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Estimated confidence interval from single blood pressure measurement based on algorithmic fusion

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ABSTRACT

Background: Current oscillometric blood pressure measurement devices generally provide only single-point estimates for systolic and diastolic blood pressures and rarely provide confidence ranges for these estimates. A novel methodology to obtain confidence intervals (CIs) for systolic blood pressure (SBP) and diastolic blood pressure (DBP) estimates from a single oscillometric blood pressure measurement is presented.

Methods: The proposed methodology utilizes the multiple regression technique to fuse optimally a set of SBP and DBP estimates obtained through different algorithms. However, the set of SBP and DBP estimates is a small number to determine the CI of each individual subject. To address this issue, the weighted bootstrap approach based on the multiple regression technique was used to generate a pseudo sample set for the SBP and the DBP. In this paper, the multiple regression technique can estimate the best-fitting surface of an efficient function that relates the input sample set as an independent vector to the auscultatory nurse measurement as a dependent vector to estimate regression coefficients. Consequently, the coefficients are assigned to an eight-sample set obtained from the fusion of different algorithms as optimally weighted parameters. CIs are also estimated using the conventional methods on the set of fused SBP and DBP estimates for comparison purposes.

Results: The proposed method was applied to an experimental dataset of 85 patients. The results indicated that the proposed approach provides better blood pressure estimates than the existing algorithms and, in addition, is able to provide CIs for a single measurement.

Conclusions: The CIs derived from the proposed scheme are much smaller than those calculated by conventional methods except for the pseudo maximum amplitude-envelope algorithm for both the SBP and the DBP, probably because of the decrease in the standard deviation through the increase in the pseudo measurements using the weighted bootstrap method for each subject. The proposed methodology is likely the only one currently available that can provide CIs for single-sample blood pressure measurements.

1. Introduction

To maintain quality of life, the elderly population and patients with chronic conditions are employing self-monitoring using non-invasive medical devices such as automated oscillometric blood pressure devices. Interestingly, there are still no standard protocols for these devices. Most blood pressure devices provide only single-point estimates with no confidence ranges, and the user may not be able to distinguish the statistical variability in the estimates from the intrinsic variability due to the physiological process [1]. As there is no golden standard other than auscultation, there is no method to determine fluctuations in blood pressure and distinguish them from variabilities due to physiological processes. If a confidence interval (CI) is too broad, an alert can recommend discarding the measurement and initiating another measurement. Without the CI, it is difficult to make any meaningful decision based on blood pressure estimates. According to some aggregated statistics, in a home-based monitoring setting, repeated broad CIs can trigger an alarm or alert either the nurses station or the family doctor. Although this is an important aspect of blood pressure estimation, there has not been much research done to develop CIs for the estimates provided by oscillometric devices.

A large number of measurements (more than 30) are required to derive a CI, and traditionally, an asymptotic normal distribution

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is assumed. As described in [2], for each subject, a large number of measurements are required to determine a CI using the standard Student's t (ST)-distribution. It is not feasible to obtain a large number of measurements for each subject using a non-invasive oscillometric blood pressure measurement device, as repeatable conditions for reproducible measurements can never be guaranteed. Hence, it is best to obtain a CI using fewer measurements. However, standard methods of obtaining CIs such as the one presented in [2] cannot be used to obtain CIs for blood pressure measurements in a practical setting. This calls for innovative methods that can obtain CIs from smaller sample set.

Recently, we introduced the use of a non-parametric bootstrap technique to obtain CI estimates of oscillometric blood pressure measurements [3], motivated by [4]. The methodology behind [3] is that the bootstrap technique [5] is carried out to obtain CI estimates using a limited number of measurements (five) in situations where the use of the ST-method turns out to be invalid. However, in reality, one may not even have such a luxury, and often only a single measurement may be feasible. In such a scenario, the following question arises: how can a CI be obtained from the only available measurement? We are fully motivated by the technique of Blachman and Machol [6], which was proposed to determine CIs based on a single observation. However, it may be impossible to know the true CIs because these scheme's CIs are too widespread to qualify as meaningful CIs. One interesting point is that there have been no studies in the literature related to obtaining CIs from single oscillometric blood pressure measurements. In this regard, our paper is aimed at devising a solution for the above question. We present a fusion approach to obtain a CI from a single measurement; this procedure consists of the fusion of two different algorithms with the parametric bootstrap method, which is based on multiple linear regression [7]. There has been an interest in the data fusion of physiological signals in recent years. Specifically, the method of Park et al. [8] used a fusion system to decide from which single-channel electrocardiogram (ECG) respiration is derived. Another fusion method was proposed by Nemati et al. [9], who combined information through multiple channels including ECG and photoplethysmogram. More recently, the concept of fusion was adopted in ECG-assisted blood pressure estimation [10]. However, it is impossible to compare those methods directly with our proposed fusion method, since unlike our method, they were not used to find CIs.

