WEARABLE HEALTH CARE SYSTEM FOR VITAL SIGNS MONITORING

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***Abstract*-A new concept in healthcare, aimed to providing continuous remote monitoring of user vital signs, is emerging. An innovative system named WEALTHY is presented, were smart material in fiber and yarn form endowed with a wide range of electrophysical properties (conducting, piezoresistive, etc) are integrated and used as basic elements to be woven or knitted in fabric form. The simultaneous recording of vital signs allows parameters' extrapolation and inter-signal elaboration that contribute to make alert messages and synoptic patient table. WEALTHY system is implemented by integrating computing techniques, smart sensors, portable devices and telecommunications, together with local intelligence and decision support system. The system will assist cardiopathic patients during rehabilitation or subjects working in extreme stressful environment conditions.**
Keywords-Wearable, healthcare, 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. At the same time systems designed to be minimally invasive for health status monitoring, based on flexible and smart technologies conformable to the human body will help to improve the autonomy and the quality of life of patients. They are also cost-effective in providing around-the-clock assistance, for example in rehabilitation from cardiac disease or for the monitoring of professional workers engaged in extreme environmental conditions. Finally, by providing direct feedback to the users, they improve their awareness and potentially allow better control of their own condition.
In these systems smart materials in fiber and yarn form endowed with a wide range of electro-physical properties (conducting, semiconducting, electro-strictive, piezoresistive, etc) will be integrated and used as basic elements to fabricate woven or knitted fabrics possessing distributed sensor and logic functions. The simultaneous recording of vital signs will allow parameters extrapolation and inter-signal elaboration that contribute to make alert messages and personalized synoptic tables of patient's health.

II.WEALTHY SYSTEM

Strain sensors based on piezoresistive yarns, piezoelectric Polyvinylidene fluoride PVDF pressure sensors and electrodes realised with fabric containing metal, enable the realization of truly 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, pressure, temperature, can be listed as physiological variables amenable the monitoring 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, will be implemented.
The system is addressed for the monitoring of patients with heart disease during and after their rehabilitation and of subjects engaged in extreme stressful conditions

III. WEALTHY FUNCTIONS

An overview of the technology in WEALTHY is shown below in Fig. 1, where the main phases of the process are shown, namely: sensing, pre-processing, transmission, processing and data management.

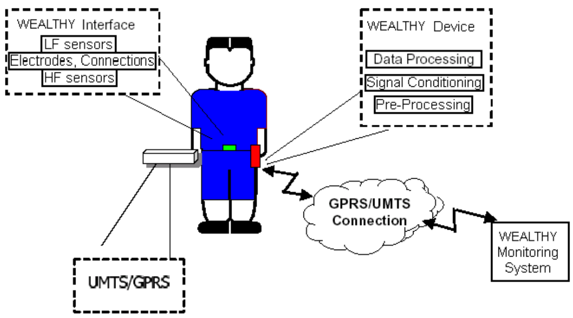

Fig. 1: The processing and communication mechanism

The garment interface is connected with the portable WEALTHY device where the local processing as well as the communication with the network is performed.
The pre-processing and processing locations depend on the selected physiological parameters. One of the main goals of the digital processing stage is to compress or even directly extract the most appropriate features to reduce communication data rates and expenses for the selected physiological parameters.
This processing may typically make use of neuro-fuzzy or other advanced processing techniques like wavelet processing, particularly suited to extract weak biomedical signals from a noisy environment (due to the user movements and activities) and to dramatically reduce the data volume.

The system enable the simultaneous acquisition of differentiated physiological parameters, this feature allows the implementation of an innovative approach to the study of health status by giving a powerful instrument for the definition of new indexes correlated to the whole set of recorded signals.
A "smart" fabric containing insulated conductive wires connected with sensors and electrodes has been used to make the garment. The whole system behaves primarily as a woven circuit port where the electronic signals detected by the electrodes and sensors will be led by means of the conductive threads of the fabric to the reading and processing station. This may either be placed on the garment or the signals may reach it by telemetry.
The intended instrumental set-up will include a number of channels sufficient to guarantee a good acquisition of ECG signals, thus to allow an efficient remote continuous monitoring. This will allow the prevention of critical phase by relaying the information to the doctor (or a suitable medical call centre) in case of alarm and providing feedback to the users and suggestions to the patients about the frequency and intensity of physical activity.
Fig.2 below shows the overall WEALTHY architecture. The system improves user comfort by avoiding wiring harnesses and by using 3G (GPRS/UMTS) wireless communication between the portable communication gateway and the mobile network. This feature allows use of the tele-monitoring system both indoor and outdoor. From the user point of view, the garment and its processing and communication units are miniaturized, and no physical connections with the fixed station for data retrieval will be provided. This helps keep user comfort unaltered. The physiological data to be monitored are transmitted, after suitable processing, to the monitoring system.

