

Chapter 106

From Non-Invasive Hemodynamic Measurements towards Patient-Specific Cardiovascular Diagnosis

Stefan Bernhard

Freie Universität Berlin, Germany

Kristine Al Zoukra

Freie Universität Berlin, Germany

Christof Schtte

Freie Universität Berlin, Germany

ABSTRACT

The past two decades have seen impressive success in medical technology, generating novel experimental data at an unexpected rate. However, current computational methods cannot sufficiently manage the data analysis for interpretation, so clinical application is hindered, and the benefit for the patient is still small. Even though numerous physiological models have been developed to describe complex dynamical mechanisms, their clinical application is limited, because parameterization is crucial, and most problems are ill-posed and do not have unique solutions. However, this information deficit is imminent to physiological data, because the measurement process always contains contamination like artifacts or noise and is limited by a finite measurement precision. The lack of information in hemodynamic data measured at the outlet of the left ventricle, for example, induces an infinite number of solutions to the hemodynamic inverse problem (possible vascular morphologies that can represent the hemodynamic conditions) (Quick, 2001). Within this work, we propose that, despite these problems, the assimilation of morphological constraints, and the usage of statistical prior knowledge from clinical observations, reveals diagnostically useful information. If the morphology of the vascular network, for example, is constrained by a set of time series measurements taken at specific places of the cardiovascular system, it is possible to solve the hemodynamic inverse problem by a carefully designed mathematical forward model in combination with a Bayesian inference technique.

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The proposed cardiovascular system identification procedure allows us to deduce patient-specific information that can be used to diagnose a variety of cardiovascular diseases in an early state. In contrast to traditional inversion approaches, the novel method produces a distribution of physiologically interpretable models (patient-specific parameters and model states) that allow the identification of disease specific patterns that correspond to clinical diagnoses, enabling a probabilistic assessment of human health condition on the basis of a broad patient population. In the ongoing work we use this technique to identify arterial stenosis and aneurisms from anomalous patterns in signal and parameter space. The novel data mining procedure provides useful clinical information about the location of vascular defects like aneurisms and stenosis. We conclude that the Bayesian inference approach is able to solve the cardiovascular inverse problem and to interpret clinical data to allow a patient-specific model-based diagnosis of cardiovascular diseases. We think that the information-based approach provides a useful link between mathematical physiology and clinical diagnoses and that it will become constituent in the medical decision process in near future.

INTRODUCTION

Diagnosis of cardiovascular diseases is an important and difficult task in medicine. Usually differential diagnostic approaches are applied, where several factors or symptoms are considered in an exclusion procedure. This procedure may lead to false assumptions that often result in misdiagnoses. Therefore, the attempt of using the knowledge and experience of experts collected in databases to support the diagnosis process by computational methods seems reasonable. This non-obvious task is valuable for decision making in today's medicine.

Typically various data mining frameworks are used to transform the data into therapeutically relevant knowledge for decision making. Several iterative subtasks process the data to discover the hidden information that diagnose diseases. Even though the amount and information content within clinical data has grown continuously and rapidly the number of accepted and reliable procedures for extracting diagnostically or therapeutically relevant information has not increased comparably.

On the one hand the difficulty in the process of information extraction of richer data sets into improved clinical therapies lies in the traditional deterministic view immanent in current mathematical models of physiological processes. On the other hand there is a lack of sufficient therapeutic options that can cope with advanced diagnostic

information. The former problem traces back to the fact that current methods have limited ability to integrate the statistical nature of clinical data obtained from a broad patient population.

Within this work we bridge the gap to a more suitable interpretation of model parameters and states observed in a broad patient population, namely by statistical analysis and interpretation. Such statistical models have been developed for a range of problems in biomedical signal analysis to remove contaminants from EEG and ECG signals (Sameni, 2008) and recently to estimate parameters of the cardiovascular system from blood pressure signals (McNames, 2008). It was shown that the extraction of information about the health condition of subgroups of the population with such methods provides the potential to develop new individualized therapeutic strategies that bring true benefit to the patients. Resolving this incongruity will pave the way for a statistical interpretation of cardiovascular system models that optimally use the information of specific subpopulations for diagnostic purposes.

The Intention of the Angiology Project Carried Out in the Innovation Laboratory

“Mathematics for Diagnosis (M⁴D)” is twofold: the collection of physiologic information and

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