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## Instrumented Wearable Belt for Wireless Health Monitoring

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### Abstract

The ability to monitor the health status of elderly patients or patients undergoing therapy at home enables significant advantages in terms of both cost and comfort of the subject. However, such non-clinical applications of biomedical signal monitoring require various improvements not only in terms of size and comfort of the acquisition systems, but also in terms of their power dissipation. The research activity is concerned with the development of a novel wearable biomedical signal sensor device for monitoring health conditions at home. The wearable monitoring system consists of two subsystems: firstly, a wearable data acquisition hardware, where the sensors for acquiring the biomedical parameters are integrated, and secondly, a remote monitoring station placed separately and connected to internet for telemedicine applications. The physiological parameters that are monitored with the proposed instrumented wearable belt are electrocardiogram (ECG), heart rate (HR) derived from ECG signals by determining the R-R intervals, body temperature, respiratory rate, and three axis movement (acceleration and position) of the subject measured using an accelerometer. In order to design and construct the signal acquisition circuits efficiently and simply, modular design concept is adopted in this research. Three basic high quality and flexible modules for signal conditioning are designed and assembled together for satisfying each sensor. Human biomedical parameters can be registered and analyzed continuously during home work activities. Proper evaluation of those parameters would let immediately know about sudden health state changes, accidental injury or another menacing danger befalling patients at home.

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*Keywords:* Body measurement; Electrocardiography (ECG); Wearable sensor; Cardiorespiratory signal measuring; Heartbeat; Respiratory cycle; Home healthcare; Sleep condition monitoring

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### 1. Introduction

In recent times, home healthcare related to the elderly people has attracted more and more attention. For aged people living at home, physiological parameter measurement is often a basic possibility to let immediately know about sudden health state changes or accidental injury. However, such non-clinical applications of biomedical signal monitoring require various improvements not only in terms of size and comfort of the acquisition systems, but also in terms of their power dissipation. Important parameters for design are portability, comfort to wear, long duration, and monitored signals. In the literature there are different types of devices for measuring human physiological

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parameters and a growing interest is noticed. In [1] a smart shirt, which measures electrocardiogram (ECG) and acceleration signals for continuous health monitoring, is designed and developed. However, the possibility of measuring the respiratory activity is also crucial to check the patient health status. Medical investigations have proven that the most important parameters are those that specify the work of heart and respiratory system. In [2] a smart vest is described that consists of a wearable vest with sensors integrated for monitoring physiological parameters. However, acceleration and position of the subject are not monitored. In [3] the wearable system transmits the data to the patient's PDA (personal digital assistant) phone through Bluetooth and further to doctor's PDA phone through Global System for Mobile communication (GSM) technology. However the PDA phone solution is probably not the best solution for elderly patients, for a monitoring at home, the use of the internet connection is easier and less expensive. Hence, the purpose of this research is to develop a novel wearable sensor device for long time and unconscious monitoring of patient's vital signs. The proposed device consists of a belt-type sensor and communication circuit. The physiological parameters that are monitored with the proposed instrumented wearable belt are electrocardiogram (ECG), heart rate (HR) derived from ECG signals by determining the R-R intervals, body temperature, respiratory rate, and three axis movement (acceleration and position) of the subject.

## 2. Operating Principle

The overall architecture of the instrumented belt is reported in Fig. 1; the circuit board, two skin electrodes, a temperature sensor, an accelerometer and a respiratory sensor are integrated in the belt. The measurement data are transmitted to a readout unit, which can be connected to PC and internet for telemedicine purposes.

