Detection of special points in a photoplethysmogram

V.Yu. Gribkov, I.B.Isupov, R.Sh. Zatrudina,
Volgograd State University, Russia

The problem of detecting special points of photoplethysmograms

The aim of the study is to develop a reliable algorithm for searching for special points of photoplethysmograms - the systolic peak B2, the dicrotic notch B3, the diastolic peak B4 - in the context of automating the contour analysis to optimize the functional diagnosis of vascular disorders.

The severity of the dicrotic notch B3, and especially diastolic peak, depending on the individual characteristics of the subject, can be very different : from clear, easily identifiable areas of the PPG contour in young, trained people (Fig.1a), to barely noticeable changes in the steepness of the decline of the pulse cycle in the elderly or in subjects with a pronounced predominance of sympathetic influences on the cardiovascular system (Figure 1.b)

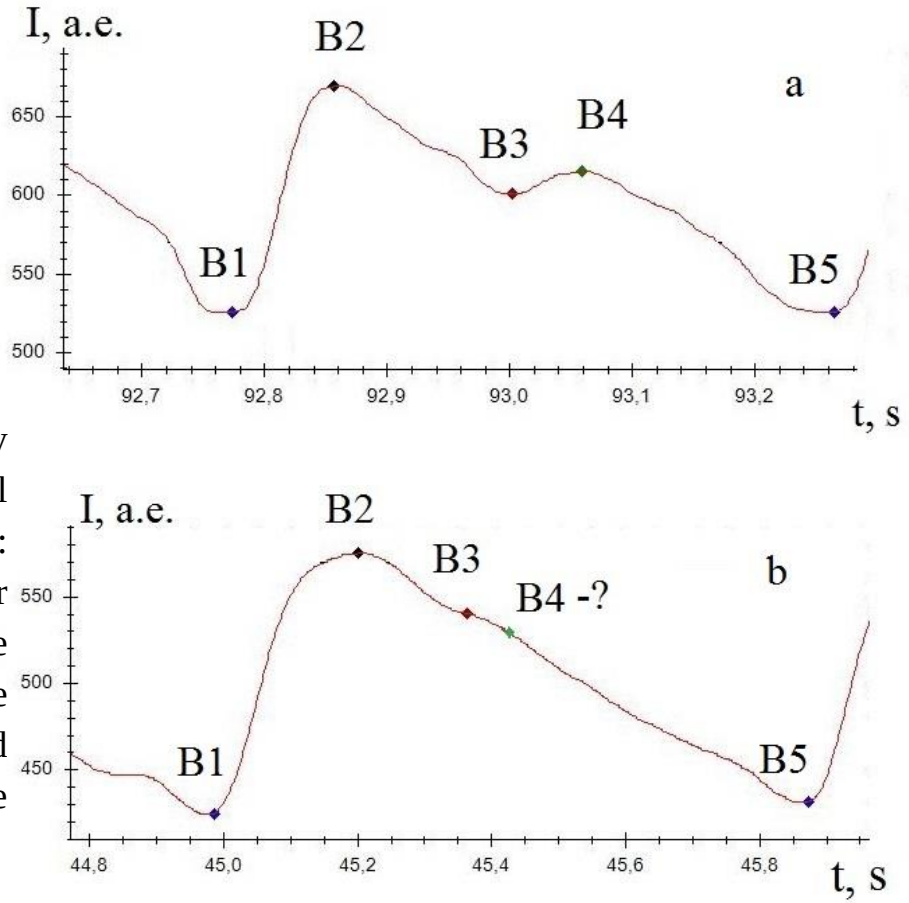


Figure: 1. The shape of the pulse cycle with a pronounced diastolic peak (a) and no peak (b).

Materials and research methods

As the object of the study, we used photoplethysmograms with a duration of ~ 300 s, recorded in 31 practically healthy volunteers under various conditions and under various loads. The sampling rate is 600 points per second.

Each photoplethysmogram was divided into separate pulse cycles - 1665 samples of pulse cycles.