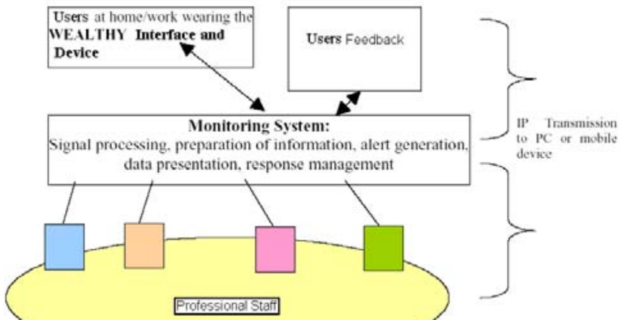

Fig. 2: The overall WEALTHY design

The WEALTHY platform will, therefore, comprise an "intelligent" system for the alert functions. It will be able to create an "intelligent environment" by delivering the appropriate information for the target professional in the most friendly and suitable way by using advanced telecommunications protocols and software development technology and tools.

A strong contribution to medical assistance can be given by the possibility to monitor and assist patients through a remote medical advice service. The use of intelligent –based systems provided 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

The long period analysis of ECG signal performed with several electrodes allows a complete observation of heart functionality, which is of basic importance in many cardiac pathologies, particularly in myocardial ischemia. The most important aspect is the acquisition of the ECG signal from a number of electrodes positioned on the thorax and the limbs. This will allow a quite good mapping of the walls of the heart.
The portable devices for ECG acquisition now commercially available usually only allow 3 acquisition channels and such configuration is enough for a simple analysis of ECG frequency and the identification of arrhythmia but not for monitoring the rehabilitation process. Commonly used holters for long period acquisition of ECG signal perform the acquisition from 3 electrodes so that successive acquisitions with different positions can be performed. Again, such information is useful for the frequency analysis of the signal and the identification of cardiac arrhythmia but is not enough for more complex investigations.
Scientific publications indicate that respiratory rate is the most sensitive respiratory parameter, but non-specific sign of respiratory dysfunction, while tidal volume estimates are sufficiently accurate for clinical decision making in children and adults under resting, sleeping and exercising conditions.
When respiratory function is recorded separately from each hemithorax, it will be useful to detect possible asymmetries in tidal volume and phase relations between right and left sides. Starting from rate and volume indexes, a number of other respiratory parameters can be computed, such as ventilation, fractional aspiratory time, both aspiratory and expiratory flows over mean aspiratory flow as well as the phase and amplitude relation between abdominal and rib cage respiratory patterns. In addition, the same set of sensors will yield a wide series of respiratory indexes useful for diagnosing several clinical conditions affecting respiratory dynamics.
Respiratory drive signifies neural respiratory center activity. The gold standard for measuring this drive is the diaphragmatic electromyogram, an invasive, technically difficult procedure that is not practical for home monitoring. Peak aspiratory flow and peak aspiratory acceleration, which can be easily obtained from the thoracogram, have been found to be a good substitutes for diaphragmatic electromyogram in measuring respiratory drive. Several clinical respiratory phenomena can be characterized by the

ratio of breath-by-breath ventilation divided by respiratory drive. For example, the ratio of ventilation to respiratory drive distinguishes psychogenic from organic causes of breathlessness and this may help to distinguish between a patient with chronic pulmonary and cardiac diseases from a patient with chronic anxiety.

In addition ECG signal can be used to evaluate the time variations of the R-R interval of the QRS component and Respiratory Sinus Arrhythmia (RSA) to study the sympatho-vagal balance [1,2]. In fact, a derivative/threshold algorithm provides the series of RR intervals (tachogram) that are used to provide the power spectral density using an FFT based approach. 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, 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. As shown in Fig.3. The increasing of hearth rate (RR distances in the tachogramm) was associated to RR spectral indices changes. In particular, is expected sympatethic activity LF was increased and parasympathetic activity HF was reduced during emotional period, as shown in Fig.4.

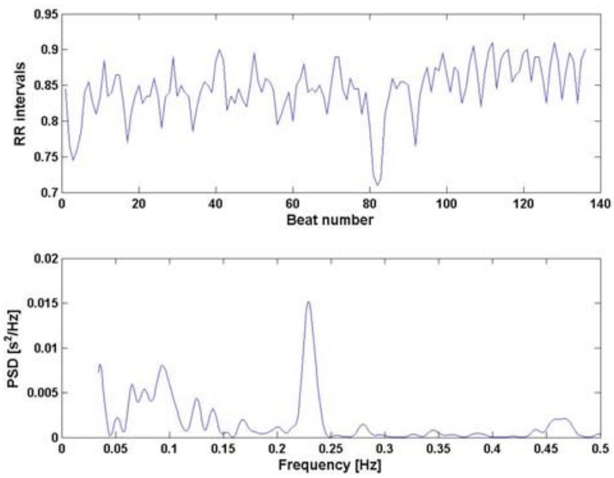

Fig. 3 Tachogramm and PSD analysis during relaxation period

From RR signal it is also possible to identify non-linear heart rate dynamics by analyzing entropy measures (E). The reduction of E may be predictive of cardiac disfunctioning.

