Imperial College London

Unsupervised Time Series Segmentation for High-Dimensional Body Sensor Network Data Streams

David Haber[1], Andreas A.C. Thomik[2] & A. Aldo Faisal[1,2,3]

[1]Dept. of Computing; [2]Dept. of Bioengineering; [3]MRC Clinical Sciences Centre, Hammersmith Hospital; Imperial College London, London SW7 2AZ

andreas.thomik10@imperial.ac.uk

www.FaisalLab.com

1. Introduction

Locating behavioural sub-sequences in body sensor network data streams of **high temporal and spatial resolution** efficiently and accurately is an open challenge.

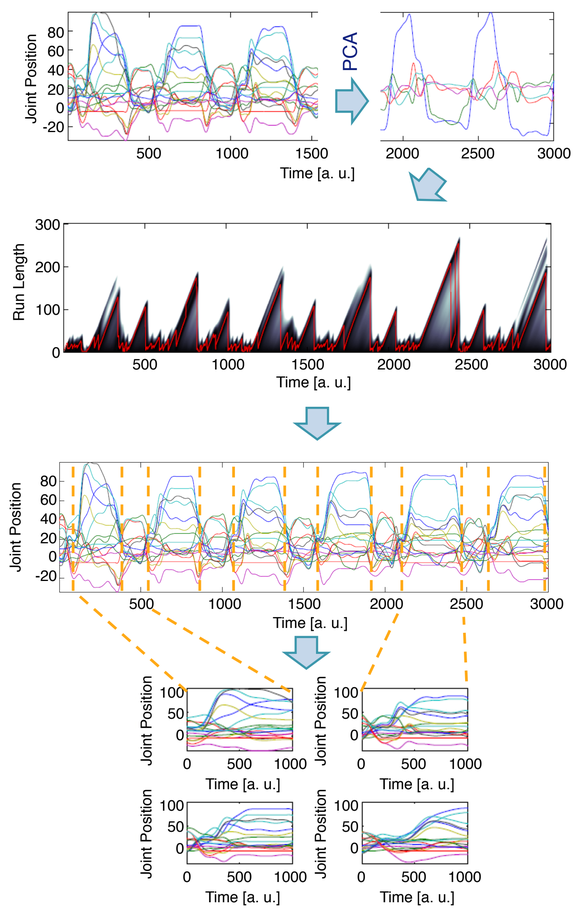
We present a novel **unsupervised machine learning method** for segmenting, extracting and recognising motion segments from long and complex time series in O(*n*).

We apply our method to a **kinematic data set** consisting of millions of samples in 18 dimensional space and demonstrate its ability to accurately segment and extract **motion building blocks**. Our method is additionally validated on an artificially-generated data set.

2. Unsupervised Time Series Segmentation and Recognition in O(n)

The method presented here allows to process long and high-dimensional body sensor network data streams:

1. **Reducing Dimensionality**
   Optimal projection onto low-dimensional space
2. **Change Point Analysis**
   Computes the most likely length for the current segment at each time step. Adapted from [1]
3. **Segmentation**
   Significant drops in run-length are marked as segmentation points and segments are extracted
4. **Comparison of Segments**
   Movement segments are re-sampled and compared using Maximum Cross-Correlation [2]

