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OSCILLOMETRIC VIRTUAL INSTRUMENT FOR BLOOD PRESSURE MEASUREMENT

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Abstract:
In this paper a simple educational model of a non-invasive blood pressure measurement device, based on the oscillometric principle is presented. The device is composed of a pressure transducer, auxiliary instrumentation for signal acquirement and digital signal processing module in the LabVIEW environment. Since the most problematic part of metrological evaluation of oscillometric devices is in proprietary algorithms of determining systolic and diastolic blood pressure, two basic algorithms are discussed. The amplitude algorithm is used for building the virtual instrument (VI). Preliminary comparisons of the built VI were done using simulated and real person's blood pressure waveform. The VI proved to be a useful tool for studying amplitude algorithms of determining systolic and diastolic pressure from the oscillations envelope.

Keywords: blood pressure, oscillometry, virtual instrument, NIBP, simulator.

1. INTRODUCTION

Blood pressure measurement using mercury sphygmomanometer is one of the oldest methods in health service, still of great importance in today's medicine diagnostics. Its basis is still the classical, one century old auscultatory method by Riva-Rocci and Korotkoff. With new technologies, decrease in price of electronic components and fast progress in measurement science, combined with increased awareness of toxicity of mercury, new methods and new BP measuring devices were designed in the last decades. Still regarding mercury sphygmomanometer as the "gold standard" for BP measurement is very much due to the fact, that inter-variability and differences between similar mercury devices of different companies are relatively small compared to other devices.

In recent years the usage and sales of simple and inexpensive electronic oscillometric blood pressure (BP) devices for home and office increased dramatically. With growing awareness of ecological and environmental threats of mercury, commonly used in today BP standards (mainly mercury sphygmomanometers), there were numerous experiments, evaluations, validations and comparisons conducted to determine some basic metrological properties (uncertainty, repeatability and reproducibility) of the oscillometric devices. Oscillometric BP monitors are difficult and expensive to evaluate, because of strong BP variability in form of measurement variations (noisy environments, cuff dimensions, parallax error, position of the arm, left versus right arm, deflation rate, etc) and biological variations (patient physiological state, patient emotional state, activities, smoking, caffeine, white-coat effect, etc) [2].

Due to different approach to determination of BP values, oscillometric devices have to be validated using clinical tests and in this way compared to auscultatory methods or invasive BP measurement. Clinical tests are performed according to different protocols (such as described in European standard EN 1060-4) and are usually expensive and time–consuming. Some basic metrological properties can on the other hand be evaluated using repeatable electro-mechanical signal generation devices (simulators).

2. PURPOSE

Designing a system and methodology for evaluation of typical metrological parameters describing oscillometric methods for BP measurements, nowadays employed in most non-invasive BP (NIBP) measurement instruments, would be of great importance in new knowledge on validating NIBP devices with unknown measurement algorithms.

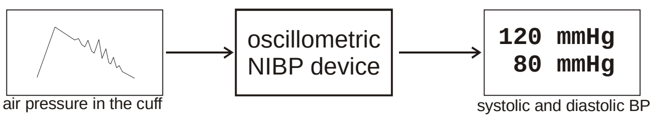

Fig. 1. Basics of oscilometry. Blood pressure dependant changes of air pressure in the cuff are measure of systolic and diastolic BP. Oscilometric device calculates both pressures according to its measurement algorithm.

As a part of investigation towards this aim, a more clear understanding of the role of algorithms for determining systolic and diastolic BP from cuff pressure oscillations is needed. We decided to build a simplified model of a NIBP device, which could be easily altered or accommodated to specific need. For this purpose we built a virtual instrument, designed in LabVIEW software environment (by National Instruments), which enabled us the flexibility we needed.

2. OSCILLOMETRY

Oscillometric method for BP measurements is based on observing the pressure oscillations occurring in the deflating cuff pressure from supra-systolic to sub-diastolic pressure, after the cuff occlusion of the blood flow in patient's extremities (figure 2). It is now generally accepted that the maximum cuff pressure oscillation amplitude occurs when the occlusive cuff pressure is equal to the mean arterial pressure (MAP).

With cuff pressure decreasing, the oscillation amplitude increases and afterwards decreases (figure 3). Systolic and diastolic pressures are determined from the oscillation envelope (figure 3). Determination of both can be done using different algorithms, which are usually proprietary and are rarely described in detail. Two basic algorithms are amplitude and differential algorithm, both based on measurement of MAP.

