The Modified Step-Wise Deflation Method in Blood Pressure Measurement

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Abstract

In non-invasive blood pressure (NIBP) measurement, most of the automatic devices use oscillometric method. There are two types of deflation in oscillometric method. One is the linear deflation and the other is the stepwise deflation method. In this study, we suggest the modified step deflation to reduce the measurement time while keeping the advantage of step deflation over linear deflation. With the control of the valve and real time signal processing, we implemented the blood pressure measurement system and new algorithm. We measure the amplitude of each systolic pulsation. For the validation of our suggested method, human observer assessed SBP / DBP according to EHS (European Hypertension Society) guideline. The mean differences between the suggested method and traditional auscultation method were 1.95 mmHg for SBP and -0.55 mmHg for DBP.

1.   Introduction

Oscillometry is the one of non-invasive blood pressure measurement techniques, which is most widely used for automatic devices due to its simplicity [1]. The method needs an inflatable cuff, a pressure transducer, and a microprocessor unit (MCU). The inflatable cuff wraps around upper-arm to occlude the brachial artery. The pressure sensor measures the cuff pressure during the inflation or deflation period. The MCU determines the systolic and diastolic blood pressure from the signal which is extracted from the cuff pressure.

There are two types of deflation in oscillometry. One is the step deflation and the other one is the linear deflation [2]. Even though the linear deflation technique has the advantage of its simplicity and quick measurement, it has the disadvantage of its weakness to the motion artifacts and other source of noise. In the step deflation, two or more consecutive pulsations in each level of the cuff pressure are required to decide the amplitude of oscillation at each step. Therefore, the step deflation has the time inefficiency for measurement. In this study, we suggest that the modified step deflation to reduce the measurement time while keeping the advantage of step deflation.

2.   Methods

- NIBP measurement hardware

Figure 1 is the diagram of NIBP system that we designed and implemented.
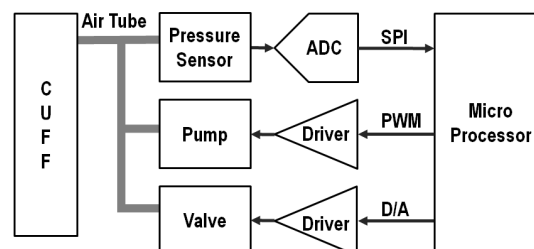

Figure 1 Block Diagram of NIBP system

The cuff is placed around the upper-arm to occlude the brachial artery. We used the cuff of 300 x 160 mm. The cuff pressure is measured by the air pressure sensor (MPX5050GP, Freescale, USA) that can measure the air pressure between 0 to 300 mmHg. MCU controls the pump to inflate, valve to deflate in the desired speed. Also the pressure signal from the sensor is digitized and processed by the MCU. The pressure signal from the sensor is directly connected and digitized by 24-bit high resolution ADC (Analog to digital Converter, ADS1222, Texas Instrument, USA) at 75 Hz. Because of its high resolution of 24 bits per sample and wide dynamic range of ADC, any analog filter is not necessary between the sensor and ADC.
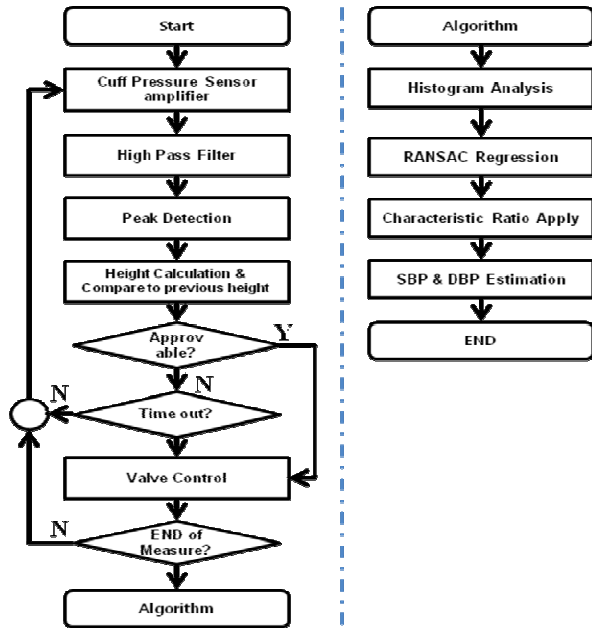
Figure 2. Flow chart of the modified step deflation to assess SBP/DBP. This flow starts after inflation. Left side is for the measurement during the deflating period. The right side is for the assessment of SBP and DBP with the oscillation components.

