Estimation of Pulse Arrival Time Using Impedance Plethysmogram from Body Composition Scales

Birutė Paliakaitė[1], Saulius Daukantas[2], Andrius Sakalauskas[2], Vaidotas Marozas[1,2]

[1]Department of Electronics Engineering, Kaunas University of Technology
[2]Biomedical Engineering Institute, Kaunas University of Technology

April 13-15, 2015

kaunas university of technology

2015 IEEE SENSORS APPLICATIONS SYMPOSIUM

- Arterial stiffness leads to the development of cardiovascular morbidity and mortality[1].
- Central (aortic) stiffness:
  - elderly subjects,
  - end-stage renal disease,
  - hypertension,
  - impaired glucose tolerance.
- Peripheral (lower-limbs) stiffness:
  - peripheral artery disease,
  - diabetic peripheral neuropathy.

[1]*S. Laurent et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. Eur. Heart J., vol. 27, no. 21, 2006.*

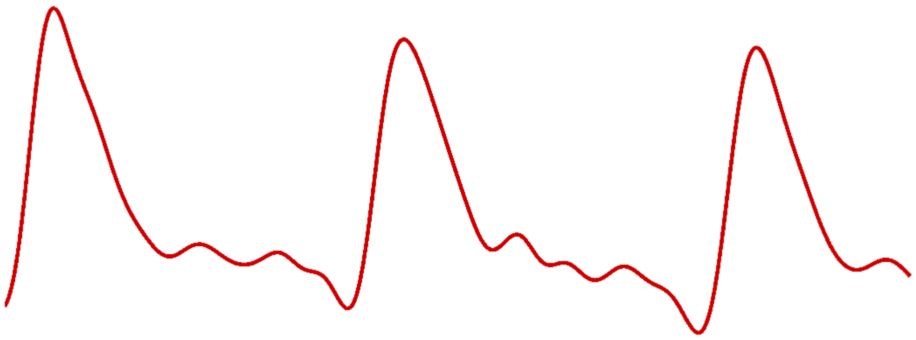
- Arterial stiffness leads to the development of cardiovascular morbidity and mortality.
- Central (aortic) stiffness[1]:
  - elderly subjects,
  - end-stage renal disease,
  - hypertension,
  - impaired glucose tolerance.
- Peripheral (lower-limbs) stiffness:
  - peripheral artery disease,
  - diabetic peripheral neuropathy.

[1] *S. Laurent et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. Eur. Heart J., vol. 27, no. 21, 2006.*

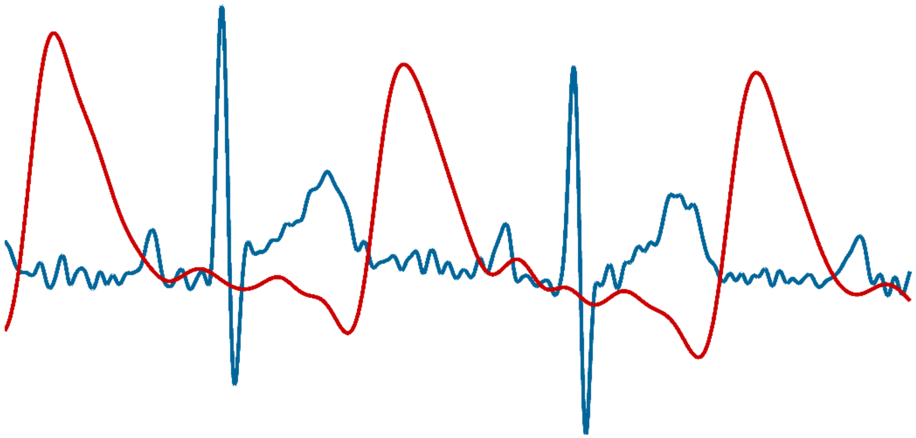
- Arterial stiffness leads to the development of cardiovascular morbidity and mortality.
- Central (aortic) stiffness:
  - elderly subjects,
  - end-stage renal disease,
  - hypertension,
  - impaired glucose tolerance.
- Peripheral (lower-limbs) stiffness:
  - peripheral artery disease[2],
  - diabetic peripheral neuropathy[3].

[2]*H. Yokoyama et al. Pulse wave velocity in lower-limb arteries among diabetic patients with peripheral arterial disease. J. Atheroscler. Thromb., vol. 10, no. 4, 2003.*
[3]*M. Edmonds et al. Blood flow in the diabetic neuropathic foot. Diabetologia, vol. 22, no. 1, 1982.*

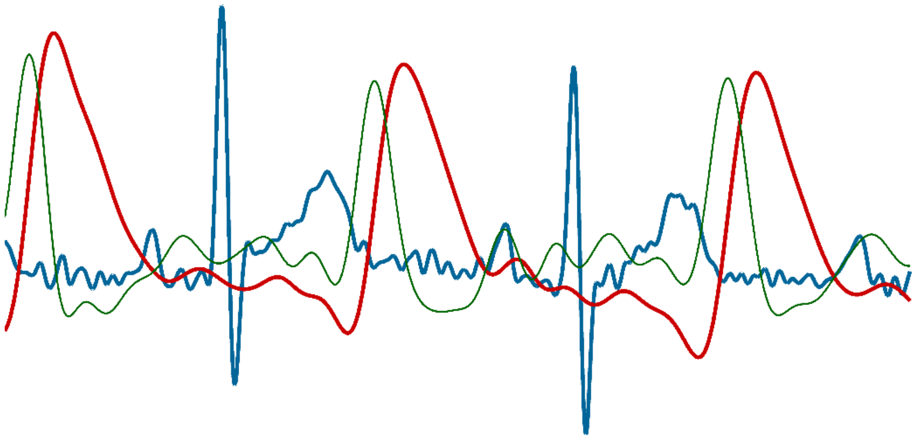
- Arterial stiffness can be characterized by the propagation of the pulse pressure wave (PPW) along the arterial tree.



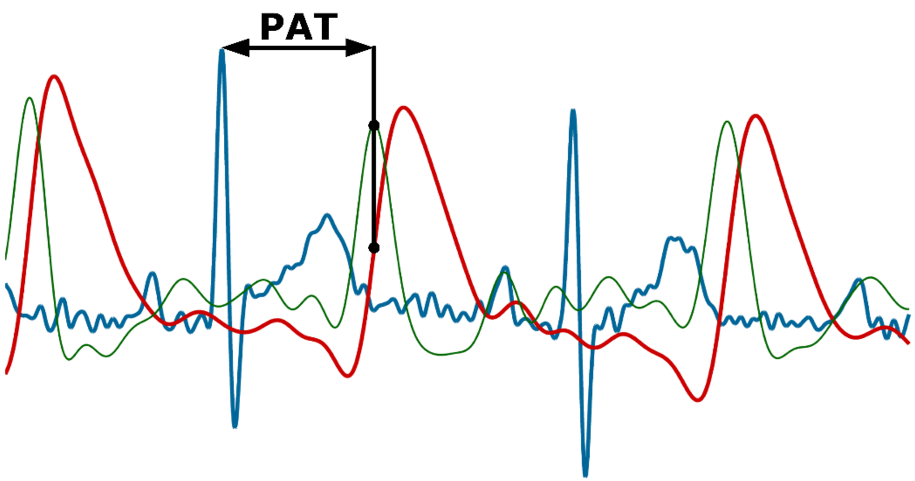
- Arterial stiffness can be characterized by the propagation of the pulse pressure wave (PPW) along the arterial tree.
- Pulse arrival time (PAT) – the time interval between the R-wave of the QRS complex and the particular point in the PPW.



- Arterial stiffness can be characterized by the propagation of the pulse pressure wave (PPW) along the arterial tree.
- Pulse arrival time (PAT) – the time interval between the R-wave of the QRS complex and the particular point in the PPW.



- Arterial stiffness can be characterized by the propagation of the pulse pressure wave (PPW) along the arterial tree.
- Pulse arrival time (PAT) – the time interval between the R-wave of the QRS complex and the particular point in the PPW.

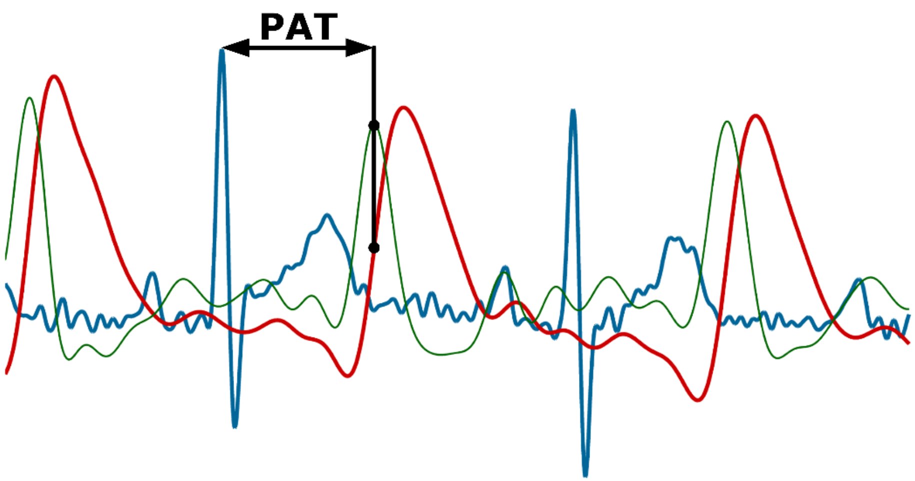


- Arterial stiffness can be characterized by the propagation of the pulse pressure wave (PPW) along the arterial tree.

- Pulse arrival time (PAT) – the time interval between the R-wave of the QRS complex and the particular point in the PPW.

