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# A SMARTPHONE-BASED ASSESSMENT TOOL TO EVALUATE PARKINSON'S DISEASE SEVERITY

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**Abstract:** In this paper, an assessment tool based on smartphone to evaluate disease severity in patients with Parkinson's disease is proposed. Parkinson's disease is a pathology widely spread in middle aged and aged individuals of any sex. It is a debilitating and degenerative disorder affecting the central nervous system. Distinctive symptoms are movement-related such as rigidity, slowness of movement and shaking. Further symptoms could be even cause of behavioural problems such as dementia. Today, the disease severity assessment is performed by means of simple visual examination or by using specific medical instrumentation. The Unified Parkinson's Disease Rating Scale is used to define the progress status of disease. However, this ordinal scale allows physician to evaluate only qualitatively the pathology severity. Moreover, this evaluation requires expert medical staff, and sometimes, even the admission of patient to hospital is needed. For these reasons, the authors propose a smartphone app, which is able to record and process involuntary tremors of patient hand. Information, concerning amplitude and frequency of acceleration levels, is compared with patient historical data in order to assess the progress of disease.

**Keywords:** smartphone app; Parkinson's disease; tremors; vibration measurement; severity assessment.

## 1. INTRODUCTION

Parkinson's disease is a chronic disorder affecting central nervous system. Generally, it occurs beyond the age of 55. The incidence and severity of pathology are proportional to age. This pathology is mainly cause of movement disorders. In detail, it entails rigidity from an increase in muscle tone, tremor during resting status, impaired balance, shuffling gait and postural instability. During voluntary movements tremor may decrease or even disappear. This pathology is due to the degeneration of dopaminergic neurons in the *substantia nigra*, [1], [2]. Dysfunction in synthesizing dopamine causes a progressive aggravation of the patient health conditions. The drug therapy is the main treatment of Parkinson's disease. Pharmacologic therapy reduces the movement disorder, however it is a palliative treatment and adverse side effects develop. Moreover, with progression of the pathology, the response to drug therapy becomes less significant over time, so an increase in rigidity and resting tremor are observed, [3]. At the moment the pathology assessment is mainly clinical and it is based on motor abnormalities observation. Different scales exist and the most widely used is the *Unified Parkinson's Disease Rating Scale* (UPDRS). It is an ordinal scale used to follow the progress of the pathology. The movement disorder is the main symptom, so the motor evaluation is basic to define the disease severity. For this reason, the UPDRS is based on evaluation of patient behaviour during his/her daily life; so common activities such as speech, swallowing, salivating, walking, cutting-food, dressing are investigated. Nevertheless, this standard evaluation method does not allow to get an objective assessment, [4]. In fact, it and other techniques are used to assess only qualitatively the severity of pathology.

In literature, several researchers have proposed objective methods to detect and quantify tremor. Body sensor networks and expensive measurement systems for long term monitoring have been developed. Such systems are based on accelerometers or gyroscopes to quantify tremor and so to evaluate the severity status of the disease, [5]-[8]. The evaluation process requires clinical specialization and the patient admission to a specialized care centre. Differently, the development of devices to be used in domestic environment, without specific expertise, could reduce patient stress and economic expenses. In addition, the project of wearable devices is become possible with the miniaturization of sensor technology. So, a growing interest in such applications has been observed in the last years.

Nevertheless, such systems are not designed to evaluate the current progress of the disease with respect to historical patient data. Moreover, we can observe a lack of alternative diagnostic and assessment methodologies which allow to define a quantitative scale rating Parkinson's disease.

For those reasons, the authors propose a portable and low cost assessment tool based on a smartphone application, the use of which does not need the assistance of a medical expert. In this way, by owning a common smartphone, the patient can assess the progress of pathology in his/her natural home-based autonomous environment. Patient is not forced to buy an expensive measurement system, the app uses the same accelerometers embedded in his/her mobile phone. At any moment, patient can check the disease severity so to plan the next clinical appointment by necessity. The proposed assessment tool has been tested and characterized by laboratory experimentation.

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In the next Section, the commonly used severity rating methods are described. The third Section describes the proposed assessment tool. The forth Section reports conclusions and considerations for future developments.

