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REMOVAL OF ARTIFACTS IN THE OSCILLOMETRIC CURVE DURING ARTERIAL BLOOD PRESSURE MEASUREMENT

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Abstract

Arterial blood pressure is one of the most important vital parameters of warm-blooded organisms, directly connected to their survival. This paper presents a method for measuring arterial blood pressure using the oscillometric technique. Algorithms for processing the oscillometric curve are discussed, with particular attention to the removal of parasitic signals recorded during measurement, such as noise and electrical and mechanical artefacts. The determination of systolic and diastolic arterial blood pressure is demonstrated. The proposed method applies to aerospace medical instrumentation for continuous monitoring of arterial blood pressure in pilots and astronauts under extreme operating conditions.

Introduction

Arterial blood pressure (BP) is one of the most important vital parameters of warm-blooded organisms, directly linked to their existence. This applies fully to humans as well. BP is the pressure exerted by blood on the walls of the arteries. Two types of pressure are measured: systolic (SP), the pressure during the contraction of the heart muscle chambers, and diastolic (DP), the constant pressure in the circulatory system during the relaxation of the heart muscle. Normal average statistical values are: 110 to 120 mm/Hg for SP, and 70 to 80 mm/Hg for DP.

Depending on the method used, BP is measured invasively or non-invasively. The invasive method is more accurate but is primarily used in cases of surgical intervention. This method is impractical in daily practice for several reasons, such as the presence of a highly qualified specialist, a sterile environment, or measurement modules often integrated into expensive operating monitors. Non-invasive methods are more widely used in practice. Some of them date back more than 3000 years. Such is the measurement of BP by "palpation" (feeling the pulse with fingers), where, depending on the heart rate and "distinctness of pulsations", 3 to 7 levels of blood pressure can be determined in

China and other Eastern countries. Centuries later, after the invention of the stethoscope, the Russian physician Korotkoff applied a simple and relatively accurate method, which remains one of the most widely used to this day. With the development of technology, a number of other non-invasive methods have been created, such as tonometric, ultrasonic, oscillometric, and temporal methods.

Each of the methods listed above has both advantages and numerous disadvantages, significantly affecting the quality and reliability of the measurements made. Of all the methods mentioned, the oscillometric method is the most widely used in modern practice. The measurement of BP using the oscillometric curve recording method has been described in numerous scientific articles [1, 2, 7].

The purpose of this paper is to demonstrate not only the implementation of an algorithm for processing the oscillometric curve but also the removal of parasitic signals recorded during the measurement, such as pathologies and artefacts of electrical and mechanical origin. These can seriously compromise the accuracy of the final results when determining systolic and diastolic blood pressure.

When measuring BP using the oscillometric method, two measurement approaches are known. Measuring BP after stopping blood flow with controlled release of pressure from the cuff, and measuring during the process of controlled increase of pressure in the cuff until blood flow stops. The second method is better due to the fact that there is no need to control the air release from the cuff, the measurement time is shorter, and the upper limit of the pressure value is accurately determined regardless of the current state of systolic pressure.

Exposition

The measurement process consists of four main phases:

- Increasing cuff pressure until blood flow stops.
- Recording and saving the oscillometric curve.
- Analysing the oscillometric curve and correcting for noise and artefacts.
- Determining the BP (Systolic and Diastolic).

The operating algorithm is shown (Fig. 1).

During the process of increasing cuff pressure (Fig. 2), shown by the red line, the maximum pulsation values caused by turbulence in the blood flow passing through the arteries narrowed by the cuff are recorded. The amplitudes of these pulsations in the cuff are very small, which necessitates the introduction of an AC amplifier with sufficiently high gain and a frequency band of 0.1–10 Hz. The oscillometric curve represents the envelope curve of the maximum values of the pulsations obtained at the output of the amplifier.