PAT ↓

Arterial stiffness ↑



- Long-term periodic monitoring needed

- Long-term periodic monitoring needed

Available devices for PPW recording

- Long-term periodic monitoring needed

Available devices for PPW recording

Illustration retrieved from http://www.atcormedical.com/

- Long-term periodic monitoring needed

Available devices for PPW recording

Illustrations retrieved from http://www.atcormedical.com/

- Long-term periodic monitoring needed

Available devices for PPW recording

Illustrations retrieved from http://www.atcormedical.com/

- Long-term periodic monitoring needed

Available devices for PPW recording

Illustrations retrieved from http://www.atcormedical.com/ and http://www.atcormedical.com/

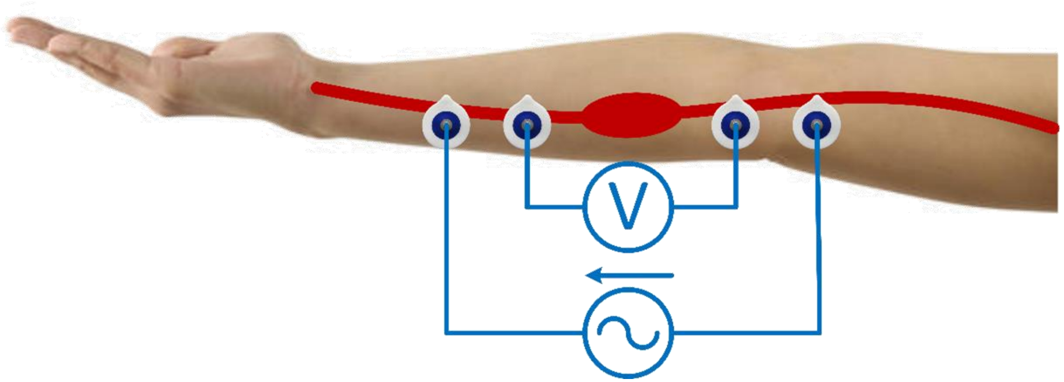
- Long-term periodic monitoring needed

Available devices for PPW recording:

- Operator dependent
- Results rely on the placement

Illustrations retrieved from http://www.atcormedical.com/ and http://www.atcormedical.com/

- Impedance plethysmography (IPG) to determine changing tissue volumes (e.g. blood)



$$\Delta \boldsymbol{R} = \boldsymbol{\rho}\frac{\boldsymbol{l}^2}{\Delta \boldsymbol{v}}$$

- Impedance plethysmography (IPG) to determine changing tissue volumes (e.g. blood).

$$R = \rho \frac{l}{A}$$

- ECG and IPG electrodes integrated into unobtrusive devices (e.g. bathroom scales)

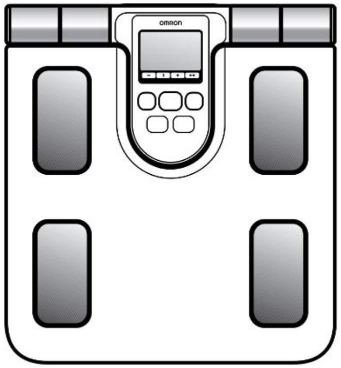


Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- The lower-body IPG signals are the sum of the local impedances of all segments between the voltage electrodes,

- The lower-body IPG signals are the sum of the local impedances of all segments between the voltage electrodes,
- but the influence of the lower parts is the greatest.

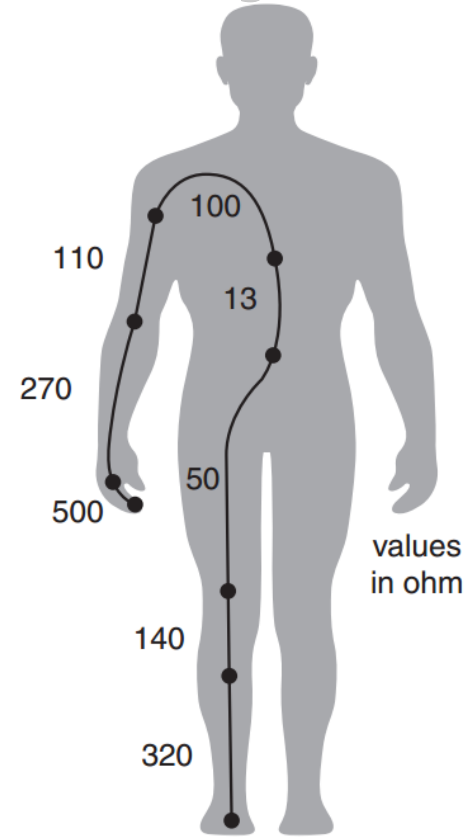


Illustration retrieved from *O. G. Martinsen, S. Grimnes, Bioimpedance and Bioelectricity Basics, 2nd ed., London: Academic Press, 2008.*

- The lower-body IPG signals are the sum of the local impedances of all segments between the voltage electrodes,
- but the influence of the lower parts is the greatest.
- The goal of this study is to demonstrate that PAT from the heart to the foot can be estimated using ECG and IPG recorded on the bathroom scales.

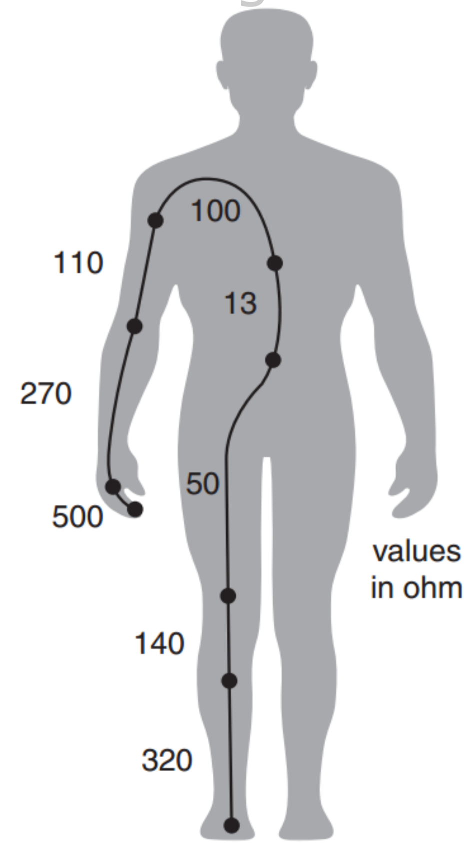


Illustration retrieved from *O. G. Martinsen, S. Grimnes, Bioimpedance and Bioelectricity Basics, 2nd ed., London: Academic Press, 2008.*

- Body composition scales (Omron)
- ECG: wireless ECG transmitter (Biopac)
- IPG: electrical bioimpedance unit (Biopac)
- IPG: photoplethysmogram amplifier unit (Biopac)

Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- Body composition scales (Omron)
- ECG: wireless ECG transmitter (Biopac)
- IPG: electrical bioimpedance unit (Biopac)
- IPG: photoplethysmogram amplifier unit (Biopac)

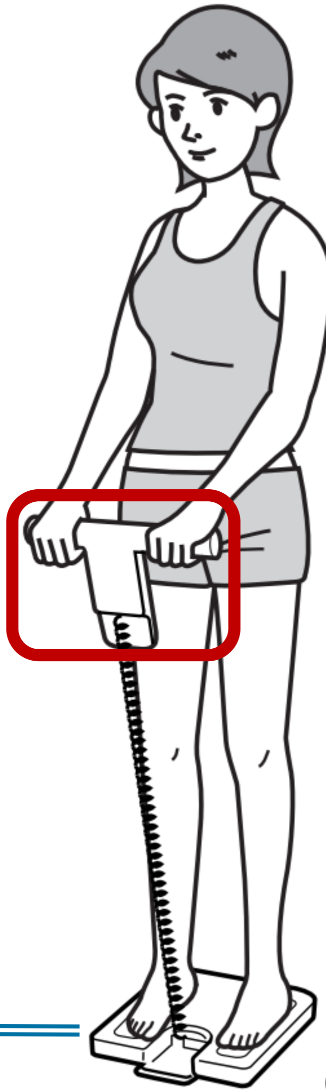


Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- Body composition scales (Omron)
- ECG: wireless ECG transmitter (Biopac)
- IPG: electrical bioimpedance unit (Biopac)
- IPG: photoplethysmogram amplifier unit (Biopac)

Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- Body composition scales (Omron)
- ECG: wireless ECG transmitter (Biopac)
- IPG: electrical bioimpedance unit (Biopac)
- PPG: photoplethysmogram amplifier unit (Biopac)

Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- Four healthy subjects (one woman)
- Paced respiration (0.1 Hz) to cause hemodynamics changes

- Four healthy subjects (one woman)
- Paced respiration (0.1 Hz) to cause hemodynamics changes

- Four healthy subjects (one woman)
- Paced respiration (0.1 Hz) to cause hemodynamics changes

Measurement cases

Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- Four healthy subjects (one woman)
- Paced respiration (0.1 Hz) to cause hemodynamics changes

Measurement cases

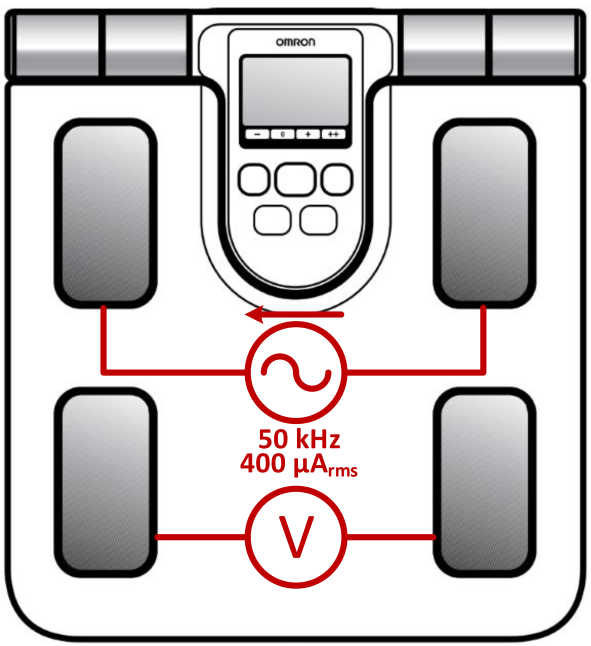


Illustration retrieved from *OMRON HBF-510 Instruction Manual*

- Four healthy subjects (one woman)
- Paced respiration (0.1 Hz) to cause hemodynamics changes

