Knitted Bioclothes for Health Monitoring

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Abstract: **An innovative system named WEALTHY is presented, where conducting and piezoresistive yarns are integrated in a knitted garment and used as sensor and electrode elements. The system allows the simultaneous recording of vital signs as well as parameters' extrapolation and inter-signal elaboration that contribute to produce alert messages and synoptic patient table. The system aims to assist cardiac patients during rehabilitation phase, patients can be continuously followed during selected time intervals, such as during physical activity or occurrence of symptoms, to discover potential threats, to tailor the best medical treatment for long term care, and to generate appropriate alerts to patient, physician or emergency medical systems. The system can also assist professional workers subject to considerable physical and psychological stress and/or environmental and professional health risks. Finally, by providing direct feedback to the users, WEALTHY can act on the level of awareness and allow better control of their own condition**.

Keywords—**Fabric sensors, fabric electrodes, integration**

I INTRODUCTION

An emerging need of renovation in health managing system, where people needs to be more and more conscious of their health status, and more interactive with the social assistance services is driving new approaches to health care supervising. Remote health monitoring needs the use of tools based on wearable sensing interfaces, easy to use and easy to be customised; the new interfaces must guarantee to users a continuous remote control, in a "natural" environment without interfering with daily activity.

Sensing interface designed to be minimally invasive, based on flexible technologies conformable to human body, are cost-effective in providing assistance, for example in rehabilitation from cardiac diseases or in the prevention of acute crisis, and for the monitoring of professional workers engaged in extreme environmental conditions. In these systems functionalised yarns are used to manufacture woven or knitted garments possessing distributed functionalised regions. Conductive and piezoresistive yarns are integrated and used as sensors, connections and electrode elements, in a comfortable, well fitting, integrated cloth. The simultaneous recording of vital signs allows parameters extrapolation and inter-signals elaboration [1] that contribute to make alert messages and personalized synoptic tables of patient's health.

II METHODOLOGY

WEALTHY System Functions

WEALTHY system is developed as the integration of several function modules, as has been presented in previous works [2,3]. The main functions of the modules are namely sensing, conditioning, pre-processing, data transmission and remote monitoring.

The WEALTHY patented interface [4] is connected with the WEALTHY device named portable patient unit (PPU) where the local processing as well as the communication with the network is performed.

Most signals are transmitted unprocessed to the Monitoring System where they can be analyzed off-line.

Local pre-processing of signals has been applied on the ECG signal in order to extract heart rate value.

In order to reduce the needed data capacity of the wireless link to the Central Monitoring System, some sensors signals are processed by the PPU to extract essential parameters.

The PPU is designed to have a simple user interface with two LEDs and a buzzer for user-warning purpose and a button to let him manually trigger an alarm.

The final action is to classify those parameters to detect an event. Several statistical tools based on a multifunctional analysis, such as PCA or IDA, may be used for this purpose.

In order to offer full mobility to the patient or the user, acquired signals are wirelessly transmitted from the PPU to the remote Monitoring System. The communication is based on TCP/IP that is the standard protocol for GPRS communication. All signals are sent in quasi real-time to the remote Monitoring Centre.

The Central Monitoring System is organized in the following modules:

- Web Server
- Database Server
- Client Application module
    - Central Control module
    - Doctor's Desktop/Laptop module

Alert functions are implemented in the monitoring system by means of an intelligent signals correlation, the system can be personalised and an appropriate set of information can be delivered to a professional target and used to set synoptic patient table.

All the above modules are able to run on a single computer without the need of dedicated high-end servers.

Garment Model and Realisation

Strain fabric sensors based on piezoresistive yarns, and fabric electrodes realized with metal based yarns, enable the realization of wearable and wireless instrumented garments capable of recording physiological signals, to be used during the routinely activity, to be wear instead of a classical garment without any discomfort for the user. Respiration, electrocardiogram, electromiogram, activity sensors, temperature, can be listed as physiological variables to be monitored through the proposed system.

In Figure 1 is shown the prototype model, electrodes and breathing sensors position, while in Figure 2 is shown the position of movement sensors.

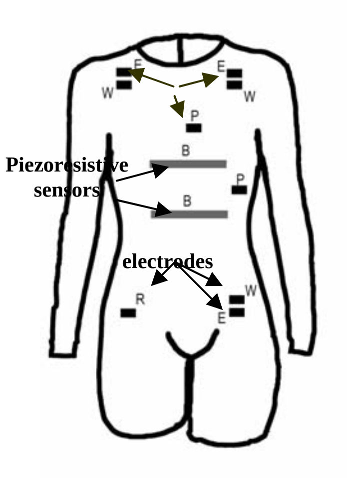

Fig.1: Prototype model, E Einthoven, W Wilson, R Referee, P Precordial leads, B Breathing sensors.

