ParkNosis: Diagnosing Parkinson's Disease Using Mobile Phones

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***Abstract*—This paper aims to provide a Parkinson's Disease (PD) symptoms assessment tool using an Android smartphone application that allows PD patients to assess their symptoms using both quantitative and qualitative tests. Simple touch screen and motion tests focus on objectively measuring PD symptoms, whereas a questionnaire targets the subjective ones. The concatenation of the collected results will allow the application to accurately target several PD symptoms without visual or traditional assessment. Physicians, hospitals, and clinics will then be able to receive this data over the network for further assessment, analysis, and research. This enables the self-monitoring of patients, as well as remote monitoring from physicians in clinics and hospitals. In addition to this, this application aims to expand PD research and provide improvements to the current treatment process. Ultimately, the aim is to enable thousands of people, anywhere and at any time, to easily diagnose and assess the PD before visiting a specialist.**

I. Introduction

Parkinson's disease (PD) is a chronic, neurodegenerative disorder of the central nervous system which most commonly affects, on average, elderly people of ages 60 and above. However, some people can be diagnosed with PD at an age as early as 40 years or younger [1]. It develops progressively and the symptoms increase in severity over time. These symptoms include [2]:

1. Tremors, usually in hands and fingers
2. Slow or jittery movement (known as bradykinesia)
3. Rigid muscles
4. Impaired posture and balance
5. Loss of automatic movements
6. Speech and writing changes

Parkinson's has affected a large percentage of people, and has no cure. However, the early detection of PD plays a huge role in the treatment process. Smart mobile phones have proven themselves capable of analyzing medical data for a few years now and this paper utilizes this capability in a profound and innovative way. In the early stages, PD can be difficult to detect and diagnose, as the nature of the symptoms is subjective, varying from person to person and sometimes being unnoticeable. However, since PD is a progressive disorder, it is imperative to diagnose it early on, in order to begin treatment as early as possible and maximize the effect. According to the Michael J. Fox Foundation for Parkinson's Research: "There is no objective test (such as a blood test, brain scan or EEG) to make a definitive diagnosis of Parkinson's Disease. Instead, a doctor takes a careful medical history and performs a thorough neurological examination" [1]. Early intervention has been shown to remarkably improve one's symptoms through medical treatment [3]. Not until recently had anyone been able to fully recover from PD condition with a full brain surgery [4].

The development of technology has revolutionized modern medicine, whereby improvements to medical methodologies and procedures are seen on a daily basis. One of these technologies is smart mobile phones, which have shown the potential to be powerful medical diagnostic tools, ranging from attachments that can diagnose an ear infection or track heart rhythms to an app that can monitor mental health [5] or detect obstructive sleep apnea (OSA) [6] or chronic obstructive pulmonary disease (COPD) [7]. The ability to diagnose medical diseases from a mobile phone can help provide patients with more accurate diagnostics and earlier detection. Furthermore, it gives us the ability to transmit the gathered data through a network for storage and remote analysis. This concept, known as mobile Health or mHealth, creates a simple unified interface where people can collaborate and share health information in one place.

As stated earlier, PD is difficult to diagnose since it has no standard test which can biologically verify whether a patient has PD or not. General clinicians often hesitate when deciding whether or not to forward a patient to a specialist. By having a mobile phone application that can quantitatively measure the symptoms of PD using both objective and subjective criteria, a general clinician can have several tools in his/her hand which can help him/her make a decision regarding his patients' diagnosis. The proposed mHealth application, called *ParkNosis*, will have open source code and upcoming improvements for future research.

This paper aims to tackle the problems in conventional and manual diagnosis of PD by offering mobile phone based methods which aim to accurately identify any possibly existing PD symptoms. Several tests are implemented in the mobile phone application. The data is collected and analyzed locally on the mobile phone to alert the user of any PD symptoms. The results are also shared with a remote server for specialists to review. The system specifications and technical approach highlight the important features and aspects of the whole system.