## 2. PARKINSON'S DISEASE SEVERITY RATING

Parkinson's disease is a neurodegenerative pathology that typically begins about age 50-60. It causes slowness of movement (*bradykinesia*), poor postural stability, soft voice, tremor, muscular stiffness (*rigidity*), shuffling gait. In severe cases, further observed symptoms are sudden cessation of movement (*freezing*) and a paucity of spontaneous movements (*akinesia*). Although medical research has made remarkable progress, today no therapy exists to prevent or cure Parkinson's disease. The preliminary diagnosis of this pathology is made by identifying its most common symptom causing motor disorders. The etiology of Parkinson's disease is due to deterioration of neurons in the *substantia nigra* area of the brain, [1], [2]. The consequent lack of dopamine is cause of an abnormal nerve functioning, see Fig.1. This neurologic condition is progressive.

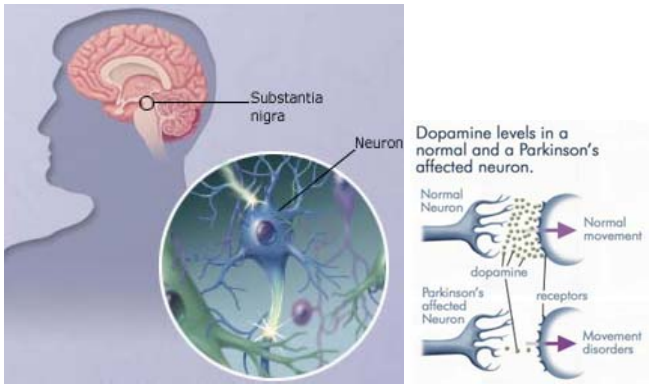


Fig. 1. Parkinson's disease etiology.

So the patient loses progressively the control of body movements. Several treatments have been defined, drug therapy is the most common one. Nevertheless, treatment provides only symptomatic benefit, in fact no treatment has been proven to slow pathology progression. In addition, as the disease progresses, treatment-related complications may develop and duration of drug response may decrease. Further side-effects could concern involuntary and extraneous movements (*dyskinesias*).

Involuntary shaking is the main characteristic of the pathology even at rest; it affects hands, arms, head, and sometimes the voice. It can become disabling for common daily activities, such as writing and eating. Typically, such involuntary tremors occur several times and for short time. Motor manifestations typically begin on one side of the body, and only later affecting the other side. The studies of Parkinson's disease require a means of rating the disease based on motor manifestations, assessment of ability to perform daily functional activities, and symptomatic response to medication, [3].

Currently, severity of Parkinson's disease is evaluated by means of the *Unified Parkinson's Disease Rating Scale*. It is the predominant method used in clinical practice for assessing the progress of pathology symptoms. This ordinal scale provides a final score of severity by means of qualitative evaluation. Clinician has to answer to a sequence of questions concerning patient health status. So such a method suffers from qualitative and subjective interpretation, [4]. Moreover, no temporal information on the progress of the pathology is provided with reference to the patient history. In detail the *Unified Parkinson's Disease Rating Scale* is divided in four subscales: I. Mentation, Behavior and Mood; II. Activities of Daily Living; III. Motor Examination; IV. Complications of Therapy.

For each subscale, specific questions are made concerning the intellectual impairment, thought disorder, depression, speech, salivation, swallowing, handwriting, cutting food, handling utensils, dressing, hygiene, turning in bed, adjusting bed clothes, falling, walking, tremor, facial expression, tremor of hands, rigidity, finger taps, hand movements, leg agility, posture, gait. The examiner asks the patient about each area of cognitive and motor functions; the rater scores the answers from 0 to 4, with 4 representing the greatest level of dysfunction. Other items requires to express a simple 'on' or 'off' state. The total score provides information on the pathology severity. Although this is the most widely used rating scale, it has substantial limitations to be considered.

Further rating scales have been defined such as *Modified Hoenn and Yahr Staging*. It reflects the degree of progression, and refers to features of disability and motor impairment. However, the scale is not linear and it is used mainly to describe subject groups. Another known scale is the *Schwab and England Activities of Daily Living Scale*. The rating is made by the examiner interviewing the patient and, frequently, a relative.

The rating scales have been developed to define the best therapy according to patient health status. So, they are basic in the severity assessment of the pathology. Nevertheless, a critical issue is to control the temporal patient response to individual doses of drug. So, the rating evaluation must be performed several times during medication administration.

