Android Application for Spiral Analysis in Parkinson's Disease

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***Abstract*—The paper presents an application for spiral analysis in Parkinson's Disease (PD). PD is one of the most common degenerative disorders of the central nervous system that affects elderly. Four cardinal symptoms of the disease are tremor, rigidity, slowness of movement, and postural instability. The current diagnosis is based on clinical observation which relies on skills and experiences of a trained specialist. Thus, an additional method is desirable to help in the diagnosis process and possibly improve the detection of early PD as well as the measurement of disease severity. Many studies have reported that the spiral analysis may be useful in the diagnosis of motor dysfunction in PD patient. We therefore implement a mobile, safe, easy to use, inexpensive, and online application for detection of movement disorders with a comprehensive test analysis according to the indices from Archimedean and octagon spirals tracing tasks. We introduce the octagon tracing task along with the conventional Archimedean spiral task because a shape tracing task with clear sequential components may increase a likelihood of detecting tremors and other cardinal features of PD. A widely used Android mobile operating system, the fastest markets share growth among smartphone platforms, is chosen as our development platform. We also show that the preliminary results of selected indices in the application could potentially be used to distinguish between PD patient and healthy control.**

Keywords– Parkinson's disease; Archimedean spiral; spiral analysis; tremor; android application;

I. INTRODUCTION

Parkinson's disease (PD) is a common degenerative disorder of the central nervous system that affects elderly with most cases occurring after the age of 50. The disease is named after James Parkinson, who published the first detailed description of the disease in 1817. Four cardinal symptoms of PD are tremor, rigidity, slowness of movement, and postural instability [1] [2]. Tremor is defined as an involuntary, rhythmic, and oscillating movement of one or more body parts. Tremor associated with PD generally occurs when the muscles are relaxed and at rest. Thus, it is called a rest tremor, maximal when at rest and disappearing with voluntary movement. Tremor is the most apparent and also the most common symptom. The symptom begins with a tremor in one of the hands for most PD patients. Rigidity is an excessive and continuous contraction of the muscles causing a stiffness and resistance to movement in joints. Slowness of movement or bradykinesia is associated with the difficulties for the whole course of the movement process including planning, initiating, and executing. An initial indication is often slowness or problems performing daily life tasks that require fine motor control such as writing, dressing, or using utensils. Assessment of bradykinesia usually includes having patients perform repetitive and alternating movements of the hand. Postural instability is usually seen in later stages of the disease.

A widely accepted method to detect PD is the Unified Parkinson's Disease Rating Scale (UPDRS). However, it is a clinical observation based system which highly depends on skills and experiences of a trained movement disorder specialist who performed the procedure. Thus, an additional method is desirable to help screen the patients and improve the detection of early PD as well as the measurement of disease severity.

One method that is relatively simple, easy to administer, and has gained momentum lately is an analysis of spiral drawing. Spiral drawing requires subjects to execute a repetitive set of standard figures such as spiral so that the drawing shape and consistency can be evaluated. Spiral analysis is a method of analyzing the drawing of Archimedean spiral to quantify motor activity and evaluate the possible movement disorders such as tremor, rigidity, and bradykinesia [3]. In 2008, Pullman et al. did a validity study of spiral analysis and suggested that it may supplement motor assessment in PD [4]. Liu et al. quantified drug-induced dyskinesias in the arms using templates of a circular and a square spiral [5]. Miralles et al. introduced a quantitative method of the drawing of an Archimedean spiral using its digitized picture [6]. Aly et al. proposed a computer-based technique for assessment of tremor in PD using a task of tracing pentagon spiral [7]. Westin et al. implemented a system for assessment in telemedicine setting using ASP.NET

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web application [8]. There are also other studies regarding the spiral analysis for PD in the recent years [9] [10] [11].