Measurement cases

foot-to-foot

single-foot

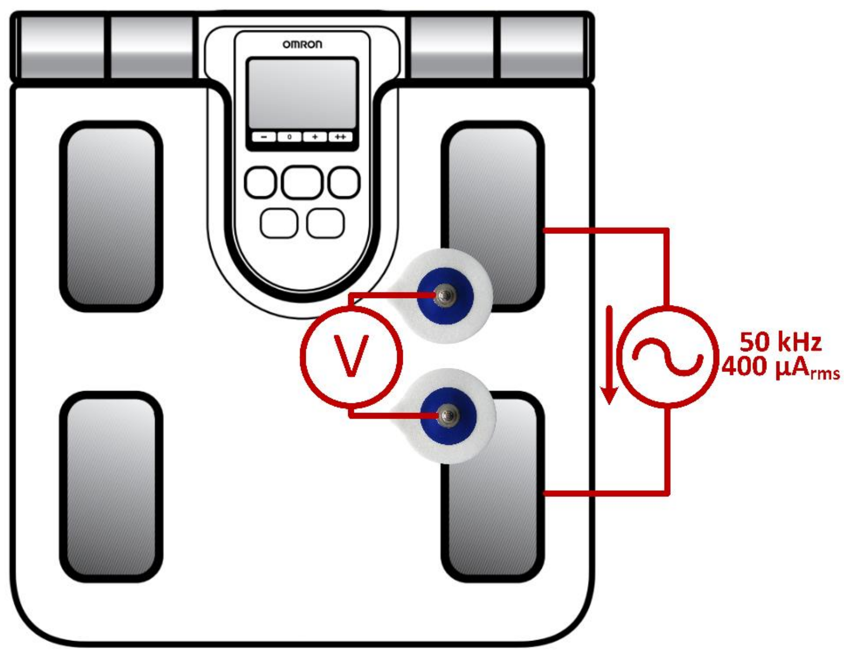
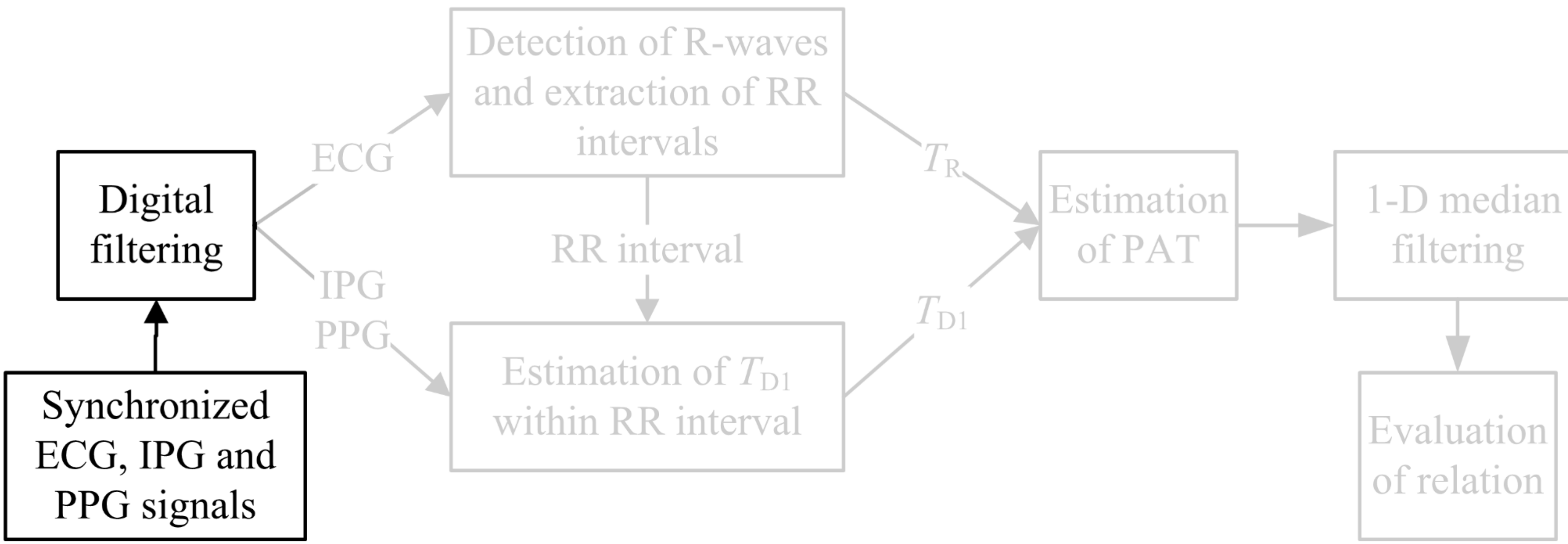
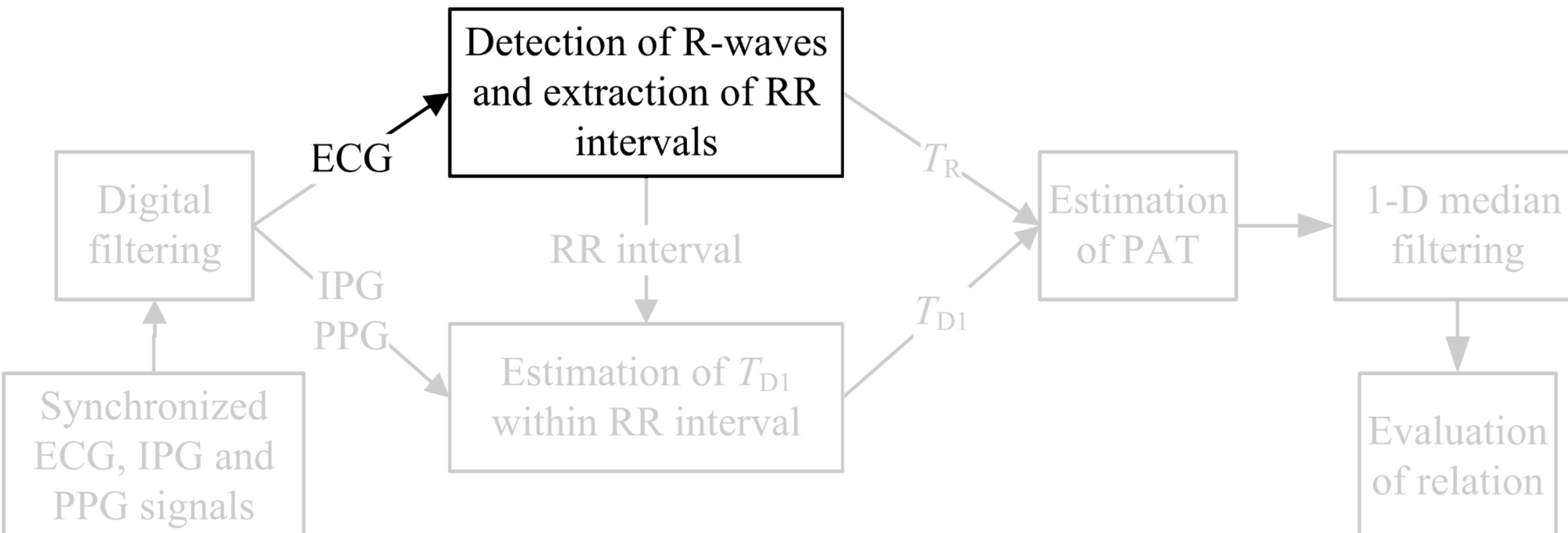
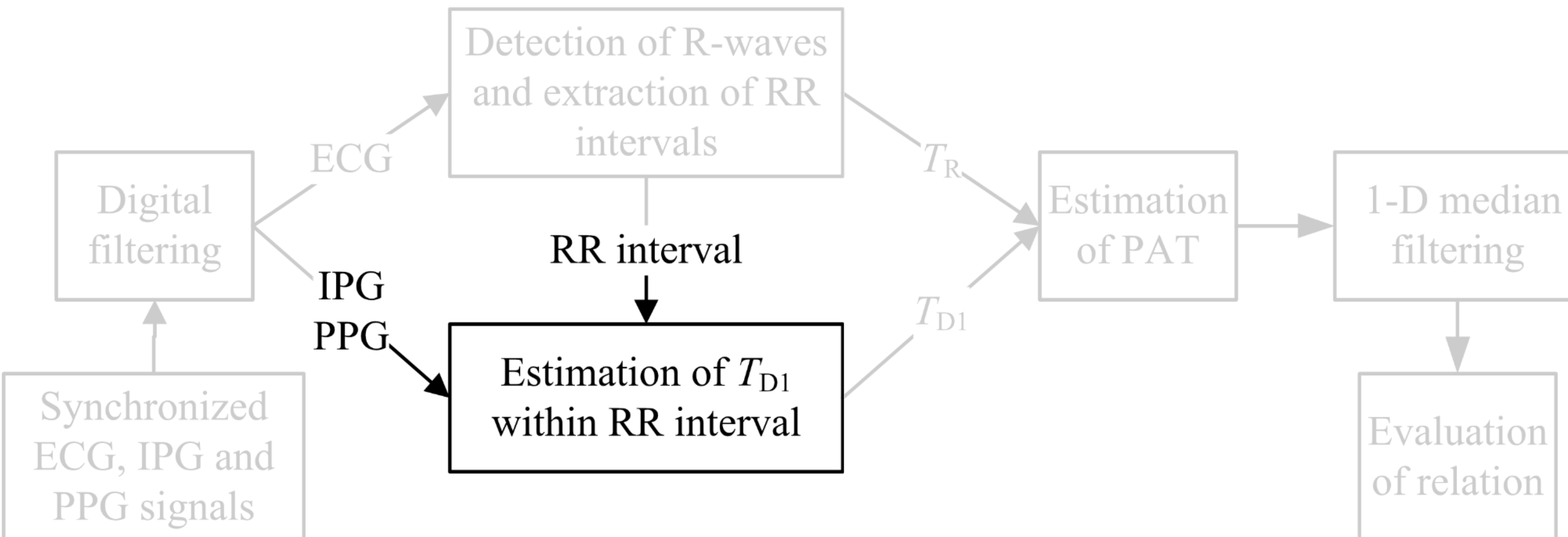


