NON-INVASIVE ASSESSMENT OF BLOOD VESSEL PROPERTIES

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I. Introduction

Aortic stenosis, thrombosis and stroke are common fatal diseases which could be predicted if a cheap, easy-to-use, non-invasive measuring method was available that estimates the state of arteries. Up to date ultrasound Doppler is the only such reliable way. Goal of this research is to asses the biomechanical properties of blood vessels via a modified photoplethysmographic (PPG) signal. An equivalent electrical model is being introduced which simulates the pressure and flow transients in the aorta and the left arm. Effects of a cuff wrapped around the upper arm are also included. The cuff-induced changes in flow conditions are measured by PPG sensor on a fingertip. The diagnosis comprises of the estimation of model parameters from the measured data.

II. Materials and Methods

A. Measurement Set-up

Photoplethysmographic signals originate from optical reflections (or transmission) of blood vessels. Volume changes in an artery generated by the pulse alter the reflecting conditions of tissues according to Lambert-Beer law. They are estimated from the arterial pressure by means of non-linear function compliance (in first approach treated as a 2/2 polynomial). Commercial PPG sensors operate in a frequency range of 0.1-20 Hz. Detection of the relatively slow transients however requires a measuring device with a useful bandwidth of 0-40 Hz. Before any diagnosis could be made a custom built PPG had to be constructed. The special pressure profiles used in the research made the development of a regulator for cuff inflation and deflation also necessary.

B. Electrical Model of Circulation

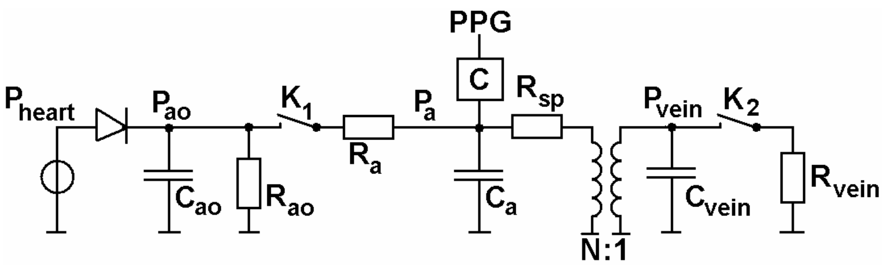

Figure 1: Simplified model of circulation

Figure 1 is a simple electrical model of the heart, aorta and the left arm artery and veins. In this representation pressure is replaced by voltage, flow by current. Capacitors represent the buffer effect of aorta, arteria brachialis and veins. Diode stands for the valve, transformer for the capillary net and resistors for flow-resistance. The pressure of the cuff is qualified into 3 different states: pressure below the venous pressure, between the venous and the systolic pressure, over the systolic value. The switches K1 and K2 are controlled according to this quantization: both closed, K1 closed but K2 open, both open. The model neglects BP auto-regulation and assumes that during measurement the vessel-properties and P_{ao} are unchanged. Viability was confirmed by comparative measurements on a physical circulation-model at the Department of Hydrodynamic Systems [1].

III. Results

Identification of the model parameters comes from two different measuring protocols. In the first one the cuff was fast inflated above the systolic pressure, held there for about 15 sec and then fast deflated. In terms of the abstract model this means the turning off and after 15 sec the simultaneous turning on of both switches. Figure 2a shows the measured data. The second cuff-intervention applied, as presented in Figure 2b, is fast inflation until 50 mmHg (below diastolic), holding it for about 40 sec, then fast deflation.

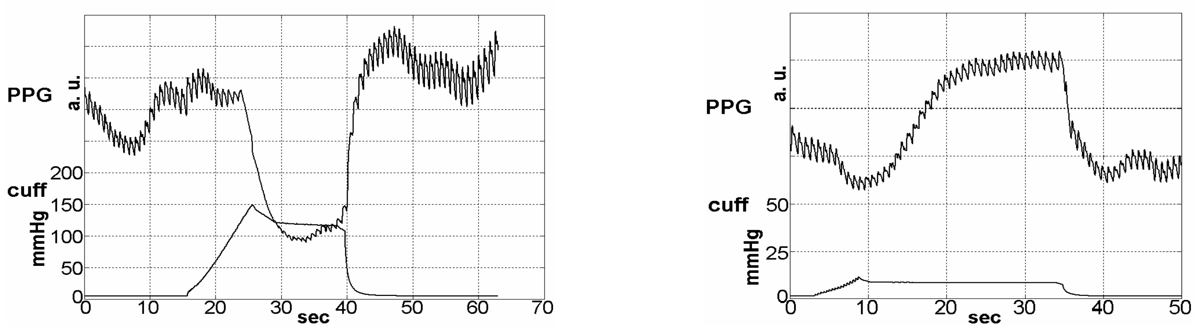

Figure 2: Measurements 1 and 2; response of a healthy patient to the excitation. PPG, cuff pressure.

The identification itself is an iterative algorithm (A detailed description can be found in [2].):

1. Measure the mean arterial pressure (MAP) by means of oscillometric method and set the initial compliance polynomial linear.
2. Transform the PPG signals to pressure values via compliance polynomial.
3. Apply ARMAX frequency domain identification for measurement data 1 according to $P_1 = \frac{1}{s} MAP \frac{s^2\alpha + s\beta + \gamma}{s^2 + s\delta + \varepsilon}$ and determine the model parameters α, β, γ_1, δ_1 and ε_1.
4. Apply ARMAX frequency domain identification for measurement data 2 according to $P_2 = \frac{1}{s} MAP \frac{s^2 + s\delta + \gamma}{s^2 + s\delta + \varepsilon}$ and determine the model parameters γ_2, δ_2 and ε_2.
5. Change the compliance parameters in a way that the gradient of estimation error, $[(\gamma_1, \delta_1, \varepsilon_1) - (\gamma_2, \delta_2, \varepsilon_2)]^2$, becomes negative.
6. If estimation error is exceptional small then STOP, else GOTO step 2.

IV. Conclusion

A simple model of circulation including heart, aorta and left arm was developed; effects of a cuff wrapped around the upper arm were investigated. Two different cuff pressure profiles were used: one blocking the whole circulation of the arm the other impeding only back flow through the veins. A measurement set-up comprising of a DC-coupled PPG sensor and a cuff-pressure controller was constructed. Model parameters were estimated from PPG signals recorded on a fingertip. The method makes evaluation of six circulatory parameters (R_a, R_{sp}, R_{vein}, C_a, C_{vein}, N) for every individual patient possible. As future work the switches should be replaced by components able to represent continuous cuff pressure and the compliance should be described by a more suitable function.

References

[1] F. Molnár, S. Till, G. Halász, "Arterial blood flow and blood pressure measurements on a physical model of human arterial system," in Conf.*Proc. of the IFMBE EMBEC'05*, paper no. 2043 on CD-ROM. ISSN: 1727-1983, Prague, Czech Republic, November 20–25 2005.

[2] A. Mersich, P. Csordás, Á. Jobbágy, "Non-invasive assessment of aortic stiffness," in Conf.*Proc. of the IFMBE EMBEC'05*, paper no. 1426 on CD-ROM. ISSN: 1727-1983, Prague, Czech Republic, November 20–25 2005.