The objective of this study is to develop a mobile, safe, inexpensive, easy to use, and online application for detecting a symptom of an early PD along with a comprehensive test analysis according to the indices from Archimedean spiral and octagon spiral tracing tasks. We introduce the octagon tracing task along with the conventional Archimedean spiral task because a shape tracing task with clear sequential components may increase a likelihood of detecting tremors and other cardinal features of PD as reported by Berardelli et al. [12]. Current touchscreen tablet with a uniform operating system is an ideal match for this project. With a tablet, subject can perform the test anywhere; it does not have to be completed in a hospital which could cause stress that might affect the test results. A developed application can also be distributed worldwide in an instant with the application store. To ensure that most people can have access to the application, it needs to be developed in a widely used platform. Google Android is an operating system for mobile devices such as smart-phone and tablet. According to Gartner Inc., Android users are increasing at the highest rate in comparison with other mobile operating systems such as iOS, RIM, Windows CE or Symbian [13]. Gandhewar et al. reviewed multiple mobile operating systems and concluded that, compared to the competitors, Android is superior and will become a leader in mobile platform [14]. Therefore, we chose Google Android as a development platform for this application.

The rest of this paper is organized in three sections. Section 2 describes the methods including spiral analysis based on polar coordinate system, characteristic parameters from spiral tracing, and application implementation. In Section 3, we present the results from the test on our application. Finally, we describe possible extensions and improvements of this study in Section 4.

II. METHODS

A. Spiral Analysis Based on Polar Coordinate System

An execution of the spiral drawing or tracing is a task that involves both distal and proximal upper limbs. It also requires subjects to execute a repetitive shape; therefore the consistency can be evaluated. Moreover, the characteristics of a spiral can be extracted and analyzed by transforming it into a polar coordinate system, each point is represented by the distance from a fixed point and the angle from a fixed direction. Spiral tracings and corresponding polar coordinates transforms from healthy control and patient with PD are

