WEARABLE SYSTEM FOR VITAL SIGNS MONITORING

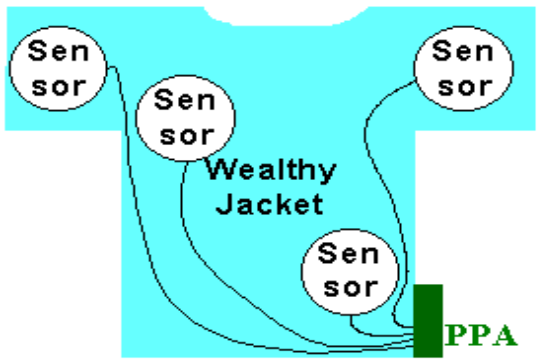
Rita Paradiso, Gianni Loriga, Nicola Taccini, Maria Pacelli, Roberto Orselli
Milior-Smartex
Via Giuntini 13 L , Navacchio Italy

Abstract
A new concept in healthcare, aimed to provide continuous remote monitoring of user's 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. Cardiac patients in rehabilitation phase can be continuously monitored during selected time intervals, such as during physical activity or occurrence of symptoms, to discover potential threats and generate appropriate alerts to patient and/or to a emergency center.
The core of the system sensing is a textile interface, in which the sensing components are elements of the fabric: the sensorised garment is comfortable like a common article of clothing and is realized with knitting machineries; furthermore, the position of the electrodes and sensors is fixed and the elasticity of the fabric allow a good fitting to the body. The system is provided of a portable electronic unit, where signals are acquired, elaborated and transmitted. A monitoring system allows extrapolation of new physiological index, data flow coordination as well as alarms management and data base creation.
Key words: Wearable, healthcare, fabric sensors, integration.

Introduction
An emerging need of our society, used to a more and more advanced telecommunication technology, is the continuous contact with a supervisor external system during normal daily activity as well as during extreme and at-risk activities. This need is both socially- (the rising cost of assistance, the need to improve early-illness detection and medical intervention) and technologically-driven. In particular, advances in sensor technology, as well as in communication technology and treatment of data, constitute the basis on which a new generation of health care systems can consolidate. Monitoring systems designed to be minimally invasive, based on flexible technologies conformable to human body, easy to use and endowed with a monitoring system customable to the specific user, represent the latest generation of health care instruments. They 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 improve their awareness and allow better control of their own condition. In these systems the electro-physical properties of materials in fiber and yarn form are used to implement woven or knitted fabrics possessing distributed sensor and logic functions. 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 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 and to be used during the everyday activity. 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.
An "intelligent" monitoring system for the alert functions, able to deliver 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 and to professional personnel at risk (working alone, working in a dangerous environment, etc.).

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.



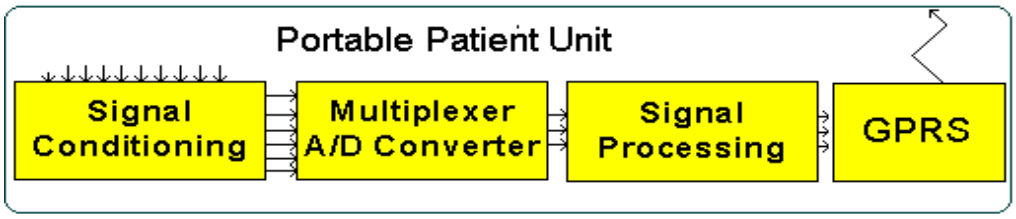
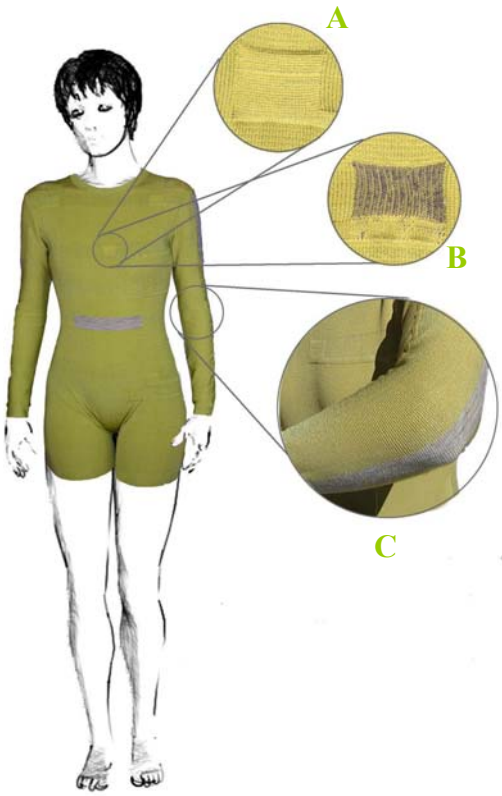


Figure 1: Overview of wearable WEALTHY's modules

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



A knitted fabric platform containing insulated conductive tracks connected with sensors and electrodes is implemented in the garment.

The textile prototype is shown in Figure 2.

In the windows A and B is shown the electrode and the related track on the face and back side of the cloth, the conductive yarn is visible only on the back side where the fabric is in contact with the body.

In the window B is visible the piezoresistive sensor. The body is realized with knitting technology, as can be observed from the figure, specific yarns are confined in a predefined insulated region by means of intarsia technique. The elasticity is increased by coupling an elastomer to the other yarns during the working process, high elasticity allows freedom of movement and comfort as well as prevents formation of pleats and crumples. The goal is to find a right compromise between the thinness and handle of cloth and the sensitiveness of yarn, from which depends the sensor features. The prototype is made with flat-knitting machineries.