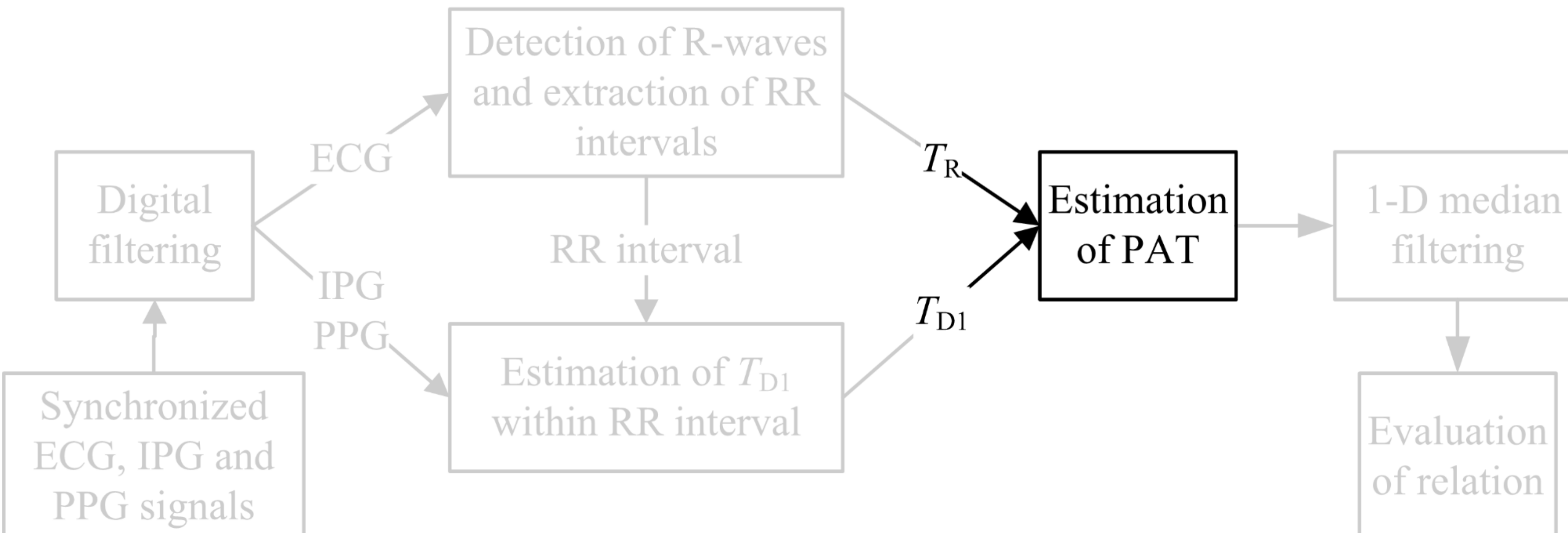
Illustration retrieved from *OMRON HBF-510 Instruction Manual*


Digital filtering
Synchronized ECG, IPG and PPG signals
ECG
IPG
PPG
Detection of R-waves and extraction of RR intervals
RR interval
Estimation of T_{D1} within RR interval
T_R
T_{D1}
Estimation of PAT
1-D median filtering
Evaluation of relation

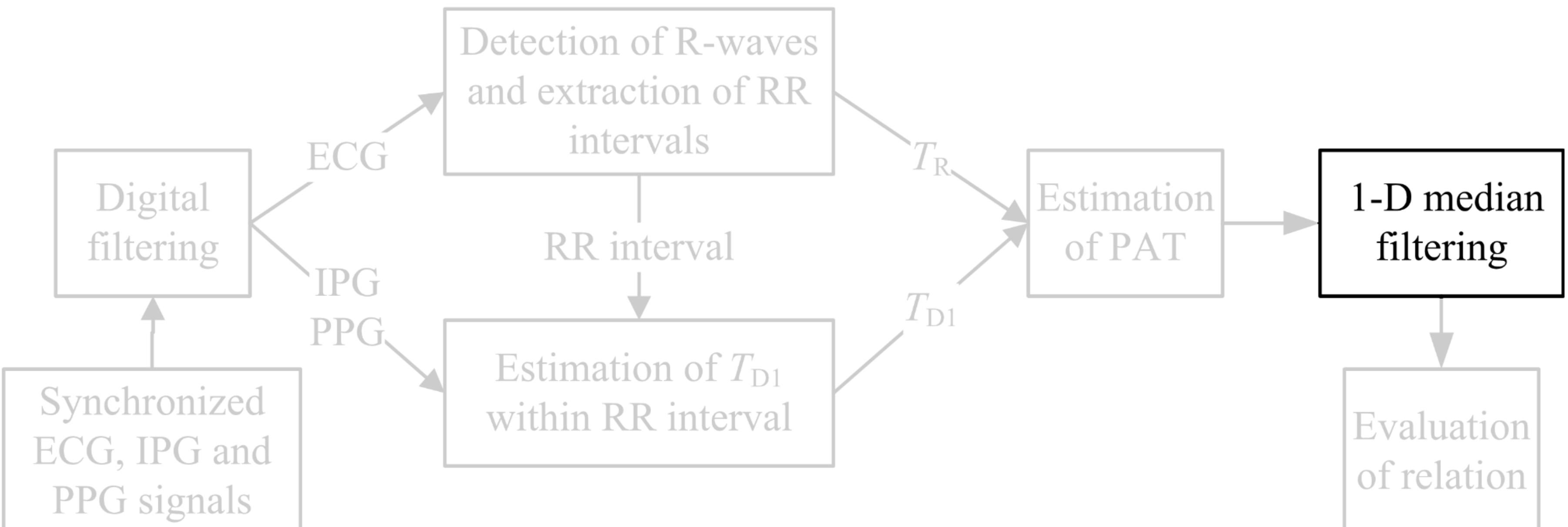


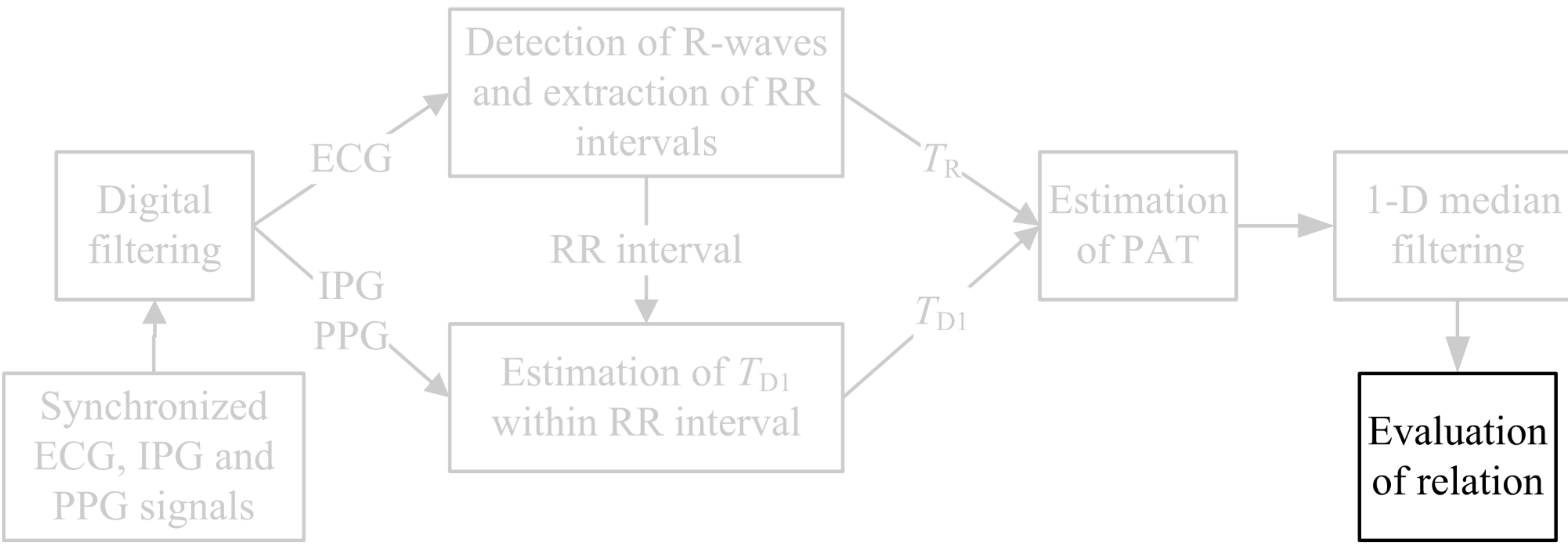
Detection of R-waves and extraction of RR intervals
ECG
Digital filtering
IPG
PPG
RR interval
T_R
T_{D1}
Estimation of PAT
1-D median filtering
Synchronized ECG, IPG and PPG signals
Estimation of T_{D1} within RR interval
Evaluation of relation


Detection of R-waves and extraction of RR intervals
ECG
Digital filtering
T_R
Estimation of PAT
1-D median filtering
RR interval
IPG
PPG
T_{D1}
Synchronized ECG, IPG and PPG signals
Estimation of T_{D1} within RR interval
Evaluation of relation

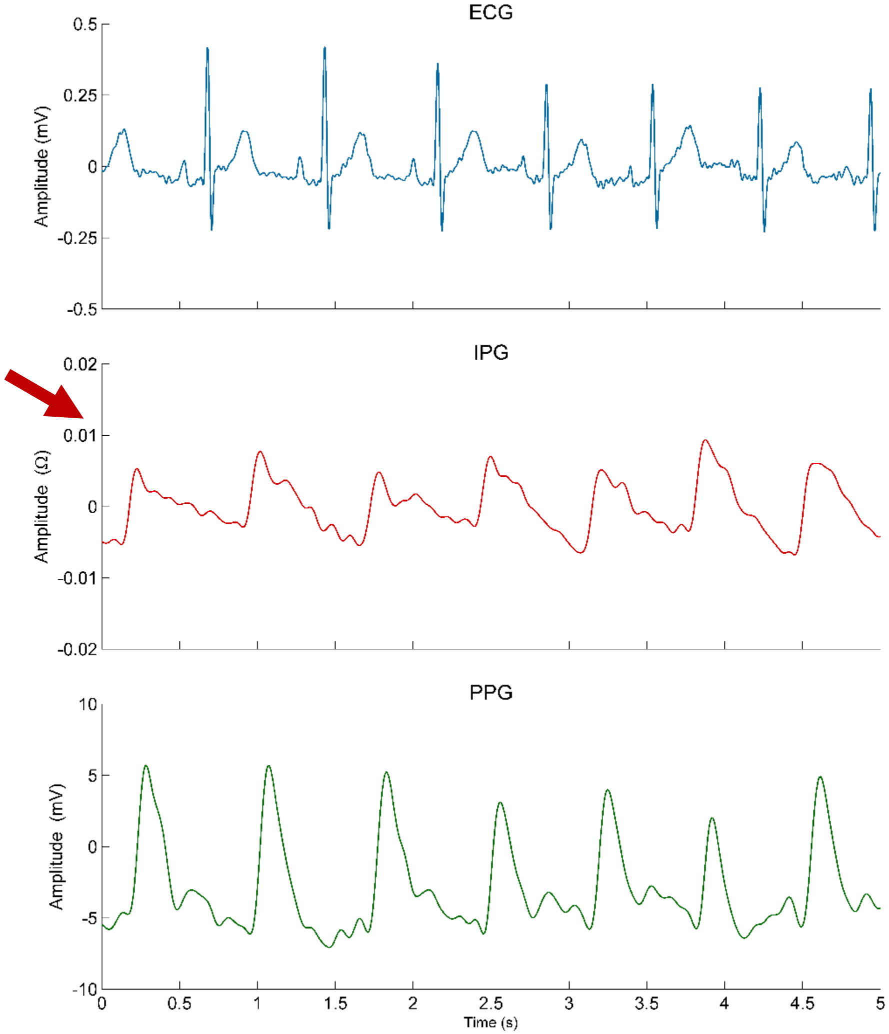


Synchronized ECG, IPG and PPG signals
Digital filtering
ECG
IPG
PPG
Detection of R-waves and extraction of RR intervals
RR interval
Estimation of T_{D1} within RR interval
T_R
T_{D1}
Estimation of PAT
1-D median filtering
Evaluation of relation