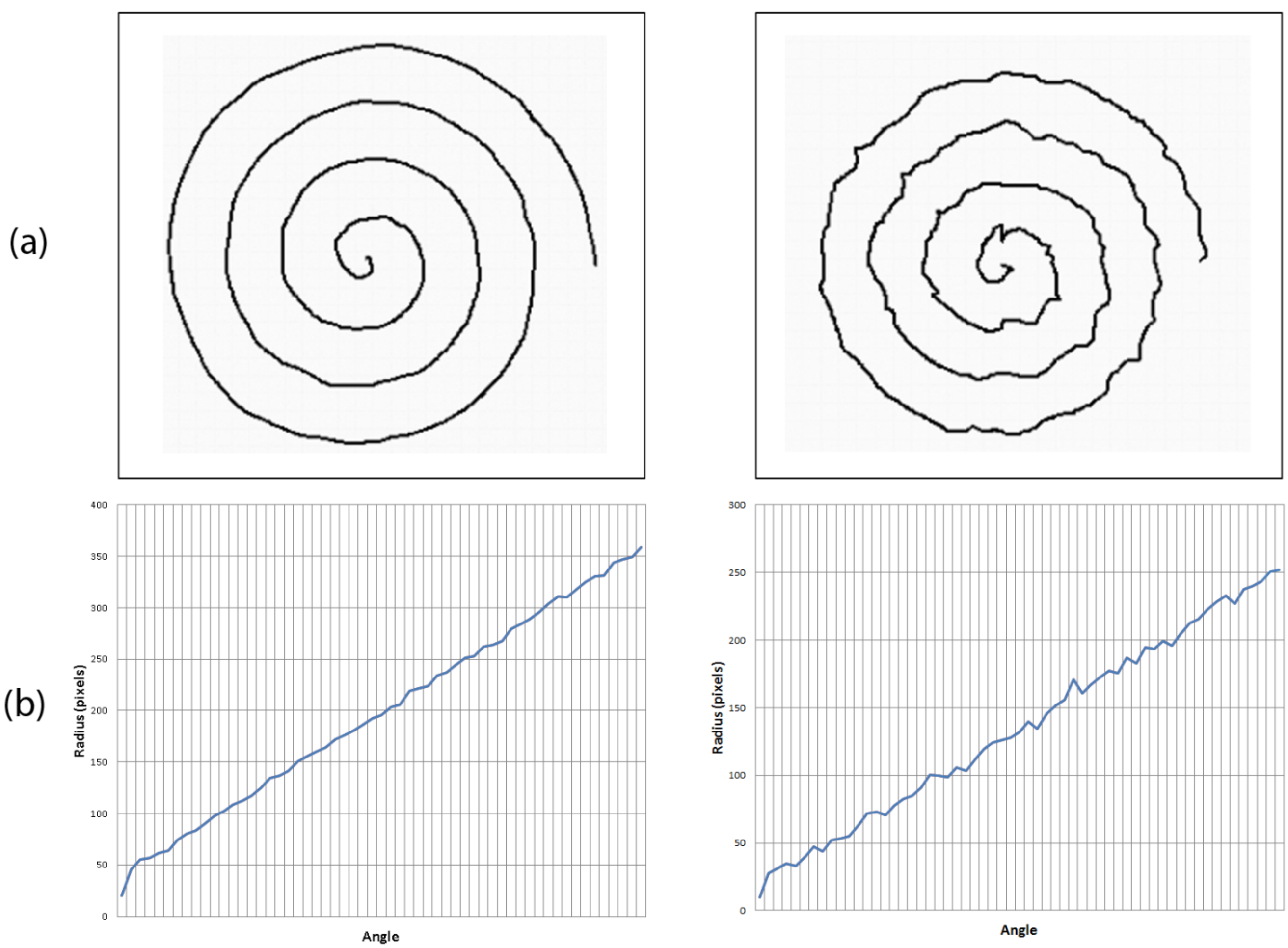

Fig. 1. Comparison of spiral tracing and corresponding polar coordinates transformation by a healthy control and a patient with Parkinson's disease. Left column is an example of figures from a healthy control, and right column is an example of figures from a patient with Parkinson's disease. (a) Spiral tracing; and (b) Corresponding radius-angle transforms.

shown in Fig. 1. The transformation of an ideal spiral would result in a perfect straight line. The transformation of a healthy control tracing should be virtually errorless in comparison with an ideal transforms, while a PD patient transform would result in much more error.

The input from a spiral tracing is in Cartesian coordinate system, each point is represented by the distances from the point to two fixed perpendicular lines. In Cartesian coordinates, let (x, y) be an input point and the position of the starting point, or the center of the spiral, is represented by (x_0, y_0). In polar coordinates, a radial distance from the spiral center and an angle is represented by r and θ, respectively. The transformation of the Cartesian coordinates into polar coordinates and vice-versa is defined as:

$$x = r\sin\theta + x_0, \quad y = r\cos\theta + y_0 \tag{1}$$

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2}, \tag{2}$$

$$\theta = \arctan\left(\frac{y-y_0}{x-x_0}\right). \tag{3}$$

An Archimedean spiral can be represented in polar coordinate system as:

$$r = a + b\theta \tag{4}$$

where a and b represent the parameters of the spiral, changing a turns the spiral and b controls the distance between successive turnings. Therefore, Archimedean spiral has a fixed distance between successive turnings.

B. Characteristic parameters from spiral tracing

To analyze the spiral tracing, a series of indices extracted from the transformation of tracing data is used for quantification. Based on the input coordinates, we can calculate average radial error, standard deviation of the radial error, maximum radial error, and crossing rate. They can be used to measure the spiral irregularity. Hemispiral pressure ratio is calculated from the input pressure from the tablet screen. A study from Yu et al. reveals that PD patients exerted significantly less pressure on one hemispiral than on another [15]. The side of the body more affected by PD corresponds to the low pressure side and the low and high pressure pattern is the same for both hands. We also consider the time taken to complete the tracing of a spiral as a key parameter. According to the study by Banaszkiewicz et al , the spiral drawing time was significantly longer in PD patients with bradykinesia when compared to normal controls [16]. The characteristic parameters are defined as follows:

- Time taken is the total time needed to complete the tracing of a spiral
- Average radial error of the tracing of a spiral, in comparison with an ideal spiral, is defined as:

$$\overline{err} = \frac{1}{n}\sum_{i=1}^{n}|err_i| \tag{5}$$

  where n is the total number of sampling points for comparison, err_i is a radial error at location i, and $\overline{err}$ is the average radial error
- Standard deviation of the radial error is defined as:

$$SD_{err} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(err_i - \overline{err})^2} \tag{6}$$

  where SD_{err} is the standard deviation of the radial error
- Maximum radial error is defined as:

$$R_{max} = Max_{i=1}^{n}(|err_i|) \tag{7}$$

  where R_{max} is the maximum radial error
- Crossing rate is equal to the total number of err changes from plus to minus and vice versa divides by the total number of sampling points n
- Hemispiral pressure ratio is the ratio between average pressure of the tracing data on the right hemispiral and on the left hemispiral