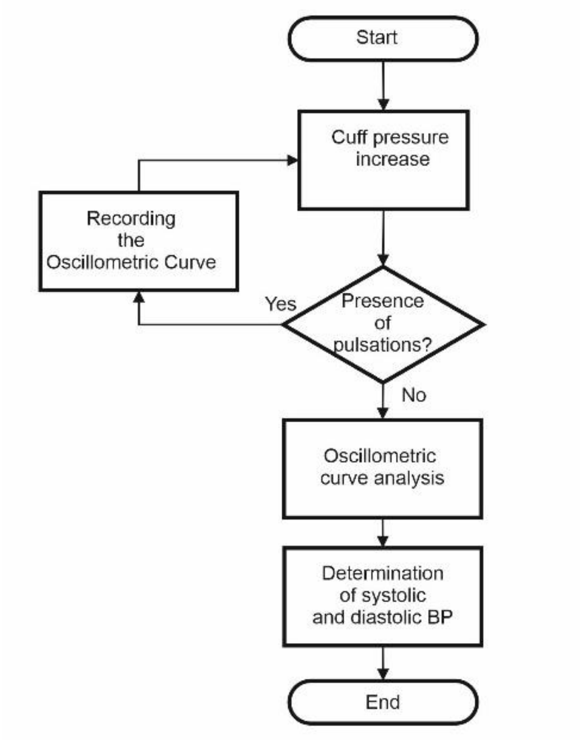

Fig. 1. Algorithm of operation for measuring NIBP using the oscillometric method

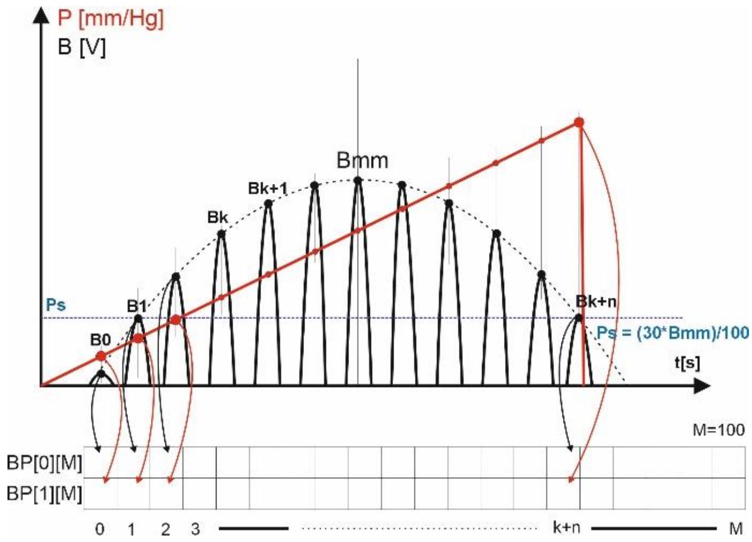

Fig. 2. Algorithm for recording the oscillometric curve

For each registered local maximum, the cuff pressure value is recorded. The data is stored in a two-dimensional array *BP[2][M]*, where M is taken as $M = 100$. The first row of the array *BP[0][M]* stores the maximum amplitude values of the registered pulsations, B_0 to B_n, and the second row *BP[1][M]* stores the instantaneous cuff pressure for each maximum. During the process of registering and recording each pulsation, B_k, B_{mm} (the pulsation with the largest amplitude among all registered pulsations) is determined. The instantaneous pressure associated with the maximum of this pulsation determines the mean blood pressure parameter. After B_{mm} is registered, the pulsation amplitudes decrease due to the increase in cuff pressure and the closure of the arterial lumen in the measurement area. When an amplitude B_{k+n} less than 30% of B_{mm} is reached, the pressure increase is stopped, the valve opens, and the cuff pressure becomes zero, which completes the recording of the oscillometric curve.

After the maximum values of the registered pulsations and their associated pressure are recorded, the pulse curve is analysed. In real conditions, the amplitude often does not increase/decrease smoothly (depending on whether the cuff pressure is below or above the mean arterial pressure, P_{mm}). This can be caused by ventricular extrasystoles, characterised by the generation of a large amplitude, as well as artefacts due to movement during the measurement. The presence of signals with amplitudes that disrupt the bell-shaped nature of the envelope curve can corrupt the measurement and lead to incorrect results. Fig. 3 shows such a disturbance for pulsation B_k in red and blue, which disrupts the nature of the envelope curve. To eliminate such parasitic signals, an amplitude analysis is applied to all recorded values in the array *BP[0][M]*.

