Multi-parameters wireless shirt for physiological monitoring

Emilio Sardini, Mauro Serpelloni
Department of Information Engineering
University of Brescia, 25123 Brescia, Italy
mauro.serpelloni@ing.unibs.it

Marco Ometto
Mechanical and Industrial Engineering Department,
Faculty of Engineering, University of Brescia, 25123
Brescia, Italy

Abstract — **The ability to monitor the health status of elderly patients or patients undergoing home therapy allows significant advantages in terms of cost and convenience of the subject. However, these non-clinical applications of biomedical signals acquisition require different monitoring devices having, between the other characteristics, reduced size, low power and environment compatibility. The research activity concerns the development of a new wearable device that can monitor the main physiological parameters of a person in a non-invasive manner. All sensors have contactless characteristics that permit to avoid the direct contact with the skin. This system is a useful solution for monitoring the health condition of patients at home. The wearable monitoring system consists of two subsystems: first, a wearable data acquisition hardware, in which the sensors are integrated for the acquisition of biomedical parameters, and secondly, a remote monitoring station located separately and connected to the Internet for telemedicine applications. The physiological parameters that are monitored are electrocardiogram (ECG), heart rate (HR), derived from ECG signals through the determination of RR intervals, respiratory rate, and three-axis motion (acceleration and position) of the subject measured using an accelerometer. All sensors are designed using contactless measurement techniques, thus avoiding the use of gel for the conduction of the signal and possible skin irritation due to contact. The electrodes for measuring ECG signal are capacitive, while the measure of respiration is obtained by plethysmography, which does not require direct contact with skin. In order to design and construct the signal acquisition circuits in an efficient and simple manner, modular design concept is adopted in this research. The flexible signal conditioning modules are designed and assembled together. The human parameters can be recorded and analyzed continuously during work activities at home. The correct evaluation of these parameters allows the medical staff to assess to the state of health, to know accidental injury or other danger occurred in patients at home.**

Keywords - Body measurement; Electrocardiography (ECG); Wearable sensor; Cardiorespiratory signal measuring; Heartbeat; Respiratory cycle; Home healthcare; Capacitive electrodes; contactless measurements.

I. INTRODUCTION

In recent times, the national health care for the elderly has attracted increasing attention. For persons of age living at home, the measurement of physiological parameters is often a crucial opportunity; known immediately to sudden changes in health or accidental injury is vital. However, these non-clinical applications of biomedical signals require different monitoring devices, not only in terms of size and comfort of the acquisition, but also in terms of power dissipation. The important parameters for design are portability, wearing comfort, durability, and control signals. In [1], a smart shirt, which measures the signals of electrocardiogram (ECG) and the acceleration for the continuous health monitoring has been designed and developed. However, the possibility of measuring the respiratory activity is also crucial to check the patient health. Medical analysis showed that the most important parameters are those that specify the functionality of the heart and respiratory system. In [2], a smart jacket is described and consists of a base layer with built-in sensors for monitoring physiological parameters. However, the acceleration and position of the subject are not monitored. In [3], the wearable system transmits data to the patient's PDA (Personal Digital Assistant), mobile phone via Bluetooth, and following the doctor's PDA via Global System for Mobile Communications (GSM). However, the solution of PDA phone is probably not the best option for elderly patients, for monitoring at home. In [4], the authors present different textile sensors to measure physiological parameters and chemical compositions of body fluids, with a particular interest in the sweat. In [5], a system of wireless real-time monitoring can capture three-axis acceleration using an accelerometer, an electrocardiogram (ECG) and temperature is integrated. The article stresses the importance of designing a non-invasive for the patient. In this regard studies on capacitive electrodes to measure the ECG signal are significant. In [6-8], different works on different electrodes for capacitive contactless measurement of the ECG signal are shown. The advantage of using these sensors is the non-invasivity for the patient; these sensors do not require direct contact with the skin, nor the use of gel. In [9], the author developed an instrumented wearable belt for the physiological parameters; however this system presents a problematic of invasivity due to the use of contact copper electrodes, which permit a high signal but cause skin irritations. Therefore, the purpose of this research, described in this paper, is to develop a new wearable device for a long time monitoring of vital signs and not invasive for the patient. The proposed mechanism consists of a T-shirt sensorized and a communication channel for the remote assistance. The physiological parameters that are monitored with the proposal are electrocardiogram (ECG), heart rate (HR), derived from ECG signals through the determination of RR intervals, respiratory rate, and subject movements through the use of three-axis accelerometer. To ensure wearing comfort ECG measurement was made using specific capacitive electrodes, which measure the electrical potential on skin without electrical contact.