The paper is organized as following. Section II proposes a general description of the proposed application and the implemented diagnosis tests. Section III proposes a brief overview of PD diagnosis mobile applications. Section IV describes the design and features of the proposed application. The hardware and software specifications are explained in Section V. Experimental results are presented in Section VI. Section VII presents the conclusion and future work.

II. Problem Statement

Parkinson's Disease (PD) affects as many as 10 million people worldwide. Those affected by the disease are typically within the range of 40 to 60 years of age. However, other sources have confirmed that even young people aged 20 to 30, may also be at risk of developing PD symptoms. This has to do with the genetics involved during growth. Treatments for PD are still under research and since no full treatment has been established yet, it is important to detect PD as early as possible, before it fully develops. People with developed PD suffer from

978-1-5090-3370-6/16/$31.00 ©2016 IEEE

chronic pains and aches, disallowing normal movement and functionality of the body.

The problem with PD is that modern medicine currently lacks the technology to make a definitive diagnosis. This is due to several reasons, mainly because, as mentioned earlier, there is no objective medical test which can diagnose PD. Furthermore, the current rate of misdiagnosis is very high due to the fact that the symptoms are similar to those of other neurological conditions [1]. Another problem exists where the current diagnosis method involves the trouble of undergoing a medical check-up that could possibly lead to a false diagnosis or a misdiagnosis. The system has to be as passive as possible with simple interactivity.

The proposed medical mobile application implements several reliable and standardized PD diagnosis tests. These tests include a range of standard hand tremor tests, finger tapping tests, and spiral-drawing tests used widely by neurologists and PD specialists for early detection and condition assessment. The tapping and drawing tests assess for movement consistency while the hand tremor test assesses the patients stability in an idle state.

Regarding the tapping test, most published algorithms for electronic devices and tablets focus on the alternation of fingers in a simple touchscreen tapping test [8]. These tests rely on the mobile phone's touchscreen response time and most of data gathered is focused around time, distance and the location on the *x*, *y* plane. The score is based on a specific scale, where if the participant would take longer to respond and move from one area field to the other, the score would indicate bradykinetic or dyskinetic movements. Even if dyskinetic movements help the participant achieve faster results, the precision and location of taps are still accounted for. The main concept behind this, comes from the original finger tapping test that is used to be done as a diagnosis method, way before tablets and smart devices became a medical tool kit [9]. The spiral drawing test uses a similar approach to calculate acceleration data and give insights on the level of bradykinesia and dyskinesia that may be invisible.

For the accelerometer test, we integrated the MOTO 360 2nd Gen watch with the Android mobile device via Bluetooth. The main purpose of this test is to detect any hand tremors that the user experiences with their arm fully extended and at rest. The user is required to wear the watch tightly around their wrist and extend their arm in the front of them and parallel to the ground. From there on the smartwatch will record accelerometer reading samples for 15 seconds. The accelerometer data is then recorded and sent to the mobile phone where it is processed. When processing the data, any involuntary tremors along the *z* axis will be detected and their rate and magnitude will be considered when scoring them using a predefined scale. Table I provides the description of the implemented tests.

TABLE I. PD TESTS IMPELEMNTED IN THE MOBILE APP.

Test Name	Description	Analysis
Hand Tremor Test	The participant wears an accelerometer or smart watch and stretches their hand to test for any tremors. Takes 15 seconds.	What the test will look are sharp accelerations in the y axis. The signal is normalized and the variance in the time series is calculated.
Spiral Drawing Test	The participant must draw two spirals on screen. Once with the spiral visible at all times and the second time with the spiral fading in and out. Takes approx. 1-3 min;	The STS is calculated by using two historical data sets of the static and dynamic spiral points (x, y plane). We look at the acceleration from one point to another in both tests and calculate the score based on that.
Tap Test (Response)	The patient has to quickly tap a button on screen. Takes approx. 1-3 min.	This test is designed to calculate the response time required for a patient to tap in screen, it shows the severity of bradykinesia and acts as a warmup test.
Tap Test (Alternating)	The user must use their index and middle finger to alternate between 2 buttons. Takes 20 seconds.	The precision, delay, and numbers of taps are all recorded when alternating from one button to the other. Taps outside the buttons reduce precision.
Tap Test (Involuntary)	The participant must place their hand 0.5 in. above the screen and try to hold their fingers for 20 seconds.	Any involuntary taps will be recorded.
Questionnaire	The participant must answer motor assessment questions. Takes about 15 min.	Subjective test. Each question has 5 answers based on a scale of 0-4 (Normal – Severe).

