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Heart Rate Detection Using a Multimodal Tactile Sensor and a Z-score Based Peak Detection Algorithm

Bruno Monteiro Rocha Lima[1], Luiz Claudio Sampaio Ramos[2], Thiago Eustaquio Alves de Oliveira[1], Vinicius Prado da Fonseca[1] and Emil M. Petriu[1]

[1] University of Ottawa, Ottawa, Canada
[2] Military Institute of Engineering, Rio de Janeiro, Brazil

Abstract— **Tactile sensing is the foundation of interaction within the environment. Tactile systems are used to gather information from its surroundings. This research contribution is to present a new feature of a recently proposed multimodal tactile sensor. Data acquisition was conducted by the Robotic Operating System (ROS) and data processing used a Smoothed Z-score Peak Detection algorithm. The heart rate was calculated by the tactile sensor and compared to a commercially available wrist monitor. The sensor and the monitor presented the same results for each trial in rest condition with the exception of one, where it differed by 1 bpm (1.8%).**

Keywords— **Tactile sensor, Heart rate detection, Z-score peak detection, ROS**

I. INTRODUCTION

The heartbeat is the recurrence of a cardiac cycle, i.e. begins with the atrial contraction (atrial systole) and ends with the ventricular relaxation (ventricular diastole) [1]. Within this process, there are physical aspects of the heart that can be measured as a means to monitor it. The change of partial pressures in the heart chamber conducts the blood flow into the circulatory system. This results in the deformation of the veins and arteries. Consequently, the skin is deformed. In this article, a multimodal tactile sensor was used to calculate this deformation and, hence, heartbeats.

Aside from pressure changes, there are other physical aspects of the heart that can be used to detect and calculate a heartbeat. For example, It is common to use the electrical signals of the heart in the form of an electrocardiogram (ECG). Another approach is to use the heart sounds generated by the blood flow.

There are many different interesting techniques used exclusively to measure a heart rate. [2] detected heartbeats with 95% to 99% accuracy using video analysis from a camera-based photoplethysmography. Alternative methods include doppler radars [3, 4]. [5] captured the frequency variation of an un-modulated wave that was transmitted by a Doppler radar and reflected by a human's chest and used an algorithm to calculate the heart rate.

Considering the most advanced ways to calculate a human's vital signs, the approach used in this article is simple to implement. Currently, from the author's knowledge, there is no literature on tactile sensors and biological readings such as pulse detection. Therefore, this article contribution is to measure heartbeats with a multimodal tactile sensor.

II. TACTILE SENSING

Within a given environment, human interaction is based on the feedback of different sensing modalities. For instance, in order to perform a task such as grasping a key in a pocket full of coins, tactile feedback is required. Contrarily, for differentiating two objects based on coloration, vision is needed. Tactile sensing should be explored in order to complement the interaction experience that robots and amputees (prosthetics) have within their surroundings, and allow them to perform more efficient tasks.

A. Tactile Sensors

In recent years, a wide variety of tactile sensors using various materials, structures, electronics, and data processing techniques have been proposed [6–9]. Although there are different methods for building tactile sensors, their performance individually is not yet sufficient enough to be considered indispensable in robotic or prosthetics tasks. To be efficient, a tactile sensor must include (1) high performance (e.g. sensitivity) (2) compliance (3) data processing & acquisition. In order to achieve these goals, the combination of different sensors in a module is promising and therefore, the Multimodal Tactile Sensing Module was designed and build by [10]. This article presents a new feature for the newly tactile module.

B. Multimodal Tactile Sensing Module

The Multimodal Tactile Sensing Module (Figure 1) comprises a 9 DOF MARG (Magnetic, Angular Rate, and Gravity) sensor, a flexible compliant structure similar to the human skin, and a deep pressure sensor. Its design is inspired by the locations and functions of the mechanoreceptors in the human skin [10].

