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Mini-Symposia Title:

Recent Advances on Cuff-Less Blood Pressure Measurement II

Mini-Symposia Organizer Name & Affiliation:

Josep Sola, Aktiia

Mini-Symposia Speaker Name & Affiliation 1:

Alberto Avolio, Macquarie University

Mini-Symposia Speaker Name & Affiliation 2:

Jay Pandit, Northwestern University/ Bold Diagnostics

Mini-Symposia Speaker Name & Affiliation 3:

Marco Di Rienzo, IRCCS Fondazione Don Carlo

Mini-Symposia Speaker Name & Affiliation 4:

Catherine Liao, Blumio

S Mini-Symposia Speaker Name & Affiliation 5:

Anand Chandrasekhar, MIT

Mini-Symposia Speaker Name & Affiliation 6:

Theme:

- ○ 01. Biomedical Signal Processing
- ○ 02. Biomedical Imaging and Image Processing
- ○ 03. Micro/ Nano-bioengineering; Cellular/ Tissue Engineering &
- ○ 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ◉ 05. Cardiovascular and Respiratory Systems Engineering
- ○ 06. Neural and Rehabilitation Engineering
- ○ 07. Biomedical Sensors and Wearable Systems
- ○ 08. Biorobotics and Biomechanics
- ○ 09. Therapeutic & Diagnostic Systems and Technologies
- ○ 10. Biomedical & Health Informatics
- ○ 11. Biomedical Engineering Education and Society
- ○ 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposia Synopsis— Max 2000 Characters

Cuff-less blood pressure (BP) monitoring is expected to improve hypertension awareness and control rates and may now be feasible due to recent technological advances in, e.g., wearable sensing. As a result, cuff-less BP monitoring devices are being widely pursued around the world. This topic is of great interest to the attendees of the IEEE EMBC. We have organized multiple mini-symposia on the topic at each of the past seven IEEE EMBCs. The in-per sessions have always been filled to capacity with 100 people or more (when the room was large enough) in attendance from academia and industry. We now propose two mini-symposia on recent advances on cuff-less BP measurement for the Guadalajara meeting. Our proposal includes ten outstanding speakers in the field from companies and universities. Half of these speakers would be attending the Guadalajara meeting for the sole purpose of participating in the proposed mini-symposia. This particular mini-symposium represents part two and covers innovative sensors and pulse transit time methods presented by two industrial and three academic speakers.

Effects of changes in blood pressure driven by cardiac, vascular, and neurogenic mechanisms on association of blood pressure and pulse transit time

Alberto Avolio, *FIEEE*

Department of Biomedical Sciences,
Faculty of Medicine, Health and Human Sciences
Macquarie University, Sydney, Australia
alberto.avolio@mq.edu.au

***Abstract*—The mechanisms that cause changes in blood pressure in the systemic circulation may be relevant in quantifying the true association between arterial pressure and pulse transit time.**

SPEAKER: Alberto Avolio graduated in Electrical Engineering (BE (1972) and PhD (1977)) from the University of New South Wales. He is currently Professor Emeritus in the Faculty of Medicine, Health and Human Sciences at Macquarie University, Fellow of the International Academy of Medical and Biological Engineering, Fellow IEEE. Current research includes pulsatile relationships of blood pressure and flow, non-invasive assessment of vascular function, cardiovascular modelling and biological signal processing.

TOPIC : *Effects of changes in blood pressure driven by cardiac, vascular, and neurogenic mechanisms on association of blood pressure and pulse transit time.*

The association of blood pressure (BP) and pulse transit time (PTT) is quantified by the inherent pressure dependency of arterial stiffness, which determines PTT along a specific path length. For cuffless measurement of BP, PTT can be determined by pulse sensors that detect displacement of the vascular wall of large conduit arteries (eg applanation tonometry) or changes in blood volume of peripheral microcirculatory beds (eg. photoplethysmography, PPG). This presentation examines the extent to which the causative changes in BP may affect the measurement of PTT and so produce potential errors in the cuffless estimation of BP.