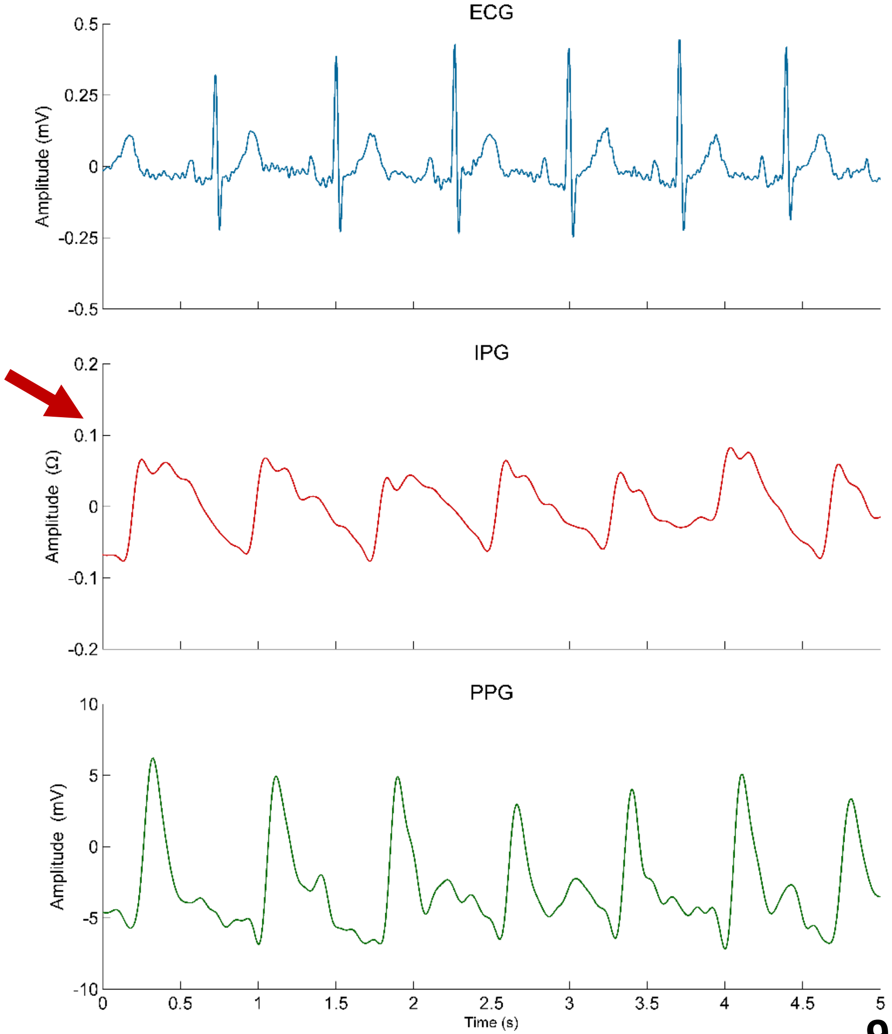

Detection of R-waves and extraction of RR intervals
ECG
Digital filtering
IPG
PPG
RR interval
T_R
T_{D1}
Estimation of PAT
1-D median filtering
Synchronized ECG, IPG and PPG signals
Estimation of T_{D1} within RR interval
Evaluation of relation


Detection of R-waves and extraction of RR intervals
ECG
Digital filtering
IPG
PPG
RR interval
T_R
T_{D1}
Estimation of PAT
1-D median filtering
Synchronized ECG, IPG and PPG signals
Estimation of T_{D1} within RR interval
Evaluation of relation