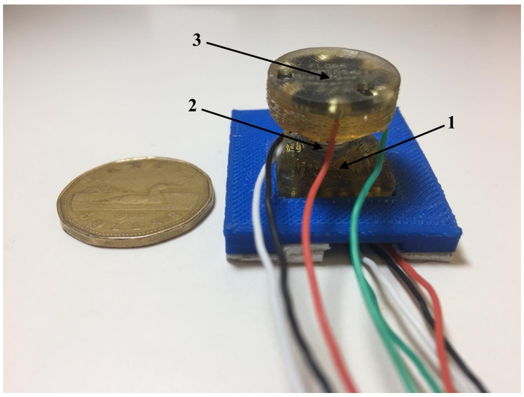

Fig. 1: The Multimodal Tactile Sensor:1 - MARG (Magnetic, Angular Rate, and Gravity) system; 2- Cone compliant structure 3 - Shallow barometer

The cone compliant structure was build in a way that interactions within the module's surface will be transmitted to the shallow barometer. The tactile module showed accurate results in determining the slope of inclined planes [10]. Moreover, the MARG unit combined with the barometer was capable of recognizing surfaces by sliding a robot finger on it [11]. The top part of the sensor has a diameter of 18.5 mm.

III. EXPERIMENT SETUP AND METHODS

The experiment consisted of measuring the heart rate using the Multimodal Tactile Sensor, and a commercially available pressure monitor was used as a control.

A. Setup

The module was put in a 3D-printed base that could be easily manipulated. The tactile sensor was turned on and placed perpendicularly on the researcher's carotid artery located in the neck. A commercially available device (an automatic wristwatch blood pressure monitor) was attached in the researcher's wrist. Each experiment lasted until the wrist monitor calculated the heartbeat (around 30 s). The first five trials were done while the researcher was in a rest position and rested. The last five trials were completed after five minutes of normal aerobic exercises, but still in a rest position. The signals were recorded at a frequency of 412 Hz. A lower heartbeat is considered to be 40 bpm, equivalent of 0.67 Hz. According to the Nyquist Theorem, the sampling rate must be at least $2f_{max}$. Hence, the experiment should be recorded at least 1.34 Hz. In this case, 412 Hz assures a reliable experiment.

B. Data Acquisition: ROS

The Robotic Operating System (ROS) is used in robotic system development. It is a collection of software frameworks that functions by integrating different modules, i.e. having multiple tasks running synchronously [12]. ROS was used in order to attribute information from the tactile module's barometer to ROS message data. ROS bags (ROS file format) is a viable option to log the data since it saves the data on-the-fly. Therefore, the barometer output data was saved in .bag and processed Offline.

C. Data Processing: Smoothed Z-score Peak Detection

A challenge faced in the data processing was that the center of the pressure signal varied through the time because the sensors were held by human hands (and therefore, different applied pressures). It is possible to see in the results that the pressure signal has a decreasing or increasing trend, which is not related to the pulses, but the pressure inflicted by the experimenter so that the module touches the skin. As a result, a method that tracks the trend of the signal is needed to identify peaks.

The Smoothed Z-score Peak Detection algorithm uses a moving mean and deviation that will select the points (peaks) that are outside the threshold. The algorithm is based on the principle of dispersion: if a new data point is a number of standard deviations away from a moving mean, the algorithm classifies this point as a peak [13]. Most peak detection algorithms have a large number of parameters, making it harder to implement. The Z-score was chosen for having only a few constraints.

There are three parameters that have to be set for a working algorithm: the lag (l), which dictates how many data points will be used to recalculate the moving mean and standard deviation; the threshold (th), which is how many standard deviations away from the mean a new data point has to be in order to be classified as a peak; and the influence (i_n), which controls the influence of peaks in calculating the new moving mean and standard deviation. The influence is set between 0 and 1, where zero assumes stationarity and it is the most robust option. Non-stationary data should assume an influence between 0 and 1.

The generic equations about z-score based adaptive peak detection are given by Eq. 1, with x_n being the pressure signal, as shown in [14].

$$\begin{aligned} \bar{s_i} &= \frac{1}{l}\sum_i^{i+l} s_i & \sigma_{s_i} &= \sqrt{\frac{\sum_i^{i+l}(s_i-\bar{s_i})^2}{l-1}} \\ s_i &= i_n x_i + (1-i_n)s_{i-1} & z_i &= \frac{x_i - \bar{s}_{i-1}}{\sigma_{s_i}} \\ th &= constant & y_i &= \begin{cases} 1 & \text{if } |z_i| \geq th \\ 0 & \text{if } |z_i| < th \end{cases} \end{aligned} \quad (1)$$

In this experiment, the following parameters were selected: $th = 2.5$, $l = 100$ and $i_n = 0.1$. Hence, a lag of 100 implies that the last 100 observations will be used to smooth the data. A threshold of 2.5 will determine if a data point is 2.5 standard deviations away from the moving mean. An influence of 0.1 gives signals 10% of the influence that normal data points have.