III. RELATED WORK

This systematic review presents the important methodologies followed by various research groups that aim to find and detect Parkinson's Disease using only a smartphone and wearables. Many of the papers presented a multitude of complex and simple analogies of various testing algorithms. This review includes only what has been thought to be improvable and useful for our design, yet, a lot of algorithms have been laid out for further research and discussion. The order of reviews starts off with a comparison of tremor analysis techniques, followed by an overview of spiral test analysis, gait cycle analysis, and finally a summary of tapping test algorithms.

A. Hand Tremors

L. Hylton and T. Sanders [10] wrote a short paper on how several signal analysis algorithms affect the results. They compared three digital signal filters known as: Least Squares, Hamming Window, and Parks-McClellan. Their research aims to discover which of the three processing techniques works best for hand tremor detection on each of *x*, *y*, and *z* axes of the accelerometer. Their test was performed on a 5.5 window of *z*-scored accelerometer data from an Android smartphone. Using the Hamming Window, Hylton and Sanders were able to spot 30 second tremor readings throughout the data and filter out the healthy movement. Hylton and Sanders used an ROC (receiver operating characteristic) analysis graph which graphed the true positive and false positive rates for different points. They concluded that the best algorithm that yielded the least false positives was the Hamming Window function. Since the paper did not mention nor refer to which type of Hamming Window was used, there is no way to find out exactly how the results were obtained.

Another study was done by V. Parra et al. [11] who used a mobile based test using accelerometers in order to quantitatively measure and analyze PD rest tremor. The data acquisition process involved strapping the mobile device onto the patients hand. Their software included measures of tremor intensity, duration, and number. The intensity measured the abruptness of the tremors, the duration was the length of time that the tremors occurred, and the number of tremors coincided with the number of times a tremor intensity passes over the upper or lower thresholds the researchers have set. In order to eliminate the effect of gravity on the accelerometer sensors, the readings were normalized with respect to the value of $g = 9.81$. However, this application was not tested on real PD patients. Instead, it was tested on healthy people simulating the tremors produced by a PD patient. This allowed the researchers to calibrate the intensity detection range and to optimize the detection effectiveness of the application [11]. The results showed that in a normal person, the acceleration would be held constant as a result of minimal hand tremors. In the simulated tremor group, the acceleration would fluctuate greatly around the value of gravity. The researchers looked at the variance coefficient and standard deviation of the data samples in order to determine the intensity of the tremors. They found that the variance coefficient was significantly higher in the simulated tremor group.

B. Spiral Analysis

M. Memedi [2] wrote a research paper on how to differentiate between tremors and dyskinetic movements using the mobile phone's touchscreen or web application. The objective of the paper is to explain how user input is processed and analyzed for tremors or abnormal motion. One famous method, also used in this paper, is the Discrete wavelet transform algorithm. The signal digitized using discrete Fourier transform.

The approach used by [2] is quite complex and to remove ambiguity, we decided to follow a simpler approach which takes advantage of the Android platform historical x and y data. By calculating the deviation from the original spiral, we can then use Spearman rank correlation algorithm to check if any correlation exists between the x and y points of the original spiral and the drawn spiral.

Isenku [12] et al. explore another way of looking at the spiral test. Their approach is to make the patients trace the spiral twice: once where the spiral is fixed and another where the spiral blinks on and off the screen. This approach looks at the instantaneous acceleration of the patients and tries to define the repetition of these instantaneous accelerations. Then this is used to find L2 norm of the acceleration between the static and the dynamic tests. To do so, displacements coordinates (x & y) are transferred to velocity, then to acceleration.