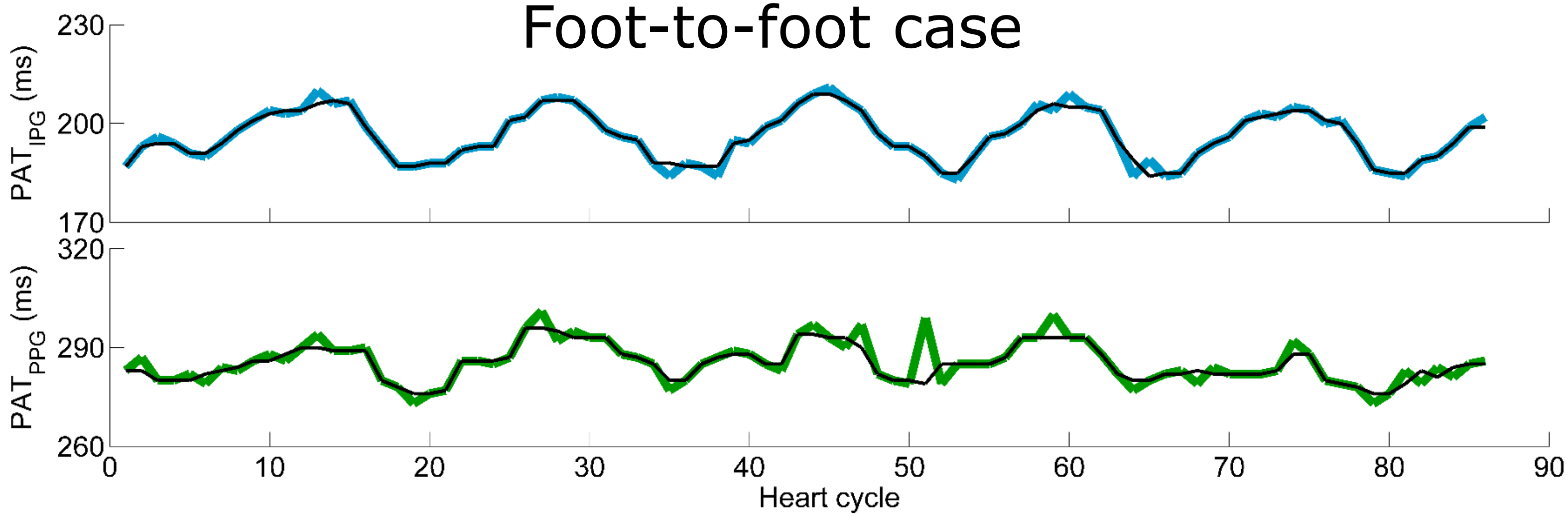
Single-foot case



Foot-to-foot case

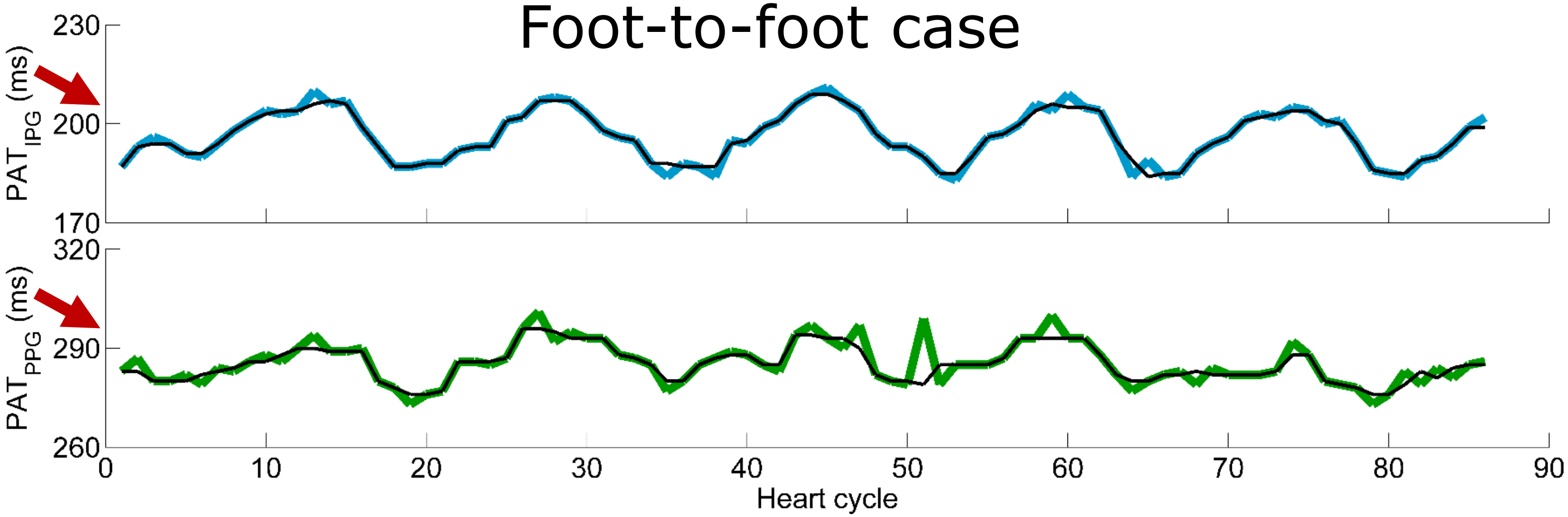


Foot-to-foot case



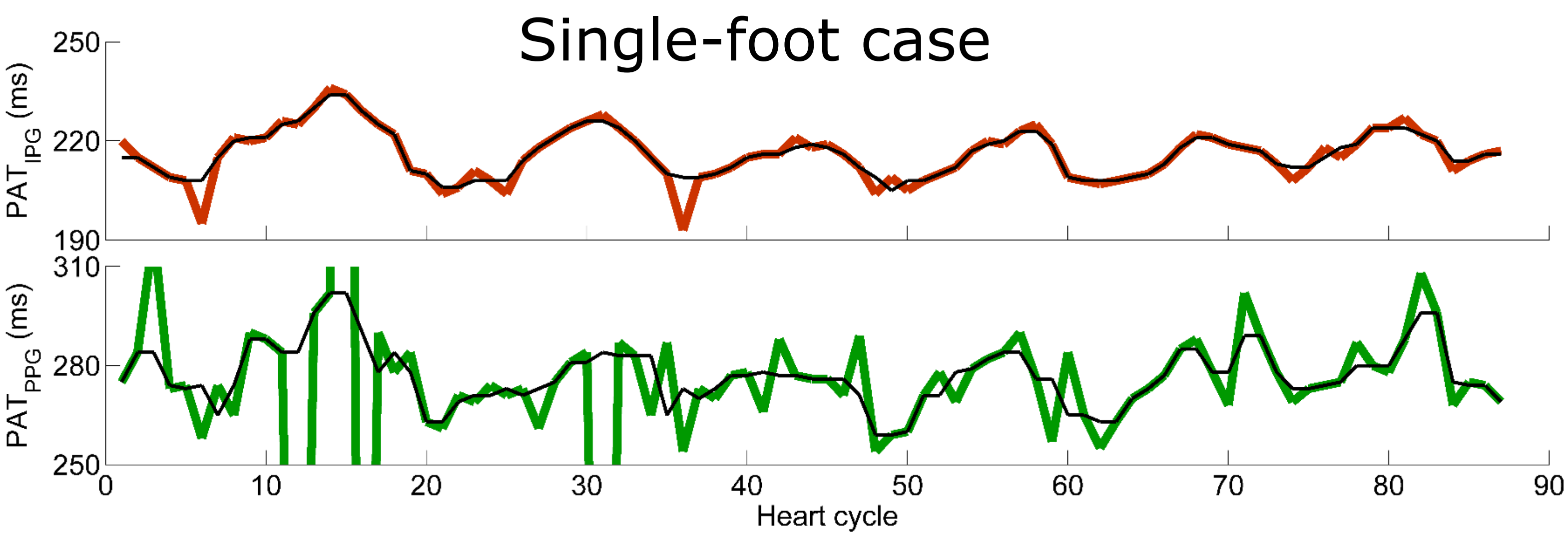
Single-foot case

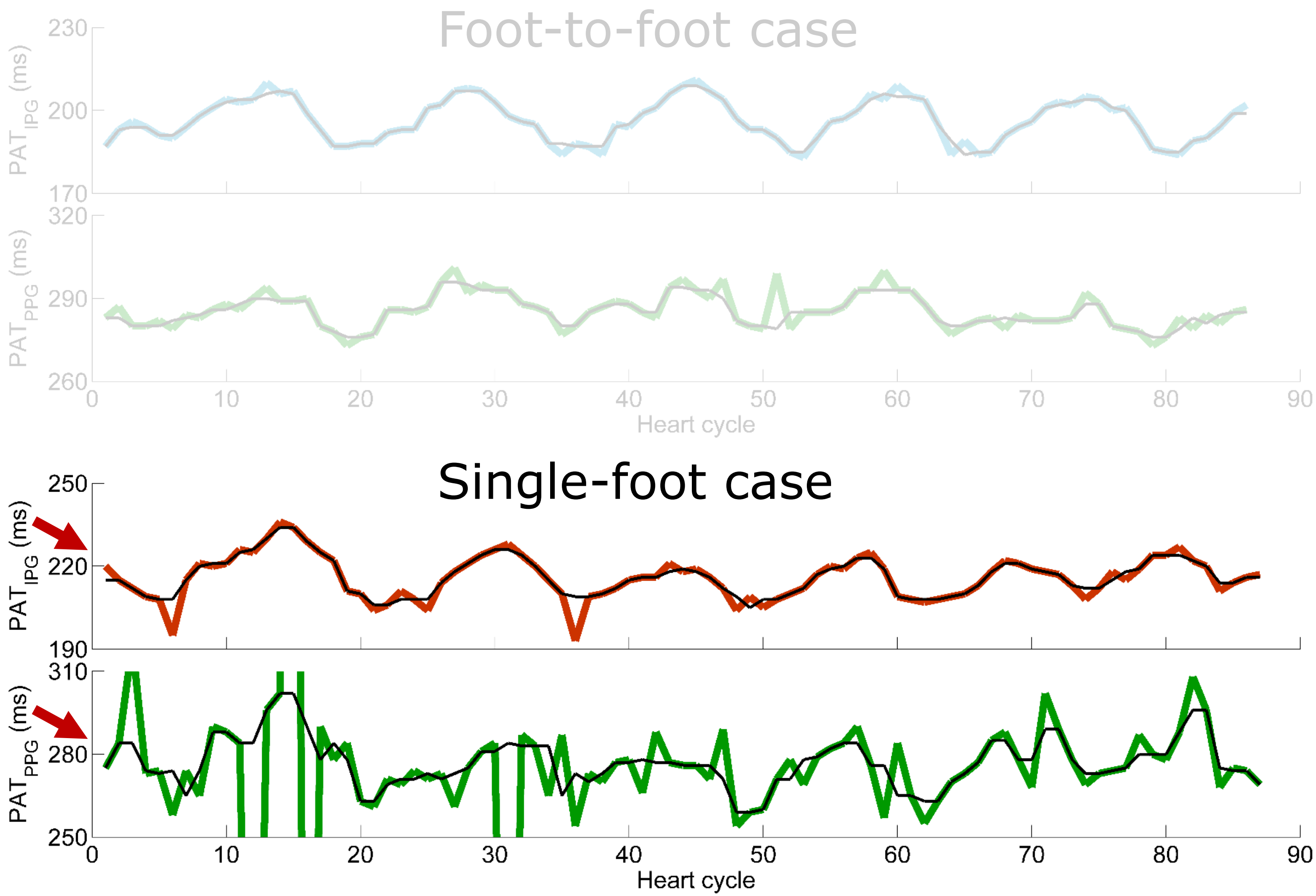
Foot-to-foot case

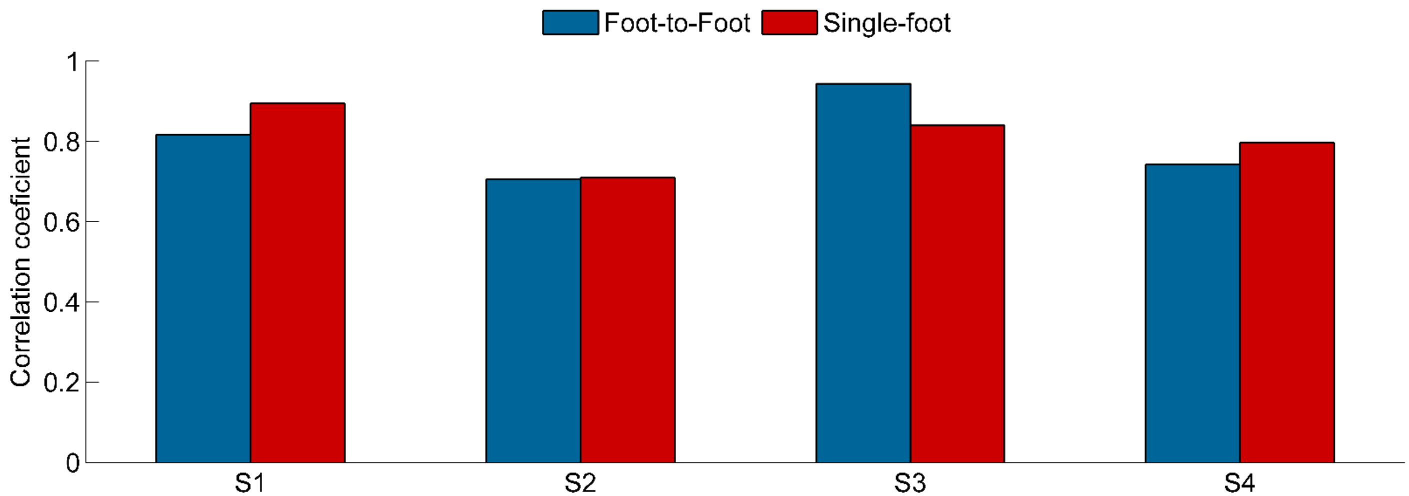


Single-foot case

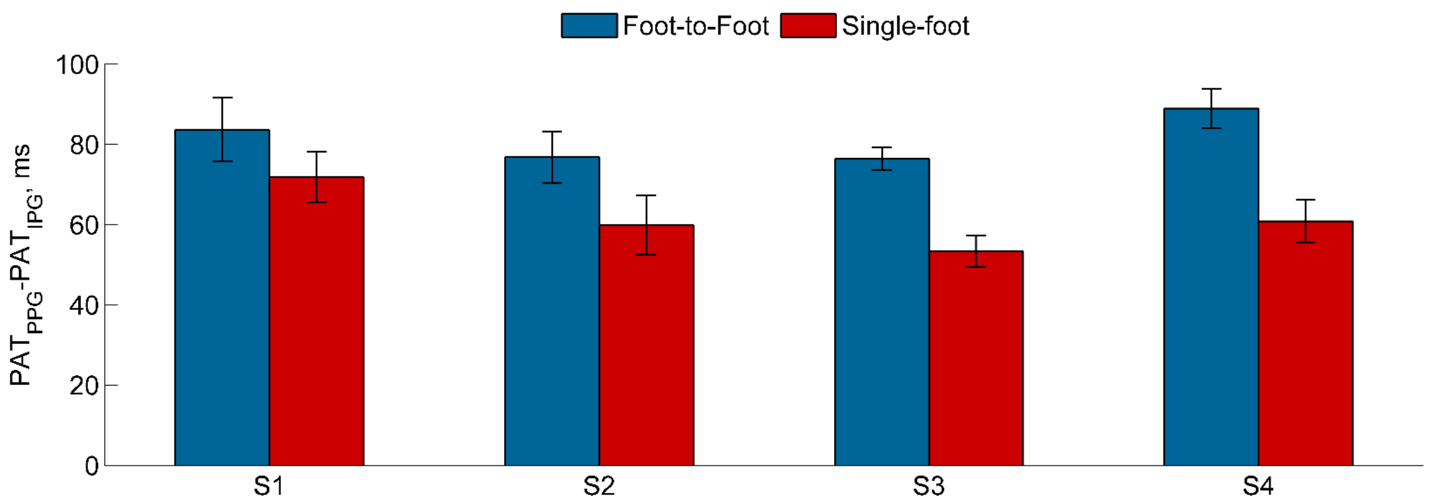
Foot-to-foot case
230
200
170
320
290
260
PATIPG (ms)
PATPPG (ms)
0
10
20
30
40
50
60
70
80
90
Heart cycle


