Validating a PPG Device for Estimating Heart Rate in Various Activity Conditions

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***Abstract*—Accurate monitoring of heart rate (HR) during various activities is crucial for assessing cardiovascular health and optimizing performance. In this study, we evaluated the accuracy of a wristband PPG device for estimating HR across different activity conditions. Seventeen subjects participated, each equipped with a wristband PPG device and an ECG as a reference, while performing office tasks, walking, jogging, and running. We compared the estimated HR provided by the PPG device to the HR estimated from the synchronously recorded ECG, calculating the relative errors (E_r) for each activity phase. During office tasks, 100% of the recordings exhibited E_r below 10% and 5%. However, during walking, this percentage decreased to 69% and 63%, and further dropped to 50% and 38% for jogging, respectively. In this work the HR provided by the wristband PPG device was validated. However, given that the device provides the raw PPG and accelerometer signals, further development of signal processing algorithms may improve HR estimation.**

***Index Terms*—Photoplethysmography, Heart Rate Estimation, Activity Monitoring, Wearable Devices, Signal Processing, Validation.**

I. Introduction

Beginning with the pioneering works of Morris et al. and Paffenbarger [1], [2] in the 1950s, which highlighted the importance of physical activity for cardiovascular health, a substantial body of high-quality evidence has accumulated, demonstrating the benefits of an active lifestyle and regular exercise for long-term health.

The reduction in the cost of wearable technologies has made the measurement of activity and health data, such as heart rate (HR), more accessible. Accurate HR estimation during different activities can be beneficial for various health-related applications. The integration of wearables into health systems for precision preventive medicine is the necessary next step, which requires the validation of the measures provided and the improvement in sensor and device design as well as in algorithms to extract significant data from the recorded signals [3]. Validating the HR estimated by a wristband under conditions of activity [4] is not a trivial issue due to the presence of artifacts and low signal quality (movement of personnel, sensor, pressure).

The objective of this work is to validate the PPG-based HR estimate provided by a wristband device in different situations, that can be used afterwards in personalised medicine.

II. Materials and Methods

A. Database and Exercise Protocol

The recordings were conducted following a structured protocol. Seventeen subjects participated comprising various activities: five minutes of office tasks, including checking emails, browsing the internet, and writing emails; five minutes of walking at 3 miles per hour; five minutes of jogging at 6 miles per hour; and five minutes of running at 9 miles per hour.This protocol received approval from the Local Ethics Committee and informed consent was obtained from all participating volunteers.

The database includes the following signals: 1) ECG from a validated reference device (Medicom MTD 2009) sampled at 500Hz; 2) HR estimated by the Matrix watch from a green-PPG sampled at 25,6 Hz, which is the device to be validated, and it is provided at a sampling rate of 25,6 Hz (repeating values until a new estimate is available). The wristband device was connected to an Android device, while the ECG was connected to a laptop running Windows. Synchronisation of the ECG and wristband-HR was achieved using Unix timestamps, which corresponded to the internal clocks of the respective devices. Manual checks were performed to ensure temporal alignment between the two systems.

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B. HR validation

A wavelet-based delineation algorithm is used to obtain the R-waves of the ECG [5], to therefore estimate the reference HR using the IPFM model [6]. To compare the HR derived from the ECG with the one from the matrix device, we took an average of both HR every second. Then, the relative error, E_r, was calculated as the percentage difference between HR provided by the device and the reference HR:

$$E_r = \frac{|\mathrm{HR}_{\mathrm{PPG}} - \mathrm{HR}_{\mathrm{ECG}}|}{\mathrm{HR}_{\mathrm{ECG}}} \times 100\% \quad (1)$$

The analysis further determined the percentage of subjects exhibiting a E_r below 5% and 10% during each phase of the exercise protocol.

III. Results and Discussion

An illustrative example of the temporal evolution of the reference HR estimated from the ECG and the HR provided by the Matrix device is shown in Fig. 1. At the beginning, HR remains low and stable, indicative of a low-intensity activity. As time progresses, there are significant increases in HR, corresponding to transitions to higher-intensity activities. These increases are captured by both the reference and the wristband device.

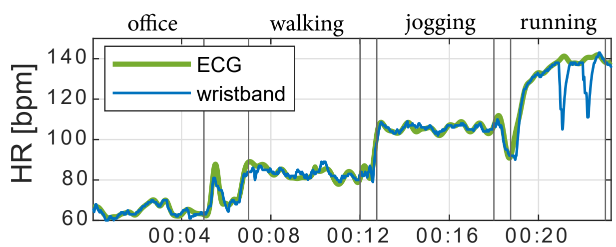

Fig. 1. Temporal evolution of the HR. In green, the reference HR derived from the ECG; in blue, the HR estimated by the Matrix Watch. The start and end of each phase are plotted with the vertical lines.

However, during phases of intense activity, discrepancies between the two measurements can be observed. Thewristband shows some variations and inaccuracies in estimating HR, especially at the highest intensity levels, where the reference maintains a smoother and more continuous curve.

Tab. I presents the mean HR and mean E_r for all subjects, and for each activity for the various physical activities. In the table, it is observed that E_r varies according to the activity, being lower in low-intensity activities like office tasks and higher in high-intensity activities like jogging and running.

TABLE I
Reference Heart Rate (HR) and Relative Errors

	Office Tasks	**Walking**	**Jogging**	**Running**
Mean HR [bpm]	78 ± 10	95 ± 12	124 ± 17	156 ± 20
E_r	0%	1%	13%	19%
$E_r < 10\%$	100%	69%	50%	38%
$E_r < 5\%$	100%	63%	38%	19%

Furthermore, the table shows the percentage of subjects whose E_r is below 10% and 5%. During office tasks, 100% of the subjects have a E_r below both 10% and 5%. However, as the intensity of the activity increases, the percentage of subjects with low E_r decreases. For example, during jogging, only 50% of the subjects have a E_r below 10%, and this percentage further reduces to 38% during running. This illustrates how the accuracy of HR measurement varies with the intensity of physical activity, showing higher accuracy in low-intensity activities and lower accuracy in high-intensity activities.

When estimating HR from PPG during physical activity (see Tab. I), it's crucial to consider the influence of arm movement frequency, which can introduce periodic motion artefacts. Activities like walking or running, where arm movements align with HR frequency, can significantly impact the accuracy of PPG-based HR estimation. However, accuracy during physical activity can be significantly improved with advanced signal processing techniques [7]. Access to raw PPG and accelerometer data allows for the development of sophisticated algorithms that better account for motion artefacts, thereby enhancing HR measurement accuracy during dynamic activities.

IV. Conclusion

This work has validated the HR estimation provided by the Matrix wristband device during different activity conditions. During office tasks, 100% of the recordings exhibited E_r below 10% and 5%, while during walking, this percentage decreased to 69% and 63%, respectively. While some subjects showed good HR estimation even during running, others experienced significant underestimation, likely due to movement artefacts affecting the periodicity of PPG signals. This study has shown that the reliability of wristband metrics can vary with the intensity of the activity. By understanding these variations, one can make more informed decisions about the appropriate contexts for using wristband HR data, ensuring that the data collected is suitable for the intended analytical or clinical purposes.

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