After that, the highest 10 values of their histograms are processed to give the L2 Norm based on the following formula:

$$L2Norm = \sum_{i=1}^{10} (Hstat(i) - Hdyn(i))$$

Where *Hstat* represents the Histogram acceleration values of the static spiral and *Hdyn* represents the Histogram acceleration values of the dynamic spiral.

TABLE II. SUMMARY OF TEST RELIABILITY

Assessment Algorithm/Type	Validity	Complexity	Cost	Patient Effort
Touch Screen Tapping (Response Time)	High	Medium	Low	Medium-High
Spiral Drawing	Medium	Easy	Very Low	Medium-High
Idle Hand Tremor Test (At Rest)	Very High	Easy	Very Low	Low
Voice Tremor Analysis	High	Extreme	Low-Average	Average
Gait Cycle Analysis/Moving/Turning (Accelerometer)	High	High	High	High
Gait Cycle Analysis/Moving/Turning (IMU Gyroscope)	High	Extreme	High	High
Questionnaire	High	Easy	Very Low	Low

C. Overall Scoring & Questionnaire

Memedi developed several mobile tests which allow self-assessment of common symptoms by having the patients complete a survey as well as on-screen motor skill tests using a stylus. The self-assessment tests identify the subjective symptoms whereas the motor tests identify the objective ones. The tests are scheduled and performed several times per day. The results are transmitted to a central server for analysis. The survey includes questions that ask the patient about their daily activities (walking, etc.) as well as their PD symptoms (dyskinesia, cramps, etc.) and asks the patient to select from several choices in order to rate themselves.

Results show that there is no method that can differentiate between voluntary in involuntary movements that PD patients suffer from (tremors and drug-induced dyskinesia). Also, the spiral method could not correctly classify drawing impairments in categories from a scale of 1-10. Furthermore, the spiral method only detects disabilities but cannot distinguish which symptoms are responsible for causing the disability. Memedi concluded that the scores obtained by the computer tests were highly correlated with the rating scales.

D. Tapping Tests

For the tapping tests, Memedi et al. [8] involves critical factors such as time taken to alternate, precision of each tap, and distance from the center fields of each button. Memedi et al. [6] described the speed equation as follows:

$$MTS = \sum_{i=1}^{n} \sqrt{\frac{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}{t_{i+1} - t_i}}$$

The Mean Tapping Speed (MTS) looks at the distance between two alternate taps on different buttons. In the above equation, x_i is the initial tap while x_{i+1} is the x-axis location of the alternate tap on the opposite button. The values for y_i and y_{i+1} and time stamps (t_i , t_{i+1}) are recorded in a similar way. The total sum of distance over time is calculated over n taps. The other factor [6] looks at is fatigue over the course of the test. Fatigue is calculated using the Mean Tapping Speed per Cycle and other equations that are added up to the final score.

As for accuracy and precision, [8] looks at an interesting relation between the sum of distances and the number of taps, this relation is called Overall Distribution of Taps (ODT). Similarly, the Overall Tapping Precision (OTP) is calculated by looking at the individual x and y coordinates of each tap on each button separately. To calibrate the Center Field (CF), the first tap performed is set as the center field of each button.

The survey in Table II provides a quick summary of each technique and algorithm found for Parkinson's Disease detection. Some of the algorithms such as voice analysis and gait analysis will not be used in the paper.

IV. Design Objectives

A. Objectives

The main purpose of the app is to collect sensor data, analyze it, then use a predefined scale to assess the patient and inform the user of their PD status. The scale will be based on multiple factors linked to the formation of specific symptoms, such as excessive hand tremors. The app takes into consideration that a normal person may also have hand tremors. However, the idea is to differentiate between what is a normal tremor and what is a PD tremor. To perform this differentiation, we need to collect data from multiple patients that have PD and normal people who do not have PD. We then compare tremors of those who do not have PD to those who do have PD and form a scale.

