ParkDetect

Early Diagnosing Parkinson's Disease

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***Abstract*— Parkinson's Disease is one of the most common neurodegenerative disorders of the central nervous system that affects elderly. There are six main symptoms: tremors, rigidity, bradykinesia (slow movements), hand asymmetry, posture instability and freezing of gait. Nowadays any type of diagnose for this disorder is done through observation by a health care professional specialized in this area. Therefore a simpler and more efficient method that General Practioners can use to have some grounded information to decide to forward a possible patient to a specialist is needed. With this in mind different systems were studied coming to the conclusion that a mobile application is among the best options. This work can be split in four important phases (see Figure 1): (1) study of the current market for this problem and for the solution to be developed, (2) development of a smartphone application capable of gathering data of the early symptoms of Parkinson's taking into consideration all the smartphone's specifications; (3) use the application to gather data from real patients and a control group and (4) test and select a classification algorithm. The first phase involved two research topics: problem and solution. The problem consisted in studying all the symptoms that could theoretically be detected by the different smartphone components. The solution consisted in studying the different methods used to solve such a problem using data mining techniques (different feature selection and classification algorithms that best take advantage of the nature of the data gathered). The second phase consisted in the development of the smartphone application with four components (spiral analysis, tap analysis, simple questions and gait analysis). The third phase was dedicated in building the control group gathering data from healthy people and a Parkinson patients group for a total of 35 subjects. Finally, the fourth phase was using the studied algorithms to filter the different features and compare the different algorithms selected. With the available data from the test subjects it was possible to achieve promising results from the gait analysis of the patients where the pelvic sway was a good feature to help differentiate Parkinson patients from healthy ones.**

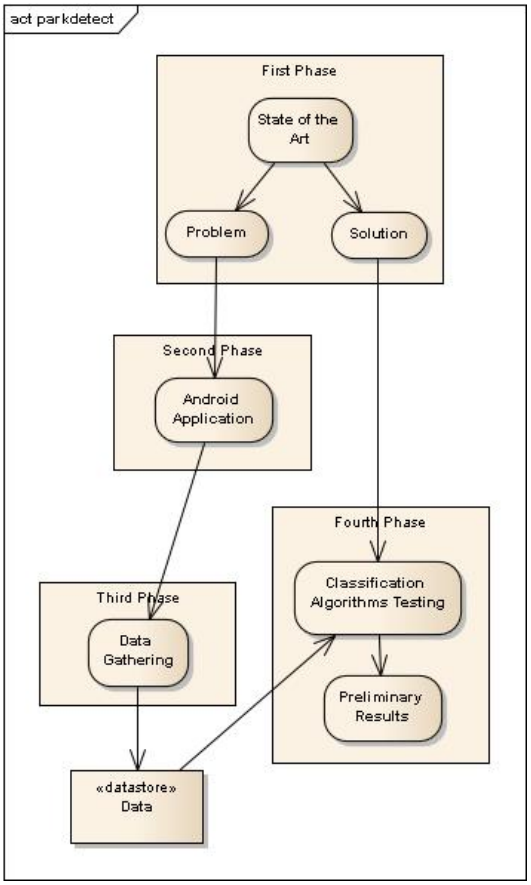

Figure 1 - Flowchart of activities

Keywords—Parkinson; diagnostic; mobile; data mining;

I. INTRODUCTION

Parkinson's Disease (PD) is one of the most common neurodegenerative disorders of the central nervous system. PD is most often diagnosed in persons with over 50 years of age and affects the lives of 2 million people in Europe alone. There are six symptoms that characterize this disease in its early stages: (1) tremor, defined as an involuntary oscillating movement of one or more body parts (mainly extremities) of the patient that is only visible when the part in question is at rest, therefore is called rest tremor. This type of tremor

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disappears when any voluntary movement is executed. This is one of the most common symptoms and is, most of the times, one of firsts ones to manifest its appearance; (2) rigidity, mainly affects the movement of joints caused by the excessive contraction of muscles; (3) bradykinesia, slowness of movements affects the whole movement of the patient, although at early stages is more evident in the daily tasks such as writing, dressing or using tools; (4) Hand Asymmetry, related with bradykinesia and the rest tremors that normally have a greater incidence on one side of the body resulting in an asymmetry between the movement and responsiveness of both hands; (5) posture instability, is only detected in later stages of PD and (6) Freezing of Gait (FoG), is the final stage of bradykinesia that totally shuts down any voluntary movement for short periods of time of the patient [1][2][3]. Although there are more symptoms such as numbness, problems with speech, blurry vision, micrography (smaller handwriting), sleep disorders, muscle pain, etc., they may not be truly related to PD[4].

