

Development of an Assessment Method of Forearm Pronation/Supination Motor Function based on Mobile Phone Accelerometer Data for an Early Diagnosis of Parkinson's Disease

Ji Hun Choi¹, Hyeo-II Ma², Yun Joong Kim³, and Unjoo Lee¹

¹*Department of Electrical Engineering, Hallym University, 1 Hallymdaehak-gil, Chuncheon, Gangwon-do, Republic of Korea*

²*Department of Neurology, Hallym University Sacred Heart hospital, Hallym University College of Medicine, Hallym University*

³*Department of Neurology, Hallym University Sacred Heart hospital, Hallym University College of Medicine, Anyang, Republic of Korea*

wlgn203@gmail.com, hima@hallym.ac.kr, yunkim@hallym.ac.kr and ejlee@hallym.ac.kr

Abstract

A series of forearm pronation and supination motor tasks (FPSMT) has been developed to quantitatively assess various primary motor symptoms such as resting tremor, bradykinesia, rigidity, and posture disturbance using an accelerometer built into a smartphone, which is portable, comfortable and cost-effective. The FPSMT has two series of tasks, Flat and Up, which differ according to initial forearm posture. The results from 33 subjects including 6 PD patients showed sensitivities and specificities greater than 85% in rating of primary motor symptoms. This suggests that FPSMT could be used to collect forearm motor-related information on a daily basis, allowing for early diagnosis of patients with PD and also for constantly informing physicians about their patients' clinical status so as to quickly readjust and personalize treatment plans and minimize side effects.

Keywords: *Parkinson's disease, motor symptoms, accelerometer, sensor*

1. Introduction

Parkinson's disease (PD), a progressive neurological disorder resulting from the degeneration of dopamine neurons in the midbrain or mesencephalon, greatly affects an individual's quality of life. Common symptoms include akinesia, bradykinesia, hypokinesia, postural instability, rigidity, and resting tremor. At present, seven to ten million people worldwide are living with PD and fifty thousand to sixty thousand people every year are diagnosed with PD according to statistics from the Parkinson's Disease Foundation, Inc., USA. Approximately 4% of people with PD are diagnosed before the age of 50, and the rate of diagnosis increases with age. Several drugs, which include Carbidopa/Levodopa and dopamine agonists, and surgical procedures such as deep brain stimulation, have been developed for treatment of PD symptoms or neuroprotection and long-term motor improvement. However, the current state of medical care is inadequate because of the progressive nature of the disease. Furthermore, treatment relies on neurological examinations during short-time hospital stays, which may not give enough information to the neurologist, and/or home diaries, which are highly subjective. Both are insufficient to make an objective and reliable assessment of the executive functions of PD and reduce the side-effects of medication. Long-term hospital stays are necessary to monitor the progression of the disease over time and adjust the patient's treatment. However, these cause financial burdens. Therefore, there is a need for a convenient and

quantitative method to record data on medications and motor symptoms in order to provide early diagnosis and properly personalized medical treatments for PD.

