Visualization and Off-line Processing of Blood Pressure Signals

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Abstract: In the public health care it is very common that microcontroller calculates the result of oscillometric blood pressure measurements. In this case the result can be imprecise; it does not inform the patient and the doctor accordingly. The recordings collected by the microcontroller can be sent to an application which runs on a PC. The recording can contain only one measurement or sequence of measurements created during 24 hours. The advantage of the PC side application is that it can use more memory and processor capacity, so it is faster and more precise. The task of the application is to calculate and visualize the values of blood pressure. The application determines the values of the blood pressure based on an oscillometric blood pressure algorithm. The application visualizes the result of each step of the algorithm. The algorithm decides whether the result is acceptable and authentic based on the characteristic of the recording. The other part of the application helps in the validation. It executes the algorithm on mass of the recordings which have result of reference measurement. The application shows the differences between the results of the algorithm and the values of reference. The application helps to qualify the algorithm according to the international standards. The application works well under laboratory circumstances. But application needs further validation so that it can be put to the market.

1 INTRODUCTION

Nowadays the blood pressure measurement is one of the most common techniques to characterize the condition of the patient. The blood pressure measurement helps to diagnose the hypertension and the hypotension. The examination and treatment of the deviation can discover or prevent diseases like stroke, heart attacks, heart failure, aneurysms of the arteries, peripheral arterial disease, chronic kidney disease, hormonal changes, anemia, endocrine problems, etc. The values of the blood pressure during an operation reflect the status of the patient. The blood pressure can be measured in many ways. There are two main groups of the methods: the invasive and the non-invasive. The invasive techniques are complicated to use, so the general public uses the non-invasive techniques. The main common methods are the auscultatory and the oscillometric. Both of them are suitable to measure blood pressure easily, painlessly without any risk under domestic circumstances.

In this article we use only an oscillometric method. In the next sections we describe an application of the Cardiospy of Labtech Ltd, Hungary. The Cardiospy system is built above all for cardiologists, and medical scientists; it is used by many hospitals in Hungary and other countries. The system is very simple and user friendly. It has many functions which help recognize and manage the cardiovascular illnesses (Labtech, 2013). Blood pressure module named BP Service visualizes the result of the steps of an oscillometric method. The next sections describe the used method, and the visualization of each step. In the last section we describe an application which makes the validation easier.

2 OSCILLOMETRIC METHOD

In the case of the oscillomteric method, there is a sensor built in the cuff. The sensor perceives the pressure of the artery and the cuff. After we remove the pressure values caused by the deflation of the cuff we get an oscillation waveform, the oscillogram. First the changes of the pressure on the waveform increase, then decrease. The oscillometric method calculates the value of the systole (SP), the diastole (DP) and the mean arterial pressure (MAP) based on the changes of the pressure on the oscillogram (Ball-llovera et al., 2003) (Wang et al., 2002) (Lin, 2007).

Figure 1 shows an example of the cuff pressure curve and the corresponding oscillometric waveform.

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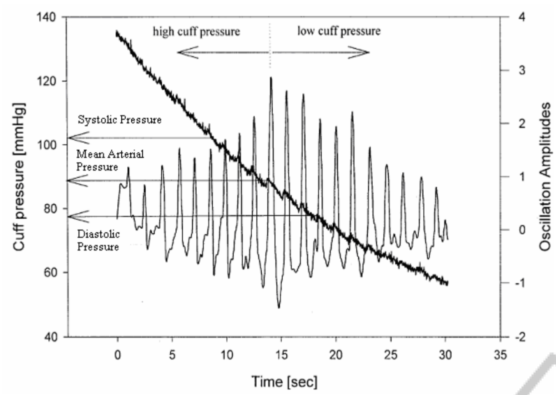

Figure 1: Cuff pressure signal and oscillation waveform (Lin et al., 2003), (Lin, 2007).

The values of blood pressure can be determined based on the cuff press curve at a given point. The method determines the point of the systole, the diastole and the mean arterial pressure. The point of the mean arterial pressure is the maximum point of the oscillogram. There are two algorithms to determine the point of the systole and the diastole: the height-based method and the slope-based. The slope-based method fits a curve to the changes of cuff pressure. The method specifies the inflection point of the curve as the points of systole and diastole (Ball-llovera et al., 2003) (Sapinski, b) (Lin, 2007). The height-based algorithm has two previously given ratios, one of them for the systole, the other for the diastole. The two ratios are not necessarily the same. The pressure change at the point of mean arterial pressure is 100%. The method finds the point where the pressure change corresponds to the given ratio. The point of systole is before the mean arterial pressure, the diastole is after it (Ball-llovera et al., 2003) (Lin et al., 2003) (Lee et al., 2001) (Lin, 2007).

