Analysis of Time Series Measured by Medical Diagnostic Devices Using Methods of Mathematical Physics

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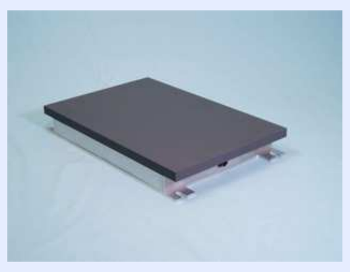
Differential geometry of curves is employed to analyze multivariate time series obtained by force plate measurements. The proposed technique is subsequently applied to display marks of cardiac activity. We also suggest how to use random matrix theory to handle human EEG data. This is a joint work with Petr Šeba.

Introduction

The aim of this poster is to present how to use differential geometry to analyze time series obtained by a force plate measurements. The force plate measures the components of a force and of related force moment acting on specified platform.



It is designed for gait, balance, sports, etc., both static and dynamic analysis (due to strain gauge technology). When a special bed with a reclining subject is placed onto the force plate, measured signals correspond to the blood mass transient flow and to the movement of heart itself. The cardiac activity is triggered by electric signal. Therefore, the ECG is measured simultaneously.

Mathematical method

We understand the measured time series as coordinate projections of 6-dimensional time parameterized curves and investigate Cartan curvatures (geometric invariants) of this curve. The main hypothesis is that a studied process is adequately reflected by total curve and not merely by its projections. Although recorded signals (projections) modify by changing of a position of a subject on the bed, studied process (heart movements and hemodynamics) does not depend on the particular position of the subject.

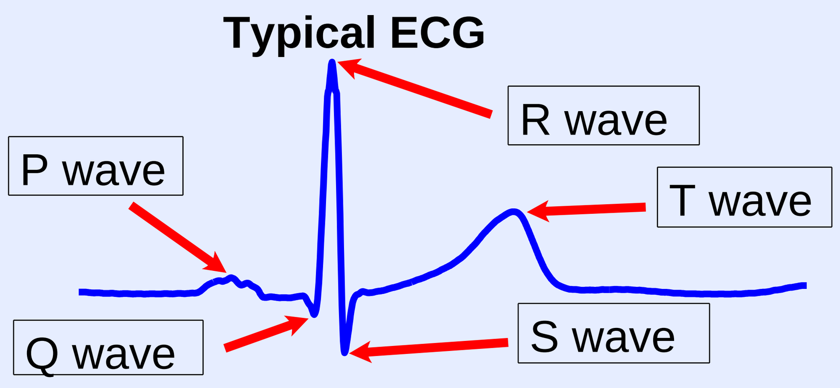
According to the Frenet-Serret theory a (sufficiently regular) n-dimensional curve is uniquely (up to Euclidean transformation) determined by $n-1$ curvatures, see *eg* [J. Gallier, Geometric methods and applications for computer science and engineering, Springer Verlag, Berlin 2000]. Consider a smooth curve c, *ie* a mapping of an interval I into $\mathbb{R}^n$. Assuming that the derivatives $c'(t)$, $c''(t), \ldots c^{(n-1)}(t)$ exist and are linearly independent for every $t \in I$, there exists unique family $(E_1(t), \ldots, E_n(t))$ (called distinguished Frenet frame) of orthonormal vectors having a positive orientation, so that for every k, $c^{(k)}(t)$ is a linear combination of $(E_1, \ldots, E_k)$.

