Non-invasive Acquisition of Blood Pulse Using Magnetic Disturbance Technique

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Abstract — **Blood pulse is an important human physiological signal commonly used for the understanding of the individual physical health. Current methods of non-invasive blood pulse sensing require direct contact or access to the human skin. As such, the performances of these devices tend to vary with time and are subjective to human body fluids (e.g. blood, perspiration and skin-oil) and environmental contaminants (e.g. mud, water, etc). This paper proposes a novel method of non-invasive acquisition of blood pulse using the disturbance created by blood flowing through a localized magnetic field. The proposed system employs a magnetic sensor and a small permanent magnet placed on the artery (major blood vessel) of the limbs. The magnetic field generated by the permanent magnet acts both as the biasing field for the sensor and also the uniform magnetic flux for blood disturbance. As such, the system is able to operate at room temperature, reliable for continuous long term acquisition, compact (small size) and convenient for daily usage. The heart rate obtained from the proposed system when measured through non-conductive opaque fabric, is found to be highly correlated to commercially available cardiac monitoring system such as ECG and pulse-oximetry.**

Keywords — **blood pulse, magnetic biasing, non-invasive, magnetic disturbance**

I. Introduction

A. Context of the study

With the advancement of bioelectronics, portable health monitoring devices are getting popular because they are able to provide continuous monitoring of an individual's health condition with ease of use and comfort. Portable health monitoring devices are increasingly required at places such as home, ambulance and hospital, and at situations including military training and sports.

Pulse rate is a measurement of the number of times the heart beats per minute. The heart pushes blood through the arteries, which expand and contract allowing blood to flow.

Heart or pulse rate is an important parameter subject to continuous monitoring because they are representative in assessing the physical health condition of an individual. Healthcare institutes such as the hospitals and elderly care centers can use this information to monitor the health conditions of their patients. This is particularly important for patients with cardiac arrhythmia whose heart rate variability needs to be monitored closely for early detection of cardiac complications.

Furthermore, pulse rate information of individuals subjected to mentally or physically stressful conditions may be utilized to trigger alert for immediate attention when large changes in heart rate variability indicate potentially fatal events such as heat stroke, cardiac disorder and mental break down. Finally, it can be also important to monitor pulse rate of personnel working in dangerous environments such as deep sea condition (divers), high temperature (fire-fighters), and deep underground (coal miners).

B. State of the art

Current methods of heart or pulse rate acquisition can be classified into electrical [1-2], optical [3,7], microwave [4], acoustic [5,8,11], mechanical [6,9] or magnetic [10,12,13] means. The use of electrical probes to measure heart rate was discovered in 1872. Such a method normally requires good electrical contact with the human skin and the performance is subjective to human body fluids (e.g. blood, perspiration, skin-oil) and environmental contaminants (e.g. mud, water, etc). In most deployment, reference electrodes are usually required to ensure such a system is less susceptible to electrical noise [2]. Recent research [1] had also reported a new method of ECG acquisition using contact free capacitive sensing. However, this method is highly subjective to noise and motion artefact.

Examples of commercially available heart rate acquisition systems include ECG monitoring devices, pulse rate monitoring watches and chest strips. All of these devices require electrical contact between the probes and the human skin.

The use of optical sensors in pulse oximetry [3,7] is getting popular due to its compact nature and the ability to concurrently acquire SpO_2 concentration in blood. The basic operating principle of such a system requires a light source and a sensor where the reflected light content is measured to determine the blood pulse and SpO_2 concentration in blood. Typically, such a system is worn on the tip of the fingers or toes where optical transmittance of the human skin is important to ensure signal quality.

Microwave radar [4] has also been reported for non-invasive detection of heart rate. However, such methods are highly subjective to motion artifacts created due to movement of the subject.

Acoustic method of acquiring heart rate on the human chest was available through the invention of the stethoscope since 1816. Over the years, this method, which has progressed with electronics and innovative signal acquisition systems, is widely reported [5,8,11].

Biomagnetic signal from the heart was detected in 1963 by Baule and McFee. The basic principle involves the mapping of the magnetic field around the thorax while the heart magnetic vector is acquired and is commonly known as magnetocardiogram (MCG). Such a method requires highly sensitive magnetic sensors such as SQUID (Superconducting QUantum Interference Device) and is currently not readily deployed for clinical use as ECG proves to be more reliable, convenient and less expensive.

Another way to measure the blood pulse is based on Hall Effect [10,13]. Such system applies a uni- or bi-directional magnetic field on the human body to create polarization of blood molecules. Electrodes are placed on the human skin near the applied magnetic field to pick up the potential difference created by the induced magnetic signal.

Mechanical methods to acquire heart or pulse rate varies from the use of pressure cuff to piezo-electric materials worn over the limbs or body [6,9]. Such mechanical methods to acquire heart or pulse rate requires the application of localized pressure on the human subject and are not well suited for continuous signal acquisition.

