Measuring Local Pulse Transit Time for Affective Computing Applications

Nils Beckmann (1), (2), Reinhard Viga (1), Aysegül Dogangün (2) and Anton Grabmaier (1)

(1) Electronic Components and Circuits,
Department of Electrical Engineering and Information Technology, University of Duisburg-Essen,
D-47057 Duisburg, Germany

(2) Competence Center Personal Analytics,
Department of Computer and Cognitive Science, University of Duisburg-Essen,
D-47057 Duisburg, Germany

E-Mail: nils.beckmann@uni-due.de
Web: www.uni-due.de/ebs, www.uni-due.de/panalytics

Abstract – In the research area of Affective Computing user data is analyzed to get access to human emotions. Physiology parameters can be used as a source of information in this context. A high number of physiological parameters (e.g., from respiratory or cardiovascular system) have been investigated regarding their correlation to psychological processes [1]. Wearable devices offer the opportunity to measure these parameters and hereby to develop Affective Computing applications. However, developers of wearable devices have to find a compromise between functionality (e.g., quantity and quality of parameters) and usability (e.g., simplicity, comfort).
We present a novel approach which is supposed to enable a device to measure an additional parameter and to improve parameter's accuracy compared to present devices. Our focus is on the cardiovascular system and a commonly used method in this context is the Photoplethysmography (PPG). PPG-based sensors are used in many wearable devices like smartwatches and fitness trackers to measure Peak to Peak intervals (t_{PP}) between successive blood pulse waves and hereby derive Heart Rate (HR) or Heart Rate Variability (HRV). HRV describes changes of t_{PP} over time and is frequently used in Affective Computing. However, compared to the R-Peak to R-Peak intervals (t_{RR}) derived by Electrocardiography (ECG, the gold standard for HRV measurement) this method is inaccurate in particular, if the user is physically active or experiencing mental stress [2].
Our approach also uses PPG-based sensors, but extends the devices capability by using two sensors (PPG1 and PPG2) placed at a known distance ($\mathrm{d}_{\mathrm{x1}\rightarrow\mathrm{x2}}$), for example, at the forearm. Through this extension a device is expected to measure the time delay the blood pulse wave needs to travel from one point to another. This time is called local Pulse Transit Time ($t_{PTT,local}$). The state of the art is measuring global Pulse Transit Time ($t_{PTT,global}$) using an ECG and a PPG. $t_{PTT,global}$ is defined as the time between the contraction of the heart (R-Peak) measured by an ECG and the arrival of the corresponding blood pulse wave (e.g., at a wrist) measured by a PPG [3]. It can reflect states of the cardiovascular system which can respond to psychological processes [1].
Figure 1 shows how calculation of $t_{PTT,local}$ can be done using two PPG Signals. The inflection point of the wave is detected by the zero crossing in the second derivative of the PPG signal. The delay between corresponding inflection points is $t_{PTT,local}$.
Equation 1 shows that global PTT ($t_{PTT,global}$) can also be seen as a possible source of error when comparing t_{RR} and t_{PP}.

$$t_{RR} = t_{PP} - |t_{PTT,global}(n) - t_{PTT,global}(n+1)| \quad (1)$$

Because $t_{PTT,global}$ can vary from heart beat to heart beat it induces an error in PPG-based HRV measurement. The variation of $t_{PTT,global}$ is affected by two variables (eq. 2).

$$t_{PTT,global} = t_{PEP} + \frac{d_{Heart\rightarrow x}}{\bar{v}_{PWV,global}} \quad (2)$$

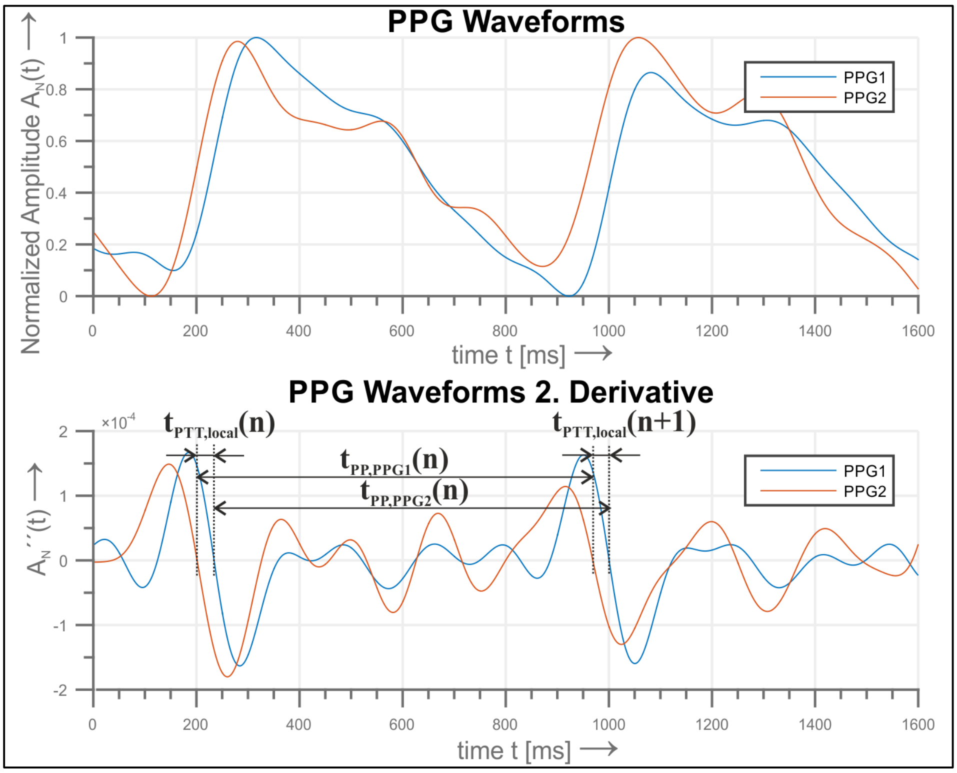

Fig.1: PPG Waveforms measured by two sensors in a short distance (upper graph). Second derivative of the waveforms and derivable parameters (lower graph).

The first one is the so called Pre-Ejection Period (t_{PEP}) which is the time delay between the electrically measurable contraction of the heart and the actual ejection of blood [4]. The second influence factor is the time delay based on the fixed distance the pulse wave has to travel ($d_{Heart\rightarrow x}$) and the variable mean Pulse Wave Velocity ($\bar{v}_{PWV,global}$) correlating to the current state of the cardiovascular system. By measuring the variability of $t_{PTT,local}$ we want to estimate changes in the state of the cardiovascular system. This data could be directly used in Affective Computing applications. Furthermore, we want to develop a model using $t_{PTT,local}$ as an input parameter to increase the accuracy of PPG-based HRV measurement. This approach can be integrated into a single device and therefore functionality as well as usability can be considered.

Our preliminary results of short term $t_{PTT,local}$ measurement under resting conditions proved the practicability of our approach. We achieved values within an expected range derived from literature. Due to the fact that we are not able to capture t_{PEP} and measure $t_{PTT,local}$ instead of $t_{PTT,global}$ our approach is limited (eq. 2 and 3).

$$t_{PTT,local} = \frac{d_{x1\rightarrow x2}}{\bar{v}_{PWV,local}} \quad (3)$$

Therefore, further investigations focusing on variations in $t_{PTT,local}$ and its impact on HRV measurement are necessary.

References

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