

# Quantitative Measurement of Bradykinesia in Parkinson's Disease using Commercially Available Leap Motion

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**Abstract:** Parkinson's Disease (PD) is a neurodegenerative disease caused by the depletion of dopamine in the brain. Tremor, bradykinesia, rigidity and postural stability are the four major symptoms. Like other symptoms, bradykinesia causing unnatural stillness/slowness in motions affects the daily life of the patients. The levels of these symptoms are clinically assessed by a scoring system based on Unified Parkinson's Disease Rating Scale (UPDRS). However, UPDRS relies on the visual observations of physicians rather than a test based on quantitative measurements. This makes it not only difficult to repeat but also subjective. Because of these two major disadvantages, researchers build custom devices for their studies. But this leads to the reliability issues and non-standard measurements. Thus, 24 PD patients were bilaterally UPDRS III (motor subsection) scored and recorded for finger motion (pinching) by using commercially available off-the-shelf (COTS) product called Leap Motion. The various features extracted from recordings and UPDRS III scores were analyzed for correlation. After the analysis, a linear model was created to estimate UPDRS III score. The study revealed that Leap Motion, a COTS device, can be used to estimate bradykinesia of a patient with PD.

## 1 INTRODUCTION

Bradykinesia which results in unnatural stillness/slowness in the motions is one of the early symptoms of Parkinson's Disease (PD). Together with tremor, rigidity, and postural instability, they are named as four cardinal symptoms of the disease (Calne et al., 1992). The main cause of bradykinesia is the dopamine deficiency in basal ganglia from which the inhibitory signals are sent to the motor systems to prevent involuntary actions. Under normal circumstances when the dopamine is present, basal ganglia promotes those motor actions so that the body can act swiftly (Blandini et al., 2000). Because of further depletion of dopamine in later stages, bradykinesia follows the progression of the disease and it gets worse.

The level of disease and its symptoms are evaluated by Unified Parkinson's Disease Rating Scale (UPDRS). UPDRS scoring, which is based on the observations of the physician conducting it, is the main clinical approach to diagnose and assess the progression of the disease. Even though UPDRS

III (motor subsection) covers almost all the aspects of the motor symptoms (Fahn et al., 1987) it depends on the subjective scoring of the physicians. In addition to this inconsistency, the discreet rating scale cannot detect the subtle changes in the symptoms such as bradykinesia. Therefore, UPDRS solely is not adequate for research or treatment of PD.

Various researchers (Dunnewold et al., 1997; Salarian et al., 2007; Kandori et al., 2004; Ghassemi et al., 2006; Sande de Souza et al., 2011; Marsili et al., 2014; Daneault et al., 2013) have tried many different assessment techniques to overcome the inadequacy of UPDRS for detecting bradykinesia. All these techniques are mostly focused on rapid alternating movements (RAM) or finger tapping/pinching. For example, Dunnewold et al. (1997) used tap rate (TR) and movement time (MT) to assess slowness in the motion. Similarly, Ghassemi et al. (2006) used another RAM which is pronation-supination action to measure bradykinesia. However, in Ghassemi et al.'s work, the pronation-supination action did not show a significant

correlation with the bradykinesia level unlike the tapping and alternating hand movements used in other studies. Nonetheless, Daneault et al. (2013) clarified those odd findings by showing that the maximal and mean velocity of pronation-supination cycles has significant correlation rather than the cycle duration. Even though all the studies agree that RAM based tasks can be used in assessing bradykinesia level, the measurement techniques are relying on wide variety of devices such as accelerometers (Dunnewold et al., 1997), gyroscopes (Salarian et al., 2007), magnetic devices (Kandori et al., 2004; Ghassemi et al., 2006), and EMG sensors (Sande de Souza et al., 2011). The common problem of all these devices is that they are depending on custom designs or setups. In other words, they are not commercially available off-the-shelf (COTS) products.

The objective of this study is to develop a new method to measure bradykinesia in PD patients by using COTS product called Leap Motion. Thus, the efficiency of Leap Motion is studied by recording various motor tasks performed by PD patients. The recorded data is analyzed for its various features against the UPDRS scores. The aim is to be able to utilize this easily available and relatively cheap device for daily tracking of patients and their treatments. The study is approved by the local Ethics Committees of Koç University Hospital, İstanbul, Turkey and all participants gave informed consent prior to the study.

