MICROWAVE APPLICATION IN BALISTOCARDIOGRAPHY AND NON-INVASIVE MONITORING OF CARDIORESPIRATORY ACTIVITY

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Abstract: This work presents the results of a study concerning the use of microwave Doppler transducer for some applications in Medicine such as balistocardiography and contact - less detection of cardiorespiratory activity. The main element of the installation is a microwave Doppler transducer working on 8 GHz. The Doppler signal resulting from the movement of the anatomical structures – thorax, lung and heart has a complex structure due to the cumulative effects of all the moving organs. For this reason the detection and the amplification must be followed by a frequency-processing in order to set apart the signal given by the heart beats. The experimental setup also includes an electrocardiograph, a photopletismograph and a pneumatic sensor attached to the thorax to detect breathing motions. The optimum position of the Doppler sensor has been established to detect the heart cavity. At the same time, two types of breathing were identified: the thoracic and the abdominal ones. A good correlation was noticed between the ECG reference signal and the Doppler signal. The send - receive element is a horn antenna. The microwave oscillator and receiver are produced by a microstrip technology and have a continuous operating regime. The radiant energy is about 4 mW.

Introduction

Balistocardiography (BCG) [1, Journals]is a method where through global body vibrations due to cardiac activity could be registered [1, Books]. Dynamic analysis of cardio - vascular system is made by cantitative seismography. The applied force is registered without phase and amplitude distortions, developing a new noninvasive method for monitoring. Quantitative seismocardiography offers a complex view for operators exposed to medical risks [2, Journals].

Ballistic forces [3, Journals] which give movement to bodies made a spatial vector which varies in space with dimension and direction in the course of a cardiac cycle. Most of balistocardiographic registering techniques are using vector projection on cranio-caudal direction (longitudinal axis of body). Other techniques are using components of forces which are acting on orthogonal directions or simultaneous registering of ballistic movement in three directions (vertical, horizontal and sagital).

In the cardio respiratory monitoring is interesting in a number of situations, the most interesting being in the case of the patients under intensive care, the patients that were given sedatives which can result in a diminished reflexes the new born babies, etc. At present, the cardio respiratory activity is monitored by the direct contact of the patient with the respiration sensors using the tensiometer marks, capacitive sensors of motion, pulse, or the electrodes that detects the heart bioelectric activity [4, Journals]. The problem consists in detecting the cardio respiratory activity by means of a microwaves Doppler detector of motion, which should permit the detection without a intimate contact with the patient. Another problem is to set apart the signals due to the cardiac activity from the signals produced by the respiration activity.

Materials and methods

On use for microwave application in *balistocardiography* a microwave Doppler transducer for movement of the platform. The subject has a sagital position on a platform fixed on bows. The main element of the installation consists of the Doppler transducer made of a sender-receiver set coupled to a wave-guide having as load a rectangular horn antenna with an aperture of 100x130 mm. The balistocardiograph is made of a wood platform for a lower weight which is suspended through 4 cables on a metallic masive support [1, Conference Proceedings]. The generator frequency is 8 GHz. The very low frequency Doppler signal resulting from the detection's amplified (at a gain of 40 dB) and then applied to a DAS 1601 Keithley data acquisition system. The subject is set horizontally lain down and with the horn antenna directed perpendicularly toward his body, at a distance of 10cm from his skin surface. The bioelectric heart activity is recorded by means of the electronic module for ECG made with INA 118 (Burr Brown) integrated circuit and on used electrodes made of silver.. The resulting ECG signal is applied at the DAS 1601 data acquisition system input. In order to register the pulse, a photopletismograph was fixed on a finger. This represents the 4th measuring channel and lets us to get information about the breathing amplitude and frequency as well as to record the apnea condition after expiration or inspiration. The pressure transducer is connected to a digital manometer, which also delivers an analog signal applied to the DAS 1601 data acquisition system. The registered Doppler gives information about body and platform speed and we can calculate the movement of subject. The body ballistic movements caused by blood movement due to mechanical heart activity unfold the 3rd Newton Law (to each action is necessary an equal and oppose reaction) [10, Conference Proceedings].

$$m*v = M*V \Rightarrow V = \frac{m*v}{M} \Rightarrow V = \frac{0.05*0.25}{60} \Rightarrow V = 0.021 m/s$$

$$T = 2*\pi*\sqrt{\frac{l}{g}} \Rightarrow T = 6.28*\sqrt{\frac{0.52}{9.8}} \Rightarrow T = 1.44s$$

The BCG peaks coincide with the down slope of the ECG T wave. The subject is set horizontally lain down and with the horn antenna directed perpendicularly toward his body, at a distance of 10 cm from this skin surface [5, 6 Conference Proceedings].

