Chapter 45
A Review on Noninvasive Beat-to-Beat Systemic and Pulmonary Blood Pressure Estimation Through Surrogate Cardiovascular Signals

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ABSTRACT

Blood pressure monitoring is essential in hospital and home monitoring scenarios, with applications requiring on-line beat-to-beat blood pressure estimation, such as tele-monitoring of neurally mediated syncope. This chapter presents a comprehensive review of investigated approaches and reported performance, using different noninvasive correlates of the circulatory and cardiovascular system. Papers of interest were located in Scopus, IEEE Xplore and PubMed databases. The resulting pool of papers was then methodologically reviewed using 5 thematic taxonomies developed: 1) pulse arrival time and pulse transit time, 2) vascular transit time, 3) RS2 time, 4) heart sound characteristics, 5) PPG characteristics. The status of evidence in the literature demonstrates that cardiovascular signals such as the electrocardiogram, photoplethysmogram, and phonocardiogram contain important information for the estimation of blood pressure. Still, there are open issues regarding the validity, reliability and stability of these methods.

DOI: 10.4018/978-1-5225-3158-6.ch045

INTRODUCTION

Cardiovascular system monitoring includes a myriad of tools and methodological approaches for the adequate diagnosis, treatment of patients, and preventive medicine (Webster, 2006; Akay, 2006). The cardiovascular system is a complex network centered on the heart, a self-paced organ that pumps blood through the pulmonary and systemic circulations. Heart activity may be analyzed via various physiological signals that are related such as the electrocardiogram (ECG), impedance cardiogram (ICG), the phonocardiogram (PCG), or blood pressure (BP). These different signals represent different information, related to electrical and hemodynamic processes (Guyton and Hall,2006).

Reliable, noninvasive and continuous assessment of the cardiovascular state is extremely important in clinical practice since the cardiovascular state may shift rapidly e.g. in anesthesia care or neurally mediated syncope onset (Meyer et al., 2011). The advantages of noninvasive physiological signal analysis have long been known (Lewis et al., 1977), but recent studies have focused in the noninvasive signal analysis of the cardiovascular state to estimate hemodynamic variables such as BP and Cardiac Output (Smith and Ventura, 2013; Couceiro et al., 2011). Noninvasive monitoring of the cardiovascular state of a patient is gaining a lot of interest for a safer, continuous, and comfortable patient assessment, in clinical and home-based scenarios (Zheng et al., 2014; Ha et al., 2014).

Two reviews on noninvasive methods to estimate BP were recently published: (Peter et al., 2014) focused on the noninvasive estimations using the auscultatory, oscillometric and tonometry techniques, as well as on pulse wave velocity and pulse transit/arrival time as BP surrogates; in (Buxi et al., 2015), the authors focused on pulse transit/arrival time methodologies, discussing calibration, acquisition and processing of the non-invasive signals, and the design of measurement systems. This chapter focuses on the review of the noninvasive surrogate cardiovascular signals only, addressing not only the pulse transit/arrival time methodologies, but also the combined and individual use of heart sound (PCG) and photoplethysmography (PPG), discussing their limitations.

The use of surrogate measures for BP inference is gaining commercial traction and products for clinical use are already available (Nihon Kohden, 2015; Sotera Wireless, 2015). Pulse wave transit time calculated from the ECG and the PPG is analyzed to detect changes in the BP in order to trigger a cuff-based BP measure (PWTT, Nihon Kohden) (Nihon Kohden, 2015). Recently, a first system was approved by the FDA for BP monitoring in general ward based on pulse arrival time (ViSi Mobile, Sotera Wireless), which requires intermittent recalibration by standard cuff-based BP measurements (Sotera Wireless, 2015). Due to this market interest, the need in the standardized characterization of these new BP measurement approaches has been addressed by a first IEEE-standard for wearable cuffless blood pressure measurement devices dealing with the calibration issue and performance evaluation (IEEE-SA, 2014).

This chapter presents a review of approaches for the noninvasive BP estimation based on noninvasive surrogate metrics of the cardiovascular state. It is organized in the following sections: Blood Pressure Monitoring, where current methods in clinical use will be briefly described; Physiology of the Cardiovascular System, where basic principles and their relations to different noninvasive signals are presented, as well as BP regulation mechanisms are discussed; Methodological Review, where the main approaches for the noninvasive BP estimation will be described with a review on the most relevant studies; and finally, a critical Discussion is presented.