Validation of Automated Mobility Assessment using a Single 3D Sensor

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Introduction

- **Motivation:** Reliable human mobility assessment can be critical in many medical applications, where it can be an essential tool for diagnosis or monitoring.

- Increasing availability of sensing technologies, e.g. wearable sensors and 3D sensor, is now creating the opportunity to provide portable, continuous and unobtrusive human mobility assessment.

- We present a methodology to design an automated mobility assessment system based on motion data captured via cost-effective 3D sensors.

Contributions

- We introduce a methodology to develop an automated mobility assessment system based on single 3D sensor and we verify its utility.
- We propose a novel graph-based feature extraction technique to reveal the dynamic coordination between parts of body, which achieves comparable results to data-driven features with many desirable properties.
- In a case study on PD subjects, we achieve a system that can successfully predict the medication states of subjects with the accuracy achieving 84% using a relatively small number of movements.

Feature Design

Gait Measurements
- step lengths, stride time, stride width of each 2-step segmentation (SAU)

Angular Statistics
- For each SAU, extract 5 statistics, i.e., average, standard deviation, min, max, angular speed out of the angles at each joint.

Graph-based Features
- Can capture the coordination between two parts of body and dynamics
- Human skeletal structure is modeled as a fixed undirected graph $G = (V, E)$ with the vertex set V corresponding to the 15 joints detected at each frame.
- The edge set E consists of the unweighted edges corresponding to the directly connected physical limbs of the human body.
- The difference in coordinates of all the joints between each pair of consecutive frames in one SAU can be regarded as a graph signal lying on the above defined skeletal graph G.

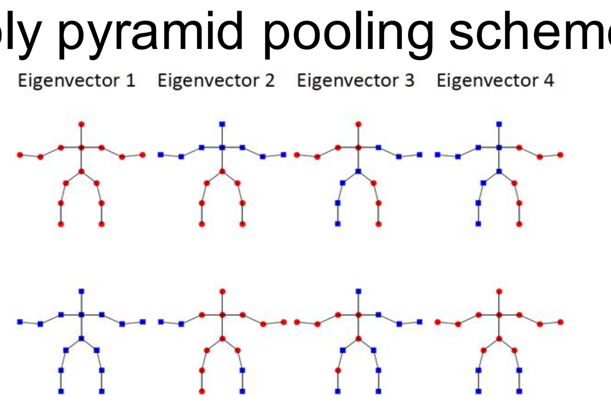
$$\boldsymbol{p}_{t,i} = [x_i^{(t)}\ y_i^{(t)}\ z_i^{(t)}],\ i \in \{1, \dots, 15\}, t \in \{1, \dots, T\},\ \boldsymbol{v}_{t,i} = \boldsymbol{p}_{t+1,i} - \boldsymbol{p}_{t,i}$$

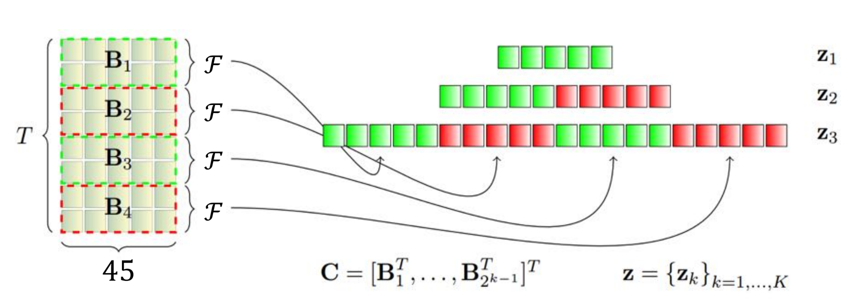
$$\mathbf{f}_a^{(t)} \in \mathcal{R}^{15} \text{ defined as } \mathbf{f}_a^{(t)}(i) = \boldsymbol{v}_{t,i}(a),\ a = \{x, y, z\}$$