Sensor and smartphone technologies show promise in addressing these requirements in terms of keeping track of individuals with PD under varied circumstances and collecting and analyzing quantitative data on a daily basis. In particular, sensors such as accelerometers and gyroscopes built into smartphones can collect information regarding the patient's movements; the sensors can measure muscular displacement, velocity, angular velocity, acceleration, etc. [1-8]. Convenient technical methods to record data on motor symptoms related to PD can improve the quality and efficiency of proper medical treatment and care [9-13]. An algorithm was developed for a calibration-free smartphone application, the six-minute walk test (6MWT), using a smartphone accelerometer and gyroscope [14]. The application 6MWT reports the total distance walked, step timing, gait symmetry, and walking changes over time. Algorithms for detecting PD-related tremors were implemented by analyzing accelerometer data from an Android smartphone [15-17], in which researchers used a wireless glove-mounted accelerometer to measure simulated PD hand tremors using a G-Link Wireless accelerometer node. Measurements of PD-related hand tremors were obtained with acceleration waveforms sampled at multiple sampling rates during 20 trials of simulated tremors compared to a static control. Kostikis et al. compared quantitative measurements, which used four metrics obtained with a smartphone-based platform, of hand tremor in 23 PD patients using UPDRS grade [18]. An Android application was proposed to quantify Parkinson's disease tremors during the execution of routine movements through the use of a smartphone's accelerometer [19]. Essential tremor was differentiated from PD tremor by evaluating data with wavelet and coherence analysis and Kalman filtering [20]. Gait and postural sway of PD patients was quantified by extracting data in the time and frequency domains from accelerometers built into a smartphone [21]. A gait abnormality measure was proposed that used the root mean square ratio of data obtained with a wireless sensor unit that included an accelerometer, an infrared remote control receiver, and a bluetooth module [22]. A PDR-based method was suggested that continuously monitored and recorded the characteristics of a patient's gait using a smartphone [23]. An activity classification method applied a support vector machine (SVM) and a regularized logistic regression method to analyze data from an accelerometer built into a smartphone; the method could differentiate between activities such as walking, standing, sitting, holding the phone, and not wearing the phone [24]. Full-body motion capture of Parkinson's patients with deep brain stimulators was performed by measuring the spatiotemporal characteristics of the motion capture data and using an SVM classifier to discriminate between mild and severe symptoms [25]. Severity of symptoms and motor complications such as tremor, bradykinesia, and dyskinesia in patients with PD was estimated using an SVM classifier for data obtained during motor tasks including finger to nose, finger tapping, opening/closing the hands, and heel tapping in patients with wearable accelerometers [26]. An intelligent closed-loop system, PERFORM, was developed for remote monitoring, assessment, and management of patients with PD; it consists of a wearable multi-sensor monitor unit, a local base unit, and a centralized hospital unit and uses a wide range wearable sensors to evaluate and quantify PD motor symptoms related to end-of-dose deterioration such as tremor, bradykinesia, and freezing of gait (FoG) as well as those related to medication overdose such as Levodopa-induced dyskinesia [27,28]. A smartphone-based system that identified FoG events was presented based on wirelessly streamed accelerometer signals in which feedback was provided to help the user recover gait control [29]. Kim et al. proposed a method for measuring forearm pronation and supination using angular velocity for quantification of bradykinesia in idiopathic PD patients [30]. Methods were suggested for a quantitative assessment of forearm pronation and supination based on a smartphone accelerometer [31, 32].

In this study, a series of forearm pronation and supination motor tasks (FPSMT) is developed to quantitatively assess various primary motor symptoms such as resting tremor, bradykinesia, rigidity, and postural disturbance using an accelerometer built into a smartphone, which is portable, comfortable, and cost-effective. The FPSMT has two series of tasks, Flat and Up, which differ according to initial forearm posture. The results from 33 subjects including 6 PD patients showed sensitivities and specificities larger than 85% in rating of primary motor symptoms. This suggests that FPSMT can be used to collect forearm motor-related information on a daily basis, allowing for early diagnosis of patients with PD and also for constantly informing physicians about their patients' clinical state so as to readjust and personalize treatment plans and minimize side effects.

2. Materials and Methods

2.1. FPSMT

Figure 1 shows the flowchart of the FPSMT task. The FPSMT task consists of a series of 4 tasks (resting, LRRR proSupino, LRR proSupino, and LR proSupino) for the UP series or 7 tasks (resting, BendingUp, BendingUp and Supination, BendingUp and Pronation, LRRR proSupino, LRR proSupino, and LR proSupino) for the Flat series. In Flat, the forearm is initially supinated with both the elbow and the palm on the table. In Up, the forearm is initially neutralized and bent up with the elbow at the level of the shoulder. In the rest task, a subject sits down at a table and rests for 30 sec with his or her forearm in the Flat posture. In the BendingUp task, a subject is instructed to bend the lower arm up and rest it down as prompted by random-interval beeps for 30 sec while putting his/her elbow on the table. The BendingUp and Supination task is similar to the BendingUp task, except that the lower arm is neutralized and then supinated as it is bent up and then rested, respectively. The BendingUp and Pronation task is similar to the BendingUp and Supination task, except that the initial posture of the arm is pronated, that is, the palm is down, and the lower arm is neutralized and then pronated as it is bent up and then rested, respectively. In Posture Initialization, the forearm of a subject is in the initial forearm posture according to the condition (Flat or Up), and then the lower arm is bent about 45 degrees in the Flat condition only. During the LRRR proSupino task, a subject is instructed to pronate and supinate the lower arm in turn for 30 sec with 2 sec holding times between each turn. The LRR proSupino task is similar to the LRRR proSupino task, except that there is a 2 sec holding time in every pronation and supination cycle. In the LR proSupino task, a subject is instructed to pronate and then supinate the lower arm without taking any time between turns.

