# Introduction

Hemodynamic parameters describing the state of circulatory system are blood pressure (BP) and heart rate (HR). Additional important parameter is blood flow. While BP and HR can be measured easily, blood flow and generally blood distribution noninvasive measurement is complicated and inaccurate.

# Stroke volume estimation techniques

Estimation from Arterial Pressure

The indirect estimation of SV from circulatory parameters is called pulse wave analysis (PWA) [1]. The flow of blood occurs because of the pressure difference created by pumping action of the hearth. The relation between pressure difference and flow can be described by Darcy’s law (1) [6],

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Where is a pressure difference, is a Stroke volume and is total vascular peripheral resistance. This law is analogous to Ohm’s Law for electrical current. The pressure difference is the difference between systolic arterial blood pressure and diastolic arterial blood pressure, also known as pulse pressure (PP). One of circulatory parameter used for SV estimation is PP [2,3]. It is assumed that PP is proportional to SV [4]. However although SV and PP correlate it seems the relation is not linear [5]. One of commercial devices measuring SV from blood pressure is Nexfin. It computes Stroke volume on beat-to-beat basis.

V =

# Models of bioimpedance

# Parameters for stroke volume computation

# Multichannel monitor

# Ciele dizertácie

Cieľom tejto prace je štúdium metód slúžiacich na výpočet SV z impedancie hrudníka, impedancie krkavíc, impedancie dolných končatín, srdečných zvukov a EKG. Budú navrhnuté nové metódy na detekciu parametrov slúžiacich na výpočet SV. Najdôležitejšími parametrami pri výpočte SV sú dĺžka systoly (LVET - detekovaný hlavne zo srdečných zvukov) a maximum zápornej derivovanej impedancie (-dZ/dtmax). Dôraz je kladený na potlačenie vplyvu respirácie a iných nežiaducich zložiek signálu hrudníkovej impedancie. Následne budú nové metódy použité na výpočet kontinuálneho SV na rôznych skupinách pacientov. Výpočet SV novými metódami bude porovnaný s výpočtom SV pomocou Dopplerovskej echokardiografie.

Návrh a otestovanie novej metodiky detekcie parametrov pre výpočet SV ktorá zahrňuje:

* Detekcia prvého srdečného zvuku - S1 o správne nastavenie filtrácie, ukazuje sa že pre každý subjekt je potrebné nastaviť filtráciu individuálne
* Detekcia druhého srdečného zvuku - S2
* Detekcia parametru -dZ/dtmax

Overenie metodiky na základe variability parametrov:

* Detekované parametre by mali korelovať s fyziologickými procesmi – s respiráciou
* Zistiť akým pomerom sa na zmene SV podieľa zmena LVET intervalu a akým zmena - dZ/dtmax

Aplikácia metodiky na rôzne skupiny pacientov:

* Zdravý dobrovoľníci
* Ľudia po transplantácií srdca
* Ľudia s kardiostimulátormi

Porovnanie výsledkov novej metodiky na dátach z rôznych častí tela:

* Porovnanie relatívnych zmien detekovaných parametrov -dZ/dtmax z hrudníka, krkavíc a dolných končatín

# The first heart sound detection

According to the literature the first heart sound frequency reaches 20-150Hz [p9] respectively 50-150Hz [p10].

1. [1] T. G. Papaioannou, O. Vardoulis, and N. Stergiopulos, “The “systolic volume balance” method for the noninvasive estimation of cardiac output based on pressure wave analysis,” The American Journal of Physiology—Heart and Circulatory Physiology, vol. 302, no. 10, pp. H2064–H2073, 2012. [View at Google Scholar](http://scholar.google.com/scholar_lookup?title=The+%e2%80%9csystolic+volume+balance%e2%80%9d+method+for+the+noninvasive+estimation+of+cardiac+output+based+on+pressure+wave+analysis&author=T.+G.+Papaioannou&author=O.+Vardoulis&author=N.+Stergiopulos&publication_year=2012" \t "blank)

[2] T. A. Parlikar, T. Heldt, G. V. Ranade, and G. C. Verghese, “Model-based estimation of cardiac output and total peripheral resistance,” in Proceedings of the Computers in Cardiology, pp. 379–382, October 2007.[View at Publisher](https://doi.org/10.1109%2fCIC.2007.4745501) · [View at Google Scholar](http://scholar.google.com/scholar?q=https://doi.org/10.1109%2fCIC.2007.4745501" \t "blank) · [View at Scopus](http://www.scopus.com/scopus/inward/record.url?eid=2-s2.0-61649103520&partnerID=K84CvKBR&rel=3.0.0&md5=84f4405c2b38aada116be4bbfb01d902" \t "blank)

1. [3] L. Mathews and K. R. K. Singh, “Cardiac output monitoring,” Annals of Cardiac Anaesthesia, vol. 11, no. 1, pp. 56–58, 2008. [View at Publisher](https://doi.org/10.4103%2f0971-9784.38455" \t "blank) · [View at Google Scholar](http://scholar.google.com/scholar_lookup?title=Cardiac+output+monitoring&author=L.+Mathews&author=K.+R.+K.+Singh&publication_year=2008" \t "blank)
2. [4] H. Ishihara, H. Okawa, K. Tanabe et al., “A new non-invasive continuous cardiac output trend solely utilizing routine cardiovascular monitors: comparison with the continuous thermodilution method early cardiovascular monitors,” Journal of Clinical Monitoring and Computing, vol. 18, no. 5-6, pp. 313–320, 2004. [View at Publisher](https://doi.org/10.1007%2fs10877-005-2452-5" \t "blank) · [View at Google Scholar](http://scholar.google.com/scholar_lookup?title=A+new+non-invasive+continuous+cardiac+output+trend+solely+utilizing+routine+cardiovascular+monitors%3a+comparison+with+the+continuous+thermodilution+method+early+cardiovascular+monitors&author=H.+Ishihara&author=H.+Okawa&author=K.+Tanabe+et+al.&publication_year=2004" \t "blank) · [View at Scopus](http://www.scopus.com/scopus/inward/record.url?eid=2-s2.0-20944444823&partnerID=K84CvKBR&rel=3.0.0&md5=d68d0c6bf29523861c50495a75d20d52" \t "blank)
3. [5] X. Monnet, A. Letierce, O. Hamzaoui et al., “Arterial pressure allows monitoring the changes in cardiac output induced by volume expansion but not by norepinephrine,” Critical Care Medicine, vol. 39, no. 6, pp. 1394–1399, 2011. [View at Publisher](https://doi.org/10.1097%2fCCM.0b013e31820edcf0" \t "blank) · [View at Google Scholar](http://scholar.google.com/scholar_lookup?title=Arterial+pressure+allows+monitoring+the+changes+in+cardiac+output+induced+by+volume+expansion+but+not+by+norepinephrine&author=X.+Monnet&author=A.+Letierce&author=O.+Hamzaoui+et+al.&publication_year=2011" \t "blank) · [View at Scopus](http://www.scopus.com/scopus/inward/record.url?eid=2-s2.0-79957656409&partnerID=K84CvKBR&rel=3.0.0&md5=e432c5a7a46c3db4f4d87c570709cf01" \t "blank)

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