At each pulse cycle, the positions of the special points are determined:

- the systolic peak (B2),
- the dicrotic notch (B3),
- the diastolic peak (B4)

Histograms showing the statistics of the position of special points relative to the beginning of the pulse cycle are shown in Fig. 2. Most of the points are located in a fairly narrow time range: B2 - from 90 to 170 ms, B3 - from 250 to 370 ms, B4 - from 300 to 450 ms.

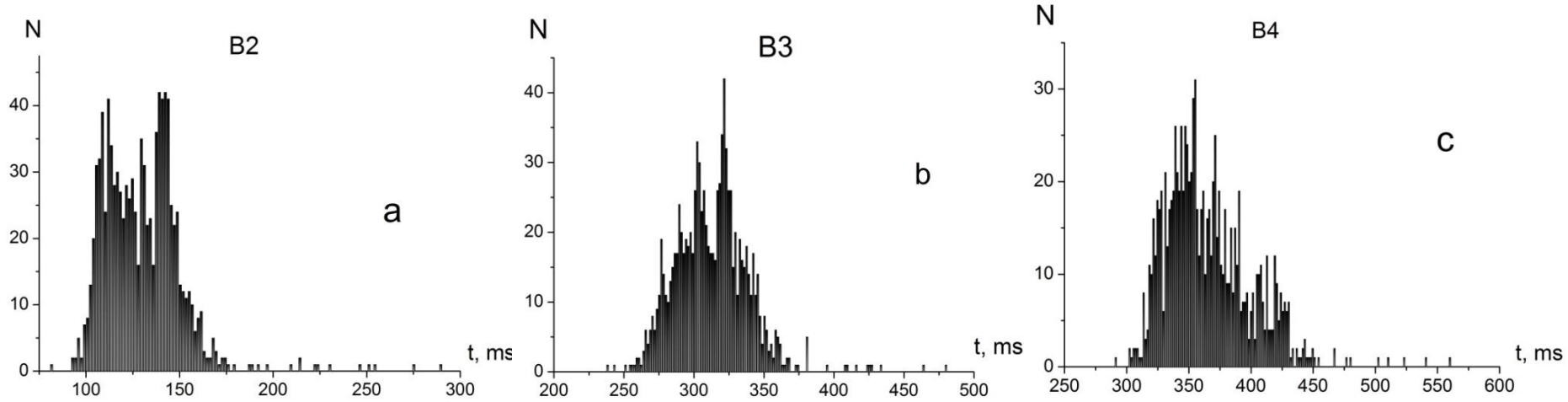


Figure: 2. Statistics of the position of the points relative to the beginning of the pulse cycle. a - Position of the systolic peak B2, b - position of the dicrotic notch B3, c - position of the diastolic peak B4.

Approximate relationship of the position of the singular point with the duration of the pulse cyclea

The relationship between the position of the special point and the duration of the pulse cycle can be approximately described by a polynomial of any order. To assess the quality of the description of the statistical dependence by polynomials of the first, second, and third orders, we use the unnormalized root-mean-square error.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N=1665}\left(x_{i\,exp} - x_{i\,num}\right)^2},$$

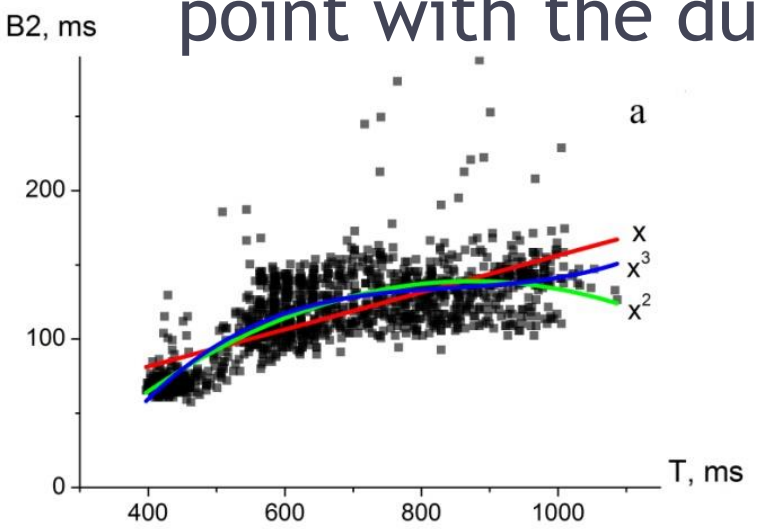
, $x_{i\,exp}$ - the real time of the location of the special point,
$x_{i\,num}$ – time calculated by a polynomial.

