HEART RATE MONITORING USING INFRARED THERMOMETRY IN AN EARPIECE

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***Abstract*— Heart rate is a key factor in cardiovascular system monitoring and sports science. Some recent commercial applications use sensors in the ear but are faced with motion artifacts which corrupts the signal. Infrared thermography is a non-contact technique and may minimize motion effects with better user comfort and lower power consumption. We propose a novel system that uses infrared differential thermometry to detect the heart rate in the auricle. The signal analysis is performed using a continuous wavelet transform which extract frequency features of the bioheat transfer waveforms. Preliminary results taken from the neck provide proof of concept and similar results from the ear are expected.**

Keywords—Heart rate; Infrared Thermometry; Wavelet Transform.

I. Introduction

Cardiovascular disease is a prominent health problem in the world. Over 30% of the world's population is either overweight or obese [1]. Sport wearables are a trend that aims to provide health solutions by providing fitness markers to people. Continuous monitoring of the cardiovascular system is also an important requirement for the incoming aging population.

Heart rate is a vital sign that directly correlates to the intensity of the physical effort being performed during training [2]. Heart rate tracking exercise is recommended in many sources in literature and has become a trend even outside of professional athletes [3]. Traditionally, the most common way to track the heart rate was using an Electrocardiogram (ECG) chest band. After this, advances in photoplethysmography (PPG) made for the clinical setting were transferred to consumer applications and activity trackers wristbands using the technology were popularized [4].

Wristbands are more comfortable for the user but have issues with motion artifacts during activities that involved arm movements [5] [6]. In order to solve this, the technology was applied into earphones taking advantage that the head is more static during exercise. However, PPG technology requires a good fit to reduce the motion artifacts and ear morphology variations are translated into noise. PPG also requires a light source that is disadvantageous for wearable technology relying on batteries. The quality of the heart rate signal measured in the ear is therefore poor.

Unlike PPG, Heart rate measurement using thermometry has not been studied thoroughly. Research has been done on heart rate measurements in the wrist using thermocouples [7], while other researchers aimed to study the heart rate in the nose [8] and the neck [9] using Infrared (IR) thermometry. The neck is near one of the main arteries and it is open to cooling. However, locating the sensor in these parts lowers considerably the usability of the system and sacrifices user comfort.

Infrared technology has the potential to reduce motion artifacts while maintaining signal quality and significantly reducing power consumption. The technology has already been demonstrated in the neck and it is possible to apply the same concept to the ear, given their similar blood flow properties. To our knowledge there have been no reports on the detection of the heart rate signal in the ear using thermometry. This project aims to explore the possibility of detecting the heart rate by measuring changes in heat flow from the ear to the environment. For this, it is required to miniaturize the complete system.

II. Detection Principle

A. In-ear bioheat transfer

The ear is a location where other electronic devices, such as the earphones of a headset and hearing aids, are already placed or can be placed with minimum discomfort during exercises. Also it has the advantage of reduced movement compared to most other parts of the body. The body's core temperature is developed in the central part of the body where the major organs are located (heart, lungs, pancreas, etc.) and it is transported by the blood through the arteries to the rest of the body. Because the environment is usually lower than the core temperature (37 °C), there is a cooling effect from the skin to the environment and heat transfer from the blood into the surrounding tissue and to the environment takes place. This heat transfer results in changes in temperature that can be measured by infrared thermometry. The ear anatomy and its temperature distribution are therefore of key importance for placement of the sensor

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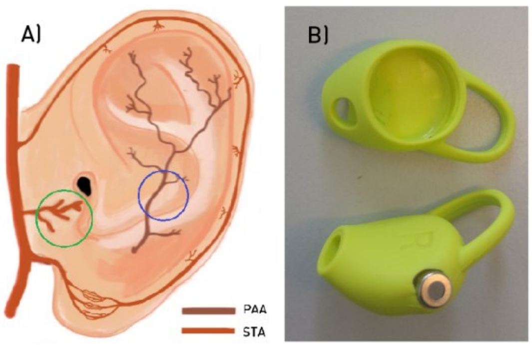

Fig 1. A) Brown artery corresponds to the Posterior auricular artery while the red artery corresponds to the superficial temporal artery. Green circle marks the Tragus area and blue circle signals the cavum conchae area. B) Example of the sensor locations in the headset used. Upper earpiece (No sensor) positions the sensor towards the anti-tragus. Lower earpiece (Sensor for reference) positions the sensor towards the cavum conchae.