II. Operating Principle

The overall architecture of the T-shirt tool is shown in fig. 1, the circuit board, with three electrodes, an accelerometer and a breathing sensor are integrated in the T-shirt. The measured data are transmitted to a readout unit, which can be connected to the PC and Internet for the purpose of telemedicine.

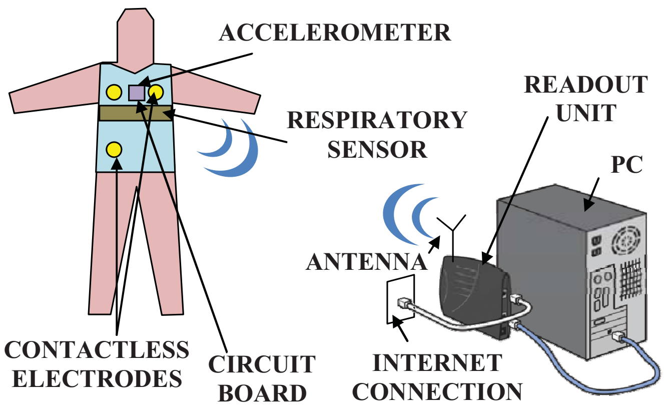

Fig. 1. Overall architecture of instrumented belt.

Table 1 shows the characteristics of physiological signals monitored. An ECG is a bioelectric signal that records the electrical activity of the heart as function of time.

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: 0.05 Hz –10 Hz
Position	0-360° 3-axial
Acceleration	±2 g

The electrocardiogram is obtained by measuring the electrical potential between two points on the body using specific conditioning circuits and capacitive electrodes properly developed, which do not require direct contact with skin. The respiratory rate is one of the physical parameters that are related to the healthy status. The inductive plethysmography is a non-invasive technology available for the measurement of respiratory function. The technique employs inductive sensors to measure changes in a cross section of the rib cage and abdomen during a cardiac and respiratory cycle. The developed sensor consists of an array of wires excited by sinusoidal oscillating electric circuit having a low current and high frequency (300 kHz). The movement of the chest and abdomen, because of the breathing cycle, generates a change in the sensor inductance, which is measured as voltage change over time. Whereas the sensor is not in contact with the skin as it is located outside of the shirt, no electric current passes through the monitored patient. Another important part of home care is to monitor the possible accidental falls and physical activity in everyday life of the patient. A three-axis accelerometer is used for low-power motion detection and fall. The acceleration signals provide important information regarding the activities of the wearer, such as walking, running and resting. The system can pick up signals of the accelerometer to determine whether the person has fallen or not and control the movements.