All of the required signal processing is done in digital domain in MCU. (Figure. 2, left side)

After digitizing, to pick up the oscillometric pulse signal, the high pass filter (cutoff frequency = 0.5 Hz) is applied. In each step, the program detects the existence of a peak and calculates the height of the peak as shown in figure 3. If the height of the peak is considered as meaningful one, MCU opens the valve to deflate into the next step. This deflation process should be finished during the diastolic period not to miss any heartbeat. If the systolic epoch overlaps with the deflating period, the detection and the calculation of the height are not possible. In figure 3, the MCU detects one heartbeat in each step, and deflates to next step within diastolic period.

- Peak Detection & Valve Control

To detect one pulse in each step, the algorithm localizes the minimum and the maximal points around the fast rising point. The minimum point considered as the start of systolic period. In general, the minimum and the maximal values are located within 250mse interval. Based on our experience, the systolic period occurs in this time interval. The height of each pulse is between 0.4 to 4.0 mmHg in our measurement system.

When the algorithm is searching for the fast rising point, the threshold is adjusted based on the steepest

rising slope value in previous beat. The threshold value of next step is set as following.
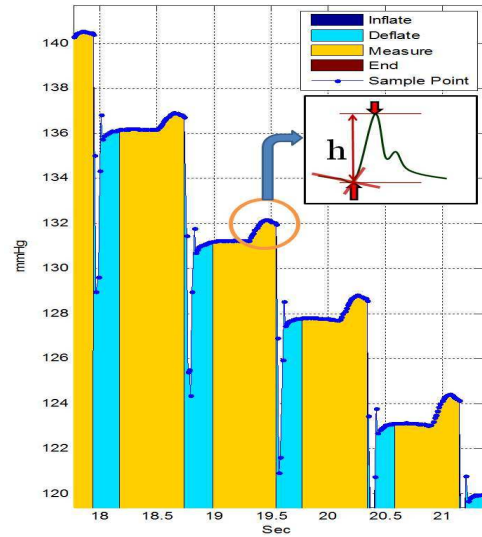

Figure 3. The measurement and valve control example of suggested system. In each step of cuff pressure, the MCU detects systolic beat and calculates the height.

$$Threshold_{next} = \frac{MaximumSlope_{Peak}}{4} \qquad (\ 1 \ )$$

In step deflation, the control of the valve is very important. The pressure difference between steps is the function of opening area of the valve, valve opening time interval, and the cuff pressure at that time. We choose the control of the opening time interval because opening area control is not stable because the current-to-opening area characteristic is different for each valve even in same model of one manufacturer.
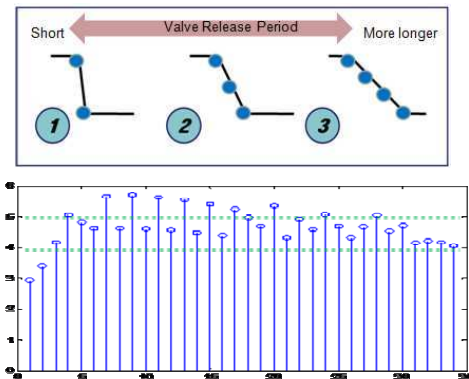

Figure 4. The control of valve opening period (upper) and its resultant pressure difference in each step (lower). We can see the pressure differences between the successive steps are between 4 to 6 mmHg through the measurement period.