B. Context & Goals

The design is typically based on the assumption that people nowadays almost always carry their phones with them, and a majority of the population carries smart mobile phones with them. A network of phones can generate enormous research data for analysis, this is why the best way to carry out this research is to allow users the convenience of performing short tests and obtaining immediate results. In this particular research, an examiner, caretaker or patient will have access to a simple mobile application for Android. The goal of this application is to allow the examiner to perform tests on the patient (or him/herself in some cases), and obtain immediate objective and subjective results which quantify to which extent the patient shows symptoms of Parkinson's Disease. The analysis is done locally on the mobile phone. The test data is also stored remotely on a server, which makes it accessible from anywhere by someone with the allowed permissions. This allows physicians and researchers to perform research and analysis on the collected results. Security measures are implemented on the data stored on the phone and server to ensure the security and privacy of the generated data [13].

C. Core Features

The application will mainly feature four tests: Spiral, Tapping, Hand Tremor and Questionnaire.

1. The Spiral test aims to identify any PD-related drawing impairment such as the ones affected by involuntary movement (tremor, bradykinesia and drug- induced dyskinesia).
2. The Tremor test attempts to detect any involuntary tremors due to PD symptoms in the patients arms.
3. The Tapping tests record the x and y coordinates of each tap and measure the delays between each consecutive tap. Also provides the user with an overall average delay in milliseconds. Measuring the delay targets any bradykinesia and dyskinesia present in the user.
4. The Questionnaire performs a semi-objective assessment that greatly improves the results by looking for kinetic, postural and motor symptoms in the user.
5. The Results and Analysis function of the app shows the user their overall performance in all tests using graphs and detailed advice.

D. Improvements to Current Methods

Many researches try to replicate existing standard tests for PD diagnosis. As part of the design, the goal of the app was to also add new and enhanced features that would improve the test procedures and results. The following are the improvements:

1. Use Android Wear smartwatch, instead of phone, to take hand tremor readings. This is really important for accurate readings of shaking and tremors.
2. Add a warmup tapping test and a new Involuntary tap-ping test for additional motor assessment. Most other apps do not have involuntary movement detection.
3. Combine spiral drawing with other standard tapping and hand tremor tests. Spiral drawing tests are typically done independent of other tests, but by combining all of them together, the app can be able to make better decisions.
4. Present the score to the user immediately after testing using well developed algorithms. Most other projects do not provide instant feedback or do the processing of data manually.
5. Use a remote database rather than a local one, data can be accessed anywhere and anytime by authorized users.
6. A simple GUI with guidelines and tooltips that is easy to comprehend and can even be used by users with no technical knowledge. Most of the apps use complicated GUIs that are designed to be used by assessors who developed the test tool.

V. Technical Approach and Solution

A. System Design

Without digital devices, the diagnosis of Parkinson's dis-ease is a semi-subjective diagnosis that relays on physicians evaluation to patients condition. The goal of this paper is to develop an application that runs on Android operating system to deliver a collection of accurate-enough tests with zero additional cost. This app will use basic features that come with the majority of android mobile phones in addition to an optional external wearable device such as an accelerometer or a smart watch.

The system architecture will contain an Android mobile phone, an external accelerometer/smart watch and a web-server (Parse) that maintains mongo databases and uses a BSON handler. Users will interact with the android phone, which will run the tests, fetch readings from smart watch/accelerometer using Bluetooth and manage and analyze data then send it to the web server which will store it in a mongo database. The server will use a BSON handler to communicate with the phone (See Figure 1).