The limitations of each of the above methods to acquire heart or pulse rate motivated the research on a simple and yet reliable magnetic means to acquire blood pulse. Such a method will support the acquisition of blood pulse without the need for a good electrical or optical contact and can be used over a prolonged period of time on the limbs. One of the objectives in developing a non-invasive magnetic based blood pulse acquisition system is to use commercially available magnetic sensors in place of SQUID or electrodes. This will allow the system to operate at room temperature, to be reliable, compact (small size), cheaper, and more convenient for daily usage.

II. Experimental set-up

The experiment on blood pulse acquisition utilizes the concept of placing a magnetic field in the vicinity of the major artery where the blood flowing through the magnetic field will disturb the magnetic field, thus creating a magnetic disturbance. Such a magnetic disturbance is acquired using a magnetic based sensor operating at room temperature as shown in Figure 1. In this experiment, the variation of magnetic field is termed Modulated Magnetic Signature of Blood (MMSB).

The relative position between the magnet (1), sensor (2) and the artery (major blood vessel) was varied and the final set-up for measurement is shown in Figure 2 where the sensor output was sufficiently amplified and then connected to an oscilloscope. The configurations of the sensor on the limbs are illustrated in Figure 3.

To achieve the objective of small size for portability and operation at room temperature, the uniform magnetic field is created by the use of a button-sized permanent magnet (3mm diameter) with magnetic strength of 1000 Gauss. The magnet is placed over the major arteries on the limbs with a magnetic sensor placed in close proximity. The measurements will depend on several aspects: the distance between the sensor and the magnet (approximately 15mm) providing a uniform magnetic field that ensures proper biasing, the magnet strength that does not saturate the sensor, and the appropriate penetration of the magnetic field into the skin tissues.

The magnetic sensor has typical performance characteristics as shown in Figure 4. Magnetic biasing is illustrated in Figure 4 where the sensitivity of the sensor is improved by operating it in the linear region. As such, the sensor is able to amplify any minute changes to the magnetic field due to the flow of pulsatile blood in the uniform magnetic field.

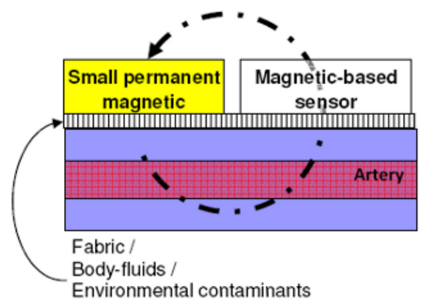

Figure 1. Cross-sectional view of the experimental setup to acquire MMSB

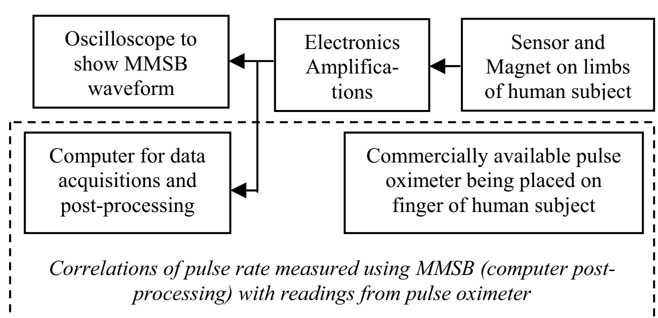

Figure 2. Block diagram of experimental setup to acquire MMSB with correlation of results using commercially available pluse oximeter.

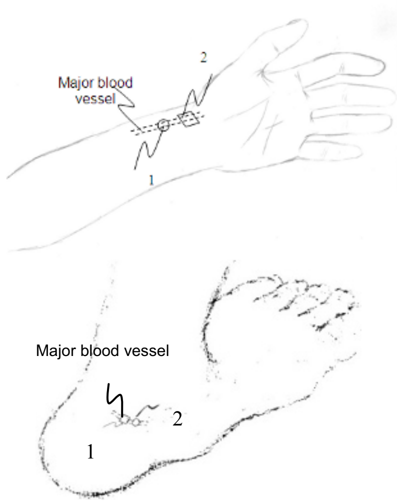

Figure 3. Illustrations of the relative position of the magnet(1), sensor(2) and a major blood vessel

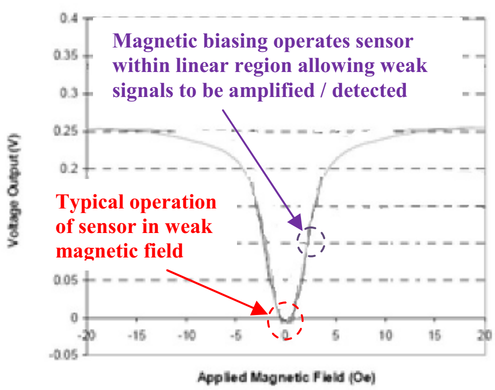

Figure 4. Typical sensor response with illustration of magnetic biasing to increase its sensitivity

III. RESULTS AND DISCUSSIONS

The experimental setup to acquire MMSB on the wrist was done in a laboratory condition where subjects are in a sitting position and their arms are well rested on the table. The magnet is secured on the wrist using a non-magnetic adhesive tape while the sensor is positioned on the artery, near to the magnet. Similar experimental setup to acquire MMSB on the heel was performed on subjects in a sitting position with their heels rested on the floor.

