# A New Low-Complexity Algorithm for the Pulse Transit Time Evaluation

Radjef Lilia and Omari Tahar

Department of Electrical Engineering Systems, Boumerdes University, Boumerdes, Algeria

## *Abstract*

*The pulse transit time (PTT) is a physiological parameter commonly derived from Electrocardiogram (ECG) and Photoplethysmogram (PPG) signal. It is defined as the time taken for the arterial pulse to travel from the heart to a peripheral site, and can be used as a direct indicator of Cardiovascular Diseases (CVD). In this study, we propose a new low-complexity algorithm for the (PTT) estimation. The (PTT) is calculated as the interval between the peak of the ECG R-wave and a time point on the PPG. We considered a dataset of 37 subjects containing a simultaneous recording of the (ECG) and the (PPG). The computation of the (PTT) consists of detecting the peak and foot points of a (PPG) and the R peak of the (ECG) signal. Our algorithm is improved by a temporal analysis by windowing. The results obtained are promising. The average sensitivity (SEN) and accuracy (ACC) obtained are respectively (97.5%, and 96.82%) for the detection of R peaks and (97.77%, and 97.64%) for the detection of PPG peaks. The sensitivity (SEN) and accuracy (ACC) of the foot (PPG) detection were 98.33% and 94.14%.*

## *Keywords*

*Pulse transit time (PTT), Cardiovascular Disease (CVD), Electrocardiogram (ECG), Photoplethysmography (PPG), Algorithm, Peaks detection, Sensitivity (SEN), Accuracy (ACC).*

## 1. Introduction

Cardiovascular disease is the leading cause of death in the world, according to the World Health Organization (WHO). The early detection of vascular diseases can be the key to effective prevention and treatment [1, 2, 3]. Pulse transit time (PTT) provides information from the arterial tree on arterial stiffness (AS) [4], vessel compliance, and blood pressure (BP) [5, 6, 7, 8]. The pulse transit time (PTT) is defined as the time taken for the pulse wave to travel from a proximal point to a distal point in the arterial system. It is based on the Moens-Koertweg and Bramwell-Hill equations [9] and is inversely related to the pulse wave velocity (PWV), which is calculated as the distance traveled by the pulse wave divided by time. The use of (PTT) dates back to 1964 when Weltman et al [10] designed the PWV computer based on the use of the (ECG) complex and a downstream pulse signal to determine the pulse transit time over a known arterial length. The (PTT) can be measured using pulse wave transducers placed close together in a homogeneous arterial segment [11] (as shown in Figure 1).

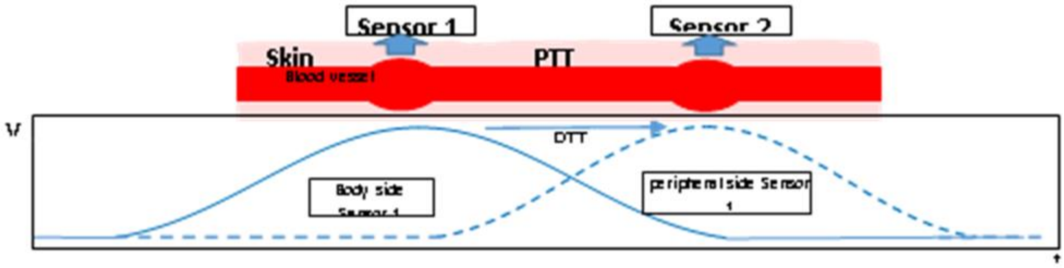


Figure 1. The pulse transit time (PTT)

There are different non-invasive techniques to measure (PTT), such as arterial tonometry, doppler ultrasound, electrocardiography (ECG signal represents the electrical activity of the heart) - photoplethysmography (PPG signal measures changes in blood volume), and pressure transducers [12, 13, 14,15,16]. The (PTT) techniques are reproducible, non-invasive, easy, and safe, it is therefore not necessary for specialized training required for medical staff to handle them. Depending on the equipment used and the applications, the (PTT) can be defined as the time difference between the onset of cardiac ejection approximated by the R-peak in the electrocardiogram (ECG) and the arrival of the pulse at the fingertip as determined by the photoplethysmogram (PPG) [17, 18, 19, 20, 21, 22] (shown in Figure 2). Promising applications of (PTT) include the detection of stroke and myocardial infarction [23], sleep-disordered breathing [24], monitoring of ductus arteriosus closure in neonates [25], detection of sympathetic nervous system (SNS) excitation [26], etc. The evolution of (PTT) is related to changes in the cardiovascular system. For example, changes in systolic blood pressure (SBP) and/or arterial stiffness (AS) [27].

