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RESEARCH ARTICLE

A SURVEY OF CONTACTLESS HEART RATE MONITORING SYSTEM

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ABSTRACT

Cardiovascular diseases are the major causes for the death worldwide according to World Health Organization. Among the many vital signs like oxygen saturation, respiration rate and blood pressure of the arteries, "heart rate" is the vital factor monitored (LorenzoScalise, 2012). It is the vital sign required for patient approach both in clinical and emergency situations. Heart rate variability (HRV) is then performed on the processed data to have the record of any cardiac abnormalities. This literature survey is mainly about various contacted methods which are used so far to measure heart rate and their various effects on human beings (LorenzoScalise, 2012). The study also supports non contact methods of measuring heart rate which are quite ineffective when compared to the former.

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INTRODUCTION

The human heartbeat is divided into two parts namely Ventricular systole i.e., ejection of blood from ventricles and Ventricular diastole which is filling of ventricles (LorenzoScalise, 2012). The heart rate data is mainly used for measuring other factors like sympathetic nervous activity and synchronization with respiration rate. Around the year 1842 scientist have analyzed that electric current is present with each heart beat. The heart rate monitoring system "Electrocardiograph (ECG)" was mainly recorded using string galvanometer. ECG measurements can be either "fixed on body" or "fixed on appliances" (LorenzoScalise, 2012). ECG is the skin surface measurement of electrical activity of the heart over time. ECG's are mainly used to detect myocardial infarctions (heart attacks) and arrthymias (abnormal heart rhythms). It has been become the routine part of any medical evaluation and has been used as a diagnostic test for nearly 70 years (Aubert *et al*., 1984). An ECG signal is the small voltage difference between two electrodes. It is in the order of a few milli volts.An ECG detects the movement of ions through heart muscle known as the myocardium, which changes with eachcycle. The atria depolarize first which results in the initial wave formation known as P wave. The ventricles depolarize next which forms QRS complex. Finally the ventricles repolarize resulting in the T wave. Spacing between the waves have their own physiological significance. The P-R interval indicates the time of atria and ventricular depolarizing. If the P-R interval is long, then it indicates the conduction delay between atria and ventricles known as "heart block". The S-T segment is at a is o-electric voltage (i.e, 0mv).Elevations and depressions of the S-T segment indicates the conduction delay abnormality or loss of blood to the heart[(1)].Though fixed on body electrodes are reliable and having good signal quality they are inconvenient and inadequate for longer term, every day measurements. It limits the patient's mobility and comfort since they stay in the same initial position till the end of monitoring period (Aubert *et al*., 1984). Fixed in environment method is nonintrusive and adequate for long -term monitoring.

Phonocardiography (PCG) is another alternative method used for measurements. The processing is mainly based on the acoustic waves produced by the heartbeats which travel through the body upto the skin. Acoustic waves give information on the periodic variation of pressure and valve movements. PCG uses acoustic transducer which is highly sensitive and so it also comes under contacted method. Pulseoxymetry is another contacted method to measure heart rate (Alexander *et al*., 1989). The periodic expansion and contraction of micro vessels in the skin are monitored using LED and Photo diodes. The drawback here is that it should be maintained standstill so that variations may causes errors. Human beings are prone to electrical hazards and skin irritations. Some electrodes are sensitive to very small movements and the maintenance of recording set up is quiet difficult (LorenzoScalise, 2012). So comparatively non-contact methods are more advantageous.

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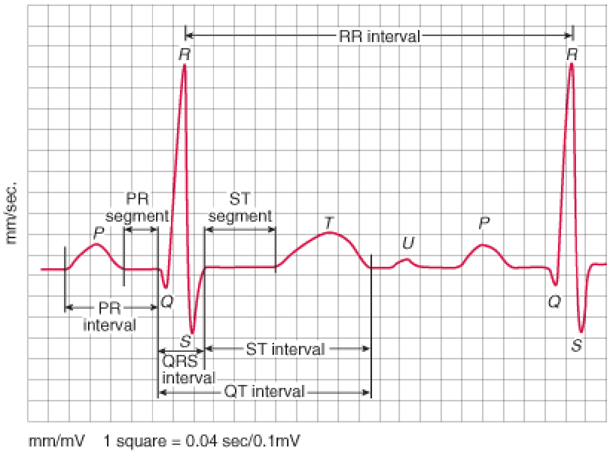