Table 1 illustrates the specifications of the monitored physiological signals. An ECG is a bioelectric signal which records the heart's electrical activity versus time. The electrocardiogram is obtained by measuring electrical potential between two points of the body using specific conditioning circuit. The temperature of a healthy person is about 37 °C; it may slightly or temporarily increase in hot environment or in physical activity, in extreme effort, the increase may be very high. Respiratory rate is one of the physical parameters that are related to mechanical model of respiratory system. Inductive plethysmography is one of the most promising noninvasive technologies available now for measuring respiratory function. The technique employs sensors to measure changes in a cross-sectional area of the rib cage and abdominal compartments during a respiratory and cardiac cycle. The developed sensor consists of arrays of sinusoidally arranged conductive wires excited by a low current, high frequency (300 kHz) electrical oscillator circuit. Movement of rib cage and abdominal compartments, due to respiration cycles, generates a variation of the inductance of the sensor, which are measured as voltage changes over time. No electricity passes through the monitored patient. Another important part of home healthcare is to monitor the behavior and physical activity in daily life. A three-axis accelerometer is used for the movement and fall detection. Acceleration signals provide valuable information about wearer's activity classification such as walking, running and resting (standing). The system can collect the accelerometer signals to determine whether the person has fallen or not and monitor the movements.

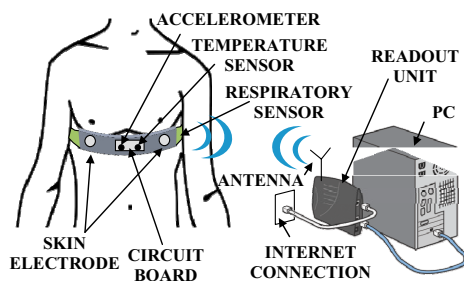


Fig. 1. Overall architecture of instrumented belt.

Table 1: Specification of various physiological parameters monitored.

Physiological Parameter	Specifications
Electrocardiogram (ECG)	Frequency: 0.5 Hz – 100 Hz Amplitude: 0.25 – 1mV
Heart Rate (HR)	40 – 220 Beats per minute
Respiratory Rate (RR)	2 – 50 breaths/min Frequency 0.1 – 10 Hz
Body Temperature	32 °C – 40 °C
Position	0-360° 3-axial
Acceleration	±2 g

### 3. Experimental System

In Fig. 2 the block diagram of the wearable data acquisition hardware is described. The device is tiny in size, and has miniature rechargeable batteries. Fig. 2 illustrates the block diagram of the various components: sensing elements and signal conditioning, power supply circuit, and control board. The sensors measure the physiological data and the signals are conditioned by dedicated circuits (amplification and filtering) to levels suitable for digitization. The digitized data is transmitted to the readout unit by a wireless module at 13.56 MHz. A microcontroller is programmed to control and coordinate the activities of the system for data acquisition, establishing communication with the readout unit and putting the system into sleep and wakeup modes. The remote monitoring station is generally located far away from the patients. At the remote monitoring station, the physiological parameters are analyzed and automatic alarms are generated or transmitted to internet.

ECG signals from the electrodes are amplified with a gain of 300 and filtered with the cut-off frequencies of 0.5 Hz in the high pass filter and 100 Hz in the low pass filter. The ECG signals are typically 1mV<sub>peak-to-peak</sub>; an amplification of 300 is necessary to render this signal usable for heart-rate detection and realizing a clean morphological reproduction. A differential amplifier with gain of 20 avoids the noises overriding the ECG signals, this is achieved by an instrumentation amplifier (INA 333), CMRR of 100 dB and at the end an operational amplifier (Analog AD8625) is used to amplify the signal with a gain of 15. The ECG signals are restricted in bandwidth of 0.5–100 Hz using a second order Butterworth high pass and low pass filters after the first stages of amplification. The power line interference in the ECG signal is filtered by a 50 Hz notch filter, which is user selectable to avoid loss of 50 Hz component of the ECG signals. The respiratory rate technique employs sensors to measure changes in a cross-sectional area of the rib cage and abdominal compartments during a respiratory and cardiac cycle. The sensors consist of arrays of sinusoidally arranged conductive wires excited by a low current, high frequency (300 kHz) electrical oscillator circuit. An impedance variation is measured by an I/V amplifier and the real part is extracted using a four quadrant multiplier (Intersil HA2556) and a low pass filter. The temperature sensor (LM94022) is a CMOS integrated-circuit temperature sensor, while the accelerometer a three axes digital output linear accelerometer (LIS3LV02DL) that includes a sensing element and an IC interface.