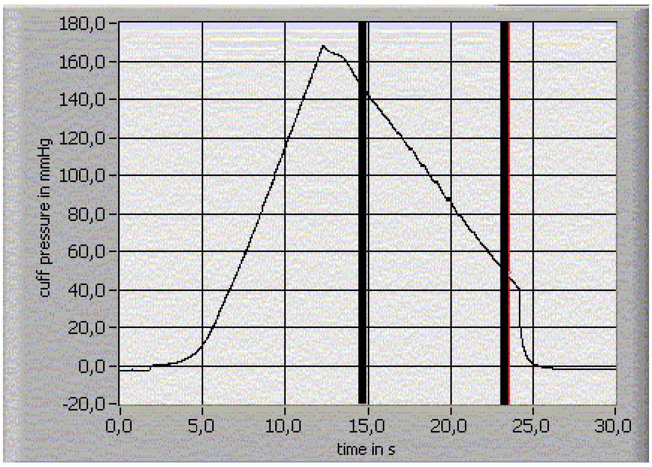

Fig. 2. Acquired raw signal. Pressure in the cuff is increased above systolic BP, afterwards decreased to zero. Pressure oscillations occur in deflating cuff. Vertical lines mark section of interest where the oscillations occure. (1 mmHg = 133.3 Pa)

Amplitude algorithm determines systolic pressure (SYS) as the cuff pressure, larger than MAP, where the ratio of its amplitude and the MAP amplitude equals to priory set factor – systolic ratio. In the same manner diastolic pressure (DIA) is determined as the cuff pressure, lower than MAP, with the amplitude ratio equal to diastolic ratio. Both ratios are dependant of cuff size and shape and other mechanical properties of the cuff, deflation rate, compliance of the blood wall, etc and are determined empirically (typicaly systolic ratio equals 0.5 and diastolic ratio 0.7) [4, 5].

Differential oscillometry algorithm uses the slope of the oscillations envelope to determine both SYS and DIA pressures. Maximal and minimal slopes (or envelope derivatives) are measures of DIA and SYS pressure. MAP is determined as the point of zero derivative (figure 3). This type of algorithm is rarely used in inexpensive devices, because of their low-performance central processor unit, not capable of demanding envelope detection processing in real-time. In inexpensive commercial monitors commonly only amplitude algorithm is employed. Our research was therefore conducted focusing on this method only.

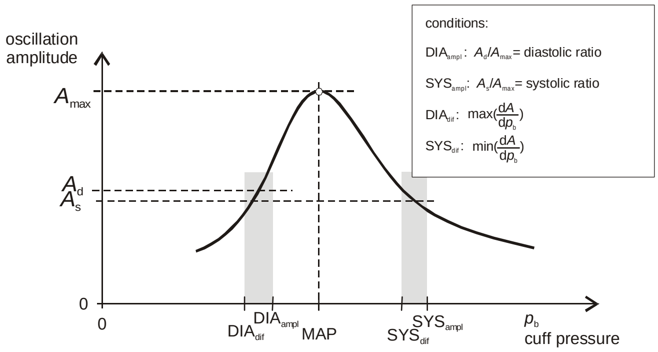

Fig. 3. Pressure oscillations envelope versus cuff pressure and characteristic parameters (DIA, SYS, MAP) determined using two algorithms (amplitude and differential algorithm).

3. VIRTUAL INSTRUMENT (VI) FOR BLOOD PRESSURE MEASUREMENT

Virtual oscillometric NIBP was designed in LabVIEW environment. Its main task was measuring the cuff pressure and determination of SYS and DIA pressure by using a simple amplitude algorithm.

Input parameters of the VI were frequency from pressure transducer (pressure-to-frequency transducer) and values of systolic and diastolic ratios.