Fig.1. ECG signal

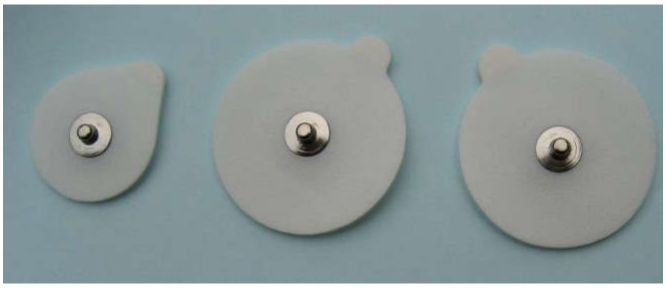

Fig.2. Electrodes used for ECG signal measurement

Non-contact methods

The basic idea for approaching non-contact method is considering the safety measures while using electrical apparatus and also the patient's health conditions (Abowd *et al*., 2002). Monitoring both the contaminated patients as will as the environment becomes easier.Initially non-conductivity of the electrodes were proposed in ECG recordings which used the principle of fixed in the environment." Ballistocardiography" was the technique in which the sensing part was attached to the bed or any furniture or the vibrations of the skin were monitored using seisomocardiography (Chan and Lin, 1987). The actual heart movements can be monitored using "ultrasound" which employs the sound waves produced by the heartbeat. It can be used to figure out the images of various heart parameters. Some expensive methods like "Magnetic Resonance Imaging (MRI)" and "Computer Tomography (CT)" gives the detailed images of entire human body (Castellini *et al*., 2006). Initially proposed methods were based on heavy and expensive components which were ready to afford by everyone. Later on light-weight and compact methods were given as solutions (Bronzino, 2000). Another interesting fact is that non-contact method offers the data required with the help of electromagnetic waves at certain frequencies can penetrate through some of the body tissues. Different laboratorial solutions. Image based monitoring systems, electrical impedance, acoustics, ultrasound forms the basic principle of non-contact heart rate monitoring (Scalise, 2012). Since they do not involve the physical contact with our body, the actual reflections from the heart is not observed. Only the body surface movements were recorded. The alternative method to overcome Sudden Infant Death Syndrome (SIDS) and burn victims were mainly related to contacted approaches only which require a lot of control. Non-contact methods are in progressive scenario currently. Four different categories of non-contact methods are being analyzed namely

- Radar based system
- Laser based system
- Image based system
- Other monitoring systems.

All the above mentioned methods aim to measure the surface displacements which were caused during systole and diastole movements. Because of this there is a heart wall movements changes slightly (Aubert *et al*., 1984). The systole movement moves the tissues under the tissues and other soft inter coastal tissues which causes the "heartbeat" which is experienced by everyone by placing their hands in left upper part of the thorax (Aubert *et al*., 1984).

EM based-medical radar system

Electromagnetic waves of considerable frequency are used to monitor the physiological movements of the human body. With medical radar technology human heart rate can be detected from a few meters distance or by placing antenna's on human body (Azevedo and McEwan, 1996). The acronym RADAR means Radio Detection and Ranging. Radar senses the range angle of the object and range velocity of the object with the help of radio waves. Radio waves have the frequency ranges of around 3 KHz to 300GHz.Radars can also be used to monitor the BP and also other changes in the heart rate so that different diseases can be detected. Consideringthe frequency range, a few MHz to 200GHz can be applicable to measure the heart beat from a certain distance (Azevedo and McEwan, 1996). Wireless recordings of the patient's heartbeat can be made instantly without connecting the patient and measurement equipments. There are many diagnostic possibilities in heart rate measurements using this wonderful tool called radar (Scalise *et al*., 2013). Unlike ECG which captures only the electrical activity of the heart, radars actually portray the exact chest actions caused by the heartbeat (Chen *et al*., 2005).

