Contactless Heart Monitoring (CHM)

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Abstract— **An apparatus for measuring mechanical heart movement, and heart rate monitoring without physically connecting electrodes or other sensors to the body was developed. Contactless heart monitoring (CHM) based on Doppler radar with frequency of 2.4GHz at a distance of up to 30cm is capable of detecting the mechanical vibrations of the heart, without any contact with the person's body, and it can operate and record the heart rate through a mattress, wall or other barriers. In this paper we present the theory, and preliminary results of our basic CHM setup.**

Keywords: Doppler radar; balistocardiography (BCG); heart monitoring; mechanical heart activity

I. Introduction

Microwave Doppler radar has been used for wireless sensor applications for many years. It was first applied to the measurement of respiration rate and the detection of sleep apnea in 1975 [1,2]. Starting in the early 1980s, similar systems were proposed to search for victims trapped in earthquake rubble or avalanches [3] and to sense human presence behind walls or other barriers [4]. All of these systems used bulky heavy microwave components and large antennas. These systems are acceptable for use in diagnostic or emergency situations, but are impractical in general. Other options for home monitoring of heart and respiration include the Polar strap for heart rate, straps that measure chest expansion for respiration, such as Respitrace [9], acoustic monitors, nasal/oral airflow sensors, and pulse oximetry. All of these require contact with the body, and most require careful placement. Many commercially-available devices are available for monitoring the heart, but most of them are electrode-based requiring physical contact with the body of the patient. Devices requiring physical contact, however, are difficult to use on children susceptible to sudden infant death syndrome (SIDS) or burn patients who cannot tolerate the touch of electrodes [5]. There are many other needs for such technology as well.

Ballistocardiography (BCG) [6] is one of the oldest non-invasive methods for cardiac evaluation, and closely reflects the strength of myocardial contraction. When the heart pumps blood from the atrium via ventricles to the pulmonary arteries and ascending aorta, through the aortic arch to the peripheral circulation, recoil in the opposite direction is applied to the body and its force and direction changes according to the cardiac cycle.

The contracting heart forms ballistic recoil via blood flow to the aorta and pulmonary arteries and this pulse wave travels through the vascular system and diminishes gradually. The pulse wave travels at 4-5m/s and the propagation speed is dependent of the elasticity of the veins and the level of blood pressure. A normal BCG signal is shown in Fig.1.

The electrocardiogram(ECG) signal is easily accessible and provides information about the electrical activity of the heart. It lacks information about the mechanical activity and this direct functional activity of the heart. BCG as an unobtrusive method can be used to get information about the activity of the heart, the condition of the heart and breathing patterns. By studying the speed of propagation of the pulse in peripheral circulation, it is possible to evaluate the state normal and abnormal patterns of the heart.

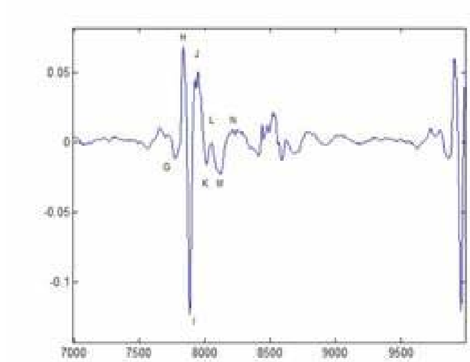

Fig.1. BCG wave names according to American Heart Association.

II. Methods

In CHM apparatus a microwave Doppler radar sensor operating in the range of 2.45 GHz, and in continuous wave mode is being used. The microwave Doppler radar contains a 2.45 GHz oscillator, a transmitter and a receiver in the same housing. A beam of frequency-modulated, continuous-wave radio frequency energy is directed towards the body of the subject by the microwave transmitter. The reflected signal will be frequency shifted due to the Doppler effect (the apparent

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change in frequency and wavelength of a wave that is perceived by an observer moving relative to the source of the waves), thereby permitting the measurement of slight body movements from which physical heart movement information can be obtained.

According to Doppler theory, a constant frequency signal reflected off an object with a periodically varying displacement will result in a reflected signal at the same frequency but with a time varying phase, $\varphi(t)$.

