Measurement of bradykinesia for the detection of Parkinson's disease

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ABSTRACT

Non-motor and motor symptoms that are linked with Parkinson's disease are often clinically assessed by neurologists using the Unified Parkinson's Disease Rating Scale (UPDRS). UPDRS scores are described as qualitative and are dependent on neurologist's experience. Consequently, clinical scores may differ among neurologists. We develop an application for measuring bradykinesia in the UPDRS finger tapping task, with which patients are recorded with a depth camera and by analyzing videos, given a more objective rating. In the first stage, we detect touches and thumb's and pointer's fingertips. Following, we calculate distances between the fingertips. From distances we then extract finger tapping features. We record a group of people with Parkinson's disease and a control group. Furthermore, we define a model that best separates instances with different UPDRS scores. Considering the small number of training data, the model successfully separates the instances, however, we need to obtain more data for classification.

Keywords

bradykinesia, finger tapping, Unified Parkinson's Disease Rating Scale

1. INTRODUCTION

Parkinson's disease is a progressive neurodegenerative chronic disease, where early diagnosis is of utmost importance for inhibition of further progression of the disease and the onset of more serious symptoms that do not effect only quality of life [3]. Due to the lack of a diagnostic test, Parkinson's disease is often misdiagnosed or overlooked because of common symptoms with other diseases. Bradykinesia, which is one of the motor symptoms of Parkinson's disease, refers to the slowness of movement, decrease in amplitude and speed during performing repetitive movements of body segments [2].

For assessment neurologists usually use the Unified Parkinson's Disease Rating Scale (UPDRS) [4], that consists of four parts. The first part deals with self-evaluation of non-motor experiences of daily living, second with self-evaluation of motor experiences of daily living. The third part deals with motor examination and the fourth part assesses complications in treatment.

We develop an application for assessing finger tapping, which is one of the motor tasks examined in the UPDRS, with a more objective rating. Finger tapping task consists of 10 taps, where the patient is instructed to tap their index and thumb fingers 10 times as quickly and as big as possible. In the first stage we detect touches and thumb's and pointer's fingertips, then calculate distances between the tips. From the distances, we define features that represent UPDRS characteristics such as amplitude decrements, slowness, interruptions, hesitations and halts.

Individual tasks in UPDRS are rated with a score, ranging from 0 to 4. Both the left and the right hand is rated, separately. Requirements for each score of the finger tapping task are as follows:

- 0: Normal: No problems.
- 1: Slight: Any of the following: a) the regular rhythm is broken with one or two interruptions or hesitations of the tapping movement; b) slight slowing; c) the amplitude decrements near the end of the 10 taps.
- 2: Mild: Any of the following: a) 3 to 5 interruptions during tapping; b) mild slowing; c) the amplitude decrements midway in the 10-tap sequence.
- 3: Moderate: Any of the following: a) more than 5 interruptions during tapping or at least one longer arrest (freeze) in ongoing movement; b) moderate slowing; c) the amplitude decrements starting after the 1st tap.
- 4: Severe: Cannot or can only barely perform the task because of slowing, interruptions or decrements.

2. APPLICATION IMPLEMENTATION

Our application includes a simple user interface, logic for recording and analyzing recorded videos, and a database for storing and reviewing results. Recording is done with an

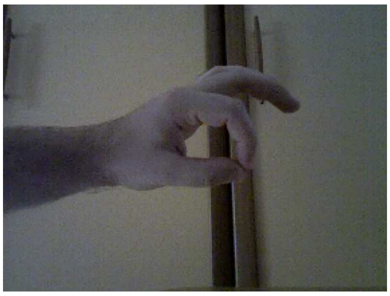

Figure 1: Example of a hand perpendicular to the camera's direction of recording.