C. Application Implementation

With an input from a touchscreen tablet, we can collect data in three axes, coordinate X and Y and pressure Z, where paper based drawing only provides coordinates data. The computer system can also provide information on further analysis of the spiral. We chose a widely used Android mobile operating system as a development platform. The application is developed in Java language using Android software development kit. The target version of the operating system is Android OS 3.0 Honeycomb and to be used with 10.1 inches tablet. The big screen size is preferred as one of the goals is to preserve a traditional testing environment as much as possible. For drawing device, a stylus pen similar to a ball-point pen in both shape and feel is used. The background color of the application is white and the tracing color is blue, similar to tracing with ballpoint pen on the paper.

Tracing a spiral is better than other standard figures because there are changes in the overall size, as the diameter increases, and direction, as in circle motion. These changes require an activation of multiple muscle groups and joints in the arm. Therefore, we assigned an Archimedean spiral tracing as the first task in the application. The second task is the octagon spiral tracing. Octagon spiral is an Archimedean spiral with octagon shape instead of circle. PD patient may have difficulty performing tracing in which changes of movement direction are discrete like square or octagon compared to gradual and continuous in Archimedean spiral. Both patterns of spirals are equivalent in overall size, number of turns, and incremental distance.

Users are required to trace the Archimedean spiral first and then the octagon spiral according to the templates provided in our application as seen in Fig. 2. They are instructed to draw at their own paced without allowing the forearm to rest on the table and informed that the time will be measured. The drawings start from the center outward in clockwise direction as seen in Fig 3. The process is then repeated. Thus, two tests for each spiral for the total of four drawings.

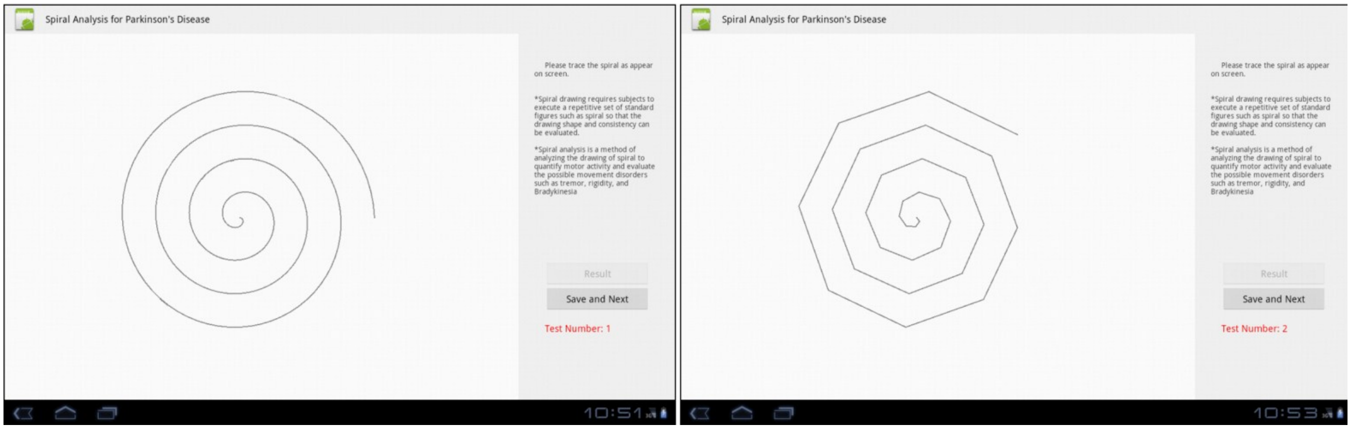

Fig. 2. Templates of Archimedean and octagon spirals in our application. A shape tracing task with clear sequential components such as octagon may increase the likelihood of detecting tremors and other cardinal features of Parkinson's disease.