II. Context

Nowadays there are a few different methods to try to diagnose PD, the most used one is the Unified Parkinson's Disease Rating Scale (UPDRS). The UPDRS is a clinical metric used to quantify PD impairment. It consists on 42 items where some may have some subdivisions and we shall refer to each item and subdivision as a section. There are four main components UPDRS relies on: (1) Behavior, mood and psychological state (4 sections, 1-4); (2) Daily routine activities (13 sections, 5-17); (3) Motor, regarding muscle control (27 sections, 18-44) and Therapy related complications (11 sections, 45-55). The third component, many times designed as motor-UPDRS, is the one that most influences the final UPDRS score. The motor-UPDRS component scores between 0 and 108: 0 represents a healthy patient and 108 one with severe disabilities [4]. Another vastly used method is the Hoehn and Yahr (H&Y) that provides overall PD stage assessment. This scale goes from 1 to 5 (having 1.5 and 2.5 in the modified version) where at 1 the patient shows unilateral involvement only (e.g. tremors in one hand only) and at 5 means that the patient is confined to a bed or wheelchair. Studies have shown that this method can be mapped to the UPDRS [6].

However both methods are only used by neurologists due to the required expertise. Therefore the goal of this work is to provide a simple method to be used by General Practioners that may confirm the possible suspicious of PD and, in this way, sending the patient to a Neurologist as early as possible, thus allowing the beginning of treatment in earlier phases of the disease.

III. Application

For this problem an application for a smartphone was the selected one for different reasons: a regular smartphone is equipped with different types of sensors that can be used to collect physical data of the user (accelerometer, compass, GPS and touch screen); in the first half of 2013 over 95% of cellphone sales were smartphones, giving them an high impact on the current market [7] and the size of the device that allows the user to properly perform all the tasks related to this work, as it will be discussed further in this document. The Operating System (OS) selected for this project was Android because it is free and is easy to develop for, thus allowing to prove the concept of this work. Android is also a good choice because it's current market share is over 75% of all smartphones sold in 2013 [7]. Taking into account the specifications necessary the smartphone selected was the Google Nexus (I9250) equipped with a Super AMOLED capacitive 4.65 inches (~316ppi) touchscreen and a digital, triaxial acceleration sensor capable of measuring within ranges of 2 to 16g depending on its configuration.

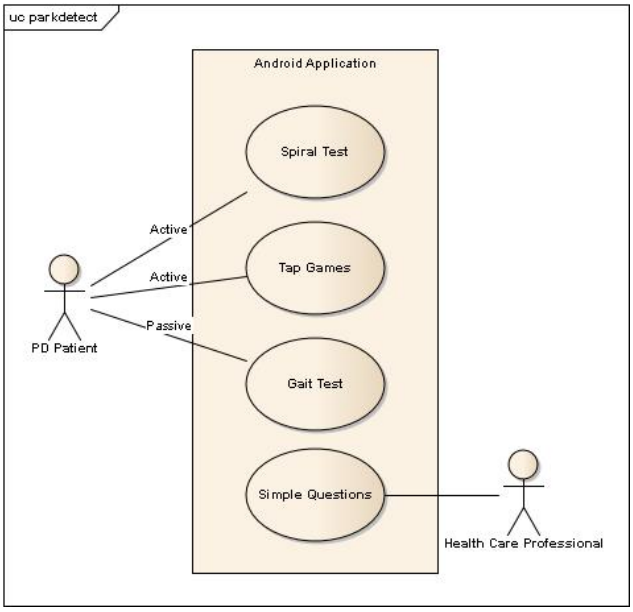

Figure 2 - Application Components

The smartphone application has four different components (see Figure 2): two of them require active interaction of the patient with the smartphone (spiral and tap analysis), one requires passive interaction (gait analysis) and the last component is used by the health care professional (simple questions with simple observation skills). The first component is the analysis of a patient drawn Archimedean spiral that allows to evaluate movement disorders such as tremor, rigidity and bradykinesia [8][9]. Many different approaches were made in this area to prove the concept [10][11][12][13] using different platforms or types of spiral [8][14][15][16][17] however none ever used a smartphone or combine different types of diagnosis methods. Due to the fact that the portability of the device is a main concern for the gait analysis component (to be discussed further in this document), this approach has one main concern: the screen size of the device (see Figure 3).