ASUS Xtion PRO LIVE depth camera. The resolution of the depth image is set at a maximum of 640×480 pixels at 30 frames per second. Some rules were set for recording for better results:

- There must be only one hand in the scene,
- the hand should be positioned as perpendicular as possible to the camera's direction of recording as visible in figure 1,
- the hand must be at least 0.6 meters away from the camera due to the range of the camera and must not be too far,
- other fingers should not be curled into a fist,
- recording should take place in a room not too exposed to sunlight,
- fingertips must be tapped 10 times as fast as possible and as big as possible.

2.1 Fingertip and touch detection

In the first stage, the hand needs to be separated from the background. Since patients are recorded in a way that the hand is the closest object, the closest pixels in a defined area can be taken. We also crop the image to exclude a portion of the arm we have no interest in.

Firstly, to detect fingertips we blur the image, using a median filter. Next, we remove excessive fingers using Canny edge detector. The hand is not always completely perpendicular to the direction of recording, so thresholds of Canny edge detector are not set too high, otherwise needed parts of the hand could be deleted. After deletion, we apply a morphological operation of closing to fill any holes that formed.

Occasionally excessive fingers do not get deleted with Canny edge detector. We use an algorithm that reduces an image to a 1-pixel wide skeleton. We iterate through the skeleton pixels and check for an adequate difference in depth of neighbouring pixels. Pixels further away get deleted along with the branch of the skeleton they were on. Two closest tips of branches are accepted as index and thumb fingertips, where the higher positioned tip is the index fingertip.

After deletion, we apply a morphological operation of dilation on the skeleton and then extract contours from the

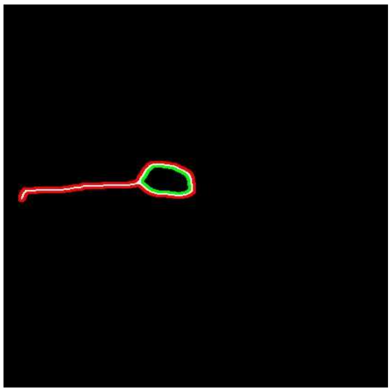

Figure 2: Example of a hand perpendicular to the camera's direction of recording.

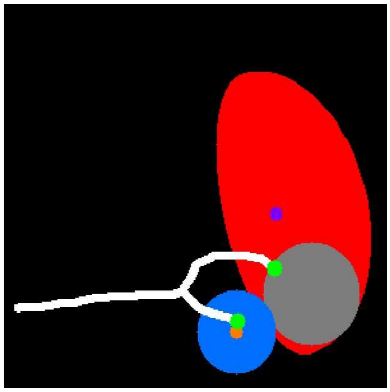

Figure 3: Typical regions of interest and the skeleton of a hand. Green circles represent the fingertips, the orange circle is the median of the fingertips of the thumb, and the purple circle is the median of the fingertips of the index fingers. The blue circle represents the first region, the gray region the second region, and the red image represents the third region composed of two parts.

image. The largest contour represents the whole hand, in case of a touch, a smaller contour on the inside of the fingers, as illustrated in figure 2, is formed, with which a touch is detected.

2.2 Correcting misdetections

The closest points do not always represent the tips of the thumb and index fingers. To correct fingertip detection errors, we calculate the median of index and thumb fingertips every 20 images where a touch has not been detected. This way we reduce the impact of smaller hand movements and amplitude decrements. Based on the distance between the medians of fingertips, we define 3 regions of interest. The first one is a circle with it's center in the median of the thumb's fingertips. The second one is located in the middle of the distance offset from the hand. The last one is composed of an angled ellipse and semi-ellipse, so it captures the index finger movement better. Regions are displayed in figure 3. Most of misdetections occur when there is an excessive branch originating near the joint of the index finger where it's tip is closer than the index's fingertip. By making the 3rd region's ellipse narrower, we can avoid those misdetections. Tips of branches are accepted as fingertips based on if the tip is in the regions and the distance to the centres of regions. Besides, we calculate the median length of index and thumb fingers. Branches where the tip is located on must be approximately the right length, for it to be considered a thumb or index finger.