The reflected signal is effectively phase modulated (PM). If the change in displacement is small compared to the wavelength of the signal, the phase change will be small, and the PM signal can be directly demodulated by mixing it with a portion of the original signal [8]:

$$\sin(\omega t+ \varphi(t)) \cdot \cos(\omega t) = \sin(\varphi(t)) + \text{high freq. terms} \qquad (1)$$

Where $\cos(\omega t)$ is the original signal with constant frequency ω, and $\sin(\omega t + \varphi(t))$ the reflected signal with phase shift. The right-hand side of (1) can then be filtered for the phase shift term $\sin(\varphi(t))$. The phase can be extracted from this term by using a small signal approximation: $\sin(\varphi(t)) \approx \varphi(t)$ for small $\varphi(t)$.

Analogous to the phase shift on a transmission line terminated with a load at a varying position, this time-varying phase is proportional to the displacement $x(t)$:

$$\varphi(t)=(4\pi/\lambda)x(t) \qquad (2)$$

where λ is the wavelength of the signal. The demodulated signal is thus proportional to the periodic displacement of the reflecting object, as in (2). If the change in displacement is small compared to the wavelength, the demodulated signal is proportional to the periodic displacement of the reflecting object. If this object is a person's chest, the demodulated voltage waveform represents displacement due to respiration and heart activity.

At the electromagnetic frequency of 2.4GHz that is being used in the CHM device, the surface of the body is highly reflective to incident electromagnetic fields. In addition, biological tissue is very lossy at these frequencies and there is minimal penetration of radiated electromagnetic energy into the body. Therefore, a return signal from a radiated electromagnetic field incident on the body will primarily contain information associated with movement events [7].

Motion of a target with an electromagnetically reflective surface can be detected by transmitting an interrogating signal at the target surface, and then measuring the motion related time-delay of the return signal that is reflected back from the target. The interrogating signal travels at the speed of light and the time delay experienced by the return signal is equal to the round-trip distance to the target surface, divided by the speed of light. Thus, the time delay of the return signal is proportional to the range or distance to the target surface. If the target is moving in a manner that varies the target range, variations in the measured time delay can be used as a measure of target motion.

The heart signal received from the microwave sensor is filtered and amplified. A diagram of the CHM amplifier is shown in Fig.2.

A sub-millivolt range signal at the output of the receiver is not large enough for accurate measurement, thus making amplification necessary. To obtain a visible output for the heart signal, a high gain of about 1000 is needed to amplify the sub-millivolt signal. In addition, the BCG amplifier must also contain filtering stages. In order to constrain the signals to frequencies of interest and to provide for anti-aliasing in anticipation of digitizing we designed a low pass filter of 100Hz and a high pass filter of 1Hz. One final aspect of amplification of heart signal involves the common mode rejection ratio (CMRR). CMRR is defined as the differential gain over the common mode gain. In the differential amplifier, a common signal in both inputs is not desired for amplification. Therefore, that signal must be reduced greatly by setting CMRR extremely high.

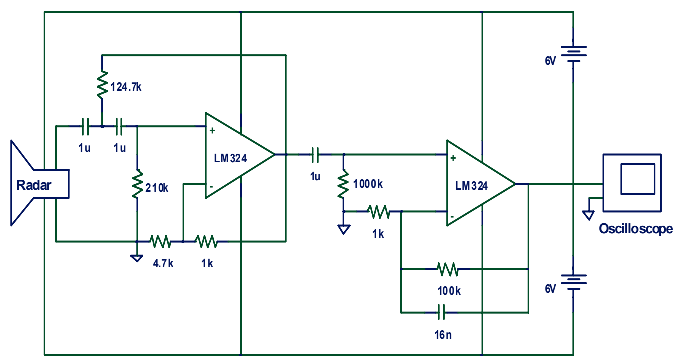

Fig.2. Schematic circuit of the CHM amplifier connected to the recording oscilloscope.

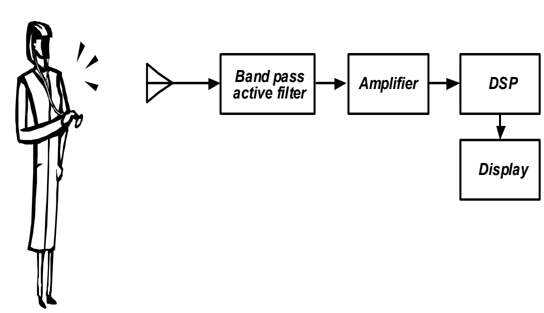

Fig.3 Schematic Setup of the CHM system.