III. Experimental System

In fig. 2 a block diagram of wearable data acquisition hardware is described. The device has a compact size and rechargeable batteries. All the sensors are placed not in contact with the patient's skin. Figure 2 shows the block diagram of the various components: the sensing elements and signal conditioning, the power supply circuit and the control board. The different sensors measuring physiological data are connected to the wearable data acquisition hardware and the sensor signals are conditioned by dedicated circuits (amplification and filtering) to levels suitable for digitization. The digitized data are transmitted to the reading device (PC or mobile phone) by a wireless module, Bluetooth 2.4 GHz module marketed by (EDS200) Parani, and it creates a channel between the control unit and the unit of T-shirt. A microcontroller is programmed to control and coordinate the activities of data acquisition system, establishes communication with the reading device and put the system in sleep mode and wake. The monitoring station is generally located a distance away from the patient up to 10 m. At the remote monitoring station, the physiological parameters are analyzed and automatic alerts are generated or transmitted to the Internet for remote assistance. The measurement of ECG signal requires a first capacitive conditioning electronic stage directly on the opposite side, reported in fig. 3. When the ECG signal is measured using a differential amplifier as in this system, the common voltage of the patient should be minimized, because it has a negative effect on the ECG signals. The most effective way to minimize the voltage is to use third common reference electrode (fig. 3). The first opamp is configured as a unity-gain voltage buffer. The 10kΩ resistor and 10nF are used to protect and isolate the input of the amplifier output from the active shield. A passive RC high-pass filter with a corner frequency of 0.7 Hz is used to center the signal on Vref. The second opamp is a buffer and guides the cable connecting the electrode to the base unit. A resistor 100 is used to isolate the capacitance of the cable output. The ECG signals from the electrodes were amplified with a gain of 300 and filtered with a cutoff frequency of 0.5 Hz in 100 Hz high-pass filter and low pass filter. The ECG signal is typically 1mV peak to peak, a gain of 300 is needed to make this signal can be used to detect heart rate and implementation of effective monitoring. A differential amplifier with a gain of 20 is achieved by an instrumentation amplifier (INA 333); CMRR of 100 dB and at the end of an operational amplifier (Analog AD8625) is used to amplify the signal with a gain of 15.

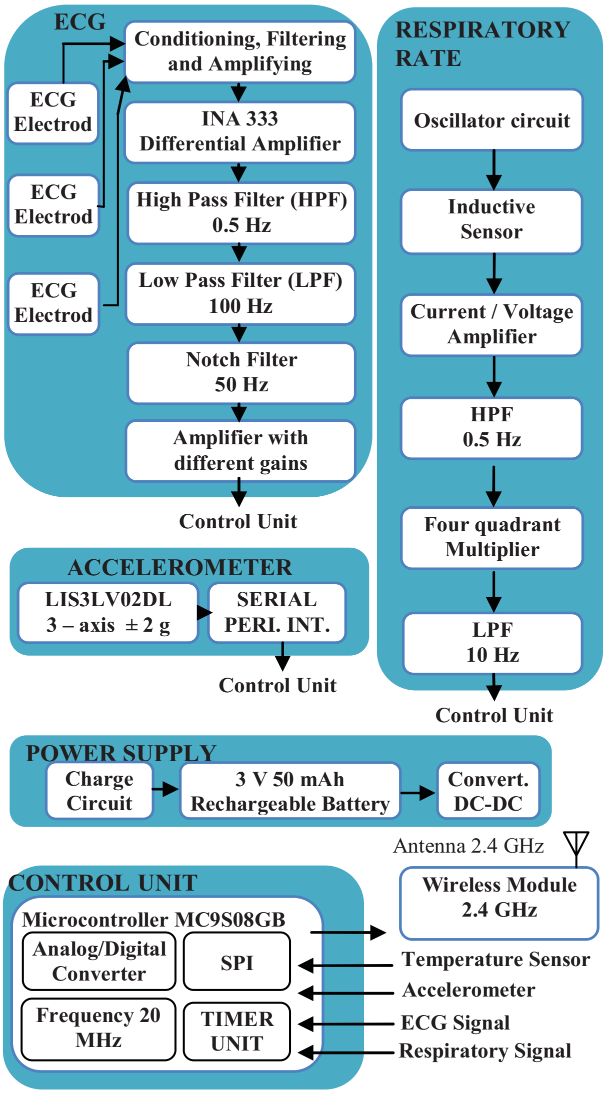

Fig. 2. Block diagram of wearable data acquisition hardware.