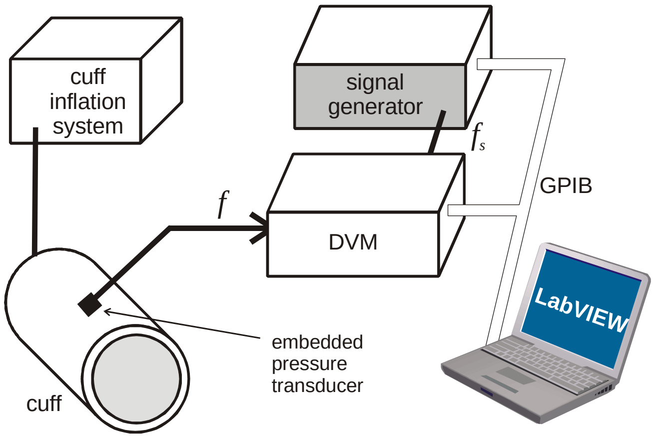

Fig. 4. Measuring set-up

VI controlled a DVM (Agilent, model 3458A), which acquired frequency f of the pressure transducer (output square signal up to 2.7 MHz, 4 V_{pp}) with desired sample rate (f_s). Sample rate was set using external trigger from signal generator (Hewlett-Packard, model HP 33410A). It was found out that 100 Hz sample rate is sufficient for the reliable SYS and DIA detection. Fast enough frequency acquisition was performed using internal memory of the DVM. A simple cuff inflation system (air pump) was used to inflate the cuff to around 20 to 30 mmHg above expected systolic pressure. An air valve was deflating cuff pressure at constant rate 10 mmHg/s. After the completed cuff deflation, the internal memory was read into a data array to the personal computer in form of raw data (see example in figure 2).

Data was processed in LabVIEW environment. It was preconditioned (removing the outliers, preparation for the processing). The oscillations were filtered from the raw signal by using a simple subtractive method. The cuff pressure was fitted by a linear function and thus the negative pressure ramp was gained (figure 5).

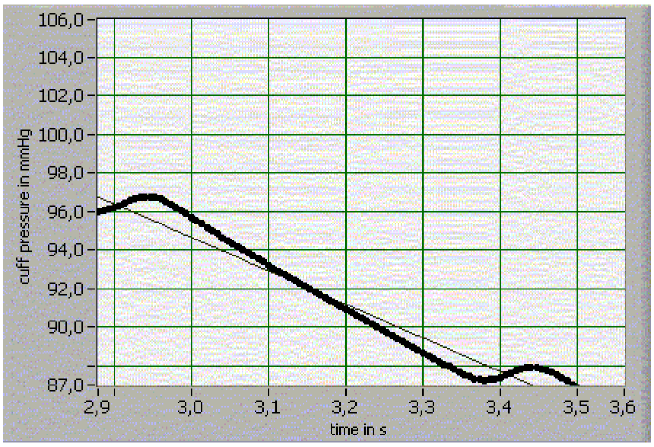

Fig. 5. Fitting the cuff pressure curve (thin line represents linear fit). The solid line represents the raw acquired signal (two oscillation peaks showed).

The ramp was subtracted from the acquired raw signal, resulting in a time dependant function of the oscillations' amplitudes (figure 6). From figure 5 it can be observed, that filtering using the fitted ramp is not equivalent to subtracting the base cuff pressure (cuff pressure as it would be without BP oscillations) from the acquired signal. It forms a certain averaging, resulting in waveform shown in figure 6.

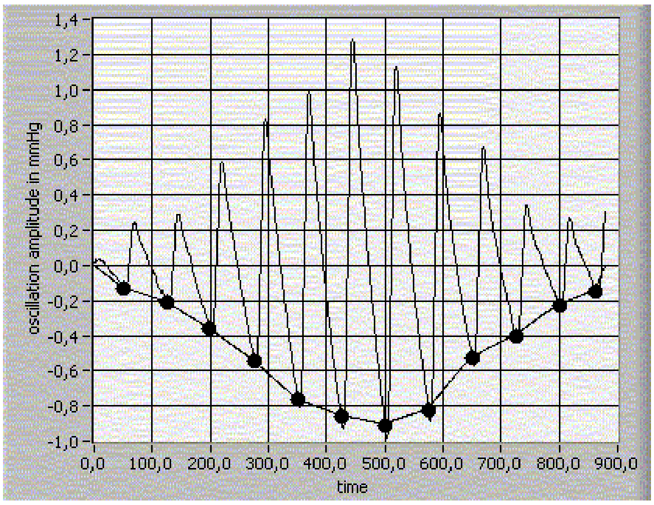

Fig. 6. Resulting graph of oscillations amplitude versus time (in tens of miliseconds) after subtraction the negative cuff pressure ramp from the raw signal and before conditioning process.