The values of the ratio are not exactly determined. It depends on the realization of the oscillometric algorithm. Most researchers take these values between 40% and 60% (Ball-llovera et al., 2003) (Lin, 2007) (Sapinski, a)(Geddes, 1991).

The oscillometric method is realized in many ways, like prediction and smoothing algorithm, fuzzy logic, neural network, pattern recognition, mathematical modelling, etc (Lin, 2007). We based our method on the oscillometric method of Aboy (Aboy, 2011). The main difference between the article and our method is that we fit one polynomial instead of two wrapping curves. The polynomial curve is used by Zheng (Zheng et al., 2011).

3 THE MAIN STEPS OF OUR OSCILLOMETRIC METHOD

The input data is an oscillometric recording which is created by a microcontroller during blood pressure measurements. It is an C8051F064 mixed-signal MCUs of Silicon Laboratories. It is a reliable high-speed 8051 architecture MCU with two 16-bit ADCs. It has 64kB Flash memory which is in-system programmable in 1kB sectors and it has 4kB data RAM. The recorded data is stored on the micro SD card.

During a measurement the deflation of the cuff pressure is continuous. One recording can contain only one measurement or sequence of measurements created during 24 hours.

1. The algorithm splits the recording into measurements. It processes only one measurement at a time.
2. It finds the beginning of the deflation. It processes the part of the measurement after the deflation.
3. The algorithm creates an oscillogram based on the measurement using a band-pass filter.
4. The algorithm finds the local minimum and maximum points and values.
5. It creates a histogram from the local extrema. The histogram shows the change of the cuff pressure at a minimum point.
6. The algorithm fits a wrapping curve which is a polynomial to the histogram.
7. It determines the SP and the DP both height-based and slope-based.
8. Based on the character of the measurement it gives information whether the result is acceptable or not. In the result of the algorithm there is a sign which shows that the blood pressure values are acceptable, not acceptable, or they can be accepted only after manual analyzing.

4 BP SERVICE VISUALIZATION INTERFACE

The BP Service realizes a unified, structured, and interactive data visualization. The user can turn various data elements on and off using controls. If a control is set the surface is drawn again in an interactive way. The BP Service uses the results and the data of other modules of the Cardiospy system (e.g.: ECG, auscultation blood pressure). On the surface they appear, but they are not relevant to the topic of the article. We use colors on the surface to distinguish the curves, the

Figure 2: The parts of the visualization interface.

lines, and other information. E.g. the curve of the cuff press is green, the oscillogram is yellow. The visualization surface can be divided into 4 main parts based on functions. (Figure 2) These are: 1. the panel for displaying the results, 2. the canvas, 3. the buttons, 4. the oscillometric control page.

4.1 The Panel for Displaying the Results

The panel displays the results of the blood pressure measurement. After the label of Calculated BP there is the serial number of the actual measurement of the recording and the number of the measurements in the recording. There are three rows which show the blood pressure values. The first blue row shows the results of the auscultatory results, the second yellow one shows the oscillometric results, and the third black one shows the manual reference values. All the three rows contain the SP, the DP, the MAP and the heart rate. If the item of recording has no reference values the third black row contains 0 values.

4.2 The Canvas

This unit visualizes the data. There are two panels. The upper panel displays the data of the whole measurement from the beginning of the inflation of the cuff to the end of the deflation. The lower panel gives an enlarged picture of gray stripe of the upper panel. There are two scrollbars between the two panels. If the upper scrollbar is changed, the picture jumps to the next or the previous measurement of the recording. If the lower scrollbar is scrolled the gray stripe moves, so the user can navigate in the measurement to analyze the parts of the curves.

The canvas visualizes the data of each step of the blood pressure algorithm. These data are the next:

- Cuff pressure: The waveform of it is drawn by green color on both panels of the canvas.
- Oscillogram: it is drawn by yellow color on both panels of the canvas.
- Histogram: It is drawn by orange only on the upper panel of the canvas. The point of each item of the histogram is accurate at the point of the local minimum of the oscillogram. The height of each item of the histogram shows the size of the press change.
- Wrapping curve: It is drawn by pink on the upper panel of the canvas. The wrapping curve is a polynomial, which fits to the points of the histogram.
- SP and DP: The systole and the diastole are visualized by red. The systole is represented by the beginning point of the red part on the wrapping curve. The diastole is represented by the end of the red part. The algorithm calculates the SP and DP in both ways: height-based and slope-based. Our algorithm works better with the height-based method. So the application visualizes the height-based results.