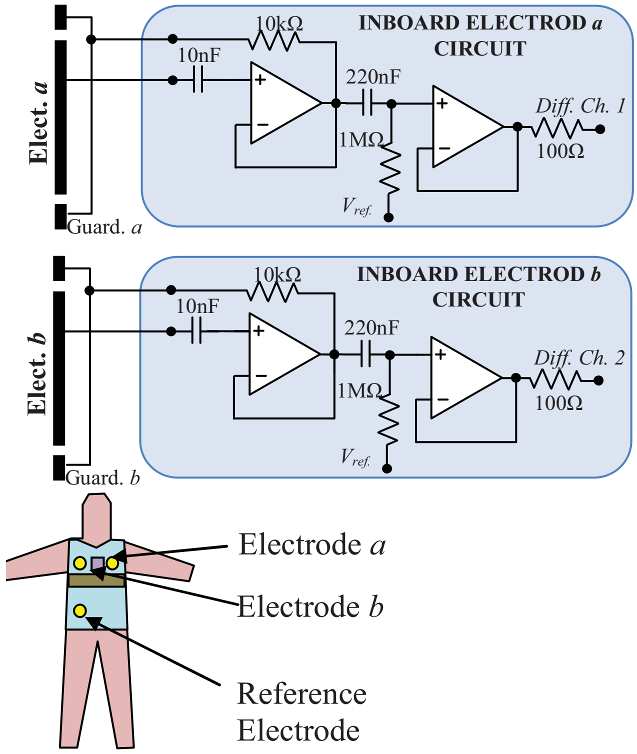

Fig. 3. Contactless electrode pictures for ECG monitoring and inductive bend for respiratory rate monitoring.

The ECG signals are limited in bandwidth of 0.5 to 100 Hz with a second pass and high-order Butterworth low-pass filters after the first stage of amplification. The interference of power line of the ECG signal is filtered by a selective filter at 50 Hz, which is selectable to prevent the loss of the component of ECG signals at 50 Hz. In fig. 4, pictures of the three ECG contactless electrodes are reported; the top side clearly shows the active area and guard ring. While the bottom side shows the initial stage of conditioning. The respiratory rate measurement technique uses an inductive sensor to measure changes in a cross section of the rib cage during a respiratory cycle. The sensor consists of an array of wires and sewn to an elastic band as shown in fig. 4. To perform the measure the sensor is excited by an oscillator circuit with low-power consumption and high frequency (300 kHz). A change in impedance is measured with an I / V amplifier and the measurement signal is extracted using a multiplier of four quadrants (Intersil HA2556) and a low pass filter. The measurement of position and acceleration of the patient entrusted to a ST's three-axis accelerometer with digital output (LIS3LV02DL) that includes a sensor interface to directly connect the accelerometer to the microcontroller. Sampling rate and measurement range can be set using Serial Peripheral Interface SPI. All transmitted data are collected by the shirt device the acquisition, which allows either viewing by computer or sent via internet for remote assistance activities. In fig. 5, the front panel is designed using LabVIEW.

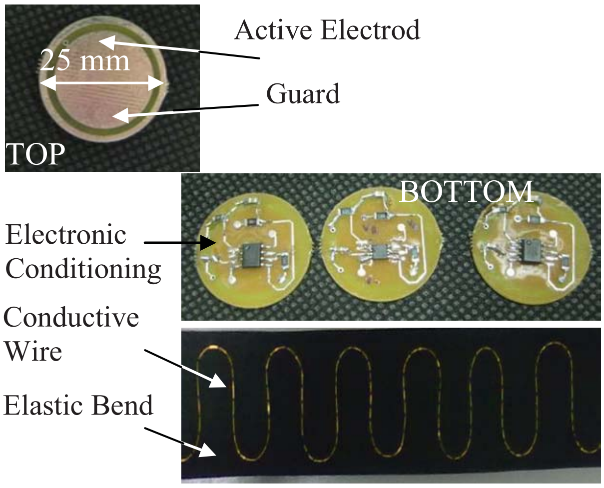

Fig. 4. Contactless electrode pictures for ECG monitoring and inductive bend for respiratory rate monitoring.

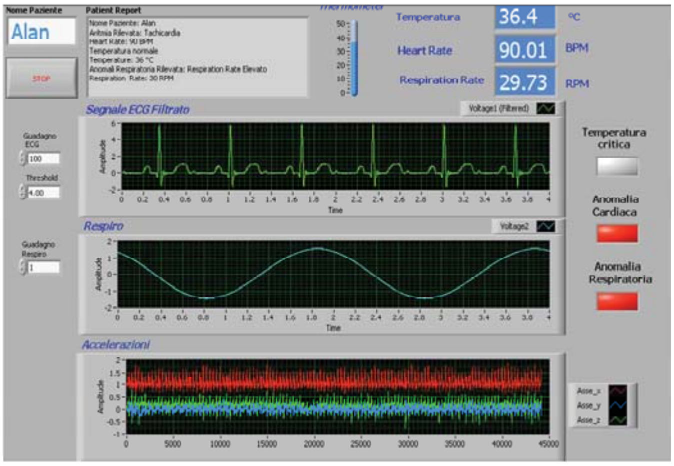

Fig. 5. LabVIEW front panel of the readout unit indicating the patient data, the ECG signals, the Respiratory rate, the accelerometer data and different alarms.