After setting the desired difference (in our case 5mmHg), we monitors the actual difference of pressure between steps. If the actual value is too small (less than 4mmHg in our case), we extend the opening time interval. If the actual value is too large (bigger than 6mmHg in our case), we reduce the opening time interval of the valve. We could achieve the desired pressure difference through the measurement period. Also this algorithm is successful for the variation of the cuff size.

- Systolic and diastolic blood pressure assessment

When the cuff pressure arrives at the completion pressure, the measurement phase is finished. In each step, there is one peak height value as shown in the middle of figure 5. By regression the points into two lines, they estimate mean arterial pressure (MAP), SBP, DBP sequentially in conventional algorithm. In our suggested method, we exclude some of the peaks to enhance the accuracy. At first, if the peak is bigger than 120% (or smaller than 80%) of previous peak, the point is excluded in regression because the peak is considered as motion artifact.

After eliminating the motion artifact, we check the histogram of the height. In theory, the distribution should be uniform between SBP and DBP. In reality, there are some region where many pulses have similar height. This problem makes error in regression. In figure 5, there is one crowded region between SBP and MAP and one crowded region between MAP and DBP (red arrows). We did not include these beats in regression. The last step to eliminating the outlier, RANSAC [3] algorithm is used. This procedure is summarized in right side of figure 2.
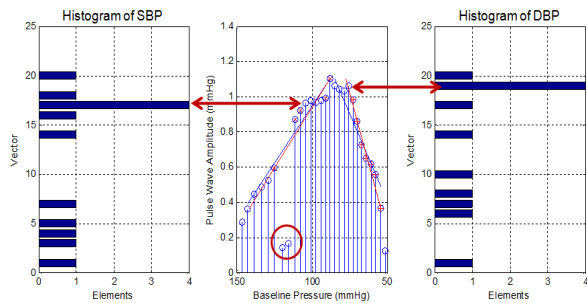

Figure 5. One example of measurement. In the middle, the successive heights are plotted. The left is the histogram of height before MAP. The right is the histogram after MAP. The circle means the excluded heights by our suggested algorithm. By excluding the outlier, the accuracy of the regression can be better.

To set the proper characteristic ratio (CR) in our system, we used the simulator from SmartArm(Clinical Dynamics, USA). With the signal and known SBP/DBP

value from the simulator, by comparing our regression method, we set the CR as table 1. We divided into 6 ranges based on the MAP values, and set the CR values in each range.

Table 1. The Characteristic ratio table for our system

MAP	SBP Ratio	DBP Ratio
Above 165	0.38	0.60
116 ~ 165	0.46	0.58
95 ~ 115	0.57	0.62
77 ~ 94	0.55	0.6
60 ~ 76	0.65	0.68
40 ~ 59	0.65	0.65

3.   Validation experiment

To evaluate the accuracy of our suggested method, we compared the SBP/DBP that are assessed by observer following the guidelines from the EHS (European Hypertension Society) [4]. Because the gold standard of NIBP measurement is still Korotkoff sound method, we recorded the sound and pressure wave from the subject as shown in figure 6. Using the pressure sensor for cuff pressure (TSD120, Biopac Co. Ltd., USA) and the stethoscope module (SS30L, Biopac Co. Ltd., USA) Korotkoff sound were recorded and assessed by the observer after the measurement.
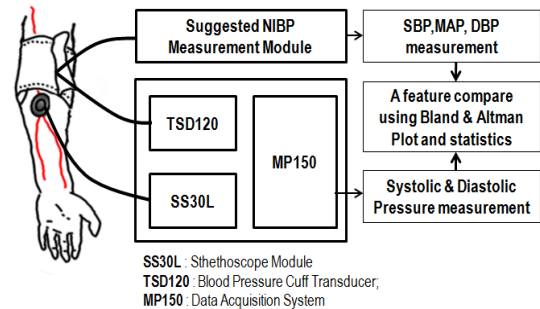

Figure 6. Measurement configuration for evaluation.