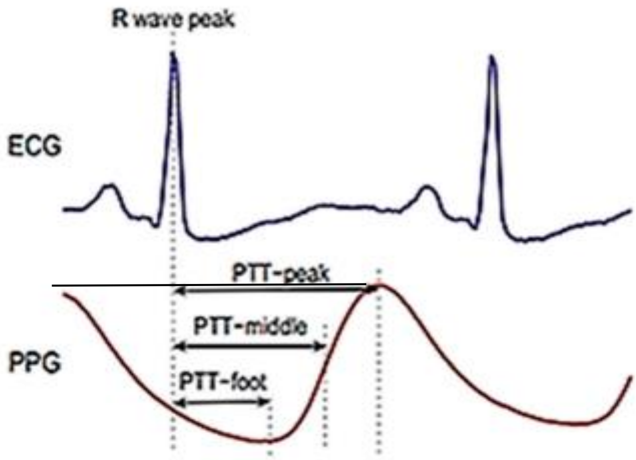


Figure 2. Graphical explanation of the (PTT) calculation using (PPG) and (ECG) signals

A combination of the (ECG) and (PPG) signals leads to the measurement of another cardiovascular parameter called pulse arrival time (PAT). The (PAT) includes not only the desired (PTT) but also a rejection period (PEP). This approach has been extensively reported in the literature [28, 29, 30]. Another approach (2), the (PTT) can be acquired by observing two (PPG) waves distant from each other [31,32], or by using only one (PPG) signal [33, 34, 35, 36], different measurement sites exist in the periphery including the finger, ear lobe, toe, and forehead although they are less practical. To measure the (PTT) (or PAT), various vital signals such as Photoplethysmograph (PPG), electrocardiogram (ECG), ballistocardiogram (BCG), gyrocardiography (GCG), impedance plethysmography (IPG), electrical bio-impedance (Bimp), the PPG/tonoarteriogram (TAG), impedance cardiography (ICG) and seismocardiogram (SCG) can be used [37]. The features obtained from the (ECG) and (PPG) signals depend on the purpose or type of disease and diagnosis to be estimated. In the literature, several algorithms based on characteristics of the pulse waveform analysis have been proposed, mainly focusing on the determination of the characteristic point's peak detection [38, 39, 40, 41], and located at the foot of the wave. The robust determination of characteristic points is still a difficult task in the (PTT) estimation due to motion artifacts, electrical interference noises, and signal crossovers among others, and also due to respiration. This article presents a new algorithm for non-invasive measurements of pulse transit time (PTT), obtained by measuring the pulse time between the heart and the finger. The (PTT-Peak) and (PTT-Foot) are the time delays between the peak of the wave (ECG-R) and the peak and foot (PPG), respectively.

## 2. METHODOLOGY

The (ECG) and (PPG) signals were processed to measure the (PTT), which is estimated using the algorithm illustrated in Figure 3. The (PTT-foot and PTT-peak) values are obtained by the measurement of the differences between the (PPG) (foot, peak) locations and R-peak locations.

### 2.1. Training Dataset

First, we constructed a data set of 37 subjects containing a simultaneous recording of (ECG) and (PPG). All subjects signed a voluntary participation agreement for this study. Approval for data acquisition was granted by the ethics committee of the University of Tlemcen.

### 2.2. The PTT Algorithm

First, the (PPG) is normalized at the value of 1 according to the equation (1):

$$PPG\,(\text{normalized}) = (PPG\,.(n)/\,(\max\,(PPG)) \qquad \textbf{(1)}$$

Where n: is the normalization factor. In our case, it equals 1.

