A Computer Vision Framework for Finger Tapping Evaluation in Parkinson's disease

Taha Khan[1, 2], Dag Nyholm[3], Jerker Westin[1] and Mark Dougherty[1]

[1]Computer Engineering, School of Technology and Business Studies, Dalarna University, Falun, Sweden SE-78188

[2]School of Innovation, Design and Technology, Malardalen University, Vasteras, Sweden, SE-72123

[3]Department of Neuroscience, Neurology, Uppsala University, Uppsala, Sweden, SE-75185

DALARNA UNIVERSITY

BACKGROUND

In the paced finger-tapping test (PFT), subjects attempt to reproduce a sequence of stimuli by pinching their index finger and thumb together with a (near) constant time interval. The varying amplitude in tapping and the series of inter-tap intervals are important clinical features for symptom assessment. Typically, the PFT is visually assessed in clinical practice. In order to avoid cost and effort of applying wearable sensors, a computer-vision method is introduced for non-invasive PFT evaluation.

OBJECTIVE

To define and evaluate a Computer-Vision (CV) method for scoring PFT in Parkinson's disease (PD) using quantitative motion analysis of index-fingers and to compare the obtained scores to the UPDRS (Unified Parkinson's disease Rating Scale) finger-taps (FT).

METHODS

A database consisting of 221 PFT videos from 6 PD patients was processed. The subjects were instructed to position their hands above their shoulders besides the face and tap the index-finger against the thumb consistently with speed. The subjects were facing towards a pivoted camera during recording. The videos were rated by two clinicians between the symptom severity levels '0: normal', '1: mild', '2: moderate' and '3: severe' using UPDRS-FT.

The CV method (figure 1) incorporates a motion analyzer [1] and a face detector [2]. The method first detects the face of testee in each video-frame (figure 2b). The frame is split into two images from face-rectangle centre. Two regions of interest are located in each image to detect index-finger motion of left and right hands respectively (figure 2c). The tracking of opening and closing phases (figure 3) of dominant hand index-finger produces a tapping time-series (figure 4). This time-series is normalized by the face height (figure 2a). The normalization calibrates the amplitude in tapping signal which is affected by the varying distance between camera and subject (i.e. farther the camera, lesser the amplitude).

Figure 1. System diagram of video-based Finger-Tapping Quantification

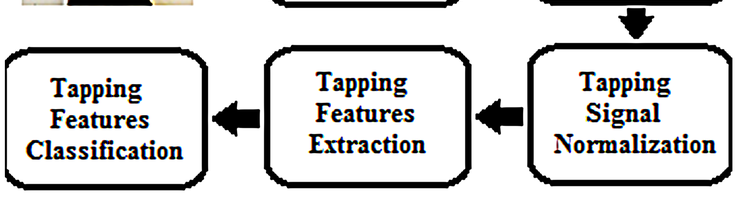
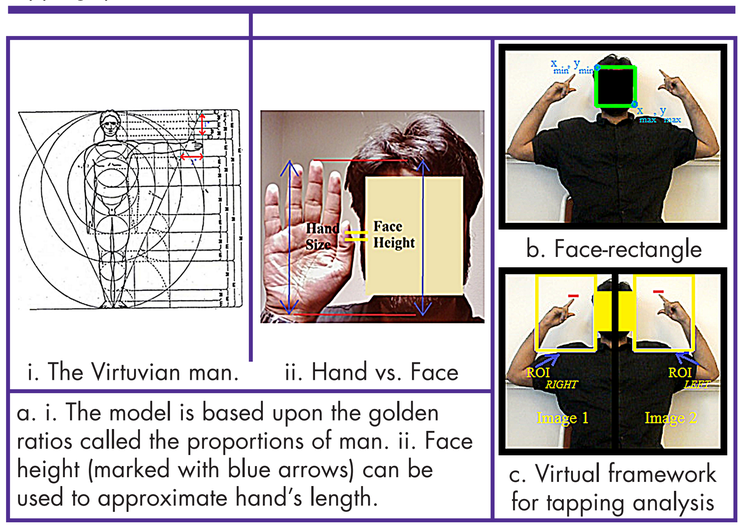