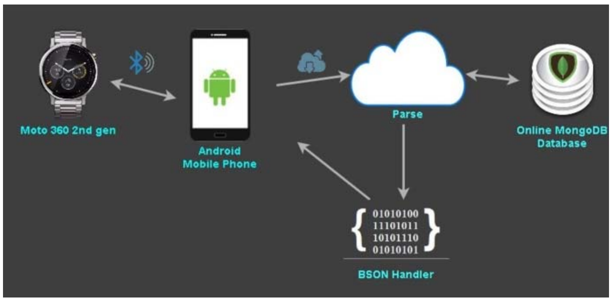

Fig. 1. System Architecture

Software architecture of the system consists of a data-centered architecture built around the database and an object-oriented architecture (JAVA) for developing Androids code, which by default uses call and return architecture.

The Graphical user interface of the main Activity consists of buttons that allow the user to access the tests and check their results. The Questionnaire consists of radio button groups, that represent questions, which come in multiple choice format. Spiral test has a spiral shape drawn in dark color, and a light stroke color to draw over it. Tremor test shows the *x, y, z* coordinates, coming from the watch or phones accelerometer, plotted on a graph. Figures 2 and 3 show screenshots of the mobile phone application and the watch.

Fig. 2. Application Screenshots

Fig. 3. Android Watch

B. Software Design

The software architecture is mainly based on the Model View Controller (MVC) framework. This framework suits our mobile application structure and design. In Figure 4, the Model represents the database where all medical data is stored for each patient. Whereas the View and Controller resemble the application GUI and logic respectively.

To highlight the components of our software, the application was divided into multiple interfaces, namely: App Logic, Database (DB) and GUI. In Figure 5, the Application logic plugs into the GUI and DB interfaces to access external functions. These functions help the application store, retrieve, and update the data for viewing as necessary. Hence, the logic component of the app must always have access to the functionality provided by the the external database and GUI Application Programming Interfaces (API).

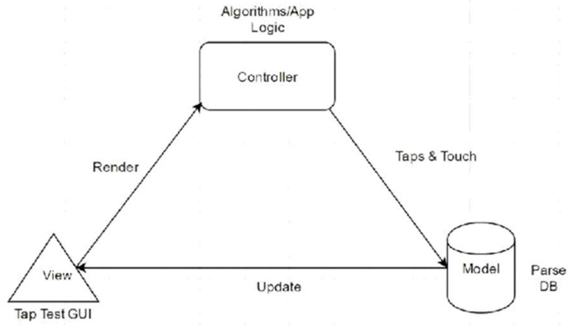

Fig. 4. MVC Application Framework

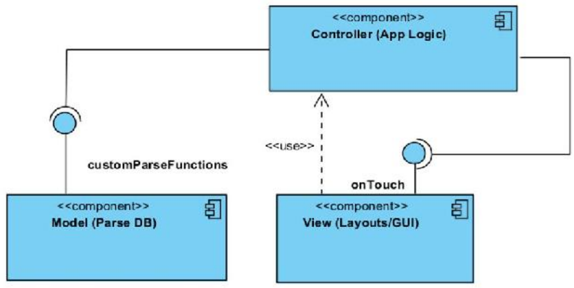

Fig. 5. Component Diagram

To summarize the database structure and to visualize how the data is related and stored in the DB an Entity-Relationship (ER) diagram was developed. Each user is stored as an entity, with multiple sub entities such as: spiral test data, tremor data and tapping data. Each of these test entities stores the necessary and required data for the analysis phase. Each user entity is also linked to an authorized session, sessions may expire when the user is idle or logs out.

C. Hardware Design

As for the hardware, only three nodes exist at any given time: The smartphone, smartwatch and external database. Listener services typically relay data between the watch and smartphone, this service was specifically used for sending and receiving tremor data from the smartwatch accelerometer. As for the analysis algorithms, which are locally available on the phone at all times, this gives the application a great advantage of being able to process the results without a constant connection to the internet.