2.2. Data Collection

A controlled study was conducted that included 33 subjects. 6 of them (4 males and 2 females; mean age, 65 years) were diagnosed with PD, 9 of them (7 males and 2 females; mean age, 64 years) were healthy and age-matched and had no PD symptoms and 18 of them (9 males and 9 females; mean age, 24 years) were healthy young subjects. All subjects were right-handed. The subjects with PD were classified according to the UPDRS. This study was reviewed by an institutional review board and an informed consent was obtained from all subjects.

All subjects were instructed to perform the series of tasks discussed above. 19 of them (3 with PD, 4 without no PD and age-matched, and 12 healthy young subjects) carried out the Up series, which consists of four tasks (resting, LRRR proSupino, LRR proSupino, and LR proSupino). 14 of them (3 with PD, 5 without PD and age-matched, and 6 healthy young subjects) were carried out the Flat series, which consists of 7 tasks (resting, BendingUp, BendingUp and Supination, BendingUp and Pronation, LRRR proSupino,

LRR proSupino and LR proSupino). Figure 2 presents the paradigms of the experiments UP and Flat.

Three axial accelerometer sensors built into an android smartphone held in a certain way in the right hand were used to record motor movement during the tasks.

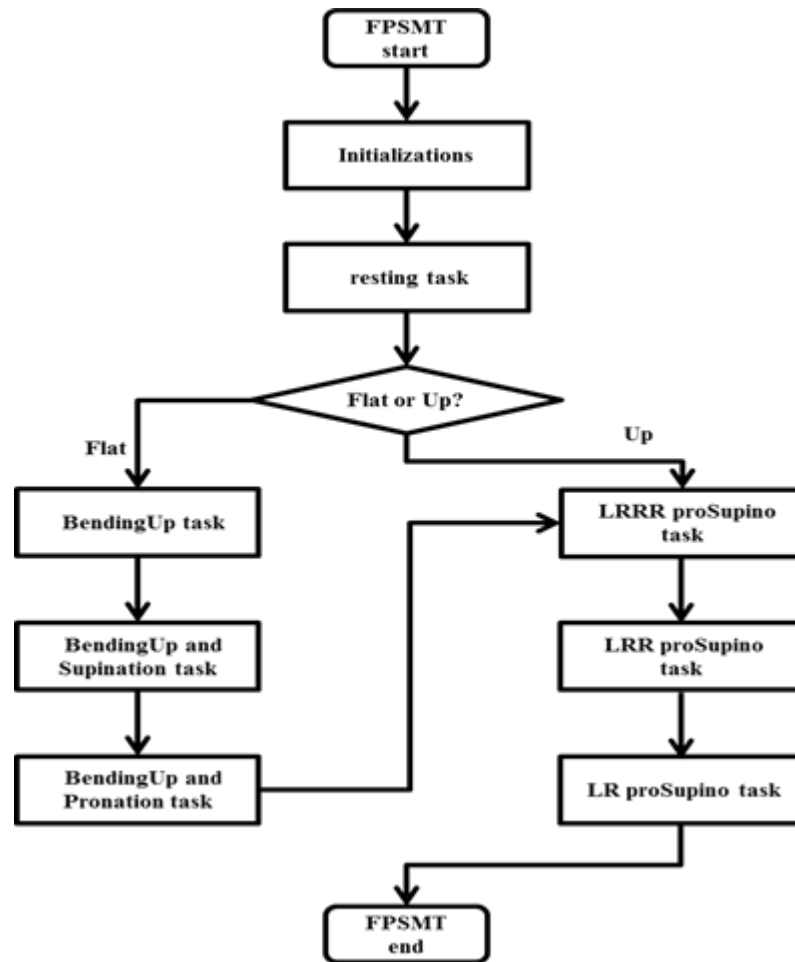


Figure 1. Flowchart of the FPSMT task

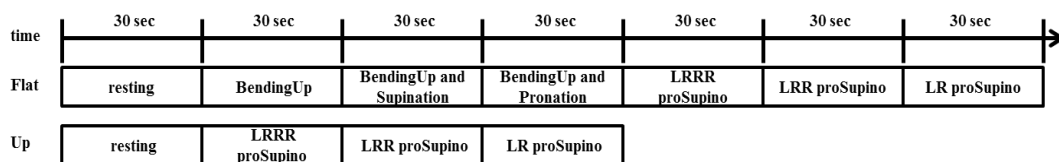


Figure 2. Paradigms of UP and Flat

2.3. Data Analysis

