Proceedings of the 25th Annual International Conference of the IEEE EMBS
Cancun, Mexico • September 17-21, 2003

KNITTED BIOCLOTHES FOR CARDIOPULMONARY MONITORING

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Abstract-A new concept in healthcare, aimed to provide continuous remote monitoring of user vital signs, is emerging. An innovative system named WEALTHY is presented, where conducting and piezoresistive materials in form of fiber and yarn are integrated 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 will 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 will 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.
Keywords- Wearable, healthcare, fabric sensors, integration.

I. INTRODUCTION

A new concept in health care, aimed at providing continuous remote monitoring of patient vital signs, is now emerging. This paradigm shift is both socially driven- the rising cost of assistance, the need to improve early illness detection and medical intervention- and technologically driven. In particular, the advances in sensor technology, as well as in communication technology and treatment of data, constitute the basis on which this new generation of health care systems can consolidate. Systems designed to be minimally invasive, based on flexible and smart technologies conformable to the human body help to improve the autonomy and the quality of life of patients. They are also cost-effective in providing around-the-clock assistance, in helping physicians to monitor cardiac patients during rehabilitation phase, in decreasing hospitalization time. Finally, by providing direct feedback to the users, they improve their awareness and potentially allow better control of their own condition.

In these systems conductive and piezoresistive materials in form of fiber and yarn are used to realize clothes where knitted fabric sensors and electrodes are distributed and connected to an electronic portable unit, these systems are able to detect, acquire and transmit physiological signals. The simultaneous recording of vital signs allows parameters extrapolation and inter-signal elaboration that contribute to produce alert messages and personalized synoptic tables of patient's health.

II. 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 and to be used by the patient during the everyday activity. Breathing pattern, electrocardiogram, 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.

An "intelligent" system for the alert functions, able to create an "intelligent environment" by delivering the appropriate information for the target professional is the complementary function to be implemented.

The system is addressed for the monitoring of patients with heart disease during and after their rehabilitation.

III. WEALTHY FUNCTIONS

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

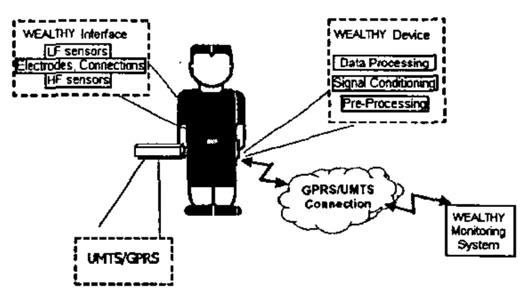

Fig. 1: Overview of WEALTHY system

The garment interface is connected with the portable WEALTHY device where the local processing as well as the communication with the network is performed.

A knitted fabric platform containing insulated conductive tracks connected with sensors and electrodes has been implemented to make the cloth.

- The work has been funded by European Commission in the 5TH Framework Programme IST

A particular of the textile prototype is shown in Fig. 2.

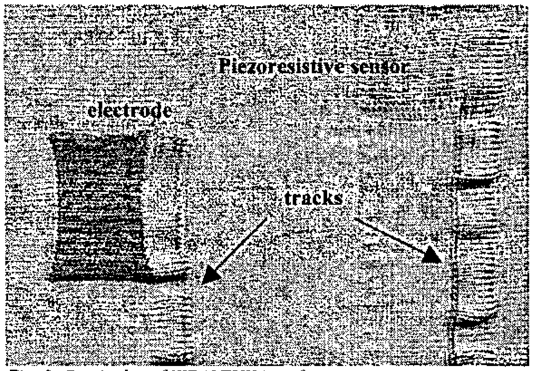

Fig. 2: Particular of WEALTHY interface

Most signals are transmitted unprocessed to the Monitoring System where they can be analyzed off-line. 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. Local pre-processing of signals have to be decided in a trade-off between the gain in term of wireless link occupancy and the increase of needed local processing power.

The heart rate is a good candidate for local extraction from the ECG trace, where a relatively high resolution is needed for the computation of vital parameters, but a lower resolution is sufficient to be presented graphically to the doctors.

Off-line processing, depending on the wanted diagnosis, will also be made at the monitoring centre. A preliminary list includes:

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

The PPU is designed to have a simple user interface, a few LED 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, the acquired signals are transmitted wirelessly 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.

Fig.3 below shows the overall view of WEALTHY monitoring system.