## 2 METHODS

### 2.1 Measurement Device

Leap Motion (Leap Motion, Inc., San Francisco, USA) is a motion controller device to capture hand gestures by using pair of cameras and infrared lighting. It is a fairly compact device and very powerful to capture obvious hand motions like pinching and pronation/supination. Figure 1 shows the device interior and its compact design.



Figure 1: The representation of interior design of Leap Motion taken from its product page.

Weichert et. al. (2013) analyzed the accuracy of leap motion controller and found that it can achieve 0.7 mm overall average accuracy in all 3 axes. This result is comparable to the average human hand accuracy, 0.4 mm. Besides the accuracy, the controller is able to sample the hand motions around 100 Hz.

### 2.2 Recorded Motor Tasks and Features

Pinching and Pronation-Supination are the two motor tasks given to the subjects. In this study, we will report preliminary results from the pinching task only. Other data will be reported separately. With the software developed on top of Leap Motion SDK, the positions and rotations of the finger joints and wrist are recorded during these tasks. After the recording session, the raw data is processed and several features are extracted. For the pinching, the local minima and maxima of the distances between thumb and index finger are marked. Afterwards, the time difference between the consecutive minimum and maximum is calculated.

By using the time difference and distance obtained from the raw data processing, the speed, acceleration, and frequency of a motion are calculated. In previous studies, it was shown that those three measures can be used to assess bradykinesia. (Dunnewold et al., 1997; Daneault et al., 2013)

### 2.3 Subjects and Experiment Protocol

24 patients (7 female, 17 male, mean age  $\pm$  SD =  $57.08 \pm 8.91$ ) who were diagnosed by neurologist for PD participated in the experiment. All patients were under dopaminergic replacement treatment and their disease duration was  $8.04 \pm 3.88$  years. 20 patients were right-handed whereas 4 patients were left-handed. They came to the hospital in 12-hour OFF state (without medication) and two independent neurologists immediately evaluated UPDRS III (motor section) bilaterally. The average of those two scorings was considered as the final bilateral UPDRS scores ( $\mu_{left} \pm SD_{left} = 11.49 \pm 4.61$ ,  $\mu_{right} \pm SD_{right} = 12.28 \pm 5.15$ ). The patients were not specifically marked as tremor or bradykinesia dominant.

The patients visited hospital multiple times for another ongoing study for the data acquisition. There was at least one week difference between visits. 9 patients came to hospital twice and 15 remaining patients were recorded three times. In every case, the

patients were seated against a laptop computer to which the leap motion controller is connected. The controller was laid on the table. To familiarize the patients with the device and to test the setup, they were asked to put their hand above the controller and move their fingers as shown in Figure 2. It was visually verified that the controller was capturing the gestures.

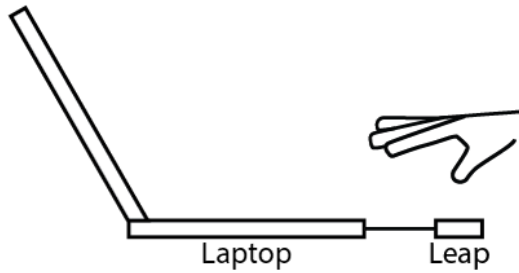


Figure 2: Basic recording setup with laptop and leap controller.

After the initial UPDRS scoring and familiarization was completed, the participant started to experiment. During the study, the motor tasks given to the patients were recorded in 3 successive sessions for both hands. Namely, one patient has total 12 recordings (6 pinching, 6 wrist motion) per hospital visit. At the end of the data acquisition phase, total 378 recordings were taken for pinching. The important part of the study is that before each session, bilateral UPDRS III scoring was evaluated by the same neurologists. The reason for the repeated scoring is to capture the subtle changes in the symptoms between the visits and different sessions. Each motion task was recorded at least 10 seconds for both hands one after another.

### 2.4 Analysis and Statistics

Regardless of the session and action hand, the feature extraction was applied onto all recordings. Because of the fixation problems observed in the data (Figure 3), the first several extracted values of each feature (time difference, distance, and angles) were removed. With remaining features, the mean and standard deviation of speed, acceleration, and frequency were calculated. By comparing the mean and standard deviation of each metric, it was decided if the patient could perform the task correctly or not. Table 1 lists several exemplary values discarded because of having large deviations. In other words, the examples in the table have SD values which are almost comparable to the corresponding mean values.

