Hypotension Prediction
Arterial Blood Pressure Variability

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Abstract — Hypotension is the formal medical term for low blood pressure. A review of the literature suggests the very strong coherence between heart rate and blood pressure. A sudden episode of hypotension can lead to serious brain injuries and damage. In the case of the sepsis patients our research focused on, the episodes lead in some cases to death.

This paper describes the parametric and nonparametric methods used to analyze and characterize Arterial Blood Pressure (ABP) prior to hypotension episodes. The analysis of ABP variability and shape, have shown the potential of predicting hypotension.

Our study focused on data sets provided by the Complex Systems Lab at Doernbecher’s Children’s Hospital (OHSU). Twenty eight (28) ABP drop episodes were carefully chosen and analyzed from five (5) different sepsis patients. We were interested in the variability of the frequency content and the shape of the signals prior to hypotension episodes. The local analysis of the signal has shown that significant change occur in the shape of ABP prior to hypotension.

Keywords — Autocorrelation Function, Kernel Density Estimator

I. Introduction

Arterial blood pressure is primarily controlled by the autonomic nervous system, which is composed of two branches; the parasympathic and the sympathetic systems. The parasympathetic control reduces both the heart rate and blood pressure, though less dramatically than the sympathetic increases it. These acute and short term changes, are considered normal physiological variations. However, we are concerned with the long term variations of blood pressure outside of acceptable limits: falling edges of 20 mmHg within 2 minutes.

Septic shocks, for instance, are characterized by hypotension episodes, which in adults generally refer to a mean arterial blood pressure below 60 mmHg. According to the European Course Trauma Care, the common and important signs of hypotension in sepsis patients are changes in blood pressure, and heart rate. The goal is to show that such changes can be detected by conducting an analysis of the variability of ABP shape.

Autocorrelation coefficients are commonly used in time series analysis to determine whether a substantial linear relation exists between the series and its own lagged values. The ACF\(^1\) gives a profile of the linear correlation at all possible lags and shows which values of lag lead to the best predictability\(^2\).

My analysis is a new approach which uses autocorrelation coefficients not only as a indicator of linearity relationship, but also as a measure of self-similarity within a quasi-periodic signal. For quasi-periodic signals, there exists a strong coherence between the shape of the signals and its ACF. Thus a change in the shape of the signal will cause a change in the distribution of the autocorrelation coefficients, which can be detected using statistical procedures.

II. Methodology

This section describes the methodology used to analyse ABP shape variability and characterize ABP signals.

A. Data Collection

Twenty eight samples containing hypotension episodes were analyzed. The episodes were detected using an Algorithm developed by James McNames\(^3\). Each sample corresponded to 10 minutes of arterial blood pressure: 5 minutes before shocks and 5 minutes after the shocks. The sampling rate of the signal is 125 Hz.

B. Statistics Summary

After the data collection process, I generated statistical summaries of the signals: mean, standard deviation, variance, skewness, Quantile-Quantile plots. The statistical summaries suggested a considerable change in ABP shape prior to hypotension episodes. In fact, the Arterial Blood Pressure closest to hypotension tension episodes had smaller skewness coefficients. To characterize and detect those changes, the autocorrelation function was used.

C. Estimate of Autocorrelation Function

As mentioned earlier, the ACF gives a profile of the signal’s shape. It is defined as:

\[
ACF(h) = \frac{1}{n} \sum_{i=1}^{n-h} (x_{i+h} - \bar{x})(x_i - \bar{x})
\]

The use of ACF as a mean to characterize the shape of ABP has several advantages as it allows the signal to be

\(^1\) Autocorrelation Function
\(^2\) Robert H. Shumway, Time Series Analysis and Its Applications
\(^3\) Assistant Professor, Portland State University
divided into small samples, which can be analyzed independently. Self-similarity and local analysis of ABP waveforms become thus possible. The approach is to select a patient, subdivide the ABP waveform in samples of 80 seconds long each; 80 seconds is an arbitrary choice here. The analysis doesn’t change much for bigger or smaller interval. However, care must be taken in the choice of the interval: very large interval are useless for the purpose of local analysis whereas very small interval can lead to erroneous results. The ACF is then estimated and plotted for each 'subsample'.

D. Kolmogorov-Smirnov Test

This nonparametric procedure was used to test the changes in the long term variations of ABP’s shape. The test relied on the autocorrelation coefficients computed for each 'subsample'. The goal is to show that the ACF changes significantly as we get closer to septic shocks.

III. Results

Arterial blood pressure pulse, which is one of the most fundamental physical quantities related to haemodynamics Arterial, is formed due to interaction of arterial impedance, and arterial flow waveform.

The samples analyzed in this project corresponded to 10 minutes of measurement: 5 minutes before hypotension shocks and 5 minutes after the shocks. Fig. 1 shows a typical waveform of arterial blood pressure.