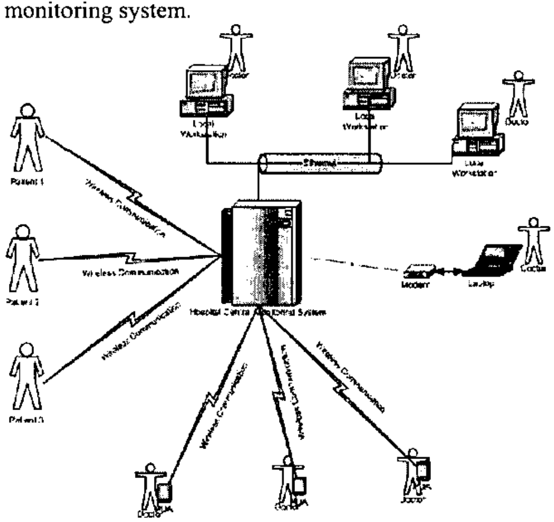

Fig. 3: The overall of WEALTHY monitoring system

The WEALTHY platform will give the possibility to monitor and assist patients through a remote medical advice service. The use of intelligent systems provide to physicians the data to timely detect and manage health risks, early illness diagnose or injury, recommend treatment that would prevent further deterioration and, finally, to make confident professional decisions based on objective information - all in a reasonably short time.

IV: SIGNALS ANALYSIS and RESULTS

WEALTHY system for cardiac patients will represent a telemedicine device to provide improved out of hospital care. 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.

Standard Holter ECG (24 hour continuous recording of 2-3 ECG leads) or ambulatory blood pressure devices are actually simple recorders that need to be put on and then removed in hospital or clinics. Data analysis is off-line and only a delayed medical response can be generated when abnormalities are detected. These systems are therefore used to reach a non urgent diagnosis (for example verify that palpitations referred by a patient are due to cardiac arrhythmias) or to obtain a spot control on the efficacy of therapy (for example of a drug that lowers blood pressure), yet they are not practical when medical data have to be obtained more frequently.

WEALTHY will more closely resemble a monitoring device, such those use in intensive care units, that can continuously transmit ECG, respiratory trace, etc and are extensively used for the management of critically ill patients. The experience gained with these devices can be used for some of the features of the WEALTHY: automated ECG analysis and alarm generation, monitoring of respiratory function, etc. Moreover the transmission of the ECG by freely moving subjects will be close to the situations encountered in clinical ECG stress testing in which detection of ECG signs of myocardial ischemia is possible.

The system can be used by patients for selected time intervals, i.e. a few hours every day or a few hours for a few days a week. This will allow:

1) Collect sufficient data on the clinical status of the patient on a regular basis (e.g. recording of heart and respiratory rate for one hour every morning during rest and common activities) in order to provide an optimally tailored therapeutic strategy.
2) Monitor patients during activities which are particularly demanding for the cardiovascular system to check for threatening situations (e.g. the patient could wear the system when willing to perform more than ordinary physical activity).
3) Monitor patients during regularly prescribed cardiovascular and respiratory training to provide an effective telerehabilitation program.
4) Monitor patients when they experience critical symptoms to have an immediate medical control.

Longer uses of the system, such as the whole day or the whole night, can be advised for frailer patients or in the effort to diagnose the cause of sporadically occurring intermittent symptoms (such as palpitations due to a self terminating arrhythmia or chest pain due to myocardial ischemia). A continuous use (24 hours every day) of the system is not expected since only very critically ill patients would need it, but they should be in a hospital and not at home.

As the system enables the simultaneous acquisition of differentiated physiological parameters, this approach allows the definition of new indexes correlated to the whole set of recorded signals.

In Figure 4 is reported a typical set of ECG and respiration activity signals recorded simultaneously with our textile sensors.

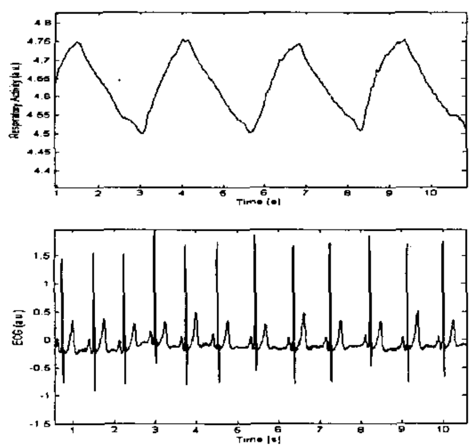

Fig. 4 Respiration activity and ECG trace

The ECG and the respiration signals can be correlated, one of the most significant result is given by the possibility to study the sympatho-vagal balance [1,2]; it is possible for instance to evaluate the time variations of the R-R interval of the QRS component and check the correlation among respiration and heart activity.

