Study and Evaluation of Palmar Blood Volume Pulse for Heart Rate Monitoring in a Multimodal Framework

Hugo Silva[1,2], Joana Sousa[1,2] and Hugo Gamboa[1,3]

[1]PLUX - Wireless Biosignals, S.A., Av. 5 de Outubro, n. 70 - 6, 1050-059 Lisbon, Portugal
[2]IT - Instituto Superior Técnico, Av. Rovisco Pais, n. 1, 1049-001 Lisboa, Portugal
[3]CEFITEC - Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

Abstract. Within the field of biosignal acquisition and processing, there is a growing need for combining multiple modalities. Clinical psychology is an area where this is often the case, and one example are the studies where heart rate and electrodermal activity need to be acquired simultaneously. Both of these parameters are typically measured in distinct anatomical regions (the former at the chest, and the later at the hand level), which raises wearability issues as in some cases two independent devices are used; finger clip sensors already enable heart rate measurement at the hand level, however they can be limiting for free living and quality of life activities. In this paper we perform a study and evaluation of an experimental blood volume pulse sensor, to assess the feasibility of measuring the heart rate at the hand palms, and thus enabling the design of more convenient systems for multimodal data acquisition.

1 Introduction

Blood Volume Pulse (BVP) sensors are a commonly used method for assessing the cardiovascular activity at the arterial level [1]. Their operating principle is based on photoplethysmography, that is, by externally applying a light source in the visible or invisible wavelengths to the tissues, and measuring the amount of light that reaches a photodetector [2]. The detector can be positioned to measure either by reflection or transmission; as the heart pumps blood through the arteries, and subsequently through the peripheral vessels, the translucency of the vessels changes due to the increased blood volume, modifying the way that the emitted light is reflected or transmitted to the photodetector [3]. The typical output of the sensor is then a signal where each cardiac cycle is expressed as a pulse wave (Figure 1(a)).

In this paper we present a study and evaluation of a palmar BVP sensor for heart rate measurement, designed to be integrated in multimodal systems for biosignal acquisition at the hand level. The studied arrangement further expands the current state-of-the-art in the field by improving wearability aspects. Unlike existing systems, taking into account that the sensor is placed at the hand palm, no additional volume is moved on to the fingers, enabling the wearer to make normal use of the hand. Experimental results have shown a good correlation between the measurements taken at the hand palm and at the fingertip, validating the palmar placement as an adequate alternative to

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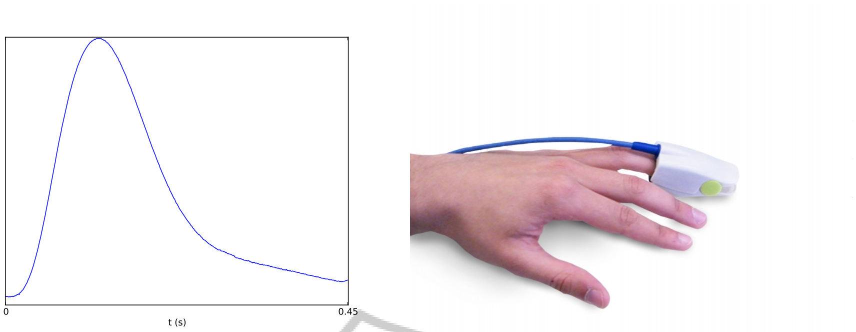


(a) Pulse wave signal (b) Common sensor placement

Fig. 1. Example of a Blood Volume Pulse (BVP) signal and typical fingertip sensor.

standard approaches. The remainder of the paper describes the motivation for our work in Section 2, presents the materials and methods in Section 3, and highlights the results and conclusions in Sections 4 and 5 respectively.

2 Motivation

The heart rate has became a widespread biosignal measurement for self-management and assessment, with extensive application in a variety of contexts such as clinical diagnosis, sports activities, and affective computing, among others [4–6]. Chest straps have risen as a standard for unobtrusive data acquisition, and although these form factors are concealed by the clothing and thus, discrete for regular use, a growing number of applications require the measurement of multiple parameters simultaneously. This is the case of clinical psychology [7, 8], where besides the heart rate and derived information, electrodermal activity is also used as a psychological or physiological arousal indicator. As electrodermal activity is more noticeable at the hand palms and fingers, several usability difficulties arise when both parameters need to be measured simultaneously, since two independent devices are generally required.