The peaks (PPG) were detected using a thresholding operation (a threshold of 0.5). To detect local maxima and minima, the first derivative was calculated and thresholded symmetrically (+0.5 and -0.5). Subtracting each peak location (in the PPG signal) with the difference between its minima and maxima location (in the derivative signal) perfectly detects the (PPG-foot). The (PPG-foot) detection process evolved mathematically from a Gaussian pulse (which strongly corresponds to a (PPG) pulse) and its first derivative, all steps (shown in Figure 4). Signal processing (ECG) begins with normalization (to the value of 1) followed by a thresholding operation (to the value of 0.3) to detect peaks R. A threshold value is set to less than 1% of the pulse value. The threshold value is set to less than 50% of the normalized signal to avoid any loss in detection, as well as to avoid misleading detection of R-peaks resulting in some cases from large amplitude T-waves. The algorithm is improved by a temporal analysis by windowing, from which the maximum value in each window perfectly locates the R peak, (as shown in Figure 5).

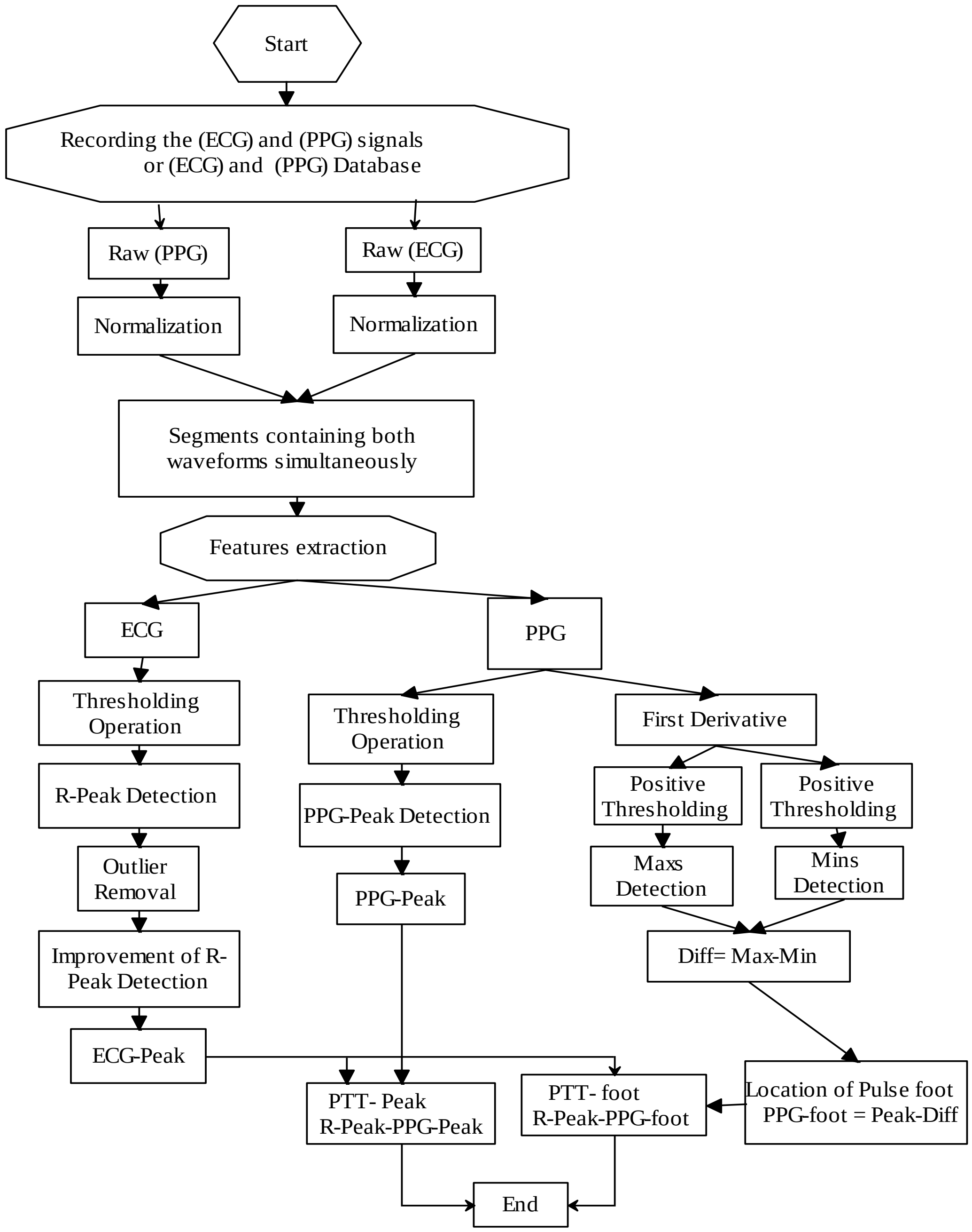


Figure 3. The algorithm developed for the (PTTs) (PTT-f and PTT-p) detection

# 3. RESULTS

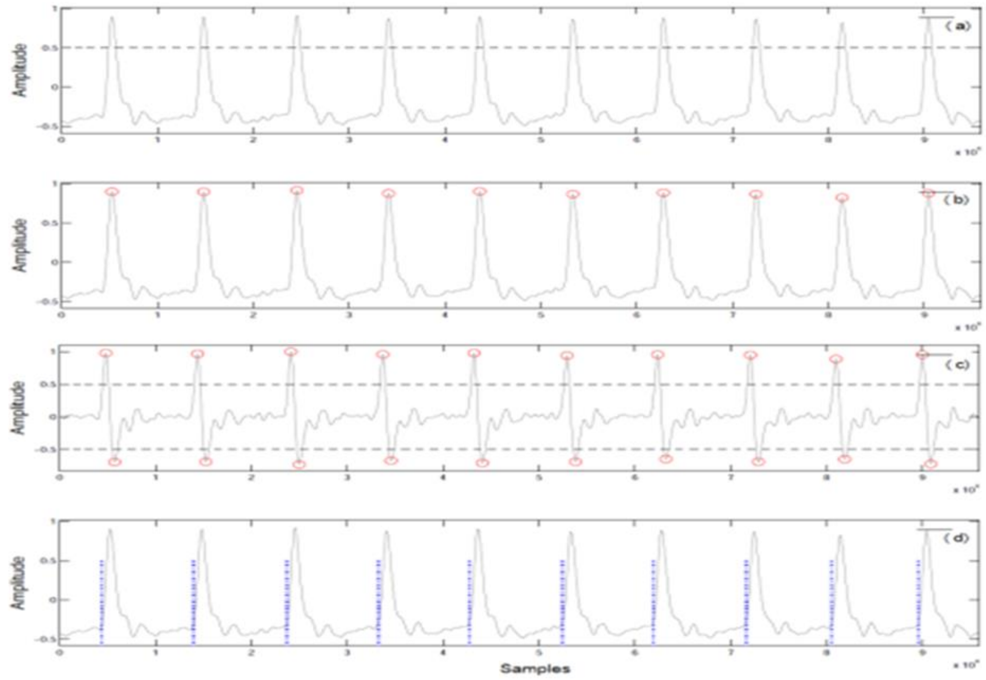


Figure 4. Localization result of (PPG-foot) and (PPG-peak). (a): normalization and thresholding operation, (b): (PPG-Peak) detection, (c): the first derivation of (PPG) signal and detection of local maxima and minima, and (d): (PPG-foot) localization