The curvatures κ_i, are defined as

$$\kappa_i(t) = \frac{E_i'(t) \cdot E_{i+1}(t)}{\|c'(t)\|}.$$

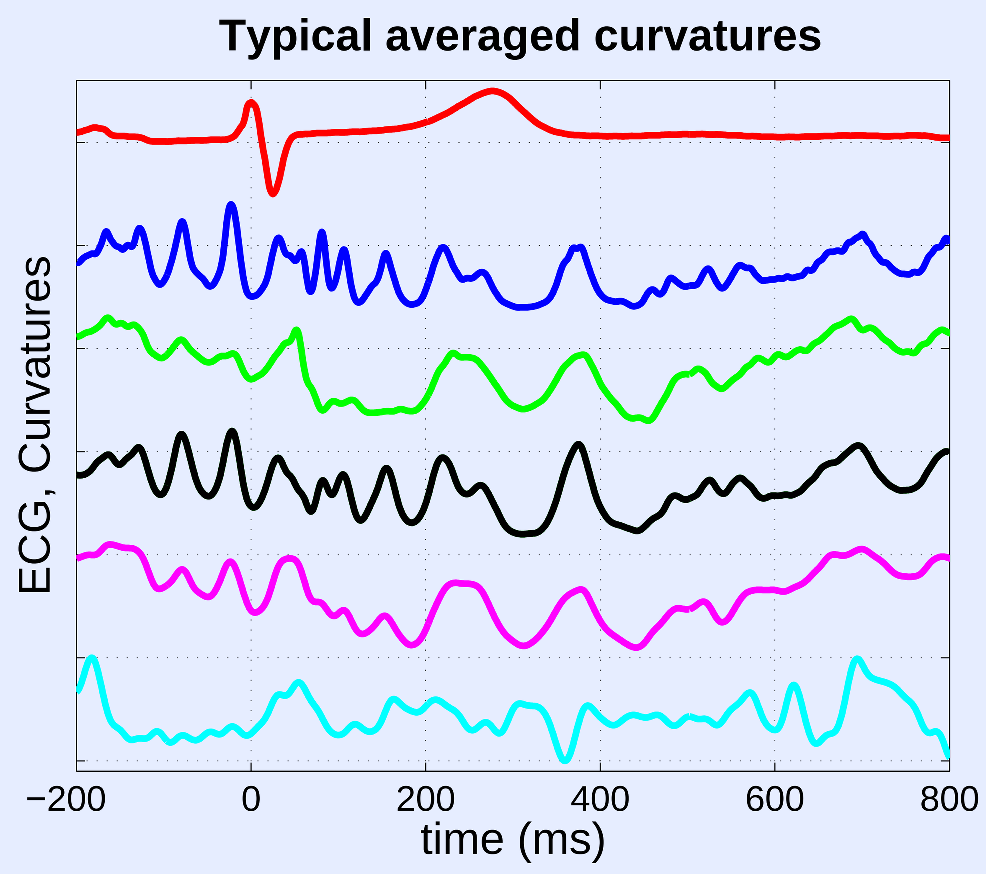
In our case, the 6-dimensional force plate signal is characterized by 5 curvatures.

The cardiac activity (and so the studied process) is quasiperiodic. The length of each cycle is approximately 1000 ms. We regard the process as being time locked with ECG R-wave. We evaluate the curvatures for time periods of 1000 ms starting 200 ms before each R-wave and take the mean over all R-waves.



Results

We measured 20 healthy adults with the sampling frequency of 1000 Hz. The observations lasted 8 minutes. The overall pattern of all curvatures appears to be reproducible across the sample of all examined subjects.