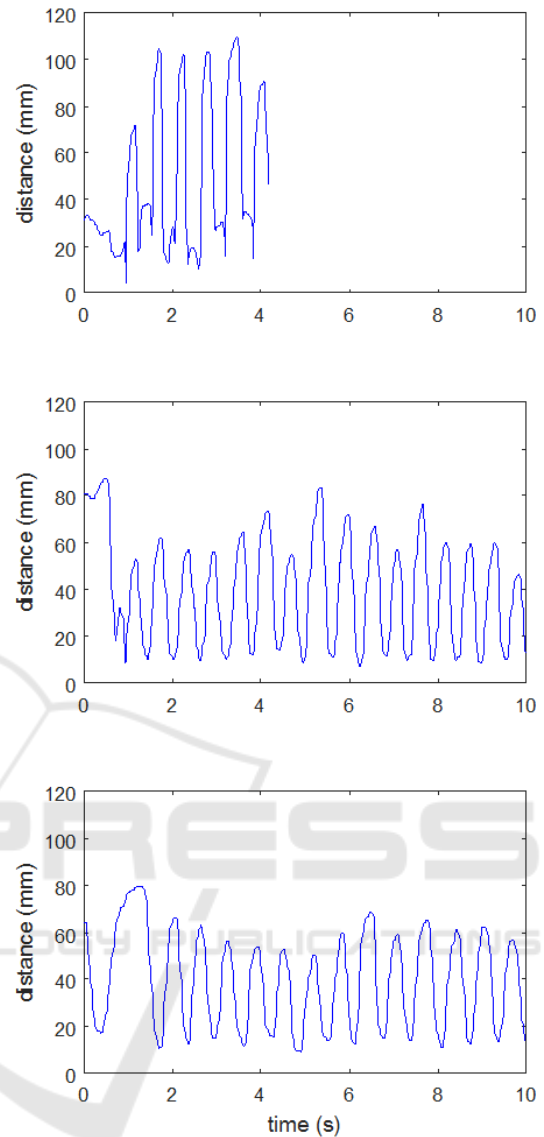


Figure 3: Change of the distance between thumb and index finger during pinching for 3 different patients. The fixation problem can be seen at the start (before 2 seconds) of signal where the pattern is distorted.

Table 1: Discarded speed values because of large SD.

Mean Value (mm/s)	SD (mm/s)
216.80	129.36
689.53	543.78

Since the bilateral UPDRS scores were independently taken before each session, the values calculated for both hands were pooled together as Marsili et al. (2014) did. Similarly, the recordings of all the visits and their three distinct sessions were also combined. This data pooling process was done separately for each motor task. After obtaining the

two big sets of recordings, the correct metric was selected for pinching and pronation-supination, respectively. Thus, Pearson's correlation was applied between UPDRS scores and three metrics derived from extracted features.

Later, by using all the metrics of both motor tasks, a linear regression model as in Equation 1 was derived to improve the link between UPDRS III and the data gathered from the controller. The correctness of the model was evaluated by the root-mean-square error defined by Equation 2.

$$U' = a_1 f_1 + \dots + a_n f_n + b \quad (1)$$

$$e_{rms} = \sqrt{\frac{\sum_{i=1}^n (U'_i - U_i)^2}{n}} \quad (2)$$

### 3 RESULTS

Some patients couldn't complete the tasks given to them. There were 9 such sessions that were excluded from the study. Unrelated to the data content, the data belonging to one patient were discarded because of invalid UPDRS scoring. The features of 43 pinching recordings couldn't be extracted because of invalid or missing data. As a result, these 43 data were also removed from the data pool.

The investigation of mean and standard deviation of metrics calculated for remaining sessions revealed that almost half of the data for each metric have large deviations (*speed* = 49%, *acceleration* = 59%, *frequency* = 40%). Since it is not possible to include these inconsistent values, the correlation study was completed by discarding them.

Firstly, the pinching task was analyzed and it was found that there were very low correlations ( $r_{speed} = -0.222$ ,  $r_{acc} = -0.112$ ,  $r_{freq} = -0.144$ ) between the pinching metrics and their respective contra-lateral UPDRS III scores. However, when the analysis was conducted against the ipsi-lateral scores, a moderate correlation was obtained ( $r_{speed} = -0.512$ ,  $r_{acc} = -0.398$ ,  $r_{freq} = -0.337$ ,  $p < 0.001$ ). UPDRS III motor section contains many items focusing on a specific symptom. Thus, the correlation study was repeated against the bradykinesia subset of UPDRS III because the pinching performance should be mostly affected by bradykinesia. As expected, the results ( $r_{speed} = -0.562$ ,  $r_{acc} = -0.453$ ,  $r_{freq} = -0.388$ ,  $p < 0.001$ ) got better for all three metrics. In the end, the speed is the best metric for the pinching.