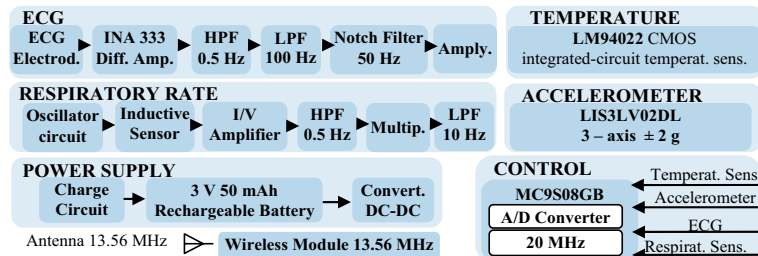


Fig. 2. Block diagram of wearable data acquisition hardware.

### 4. Experimental Results

Preliminary experimental results were obtained for each sensor and conditioning electronics. In Fig. 3, the ECG signal during resting activity is shown and the principal waves highlighted. All the information about the hearth rate, frequency and amplitude can be calculated easily. In Fig. 4, the respiratory data are reported during resting activity; the movement of the rib cage, due to the inhale and exhale activities, is clearly visible. In Fig. 5, acceleration and position during walking activity and after a fall are obtained using the 3-axis accelerometer and the conditioning circuit. The X-axis acceleration data among three-axes data is most sensitive to the motion of human body because X-axis is one's height direction. The experimental results show a good sensitivity, further experimental data and energy consumption tests are being carried out.

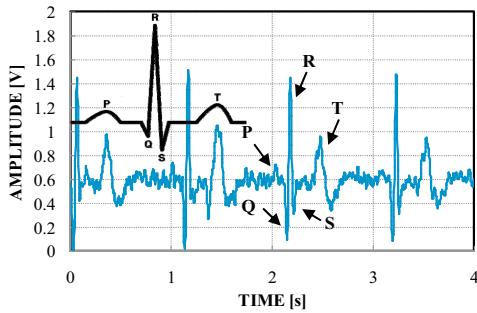


Fig. 3. ECG monitoring during resting activity.

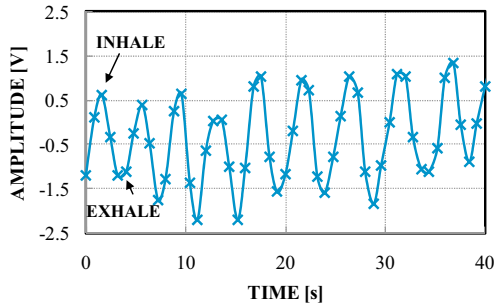
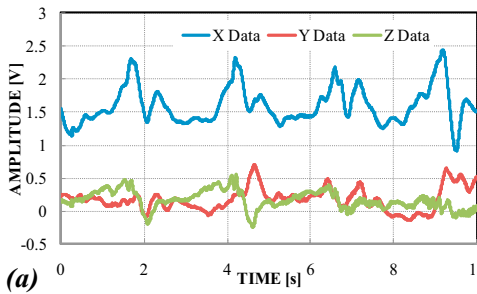
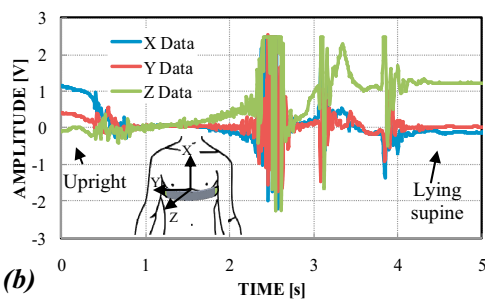


Fig. 4. Respiratory rate data during resting activity.



(a)



(b)

Fig. 5: Acceleration and position during a walking activity (a) and after a fall (b).

## 5. Conclusions

An instrumented wearable belt for wireless health monitoring was presented. The instrumented wearable belt device is composed of the electronics and sensors for the monitoring of electrocardiogram (ECG), heart rate (HR) derived from ECG signals by determining the R-R intervals, body temperature, respiratory rate, and three axis movement (acceleration and position) of the subject measured using an accelerometer. The experimental results showed that the cardio-respiratory signals, the heartbeats, the respiratory cycles and the patient movements can be obtained clearly by the device. The instrumented wearable belt makes possible physiological parameter measurements for telemedicine diagnosis, especially for home health care management of aged people.

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