Twenty volunteers (59 readings) were recruited for the evaluation (mean age was 25.76±1.73 years, 16 for male, 4 for female), who have no pathological experience of cardiovascular disease. For each subject, we measured twice or three times in the morning, afternoon and mid-night. Finally, we collected 48 cases of data. After measuring with the reference method, we measured data also with our suggested system.

4.   Results

Figure 7 and 8 show Bland & Altman plot of the result [5]. 'Est' means that result of suggested method and 'KS' means the conventional auscultation method using

Table 2. Comparison result SBP and DBP assessment of 20 volunteers between suggested and Korotkoff sound method

Blood pressure	Blood Pressure Values (mmHg±SD)			Absolute of blood pressure difference [Number of cases (Percentage)]				
	NIBP	Korotkoff	Difference	0-5 mmHg	6-10 mmHg	11-15 mmHg	16-20 mmHg	More than 20mmHg
SBP	119.88±10.42	117.93±10.78	1.95±4.26	37(77)	7(15)	4(8)	0	0
DBP	65.42±8.28	65.97±9.20	-0.552±5.49	29(60)	17(35)	1(2)	1(2)	0

Korotkoff sound. The average systolic BP difference of all the 48 readings was 1.95±4.26mmHg and diastolic -0.56±5.49mmHg (Table 2).
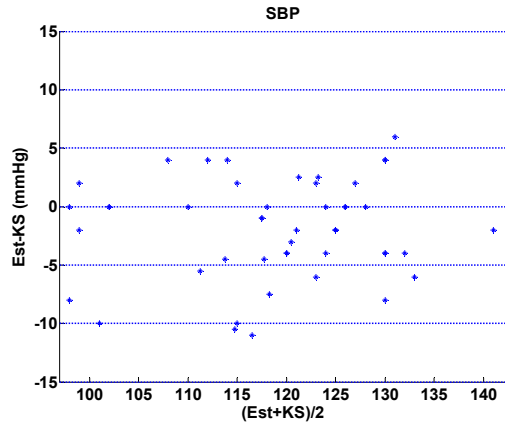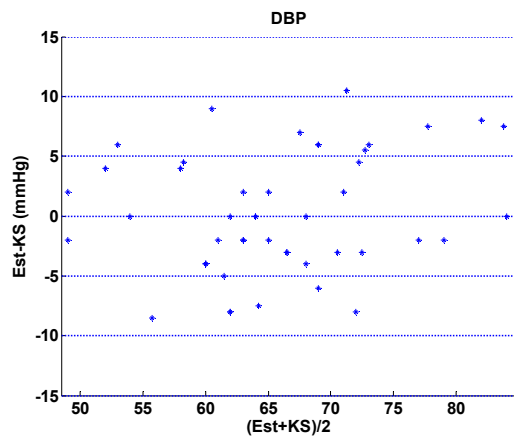

Figure 7. Bland - Altman plot of SBP.

Figure 8. Bland - Altman plot of DBP

For SBP, 77% was located within 5mmHg of difference. 92% was included within 10mmHg of difference. For DBP, 60% was located within 5mmHg difference and 95% was within 10mmHg difference.

5.   Discussion and conclusions

This study presents the modified step deflation using single pulse detection in each step. When we want to increase the accuracy, we can design the step difference as low (2~3mmHg) but it takes long measurement time. To increase the accuracy, it is important to exclude the signal by the motion artifacts and other source of noise. Traditional step deflation method is one of the solutions but it makes the measurement time be longer. In our suggested method, we measure only one beat in one step and deflates within diastolic period. It can reduce the measurement time a lot. By eliminating outlier in the regression process, it can do the role of motion artifact removal partly. By using this method, we could implement NIBP measurement system.

There are some limitations of our study. The direct comparison study between the conventional step deflating method and our suggested method is planned. Also the validation data were only from the young and healthy subjects.

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