Commonly, there are three main possibilities of conditioning the oscillation amplitudes; peak-to-peak oscillation amplitude, function of partial or full time-integral of the oscillometric pulses and baseline-to-peak oscillation amplitude [6]. In our work due to simplicity we decided on the latter (figure 7).

Outputs of the virtual instrument were systolic and diastolic pressures (SYS and DIA), MAP pressure, graphs of the cuff pressure oscillations, and oscillations envelope shape. In-time conditioning was included, enabling manual improvement of the shape of envelope to exclude errors due to incorrect sampling process, motion artefacts, tremor or cardiovascular abnormalities during the measuring period, etc.

Before using the VI to measure BP, its main parameters (systolic and diastolic amplitude ratio) were adjusted using a patient simulator.

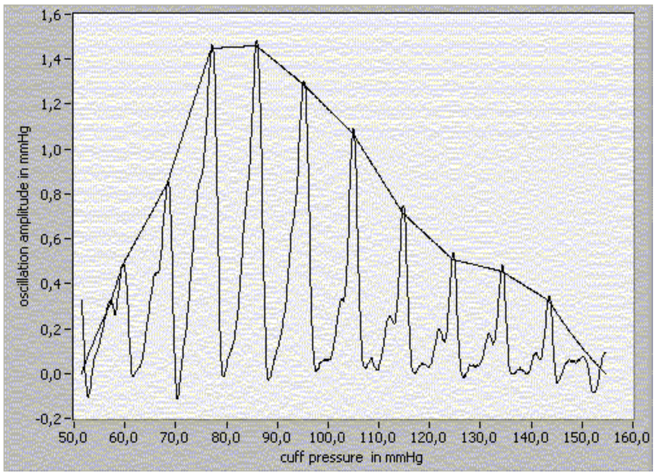

Fig. 7. Digital envelope detection of a real person's blood pressure measurement. Using a differential algorithm the SYS and DIA determination would be very complex, oppose to relatively simple and robust amplitude algorithm.

3. EXPERIMENT AND RESULTS

The main processing part of the virtual instrument was oscillation envelope detection. Since from this envelope systolic and diastolic pressures are calculated, detection of the oscillation envelope is of importance for measurement uncertainty and error. It can be problematic, especially regarding very common non-regularities and sensitivities to extraneous factors in measuring such a physiologically variable parameter as blood pressure.

Our virtual instrument was adjusted using a non-invasive blood pressure simulator (Clinical Dynamics, model SmartArm). This simulator can generate simulated oscillation signals, dependant on specified blood pressure and superposed on base cuff pressure negative ramp. The main advantage of such an electromechanical pressure generator is repeatability of its output. Thus, in order to determine the proper systolic and diastolic ratio simulator repeatability was used.

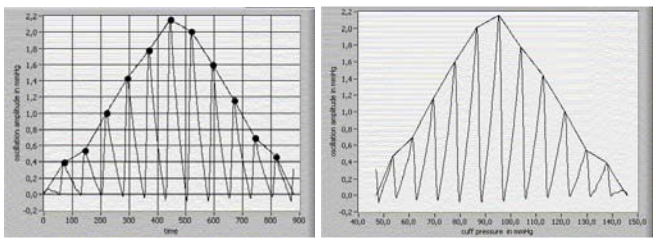

Fig. 8. Oscillation envelope shape when using patient simulator. Left - detection of peak values in baseline-to-peak oscillation amplitude waveform (detected peaks are presented as black dots). Right - digital envelope detection of a simulated blood pressure measurement. Envelope detection results in a graph of the oscillations amplitude versus base cuff pressure. MAP, systolic and diastolic blood pressures are determined from this envelope.

Since the simulator generates oscillations of artificial shape (see figure 8), test measurements on real person were also performed. These tests were done by comparison to an inexpensive self-measurement home NIBP device (Omron, model M5-I, passed validation according International Protocol of the European Society of Hypertension [7]).

Table 1. Comparison of an inexpensive HNIBP and the built virtual instrument (VI) using a patient simulator (SA), set to 120/80 mmHg. Third row shows the average value, fourth row shows standard deviation of 12 measurements. HNIBP had no MAP indication. All values in mmHg.