In addition, the evaluation process has to be carried out by specialists and the patient must be admitted to hospital or specialized clinic during the examination period. As a consequence, in the last years, there is a growing interest in developing innovative devices and assessment tools, which can be used at home without expert medical staff. This would allow to reduce health expenses. Moreover the patient could perform the evaluation at his/her home, in a friendly environment so reducing stress.

An important challenge for researchers working in this field is to define an objective rating scale based on quantitative information. So, with reference to the motor manifestations of Parkinson's disease, measurement instrumentation has been developed to measure the tremors of hand and arm. To this aim, accelerometers are extensively used to acquire vibration due to involuntary movements. The main weakness of such solutions is the cost of instrumentation. In this view, the authors have developed an innovative assessment tool based on smartphone to evaluate the pathology severity.

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## 3. THE PROPOSED ASSESSMENT TOOL

Tremor at rest is generally considered as the characteristic feature of patients with Parkinson's disease. In fact, it is the most common symptom of this pathology, which can be even easily recognised by a simple visual examination. Resting tremor has a typical frequency of 4-6 Hz, [9]. Usually, it appears unilaterally, and with the passing of time it becomes bilateral showing similar frequencies on both sides. The power spectral density function of angular velocity signals has been used in [10] to investigate the distribution of movement power over the frequency. To this aim, rest movements of hand of subjects with Parkinson's disease have been recorded. In this study, the authors define three frequency bands. The first band includes frequencies lower than 3.5 Hz. This band refers to voluntary movements. The second band includes frequencies in the range 3.5-7.5 Hz, and it refers to involuntary movements or tremor at rest. The third band includes frequencies in the range 7.5-15 Hz, and it characterizes normal physiological tremor.

In the present paper, the authors focus attention on tremor and involuntary movements at rest affecting hand. The aim is to provide an user-friendly tool which can be used by patient in order to test the progress of the pathology and its severity. Although several devices and measurement systems have been proposed in literature, the authors aim to propose an assessment tool based on a smartphone without forcing the patient to buy additional expansive systems or devices. In detail, an application (app) has been developed to analyse the tremor at rest of patient so to make a diagnosis about the current status of the pathology progress. The app runs on a simple smartphone and is able to acquire the acceleration levels along the axes of an orthogonal Cartesian system *x*, *y*, *z*. Acceleration levels are processed in order to evaluate the maximum and mean values. By means of *FFT* algorithm, the acquired signal is analysed in the frequency domain so to characterize the contributions due to voluntary movements, physiological movements and involuntary tremors. Time and frequency parameters are compared with reference levels and information concerning the patient history in order to evaluate the disease severity.

The app has been built by using *Objective-C language* with *Xcode*. It can be executed by any *iOS* mobile devices having integrated accelerometers. The interface is user-friendly so to allow patient of any age to use easily it, see Fig. 2. A start/stop button allows user to execute the application and to stop it, in this way the smartphone begins the data acquisition.

The acceleration levels are sampled with a sampling frequency of 100 S/s in a time-window of 60 s. A digital filter allows to reject aliasing and spectral leakage components. Before the analysis stage, the signal is filtered with a cut off frequency of 0.25 Hz (2nd order non-causal Butterworth filter). At the end of acquisition, data are processed, and the *FFT* algorithm provides the frequency spectrum of the signal with a spectral resolution of 0.024 Hz.

A graph shows the trend of the acceleration modulus, as an alternative, it is possible to show the acceleration levels along a specific axis or to depict the frequency spectrum of the signal. Six indicators show the peak value of acceleration for each axis, and the respective frequency of the spectral content.