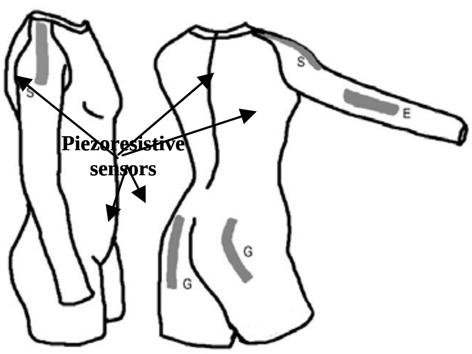

Fig. 2: Movement sensors.

A particular of the textile prototype is shown in Figure 3.

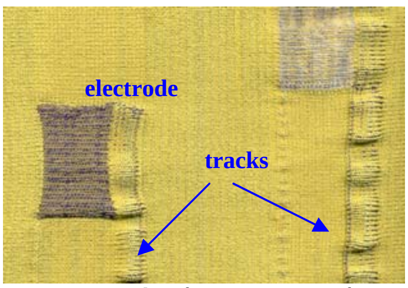

Fig.3: Particular of WEALTHY interface

An alternative strategy to measure respiratory activity is the use of the impedance pneumography [5]. In this case four electrodes are placed on thoracic position. The two external ones are used to inject a high frequency current (50 kHz) and the other ones allow capturing the voltage variation caused by thoracic impedance change. The output signal is modulated by changes in the body impedance accompanying the respiratory cycle. The change in impedance corresponding to each respiratory cycle is of the order of 1-4 % of the base impedance. The relationship between impedance change ΔZ and volume of air moved (ΔV) is approximately linear under most circumstances. In Figure 4 is shown the position of the electrodes for the impedance pneumography.

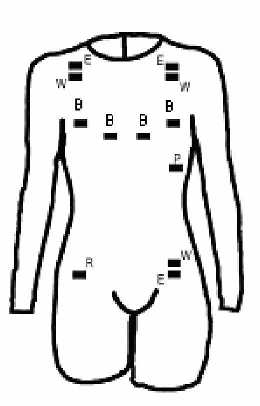

Fig.4: Electrodes position for impedance pneumography

III RESULTS

WEALTHY system is an innovative tool able to provide improved health care to users. The integration of multiple parameters and their continuous transmission to a monitoring clinical center makes the system quite unique and different from currently used medical devices [6].

In Figure 5 is reported an example of simultaneous acquisition of signals obtained from ECG leads and piezoresistive sensors during movement (left shoulder and elbow) and respiration (abdominal and thoracic), an enlargement of the ECG signals is shown in Figure 6.

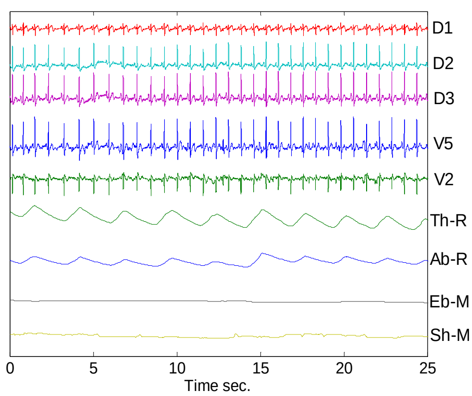

Fig.5: Signals in basal condition, D1, D2, D3 Einthoven leads I, II, III. V2, V5: Standard precordial leads V2 and V5. Th-R, Ab-R: Respiration sensors on thoracic and abdominal position respectively. Sh-M, Eb-M: Movement sensors on the left shoulder and elbow, respectively.

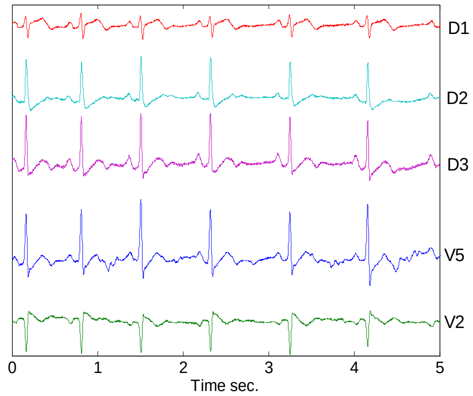

Figure 6: Enlargement of ECG signals in basal condition

The same signals has been acquired during some movements, for instance during the complete flex-extension of the elbow. In Figure 7 are shown the results of this experiment and Figure 8 an enlargement of the ECG signals.