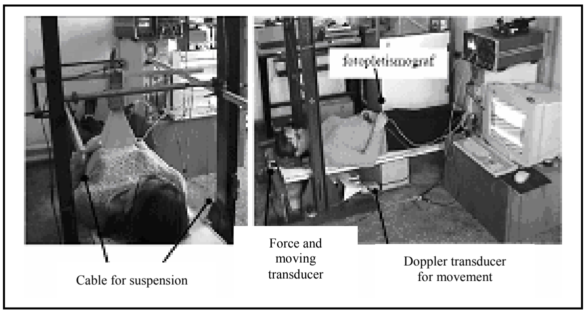

Figure 1: Installation for balistocardiography

The microwave transducer makes use of the Doppler effect in the microwave range [5, Journals] in order to detect the complex motion of the thorax anatomic structures as the result of the cardio respiration activity. In order to study the possibility of using a Doppler transducer, the experimental setup presented in figure 2 was used.

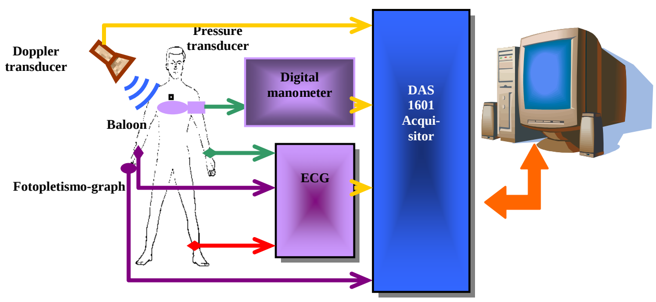

Figure 2: Installation for cardio-respiratory monitoring

The main element of the installation *for non invasive monitoring of cardio respiratory activity* is a microwave Doppler transducer [2. Conference Proceedings]. The Doppler signal resulting from the movement of the anatomical structures has a complex structure due to the cumulative effects of all the moving organs and for this reason the detection and the amplification must be followed by a frequency - processing in order to set apart the signal given by the heart beats and the respiratory movement of the thorax [3, Conference Proceedings].

The experimental setup also includes an electrocardiograph, a photopletismograph and a pneumatic sensor attached to the thorax to detect the breathing motions [4, Conference proceedings].

The use of high frequency electromagnetic waves implies certain difficulties connected to the electromagnetic waves propagation through biological structures, because of the complex phenomena of reflection, refraction, absorption, diffusion and interference that can occur the skin depth in certain tissues, a different electromagnetic field absorption at the input and output of the wave from the human body. In order to ensure a minimum level even bellow the one permitted by standards for the electromagnetic field intensity, on has used generators of small power, on the order of a number of milliwats [6, Journals]. We preferred to use a frequency of some GHz, given by the fact that the specific phenomena of microwaves propagation are more obvious at those frequencies; another reason is determined by the simplicity of the Doppler transducer at these frequencies. At this frequencies, the skin depth in muscles, lung and blood is of some millimeters, reaching 2-9 mm in fat [7, Journal].

Results

In Figure 3 we present a balistocardiogram obtained through detection of movement of the anatomic structures of the thorax caused by heart contractions. The Doppler signal has a variable amplitude between two contractions. On observe a coincidence with T wave of ECG signal [7, Conference Proceedings].

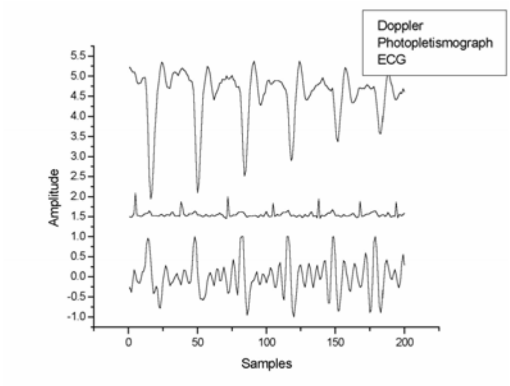

Figure 3 Photopletismograph, ECG and Doppler microwaves map - signal generated by the cardiac activity

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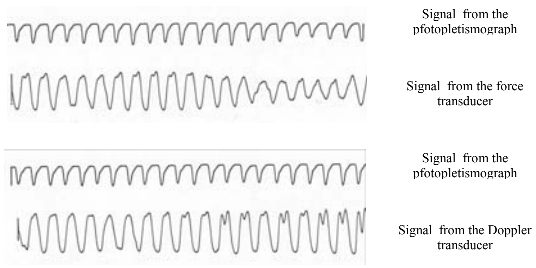