A. Statistics Summary

The waveforms of ABP were plotted and contrasted. A visual inspection of the signals suggests a change in the shape of ABP prior to septic shocks. Fig. 2 contrasts the shape of Arterial Blood Pressure 1 minute and 4 minutes prior to the septic shock for Patient DipS110E002S03. The plot suggests a significant change in the shape of ABP signal prior to the drop of blood pressure. The Arterial Blood Pressure 1 minute before the shock seems skewer and has more peaks.

To support these observations, I decided to perform a local analysis of the signal. Each sample was divided in 'subsamples' of 80 seconds long; and for each sample, statistical summaries such as mean, standard deviation, skewness coefficient were generated. The goal was to evaluate statistically:
- the hypothesized change in variance few seconds prior to shocks
- the hypothesized change in shape for ABP prior to shocks
- normality of the data.

An example of the conducted analysis is shown below for Patient DipS110E002S03. The original sample was subdivided in samples of 100 seconds each. The hypotension episode is known to have occurred in Sample 4.

The statistics summary was calculated using MATLAB.

** Statistics Summary **

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Fig. 1. Plot of the arterial blood pressure versus time during 1 second for Patient DipS110E002S03. This figures also illustrates the amplitude of arterial blood pressure in sepsis patients.

Fig. 2. Plot of Arterial Blood Pressure 4 minutes (Top) and 1 minute (Bottom) before hypotension.
The statistics summary confirms a significant change in the skewness of ABP prior to a shock. Such a change can certainly be quantified and detected using a good measure of signal shape variability.

Histograms can be used to assess shape variability for quasi periodic signals. The shape of a signal is closely related to the density function of the signal. A change in the shape of ABP over a period of time should cause a change in the density function of the signal over the same interval. The histograms for the 'subsamples' in Patient DipS110E002S03 are shown in Fig. 3. They confirm the hypothesized change in ABP shape prior to hypotension episodes. As expected, the density function for Sample 4 is significantly different.

B. Change in ABP shape

B.1 Autocorrelation Function

- Background
ACF is often used in time series analysis for autoregressive characterization. It displays graphically and numerically serial correlation coefficients (and their standard errors) for consecutive lags in a specified range of lags. For quasi-periodic signals, we expect thus the ACF to have a periodic shape and to be consistency throughout the data set being analysed. A change in the shape of the signal will also induce a change of the linear correlation coefficients. Thus ACF can be used to perform a local analysis of the signal. The plots of ACF for Patient DipS110E002S03, 5 minutes and 1 minute before the hypotension episode are shown below in Fig. 5.

All previous results strongly agree with the hypothesized change in ABP shape prior to septic shocks. Statistical inference was used to determine the significance of the change in the shape of ABP.

The Quantile-Quantile plots of the samples, shown in Fig. 4 indicate that the samples are not normally distributed.
The plot shows a difference in the autocorrelation coefficients of the two samples. The difference in the values taken by the ACF one minute prior to the drop, can be associated with a change in the shape of ABP. To support the hypothesis of a significant change in ABP's shape prior to hypotension, the Kolmogorov-Smirnov test was conducted. The next section describes the set-up and results of the test.

B.2 Kolmogorov-Smirnov Test

- **Description of the Test**
  The Kolmogorov-Smirnov Test was developed by Smirnov. The statistic test compares the cumulative frequency distribution of two independent samples and is sensitive to any kind of distributional difference: a difference with respect to local and central tendency, skewness.

- **Test Set-Up**
  The characterization of the shape of ABP using ACF gives us the liberty to subdivide ABP in many samples. The coefficients do not depend upon the starting and ending point but totally on the shape of the signal. Hypotension episodes were divided in segment of 80 seconds long. The autocorrelation coefficients for each sample was then computed and used to perform the test. The goal is to evaluate a significant difference in the acf coefficients for samples closest to septic shocks. The results shown below were obtained for Patient DipSi110E002S03. Similar results were obtained for the 28 patients.

- **Results**
  Ho: Coefficients are from same population  
  H1: Coefficients are from different population

- **Interpretation**
  The Kolmogorov-Smirnov test supports the change in ABP shape prior to septic shocks. The results are significant and show that we can statistically detect a change in the shape of Arterial Blood Pressure prior to hypotension episodes.

### IV. Conclusion

Hypotension in sepsis patients can cause serious brain injuries and damage. The prediction of hypotension is an active field of research today. This project focused on the variability of ABP prior to hypotension. My analysis has shown using autocorrelation coefficients, that significant change occur in ABP prior to hypotension. A change in ABP shape was supported, using the Kolmogorov-Smirnov Test, at a significant level of 0.01 and a p-value of 0.0001. The results are significant and constitute an important step toward predicting hypotension in sepsis patients.

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<td>H1</td>
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<td>H1</td>
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<td>1 &amp; 3</td>
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**p-value = 0.0001**