PIECEWISE LINEAR DYNAMICAL MODEL FOR HUMAN ACTIONS CLUSTERING FROM INERTIAL BODY SENSORS WITH CONSIDERATIONS OF HUMAN FACTORS

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Motivation

- Dividing motion data into discrete segments is useful
  - Training
  - Diagnosis

- Segmentation can be at different granularities
  - Walking vs. not-walking
  - Where in the gait cycle
Problems

- Typical BSN Processing Pipeline

Assumes repeatability of signals

Problems

□ ‘Human Factors’

Physical placement affects signal

Chien et al. (2013)*: Model-based estimation

Addressing Problems

- **Our Approach**

![Diagram showing the process of data pre-processing, segmentation, feature extraction, and classification.](image)
Our Approach

- Basic Approach: Piecewise Linear Dynamical Modeling

System generally non-linear, but approximately piecewise linear (over short time segments).
Our Approach

- Identifying Motion Stimulus

\[
\text{Cur} \downarrow \text{gyro} = \nabla \nabla 3 (\nabla \nabla 1 (\nabla \nabla 1 (y(t, g(1)), y(t, g(2)), y(t, g(3))))))
\]
Our Approach

- Identifying Motion Stimulus

(a) Identifying Motion Stimulus

(b) Identifying Motion Stimulus

Curvature of gyroscope data (insecure mounting)

Curvature of gyroscope data (mounting error)

Curvature of gyroscope data (correct mounting)
Overall Algorithm

Raw Data
\[ Y(t) = (y_1(t), y_2(t), \ldots, y_4(t)) \]

Preprocessing

Curvature Calculation
\[ \nu_1 \left( \nu_1 \left( y(t, g(1)), y(t, g(2)), y(t, g(3)) \right) \right) \]

Motion Stimulus Detection
(Peaks of Calculated Curvature)

Hierarchical Temporal Selection of Data Pieces based on detected moments of motion stimulus

EM Algorithm
1) Initialize a random sparse input \( X \) satisfying the constraints: \( |x(t)| \leq 1 \ \forall t \)
2) Repeat:
   (a) Given \( X \):
       Identify a LDS: \( A, B, C, S_0 \);
   (b) Given \( A, B, C, S_0 \):
       minimize \( x \) (Cost Function)
       \[ |x(t)| \leq 1 \ \forall t \]
3) Calculate histogram of \( X \) into 11 bins after recursion.
What does this buy us?

- **Coarse-grain segmentation**

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<th>PLDM</th>
<th>Insecure Mounting</th>
<th>Error Mounting</th>
<th>Correct Mounting</th>
<th>Ground Truth</th>
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- **ACA**

- **Walk Straight**
- **Run**
- **Jump**
- **Side Walk**
- **Punching**
- **Body Rotation**
What does this buy us?

- Fine-grained segmentation
- Heel-strike and toe off detection

Humans walk at about two steps per second (one per leg) so we expect about 360 event pairs per leg with some variance.

Recap

- Segmentation is important for BSNs
- Human factors can be a problem
- Linear dynamical systems modeling can help for
  - Fine grained
  - Coarse grained
Future Work

- Reduce Computation Complexity
- Optimize clustering process
- Other Applications
  - Surgery education data analysis
  - Head impact identification (in sports)
  - ...

UVA Center for Wireless Health
http://wirelesshealth.virginia.edu

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