Scale-Space Methods for Live Processing of Sensor Data

Stein Olav Skrøvseth,
André Dias, Lukas Gorzelniak,
Fred Godtliebsen, Alexander Horsch
PA in COPD

- Physical activity (PA) important for COPD patients.
- Seeing changes in PA pattern is useful for patients and providers.
- PA reduction may be an early, unspecific symptom (e.g. of exacerbation).
- PA decline linked to risk of hospitalization and mortality.
- Accelerometers provide objective assessment of PA.
Objectives

• Use sensor/accelerometer data for live monitoring of activity levels.
• Effective visualization of large temporal data.
• Detect changes in activity, on any time scale.

• Based on data from earlier trial:
  Triaxial RT3 accelerometer at waist in patients with stage IV COPD. Sampling rate 1 min.
SiZer
(Significant Zero-crossings of derivatives)

• A statistical technique to visualize significant derivatives on multiple scales.
• Which features in a signal are statistically significant?
• Based on kernel regression and/or kernel density estimation.
• Gives significance maps for investigation.

Chaudhuri & Marron, JASA, 1999
Kernel smoothing
Local linear regression

\[ \hat{f}_h(t) \]

\[ h = \begin{cases} 
1 \\
3 \\
10 
\end{cases} \]
Scale-Space

$h$

$\text{Increase}$

$\text{Decrease}$
Significance in scale space

• For every point \((t,h)\) in scale space test

\[ H_0 : f_h'(t) = 0 \quad \text{vs} \quad H_1 : f_h'(t) \neq 0 \]

• One of four results:
  – Significant increase (blue)
  – Significant decrease (red)
  – No significant derivative (gray)
  – Not enough data points to test \([\text{ESS} < 5]\) (white)
Test details

Data points: $(\tau_i, y_i)$

Test statistic:

$$\hat{f}'_h(t) = \arg\min_b \sum_i \{y_i - [a + b(t - \tau_i)]\}^2 K(t - \tau_i; h)$$

$$= \sum_i W_h(t, \tau_i)y_i$$

SD estimate:

$$\widehat{SD}[\hat{f}'(t)] = \sqrt{\sum_{i=1}^N \sigma^2(y_i|\tau_i)[W_h(t, \tau_i)]^2}$$
Causality

- Future values cannot affect current estimates.
- Use kernel with (semi-)finite support.
- Shift kernel forward in time: \( \hat{f}_h(t) \mapsto \hat{f}_h(t - h) \)

\[
\frac{1}{h\sqrt{14\pi}} \exp \left( -\frac{t^2}{14h^2} \right)
\]

\[
\mathbf{1}_{[-h,h]}(t) \frac{15}{16h} \left[ 1 - \left( \frac{t}{h} \right)^2 \right]^2
\]

Skrøvseth et al, PLoS ONE, 2012 [under review]
Change point analysis

Change points estimates can be inferred from *causal regions* in scale space.

- Early detection comparable to standard routines.
- Lower no-detection rates.
One patient
Male, 65 yo, BMI 39, severe COPD
Results
Can activity predict exacerbation?
Speculative, and no conclusive evidence so far.
Summary

• Scale-space analysis of sensor data provides live information on changes in activity.
• SiZer-type significance maps gives visual cues on signal features on multiple scales.
• Changes are detected quickly, and change points can be inferred based on analysis of the significance map.
• Further applications are to be investigated.