WEARABLE HEALTH CARE SYSTEM FOR VITAL SIGNS MONITORING - MEDICON 2004 Conference

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Abstract: An innovative system named WEALTHY is presented, where conducting and piezoresistive materials in form of fiber and yarn are integrated in a garment and used as sensor and electrode elements. The simultaneous recording of vital signs allows parameters' extrapolation and inter-signal elaboration that contribute to produce alert messages and synoptic patient table. The system can be used to assist cardiac patients during rehabilitation, not only by caring physicians to have an accurate description of clinical status of the patient at fixed and repeated time points in order to tailor the best medical treatment for long term care, but also allow the patient to be continuously followed during selected time intervals, such as during physical activity or occurrence of symptoms, to discover potential threats and 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.

Introduction

The new generation of technological tools, in particular in the field of telecommunication, has trained people to be continuously in "touch" one each other. This virtual – link is revolutionary in the way of feeling, and if coupled with innovative sensing architectures could be revolutionary also in the way of acting. There is an emerging need of renovation in our health managing system, people needs to be more and more conscious of their health status, and more interactive with the social assistance services. A remote health monitoring can be accepted and used only if the monitoring devices is based on wearable sensing interfaces, easy to use and easy customised; the new interfaces must guarantee to users a continuous remote control, in a "natural" environment without interfering with daily activity.

This need is both socially- (the rising cost of assistance, the need to improve early-illness detection and medical intervention) and technologically-driven. Sensing interface designed to be minimally invasive, based on flexible technologies conformable to human body, are also cost-effective in providing assistance, for example in rehabilitation from cardiac disease or in the prevention of acute crisis, and for the monitoring of professional workers engaged in extreme environmental conditions. Finally, by providing direct feedback to the users, they can act on the level of awareness and allow better control of their own condition. In these systems functionalised yarns are used to manufacture woven or knitted garments possessing distributed functionalise regions. Conductive and piezoresistive yarns are integrated and used as sensors, tracks and electrode elements. The simultaneous recording of vital signs allows parameters extrapolation and inter-signal elaboration [1] that contribute to make alert messages and personalized synoptic tables of patient's health.

WEALTHY System

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.

A miniaturized short-range wireless system can be integrated in the sensitive garment and used to transfer the signals to WEALTHY box/PCs, PDA and mobile phones.

Alert functions can be 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. The system is addressed for the monitoring of patients with heart disease 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.

WEALTHY Functions

WEALTHY system is developed as the integration of several function modules. The main functions of the wearable modules are shown in Figure 1, namely: sensing, conditioning, pre-processing, and data transmission.

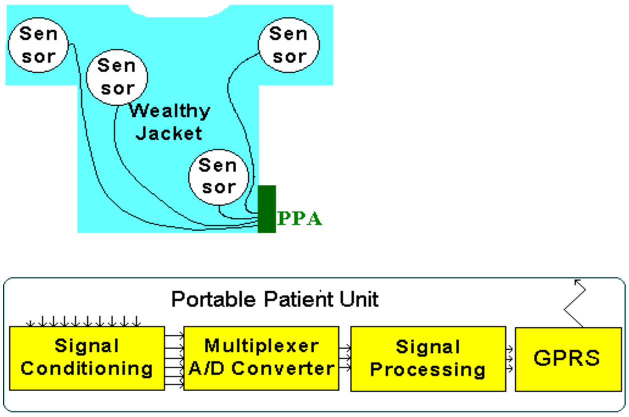

Figure 1: Overview of wearable WEALTHY's modules

The garment interface is connected with the portable WEALTHY device 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.
Off-line processing, depending on the application, is carried out at the monitoring center. A preliminary list includes:

- RR distance and tachogram
- QRS duration
- Level of the T wave with respect R wave
- T wave area

In order to reduce the needed data capacity of the wireless link to the Central Monitoring System, some sensors signals are processed by the portable patient unit (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
  - Doctor's PDA module

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

Materials and Methods

Fabric piezoresistive sensors:

Piezoresistive fabric sensors have been realised by using lycra® fabric coated with carbon loaded rubber [2] and commercial electroconductive yarn (PAC 250 dtx x 1 , by Europa NCT, Poland). These fabrics behave as strain gauge sensors and show piezoresistive properties in response to an external mechanical stimulus. The coated lycra® fabric has been used to detect respiration signal, due to the higher efficient shown in term of quality of the signal, compared with the other fabric sensor. The Europa yarn has been used for the activity sensors and knitted in the multifunctional fabric. The behaviour of a knitted piezorestive sensor is different when stretched towards warp or weft direction. Preliminary tests have been done to select the more efficient technique of knitting and the direction of stretching. The fabric sensor have been integrated and designed in the way to maximise the gauge factor according with the response shown during the preliminary tests.

Fabric electrodes:

The conductive sensors (electrodes) have been realized with a yarn where two stainless steel wires are twisted around a viscose textile yarn (Elitè by Lineapiù SpA, Italy). Electrodes were knitted by using tubular intarsia technique to get a double face, where the external part is not conductive to isolate the electrode from the external environment. The basal yarn (not sensitive) was the same yarn used as core for the conductive electrode yarn. To improve the electrical signal quality in dynamic condition a hydro gel membrane purchased by ST&D Ltd (Belfast-UK), has been used. This affects also the comfort as electrodes have a rough surface and a prolonged contact with the body can give rise to skin irritations.

Tracks:

Tracks have been realized by means of tubular intarsia technique. A supplementary layer has been woven by using of vanisé technique. The final tracks is a multi layered structure were the conductive surface is sandwiched between two insulated standard textile surfaces. The same conductive yarn is used for the electrodes as well as for the realization of the tracks.

Garment model and realisation:

Knitting fabric has been made with a flat-knitting machine (Vesta Vx 12 – Steiger).
A draft position of sensors was implemented on the knitted fabric, and then by means of the use of models was possible to cut the fabric in a way to get the sensors in the desired configuration. The garment was finally

sewed, which means that the final positions of sensors and tracks was achieved in the manufacturing phase.
In Figure 2 is shown the prototype model, electrodes and breathing sensors position, while in Figure 3 is shown position of the movement sensor.

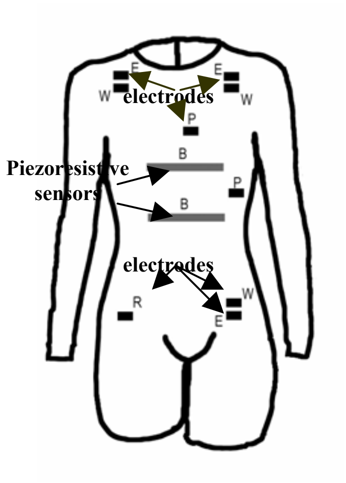

Figure 2: Prototype model, E Einthoven, W Wilson , R Referee, P Precordial leads, B Breathing sensors.

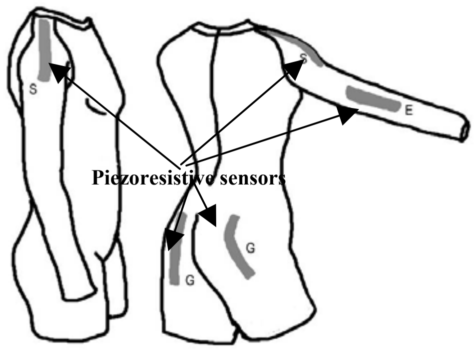

Figure 3: Movement sensors.

Washability and reusability

Conductive yarns and fabrics are resistant to repeated washing in aqueous solutions, the washed electrodes can be used to detect ECG signal, the signals detected shown that the performances of the conductive fabric are not affected by the washing process.

Results

WEALTHY system is an innovative device 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.
In Figure 4 is reported an example of simultaneous acquisition of signals obtained from ECG leads and piezoresistive sensors for movement (left shoulder and elbow) and respiration (abdominal and thoracic).