Time- and frequency-domain features were extracted from raw accelerometer data and used to analyze the activities of the forearm movement during the tasks. The results were compared to the patients' UPDRS scores. Time-domain features include root mean square, mean, velocity (standard deviation and maximum value), acceleration, jerk, interval, vertical displacement, horizontal displacement, delays in pronation and supination, and delays in proSupino cycles. The velocity and jerk data were obtained by an integral and a first derivative of the raw accelerometer data, respectively. The frequency-domain

features include the root mean square of a wavelet transformation and the mean duration of proSupino cycles. Table 1 provides a list of the features extracted in this study along with a brief description of the list of tasks and the symptoms predicted from each.

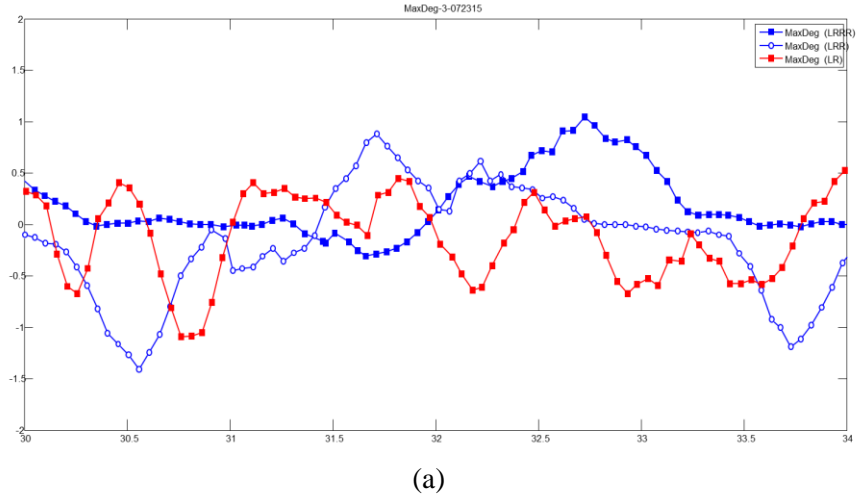
Table 1. List of the Features Extracted from the Three-axial Accelerometer Data Recorded during FPSMT Tasks

Feature	Description	List of tasks*	RT**	B**	R**	Pd**
$w(t, f_{tr})$	rms of wavelet transformation	1-7	√			
\bar{u}	rms of velocity	5-7		√		
\bar{a}	rms of acceleration	5-7		√		
\bar{j}	rms of jerk	5-7		√		
δ_t	mean interval	2-7				
ϑ_m	maximum of rotational degree	5-7				
\bar{d}_v	mean vertical displacement	5-7				√
\bar{d}_h	mean horizontal displacement	5-7				√
u_s	standard deviation of velocity	5-7		√		√
a_s	standard deviation of acceleration	5-7		√		√
j_s	standard deviation of jerk	5-7		√		√
δ_p	mean delay of pronation	5-7			√	√
δ_s	mean delay of supination	3-7			√	√
δ_c	mean delay of proSupino cycle	4-7			√	√
f_c	mean duration of proSupino cycle	7		√	√	√