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.

Figure 2. Textile prototype, (A) particular on the external view of electrode and track, (B) internal view of electrode and track, (C) particular of moving sensor

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, will be also be made 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

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

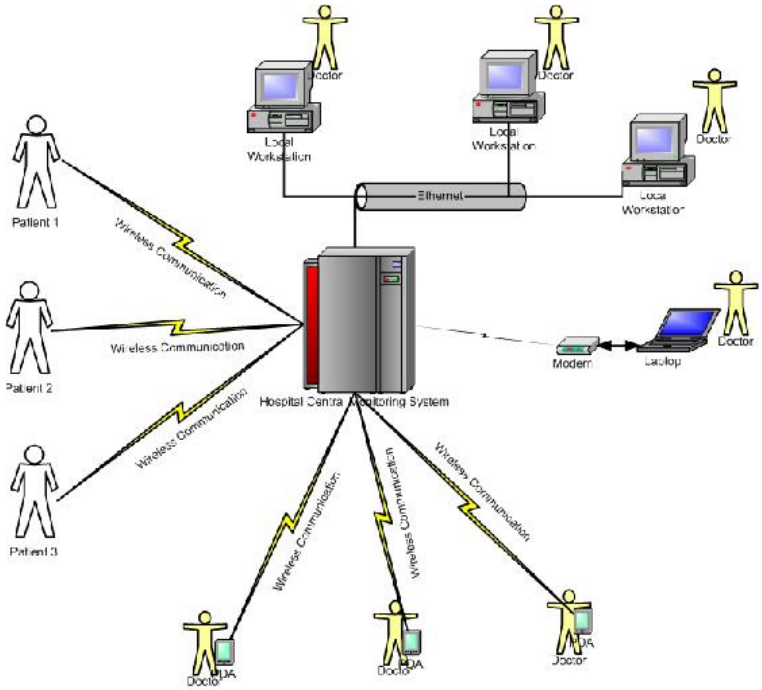


Figure 3: The overall of WEALTHY monitoring system

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

SIGNALS ANALYSIS and 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.
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 more closely resembles to a monitoring device, like those used in intensive care units, that continuously transmits 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 where detection of ECG signs of myocardial ischemia is possible.
In Figure 4 is reported a typical set of ECG and respiration activity signals recorded simultaneously with the textile prototype.

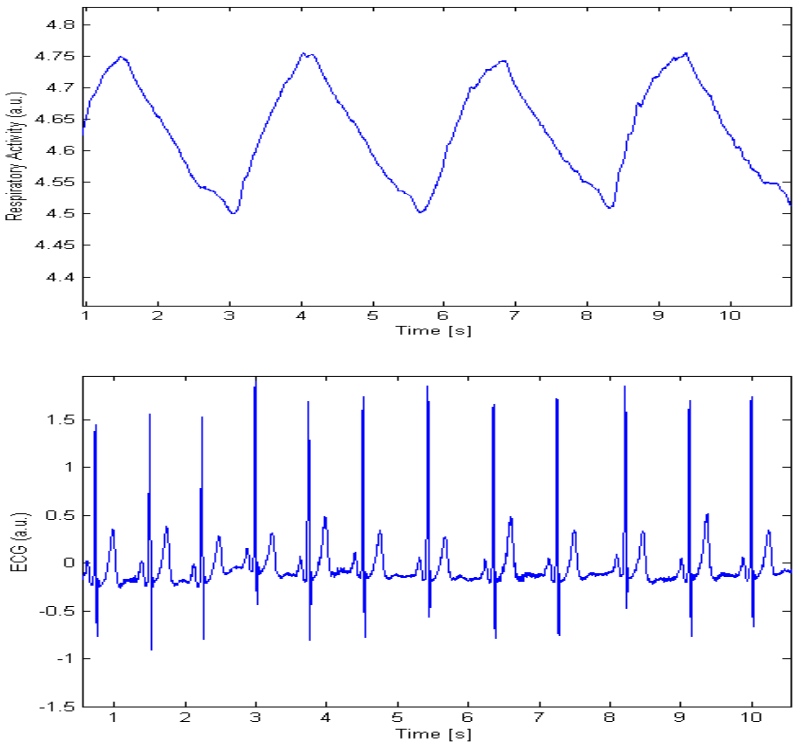


Figure 4 Respiration activity and ECG trace

DISCUSSION
The most innovative character of this system consists in the use of functionalized materials in form of fibers and yarns which can be knitted or woven into a multifunctional sensing fabric. The achieved results [1] show that the basic sensing features on which vital sign recording is based can be implemented using integrated knitted sensors and electrodes. The possibility to knit sensors, electrodes and tracks in the same textile material allows the design of a interactive platform that is manufactured in unconventional way.
Nevertheless, a material to be processed with textile machineries must satisfy very strict requirements in term of mechanical and chemical properties, and for our purposes also in terms of electrical properties.
The potentiality of using textile facilities is linked to the realization of fibers and yarns suitable to be used in the most sophisticated knitting machineries; the fineness, the composition, the mechano-elastic properties of yarns play key roles in this process. The final characteristics of the integrated textile structure are modulated by a series of factors, starting from the material, the combination of yarns, the textile processes, up to the final finishing step. An efficient, wearable, comfortable sensing system is the result of a balance among performance, number, position of the active elements, and lightness, comfort and conformability of the final cloth.
Previous authors works [2,3,4] 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.
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 (firemen, 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 this system , electrodes and bus structure are integrated in textile material, making possible to perform normal daily activity while the user clinical status is monitored by a specialist, without any discomfort.

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