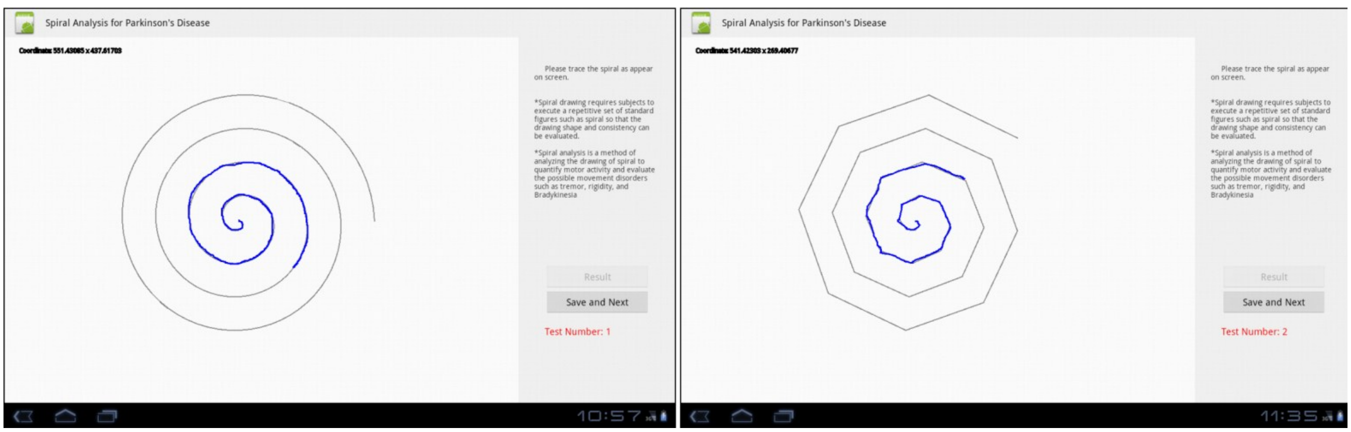

Fig. 3. Illustration of Archimedean and octagon spirals tracing in our application. The drawings start from the center outward in clockwise direction.

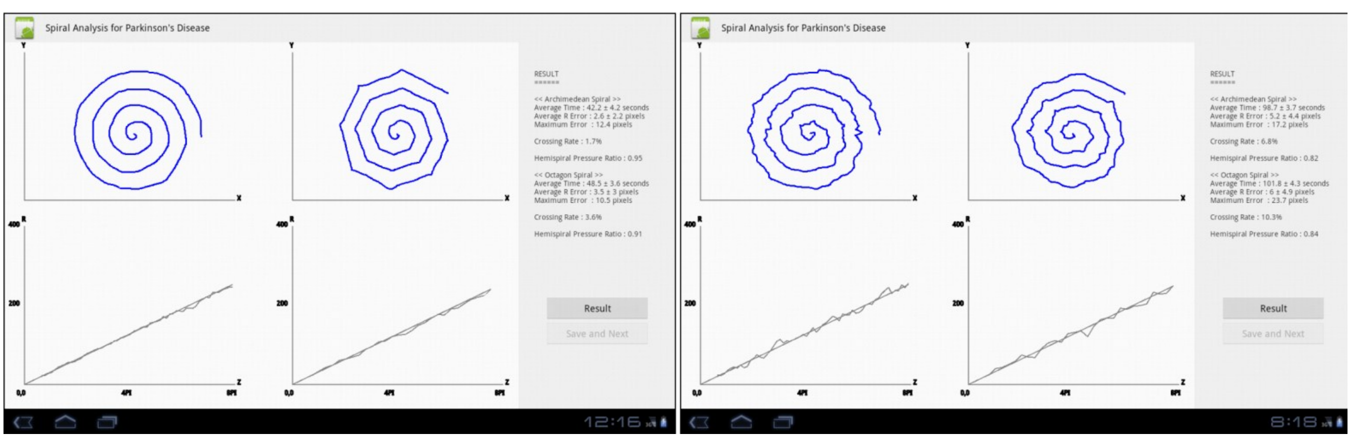

Fig. 4. Result page of the application reporting multiple indices from spirals drew by healthy control and patient with Parkinson's disease. The figures from an example of healthy control are on the left, and the figures from an example of patient with Parkinson's disease are on the right.