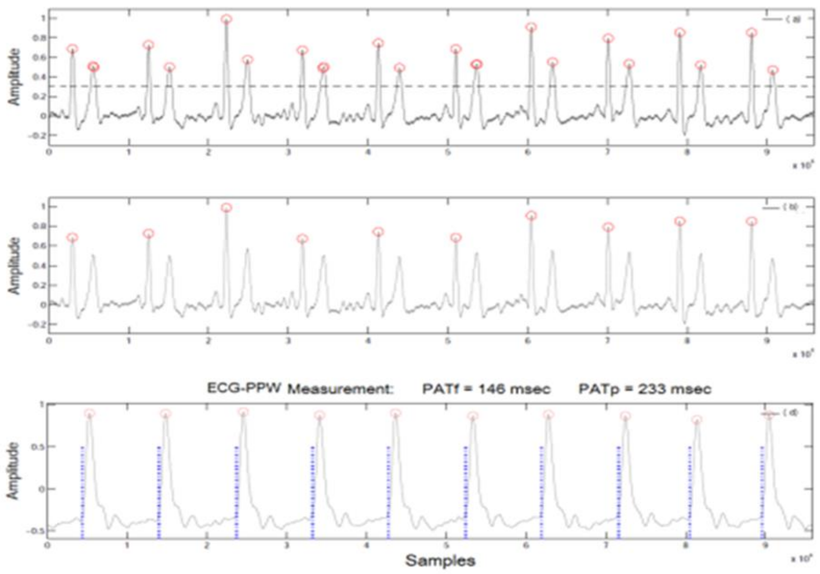


Figure 5. (ECG) processing and measurement of (PTT) foot and peak, (a): normalization, thresholding operation, and all local maxima detection, (b): improvement of R-peak detection, (c): measurement of (PTT-foot), and (PTT-peak)

## 4. DISCUSSION

Experimental results of the proposed algorithm are evaluated in terms of sensitivity (SEN) and accuracy (ACC) given by equations (2) and (3), respectively. Where TP (true positive) is the number of peaks (or feet) correctly recognized, FN (false negative) is the number of peaks (or feet) missed, and FP (false positive) is the number of false peaks (or feet) recognized as true.

$$\mathbf{SEN = TP/(TP + FN) \times 100\%} \qquad \mathbf{(2)}$$

$$\mathbf{ACC = TP/(TP + FN + FP) \times 100\%} \qquad \mathbf{(3)}$$

Where TP (true positive) is the number of peaks (or feet) correctly recognized, FN (false negative) is the number of peaks (or feet) missed, and FP (false positive) is the number of false peaks (or feet) recognized as true. Obtained results show satisfactory performances on the records. We note that only the correct detections are used in this study.

Table 1 shows the accuracy and sensitivity values of the algorithm. The total beats recorded over all subjects were 719 beats with an average of 24±9 beats. In the case of R-peak detection (ECG-p), the algorithm fails to detect 23 beats (18 FN beats and 5 FP beats) out of 719 beats. The average SEN and ACC of R peaks detection were 97.5%, and 96.82% respectively. In the case of PPG-peak detection, the algorithm fails to detect 17 beats (16 FN beats and 1 FP beat) out of 719 beats. The average (SEN) and (ACC) of PPG-peak detection were 97.77%, and 97.64%, respectively. In the case of PPG foot detection, the algorithm mislocated 54 beats (12 FN beats and 32 FP beats) out of 719 beats. The average (SEN) and (ACC) of (PPG- foot) detection were 98.33%, and 94.14%, respectively.

Table 1. Detection results of the algorithm.

| **Total beats=719(Avg=24±9 beats)** | | | | | |
|---|---|---|---|---|---|
| | TP | FN | FP | Accuracy% | Sensitivity% |
| ECG-p | 701 | 18 | 5 | 96.82 | 97.50 |
| PPG-p | 703 | 16 | 1 | 97.64 | 97.77 |
| PPG-f | 707 | 12 | 32 | 94.14 | 98.33 |

## 5. CONCLUSIONS

In this paper, a new algorithm for the estimation of (PTT) was introduced. The (PTT) is a parameter of major importance in the prevention of cardiovascular diseases, especially arterial aging and hypertension. For the estimation of (PTT), the collected data were processed. Using the (ECG) and (PPG) signals, we obtained the (PTT- foot) and (PTT- peak). A good result was found by evaluating several statistical measures.

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## AUTHOR

**Radjef Lilia** PhD student in Biomedical Instrumentation at M'hamed BOUGARA University of Boumerdes, Department of Electrical Systems Engineering Member of the Biomedical Instrumentation Laboratory (LIB) research team