B. IR sensor placement

To find the location with optimum change in temperature caused by heart rate we have performed measurements and a literature research. The relation between the body's core temperature and the tympanic temperature can be found from literature. The temperature distribution in the ear canal and the auricle however has not been described by many [10] [11]. The ear canal temperature is close to the tympanic temperature, but has a small environmental exposure and therefore a negligible bioheat flow. In order to establish the best location, a literature review on blood irrigation was done based on the artery and tissue distribution in the ear. Based on this we selected the best locations for the measurement of bioheat transfer as the tragus and the cavum conchae as marked in figure 1a [12]. These two locations have direct blood irrigation coming from the superficial temporal artery (STA) and the posterior auricular artery (PAA). These locations are also uncovered and therefore, they are exposed to cooling from the environment.

C. Infrared detection sensor

The human body temperature is considered as a black-body radiator generating an infrared radiation spectrum with a broad peak at $\lambda = 9.5\mu$m. The changes in temperature are in the low-frequency range (0.5-4 Hz) and most suitable detectors in terms of signal-to-noise ratio and bandwidth are thermal detectors. For single point measurements, pyroelectric sensors or thermopile devices give the best performance [13]. Pyroelectric sensors are not used since they are affected by the microphony effect which may induce motion artifacts in the signal. Thermopiles are already used in non-contact digital thermometers for the ear and several types from different manufacturers were compared using their noise equivalent power (NEP), time constant, signal stability and size. A ZTP-135SR sensor [14] with a responsivity of 62 V/W, an optical bandwidth of 6-14 μm and a *NEP* of 0.51 nW/√Hz was selected and fitted in earpieces at the two locations shown in Figure 1b: The top figure for the Tragus and lower figure for the cavum conchae.

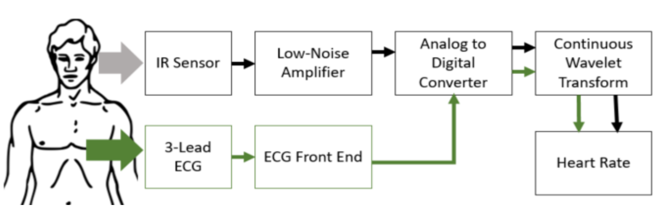

Fig 2. Block diagram of the test setup. Infrared signal taken from the ear and reference ECG signal taken from the chest of the subject.

III. Measurement Setup

A thermopile was fitted into a modified earpiece and located in the ear of the subjects in the locations of interest. The thermopile signal was amplified with a low noise (3 nV√Hz) amplifier circuit to a voltage range matching the AD converter. As a reference signal, an ECG module was used to record electrical signals of the heart of a test person, using the heart rate monitor front end IC AD8323. Heart rate from the ECG was used as the reference value for the real heart rate. Both signals were fed into a National Instruments 6211 data acquisition system and analyzed in a computer. A block diagram of the complete system as used for the measurements is shown in Figure 2.

A. Heart rate extraction

Filtering and frequency analysis of the both the ECG and the infrared signal is performed in previously recorded data to measure and compare the heart rate signals. A 1-D digital filter with a window of 0.3 was used as a low pass filter. Wavelet analysis allows for local analysis and outperforms Fourier analysis in this application since it can represent abrupt changes efficiently. The bioheat transfer waveform from the ear is not well characterized but wavelet analysis allows to use different type of waveforms and select one that brings optimal results. The Wavelet Toolbox of MATLAB 2017a was used to perform the analysis. A continuous wavelet transform (CWT) with a bump wavelet was was used in the analysis.