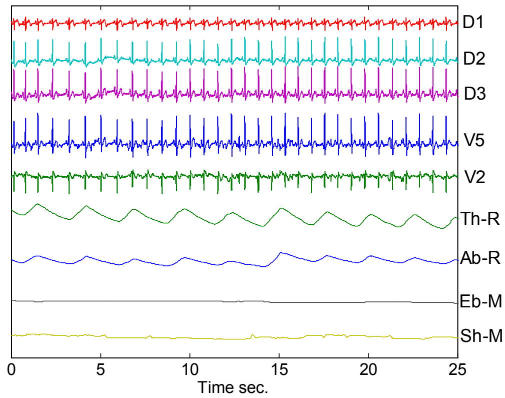

Figure 4: Signals in basal condition, D1, D2, D3 Einthoven leads I, II, III. V2, V5: Standard precordial leads V2 and V5. Th-R, Ab-R: Respiration sensors on thoracic and abdominal position respectively. Sh-M, Eb-M: Movement sensors on the left shoulder and elbow, respectively.

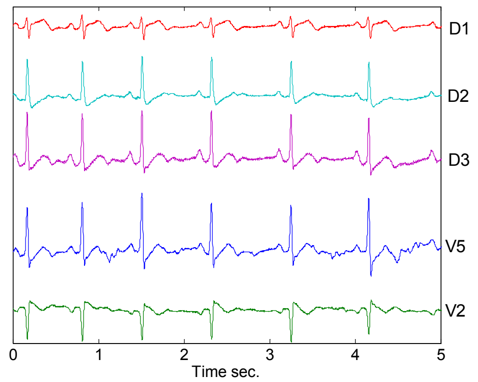

Figure 5: Detail of ECG signal in basal condition

The same signals has been acquired during some movement, for instance during the complete flex-extension of the elbow. In **Figure 6** are shown the results of this experiment and in **Figure 7** an enlargement of the ECG signals.
Acquiring more ECG leads is possible to select the more significative signal. Movement artefacts are present only in some leads, as shown in **Figure 7** 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 noticed analysing the signals. In this case, the signal obtained by the shoulder sensor can help in the revealing of artefacts on the thoracic respiration sensor, due to movement.

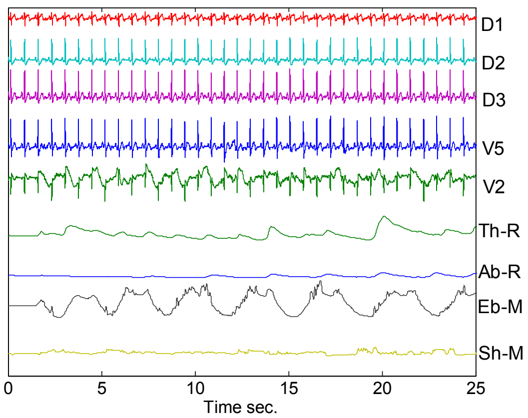

Figure 6 Signals obtained during flex-extension of the left elbow

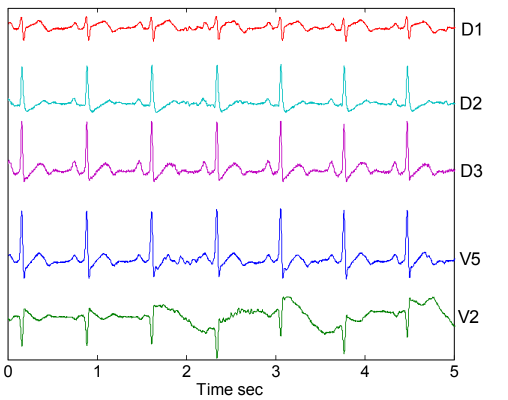

Figure 7 Detail of ECG signals obtained during flex-extension of the left elbow

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 [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 [4] 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 [5].
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.

Conclusions

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 perform normal daily activity while clinical status is monitored by a specialist, without any discomfort.

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