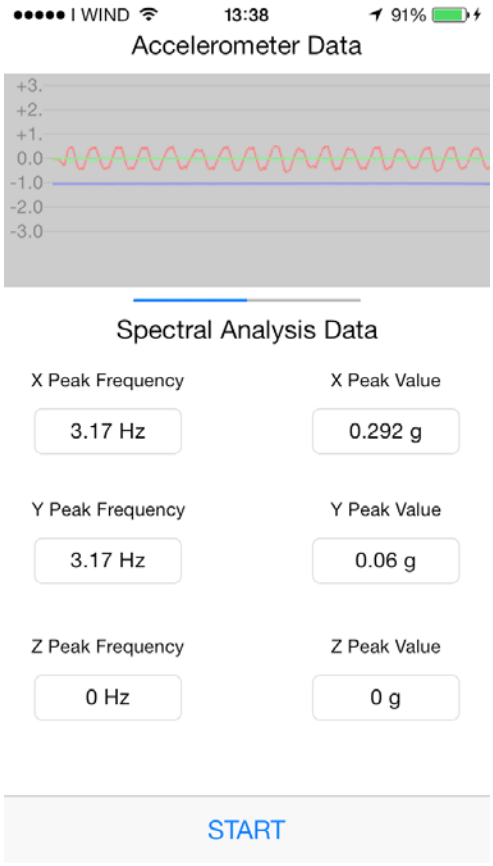


Fig. 2. App user interface.

The patient has to hold with his/her hand the smartphone and press the start button. He/she must be at rest during the measurement process for 1 minute. Then, the app performs the data processing and shows the results on the smartphone screen. Information concerning last check of patient is stored in the internal memory of smartphone. In this way, the app compares the current tremor levels with the last ones in order to assess the progress of pathology. A final score bar shows to patient his/her current percentage level of pathology severity. If a deterioration of patient health status is observed, the patient has to consult doctor for further medical screenings. Typically, such a feedback can allow clinician to define the best drug therapy for patient according to the advancement of pathology. In this way, the patient can keep the evolution of disease under continuous control by checking intensity and frequency of involuntary tremors of hand. Progress of pathology is stored in the internal memory of the smartphone. As a consequence, tremor characteristics and temporal information of disease can be readily quantified. In any time, doctor can get information on patient history for making further analysis.

In order to verify the accuracy of the used smartphone accelerometers, they have been tested by means of a vibration calibrator. Calibration has been performed on a specific model of *iOS* mobile phone. The results have shown an accuracy compliant with the resolution required for the

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specific application. Further tests have been carried out by simulating vibrating movements and comparing the smartphone response with three accelerometers orthogonally displaced (*PCB PiezotronicsINC. 393B04*), [11], [12]. The comparison has shown a maximum standard deviation of 7%, which can be considered tolerable with reference to the aim of the proposed assessment tool.

At the present moment, the developed app allows only to quantify the tremor characteristics and compare it with previous records in order to evaluate the progress of the pathology. Therefore, the task of the assessment tool is to characterize possible deterioration of patient health status. As a consequence, a relative rating score of disease severity is provided. Currently, medical trials are in progress in order to define an absolute quantitative rating scale by comparing the tremor characteristics with the doctor diagnosis using the *Unified Parkinson's Disease Rating Scale*, [13]. In this way, it will be possible to define an absolute model for assessing objectively the current health status of patient.

## 4. CONCLUSION

In the paper, an assessment tool to evaluate Parkinson's disease severity has been proposed. A mobile application based on smartphone has been developed in order to measure the involuntary movements of patient hand. The proposed mobile application is user-friendly. It has been developed in *Objective-C language* by *Xcode* for *iOS* mobile devices. The interface allows patient to start the acquisition of tremor at rest by means of the built-in accelerometers of the same mobile phone. A *FFT* algorithm performs the spectral analysis. The tremor characteristics in the time and frequency domains are put in comparison with the results of the last check-up. In this way, the tool evaluates the progress of the pathology so to characterize possible deterioration of patient health status.

The severity of Parkinson's disease is evaluated by means of qualitative rating scales. Such an evaluation is influenced by specialist, who has to express a judgement on patient health status by considering his/her behaviour. So the final score is merely qualitative and subjective. The final aim of the present research activity is to define an absolute model based on quantitative information. At the moment, the app allows to assess only the relative disease severity so to characterize deterioration or enhancement of patient health status. In fact, by comparing the tremor characteristics with previous records, the tool evaluates the disease progress. In this moment, medial trials have been planned to compare the tremor characteristics with the *Unified Parkinson's Disease Rating Scale* so to define a new quantitative rating scale. Experimental validation of the proposed model is therefore in progress. Results and further developments will be reported in future works.

In conclusion, the proposed assessment tool allows patient to keep continuously under control the advances of Parkinson's disease at his/her home.

No admission at hospital and no specialist intervention are required during the test. Moreover, no additional devices or further instrumentation are required, the patient must own only a *iOS* smartphone and to install the app. The device is able to store the progression of Parkinson's disease in a database so to help clinician in the definition of drug therapy.

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