Mean blood pressure (MBP) is a product of stroke volume (SV), heart rate (HR) and total peripheral resistance (TPR) [MBP = SVxHRxTPR] Hence the relative changes contributing to change in MBP are additive (ΔMBP/BP = ΔSV/SV + ΔHR/HR + ΔTPR/TPR). Similarly, to a first approximation, pulse pressure (PP) depends on SV and arterial compliance (C) [PP = SV/C] and the relative changes are ΔPP/PP = ΔSV/SV – ΔC/C. The quantities ΔSV/SV and ΔHR/HR are mainly cardiac dependent, ΔC/C depends on stiffness of large arteries and ΔTPR/TPR depends on microcirculatory properties affected by neurogenic mechanisms.

Since cuffless devices estimate relative changes in BP (ΔMBP/MBP, ΔPP/PP) by relative changes in PTT (ΔPTT/PTT), it is important to establish whether the components that contribute to BP could also contribute an additional error in the measurement of PTT, such that the association of BP and PTT through the pressure dependency of arterial stiffness is not entirely preserved.

***For example*:**

(i) Effects of ΔSV/SV: change in SV would likely alter the amplitude of the PPG signal that could affect detection of fiducial points for accurate PTT estimation, depending on the measurement site (this would be expected to produce low error).

(ii) Effect of ΔHR/HR: change in HR would alter the upslope of the peripheral signal that could affect fiducial point detection for PTT measurement (this would be expected to produce low error, although arterial pulse wave velocity has been shown to have a dependency on heart rate).

(iii) Effect of ΔC/C: arterial stiffness would be mainly affected by BP, but some (likely small) error could be produced by a neurogenic effect on regulation of smooth muscle tone of large muscular arteries that might produce a potential error in the PTT measurement.

(iv) Effect of ΔTPR/TPR: This could be a significant source of error due to the neurogenic effect on arterioles, such that an increase in BP due to vasoconstriction could produce an additional delay on the arterial pulse as detected by PPG, thus significantly underestimating the true change in BP.

Making the Clinical Argument for Continuous Blood Pressure

Jay Pandit, Northwestern University

***Abstract*—This talk is about making the clinical argument for continuous blood pressure by a practicing cardiologist and medical device entrepreneur.**

Dr. Jay Pandit is an Assistant Professor in Medicine and Cardiovascular Diseases at the Northwestern University Feinberg School of Medicine. He is also the Regional Director of Research of the Bluhm Cardiovascular Research Institute, Faculty Director of the NuVention Medical Biodesign Program and Director of Remote Cardiovascular Monitoring for the West Region. He did his undergraduate studies at Stanford University, earned his Doctorate in Medicine and his Internal Medicine training at the University of California San Francisco. He completed his fellowship in Cardiovascular Diseases at Northwestern University. He has developed intellectual property on the approach of Differential Pulse Arrival Time and is now interested in helping facilitate the move from snapshot hemodynamics in blood pressure management to continuous ambulatory trends for better blood pressure management.

With increasing work on cuffless blood pressure monitoring algorithms and standardization of technical thresholds for cufflesss blood pressure monitoring devices, the next step is how to integrate it into clinical work flows. The most utilized method for blood pressure measurement today continues to be office based cuff or home based cuff blood pressure. To move the clinical community from a cuff based snapshot to a continuous trend is a complex process. With this talk I hope to discuss the outcome measures needed in validation studies, the discussion about what control measure to use, sample size requirements and ultimately use case scenarios.

Simultaneous measure of PTT and PAT at finger, ear and forehead and their relations with continuous blood pressure

Marco Di Rienzo, IRCCS Fondazione Don Carlo Gnocchi, Milano (Italy)

Abstract— **This presentation will focus on the complex relationship among PTT and PAT simultaneously detected at different body sites, and beat-by-beat blood pressure. The innovative multisensor wearable device used for the data collection will be also illustrated.**

Marco Di Rienzo. MSc degree in Electronic Engineering from the Politecnico di Milano, Italy in 1980. Coordinator of the technological research in cardiovascular, wearable sensors and telemedicine areas at the IRCCS Fondazione Don Carlo Gnocchi. Adjunct Professor at the Faculty of Medicine, Università Statale, Milan. Research interests in signal processing, modelling of the cardiovascular control, cardiac mechanics, sleep, space physiology, seismocardiography and development of wearable systems for bio-signal monitoring. He is author of more than 140 papers in peer-reviewed journals, co-inventor on four patents and serves as a referee for several international journals.

His presentation will focus on the complex relationship among PTT and PAT simultaneously detected at different body sites, and beat-by-beat blood pressure. The innovative multisensor wearable device used for the data collection will be also illustrated.