SYS			DIA			MAP	
SA	HNIBP	VI	SA	HNIBP	VI	SA	VI
120	116,4	116,3	80	77,5	77,5	93	94,0
0	0,5	0,5	0	0,7	0,7	0	2,0

In case of using the simulator, standard deviations of virtual instrument were comparable to the one of commercial HNIBP, indicating that even a very simple amplitude algorithm was robust enough for the device to measure accurately. When on the other hand measuring a real person, the standard deviations of both devices were again of the same order, but increased by more than 3 times compared to simulator case, clearly showing the physiological variability of the BP. In our further tests, when setting different BP of the simulator, the average difference of the HNIBP and VI against simulator was never larger than 5 mmHg and average HNIBP-VI difference and standard deviation was less then 1 mmHg.

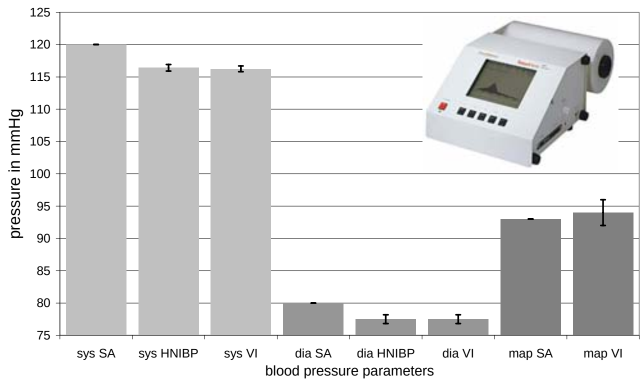

Fig. 9. Results of comparison of MAP, SYS and DIA for the built virtual instrument (VI) and a self-measurement device (HNIBP) using a patient simulator (SA). Error bars represent standard deviation of 12 measurements. Standard deviations are comparable, except in case of MAP determination, where VI measured less repeatable.

3. CONCLUSIONS

The main disadvantage of the oscillometric blood pressure measurement method is that only mean arterial pressure (MAP) is determined directly, systolic and diastolic pressures are merely calculated using empirical algorithms and thus prone to sampling, calculative and fitting errors. The method is sensitive to motion artefacts, heart arrhythmias, age-dependant stiffness of arteries, anatomical position of cuff, etc [3, 4].

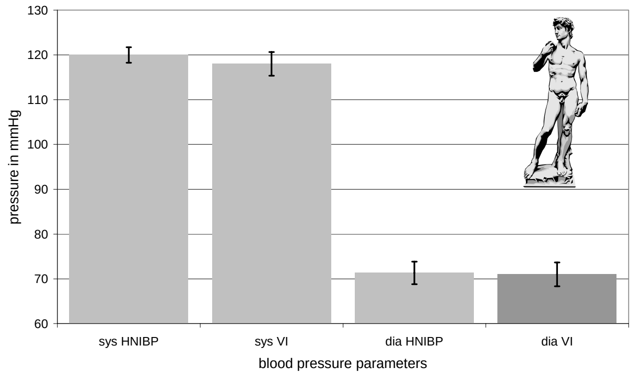

Fig.10. Results of comparison of the built virtual instrument (VI) and a self-measurement device (HNIBP) measuring a real person's blood pressure. Error bars represent standard deviation of 6 measurements. Standard deviations of HNIBP and VI are comparable.

The built VI enables investigating, studying and evaluating different empirical algorithms (an example of this in figure 11). In first tests the designed virtual instrument proved to be a useful tool for parametric analysis of finding the optimal systolic and diastolic ratios with regard to detected SYS and DIA. It enabled analysis of influence of oscillations envelope shape on the SYS and DIA determination. It was proven, that slower deflating rate of cuff pressure would be more appropriate than 10 mmHg/s, since larger number of oscillation peaks would be detected and thus the envelope determined more accurately and uncertainty of SYS and DIA determination would be smaller.

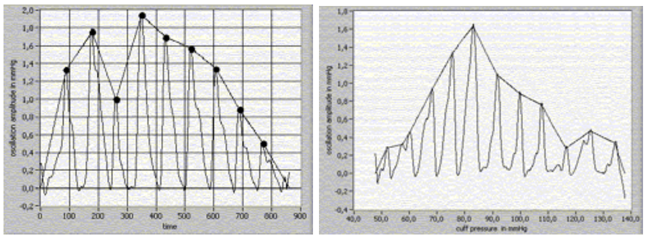

Fig. 11. Two examples of non-regular envelopes, gained by a real person's blood pressure measurement. Left – MAP is not determined correctly, resulting large determination error of SYS and DIA. Right – the resulting SYS was less than 3 mmHg from the displayed value of HNIBP.

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