Single-foot case
250
220
190
310
280
250
PATIPG (ms)
PATPPG (ms)
0
10
20
30
40
50
60
70
80
90
Heart cycle

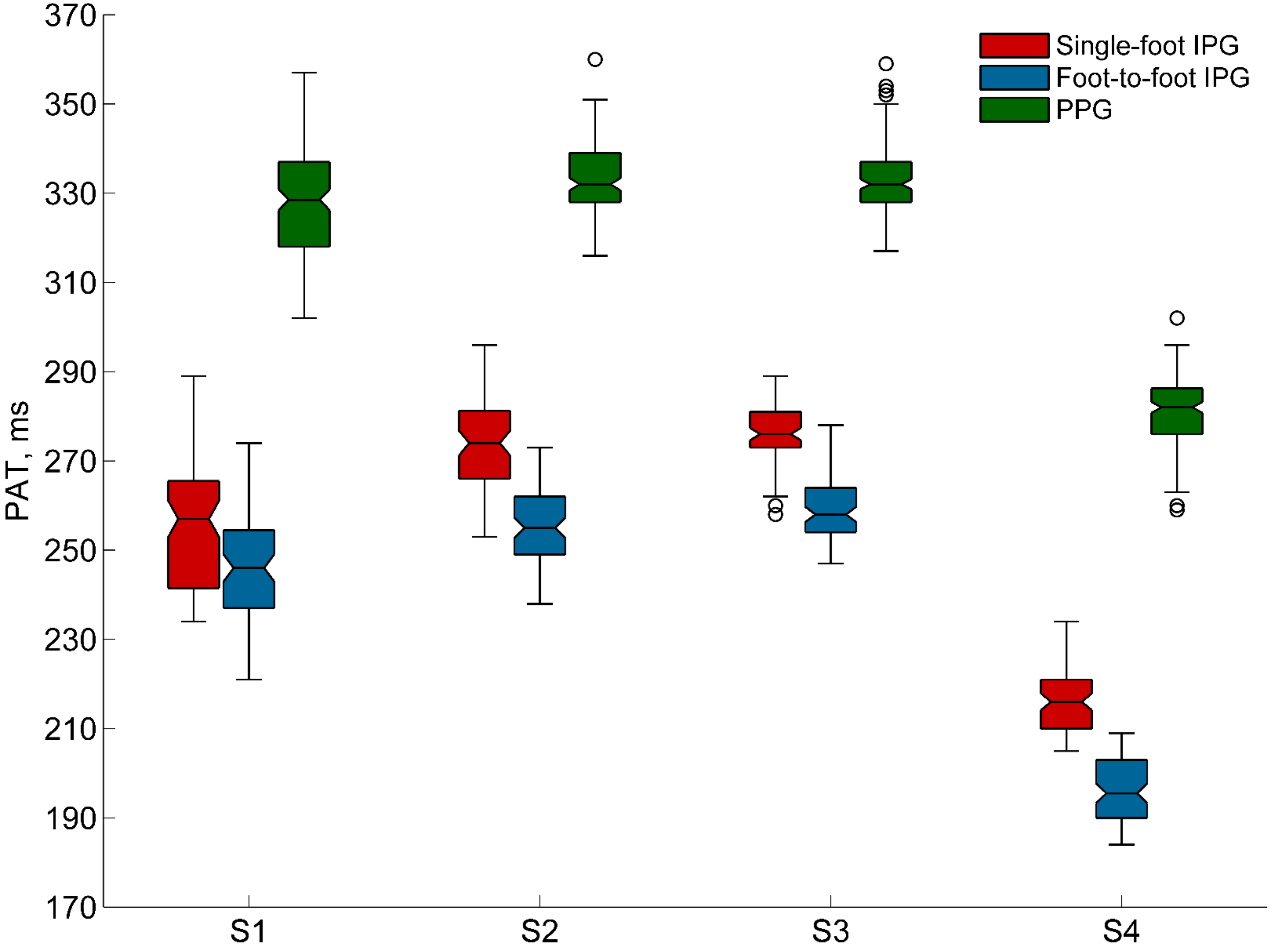

Foot-to-foot case
230
200
170
PAT_{IPG} (ms)
320
290
260
PAT_{PPG} (ms)
0 10 20 30 40 50 60 70 80 90
Heart cycle
Single-foot case
250
220
190
PAT_{IPG} (ms)
310
280
250
PAT_{PPG} (ms)
0 10 20 30 40 50 60 70 80 90
Heart cycle