III. Results

A touchscreen tablet can provide us with two coordinates X and Y, pressure, and time as input data. Multiple indices are extracted from those data based on the spiral drawing and reported in this experiment. Fig. 4 shows the result pages of the application. Figure on the left is an example of a healthy control and figure on the right is an example of a patient with PD. The healthy control drawing was noticeably smoother and had much less error in comparison with the drawing from PD patient. The radius-angle polar coordinates transformation in this figure also complies with the visual observation.

Table 1 and Table 2 compare the numerical result of the spiral analysis between healthy control and PD patient. Table 1 is the result from tracing of Archimedean spiral and table 2 is the result from tracing of octagon spiral. For both cases, the results are similar as expected. The average radial error, maximum radial error, and crossing rate are higher and the average time was significantly longer in PD patient compared to healthy control. The hemispiral pressure ratio of more than one means the user exerts more pressure on the right side of the spiral than on the left. This parameter could indicate the side of the body more affected by PD.

TABLE I

COMPARISON OF DIFFERENT INDICES FROM SPIRAL ANALYSIS OF ARCHIMEDEAN SPIRAL BETWEEN HEALTHY CONTROL AND PD PATIENT

	Healthy	**PD**
Average time (seconds)	42.2	98.7
Standard deviation	± 4.2	± 3.7
Average radial error (pixels)	2.6	5.2
Standard deviation	± 2.2	± 4.4
Maximum radial error (pixels)	12.4	17.2
Crossing rate (percentage)	1.7	6.8
Hemispiral pressure ratio (right/left)	0.95	0.82

TABLE II

COMPARISON OF DIFFERENT INDICES FROM SPIRAL ANALYSIS OF OCTAGON SPIRAL BETWEEN HEALTHY CONTROL AND PD PATIENT

	Healthy	**PD**
Average time (seconds)	48.5	101.8
Standard deviation	± 3.6	± 4.6
Average radial error (pixels)	3.5	6.0
Standard deviation	± 3.0	± 4.9
Maximum radial error (pixels)	10.5	23.7
Crossing rate (percentage)	3.6	10.3
Hemispiral pressure ratio (right/left)	0.91	0.84

IV. Conclusion

PD is a chronic neurodegenerative disease that affects many older people. The diagnosis is based on the clinical observation which highly depends on the skills and experiences of a trained movement disorder specialist who performed the procedure. In this study, we developed a Google Android application for spiral drawing and analysis for patients with PD. The computer software might not be able to replace a neurologist but it could be as a valuable diagnosis tool to supplement the clinical exam. Furthermore, it could be used as a long distance screening for patient at home. With the popularity of Android and the availability of the Android marketplace, the application can easily be distributed world-wide. Therefore, it can serve as a supplement to the clinical motor assessment in the hospital anywhere as well as a portable diagnosis tool at home.

In order to preserve a traditional testing environment, a stylus similar to regular pen is used as a drawing apparatus. The application interface is designed to simulate the drawing on a paper environment. In comparison with the drawing on the paper, a touchscreen tablet can also acquire an additional input pressure. Multiple indices based on coordinates, pressure, and time can be analyzed in order to assess the motor dysfunction associated with PD. Two patterns of spiral, namely Archimedean and octagon spirals, which represent continuous and discrete motions respectively, are used in the application. Including octagon spiral in the testing process might provide a better assessment as the task is more difficult especially for PD patient with rigidity and bradykinesia.

The paper briefly summarized our early experience on the initial spiral drawing application experiment. We reported some encouraging, albeit preliminary, results that motivate further work in this direction. In our future research, more clinical experiments with a large group of PD patients will be done to learn more about the correlations and validate the usefulness of the application. We might be able to find correlations between parameters and specific PD symptoms such as speed might associate more with rigidity and bradykinesia while crossing rate might have more association with bradykinesia as reported by Pullman et al. [4]. Moreover, additional parameters in frequency domain could be added to provide more information.