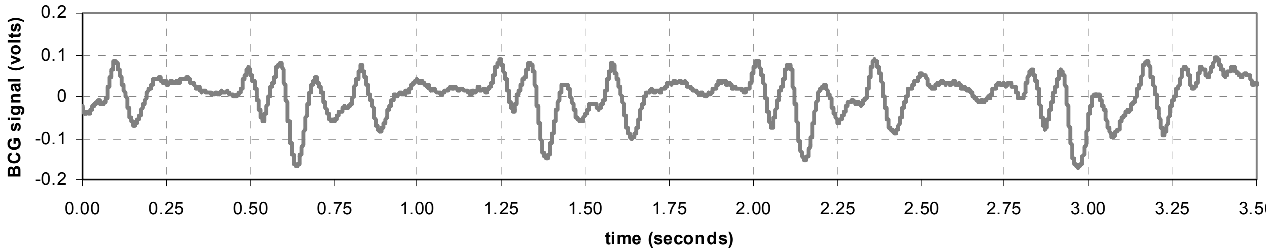

Fig. 4a A sample BCG recording of a male subject

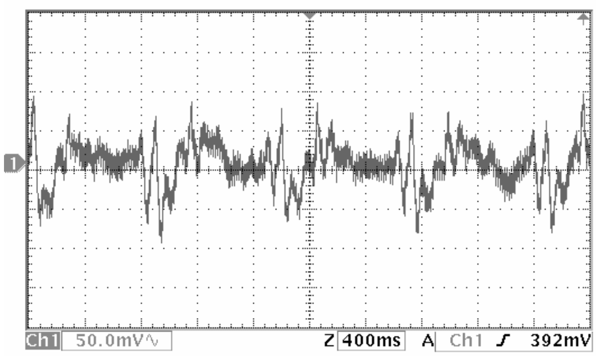

Fig. 4b. Oscilloscope screen shot of a pre-processed sample BCG recording from a male subject

III. RESULTS

BCG signal was taken from a few persons and the duration of the recordings was relatively short, therefore the results shown can be considered only preliminary at the moment. A sample BCG recording from a male subject is shown in Fig.4a. and 4b.

However the main components (H, I, J, L, N) of BCG signal can be recognized from the BCG signal that we detected. All the subjects were sitting on a chair during our experiment and the BCG measurements were inspected by a physician.

Respiration and any other movement of the body caused fluctuation mostly in the BCG signal, which is due to the chest moving during inspiration and expiration in front of our sensor; therefore we need to make the subject feel as comfortable as possible.

IV. FUTURE DIRECTION

We are working on extracting the heart signal from the breathing signal. This can be accomplished with digital signal processing MATLAB based software. When performing signal processing using MATLAB, the heart and breathing signals can first be separated by a 4^{th} order Butterworth low-pass filter. Then these two filtered signals are windowed and then auto-correlated to find the periodic breathing and heart signals simultaneously.

REFERENCES

[1] C. Hoffman, D. Rice, and H. Sung, “Persons with chronic conditions: Their prevalence and costs,” J. Amer. Med. Assoc., vol. 276, pp. 1473-1479, 13 Nov. 1996.

[2] J.C. Lin, “Microwave sensing of physiological movement and volume change: A review,” Bioelectromagnetics, vol. 13, pp. 557-565, 1992.

[3] K. M. Chen, Y. Huang, J. Shang, and A. Norman, “Microwave life-detection systems for searching human subjects under earthquake rubble or behind barrier,” IEEE Trans. Biomed. Eng., vol. 27, pp. 105–114, Jan.2000.

[4] J. Seals, S. R. Crowgey, and S. M. Sharpe, “Electromagnetic vital signs monitor,” Georgia Tech. Res. Inst., Atlanta, GA, Final Rep. Project A-3529-060, 1986.

[5] Weissler, A.M, Noninvasive Cardiology; Clinical Cardiology Monographs, Grune&Stratton Inc. NY.1974

[6] D. L. Hoyert, M. A. Freedman, D. M. Strobino, and B. Guyer, “Annual summary of vital statistics: 2000,” Pediatrics, vol. 108, no. 6, pp.1241–1255, Dec. 2001.

[7] non-contact vital sign monitor us patent 4958638

[8] A. Droitcour, V. Lubecke, J. Lin, andO. Boric-Lubecke,“A microwave radio for Doppler radar sensing of vital signs,” in 2001 IEEE MTT-S Int. Microwave Symp. Dig., 2001, vol. 1, pp. 175-178.

K. Leino, S. Nunes, P. Valta, and J. Takala, “Validation of a new respiratory inductance pletysmograph,” Acta Anaesthesiologica Scandinavica, vol. 45, no. 1, pp. 104–111, Jan. 2001.