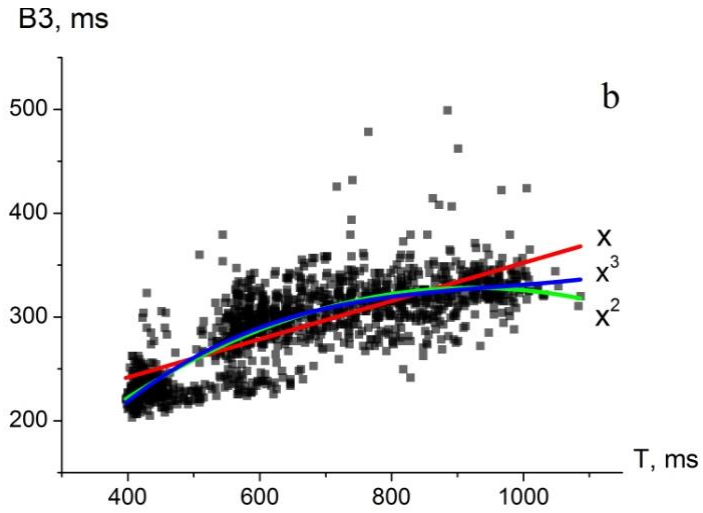
The polynomial coefficients and the minimum unnormalized root-mean-square error are presented in Table 1

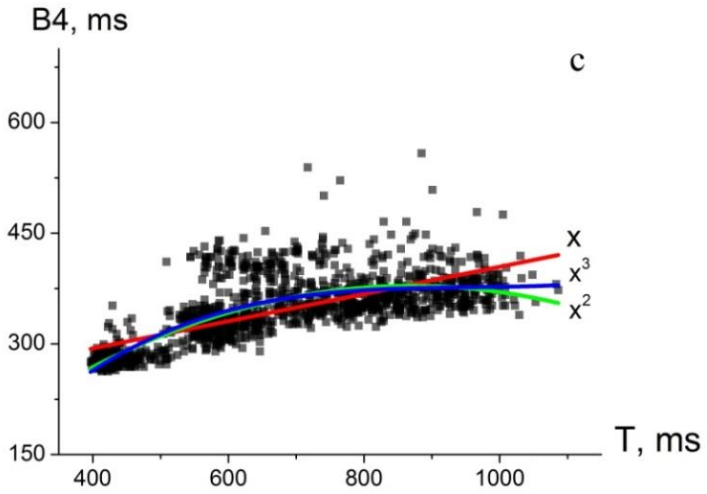
Polynomial order	Polynomial type	Unnormalized root-mean-square error (seconds)
Position of the systolic peak B2		
1	$f(x) = 0.125 * x + 19.77$	11.93
2	$f(x) = -5.273E^{-4} * x^2 + 0.576 * x - 70.56$	10.58
3	$f(x) = 1.78E^{-6} * x^3 - 0.00283 * x^2 + 1.528 * x - 195.6$	10.41
The position of the dicrotic notch B3		
1	$f(x) = 0.184 * x + 137.58$	15,77
2	$f(x) = -6.15E^{-4} * x^2 + 0.71 * x - 0.163$	14,41
3	$f(x) = 1.214E^{-6} * x^3 - 0.00219 * x^2 + 1.36 * x - 85.474$	14,35
The position of the diastolic peak B4		
1	$f(x) = 0.184 * x + 105.18$	18,76
2	$f(x) = -7.97E^{-4} * x^2 + 0.867 * x + 1.053$	16,82
3	$f(x) = 1.614E^{-6} * x^3 - 0.00289 * x^2 + 1.73 * x - 112.35$	16,73

Table 1. Polynomials and unnormalized root-mean-square error *describing the position of the PPG sipecial points.*

Approximate relationship of the position of the singular point with the duration of the pulse cycle







The red, green and blue lines in Fig. 3 denotes polynomials of the first, second and third order, respectively, in the best way, with the smallest unnormalized root-mean-square error, describing the presented dependence.

