EXPERIMENTS WITH BLOOD PRESSURE MONITORING USING ECG AND PPG

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We observed dependencies among blood pressure, pulse arrival time and pulse wave amplitude of photoplethysmogram in our studies. Measurements were made at the intensive care unit in Motol University Hospital in Prague and were compared with invasive blood pressure meter. The correlation coefficients between systolic or diastolic pressure and pulse arrival time achieved up to − 0.97, when averaging over 16 RR intervals. However, the range of the measured systolic and diastolic pressure is very low in some cases, and therefore we cannot do reliable conclusions. Correlations between pressure and amplitude of photoplethysmogram were still somewhat higher, however, a poor repeatability of such a measurement can be expected.

1. Introduction

In recent years, many studies about blood pressure (BP) estimation based on pulse arrival time (PAT) or pulse transit time (PTT) have been published. Electrocardiography (ECG) and photoplethysmography (PPG) are often used for PAT measurement, while PAT becomes input quantity for BP estimation process. However, different definitions of PAT appear ([KIM07], [TEN06], [PAN08], [PAY06]). We decided to compare several definitions of PAT and consider their suitability for systolic (SBP) and diastolic (DBP) blood pressure estimation. Furthermore, utilisation of PPG amplitude for that purpose was also studied.

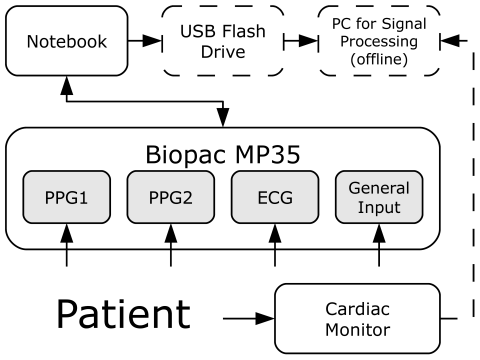

Figure 1: Apparatus for measurement in hospital

2. Measurements

Measurements were made at the intensive care unit in Motol University Hospital in Prague. For this purpose, six patients (six males) already wearing extravascular invasive blood pressure sensor were asked for participation. According to their health status (aged persons after cardiology surgery), we couldn't ask them to perform any exercising in order to induce any changes of blood pressure.

Measurement was performed in supine position, while subject was relaxing. Total length of signal recording was 3 minutes.

For ECG and PPG recording, Biopac MP35 system was utilised as shown in Figure 1. ECG was recorded as lead II, PPG was acquired from finger and from earlobe. Sampling frequency was set to 1 kHz. Signals were stored in text format and processed offline in Matlab. Blood pressure was recorded separately through the cardiac monitor.

3. Method

Stored signals from Biopac were loaded into Matlab, together with the blood pressure record. We detected R-peaks of ECG to recognize individual cardiac cycles. For every cardiac cycle, several parameters of PPG were computed: time till minimum of PPG, time till 10 % of ascending edge of PPG, time till inflection point of ascending edge, time till 90 % of ascending edge and time till maximum of PPG (in all cases measured from previous R-peak of ECG, see Figure 2 for details). To process amplitude of PPG, minimum and maximum of PPG and maximum of derivative PPG were computed for every cycle. Various linear combinations of mentioned parameters were also considered in order to improve robustness of this method. To reject disturbing jitter of quantities, averaging over 16 cardiac cycles was utilised.

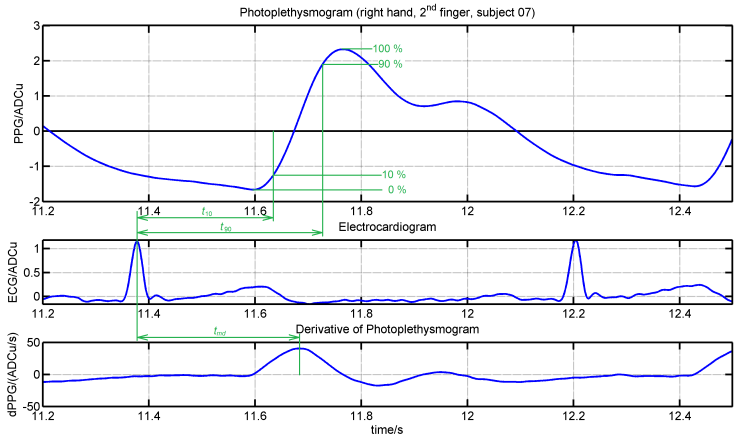

Figure 2: PAT defined as time interval between R-peak of ECG and 10 % (t_{10}) or 90 % (t_{90}) of ascending edge of PPG or maximum derivative PPG

As it is written above, PPG was acquired from finger and from earlobe and these signals were processed separately.

For every extracted parameter, coordinates of corresponding pairs parameter vs. (SBP or DBP) were plotted and linear regression line was marked. Linear regression equations were derived and cross-correlation coefficients computed. As the last step, we tried to reconstruct blood pressure curves using mentioned linear regression equations and parameters derived from ECG and PPG.

4. Results

PPG from finger was generally better, while earlobe-PPG comprised more artefacts and noise. Thus, following results refer to the PPG from finger. Due to poor quality of the BP record from subjects 1 and 3, we were unable to process these signals, hence there are only results for subjects 2, 4, 5 and 6 in tables.

Correlation coefficients between SBP or DBP and quantities derived from ECG and PPG are summarised in Tables 1 and 2.