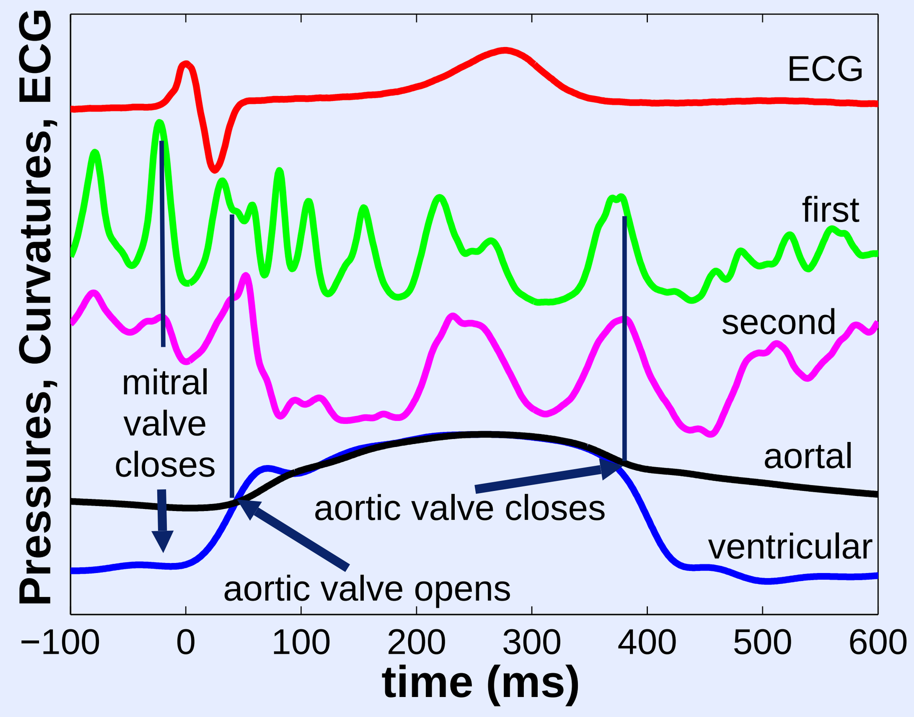


Interpretation

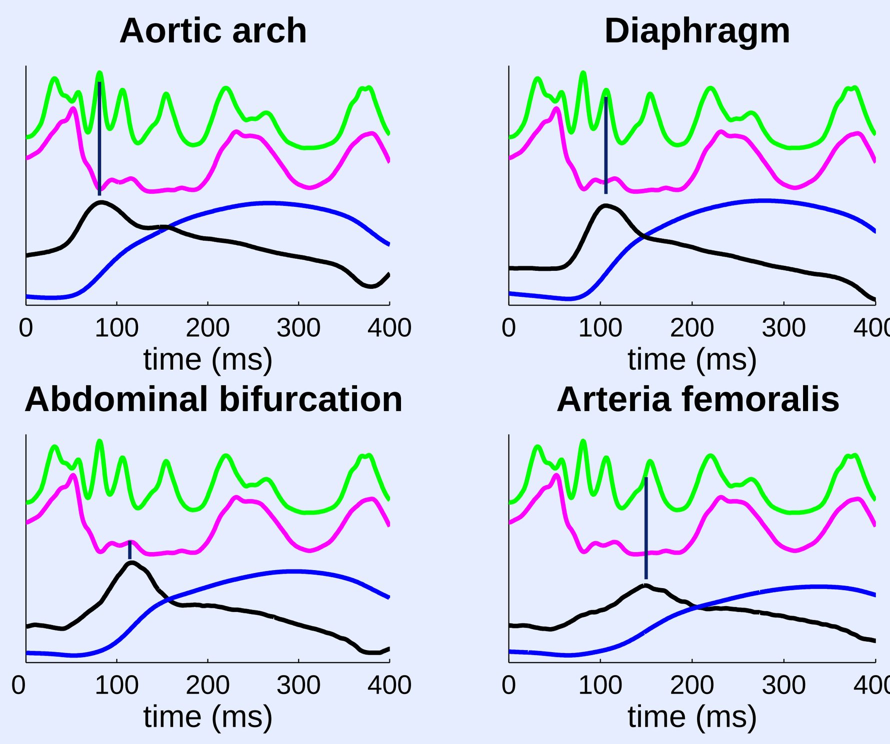
The ejection of blood by ventricular contraction spreads over the elastic central arteries. The augmentation propagates in the form of pulse wave. On branching places of large arteries the pulse wave is scattered. A similar scattering is expected also when the artery changes promptly its direction (*e.g.* aortic arch).

A mechanical event like a rapid heart movement or the scattering of pulse wave leads to changes in the force plate response. It is reasonable to assume that such event suddenly changes the geometry of the total signal curve and is visible as a maximum of the curvature.

To assign the curvature peaks to particular hemodynamical events we compared the results of our analysis with the direct blood pressure measurements during cardiac catheterization. The next figure shows the comparison of the first two curvatures with the pressure inside the left ventricle and in the aorta just above the aortic valve.



The first two curvatures together with the pressure and the derivative of the pressure at four various places inside aorta (or its branchings) are plotted in the following picture.



In such a way we classified 7 peaks in the first and second curvatures and associated them to particular hemodynamical events.

What is it good for

- ◇ Estimating the pressure wave velocity in aorta
- ◇ Observing pathological reflections (recoils)
- ◇ Testing the effect of medicaments on the aortal wall properties

All this fully noninvasively! Cooperation of the patient is not needed.

EEG data analysis

P. Šeba used the **random matrix theory** to demonstrate an existence of generic and subject independent features of the ensemble of correlation matrices extracted from human EEG data, [*Phys. Rev. Lett.* **91** (2003), art. no. 198104]. We would like to use this fact for studying an evoked brain activity. In this case the brain activity is triggered by an external stimulus. Different parts of human brain then cooperate to process the stimulus. To extract the relevant information from EEG signal, we plan to study the differences between the ensemble of correlation matrices and the ensemble of random matrices.