In addition, Respiratory Sinus Arrhythmia (RSA), computed as the difference between the longest electrocardiographic RR interval during expiration and the shortest RR interval during aspiration, can be used as an index of the balance between sympathetic and parasympathetic neural activity: high values are linked to an increase of parasympathetic activity, and low values a predominance of sympathetic activity [3,4,5].

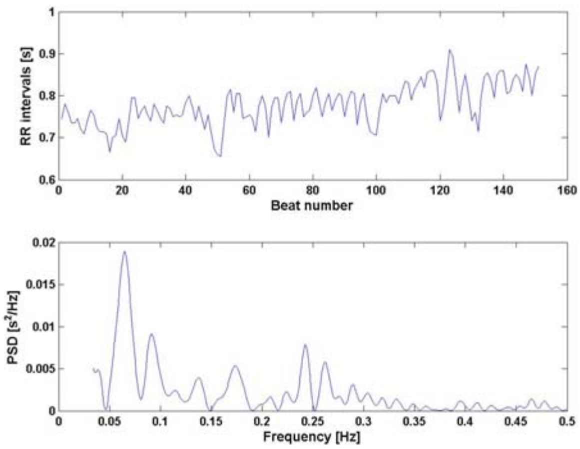

Fig. 4 Tachogramm and PSD analysis during emotional period

In some cases, though, physiological parameters cannot be directly interpreted. This is the case, for example, in the monitoring of complex situations (e.g. congestive heart disease), or if one wants to monitor several different conditions with the same system (e.g., cardiac, pulmonary and metabolic disease). Taking the example of cardiac monitoring (using such variables as heart rate, ECG abnormalities, estimates of Central Venous Pressure, estimates of oxygen capillary saturation), the integration of these variables is best done with model-based diagnosis rather than rule-based decision systems.

Model-based diagnosis in clinical medicine can only be implemented when a pathophysiological model is available, but this is generally the case where physiological parameters are monitored, especially in cardiology. Besides, a model-based representation facilitates the generation of explanations, including the generation of causal explanations that are required to give feedback and advice to the patient in non-technical terms.

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. Preliminary work done by the authors [6] has shown that the basic sensing features on which vital sign recording is based can be implemented using wearable fibers and yarns.

Low frequency mechanical signals of cardiopulmonary origin (respirator signals, ballistogram) or generated by body segments relative motion (kinesthesia) have been faithfully recorded by fiber strain gages made of polypirrole (a π-electron conjugated conductive polymer) treated cotton/lycra fabric [7,8] or carbon loaded rubber coatings onto cotton/lycra yarns.

High frequency mechanical signals have also been recorded by ferroelectric polymers (PVDF) thin elements which can be spun into wearable yarns. These high frequency signals proved to be essential to detect peripheral pulse (carotid, wrist) and even, under controlled conditions sounds of cardiopulmonary origin.
Finally bioelectric potentials related to cardiac or skeletal muscle activity (ECG, EMC) have been faithfully recorded by woven stainless steel fabrics.
The integration of these different components with appropriate elastic electrical conductors and properly designed connectors to the wearable electronic unit will lead to a truly wearable garment which has no counterpart in any existing monitoring system.
State of the art and advanced textile technology is used in the components integration also considering comfort and form fitting components, leading to new woven or knitted systems enabling applications extending even beyond the clinical area to open new avenues in sport, ergonomics and monitoring operators exposed to harsh or risk conditions (fire fighters, soldiers etc.)
The possibility of simultaneously recording different physiological signals provide an integrated view of normal and abnormal pattern of activity which could be otherwise impossible to detect 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.

CONCLUSION

Leveraging the disparate materials, technologies and techniques available within the established electronics and textile industries is leading to a totally new class of large-area, flexible, conformable informative /interactive systems; essential instrumental functions (power supply, sensor, actuator, processor) can be implemented onto fabric substrates [7], as proved by the recent realization of “all-polymer” devices acting as active electronic components (transistors) and “all polymer” batteries.
The innovative approach of this work is based on the use of standard industrial processes to realize the sensing elements. Transduction functions are implemented in the same woven system, where movements and vital signs are converted into readable signals, which can be acquired and tele transmitted.
In others systems, as the Smartshirt system (Sensatex), the sensors are realized by adapting existing technology to the garment, from a technological point of view the innovative idea is given by the use of optical fibers woven into the fabric, while the sensors are plugged in the connection clips. For the Lifeshirt system (Vivometrics) the innovative aspect is not contained in what it measures and how, but what it can be done with the resulting information.
In our fabric sensors, electrodes and bus structure are all integrated in textile material. Physiological data detected are intrinsically redundant; with this configuration it is also possible to increase the efficiency of the system by reducing motion artifact signals.

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