A derivative/threshold algorithm provides the series of RR intervals (tachogram) that are used to draw the power spectral density using an FFT based approach.

The same approach is used on the curve (respirogram) obtained by sampling the respiration signal in correspondence with the R-R peaks. Two major oscillatory components are usually detectable in RR variability, one of which, synchronous with respiration and related to parasympathetic activity, is described as HF (High Frequency, about 0.25 Hz and varying with respiration), whereas the other, corresponding to the slow waves of arterial pressure and mainly related to sympathetic activity, is described as LF (Low Frequency, about 0.1 Hz). The LF-to-HF ratio can thus be calculated to provide an indication of the sympatho-vagal balance.

Negative emotional stimulus, for a period of 3min (such as pictures of mutilations, car crash, etc), was administrated to subject following a long lasting (18 min) normal relaxation period. Hearth and respiratory rate increase during the negative emotional stimulus with respect to the relaxed period. The increasing of hearth rate (RR distances in the tachogramm) was associated to RR spectral indices changes. In particular, it is expected that sympatethic activity LF increase and parasympathetic activity HF decrease during emotional period, as shown in Fig.5 and Fig. 6.

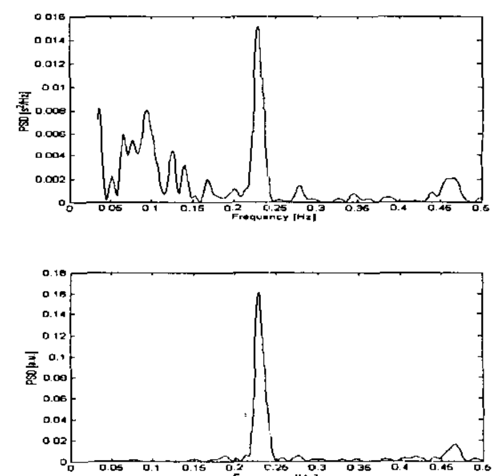

Fig. 5 PSD analysis Fig. 3 PSD analysis tachogram and respirogram during relaxation period

The signals obtained with subject during the relaxation phase are reported in Fig. 5, as can be seen, there are two peaks in the HF region in both the analyzed signals during the relaxation phase, this behavior underlines the correlation between the respiration activity and the cardiac activity, under the control of the para-sympathetic system.

In Fig. 6 is reported the PDS analysis of tachogram and respirogram during the emotional phase, looking at the cardiac signal, there is an increase of the peak value in the LF range, while the peak value in the HF domain decrease. In the same time the respiration and cardiac activity are no longer correlate, this can be associate with the preponderance of sympathetic activity.

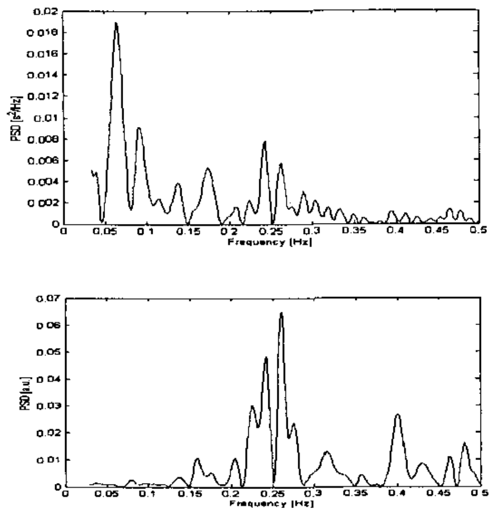

Fig. 6 PSD analysis of tachogram and respirogram during emotional period

Taking the example of cardiac monitoring (using such variables as heart rate, ECG abnormalities, estimates of Central Venous Pressure, oxygen saturation), the integration of these variables is best done with model-based diagnosis rather than rule-based decision systems.

DISCUSSION

The most innovative character of this system consists in the use of smart 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 [4,5] 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.

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.

In our fabric sensors, electrodes and bus structure are all integrated in textile material, making possible to perform normal daily activity while our clinical status is monitored by a specialist, without any discomfort.

ACKNOWLEDGMENT

The author would like to thank all the European partners involved in the project: University of Pisa, Italy; Centre Suisse d'Electronique et de Microtechnique, Switzerland; Atkosoft S.A., Greece; INSA de Lyon, France; Istituto Scientifico H San Raffaele, Italy; CRSSA, France; Messe Frankfurt GmbH, Germany.

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