Figure 4: Registered balistocardiogram

Due to these complex phenomena, it is quite difficult to state precisely which of the anatomical structures contribute the most in rendering evident the cardiac activity. What concerns the respiratory activity, it is quite easily to detect the Doppler signal having a relatively high amplitude. From figure 5 one can notice a good correlation between the complex Doppler signal and the signal due to the respiratory activity. The signal given by the manometer follows the respiratory activity, its maximum values corresponding to the thorax outward motion by air inspiration and its minimum values corresponding to the reverse thorax motion. As one ca see, the corresponding Doppler signal quickly changes its phase by 1800.

Taking into account the relatively small (4mm) skin depth within the tissue, one can state the respiratory activity is only detected due to the motion of the thorax outer layers. Concerning the cardiac activity, the Doppler signal is move complex, being generated on the one side by the modification in size and position of certain anatomical structures as parts of the cardiac circuit, and on the other side by the changing in the tissues electric properties due to the motion and changing blood irrigation during a cardiac cycle.

The electric signals picked up from a patient by the ECG electrodes or by electronic circuits are processed by means of the data acquisition system DAS 1601. With the view to determine the most adequate zones for detecting the cardiac activity, records have been made in different thorax zone, by placing the horn antenna in different positions, as shown by figure 5.

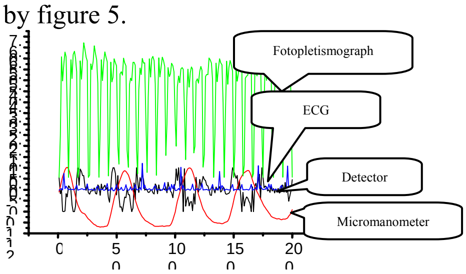


Figure 5: Cardio-respiratory activity monitored by ECG, Doppler effect, thorax transducer and photopletismograph

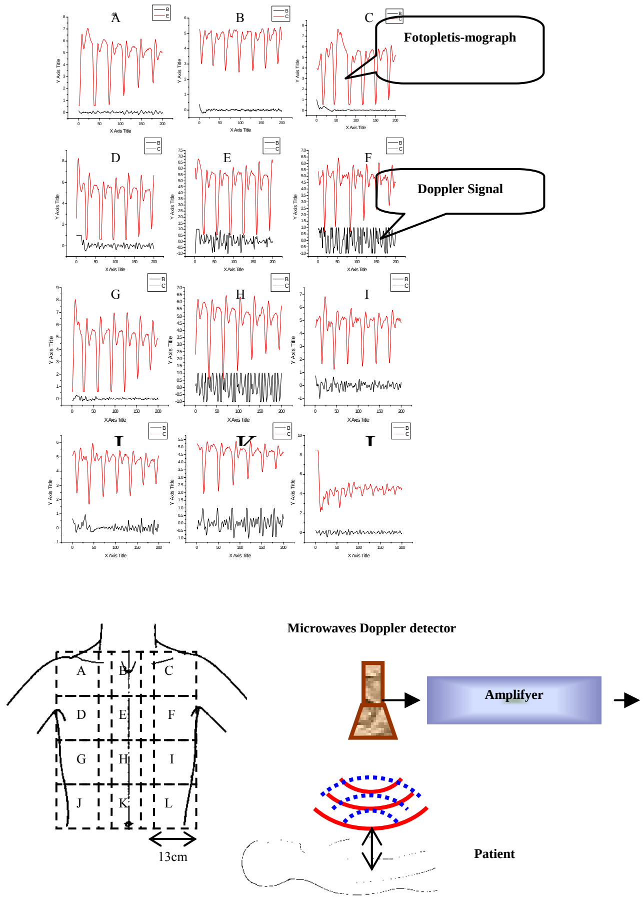


Figure 6: Doppler microwaves map - signal generated by the cardiac activity

The records from figure 6 were made the apnea condition after inspiration. The diagrams present the signals picked-up by the photopletismograph as a reference signal, and the Doppler signals corresponding to the zone against the thorax. In most of the diagrams, one can remark a time alteration of the amplitude of the signal pick-up by the photopletismograph; this is the result of the apnea state installed at the beginning of every measurement. From the A, B… L, diagrams one can remark variable amplitude of the Doppler signal depending on the transducer's position as related to the thorax. As one can see, the highest signal amplitude is in the zones E, F, H zones meaning the region were the heart is placed, due to the heart's contraction motions and to the larger blood volume pumped through the organism by means of the aortic artery. At the same time increased signal values are recorded in the K zone corresponding to the direction of the descending thoracic abdominal aorta.