On the two panels of the canvas there are scales. On the right side of the upper panel there is a yellow scale which belongs to the histogram. It has six grades with equal distances. On the right side of the lower panel there is an orange scale which belongs to the oscillogram with eight grades. On the left side of both panels there is a green scale, which belongs to the cuff press with six grades. The scales help the user to read the values of the cuff press, the oscillogram and the histogram. The units of the scales is mmHg. The scales are static, because the grades are fixed. The scales are dynamic, because the values of them are counted based on the values of each object.

The surface is interactive. This means, if the user changes something on the surface, the results are intermediately shown. If the user changes the zoom of the canvas with the Track Bar on the Control Page, the curve of the cuff press, the oscillogram, the histogram are dynamically redrawn and the values of the grads on the scales are also recounted. If the ratio of the height-based method changes, the SP and DP are recounted and the red part of the wrapping curve also changes.

In the point of the mouse there is a rectangle on the canvas. In the rectangle there is information about that point. This information is the cuff pressure, the time passed from the beginning of the inflation and the height of the oscillogram. If the mouse moves the values are recalculated.

On the canvas there is a red vertical line. It shows the exact place of the mouse horizontally. If the user moves the mouse the red line goes together with it. The line helps the user to find the points of the cuff press, the oscillogram and the histogram are connected together. The user can examine the connection of the three objects.

4.3 The Buttons

The user can navigate to the previous and the next measurement in the recording with the ”Prev” and the ”Next” labeled buttons. The ”Validation” button executes the validation application.

4.4 The Oscillometric Control Page

On this page the user can control the visualization of data of the oscillometric algorithm. The Oscillometric named Control Page is divided into five main parts as Figure 3 shows.

1. With four Check Boxes the user can turn the curves on the canvas off or on. Each Check Box represents the oscillogram, the histogram, the wrapping curve and the red part of the wrapping curve representing the systole and the diastole.
2. The part of the Control Page shown by number 2 connects to the height-based method. There are two Spinners, which show ratios of the height-based method. If the user changes these values

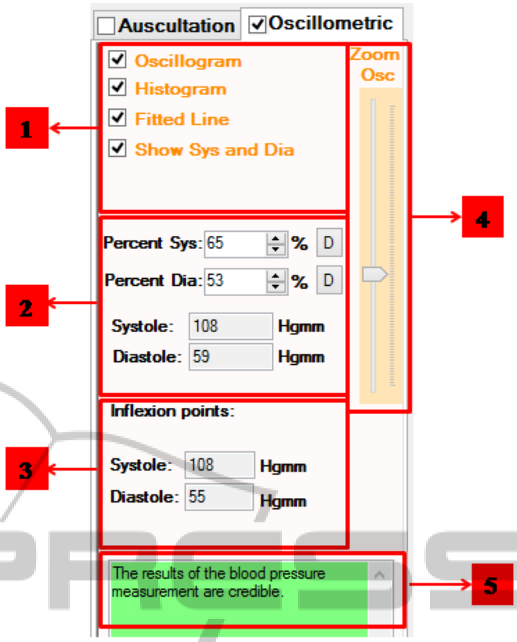

Figure 3: Oscillometric Control Page.

the SP and the DP are refreshed. The range of the Spinners is 0..100. There are two Buttons next to the Spinners which restore the default ratios. In the two Text Boxes there are the SP and the DP calculated by the height-based method.

3. This part shows blood pressure result of the slope-based method.
4. If the user changes the Track Bar the curves on the canvas are vertically enlarged or diminished.
5. The green panel gives information to the user about the results of the process of acceptability and the authenticity.

4.5 Acceptability and Authenticity of the Results

The algorithm gives information about the recording. If the recording is very noisy the algorithm recognizes it. In this case the algorithm may give results, but it can be useless and not authentic information. If the algorithm decides that the recording is very noisy the application shows a white, empty text on the Control Page, the SP and the DP are 0, and there is a big red sign in the right upper corner on the surface which warns the user that the recording is ”INVALID”.

