Attractor-shape Descriptors for Balance Impairment Assessment in Parkinson’s Disease

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What is Parkinson’s Disease?

- Chronic, progressive and idiopathic disorder of the central nervous system.

- Motor symptoms include –
  - Tremor
  - Bradykinesia
  - Rigidity
  - Postural instability

- About 1 million people are affected by Parkinson’s disease in the United States alone.

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Current Evaluation Practice

• Unified Parkinson’s disease rating scale (UPDRS) sections –
  o Evaluation of mentation, behavior and mood
  o Self-evaluation of day-to-day activities
  o Motor function evaluation
  o Therapy complications
  o Hoehn and Yahr scale
  o Schwab and England scale

• Evaluated by interview and clinical observation by an expert clinician.

• Helps measure the benefits obtained from therapy and to follow the progression of the disease in a person.
Current Evaluation Practice

• **Drawbacks** of current practice –
  - Visually monitored by a trained therapist/clinician
  - Time consuming
  - Laborious
  - Subjective

• **What is the way forward?**
  - Have low cost portable systems at home, supplementing the therapist.
Towards Home System

- Development of portable and personalized therapy systems.
- Unsupervised rehabilitation and therapy at home.
- Reduce the cost of long-term therapy.

Subject with Parkinson’s disease standing on a force platform performing dynamic shifts, looking at the monitor in front of him (not shown) at his eyes level (left). The targets along with typical center-of-pressure (CoP) tracings during dynamic posture shifts of a trial are shown above (right).
What is this paper about?

• Aim –
  o To use an automated standardized framework\textsuperscript{2} that describes the level of impairment across subjects.
  o Combine theoretical concepts of nonlinear dynamical system theory and global shape analysis.

Proposed Framework

- Use the dynamics of the CoP tracings to learn more about the disease severity and balance impairment in the subject.

- Use tools from nonlinear dynamical analysis –
  - Phase space reconstruction (by method of delays).

\[ X_i(n) = \{ x_i(n), x_i(n + \tau), \ldots, x_i(n + (m-1)\tau) \} \]

(a) Lorenz attractor  
(b) One-dimensional time series of Lorenz attractor \((x(t))\)  
(c) Reconstructed phase space by delay embedding
Proposed Framework

• Use D2 shape distribution functions\(^3\) for extracting discriminative shape features from the reconstructed phase space.

\[ D_{ij} = \| X_i - X_j \|_2 \]

\(X_i\) and \(X_j\) are embedding vectors in the reconstructed phase space
\(D_{ij}\) - Euclidean distance between two random vectors

• A set of these distances for randomly chosen embedding vector pairs is computed.

• A histogram is constructed by counting the number of samples that fall into each of \(B = 50\) fixed sized bins.

\(^3\) Osada et al. “Shape distributions,” ACM Transactions on Graphics (TOG), 2002
Baseline Features

1) Largest Lyapunov Exponent (LLE):
   - Widely used measure in human activity analysis.
   - Measures the average rate of divergence of initially closed trajectories over time.
   - Requires high sampling frequency and long observation time.

2) Peak Velocity Index:
   - Maximum velocity calculated between two adjacent samples, from the time the CoP cursor leaves the starting point and completes the target reach.
   - Help distinguish between healthy people and people suffering from Parkinson’s disease.
21 healthy young subjects; 22 healthy elderly subjects; 17 subjects suffering from Parkinson’s disease (PD).

Time-series data of dynamic postural shifts of the subjects’ Centre-of-Pressure (CoP) tracings.
Subject Classification Results

- Classification of movements of healthy elderly, healthy young and unhealthy (people suffering from Parkinson’s disease) subjects.

- Subjects performed dynamic posture shifts on a force platform.

<table>
<thead>
<tr>
<th>Feature</th>
<th>$k$-NN (%)</th>
<th>SVM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Velocity Index</td>
<td>50.38</td>
<td>53.01</td>
</tr>
<tr>
<td>LLE</td>
<td>47.37</td>
<td>47.37</td>
</tr>
<tr>
<td>D2</td>
<td>70.30</td>
<td>71.43</td>
</tr>
</tbody>
</table>

Classification rates for different features using $k$-Nearest Neighbor ($k$-NN) and linear-kernel SVM classifier. Performed a round-robin leave-one-subject-out cross validation.
Subject Classification Results

Classification accuracy of both the $k$-NN classifier (left) and linear-kernel SVM classifier (right) using the D2 shape features is higher than LLE and peak velocity index features at all values of $k$ and $C$. 
Assessment of Parkinson’s disease Severity

Impaired / Healthy Subject → SVM Regression → Predicted Total UPDRS Score

Dynamical Features

Clinical Total UPDRS Score

General pipeline for prediction of total UPDRS scores using a linear-kernel SVM regression model.
Assessment of Parkinson’s disease Severity

• Performed a round-robin leave-one-subject-out cross validation.

• Pearson correlation coefficient and p-values were calculated between the clinical and predicted total UPDRS scores for each of the dynamical features.

• Plot between the clinical and predicted total UPDRS score using D2 shape function features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Correlation</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Velocity Index</td>
<td>0.8135</td>
<td>$2.8227e^{-15}$</td>
</tr>
<tr>
<td>LLE</td>
<td>0.6449</td>
<td>$2.6707e^{-08}$</td>
</tr>
<tr>
<td>D2</td>
<td>0.9006</td>
<td>$1.1847e^{-22}$</td>
</tr>
</tbody>
</table>
Conclusion

• Proposed the use of attractor-shape descriptors to assess balance impairment from posture shifts in subjects having Parkinson’s disease.

• Future work: Use proposed framework in a home setup to assess disease severity of Parkinson’s disease in patients.