IV. Measurements

A preliminary test was performed in the neck to validate that the system was working correctly. The bioheat transfer follows the same periodicity of the ECG peaks. Figure 3 shows an example of the IR output with the ECG peaks marked as vertical lines. The cooldown effect of the skin right before a surge in high temperature can be seen. Figure 4 shows the CWT of the ECG signal compared to the output of

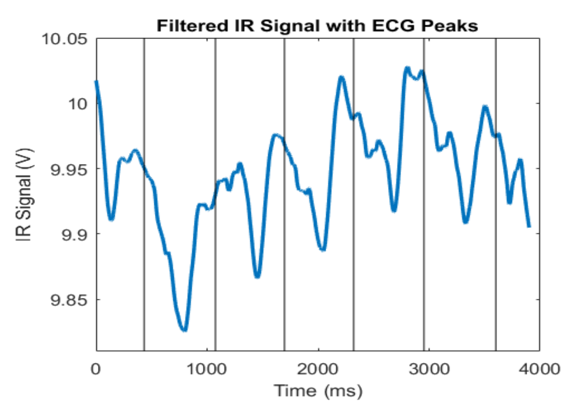

Fig 3. IR sensor output (Blue) after a digital low pass filter. ECG peak

the IR signal in the range of heart rate signal. The CWT coefficient shows the correlation of the wavelet to the analyzed signal. In both images, the largest coefficients are located between 1 and 2 Hz. Figure 5 shows the extracted heart rate value based on the largest coefficients for each moment of time of the CWT analysis.

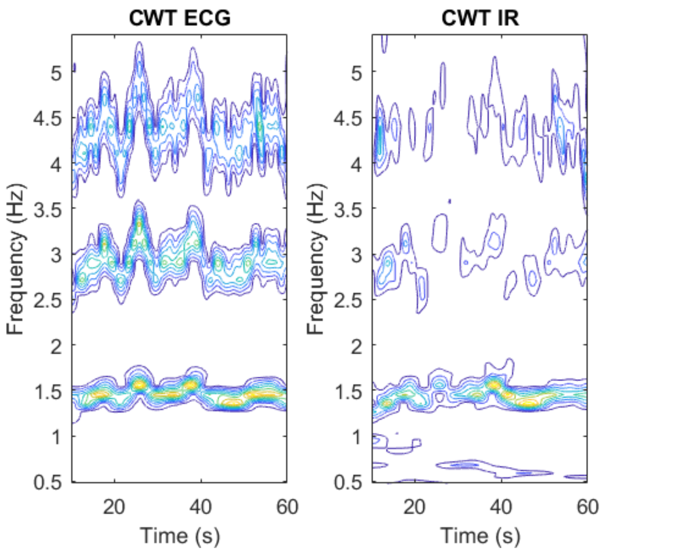

Fig 4. Continuous wavelet transform (CWT) coefficients of the signals. Warmer color coefficients signal a frequency match in the signal. A) ECG signal. B) IR sensor signal.

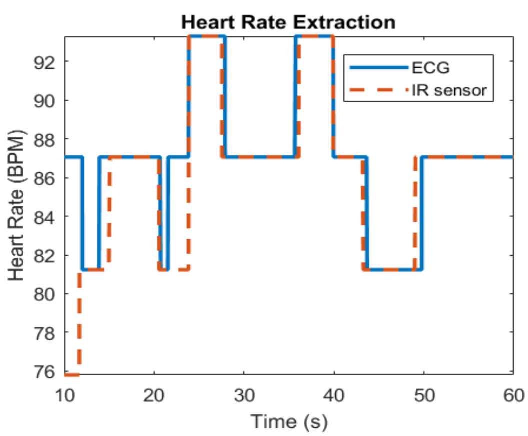

Fig 5. Heart rate extracted from the ECG signal and the IR sensor using the CTW coefficients.

V. Conclusions

A system for measuring heart rate detection based on temperature changes of the skin has been developed and tested. Wavelet analysis has been used to extract the frequency from the heart rate signal. The system has been tested successfully using arteries in the neck. At the moment the initial measurements in the ear show the heart rate with a low accuracy. The temperature changes that have been measured are near the limits of the commercial thermopile detector used. Our on-going work on the optimization of the electronics and the sensor and also its placement in the earpiece will improve our results to a level required for reliable heart rate measurements.

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