IV. Experimental Results

Preliminary experimental results were obtained for each physiological parameter measured using the sensors and conditioning electronics designed and built. In fig. 6, the ECG at rest is reported using both commercial AgCl electrodes and the designed electrodes. The diagram of fig. 6(a) also shows the complex layout of a typical curve QRST. The ECG signal obtained with the contactless electrodes (fig. 6(b)) is used to calculate only the hart rate due to high noise components, preventing proper evaluation of the ECG signal.

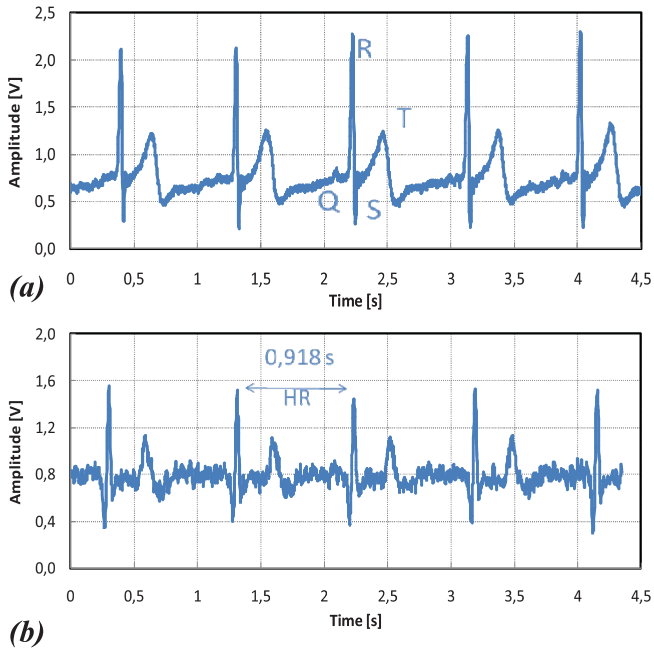

Fig. 6. ECG monitoring during resting activity. (a) ECG signal obtained with commercial AgCl electrodes, (b) ECG signal obtained with the contactless electrodes.

In the present configuration only the hart rate can be considered reliable; the information relating to frequency can be calculated easily measuring the time between consecutive picks as reported in fig. 6(b). The inductive sensor for monitoring the respiratory activity was characterized using an impedance analyzer (HP4194A). The magnitude and phase diagrams are shown in fig. 7 and show that for the operating frequency of 300 kHz the sensor is mainly inductive. This frequency was considered as the reference frequency to measure the impedance the inductive sensor.

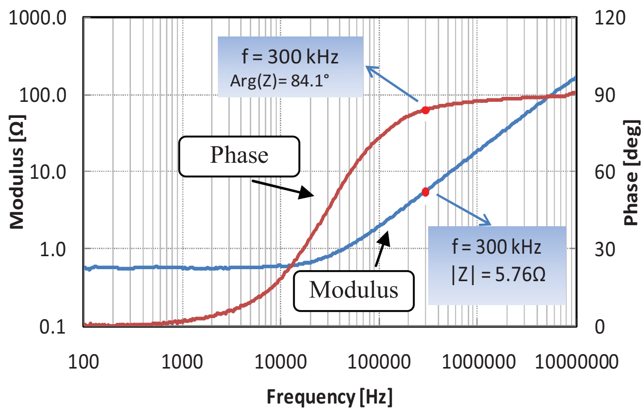

Fig. 7. Inductive sensor's impedance diagrams.