This is the first study in the literature that presents an algorithmic fusion-based approach to derive the CI of blood pressure estimates from a single measurement. To obtain a CI from a single measurement, a fusion-based approach that combines the estimates provided by two different existing blood pressure estimation algorithms is proposed. The choice of two different algorithms for blood pressure estimation satisfies the algorithm fusion requirement as discussed in [10,11]. The blood pressure estimates provided by the two algorithms, namely the maximum amplitude (MA) [12] and linear approximation (LA) [13] algorithms, are applied to provide blood pressure estimates that are used with the parametric bootstrap approach [5], to produce the CI means and ranges for the systolic blood pressure (SBP) and diastolic blood pressure (DBP) estimates. Specifically, we have the SBP and DBP values based on the algorithmic fusion approach, which is used to estimate CI for the SBP and the DBP as an input sample set. However, our eight-sample set is small for estimating the CIs of each individual subject. To solve this problem, we use the parametric bootstrap technique [5] with multiple regression [7] to generate a pseudo sample set for the SBP and the DBP. In this paper, the multiple regression technique can estimate the best-fitting surface of an efficient function that relates the input sample set as an independent vector with auscultatory nurse measurements as a dependent vector to estimate the regression coefficients [7]. Therefore, the coefficients are assigned to the eight-sample set obtained from the different algorithmic fusions as optimally weighted parameters.

Two different methods (termed as the oscillometric pulse index (OPI)) for deriving the envelope information, namely the height of each pulse from baseline-to-peak and area under each pulse (AE) [14], and two different techniques for interpolating the envelope, namely the Gaussian (GA) and the Cauchy–Lorentzian (CL) [3], were used in conjunction with the existing blood pressure estimation algorithms to provide a distinct set of estimates for producing CIs using the parametric bootstrap technique with the multiple regression model. Herein, our proposed method is referred to as the weighted bootstrap fusion algorithm (WBFA). The novelty behind this approach lies in simultaneously obtaining the blood pressure measurement through the use of different

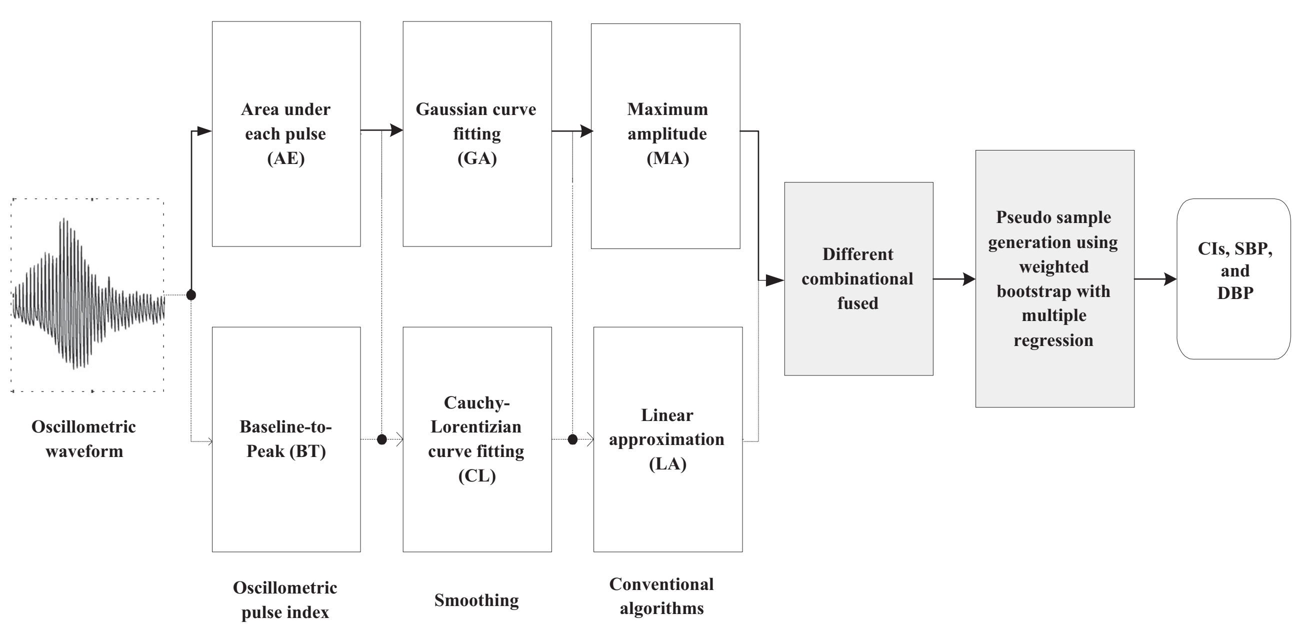

Fig. 1. The proposed method based on the weighed bootstrap with the multiple regression model.