Non-Stationary Visualization Of Biomedical Signals

Learning From Data
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Laura Jenkins

Definitions
- ICP – Intracranial Pressure
- ABP – Arterial Blood Pressure
- CVP – Central Venous Pressure, the pressure of blood in the right atrium.
- BSP – Biomedical Signal Processing
- FFT – Fast Fourier Transform
- IFFT – Inverse FFT

Data
- Data is obtained from Dr. McNames.
- The CVP, ICP, and ABP signals are recorded concurrently in 20-minute segments from 9 different patients.
- From these 9 patients, there are a total of 15 ICP spike events.

Signal Types

Signal Relations

Signal Regions
- Stable Region: 600 – 900 seconds
- Transition Region: 900 – 954 seconds
- Critical Region: 954 – 974 seconds
Introduction

◆ Normal ICP is 0-10 mmHg.
◆ Patients with traumatic brain injury are in danger of ICP increases.
◆ If ICP rises suddenly, for example, up to 50 mmHg, there is nowhere for the pressure to go and the patient experiences a rapid decline that could possibly lead to death.
◆ There is currently no method for predicting these increases in ICP.

The Big Question

◆ Are there any consistent correlated incidents that show up between ICP, ABP, and CVP signals that can predict a sudden increase in ICP before it happens?

Methodology

◆ I have created 3 non-stationary visualization tools using Matlab that will help to identify possible predictive incidents.
  - Cross-Correlogram
  - Cross-Spectrogram
  - Coherogram

Cross-Correlation

◆ Defined as the correlation between two signals in the time domain.

\[
R_{xy}(k) = \frac{E[\{x_t - \mu_x\} \ast \{y_{t+k} - \mu_y\}]}{(\sigma_x \ast \sigma_y)^{1/2}}, \quad -1 \leq R_{xy} \geq +1
\]

- \( R_{xy} = -1 \): Perfect Negative Correlation
- \( R_{xy} = 0 \): No Correlation
- \( R_{xy} = +1 \): Perfect Positive Correlation

Cross-Correlation cont...

◆ Can be calculated using the FFT:

\[
R_{xy}(k) = \text{IFFT}([\text{FFT}(x) \ast \text{FFT}(y)]), \quad \text{N} = \frac{\text{Length of } x \quad \text{N}+1 \leq k \leq \text{N} - 1}{N - |k|}
\]

- The factor \( N/(N-|k|) \) normalizes the result of the fft.
- This method reduces bias, however variance increases as \( k \) approaches \( N \).

Cross-Correlation cont...

Variance increases at the edges of the cross-correlation. This is due to the small number of points being used in the calculation.
Variance of Cross-Correlation

\[ \text{Var}(R_{xy}) = \frac{N}{(N - |k|)^2} \cdot R_{xy}, \quad N = \text{length of signal}, \ k = \text{lag} \]

Cross-Correlogram
- The whole signal is divided into many segments of overlapping windows.
- The cross-correlation is taken on each of these windows and plotted across time.
- The bottom and top 2.5 percentiles are removed from each cross-correlation due to the high edge variance.

Cross-Correlogram cont...
- The cross-correlogram is just a way to look at cross-correlation and how it changes in time across long signals.

Cross-Spectrum
- Defined as the linear association between two signals at different frequencies.
- Magnifies the joint presence of energy at the same frequency.

\[ G_{xy}(\omega) = X(\omega)Y(\omega)^* \]

\( X(\omega) \) and \( Y(\omega) \) are the Fourier Transforms of signals \( x \) and \( y \). This method is a rough estimation of the power spectrum and contains a lot of variance. The variance can be reduced by using different windowing methods.

Cross-Spectrum cont...
- Cross-Spectra of the ABP and ICP signals seen previously.
- The two signals are periodic at the same rate, hence the large peaks at about 2.3 Hz and 4.6 Hz.
- There are some frequency components below 1 Hz due to respiration.

Cross-Spectrogram
- Same principle as the Cross-Correlogram, except that the mean is removed from both signals first to remove the DC components. The signals are split into overlapping windows and the cross-spectrum is calculated over each of the windows.
Coherence

- Defined as the measure of correlation between two signals in the frequency domain.
- Unlike the cross-correlation, coherence can take into account the phase relationship between signals.
- The mean is removed from both signals before calculating the coherence to remove the DC components.
- The signal is windowed and the coherence is averaged across the windows.

$$P_{xy}(\omega) = \frac{\sum X(\omega) Y(\omega)^*}{\sum |X(\omega)|^2 \sum |Y(\omega)|^2}$$

**Coherence cont...**

- We see that both of these signals are highly correlated at 2.3 Hz and its harmonic, 4.6 Hz, as expected.
- Due to the very large values calculated by the power spectrum, unfortunately we see large values for correlation 'noise'.

Variance of Coherence

$$\text{var} = 2 |P_{xy}|^2 \left(1 - |P_{xy}|^2\right) / N$$

- $N = \text{Length of Signal}$

As you can see, variance is dependent on both the length of the signal and the value of the coherence.

Coherogram

Chirp Example

```
x = chirp(1,0,4000,2);
p = chirp(1,3,4000,0);
z = x + p;
```

Chirp Example cont...

```
z = x + p + 8.*randn
```
Chirp Example cont...

\[ y = x + 8 \cdot \text{randn} \]
\[ z = x + p + 8 \cdot \text{randn} \]
Too much random noise to see any correlation.

Chirp Example cont...

\[ y = x + 8 \cdot \text{randn} \]
\[ z = x + p + 8 \cdot \text{randn} \]
Highlights very clearly the common frequency bands of the 0 – 3 Hz chirp.

Chirp Example cont...

\[ y = x + 8 \cdot \text{randn} \]
\[ z = x + p + 8 \cdot \text{randn} \]
Highlights only the common frequencies of the 0 – 3 Hz Chirp.

Visualization of BSP Data

- Cross-Corlogram
  - ABP vs. ICP
  - ABP vs. CVP
  - ICP vs. CVP
- Cross-Spectrogram
  - ABP vs. ICP
  - ABP vs. CVP
  - ICP vs. CVP
- Coherogram
  - ABP vs. ICP
  - ABP vs. CVP
  - ICP vs. CVP

There are 15 separate ICP events in the given data. I plotted the 3 variations for each of the 15 events for a total of 135 plots. Unfortunately, I am unable to see any process differences that might predict ICP increases.

Visualization of BSP Data cont...

The data varies, some cross-correlations were very linear...

Visualization of BSP Data cont...

Others had fluctuations throughout the plots.
Conclusion

- So far, based on the data plots generated by the visualization tools, I find no predictive common incident that occurs before an increase in ICP.
- This does not mean that it does not exist. It may be, upon closer inspection of small chunks of data that statistical differences appear.
- However, I’m not convinced at this point that we would be able to see these differences using these visualization tools.