Fig. 3. The position of the special points of PPG, depending on the duration of the pulse cycle. a - dependence of the systolic peak B2, b - dependence of the dicrotic notch B3, c - dependence of the position of the diastolic peak B4. The red line corresponds to the polynomial of the 1-st order, green – 2nd order, the blue – 3rd order.

Exact value search results

To find the exact values, we will use the following simple approach.

In the vicinity of the found approximate points, we will look for the zeros of the derivative of the PPG. Vicinity mean the deviation of the value from the mean by 2σ. The zeros of the derivative of the photoplethysmogram will correspond to the position of the singular points. In the case when the zero of the derivative of the photoplethysmogram is absent in the vicinity, i.e. in the case when the diastolic peak is not observed (point B4), we are looking for the maximum value of the derivative in this time interval. It corresponds to the inflection of the photoplethysmogram , which is as close as possible to the diastolic peak.

To compare the calculated positions of the singular points with the control values, we will use the mean relative error

$$MRE = \frac{1}{n}\sum_{i=0}^{n}\frac{\left|t_i - t_{ref,\ i}\right|}{T_i}$$

where n – the number of samples, T_i – the duration of the i-th pulse cycle, t_i – the calculated position of the special point, $t_{ref,\ i}$ – the true position of the special point.

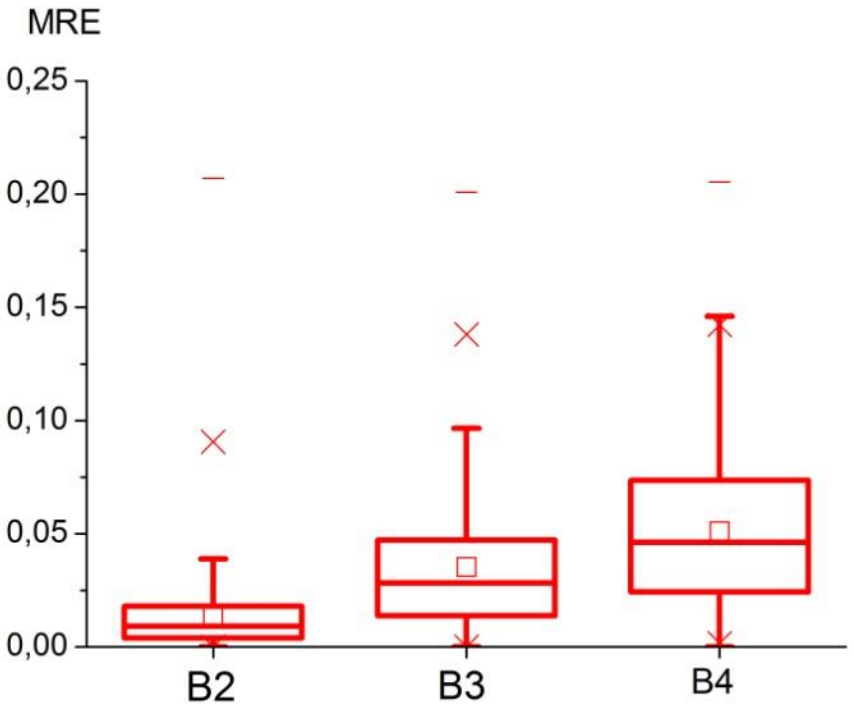


Fig. 4. Mean relative error (MRE) values for finding the singular points B2, B3, B4 using the statistical algorithm. The block plot shows the distribution of MRE values, with the lower quartile, median, and upper quartile values displayed as horizontal lines on the left, middle and right. Whiskers are used to represent extreme values within 1.5 times the center-cell spacing. Outliers (data with values outside the whiskers) are displayed as crosses. Squares represent mean values. The short lines are the highest values.

Conclusion

- A new method for analyzing the contour of photoplethysmograms of the distal phalanx of the human index finger using the methods of mathematical statistics is presented.
- The statistics of the position of special points on pulse cycles of various durations (from 400 ms to 1100 ms) are presented.
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Thank you for attention