Figure 2. The Golden Ratio and the role of face detection in finger-tapping quantification.



i. The Virtuvian man. ii. Hand vs. Face

a. i. The model is based upon the golden ratios called the proportions of man. ii. Face height (marked with blue arrows) can be used to approximate hand's length.

b. Face-rectangle

c. Virtual framework for tapping analysis

Figure 3. Index-fingers motion detection. Motion orientation of index-fingers in ROI_{left} and ROI_{right} respectively is determined to identify the opening and closing phases of tapping. Tip of index-fingers are marked (red) to locate finger coordinates over time to produce a tapping signal.

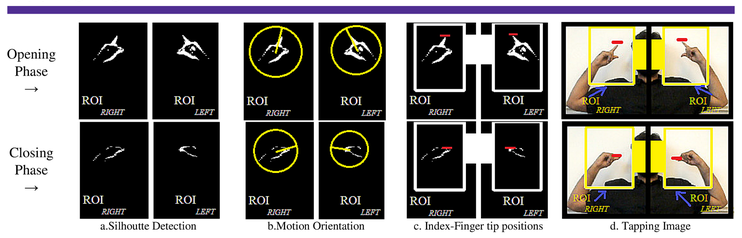
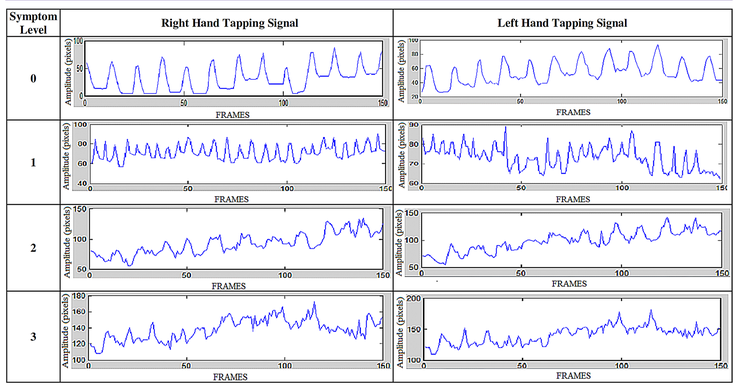


Figure 4. The tapping signals produced by the video processing of representative clinically rated samples. The tapping rhythm deteriorates as well as the amplitude decreases with the increase in symptom levels. Non-dominant (left) hand tapping signals deteriorates more than the dominant (right) hand.



The target ratings provided by the two raters were averaged. A total of 15 features (table 1) were used for tapping quantification. Guttman correlation analysis [3] between the features and the averaged UPDRS-FT ratings was performed. The strongly correlated features were selected and were used to classify the averaged UPDRS-FT levels using the K-nearest neighbor classifier (KNN) [4].

RESULTS AND DISCUSSION

The Guttman correlation coefficient (μ2) between PFT features and the averaged UPDRS-FT ratings was strong, i.e. μ2 was 0.51, -0.57, -0.57, -0.57, 0.55, -0.55 and 0.5 for ΔTn, VTs, ΔVA, VA, Tz, AvgCCNP and FS respectively. A 10-fold cross validation [5] in KNN classified the selected features between 3 UPDRS-FT levels with an accuracy of 78%. An average area under the receiver operating characteristic curves of 82.6% supports feasibility of the obtained features to replicate clinical assessments. The classification results obtained from the KNN algorithm are shown in table 2. Each matrix row represents the actual class instances while each matrix column represents the instances in a predicted class. Matrix (numbers in bold) depict high true positive rates in averaged symptom classes '0.5' (83.2%), '1.5' (80.1%) and '2.5' (86.3%).