Next, we calculate z-score for every tip of a branch for x and y coordinates calculated as

$$z = \frac{x - \overline{x}}{\sigma}$$

where: x is the coordinate, $\overline{x}$ is the mean of the coordinates and σ is the standard deviation of the coordinates.

If absolute z-scores of both coordinates of a tip are under 3 and are the lowest of all other tips' absolute z-scores, we accept the tip as a fingertip, otherwise we mark the image's fingertips as undetected.

Touches are detected if more than one contour is found in an image. The occurrence of a second contour does not always mean a touch occurred, so correction is necessary. Based on the size and position of all second contours we set a minimal size requirement and restrict the location of the contour's centre.

2.3 UPDRS score calculation and results

To calculate the UPDRS score, we recorded a group of people with Parkinson's disease at a neurological clinic at the University Medical Centre Ljubljana. Patients were instructed to tap their thumb and index finger 10 times as fast as possible and as big as possible, i.e. 10 cycles of opening and closing. Each patient was given a clinical evaluation of the left and the right hand by a neurologist. We recorded 16 people. With recordings of left and right hands we got a total of 32 recordings. Out of the 32 recordings, all touches and fingertips were correctly detected in 12 recordings. Due to the limited space at the clinic, we had to move the camera between recordings of left and right hands, which caused problems. Depth measurement was also adversely affected by sunlight. The biggest reason for misdetections was the poor adherence to rules described in the beginning of section 2. In some recordings, hands were not placed sufficiently perpendicular to the direction of recording, causing problems in detecting touches or fingertips or both. In other recordings, patients curled the rest of their fingers into a fist. Some patients tapped with their finger pads instead of their fingertips. Tapping with pads can easily turn into tapping with your thumb pad and the joint. Since we rely on the contours for detecting touches, such tapping, low resolution, camera distance, and other influences can cause errors in measuring depth and make it harder to find a contour. An example of such errors is shown in figure 4.

The control group was recorded after. By following the rules more closely, we have achieved a better result. Out of 12 recordings, we have successfully detected touches and fingertips in all 12 recordings.

The UPDRS score consists of the slowness of finger movement, amplitude decrements, number of interruptions, hesitations and halts. For the purpose of identifying the listed properties, we extracted the following attributes from distances between the fingertips:

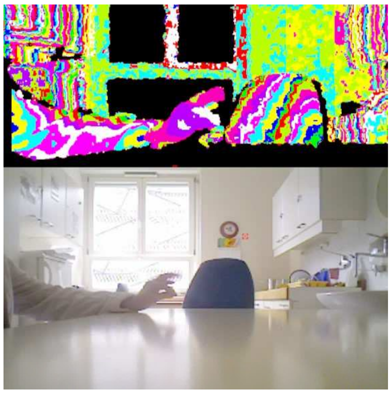

Figure 4: Errors in measuring depth. The depth image is represented with colored bands (top image).

- mean, standard deviation and slope of amplitudes (pAmp, sdAmp, sAmp),
- differences in percentage between the mean of all amplitudes except the last and the last amplitude, between the mean of the first and second half of amplitudes, and between the first and the mean of all other amplitudes (Damp1, Damp2, Damp3),
- mean, standard deviation, and slope of the mean opening, closing, and full-cycle velocities (mVopen, sdVopen, sVopen, mpVclose, sdVclose, sVclose, mVcyc, sdVcyc, sVcyc),
- mean, standard deviation and slope of maximum opening and closing velocities (mMVopen, sdMVopen, sMVopen, mMVclose, sdMVclose, sMVclose),
- mean, standard deviation and slope of percentage of time of a cycle to maximum opening velocity (mTMVopen, sdTMVopen, sTMVopen),
- mean, standard deviation and slope of cycle duration (mLen, sdLen, sLen),
- mean, standard deviation and slope of touch duration (mTou, sdTou, sTou),
- mean, standard deviation and slope of mean acceleration (mA, sdA, sA),
- number of interrupts (Inter),
- hesitation index (Hesit),
- number of halts (Halt).