Due to the close relation between BVP signals and the cardiac activity, the heart rate is one of the parameters generally extracted from the collected data. Furthermore, BVP sensors can be applied to any place in the body irrigated by blood vessels, particularly in peripheral areas, making it an appealing alternative to the more intrusive cheat mounted apparatuses. The most common placement is at the fingertip [9] (Figure 1(b)); however, for long term or continuous use, this anatomic placement limits the regular activities of it's wearer as the fingers play a fundamental role in most daily tasks. Furthermore, for patients with schizophrenia, psychosis, autism, among other, to place biomedical sensors at the finger is hard to the medical staff, because these patients have high movements and tendency to remove the finger clip. Thus, a BVP glove can overcome some of these issues, since the patient wears a glove, which is hard to remove and it as not being subject to the fingers movements.

From BVP signal, Heart Rate (HR) and RR intervals can be extracted, allowing the Heart Rate Variability (HRV) analysis in terms of time and frequency domains. HRV is widely related to the mental diseases, since it can provide information about the emotional state of the patient, by its correlation with the automatic heart modulation being a powerful tool for clinical use. For example, the HRV spectral analysis reveals that the vagal activity is the major contribution to the high frequencies component. Furthermore, it is also argued that the low frequency (LF) and high frequency (HF) ratio reflects the sympathovagal balance or the sympathetic modulation. These parameters are very important since some authors defend that there is a significant increase of LF band and significant increment of the HR for panic disorders patients and significant lower values of R-R intervals and HF peak of spectral analysis in depressive patients than in the health people.

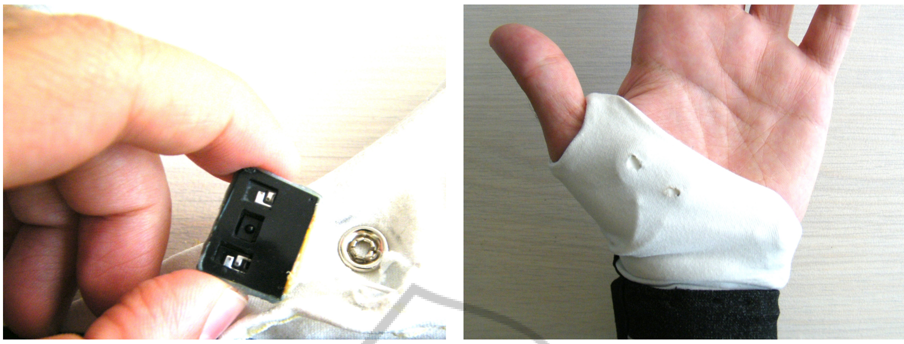
In addition to the HR and HRV analysis, the BVP sensor can be updated with other emitter, becomes in an oximetry sensor, which allows to measure both HR and oximetry parameters. BVP sensor can also be combined with an ECG sensor and through the Pulse Transient Time (PPT) technique allowing to measure the blood pressure.

Thus, sensors designed for other areas such as the earlobe can also be found, nonetheless, the placement at the hand level is particularly advantageous for the design of multimodal measurement units, as it enables the combination of BVP signals with other parameters (e.g. electrodermal activity).

3 Methodology

Our work targeted the comparison of heart rate measurements taken at the hand palm and at the fingertip, aiming at the feasibility evaluation of palmar sensors for that purpose. We used a set of two BVP sensors, a standard transmissive sensor placed at the tip of the ring finger, and an experimental reflective sensor in a side-by-side, dual-emitter, single detector configuration (Figure 2(a)), placed at the base of the hypothenar eminence, near the point where it meets the wrist (Figure 2(b)). This palmar location was identified as the least affected area within hand whenever finger movements occur. The palm sensor was compared with a finger tip since this last one is considered the gold standard to measure heart rate based on PPG technique for clinical practice. Furthermore, the finger tip used as standard it was also validated by [10], which compared the HR and HRV extracted from the finger tip sensor and ECG sensor. The authors have shown a strong positive association between all the parameters calculated using the finger BVP and ECG signals.

A bioPLUX research wireless biosignal acquisition unit was used for data acquisition, enabling synchronous sampling and real-time transmission of the collected data to a base station. For the measurements at the fingertip, a bvpPLUX sensor was used; for the experimental palmar sensor, the base circuitry of a bvpPLUX was used but the emitter/detector arrangement was adapted according to what previously described. Raw sensor data was acquired with 1000Hz sampling rate and 12-bit resolution; through offline signal processing, we computed the heart rate information and performed statistical analysis of the results. Figure 3 depicts an example of the raw signals obtained with each of the sensors.