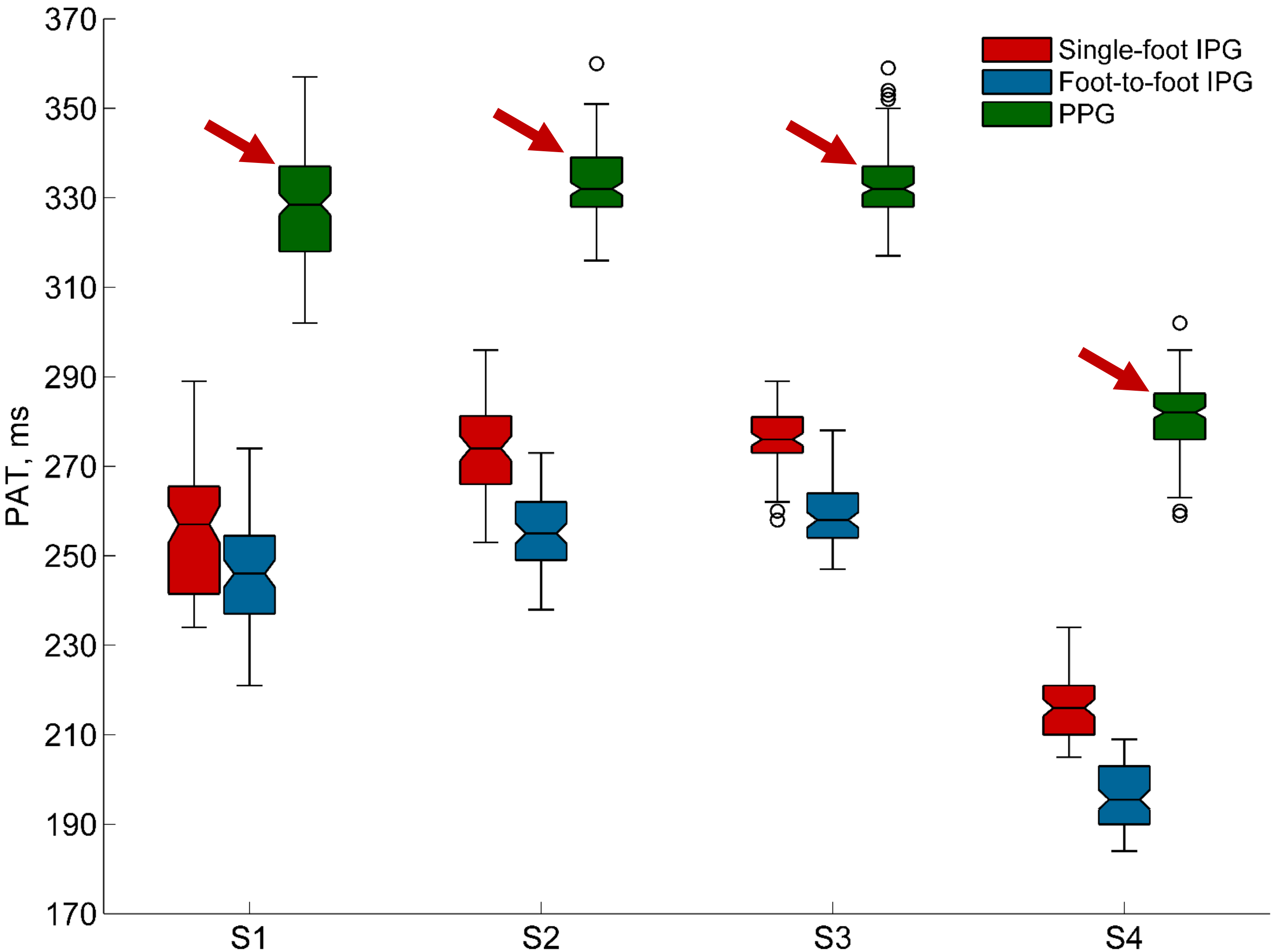


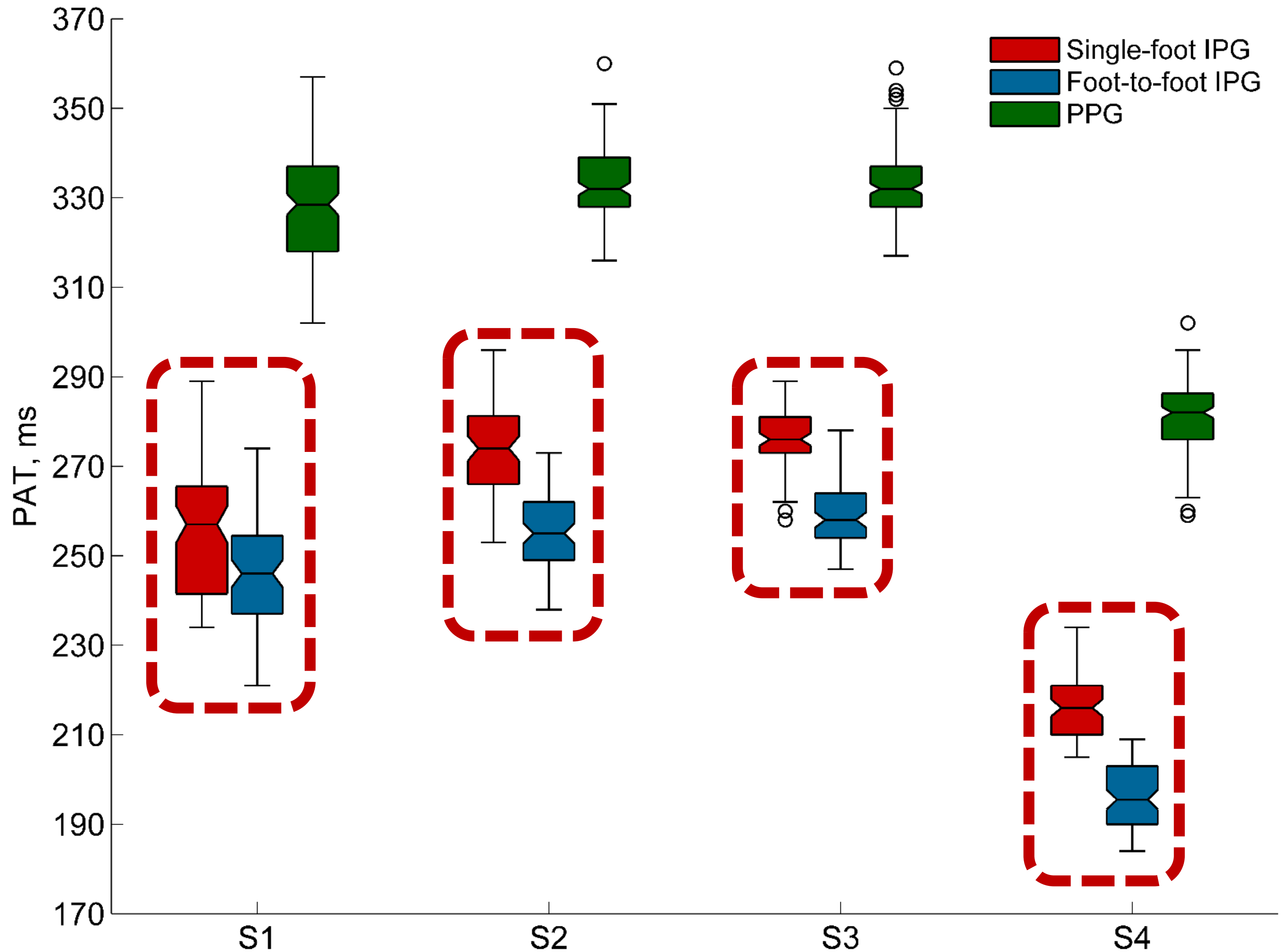
Data represent mean±SD

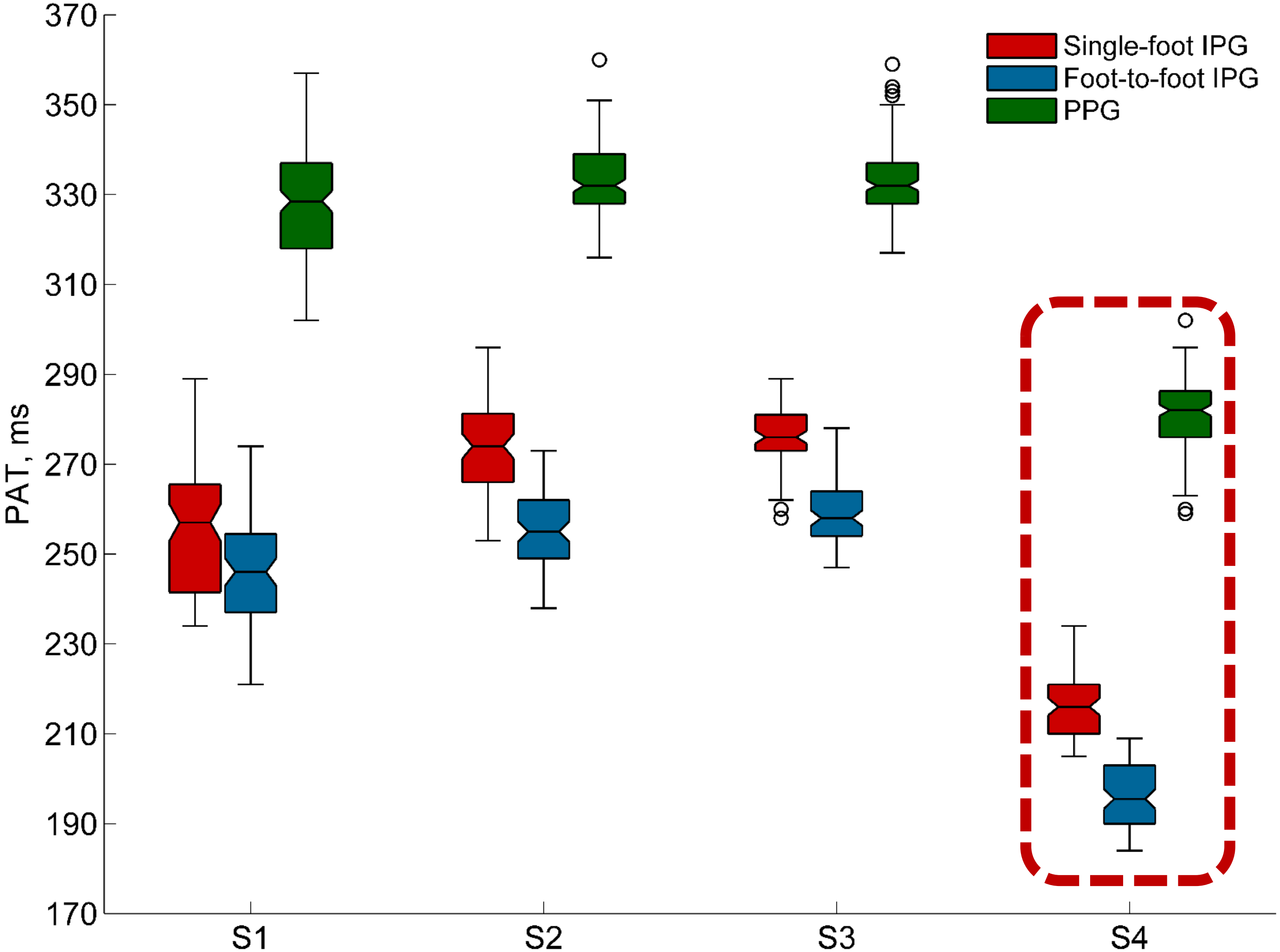


Data represent mean±SD

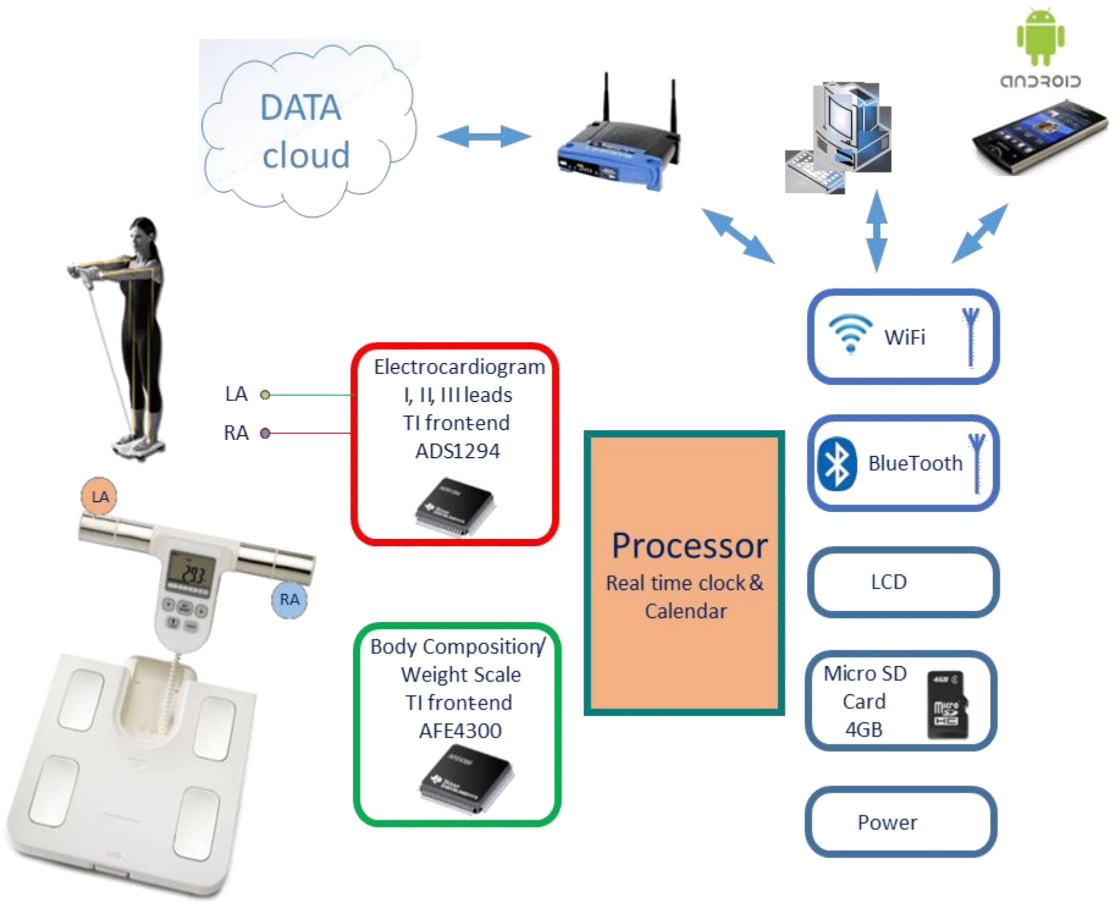

Single-foot IPG
Foot-to-foot IPG
PPG
PAT, ms
370
350
330
310
290
270
250
230
210
190
170
S1
S2
S3
S4


370
350
330
310
290
270
250
230
210
190
170
PAT, ms
S1
S2
S3
S4
Single-foot IPG
Foot-to-foot IPG
PPG


Single-foot IPG
Foot-to-foot IPG
PPG
PAT, ms
370
350
330
310
290
270
250
230
210
190
170
S1
S2
S3
S4


370
350
330
310
290
270
250
230
210
190
170
PAT, ms
S1
S2
S3
S4
Single-foot IPG
Foot-to-foot IPG
PPG

- Custom-made bioimpedance unit integrated into body composition scales



Conclusions

- PAT can be estimated by using IPG and ECG sensors, which are integrated into body composition scales;
- PAT evaluated by the method introduced in this study correlates with PPG-based PAT;
- single-foot and foot-to-foot PAT_{IPG} slightly differs.

Future directions

- testing of the custom-made system;
- development of the algorithm for the calculation of PAT;
- a wider group of subjects with different health status.

- This work was partly supported by the projects “Promotion of Student Scientific Activities” (VP1-3.1-ŠMM-01-V-02-003) from the Research Council of Lithuania and CARRE (No.611140) funded by the European Community 7th Framework Programme.

Thank you
for your attention