Accurate pulse transit time estimation in low sampling frequency environments using parametric normalization

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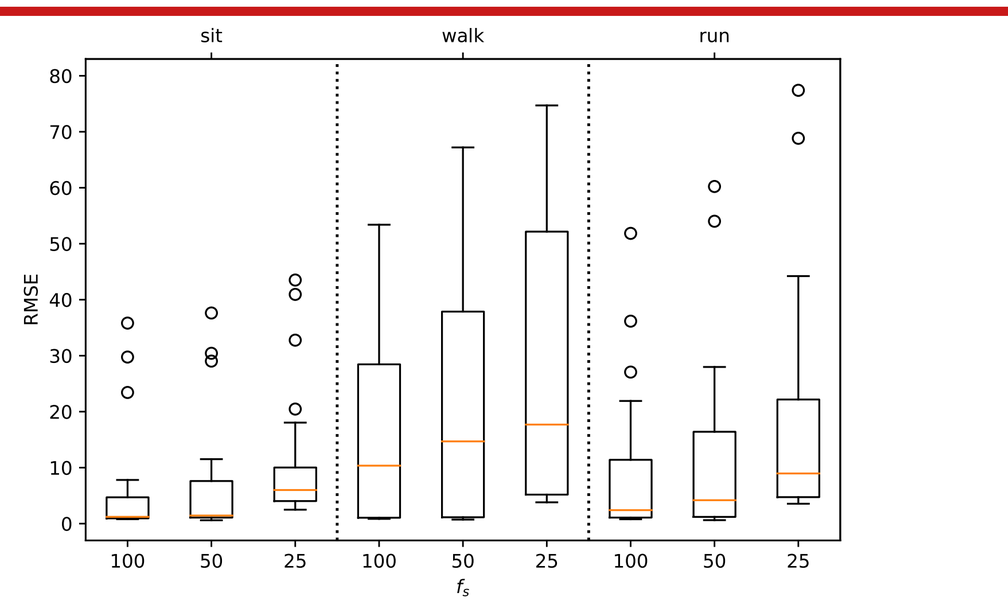
INTRODUCTION

Pulse Transit Time (PTT) is used as a measure for noninvasive, cuff-less blood pressure. Accurate estimation is vital.
Smart watches can measure PPG, but considerations need to be made for computational complexity and battery consumption.
Lower sampling frequency preserves battery, but reduces time resolution, worsening PTT estimation.
Therefore, to keep the estimate accurate, it is important to find the correct PTT, which will require precise **subsample** alignment.
Furthermore, normalization is essential in comparing pulses, but amplitude can hold important information.

Obtaining PTT

PTT is the time difference between the R peak (annotated) and the start of the PPG pulse. The start of the pulse is obtained using the intersecting tangents method.
Reference is PTT calculated on original signal ($f_s = 500\ Hz$).
Signal is then decimated to a lower sampling frequency.

RESULTS

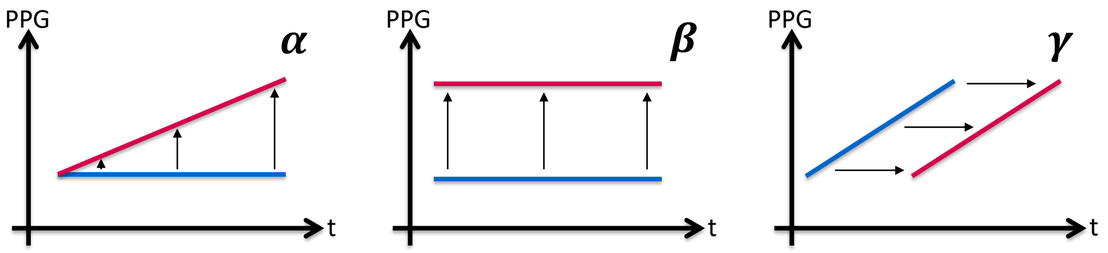


METHODS

Dataset [1]

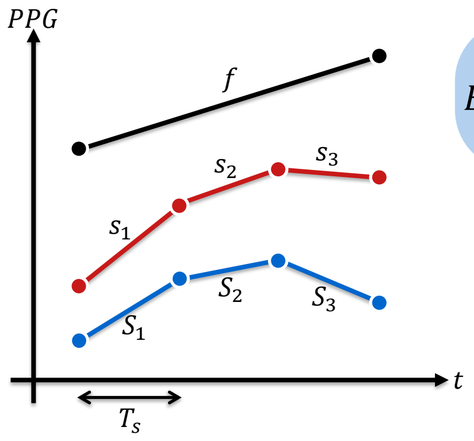
- Contains ECG with manually annotated R-peaks
- Red PPG on non-dominant index finger (500 Hz)
- 22 healthy subjects sitting, walking and running (~1 hour in total per subject)

Correction parameters



Analytical solution

The error is defined as the squared area between two pulses, and is minimized with the correction added.
Every pulse is compared to a template pulse, which is the average of the pulses within a five-minute window.
An analytical solution means no computationally expensive methods like grid search have to be applied.



$$Error = \sum_{n=0}^{N-1} \int_0^{T_s} \left(S_n - \left(s_n + f\big|_{S=S_n} \right) \right)^2 \partial t$$

$$S_n = A_n t + B_n$$
$$s_n = a_n(t - \gamma) + b_n$$
$$f = \alpha t + \beta$$

$\boldsymbol{\gamma}$ is relative to the template pulse, therefore PTT still has to be calculated for one pulse within a window.

$$\alpha_{opt} = \frac{1}{T_s \sum_{n=0}^{N-1} n^2} \sum_{n=0}^{N-1} (B_n - b_n - \beta + a_n\gamma)\, n$$
$$\beta_{opt} = \frac{1}{N} \sum_{n=0}^{N-1} B_n - b_n + a_n\gamma - \alpha n T_s$$
$$\gamma_{opt} = \frac{-1}{\sum_{n=0}^{N-1} a_n^2} \sum_{n=0}^{N-1} a_n (B_n - b_n - \beta - \alpha n T_s)$$

REFERENCES

[1]Mehrgardt, P., Khushi, M., Poon, S., & Withana, A. (2022). Pulse Transit Time PPG Dataset (version 1.1.0). *PhysioNet.* https://doi.org/10.13026/jpan-6n92.