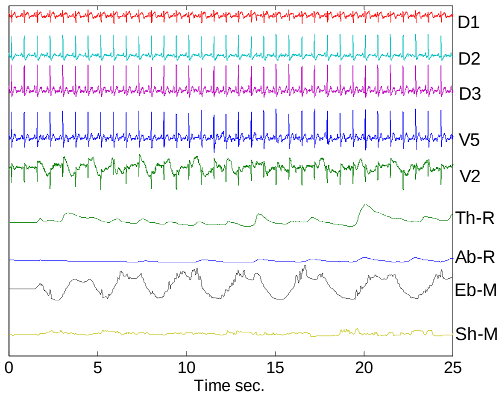

Figure 7 Signals obtained during flex-extension of the left elbow

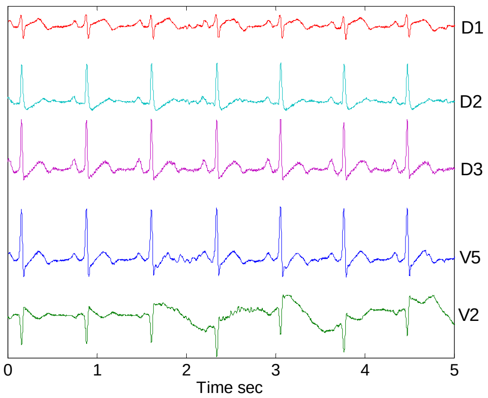

Figure 8 Enlargement of ECG signals during flex-extension of the left elbow

Acquiring more ECG leads is possible to select the more meaning signal. Movement artefacts are present only in one lead, as shown in Figure 8 so the other ones can give sufficient information. A cross-talking between the sensor on the shoulder and the one on the thorax can be done analysing the signals. The signal obtained by the shoulder sensor can help in revealing artefacts on the thoracic respiration sensor, due to movement.

In Figure 9 and 10 are shown examples of acquisition of signals using the prototype with the electrodes for the impedance pneumography. The standard precordial leads V5 and V2 are recorded simultaneously with the activity respiratory.

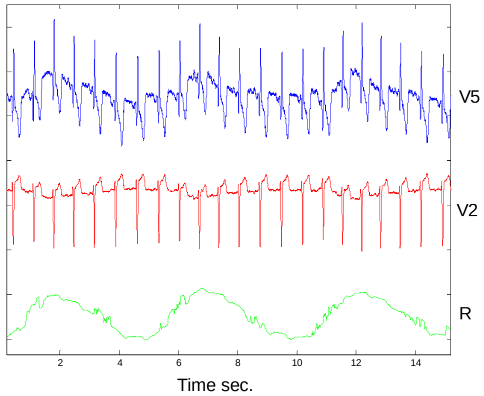

Figure 9: Standard precordial leads V5, V2 and respiratory activity (impedance pneumography)

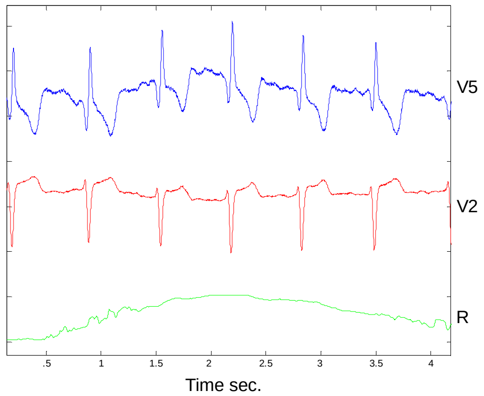

Figure 10: Enlargement of signals shown in Figure 9.

IV DISCUSSION

The most innovative character of this system consists in the use of functionalised materials in form of fibers and yarns which can be knitted or woven into a multifunctional sensing fabric. The achieved results [2, 3] show that the basic sensing features on which vital sign recording is based can be implemented using integrated knitted sensors and electrodes.

Previous authors works [7] have shown that low frequency mechanical signals of cardiopulmonary origin (respirator signals, ballistogram) or generated by body segments relative motion (kinesthesia) have been recorded by textile strain gauges. Finally bioelectric potentials related to cardiac or skeletal muscle activity (ECG, EMC) have been faithfully recorded by metal based fabric electrodes.

The integration of these different components with appropriate elastic electrical conductors and properly designed connectors to the wearable electronic unit leads to a comfortable wearable cloth which has no counterpart in any existing monitoring system [6].

These new integrated knitted systems enable applications extending even beyond the clinical area and open new possible applications in sport, ergonomics and monitoring operators exposed to harsh or risky conditions (fire fighters, soldiers etc.).

The possibility of simultaneously recording different physiological signals provides an integrated view of normal and abnormal pattern of activity which could be otherwise impossible to be detected by recording each signal in different time. Finally it must be outlined that the possibility of recording physiological variables in a more "natural" environment may help to identify the influence of the psycho-emotional state of the subject in the performance of a physical activity. This is not easily detectable when recording is done within a protected (medical) environment. A further innovation is the in-context data interpretation. While a simple telemonitoring system would just transmit or record real-time physiological signs, the WEALTHY system will be able to process physiological parameters in context, so that appropriate feedback can be given to the patient.

V CONCLUSION

The system is addressed for the monitoring of patients with heart diseases who are at intermediate risk (i.e. not requiring hospitalisation but requiring a close home/outpatient care); for example, those recovering from an acute heart attack or from cardiac surgery and those with severe chronic heart failure. Professional personnel at risk, (working alone, working in a dangerous environment), subject to physical and physiological stress can also be assisted during their performance without any impediment to their activity.

The innovative approach of this work is based on the use of standard textile industrial processes to realize the sensing elements. Transduction functions are implemented in the same knitted system, where movements and vital signs are converted into readable signals, which can be acquired and tele transmitted.

Fabric sensors, electrodes and connections are all integrated in textile material, making possible to fulfill the purposes of this work, by giving to target groups the capability to perform normal daily activity while clinical status is monitored by a specialist, without any discomfort.

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