学位報告

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主 論 文 の 要 旨

論文題目　HRV ESTIMATION FROM BP AND CODING STRATEGY ANALYSIS OF THE CARDIOVASCULAR REGULATION

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論 文 内 容 の 要 旨

Research Overview

Much has been discussed about how the cardiovascular system is under the influence of the autonomous nervous system. Yet, even with the recent advances in medicine, psychology, and physiology, the mechanisms behind the cardiac dynamics remain largely unknown. In this context, this thesis presents novel approaches to analyze cardiac dynamics. It focuses on signal processing of cardiovascular data. Herein, we explore two distinct but complementary problems in the field of biomedical engineering, whose subjects could shed some lights on the computational aspects of the cardiac processing. The first problem tackles the issue of extracting a signal from blood pressure that could mimic the modulatory behavior of the heart as described by the cardiac variability. The second problem focuses directly on what kind of guiding principles are being used by the heart to translate neuroregulatory messages into cardiac rhythm.

Objectives

The objective of this thesis is twofold. The first objective is to derive a signal from blood pressure waveforms whose stochastic behavior is analogous to heart rate variability derived from the electrocardiogram. The goal is to provide a simple noninvasive way to analyze the autonomic regulation using blood pressure instead of electrocardiogram waveforms.

The second objective is to build a bridge between the variations of the autonomous nervous system and the responses of the heart, and how it could be applied to explain the neural processing of the cardiovascular system. In particular, we propose to study the coding strategy analysis of the cardiovascular regulation based on the statistics of cardiac-derived signals. Within this analysis, we try to test whether or not the cardiac rhythm could process information in a manner consistent with principles described by information theory.

Organization of the thesis

This thesis consists of six chapters as follows.

Chapter 1 describes the motivation behind our interest in the cardiac system, the problem that we want to solve, and the structural organization of the chapters, as well as a brief overview of the principal achievements of this thesis. From a macroscopic point-of-view, this thesis deals with cardiac signal processing. From a microscopic point, however, we try to analyze the data from a neuroscientific perspective. Specifically, we have heavily biased this thesis towards computational neuroscience to understand the neural information of the heart.

In Chapter 2, we present the physiological background necessary to understand the autonomic cardiac regulation. It describes the fundamental aspects regarding the cardiovascular control: the heart, the blood vessels, and the blood. While we present cardiovascular physiology, we focus more particularly on the neuroregulatory mechanisms of the heart. Moreover, it gives an overview about the genesis of the electrocardiogram and blood pressure waveforms, which is further extended to the analysis of discrete event series that can be obtained from these biosignals. Finally, we describe the standard methods (in time and frequency) proposed to infer about the variations of the autonomous nervous system.

Chapter 3 is divided in two parts. The first part revises the state-of-the-art regarding the analysis of heart rate variability (HRV) from blood pressure (BP). The second part presents a literature review about the goal and strategy of sensory systems according to information theoretic principles. Each part focuses on the motivation, relevance, and importance of the multidimensional and coding strategy analysis of the cardiovascular control. We also explain the achievements in both lines of research and present some critics that have been subject of discussion.

Chapter 4 describes a method to estimate HRV from a BP signal based on a heart instantaneous frequency algorithm. This Chapter presents a series of experiments to compare HRV derived from BP as an alternative measurement of HRV obtained from ECG. The methodology is based on the hypothesis that ECG and BP have the same harmonic behavior. Thus, we model an alternative HRV signal using a nonlinear algorithm, called heart instantaneous frequency (HIF). This algorithm tracks the instantaneous frequency through a rough fundamental frequency using power spectral density (PSD). To verify how the estimate HRV signals derived from BP using HIF algorithm correlates to the standard gold measures, i.e. HRV derived from ECG, we use a traditional algorithm based on QRS detectors followed by thresholding to localize the R-wave time peak.

In Chapter 5, we present a generative model of the heartbeat intervals that captures the variations underlying the cardiac rhythm. Under the assumption of statistical independence, the model uses a bank of filters obtained from heartbeat intervals that are able to represent the input-output dynamics of the heart. In the model, the cardiac input is given by neuroregulatory stimuli and the cardiac output by heartbeat intervals. To validate our results, we describe another model that uses cardiac responses data derived from rabbits to compare the response of the proposed model. Moreover, a critical analysis of the learned filters is presented.

Chapter 6 concludes the dissertation with a summary of the main developments and contributions of this thesis and finalizes with few suggestions for future work.

Thesis Contributions

The following list briefly summarizes (to the research community) the original contributions fully described in the thesis:

1. Introduces (for the first time) a unique methodology to estimate heart rate variability from blood pressure waveforms.
2. Illustrates how small variations around the peak of R-waves (the highest wave of the electrocardiogram) linearly increase the spectral energy of the heart rate variability along the frequency axis.
3. Develops a generative model of the autonomic cardiac regulation by leaning efficient codes from heartbeat intervals.
4. Describes the computational aspects subserving the transformation of neuroregulatory messages into the cardiac rhythm.