- Graph Fourier transform (GFT) can provide frequency analysis to the graph signals, which defined as

$$\mathcal{L} = I - D^{-1/2} A D^{-1/2},\ \mathcal{L} = U \Lambda \mathrm{U}^{\mathrm{T}},\ \boldsymbol{F}_a^{(t)} = U^T \mathbf{f}_a^{(t)}$$

- Vectorize $C^{(t)} = \left[\boldsymbol{F}_x^{(t)}, \boldsymbol{F}_y^{(t)}, \boldsymbol{F}_z^{(t)}\right]$ to a row vector and concatenate into a transform coefficient matrix $\mathbf{C} \in \mathcal{R}^{(T-1)\times 45}$
- Apply pyramid pooling scheme to capture the dynamics





System Design

We propose a general methodology and insights into key factors for deploying an automated mobility assessment system based on cost-effective 3D sensors.

Hardware and environment:
- Field of view of the 3D sensors
- Estimation errors may be larger under certain situations.

Task:
- Prefer activities that can fully exploit and examine the mobility of all parts of the body.
- The level of difficulty in performing activities will affect the system capability.
- Better to have each task performed repeatedly by each subject

Experiments and Evaluation

Experimental Methodology
- 14 subjects with Parkinson's disease
- Perform standardized tests (e.g. walking) in front of Kinect sensor
- Skeletons are extracted in real time using Microsoft Kinect SDK
- Each action is performed 5 times when medication is in effect and another 5 times after medication wears off
- **Goal:** classify between ON/OFF medication states with captured motion data

Performance Evaluation
- Evaluate the system capability in terms of classification using different features, classifiers, tasks, schemes.

Feature	A (%)	P (%)	R (%)	F-M
Gait	63.58 (88.71/39.53)	57.26	55.40	0.51
Angle	75.30 (92.22/53.58)	75.01	74.20	0.74
Graph	82.41 (95.68/69.63)	83.04	81.93	0.82
All	84.79 (93.95/71.23)	85.43	83.38	0.84
PCA	84.66 (95.32/71.99)	85.30	84.44	0.85

Classifier	A (%)	P (%)	R (%)	F-M
SVM	84.79	85.43	83.38	0.84
Random Forest	83.09	83.68	83.09	0.83
k-NN	79.24	80.16	79.24	0.79
Decision Tree	72.66	72.92	72.66	0.73
Naive Bayes	71.02	71.64	71.02	0.70
SkR (AP)	87.41	87.61	87.40	0.87
Sk (AP)	87.28	87.49	87.29	0.87

Task	A (%)	P (%)	R (%)	F-M
Count	84.79 (93.95/71.23)	85.43	83.38	0.84
Tray	82.04 (94.44/53.63)	82.19	90.00	0.85
Walk	81.04 (96.05/48.99)	81.63	87.75	0.83

Classifier	A (%)	P (%)	R (%)	F-M
Naive Bayes	60.09	60.50	60.10	0.60
Decision Tree	62.98	63.00	63.00	0.63
SVM	67.13	67.10	67.10	0.67
Random Forest	75.67	75.90	75.70	0.76
k-NN	76.86	77.10	76.90	0.77

- Combination of three proposed features sets achieve the highest performance metrics.
- Graph-based feature are shown to be comparable to PCA-based feature, even with better interpretability, robustness to the noise and selection to the dataset, and comparability between different schemes.
- Subject-independent results are much worse because the effects of PD are highly person-dependent.
- Choosing appropriate type of captured actions can significantly improve the system capability.

Conclusion

- Propose a methodology to develop automated mobility assessment system with a single 3D sensor
- Propose graph-based feature, which achieves comparable performance while has better interpretability and robustness.
- Present an evaluation for a pilot study involving PD subjects, which supports the feasibility of using single 3D sensor to automatically assess the mobility and successfully classify the medication states.

Reference

- J.Y. Kao et al., Validation of Automated Mobility Assessment using a Single 3D Sensor, submitted to ACM SIGKDD'16.

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