The signal acquired from the sensor on each subject is repeated on at least two separate measurements and found to be repeatable. In addition, these experiments have also been repeated on fifty different subjects and the pulse rates measured are found to be within $\pm 5\%$ of the readings obtained from a pulse oximeter.

A typical waveform acquired from the sensor in this setup is shown in Figure 5 where it can be observed that it is highly periodic and has the pulse width of the subject's heart rate. The waveform obtained is also observed to have high correlations to the MCG reported in [10] as illustrated in Figure 6.

In addition, on the basis of magnetic disturbance of the pulsatile blood flow on a uniform magnetic field, MMSB can also be used to describe the activities of the heart as illustrated in Figure 7. For example, an increase in the measured magnetic disturbance can only be created by an increase in blood flow due to the compression of the heart ventricles. As the ventricles compress to their maximum, the peak of the waveform is reached. Without further force from the heart on the blood flow in the artery, the blood flow rate will reduce as shown in the decreased in amplitude of the waveform. With the relaxation of the ventricles, a back-flow of blood is present in the artery. Finally, the atrium will simultaneously compress, resulting in a small forward flow of blood as shown in the second peak detected in MMSB.

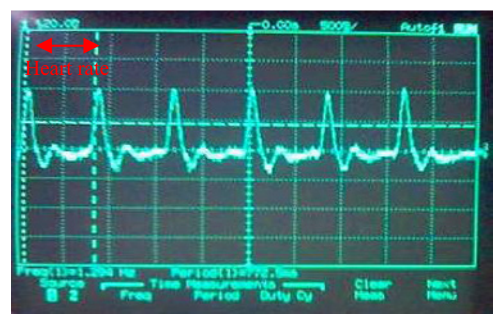

Figure 5. Waveform captured from the sensor output using oscilloscope

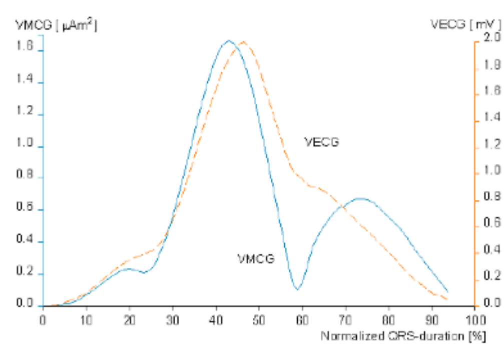

Figure 6. Simultaneous plots of the magnitude curves of the EHV (dashed curve) and the MHV (solid curve) during the QRS complex [10]

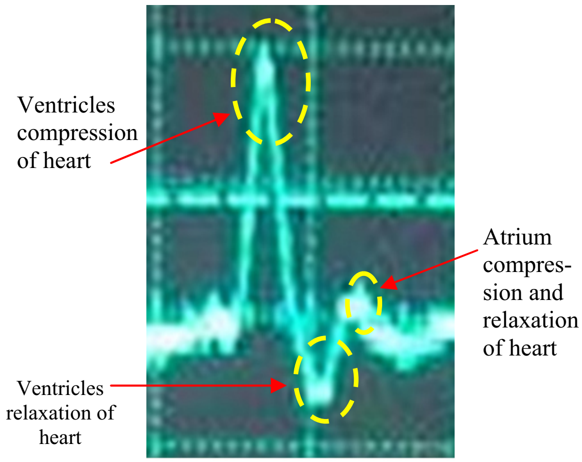

Figure 7. Illustration of MMSB and the activities related to the heart

IV. Conclusions

This experiment demonstrated the concept of magnetic disturbance (MMSB) by the pulsatile blood flowing in a uniform magnetic field. Such magnetic disturbance can be acquired by the use of a button sized permanent magnet and a commercially available magnetic sensor. The waveform obtained is highly correlated to the activities of the heart. It is conclusive that MMSB exists and has the advantage of being contact surface independent which is lacking in existing methods of heart or pulse rate acquisition systems.

Further work will focus on the modelling of the magnetic modulation using blood, to optimise the system sensitivity. This should lead to a reduction in the overall size of the sensing module (i.e. sensor and magnet).

Acknowledgment

The authors would like to thank Nanyang Polytechnic of Singapore for the opportunity to work on this development. In particular, the authors would like to express their gratitude to the School of Engineering (Electronics), Nanyang Polytechnic (Singapore) for the usage of facilities that supported this work.

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