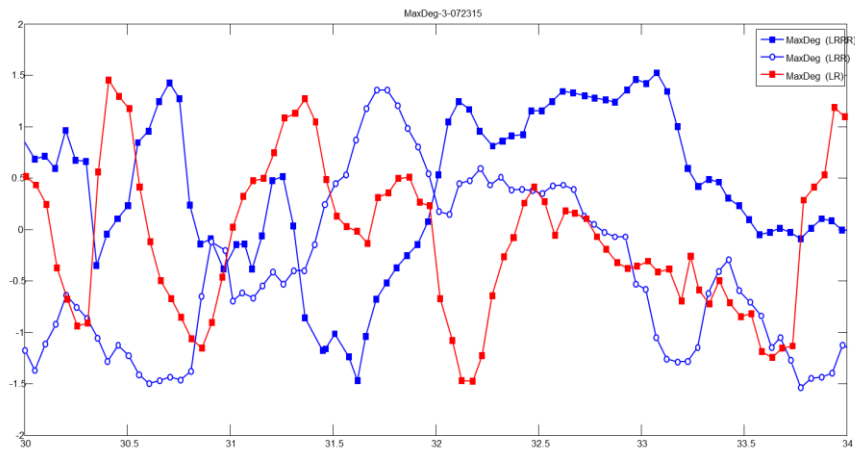
*1: resting, 2: BendingUp, 3: BendingUp and Supination, 4: BendingUp and Pronation, 5: LRRR proSupino, 6: LRR proSupino, 7: LR proSupino; ** R: resting tremor, B: bradykinesia, R: rigidity, Pd: postural disturbance

3. Results

Figure 3 (a) and (b) compares the LRRR proSupino task, LRR proSupino task, and LR proSupino task in terms of the velocities and the rotational angles, respectively which are extracted from raw accelerometer data. Figure 4 (a) and (b) show the velocities and the rotational angles, respectively of four different cases (minimum rotational degree, maximum rotational degree, minimum speed, or maximum speed) of the LR proSupino task for comparisons. Table 2 shows the performance measures, sensitivity, and specificity for the assessment algorithm developed in this study using results obtained from 33 subjects including 6 PD patients, obtained via comparison with UPDRS scores. The results show 85.63% and 89.07% mean sensitivity and specificity, respectively, in rating of primary motor symptoms. This suggests that FPSMT can be used to collect forearm motor-related information on a daily basis, which is useful for early diagnosis of PD and also for constantly informing physicians about their patients' clinical states so as to quickly readjust and personalize treatment plans and minimize the side effects of treatment.

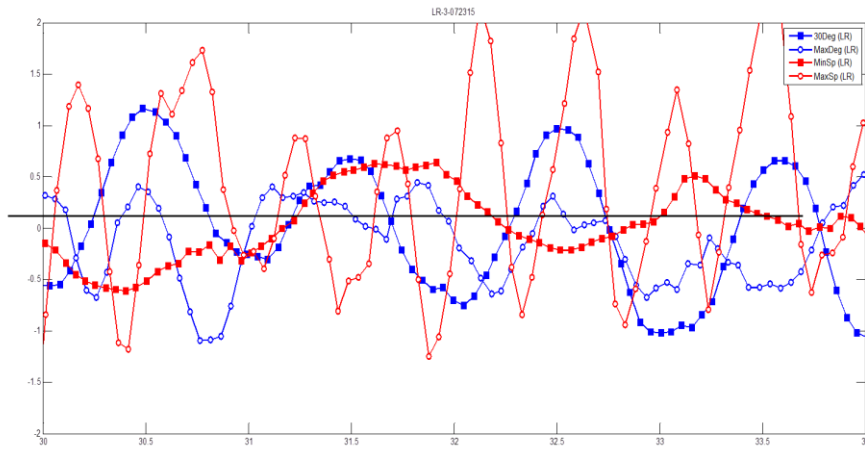


(a)