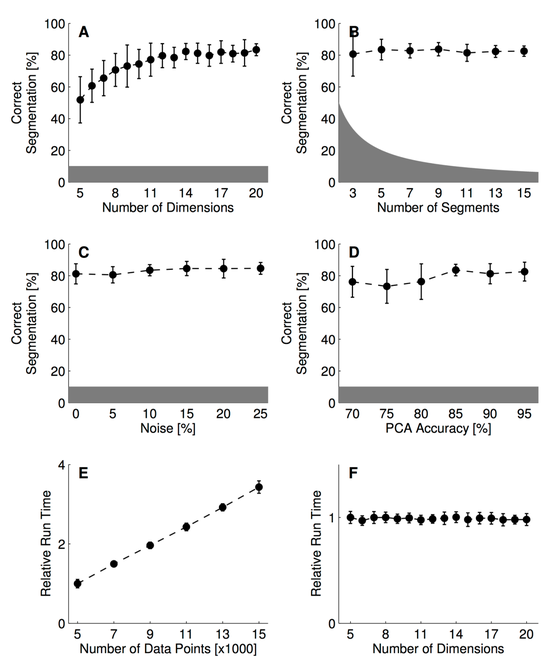


3. Artificial Data Set

- Randomly generated sequences from the family of functions

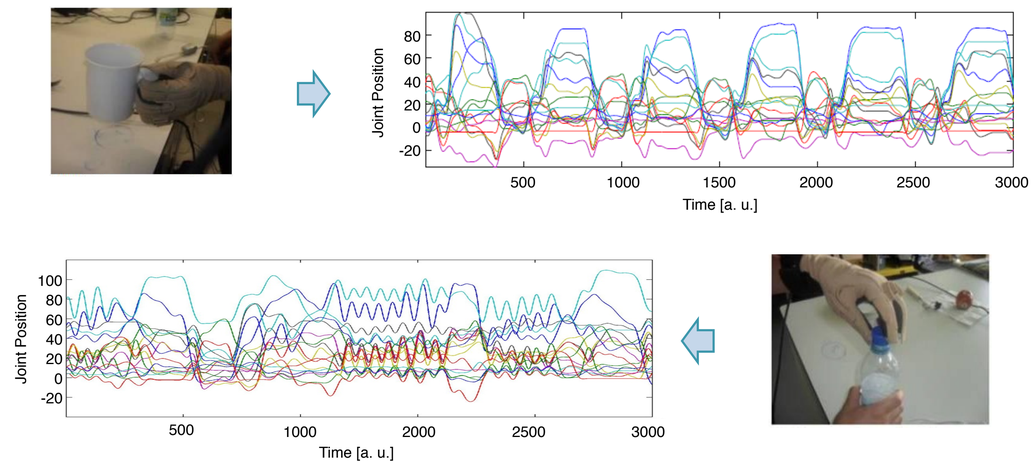
$$f = \left(\sum_{i=1}^{N} w_i \phi(t - t_i) \right) + \varepsilon$$

- Varied dimensionality, number of segment types, noise levels and method parameters
- **55** parameter combinations, each run **20** times, **1100** runs in total
- Achieved **86.5%** segmentation accuracy on artificial data set, **linear complexity** in the number of data points



4. Neurotechnology for Kinematics

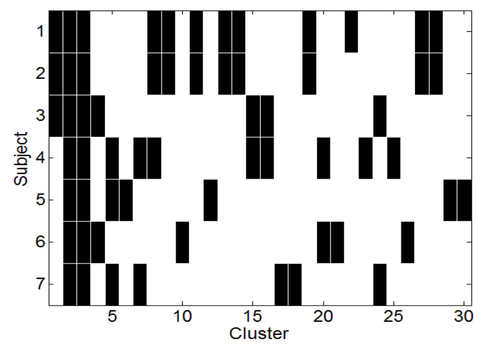
7 healthy subjects wearing CyberGlove I, 17 tasks from everyday life (eating, typing, opening doors, etc.), 18 dimensional data, 80 Hz, > 1.5M data points [3]

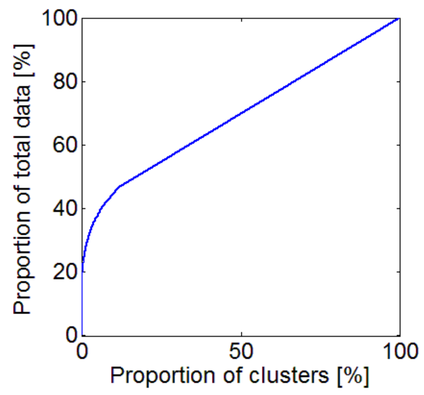


5. Detecting Recurrent Motion Building Blocks

Clusters of similar movement segments are generated using an iterative algorithm. Each cluster represents a **basic action** (building block) that can be composed into more complex sequences of movement.

- Recurrent building blocks (black in right figure) found across subjects
- Most frequently extracted actions from data set: various forms of hand openings/closings





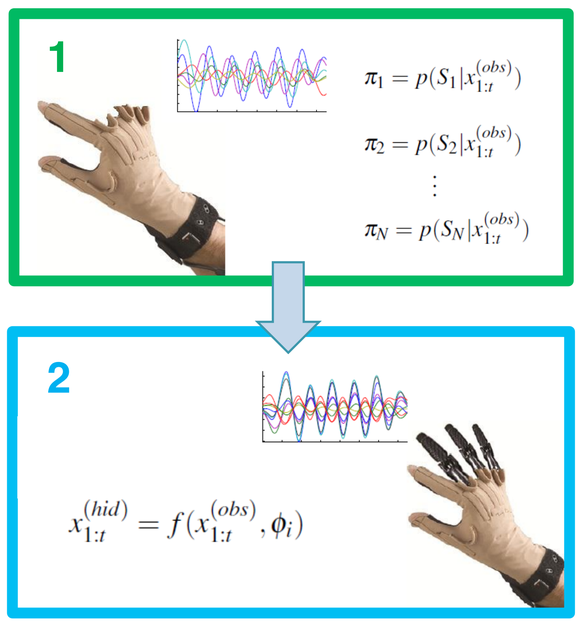
- ~ 3700 segments in 1.5M data points
- 1.5% of clusters account for > 25% of the data
- Singleton "clusters" ignored

6. Application to Neuroprosthetics

Our method enables a **Big Data driven approach** to improved control of neuroprosthetic devices [2].

The behaviour of the undamaged limb is observed to predict the most likely actions of lost limbs in **real-time** using a **two-step process** and the clusters previously generated.

- Statistically significantly **higher prediction accuracy** ($p < 0.05$)
- **Real-time** prediction of missing limb movement



7. Discussion

Segmentation/Recognition

- Very **high accuracy** (86.5%) and extremely **robust** to most variations in the data and noise
- **Recurrent patterns** (clusters) found across subjects and the execution of everyday tasks support a **modular** approach by the brain to generate movement [4, 5]
- Enables **Big Data driven** approaches to stream processing Body Sensor Network data, Brain-Machine Interfacing and Neuroprosthetics [2]

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Acknowledgments
Thanks to Jovana Belic for collecting the data [3]. AT is supported by the National Research Fund, Luxembourg (1229297).

Fonds National de la Recherche Luxembourg