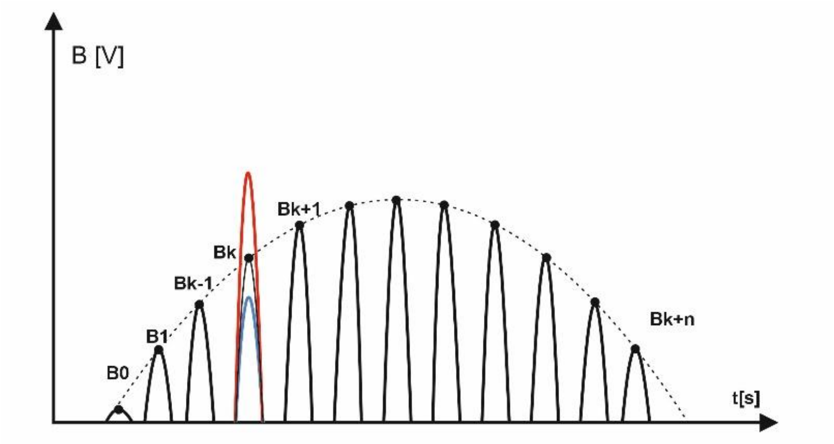

Fig. 3. Artefact and interference removal

Provided that:

(1) $B_k \geq B_{k+1} \cup B_k \leq B_{k-1}$

The value of B_k is determined by the expression:

(2) $B_k = \frac{(B_{k+1}+B_{k-1})}{2}$

After checking and correcting the amplitudes of the pulse curve, the systolic and diastolic pressure values are determined. The systolic pressure is taken as the pressure corresponding to a pulsation in the array with an amplitude of 0.5 of B_{mm}. The processing of the *BP[0][i]* array is carried out in the region for $i_{B_{mm}} < i < 100$. The calculated systolic pressure must satisfy condition (3), where P_{sys} is equal to the associated pressure for a pulsation belonging to the right half of the oscillometric curve with pressure greater than P_{mm} and amplitude 0.5(B_{mm}).

(3) $P_{sys} = 0.5(BP[1][\ i_{Bmm}\ ])$ като $B_s = 0.5(BP[0][\ i_{Bmm}\ ])$

The determination of diastolic pressure is carried out after analysing the left half of the oscillometric curve, i.e. for all indices of the *BP[0][i]* array, where $0 \leq i < i_{Bmm}$. Diastolic pressure must be less than P_{mm} and satisfy condition (4):

(4) $P_{dia} = 0.65(BP[1][\ i_{Bmm}\ ])$ като $B_s = 0.65(BP[0][\ i_{Bmm}\ ])$

Usually, the *BP[0][M]* array does not contain amplitudes with the desired values. Assuming the closest values that satisfy condition (3) for systolic and (4) for diastolic pressure would lead to significant errors. For this reason, interpolation is necessary to determine both the desired amplitude for the respective pressure and the associated static cuff pressure.

Discussion of results

To simplify the task, it is assumed that the amplitude changes linearly between two adjacent pulsations of the oscillometric curve. The processing of the recorded data in the BP array starts from the index with the largest value, $i = M$, corresponding to the highest cuff pressure (Fig. 4). The most general case is considered, in which the desired amplitude B_s, corresponding to the systolic pressure, falls between the values of the amplitudes B_k and B_{k+1}. The section of the envelope curve to the left of B_{mm}.

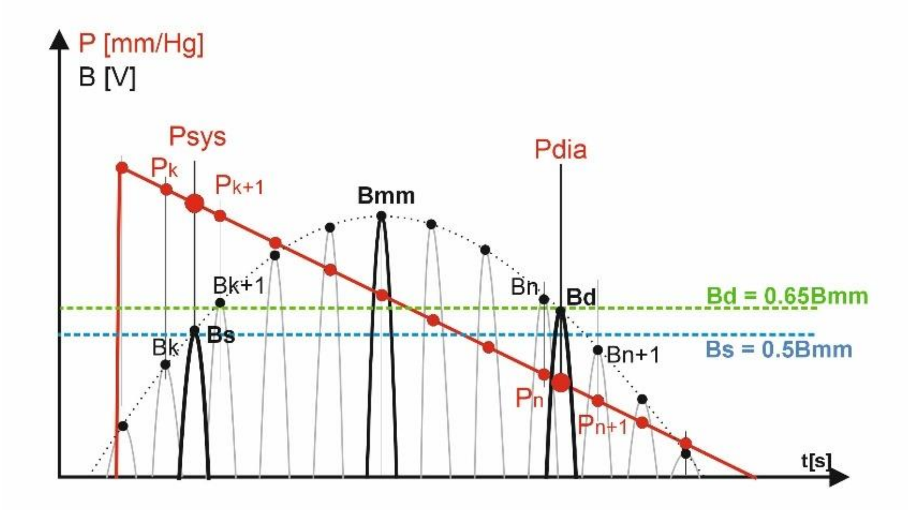

Fig. 4. Determination of systolic and diastolic BP

Then conditions (5) and (6) are valid for B_s and P_s, with processing carried out from the B_{mm} index to the end of the *BP* array.