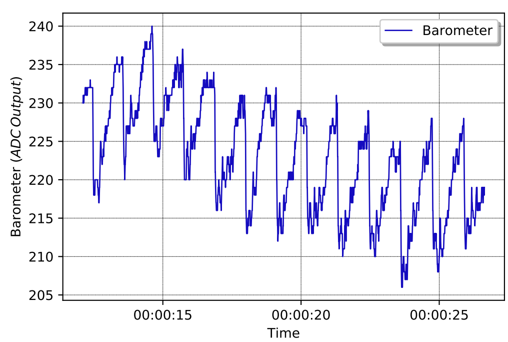

Fig. 2: Raw data with a decreasing trend from the Multimodal Tactile Sensor's barometer after one of the heart rate experiment

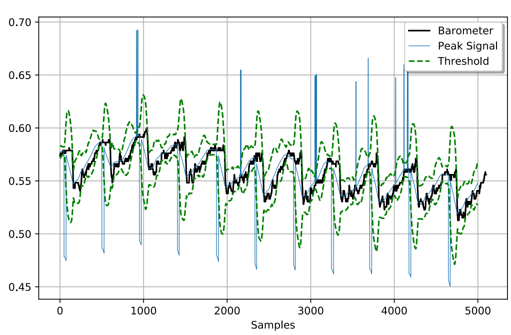

Fig. 3: Z-score algorithm applied: peak detection from the raw data

IV. Results

Using ROS as a way to collect the data, the information from the Multimodal Tactile Sensor's barometers was stored in ROS bags. The raw data collected is shown in Figure 2

Figure 3 shows the threshold (in green) and peak signals (in blue) of the processed data after using the Z-score algorithm.

The pulse rate (f_b) can be calculated by Eq. 2, where Δs is the distance (in samples) between two peaks and f_s is the sampling frequency.

$$f_b = \frac{60 f_s}{\Delta s} \quad (2)$$

Since there are several peaks in each experiment, and therefore several heartbeats calculated, the median of the values was taken in order to prevent possible outliers. Table 1 and Table 2 summarizes the heart rates calculated in rested condition and after 5 minutes of aerobic exercises, respectively, at rest position.

Table 1: Heart rate measured by the Multimodal Tactile Sensor and a commercially available pressure monitor at rest

Trial	Wrist Monitor (bpm)	Tactile Module (bpm)
1	56	56
2	53	53
3	53	54
4	55	55
5	56	57

Table 2: Heart rate measured by the Multimodal Tactile Sensor and a commercially available pressure monitor after 5 min of aerobic exercises

Trial	Wrist Monitor (bpm)	Tactile Module (bpm)
1	93	100
2	90	94
3	78	77
4	73	72
5	71	65

V. Discussion

The raw pressure signals were promising for the measurement of the pulse. It is possible to notice peaks that represent the cardiac cycle in Figure 2. The implementation of the Z-score algorithm overcomes the decreasing trend problem seen in the raw data.

The heartbeats calculated by the tactile module are approximately the same as the wrist monitor, with a difference of only 1 bpm (1.8%) in rested condition and a maximum difference of 7 bpm (7.5%) after the five minutes of aerobic exercises. The highest difference is expected for two main reasons: the respiration rate increased with the heart rate, which may have caused interference in the detection of the peaks; the wrist device is only meant to work accurately in constant heartbeats, whereas in the second trial it was decreasing (cooling time). Hence, the heartbeat calculations can be considered more reliable in normal conditions (rest) until further experimentations are performed. Future research should use more appropriate commercially available heart rate sensors that can measure non-constant heartbeats.

VI. Compliance with ethical requirements

The experiment is in accordance to [15], section 8.2: "... Self-experimentation which involves minimal risk or less is permissible without REB approval if it is for purposes of quality control of research apparatus or methods.".

VII. Conclusion

The results showed a difference of 1.8% (1 bpm) and 7.5% (7 bpm) from the multimodal tactile sensor and the wrist pressure monitor for the first and second trial sections, respectively. The high similarity in the outcomes indicates that the tactile module responded in a promising manner and, therefore, demonstrated that measuring heartbeats can be considered a new feature for the multimodal tactile sensor. Future work should use a more adequate commercially available heart rate monitor. Moreover, the inertial and magnetic sensors present in the module should be used to detect and remove motion interference that may affect the measurement of the pulse.

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

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