Another highly possible extension that should be investigated is the possibility of creating a classification model based on the input information and extracted indices. We might be able to induce important information from those data. If the prediction model is reliable, the system might be able to predict the possibility that the subject having a symptom of an early PD. Further experiments could also give us an insight on the severity diagnosis. It can then serve as a suggestion system for a physician in addition to the analysis data and conventional clinical observation.

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REFERENCES

[1] J. Jankovic, "Parkinson's disease: clinical features and diagnosis," J Neurol Neurosurg Psychiatry, vol. 79, pp. 368-376, 2008.

[2] J. M. Savitt, V. L. Dawson, and T. M. Dawson. "Diagnosis and treatment of Parkinson disease: molecules to medicine," J Clin Invest, vol 116 (7), pp. 1744-1754, 2006.

[3] S. L. Pullman, "Spiral analysis: a new technique for measuring tremor with a digitizing tablet," Movement Disorders, vol. 13, pp. 85–89, 1998.

[4] R. S. Pullman, C. Derby, K. Stanley, A. Floyd, S. Bressman, R. B. Lipton, et al., "Validity of spiral analysis in early Parkinson's disease," Movement Disorders, vol. 23, pp. 531–537, 2008.

[5] X. Liu, C. B. Carroll, S. Y. Wang, J. Zajicek, and P. G. Bain, "Quantifying drug-induced dyskinesias in the arms using digitised spiral-drawing tasks," Journal of Neuroscience Methods, vol. 144 (1), pp. 47-52, 2005.

[6] F. Miralles, S. Tarongi, and A. Espino, "Quantification of the drawing of an Archimedes spiral through the analysis of its digitized picture," Journal of Neuroscience Methods, vol. 152 (1-2), pp. 18-31, 2006.

[7] N. M. Aly, J. R. Playfer, S. L. Smith, and D. M. Halliday, "A novel computer-based technique for the assessment of tremor in Parkinson's disease," Age and Ageing, vol. 36 (4), pp. 395-399, 2007.

[8] J. Westin, S. Ghiamati, M. Memedi, D. Nyholm, A. Johansson, M. Dougherty, et al., "A new computer method for assessing drawing impairment in Parkinson's disease," Journal of Neuroscience Methods, vol. 190 (1), pp. 143-148, 2010.

[9] H. Wang, Q. Yu, M. M. Kurtis, A. G. Floyd, W. A. Smith, and S. L. Pullman, "Spiral analysis—Improved clinical utility with center detection," Journal of Neuroscience Methods, vol. 171 (2), pp. 264-270, 2008.

[10] M. Wang, B. Wang, J. Zou, J. Zhang, and M. Nakamura, "Quantitative evaluation of hand movement in spiral drawing for patients with Parkinson's disease based on modeling in polar coordinate system with varied origin," 2011 Proceeding of IEEE/ICME on Complex Medical Engineering, pp. 169-173, 2011.

[11] L. Cunningham, C. Nugent, G. Moore, D. Finlay, and D. Craig, "Computer-based assessment of bradykinesia, akinesia and rigidity in Parkinson's disease," Proceedings of ICOST, 2009.

[12] A. Berardelli, J. C. Rothwell, P. D. Thompson, and M. Hallett, "Pathophysiology of bradykinesia in Parkinson's disease," Brain, vol. 124, pp.2131-2146, 2001.

[13] C. Pettey and H. Stevens, "Gartner says Android to command nearly half of worldwide smartphone operating system sarket by year-end 2012," Gartner Newsroom, Gartner Inc, 2011.

[14] N. Gandhewar and R. Sheikh, "Google Android: an emerging software platform for mobile devices," International Journal on Computer Science and Engineering, special issue February 2011, pp. 12-17, 2011.

[15] Q. Yu, S. L. Pullman, S. Fahn, and S. F. Pedersen, "Homonymous hemispiral abnormalities in patients with Parkinson's disease," Neurosci Abstr, vol. 23, pp. 1898, 1997.

[16] K. Banaszkiewicz, M. Rudzinska, S. Bukowczan, A. Izworski, and A. Szczudlik, "Spiral drawing time as a measure of bradykinesia," Neurol Neurochir Pol, vol. 43 (1), pp. 16-21, 2009.