New Methods for Esophageal ECG Catheter Displacement Estimation

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Thesis advisor : Prof. Dr. Marcel Jacomet, Dr. Reto Wildhaber
Expert : Prof. Dr. Josef Götte

Esophageal electrocardiography is an old but rarely used medical technique to record cardiac electrical activity. This thesis provides a robust approach to track the current catheter insertion depth using novel methods based on autonomous linear state-space models, unsupervised learning, and Gaussian message passing. The goal is to give an additional modality for the diagnosis of heart diseases.

Frédéric Waldmann
frederic.waldmann@gmail.com

Introduction

Catheters for esophageal electrocardiography (EsoECG) are medical devices, recording the electrical activity of the heart from inside the patient's esophagus. Such a catheter is a soft and thin tube with multiple electrodes that are recording a multi-channel EsoECG signal. Figure 1 a) shows a brief overview of the catheter's insertion and placement. Due to the patient's breathing, swallowing, and body motions, the catheter changes continuously its position in the esophagus, which alters the signal shapes. These alternations degrade further signal processing and lower diagnostic reliability. The goal of this thesis is to develop a robust method to track the catheter position using EsoECG signals solely and to reconstruct and visualize the cardiac electrical field.

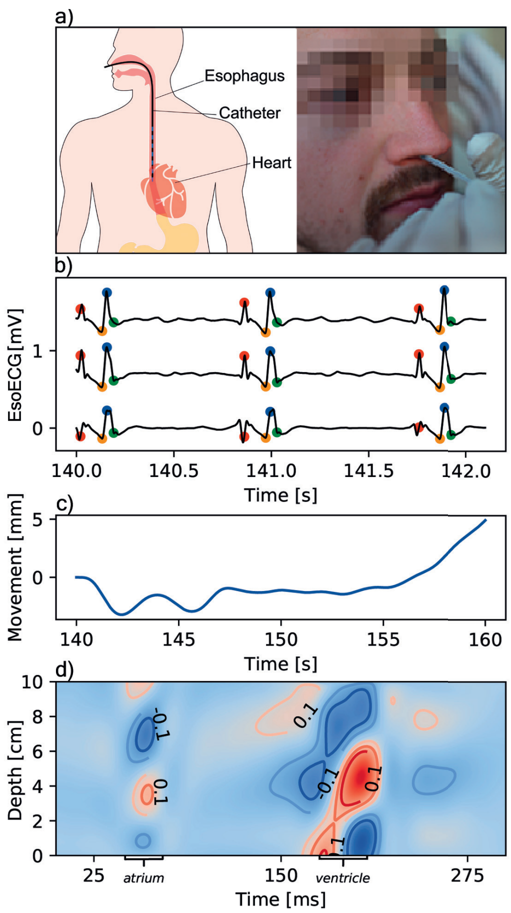

Figure 1: a) Catheter insertion and placement, b) EsoECG signals with pattern detection, c) Catheter movement, d) Esophageal iso-potential map

Concept

We split the method into two parts: the unsupervised identification of repetitive signal patterns, and the estimation of catheter motions. In the first part, we use autonomous linear state-space models to approximate the signals locally by multi-channel polynomials. This approach provides a sample-independent signal representation, which is the input for our unsupervised clustering algorithm identifying repetitive signal patterns. The second part tracks the catheter motion over time. Therefore, we compare the multi-channel signals at the repetitions and achieve an estimate of the current catheter displacement. The estimation requires a high-dimensional optimization problem to be solved, which is done efficiently by polynomial models with arbitrary resolution. Finally, a Gaussian message passing algorithm, closely related to a Kalman smoother, gives a complete estimation of the catheter motion.

Results

The detection of repetitive signal shapes, with unsupervised learning, is fast and reliable. Figure 1 b) shows three channels of EsoECG signals. Identical markers highlight the repetitions of signal patterns found by unsupervised learning. Figure 1 c) shows an estimate of the catheter movement over twenty seconds. Figure 1 d) displays a high-resolution reconstruction of the electrical field observed in the esophagus. This visualization is also denoted as the esophageal iso-potential map.