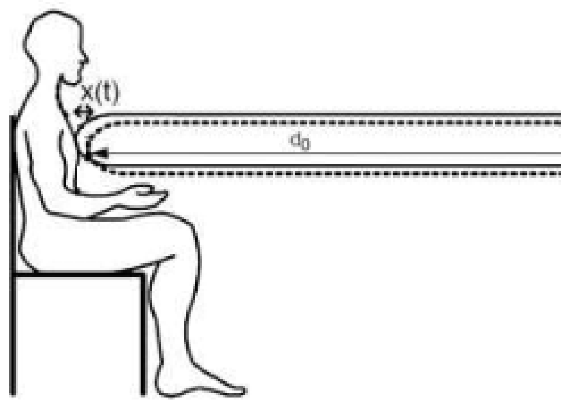

Fig.3. CW radar monitoring of the chest movement

Continuous wave or constant wave, commonly known as CW radar or Ultra Wide band radars (UWB) are used for the detections (Chia *et al*., 2005). As the name suggests CW radars generate a continuous range of electro-magnetic radiation. Anantenna which is used as a transmitter sends the signal to the targeted object and receives the reflected waves from the object (Saunders, 1961). In order to relate the movement of the target object, a mixer diode is used which produces a tension which corresponds to the phase difference between the incident and the reflected waves (Lin, 1975). A filter is needed to exclude the reflections related to respiration etc. in the beginning “microwave apexcardiography” was performed with an antenna ranging 2GHz to detect the pre-cardialmotions. Comparatively CW radars are convenient than UWB but they have the drawbacks of producing multiple reflections because of scattering effect in the environment by the target (Chia *et al*., 2005). Sometimes breathing harmonics and inter-modulation may confuse the detection of heartbeats. When a person is breathing and the heart is beating reflections definitely occur in the received radar radiations. Through some simulations optimal frequency for detecting the heartbeat is found but in real life scenario it is quite difficult to follow the same. When a carrier frequency of 10GHz is used a particular spatial resolution of around 75 micrometer is attained which can cover the entire heartbeat detection. A high pass filter of 0.7Hz cut-off frequency can be used to extract the detected portion. Both CW system and ECG system have no big variations in their observed waveforms and this can be chosen as a best alternative to ECG method (LorenzoScalise, 2012). The next interesting and possible approach to the radar monitoring of heart activity is by the use of pulse radar. Pulse radars fall under the category of UWB i.e. ultra wide band. CW systems transmit waveforms at specific frequency ranges which form a narrow band but UWB’s transmit narrow band impulse signals that pave way for wide band frequencies (Chia *et al*., 2005).

UWB applications are mainly used for military purposes since the emitted pulses spread over a wide band of frequencies they have a very short time duration lasting for nanoseconds. They usually do not disturb other equipments since they have very low spectrum. Pulse radars use pulse generator to transmit the EM waves.UWB devices mainly operate around the frequency of 6GHz and so the interference caused by other medical equipments are minimum since they use a frequency range much lesser than UWB. Though radar based systems may be used for detection purposes from a distance and through clothing and various obstacles the exact set of bandwidths and frequencies required for vital signal detections like heartrates are not studied systematically. Another important thing to be noticed is that modulations caused by the heartbeat. It’s quite difficult because radar not only measures the chest motions but also all other object movements within that antenna beam (Chan and Lin, 1987). Even a sub millimetre measurement will cause a change in the heart rate. Additionally, heart beats have a complex shape in the complex plane which cannot be determined at the first instant of the target movement. Radars were able to detect the heart beats because of the blood perfusion in the skin. But there is a dominating factor called body surface reflections which confuse the detections. An electro-magnetic wave transmitted from a human body travels in a planar fashion. Two factors mainly determine the scattering of the wave. The shape and the dielectric properties of the human body. Shape differs from person to person but dielectric properties remain the same. Though it is not suitable to real world scenario it sets the basic orders for the magnitude of reflections scattering from the body surface and the attenuation of the EM waves travelling inside the body. Heart beats causesmillimeter to sub-millimeter changes in the chest surface. Heart beat movements are also associated with throbbing blood veins and gravitational centre with the blood flow. So these movements in very minimum scale are recorded as phase change by the radar (LorenzoScalise, 2012). If low power, sensitive radar systems are used then small heartbeats can be measured. Another important thing to be noted is that ECG monitoring require a number of patches but radars do not make use of electrodes. Ultrasound and Radar systems have a different way of approaches. Ultrasound makes use of sound waves where as radars use EM waves. So tissue contractions is different in each approach. Unlike ultrasound radars do not employ the usage of gel between the probe and the skin and it can be implemented using low cost hardware. Human tissues dielectric properties say that about 70% of the incoming energy will be reflected to the air from the skin in non-contact measurements. Because of this backscattering of the human body surface is dominated by the surface reflections and heart rate modulations are due to small movements of the body surface. Hence to measure the heart movements directly antennas should be placed on the human body such that surface reflections can be minimised through coupling and smaller body movements can be captured.

