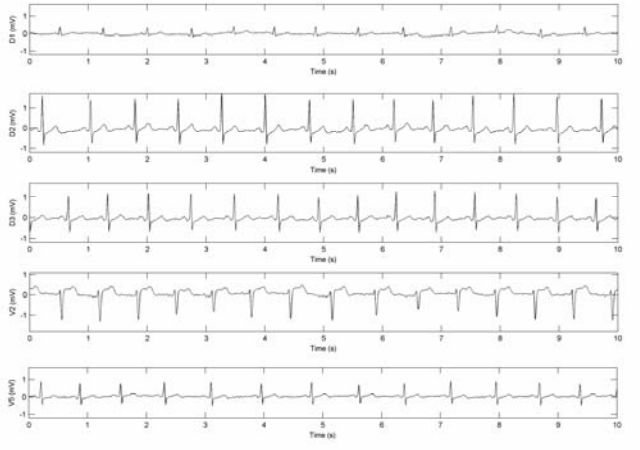


Fig. 3 Detail of the ECG signal in basal condition as recorded by fabric electrodes

Fig.4 shows the respiratory signal obtained by impedance pneumography. The trace allows to extract most of the interesting breathing parameters, such as respiratory rate, inspiratory and expiratory time and, after an appropriate calibration, the tidal volume [7], [8].

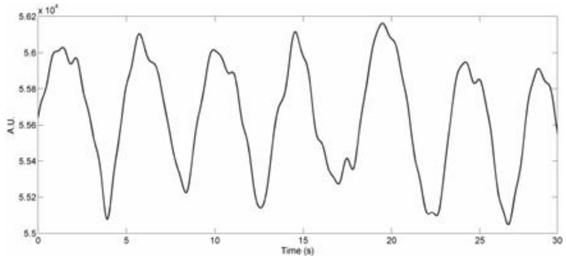
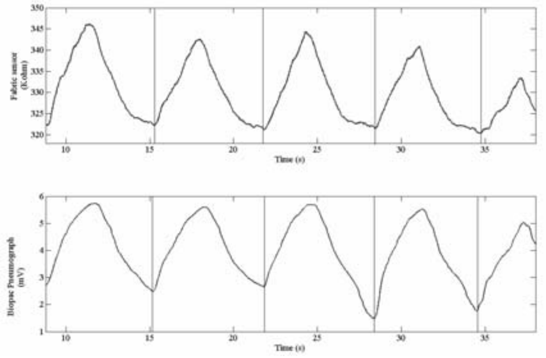
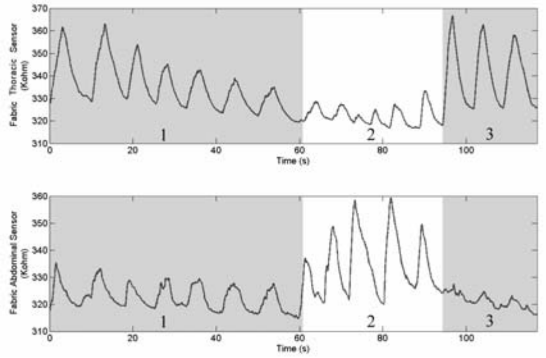


Fig.4 Respiratory signal obtained by impedance pneumography.

The comparison between the signals obtained placing both Biopac and fabric sensors in thoracic position, during normal respiratory activity is shown in Fig.5a. In order to calculate the respiratory rate it must be recognized the starting point of each breathing cycle. These points are identified by variation of slope signs, from negative or null to positive, these time values are reported in Fig. 5a as vertical lines. The observed perfect synchronicity of these time values proves the reliability of the fabric sensors.
Plethysmographic measure is intrinsically subjected to movement artefact, anyway during rest condition this methodology can provide information that are impossible to reach using impedance pneumography, such as the difference between abdominal and thoracic respiration.



(a)



(b)

Fig. 5: a) Signal derived by piezoresistive fabric sensor (upper) and Biopac pneumograph (lower) during normal respiration. b) Thoracic (upper) and abdominal (lower) respiration signal by fabric sensors.

In fact in Fig.5b are shown examples of different signals related abdominal and thoracic respiration acquired during breathing exercises. In section 1 respiration is normal, in section 2 respiration is predominantly abdominal, on the contrary, in section 3 is mainly thoracic. This is regularly pointed out by the comparison of the two signals.

Representative results from trials on the ULKG are reported. The device output (continuous line) is compared with the results of a motion detection executed by commercial electrogoniometers (dashed line). A composition of flexion and abduction of the shoulder (Fig.6) and a circling of the wrist (Fig. 7) are presented. The error is always less than 5%.

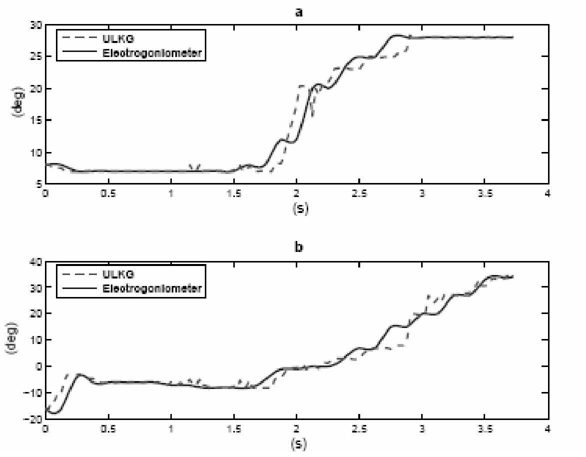


Fig. 6 Extension (a) and flexion (b) angles versus time of the shoulder. The continuous line is the goniometer output, while the dashed one represents the ULKG response

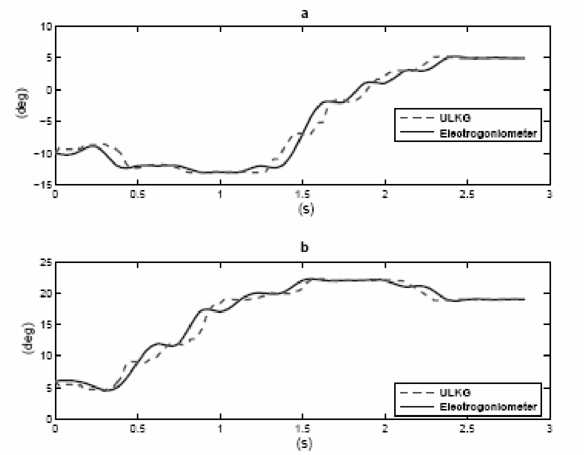


Fig.7 Flexion (a) and abduction (b) angles of the wrist versus time. The continuous line is the goniometer output, while the dashed one represents the ULKG response.

IV. CONCLUSION

In this work a collection of sensorised garments for monitoring vital signs and body gesture/posture has been presented. The main advantage ensured by these prototypes is the possibility of wearing them for a long period of time without discomfort. Several issues deriving from the employment of the new technology which has consented the realization of these unobtrusive devices have been addressed. Moreover, it has been pointed out the use of these sensorised garments as a valid alternative to existing instrumentation applicable in several health care areas. Finally, results on the performances of the sensing systems were briefly reported.

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