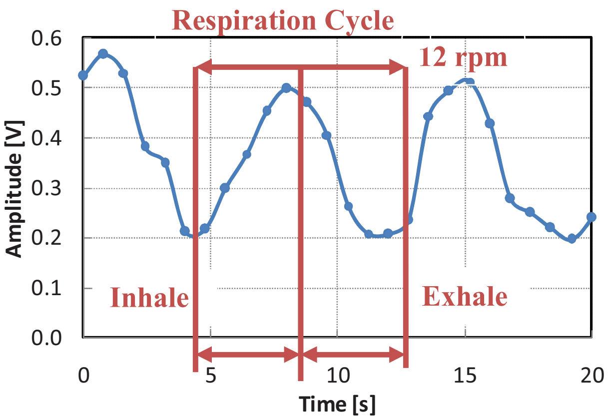

Fig. 8. Respiratory rate data during resting activity.

In fig. 8, the respiration data are reported, the movement of the rib cage, because of respiratory activity, is clearly visible. From a measurement of time to breathe in and out the respiratory rate can be calculated. The respiration signal is influenced by patient movements; the implemented system allows performing correctly the measurement of respiratory rate during the rest condition of the patient. The acceleration and position measurements were obtained using the 3-axis accelerometer and the conditioning circuit. The x-axis trace is referred to the transverse axis of the patient; the y-axis trace is referred to the sagittal axis of the patient, while the z-axis trace is referred to the coronal axis of the patient. Acceleration data for the x-axis are most sensitive to movement of the human body. In fig. 9 a fall of the patient was simulated by a mannequin. Initially, the patient is standing, then there are high accelerations and finally the patient is lying on the ground. The monitoring of accidental falls is an important parameter in the care of elderly people at home. In fig. 10, the acceleration and position of the subject during different physical activities are reported stairs (a), running (b), and walking (c). The obtained results in fig. 9 and fig. 10 show good sensitivity; further experimental data and energy consumption tests are underway.

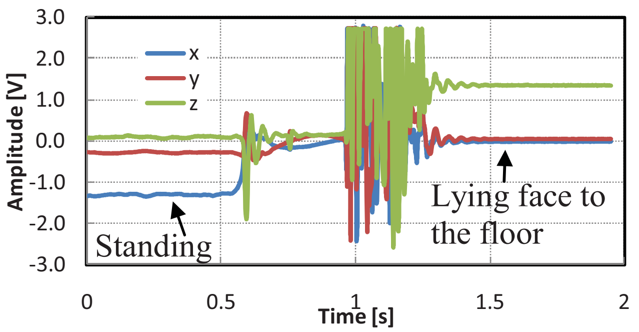

Fig. 9. Acceleration and position after a fall.