Laser based

“LASER” forms the acronym for light amplification by stimulated emission of radiation. It emits light through the process of optical amplification. Laser interferometers were mainly used for optical measurements of the skin deflections. Doppler vibrometers (Droitcour *et al*., 2004). (LDVi) are used to monitor the deflections of skin and correlate with the carotid pulse. Since interferometers can operate only in laboratory environment with least unwanted signals. LDVi led to a another method Vibriocardiography (Scalise and Morbiducci, 2007) (VCG) which is used to monitor the chest displacement due to the heart activities. The carotid-femoral pulse wave velocity (PWV) is associated with the measurement of stiffness of large arteries.VCG is mainly used for assessment of PWV.VCG method overcomes the limitations of contact method arterial tonometry which is based on piezo transducers. Cardiac resynchronization is one of the other applications of VCG which makes use of pacing devices LDVi has been proposed in the field of biometrics which measures cardio-vascular activity. Lasers can penetrate for a quite longer distance and so they can be used to detect the several important signals in quite tougher situations. The proper functioning of the heart is the very important criteria for assurance of performance of the human body as well as the sustenance of life (LorenzoScalise, 2012).

Based on imaging

The image based systems for heart rate monitoring can be visualized based on the skin deflections. The deflection of the heart beat can be viewed by the consequent deflections of the skin surrounding the important region (LorenzoScalise, 2012). The skin deflections occur by two methods. In the first method skin illuminated by a 2mW HeNe laser beam in the veins and the scattered speckle pattern is observed from which a digitized code is developed based on speckle image processing. This can be used to estimate the skin displacement caused by the arterial deflections due to the systolic pressure inside vascular branches. In the next approach a small mirror is being glued to the skin which is illuminated by the laser beam. The position of the light spot now occurred by the intersection of the reflected beam is recorded and plotted. Remote sensing of the heart rates can be done later. Though both the methods do not give quantitative analysis they are understood by the graph which are completely in non-correlation with the original reference signals i.e. ECG signals. They need a proper set up to analyze this practically since they involve laser beams and speckle image processing. The latest trend based on imaging technique is that a time lapse image from a human body can be captured using a hand-held camera and it assures of measuring heart rate at 30s on average and also breathing rate (Marchionni *et al*., 2013). This has been named as "cardio cam" and the image has been captured by the camera's like web cam. Another imaging technique is that which focuses for optical pletismography. Here non contacted reflection mode of imaging for three wavelengths has been observed. Later on a small battery operated heart rate monitoring camera system has been designed for testing the swimmers to measure the unrestrained heart rate measurement.

Other monitoring systems

This is a very large area of research where many ideas are being proposed for contactless heart rate monitoring. One such method is the magnetic induction. The principle behind this is based on mechanical actions of the heart, diaphragm, thorax (Bronzino, 2000). They circulate blood and air throughout the body. Considering the impedance point of view blood is good conducting and air is poor conducting inside the chest region. They induce eddy currents into the tissues and so re-inducted external magnetic field is measure as a signal. This setup requires a small coil which performs the excitation. The main limitation is the sensitivity between the coil and the body (LorenzoScalise, 2012). Another approach is based on capacitive coupling. The electrodes are placed away from the human's chest at a certain distance and electrostatic induction current through the electrodes are measured. The next quite interesting detection is like sensing the pressure oscillations using a sensing mat placed under a pillow. As it requires a sensory system in real time, it uses pressure sensors. Elderly people who are bed-riddenneed a different kind of approach which led to measurement by bed structure oscillations. The ultrasonic transmitter and receiver are installed on both sides of the bed so that a patient can rest in any position and the physical parameters alter the shape of the bed and then amplitude modulation of the received signal is performed (LorenzoScalise, 2012). If the patient is out of the bed the amplitude does not vary.

Conclusion

Measurement of some vital biosignals has become a very crucial part in the medical field. The patients cannot be constantly attached with electrodes for monitoring. Also, constant methods have the above mentioned drawbacks. So, it is more credible to stick on with the noncontact measurement techniques. The EM wave technique is a promising one. So, an antenna that operates in such low frequencies of 1.00Hz to 1.67Hz has to be designed. Also, an appropriate signal processing algorithm should be adapted to segregate and retrieve the necessary signals.

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