Manifold Analysis of ECG Dynamical Trajectories

Burak Erem
Dana H. Brooks

Northeastern University, Boston, MA
Introduction

- Problem: analyze multichannel cardiac electrical recordings
  - Clinical and Research interest
  - Multi-electrode catheters
  - Non-contact intra-chamber probes
  - Heart surface electrodes
  - Body surface electrodes
- 10’s to 100’s of electrodes
- Approach: analyze relationships between time waveforms from electrodes
  - Dynamical System
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads
Cardiac Electrical Dynamics

- QRS Complex: wavefront of electrical activation spreads

\[
\begin{bmatrix}
\cdot \\
\cdot \\
\cdot \\
\cdot
\end{bmatrix} = x(t)
\]
ECG Dynamics: State Space Model

Evolution Equation

\[ \dot{x}(t) = f(x(t)) \]

Observation Equation

\[ y(t) = Ax(t) \]
**ECG Dynamics: State Space Model**

**Evolution Equation**
\[ \dot{x}(t) = f(x(t)) \]

**Observation Equation**
\[ y(t) = Ax(t) \]

1. Describes curves/trajectories
2. Trajectories also observed in measurements
**Method: Manifold Learning**

- Data-driven: don’t explicitly model evolution or observation equations
- Instead, given data, learn a mapping:

\[
\left\{ x(t_1), x(t_2), \ldots, x(t_P) \right\} \xrightarrow{\text{Mapping to Manifold}} \left\{ \tilde{x}(t_1), \tilde{x}(t_2), \ldots, \tilde{x}(t_P) \right\}
\]

- Laplacian Eigenmaps:
  - Preserves local relationships
  - Similar results with other methods
Results: Canine Heart Surface

- Cardiovascular Research and Training Institute (CVRTI) data
  - Ischemia study, measured 247 electrodes
  - We analyzed QRS only! (ST more typical)
- Visualization:
  - Each time sample of 247 electrodes = single point
  - Red sphere = single point mapped to manifold

Three orthogonal views of first three dimensions after mapping
Results: Ischemia Progression

Typical Analysis of QRS Complex: Isochronal Maps of Electrical Activation Times

Manifold Analysis (yellow samples from same stage of experiment as above)

Progression of Ischemia
Results: Human Body Surface

- Data from cardiologist (Petr Stovicek)
- Heartbeats paced:
  - Tip of ablation catheter
  - Effect: controls activation patterns
- Visualization:
  - Left ventricular chamber (as volume)
  - Spheres: pacing sites
  - Colors: manual clustering
Results: Body Surface Trajectories

- Visualizations: data on manifold, same cluster coloring as pacing sites
Conclusions

- ECG data: trajectories through electrode space
- Trajectories visible on heart and body surface
- Method appears sensitive to ischemic changes during QRS (typically associated with ST)
- Future work:
  - Show correspondence of heart/body manifolds
  - Use as dynamical constraint in inverse solutions
- Questions?