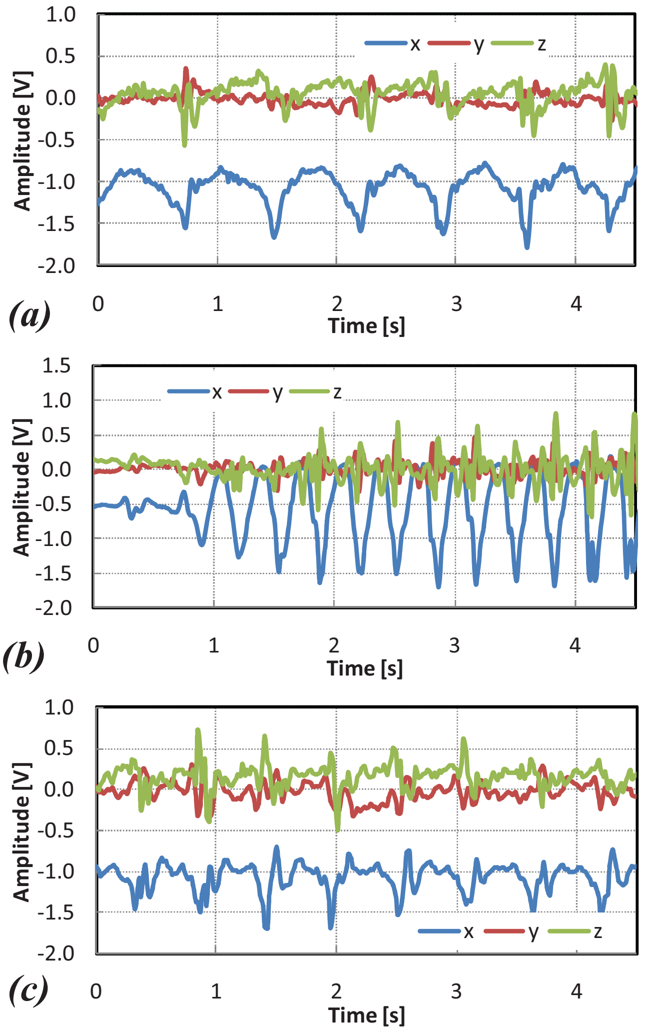

Fig. 10. Acceleration and position climbing stairs (a), running (b), and walking (c).

V. Conclusions

A multi-parameters T-shirt for monitoring wireless physiological parameters was presented. The monitoring device is completely non-invasive. The device is composed instrumental wearable electronics and sensors for monitoring electrocardiogram (ECG), heart rate (HR), derived from ECG signals through the determination of RR intervals, respiratory rate, and the three-axis motion (acceleration and position) of the subject measured using an accelerometer. The proposed sensors are all contactless, thus avoiding gels and skin irritations. The experimental results showed that the cardio-respiratory signals, heart rate, breathing movements and the cycles of the patient can clearly be obtained from the device. The T-shirt tool makes possible the measurement of physiological parameters for the diagnosis of telemedicine, in particular for the management of home health care of older people.

REFERENCES

[1] Y. Dong, L.Wan-Young, B. Chung, Wireless sensor network based wearable smart shirt for ubiquitous health and activity monitoring, Sensors and Actuators B 140 (2009), 390–395.

[2] P.S. Pandian, K. Mohanavelu, K.P. Safeer, T.M. Kotresh, D.T. Shakunthala, P. Gopal, V.C. Padaki, Smart Vest: Wearable multi-parameter remote physiological monitoring system, Medical Eng. & Physics 30 (2008), 466-477.

[3] F.E.H. Tay, D.G. Guo, L. Xu, M.N. Nyan, K.L. Yap, MEMS Wear-biomonitoring system for remote vital signs monitoring, Journal of the Franklin Institute 346 (2009), 531–542.

[4] S. Coyle, K.T. Lau, N. Moyna, D. O'Gorman, D. Diamond, F. Di Francesco, D. Costanzo, P. Salvo, M. G. Trivella, D. E. De Rossi, N. Taccini, R. Paradiso, J.A. Porchet, A. Ridolfi, J. Luprano, C. Chuzel, T. Lanier, F.R. Cavalier, S. Schoumacker, V. Mourier, I. Chartier, R. Convert, H. De-Moncuit, C. Bini, BIOTEX—Biosensing Textiles for Personalised Healthcare Management, IEEE transactions on information technology in biomedicine, 14(2) (2010), 364-370.

[5] M. Marzencki, K. Tavakolian, Y. Chuo, B. Hung, P. Lin, B. Kaminska, Miniature Wearable Wireless Real-time Health and Activity Monitoring System with Optimized Power Consumption, Journal of Medical and Biological Engineering, 30(4) (2010), 227-235.

[6] Y.M. Chi, G. Cauwenberghs, Wireless Non-contact EEG/ECG Electrodes for Body Sensor Networks, International Conference on Body Sensor Networks 2010, (2010), 297 – 301.

[7] Y.M. Chi, P. Ng, E. Kang, J. Kang, J. Fang, G. Cauwenberghs, Wireless non-contact cardiac and neural monitoring, Proceeding of WH '10 Wireless Health 2010, (2010), 15-23.

[8] S.M. Lee, K.S. Sim, K.K. Kim, Y.G. Lim, K.S. Park, Thin and flexible active electrodes with shield for capacitive electrocardiogram measurement, Medical and Biological Engineering and Computing, 48(5) (2010), 447-457.

[9] E. Sardni, M. Serpelloni, Instrumented wearable belt for wireless health monitoring, Procedia Engineering 5 (2010).