Amplitudes are calculated as the maximum distance between fingertips in a cycle. We calculate decrements as described in the UPDRS with Damp1, Damp2, Damp3 and by using linear regression.

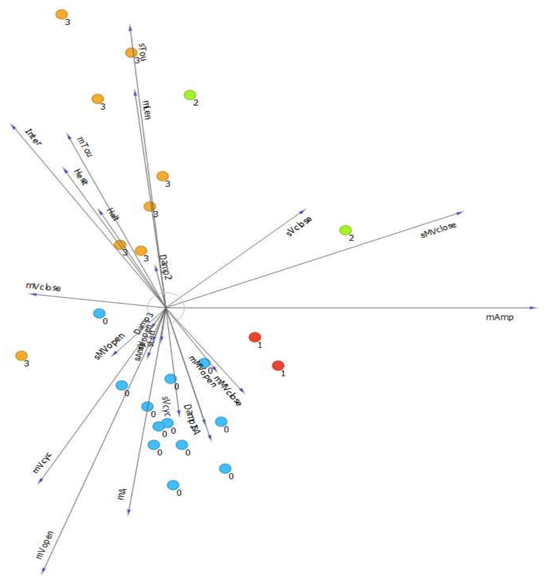

Figure 5: Optimized linear projection in Freeviz. The instances are colored according to the UPDRS scores that are displayed next to the instances.

We divide speed into mean opening, closing velocity and the velocity of the entire cycle. Opening velocity is defined by absolute differences of distances from the beginning of opening to the amplitude in the cycle divided by the travel time, similarly, closing velocity with absolute differences of distances from the amplitude to the end of closing, and velocity of the entire cycle from the beginning of opening to the end of closing. In addition to the average velocity, speed is also expressed with means of cycle and touch durations, maximum opening and closing velocities, and average accelerations in cycles. We obtain changes with linear regression.

Halts are longer arrests in movement. We detect halts if the difference between the cycle duration and the approximation, calculated by Theil–Sen estimator, is above a certain threshold as calculated in [5].

Hesitations occur at the start of an opening or closing. We detect hesitations with an index, calculated by summing up the absolute differences between the percentage of time of a cycle to the maximum opening velocity and the approximation, calculated by Theil–Sen estimator, similarly as done in [6]. In a case of no hesitations the index will be close to 0.

Interruptions are changes in regular rhythm and occur during opening or closing. A healthy person will perform one smooth opening and closing, while a person with Parkinson's disease will need multiple shorter openings or closings. We detect interruptions if velocity changes it's sign more than once as done in [5].

We visualize results in Freeviz, which is a part of an open-source programme Orange [1]. By optimizing the linear projection shown in figure 5, we get a model that best separates instances with different UPDRS scores. The usefulness of attributes is also shown with arrows. The shorter the arrow, less useful the attribute is. As seen, Damp2, sVopen, sLen are the least useful. The model groups instances with scores 0, 1, 3 rather successfully, however more recordings are required to define a classifier.

3. CONCLUSIONS

We developed an application for measuring bradykinesia with the purpose of solving the subjectivity in the evaluation of patients with Parkinson's disease. We detected touches and fingertips and calculated distances between the fingertips. From the distances, we have extracted several attributes and built a model, that best separates instances with different UPDRS scores. Due to the small amount of recordings, we could not define a classifier, however we will be gathering more data for that purpose.

We have successfully detected touches and fingertips in less than half of the recordings of the group of people with Parkinson's disease, however, by following the rules we set more closely, we have greatly improved our success rate. The biggest problems with detection are caused by improper tapping, clenching the other fingers into a fist and over-tilting the hand.

With the classifier defined, the application could be used in clinics to evaluate patients more objectively. Analysis of other motor tests described in UPDRS would be essential, since finger tapping is only one among other tests.

4. ACKNOWLEDGMENTS

We would like to thank asist. prim. Dušan Flisar, MD, for his help in evaluating patients and provided assistance.

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