Table 1: Correlation coefficients SBP vs. (parameter derived from ECG and PPG)

Subject	Correlation Systolic Blood Pressure vs.											
	Time till Minimum of PPG	*Time till 10 % of PPG*	*Time till max(dPPG/dt)*	*Time till 90 % of PPG*	*Time till Maximum of PPG*	*Average of Time till 10 % of PPG and max(dPPG/dt)*	*Average of Time till 90 % of PPG and max(dPPG/dt)*	*Average of Time till 10 % and 90 % of PPG*	*Minimum of PPG*	*Difference (max – min) PPG*	*Maximum of PPG*	*max(dPPG/dt)*
2	-0.16	-0.19	-0.16	-0.18	-0.17	-0.18	-0.17	-0.19	-0.15	0.37	0.51	0.29
4	-0.90	-0.95	-0.79	-0.84	-0.78	-0.93	-0.85	-0.97	-0.98	0.96	0.95	0.92
5	-0.35	-0.38	0.33	0.40	0.47	0.18	0.38	0.18	0.39	-0.50	-0.54	-0.52
6	-0.46	-0.69	-0.60	-0.62	-0.55	-0.66	-0.64	-0.66	0.11	-0.23	-0.29	-0.18

Table 2: Correlation coefficients DBP vs. (parameter derived from ECG and PPG)

Subject	Correlation Diastolic Blood Pressure vs.											
	Time till Minimum of PPG	*Time till 10 % of PPG*	*Time till max(dPPG/dt)*	*Time till 90 % of PPG*	*Time till Maximum of PPG*	*Average of Time till 10 % of PPG and max(dPPG/dt)*	*Average of Time till 90 % of PPG and max(dPPG/dt)*	*Average of Time till 10 % and 90 % of PPG*	*Minimum of PPG*	*Difference (max – min) PPG*	*Maximum of PPG*	*max(dPPG/dt)*
2	-0.46	-0.47	-0.41	-0.50	-0.50	-0.44	-0.46	-0.49	0.21	-0.12	0.02	-0.06
4	-0.89	-0.94	-0.81	-0.86	-0.80	-0.93	-0.87	-0.97	-0.97	0.95	0.94	0.91
5	-0.37	-0.39	0.18	0.23	0.31	0.02	0.22	0.02	0.31	-0.43	-0.47	-0.44
6	0.04	0.07	0.19	0.20	0.26	0.14	0.20	0.15	-0.50	0.49	0.48	0.51

See Figure 3 for example of measured and estimated systolic and diastolic blood pressure.

5. Discussion

Correlation coefficients between SBP and parameters computed from ECG and PPG vary strongly subject to subject. For subjects 2 and 5, only poor correlation can be observed: absolute values of correlation coefficients do not exceed 0.51 for subject 2 and 0.54 for subject 5. Subject 6 has correlation coefficients up to 0.69 (for SBP vs. time till 10 % of PPG) and subject 4 actually up to 0.98 (for SBP vs. minimum of PPG) in absolute values. Considering only time-based parameters, highest correlation is for subject 4 between SBP and average of time till 10 % and 90 % of PPG (correlation coefficient − 0.97), however, strong correlation (− 0.95) may be observed also between SBP and time till 10 % of PPG, like at subject 6. This is consistent with results published in [TEN06].

For DBP, rather worse results were observed (in accordance with [MEI06]). All but one subjects show only small correlation between DBP and any considered parameter (absolute values of correlation coefficients are smaller then 0.51). Only subject 4 has all correlation coefficients greater than 0.80 (in absolute value). Highest absolute value of correlation coefficient (0.97) appears for average of time till 10 % and 90 % of PPG and for minimum of PPG. Also the time interval from R-peak of ECG to 10 % of the ascending edge of PPG is at this subject highly correlated with DBP.

PPG acquired from the finger was better than the record from the earlobe but it is possible that the use of sensors designed specifically for acquisition from the ear would bring comparable or even better results than recording form finger.

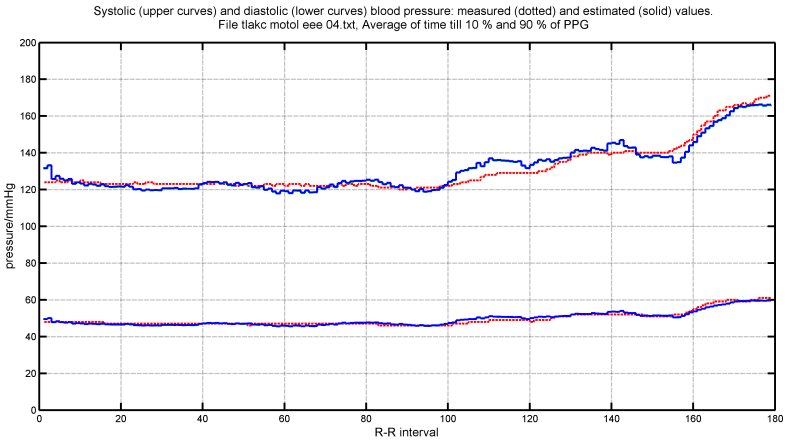

Figure 3: Blood pressure estimation based on PAT

The research carried out has various restrictions. This is essentially a small number of participants, their high age and a short time of recording. It was not possible to determine how would the measurement vary after several hours or days, and what effect would have re-touching of PPG sensor. There is no doubt that the amplitude of PPG signal depends on the force applied while attaching the sensor, and repeated applications or longer periods of measurement could distort the estimation of blood pressure. From this perspective, the use of pulse arrival time appears as more appropriate than utilisation of PPG amplitude.

6. Conclusion

For some participants, we found quite strong correlation between BP and some of parameters derived from ECG and PPG. Generally, correlations were higher for SBP than for DBP.

We are considering the utilisation of impedance cardiography (ICG) instead of the ECG to achieve better results, since the ICG is closer related to mechanical processes in heart and would allow computing of the "pure" pulse transit time, that is expected to be more correlated with BP than PAT derived from ECG and PPG.

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