Even though the speed was selected as the best metric for pinching, the values were fitted to create linear model from all metrics as in Equation 3 ( $s = speed$ ,  $a = acceleration$ ,  $f = frequency$ ) to estimate UPDRS III score.

$$U' = k_1 s_{pinch} + k_2 a_{pinch} + k_3 f_{pinch} + b \quad (3)$$

$$z_e = \frac{e_{rms}}{\max(UPDRSIII)} \quad (4)$$

The correlation between pinching and bradykinesia was significant so should be the linear model when the features of pinching is selected as sole predictors. The important point is that this model had small root-mean-square error ( $e_{rms} = 4.37$ ) for estimating total UPDRS III score. To better visualize the error, it is normalized ( $z_e = 0.078$ ) by the max value of UPDRS III as in Equation 4.

Because of stronger correlation with bradykinesia subset in pinching, the linear model was also created for UPDRS III bradykinesia score. As expected, the error of this model was similarly small ( $e_{rms} = 2.13$ ,  $z_e = 0.107$ ). Even though the normalized value was slightly bigger than the error in the total score case, it was not significantly different.

Instead of using whole data to create the model, the training procedure was repeated by using randomly selected 75% of the data. After training, the remaining 25% of the data was used for testing the model. This training-testing procedure was repeated 100 times for the different randomly selected training set. After 100 repetitions, the average RMSE values were calculated. The results of trained model were similar to the previous approach for both total UPDRS III ( $e_{rms} = 4.37$ ,  $z_e = 0.078$ ) and bradykinesia subset ( $e_{rms} = 2.12$ ,  $z_e = 0.107$ ) cases. The important finding was that error of estimations was ( $e_{rms} = 5.59$ ,  $z_e = 0.099$ ) and ( $e_{rms} = 2.90$ ,  $z_e = 0.145$ ) respectively.

### 4 DISCUSSIONS

In this study, we showed that a COTS device can be used in simple setup to assess the bradykinesia level of the patient with PD. Furthermore, it is important that the assessment was done by using a quantitative metric acquired from the device. By comparing the measurements with the UPDRS III scores which are based on the subjective observations of physicians, it was seen that this method can be used as a fast and