(5) $$B_k < B_s < B_{k+1}$$

(6) $$P_k > P_s > P_{k+1}$$

An interpolation step Δ_b is adopted, which is determined by expression (7).

(7) $$\Delta_b = \frac{(B_{k+1} - B_k)}{100}$$

For the desired pulsation with amplitude B_s, the number of increments N added to B_k is determined.

(8) $$N = \frac{(0.5(B_{mm}) - B_k)}{\Delta_b}$$

where:

(9) $$B_s = B_k + N\Delta_b$$

The same number N (8) of interpolation steps must be applied for the pressure in the range (P_k, P_{k+1}). For this purpose, the interpolation step (10) in the pressure range is determined:

(10) $$\Delta_p = \frac{(P_k - P_{k+1})}{100}$$

The systolic pressure is obtained from dependence (11).

(11) $$P_{sys} = P_k - N\Delta_p$$

Diastolic pressure is determined similarly, but it should be noted that the analysis of the pulsation amplitudes recorded in the *BP* array is performed from index *0* to index B_{mm}, i.e. $0 \leq i < i_{Bmm}$.

For B_d and P_d, conditions (12) and (13) apply.

(12) $$B_n > B_d > B_{n+1}$$

(13) $$P_n > P_d > P_{n+1}$$

The interpolation step is accepted Δ_b, defined by the expression (14).

(14) $$\Delta_b = \frac{(B_n - B_{n+1})}{100}$$

The desired pulsation with amplitude B_d is determined by the number of increments *N* added to B_{n+1}

(15) $$N_{dia} = \frac{(0.65(B_{mm}) - B_{n+1})}{\Delta_b}$$

The same number N_{dia} (15) of increments must also be applied to the pressure in the range P_n — P_{n+1}. For this purpose, the interpolation step (16) in the pressure range is determined:

(16) $$\Delta_p = \frac{(P_n - P_{n+1})}{100}$$

Diastolic pressure is determined by the dependence:

(17) $$P_{dia} = P_{n+1} + N\Delta_p$$

Conclusion

During the reference measurements performed using the Korotkoff method (with a stethoscope and sphygmomanometer), as well as with a TRANSTEK device operating on the oscillometric method principle, measurement deviations of +5/-4 mmHg for systolic and +2/-3 mmHg for diastolic pressures were achieved, from which it can be concluded that the described measurement method allows for reliable and accurate determination of blood pressure. The reviewed algorithms have been applied in various devices and have shown good results. The described algorithm has been implemented at the Oxylife Sofia medical centre, on the BeOn1 psychophysiological research equipment, and in a bilateral stimulation system for treating post-traumatic stress.

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ОТСТРАНЯВАНЕ НА АРТЕФАКТИ В ОСЦИЛОМЕТРИЧНАТА КРИВА ПРИ ИЗМЕРВАНЕ НА АРТЕРИАЛНОТО КРЪВНО НАЛЯГАНЕ

С. Танев

Резюме

Артериалното кръвно налягане е един от най-важните жизнени параметри на топлокръвните организми, пряко свързан с тяхното оцеляване. Тази статия представя метод за измерване на артериално кръвно налягане с помощта на осцилометричен метод. Обсъждат се алгоритми за обработка на осцилометричната крива, като особено внимание се обръща на премахването на паразитните сигнали, записани по време на измерването, като шум и артефакти от електрически и механичен произход. Демонстрирано е определянето на систолното и диастолно артериално кръвно налягане. Предложеният метод е приложим в аерокосмическа медицинска апаратура за непрекъснат мониторинг на артериалното кръвно налягане при пилоти и космонавти изпълняващи дейности в екстремни условия на работа.