The measurement of the recording can be incomplete because the microcontroller has finished the recording earlier. In this case the algorithm tries to give results. If there is not enough data in the measurement a big red flash sign appears in the right upper corner on the surface which shows that the measurement is a "BAD RECORDING".

If the algorithm gives results, it may be unbelievable. Lackovic (Lackovic, 2003) says the systole has to be in the range 50 and 280 mmHg, the diastole in the range 40 and 140 mmHg. The difference between them has to be at least 10 mmHg. If the result satisfies the previous condition on the Control Page the green panel gives information about it. If the result is near the limitation of the conditions or the wrapping curve is very different from the ideal on the Control Page the yellow panel informs the user that the result is questionable. If the result does not satisfy the conditions the red panel appears and informs the user that the result is not acceptable.

5 VALIDATION

In order that the BP Service application can be put to the market, the algorithm of it has to satisfy the international standards. The standards specify on what kind of and how many recordings the algorithm has to be executed. The results of the algorithm have to be compared to the reference values. The validation has to be performed on the mass of recordings. The results have to be analyzed on statistically. The standard specifies the acceptable statistical indexes.

If the user clicks on the "Validation" button in the BP Service the validation application are executed. The validation application is built to support the statistical analysis based on the standards of the British Hypertension Society (BHS) (O'Brien et al., 1993) (Kobalava et al.,) and the European Society of Hypertension (ESH) (O'Brien et al., 2010).

The application can work not only with one measurement, but mass of the measurements of recordings, too. The application executes the blood pressure measurement application on each measurement. The results can be analyzed by statistical tools. The validation application is ready to analyze the algorithm of the microcontroller.

The application builds tables to examine whether the algorithm satisfies the requirements of the standards. On Figure 4 there is the statistics window of the validation application.

There are the Bland-Altman plots on the other tab of the validation application. These plots are built to analyze the difference between the results of an algorithm and the reference values. (Bland and Altman, 1986) (Bland and Altman, 1999) Many articles use the Bland-Altman plot (Myers, 2010) (Aboy, 2011)(Lin, 2007). The application creates Bland - Altman plots for both the systole and the diastole. On the surface there is a drop-down menu, where the user can choose which values he wants to analyze, the systole or the diastole.

In the validation application the user can change the parameters of the height-based algorithm. The validation application executes the blood pressure algorithm with default values (now this is 65% for the systole and 53% for the diastole) when the recordings are imported. If the user changes the default values, the blood pressure algorithm is executed again on all the imported recordings and the values are refreshed on the validation surface.

6 CONCLUSIONS

In the article we introduce the new application of the Cardiospy system of Labtech Ltd. The application realizes the PC-side processing of the oscillometric blood pressure measurement recorded by microcontroller. The microcontroller has only limited memory and processor capacity. Therefore the microcontroller can produce inaccurate results or even no results. But the PC-side application can process the measurements in a more accurate way. The cardiologist or the researcher can analyze the steps of the processing of blood pressure measurement using the application. The application visualizes the results of each steps of the processing in an interactive way. Namely, if the user changes the parameters, the scale or the position of the mouse, the objects on the surface change immediately. The interactive visualization surface helps the user understand the information of blood pressure measurement better. The application is built above all for processing of long recordings including more measurements. Most recordings are recorded during 24 hours. The application navigates easily among the measurements of one recording. We have built a validation application to support the validation of the blood pressure measurement algorithm. The validation application can process mass of the measurements with reference and visualizes the statistical data and the Bland-Altman diagram about the difference between the results of the algorithm and the reference data. The colors make the surface of the application more vividly described and easily evaluated.

The oscillometric blood pressure algorithm works well under laboratory circumstances. Our goal is that the algorithm meets the requirements of standard protocols of BHS and EHS. To reach this goal the algorithm needs to be tested. As a result of the testing some parameters of the algorithm can be specified.

PC algorithm statistics

	Measures count	Interval (mmHG)	Avarage difference (mmHg)	Standard deviation (mmHg)	Diff <= 5 mmHg (%)	Diff <= 10 mmHg (%)	Diff <= 15 mmHg (%)
Systole	344	89-171	-1.81	6.53	66.28	86.63	96.8
Diastole	344	51-98	0.53	7.11	69.19	92.73	96.8

A / A
ESH

Systole

3/2 <= 5mmHg (%)	3/0 <= 5 mmHg (%)
23.23	4.71

Diastole

3/2 <= 5 mmHg (%)	3/0 <= 5 mmHg (%)
22.9	2.02

Figure 4: Validation tables.

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