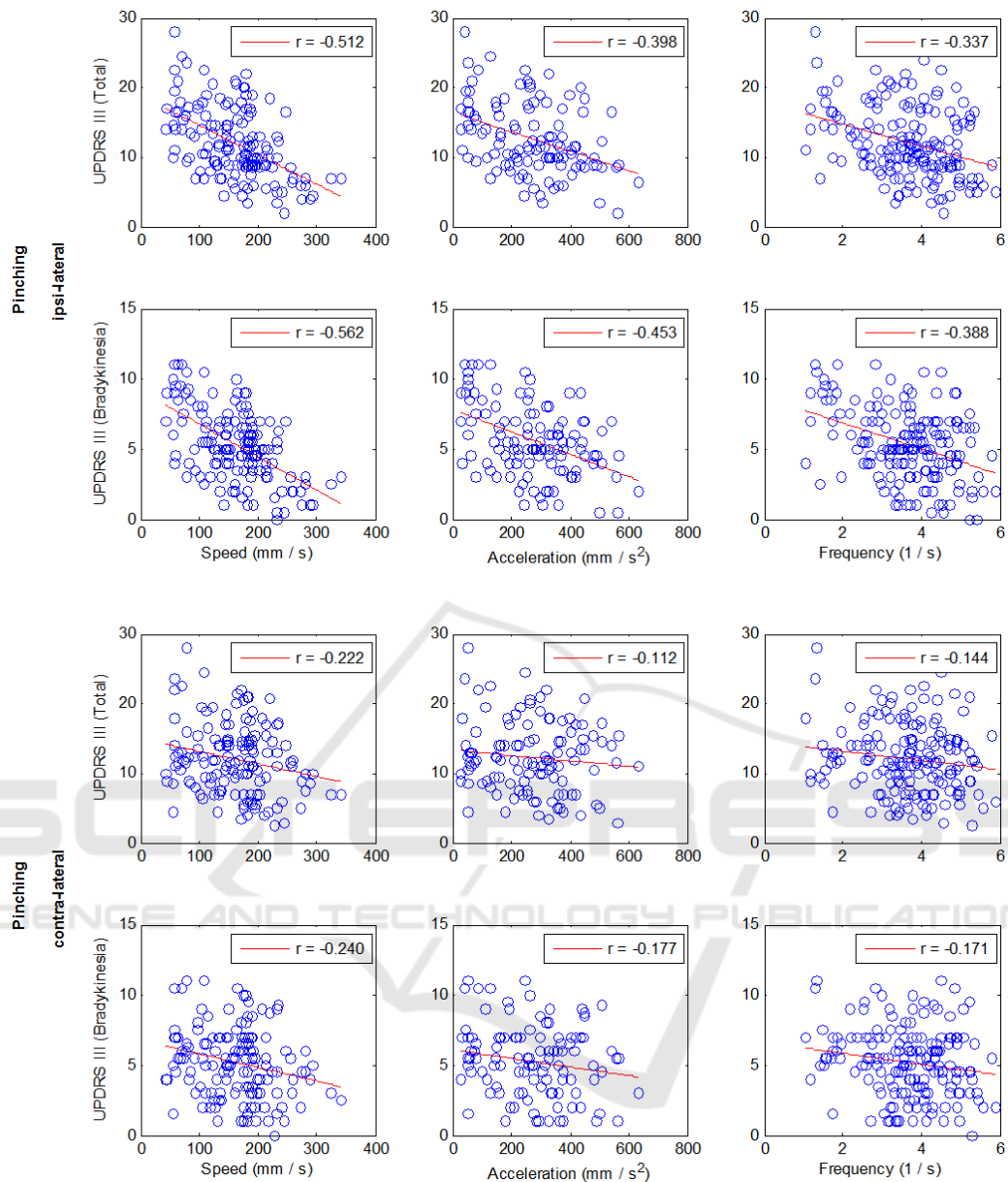


Figure 4: Distribution of UPDRS III total score and bradykinesia subset against the three metrics (speed, acceleration, frequency) extracted from the pinching recordings. The metrics are the combination of data from all the session for both hands. The upper two rows show the ipsi-lateral results while the bottom two rows belong to contra-lateral results. As expected, the speed showed the highest correlation ( $r = -0.512$ ,  $p < 0.001$ ) and the correlation ( $r = -0.562$ ,  $p < 0.001$ ) increases by using bradykinesia subset. Furthermore, the contra-lateral analysis revealed that there was no correlation between the total ( $r = -0.222$ ,  $p < 0.001$ ) and the metrics. Even using bradykinesia subset ( $r = -0.240$ ,  $p < 0.001$ ) scores did not improve it.

reliable alternative. The main advantage of this technique is that it helps the physician by keeping the process completely objective, thus, they can better decide on treatment regime. Nevertheless, the number of invalid data suggested that the patients need further familiarization with the task and device. This can be overcome by extending the recording

time and the familiarization time. The exclusion of data could be done by using z-scores of the metrics which might give further information why the patients couldn't complete the given task.

UPDRS is a subjective scoring system, although it is widely used in the clinic. Due to its subjectivity, having mild to moderate correlations of UPDRS



with an actual physical measure is not surprising. Despite this fact, UPDRS III was chosen for the validation because it is the clinical golden standard for diagnosis and prognosis. The correlation study revealed that the fine movements like pinching expresses bradykinesia well. Further testing of linear model showed that this method is less error-prone than the UPDRS. If a physician makes 1 scale-unit error for each item, the error becomes  $z_e = 0.250$  which is a value much larger than our proposed model's error.

## 5 CONCLUSION

The study proved that a commercially available cheap Leap Motion device can be used to measure bradykinesia level from simple motor tasks. In comparison to UPDRS scoring relying on the physicians' observations, it provides repeatable and quantitative measurements. These two major advantages of technique make it suitable for research purposes where the detection of subtle changes in symptoms is required. The possibility of using a COTS device can be an invaluable asset for other researchers. With further investigations such as comparison with the results of another clinical physiologic sensor, Leap Motion can be converted to the household self-assessment device. Unfortunately, in our study, the data exclusion rate was high, which calls for attention to investigate further the applicability of this procedure in the clinic.

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