(a) Palmar sensor (b) Hand placement

Fig. 2. Blood Volume Pulse (BVP) sensor and placement at the hand palm.

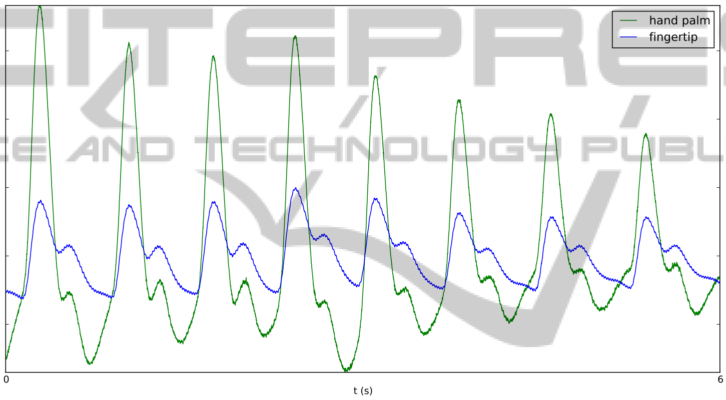


Fig. 3. Palmar and fingerprint BVP signal.

4 Results

Experimental evaluation was performed on a group of 10 healthy subjects, composed by 5 males and 5 females, with an average age of 26 ± 3 years, and quietly sat in order to avoid movement artifacts. We intend to validate the palm position with the finger and so no movement artifact must be in the signal. These artifacts mask the BVP signals, not allowing to visualize the raw BVP signal and extract the cardiac and signal parameters. Data was acquired at rest for a period of 5 minutes, and analysed with respect to the accuracy of heart rate calculation (HR), signal-to-noise ratio (SNR), and root mean square (RMS). Table 1 outlines the main results; which revealed a very strong positive association between the measurements obtained by both sensors.

The heart rate exhibits a coefficient of determination $R^2 > 98\%$, and a $p - value > 0.05$, showing that the outcomes are not statistically different. The measurement divergence between both sensors is $1bpm$ at most, as shown by the average heart rate difference of $0.25bpm \pm 0.45$. Another interesting finding is a pulse latency between

Table 1. Fingertip and hand palm BVP sensors comparison.

	Fingertip	**Hand Palm**
	$M \pm SD$	$M \pm SD$
HR (bpm)	70.13 ± 10.51	70.38 ± 10.07
SNR (dB)	132.70 ± 61.43	173.30 ± 60.21
RMS (V)	0.22 ± 0.12	0.07 ± 0.05

the hand palm and the fingertip; from the collected data, an average $0.14 \pm 0.38s$ lag was found, with the maximum being $0.73 \pm 0.08s$ for one of the tested subjects, and the minimum being $0s$ for two others. At the palmar level, the experimental BVP sensor used in the tests also presented a higher SNR, and a lower RMS.

5 Conclusions

The heart rate is one of the most widely adopted biomedical indicators in use to date, and state-of-the-art research has focused on finding wearable and easy to use acquisition methods applicable in free living and quality of life activities. While chest straps currently provide a convenient acquisition possibilities, with a very high level of discretion, a problem arises in applications that require the combination of heart rate with other indicators that need to be measured in body areas other than the chest.

Clinical psychology is one such area, where measurements as the electrodermal activity (typically measured at the hand palms or fingers), also provide important psychophysiological information. Blood Volume Pulse (BVP) sensors, stand as alternative method for heart rate assessment at the hand level, however current measurement approaches greatly limit the subjects normal activities, as they require the sensor to be clipped to a finger. In our work, we further extend the stat-of-the-art in the field, by evaluating the feasibility of using the BVP for heart rate assessment at the palmar level, thus enabling the design of more integrated and practical multimodal measurement systems.

Results obtained from real-world data have revealed a high correlation between measurements taken at the hand palm and at the standard finger tip location ($R^2 > 98\%$), as shown also by the average divergence of $0.25bpm$. Another interesting finding was a latency between the palmar and finger BVP pulses; this, together with further validation on a larger set of test subjects will be the focus of future work within our group and in daily-use condition. This will allow to lead filter studies in order to understand how to remove the movement artifacts into the BVP signal and, consequently, to improve the feasibility of the measures. Furthermore, usability and hygiene conditions will be also evaluated, which will enable to make adjustment in the glove and become it more comfortable and usable for clinical practice.

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