Application of a Noninvasive, Radar-based Arterial Pressure Sensor for Beat-to-Beat Blood Pressure Monitoring

Catherine Liao, Blumio

Abstract—**Enabling beat-to-beat blood pressure monitoring noninvasively with radar-based cardiovascular sensing.**

Catherine Liao holds an M.B.A. degree from Imperial College London, London, U.K. She is currently the CEO and Co-Founder of Blumio, Inc., San Francisco, CA, USA. She is a technologist and an entrepreneur whose passion is in using technology to solve unmet needs. Ms. Liao has held a variety of roles in business development, product marketing, technical sales, and IT operations. Prior to founding Blumio, she spent 20 years in commercializing and marketing technology solutions to healthcare organizations including Kaiser Permanente, Cardinal Health, and Cigna.

Blumio's innovative sensor utilizes a high frequency millimeter waveform radar that extracts cardiovascular metrics from arterial pulsation. Our proprietary sensor and algorithms are capable of extracting a variety of amplitude and timing features from the arterial pulsation. Using these features, we have been successful in determining diastolic and systolic blood pressures on a heartbeat-by-heartbeat basis. In this talk Ms. Liao will share our latest study results as well as discuss application of our sensor in both clinical and consumer use cases.

Absolute Blood Pressure Monitoring Via Ultrasound Signals

Speaker: Anand Chandrasekhar,
Affiliation: Postdoctoral Associate, MIT

Abstract— **Non-invasive device to measure the absolute Blood Pressure (BP) waveform may be useful in an emergency room, step down clinical ward, outpatient clinic, or even in a home setting. Hence, we developed a non-invasive ultrasound-based device that uses a machine learning algorithm to estimate the absolute blood pressure waveform from the carotid and brachial artery of the subject.**

Anand Chandrasekhar received a BE degree in electrical and electronics engineering from BITS Pilani, India, an MS degree in electrical engineering from IIT Madras, India, and Ph.D. in electrical and computer engineering from Michigan State University, USA. At present, he is a post-doctoral associate at MIT, USA. His primary research interest is on diagnostic devices to detect cardiovascular diseases, biomedical instrumentation, modeling of physiologic systems, and cardiovascular physiology.

Hypertension or High Blood Pressure (BP) is a major cardiovascular risk factor, and hence, measuring BP is of significant clinical value. At present, there are a few disadvantages for devices that measure a patient's BP. For instance, in an Intensive Care Unit (ICU), physicians use an invasive radial catheter to measure BP, and these measurements are neither easy nor feasible to perform outside an ICU. To measure BP in a non-ICU setting, clinicians use a non-invasive arm-cuff device. This measurement is convenient but only provides a systolic and diastolic pressure value and does not output the Absolute BP (ABP) waveform. Hence, clinicians use non-invasive devices based on the volume clamping method to acquire the ABP waveform. However, these volume clamping devices measure BP only from a peripheral arterial location and may require additional mathematical transfer functions to estimate the BP in a proximal artery. Hence, the academic and industrial communities are strongly interested in developing non-invasive devices to directly measure the ABP waveform from a proximal blood vessel like the carotid and brachial artery. Such a device may be a quantitative alternative, instead of a simple physical exam, to perform rapid hemodynamic profiling of patients.

We developed a non-invasive device based on ultrasound-based technology to estimate the ABP waveform from the carotid or brachial artery [1]. This device records the arterial area and blood flow velocity signals using a custom-designed two-element ultrasound probe and further uses a machine learning-based algorithm to calculate the ABP waveform. We trained the algorithm on a public domain dataset [2] with more than 4000 synthetic waveforms and finally tested it on the patient data recorded using the proposed ultrasound-based device. Results are promising, and we plan more testing to investigate the feasibility of using this device in a clinical setting.

[1] Seo, Joohyun, et al. "Noninvasive arterial blood pressure waveform monitoring using two-element ultrasound system." IEEE transactions on ultrasonics, ferroelectrics, and frequency control 62.4 (2015): 776-784

[2] Charlton, Peter H., et al. "Modeling arterial pulse waves in healthy aging: a database for in silico evaluation of hemodynamics and pulse wave indexes." American Journal of Physiology-Heart and Circulatory Physiology 317.5 (2019): H1062-H1085.

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