D. Component Summary

Below is the list of hardware & software components used:

- Android Smartphone Sony Xperia Z2 running Android Lollipop 5.0+
- Android Wear (smartwatch) MOTO 360 2nd Gen. run-ning Android Lollipop 5.0+
- Cloud DB (provided by Parse) accessed via Parse Soft-ware Development Kit (SDk)

VI. EXPERIMENTAL RESULTS

As to prepare for forming our benchmark, we performed the three primary tests on campus across several age groups. This includes ages 30-39, 40-49, 50-59. A total of 11 participants were involved with 27.3% female and 72.7% male, where the majority were right handed except for 9% being left handed. To reduce the complexity and length of the test and to prevent embarrassment, we decided not to ask participants on campus to fill in the questionnaire.

All of the aforementioned participants were never diagnosed with Parkinson's Disease before, hence, in order to further improve the study we had to look for patients with visible early symptoms to be able to make a clear differentiation. Figures 6 and 7 show a hint at what might be a sign of normal tremors or dyskinetic movement. Figure 6 displays the generated accelerometer tremor graphs while Figure 7 shows how regular and irregular movements can affect the final shape of the spiral. As for the alternate tapping test, most of the healthy users showed precision across both tapping fields and landed at the center of the buttons every consecutive tap, achieving an accuracy of about 95% and above.

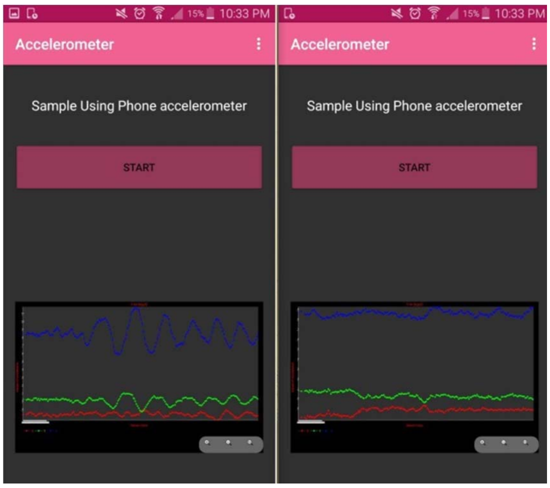

Fig. 6. Abnormal Tremors (left) and Normal Tremors (right).

In order to form better benchmarks for the tests, a larger number of participants needs to be tested and added to the control group. This will also help establish stronger correlations between age and performance, as well as other factors that we may not yet be aware of. Adding improved visual instructions to each test would also improve the final quality of the results, since many participants tend to skip reading the written instructions. Finally, we aim to conduct our tests on clinically diagnosed patients in order to set benchmarks for identifying the severity of the symptoms. This will of course require the aid of one or more medical professionals who would determine the severity of the patients symptoms using regular methods. Subsequently, we would calibrate our application to produce the expected results.

VII. CONCLUSIONS

The ever-evolving use of technology is prevalent, especially in the world of medicine. We believe that this project has potential in improving the quality of modern medical research. By utilizing modern tools such as smart wearables and high end mobile phones, users are able to perform fast diagnosis of their current condition without the involvement of any clinics. This project also paves the way for researchers to improve upon the ongoing study of early causes of Parkinson's Disease (PD). The ultimate goal of this project is to provide one click diagnosis and detection of early PD symptoms. With the support of experts, the application can eventually become part of real-time medical analytics tools for instant response and feedback.

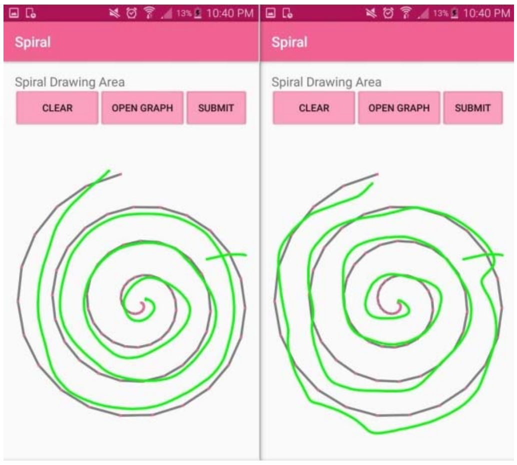

Fig. 7. Normal Spiral (left) and Abnormal Spiral (right).

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