CONCLUSIONS

The system is able to track index-finger motion to estimate tapping symptoms in PD. It has certain advantages compared to other technologies (e.g. magnetic sensors, accelerometers etc.) for PFT evaluation to improve and automate the ratings. The uniqueness of this system is the utilization of facial features to normalize the tapping signal and to cope with camera calibration. Moreover, the method only requires a computer with a webcam. The subjects can perform the tapping task naturally in the same manner as instructed by movement disorder experts. An added advantage is that the subject's face in a tapping video can be localized and blurred to avoid ethical issues in publishing and data sharing. The portability and ease of use makes it possible to perform the clinical assessments in the home environment.

REFERENCES

1. G. R. Bradski, J.W. Davis, Motion segmentation and pose recognition with motion history gradients, Mach. Vision. Appl., 13 (2002) 174-184.
2. M.A. Turk, Face recognition using Eigenfaces, in Proc. IEEE CVPR 91, 1991, pp. 586-591.
3. L. Guttman, A Basis for Scaling Qualitative Data, AM SOCIOL REV, 9 (1944) 139-150.
4. P. Soucy, G.W. Mineau, A simple KNN algorithm for text categorization, in Proc. IEEE Int. conf. Data Mining, San Jose, CA, USA, 2001, pp. 647-648.
5. M. Stone, Cross-Validatory Choice and Assessment of Statistical Predictions, JSTOR, 36 (1974) 111-147.

Table 1. The Tapping Features. Features incorporate clinical symptoms (i.e. slow paced, amplitude reduction between index-finger and thumb, fatigue and arrhythmia) visually inspected by clinicians to rate between the UPDRS-FT levels.

Symbol	Feature Description	Related Symptom (based on UPDRS-FT*)
1. T_n	Total number of taps	Slowed Pace
2. ΔT_n	Difference between number of taps in time slot 1 and 2.	Fatigue
3. T_s	Tapping Speed	Slowed Pace
4. VT_s	Variation Coefficient (VC) in Tapping Speed	Fatigue
5. ΔA	Difference between the average maximum amplitude of finger taps in time slot 1 and 2.	Fatigue and Amplitude Reduction
6. ΔVA	Difference between the VCs in average maximum amplitude of finger taps in time slot 1 and 2.	Fatigue and Amplitude Reduction
7. VA	VC in average maximum amplitude in finger taps	Fatigue and Amplitude Reduction
8. O_T	Average Opening Velocity of index-finger.	Slowed Pace
9. C_T	Average Closing Velocity of index-finger.	Slowed Pace
10. Ac	Tapping Acceleration.	Slowed Pace
11. T_Z	Average Zero-Crossings	Slowed Pace
12. T_E	Signal Energy.	Slow Pace and Amplitude Reduction
13. Avg_{CCNP}	Mean of Cross-Correlation between the Normalized Peaks.	Arrhythmia
14. Avg_{CCNV}	Mean of Cross-Correlation between the Normalized Valleys.	Arrhythmia
15. FS	Standard Deviation of face-rectangle centroid during PFT.	-

*UPDRS-FT (Patient taps thumb with index finger in rapid succession.)
0 = Normal
1 = Mild slowing (in pace) and /or reduction in amplitude
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement (i.e. mild arrhythmia)
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement (i.e. severe arrhythmia)

Table 2. Classification Matrix. The matrix presents system performance based on a comparison between the averaged UPDRS-FT ratings of tapping videos by the clinicians (y-axis) and the corresponding predicted UPDRS-ratings by the system (x-axis). The numbers in bold-italic depict a remarkable match between the system ratings and clinician ratings.

Predicted Ratings by the Computer Method \ Averaged UPDRS-FT Ratings by the clinicians	Normal-Mild '0.5'	Mild-Moderate '1.5'	Moderate-Severe '2.5'
Normal-Mild '0.5'	**53**	13	3
Mild-Moderate '1.5'	10	**72**	12
Moderate-Severe '2.5'	2	9	**47**

Corresponding author: Taha Khan, Phone: +46 23 77 80 00, Fax: +46 23 77 80 50, E-mail: tkh@du.se.