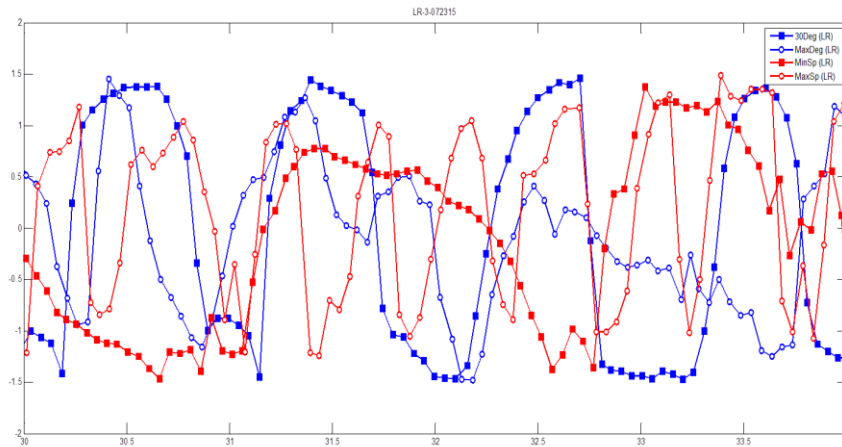


(b)

Figure 3. Comparisons of the LRRR proSupino Task, LRR proSupino Task, and LR proSupino Task in Terms of the Velocities (a) and the Rotational Angles (b)



(a)



(b)

Figure 4. Comparisons of the Velocities (a) and the Rotational Angles (b) for four Different Cases (Minimum Rotational Degree, Maximum Rotational Degree, Minimum Speed, or Maximum Speed) of the LR proSupino Task

Table.2. Sensitivity and Specificity of the Assessment Algorithm Developed in this Study, Assessed by Comparing Results to UPDRSScores

Symptom (UPDRS compared)	Sensitivity (%)	Specificity (%)
Resting tremor (20)	87.5	92.0
Bradykinesia (24,25,31)	100.0	88.8
Rigidity (22)	75.0	75.0
Postural disturbance (30)	80.0	89.28

4. Conclusions

A series of forearm pronation and supination motor tasks (FPSMT) was developed to quantitatively assess various primary motor symptoms using an accelerometer built into a smartphone, which are portable, comfortable, and cost effective. The results from 33 subjects including 6 PD patients showed mean sensitivity and specificity greater than 85% in rating of primary motor symptoms, which suggests that this method can be used to collect forearm motor-related information on a daily basis, allowing the use of FPSMT for early diagnosis of patients with PD and for quick, personalized adjustment of treatment plans.

Acknowledgements

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Authors



Ji Hun Choi

He is a current Undergraduate student at the Department of Electrical Engineering, Hallym University, Chun Cheon, Korea

He has been involved projects in the fields of u-health mobile programming, u-health sensing system, and multimedia system. He is currently doing a project for developing mobile u-healthcare system, especially applicable in an early diagnosis of Parkinson's disease.



Hyeo-II Ma

1991 MD Seoul National University, Seoul, Korea

2003 PhD University of Ulsan College of Medicine, Seoul, Korea

Current Professor, Department of Neurology, Hallym University Sacred Heart hospital, Hallym University College of Medicine, Hallym University

His research interests include movement disorder, tremor, Parkinson's disease, sleep disorder, etc.



Yun Joong Kim

1989 MD Yonsei University, Seoul, Korea

2004 PhD Yonsei University, Seoul, Korea

Current Professor, ILSONG Institute of Life Science, Hallym University, Department of Neurology, Hallym University Sacred Heart Hospital.

His research interests include Parkinson's disease, hereditary or rare neuronal disease, degenerative neuronal disorder, Creutzfeldt-Jakob Disease, etc.



Unjoo Lee

1995 PhD University of Maryland in College Park, MD, USA

Current Associate Professor, Department of Electrical Engineering,
Hallym University, Chun Cheon, Korea

Her research interests include neuroinformatics, biomedical
engineering, biofeedback, neuronal plasticity, u-health mobile
programming, u-health sensing system, etc.