A good correlation was noticed between the ECG reference signal and the Doppler signal. The microwave oscillator and receiver coupled with a horn antenna are produced by a micro strip technology and have a continuous operating regime. The noise signals due to the involuntary patient motions, mechanical vibrations or electromagnetic interferences are suppressed by means of a filter. The Doppler signal is following the change with 180^0 of phase of speed direction of anatomical thorax structures movement.

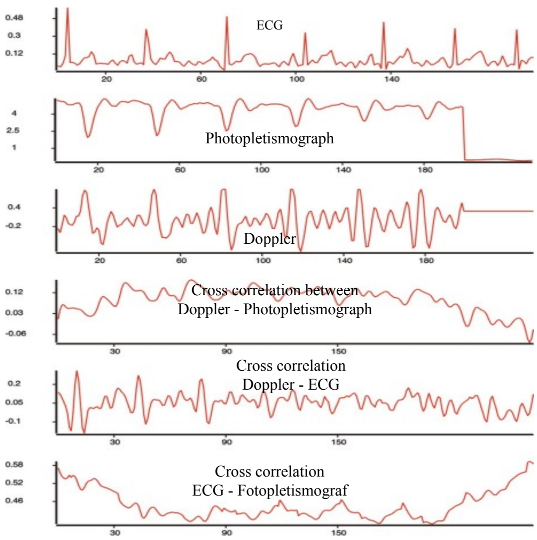


Figure 7: Cross correlation function betwen ECG, Photopletismograph and Doppler

Fig. 7 shows the results of crosscorelation between ECG signal, photopletismograph and Doppler signal coresponding to cardiac activity. It is necesarry a filtration before using Doppler signal for patient cardiorespiratory monitoring. Fig. 8 shows Doppler signal due to cardiac activity. By filtering we can extract only signal coresponding to fundamental frequence. Filtering signal as used to determine cardiac signal frecquency in concordance with bloc diagram from fig. 9.

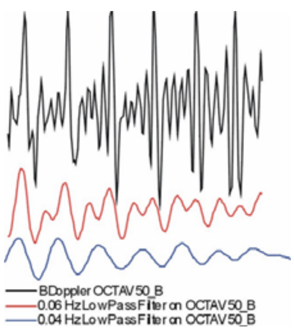
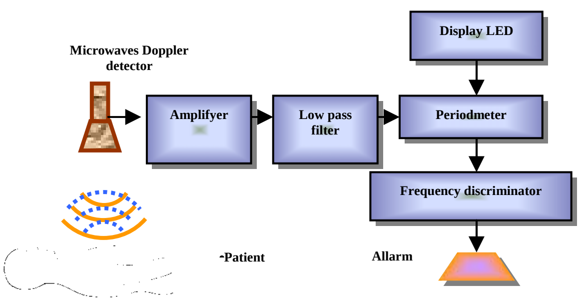


Figure 8: Filtered Doppler signal



Conclusions

Figure 9: Bloc diagram for patient monitoring devices

Complex Doppler signal is used for measuring cardiac is used for measuring cardiac activity. For this, the signal is amplified and filtered adequate to extract fundamental frequency. It is applied a filtered signal to a frequencemeter or period meter. Measured value is seen on a display. It can be used a programmable frequency discriminator which is able to detect variations and command an alarm for abnormal cardiac frequencies. Doppler signal has the same periodicity as cardiac activity. Its amplitude varies for a cardiac cycle due to surface movement of anatomic structures.

Conclusions

The movement due to body ballistic forces can be detected using a contact less microwave Doppler transducer. We can see a very good correlation between the signals from the photopletismograph fixed on patient's finger balistocardiograph platform movement. The setback force occurs after the T wave from the electrocardiogram and corresponds to minimal value of the signal from the photopletismograph.

The experimental results confirm the possibility to use a microwave Doppler detector of motion for detection, recording and explaining the signals produced by the cardio-respiratory. The method permits to detect the apnea condition, the breathing frequency, as well as the heart activity. The radiant energy is much below the admitted limits; the energy density at the horn antenna output is 0.03 mW/cm2. One can also remark a good correlation between the complex Doppler signal and the ECG signal, the breathing and the pulse photoelectric transducer.

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