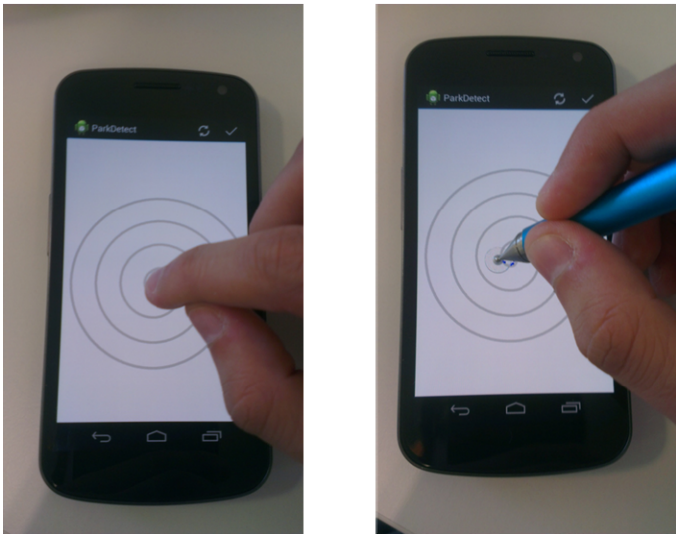

Figure 3 - Spiral Test with finger and stylus

To try to overcome this disadvantage, a smartphone with a bigger screen was used and the use of a stylus pen that allows the user to maintain vision of the screen while drawing it (see Figure 3). For the second solution an Adonit Jot Classis Stylus was used [18]. It works just like a common pen, in contrast to the regular stylus for touch surfaces that have a large end to replicate the finger's touch. So this component needs to be validated in two ways: verify if a smartphone's screen is big enough to gather relevant data and if the use of a stylus improves the performance of its users. From this component it is possible to obtain the average, maximum and deviation error of the spiral comparing to a perfect one, cross ratio (percentage of times the user crosses the spiral counting the number of times the error passes from negative to positive and vice-versa), pressure ratio (using the Android API it is possible to obtain the pressure used to draw in every single point. In this way, we compare the left side to the right side of the spiral - note that the calculated pressure is based of the area that the finger used to press the screen), number of points ratio (comparing the number of points drawn in each side of the spiral it is possible to detect differences in the drawing speed of the subject) and time taken to draw the whole spiral.

The other active component is the tap analysis that consists in two simple games (see **Figure 4**). In these games the user needs to touch the screen of the smartphone as fast as possible, performing the game each time with each hand. The first one is a replica of the "whack-a-mole" carnival game where the user needs to touch an appearing mole as fast as possible. In this case the game is played with the index finger and it is possible to compare reaction times, pressure and time the user keeps pressing the screen of each hand to verify for and asymmetry. The second game is played with the user's thumb where he needs to click as many times required to fill a bucket of water. The data gathered also allows verifying for hand asymmetry and tapping speed of the user.

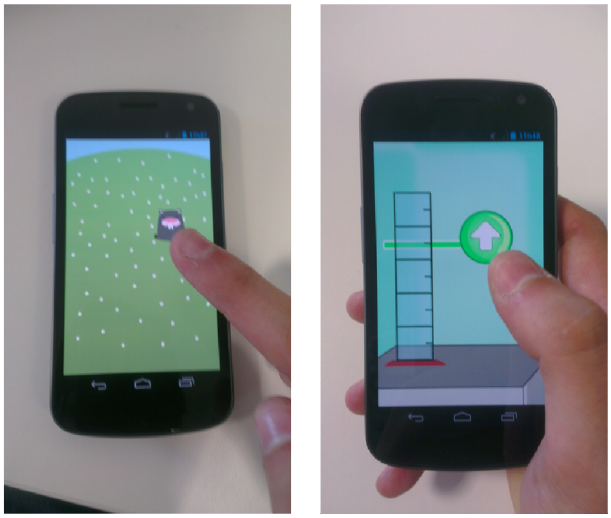

Figure 4 - Tap Games

The previous components only aim at detecting physical symptoms through the user's hand input, but PD affects the whole muscle system. Another very common affected capability of a PD patient is the patient's gait. The main symptoms that manifest in this capability are the bradykinesia and the freezing of gait, however the latter does not manifest in early stages of PD. To detect the gait characteristics of the patient, the accelerometer of the smartphone is used by fixing it to the trunk of the patient near his Center of Mass where the movements will present symmetry [19] (like in **Figure 5**) and asking him to walk in a straight line for 25 seconds.

Figure 5 - Position of the smartphone for the gait analysis component

During the gait each step coincides with the movement of the pelvis, going up or down with a left or right step and forward and backward with differences in gait speeds [19]. As such, foot contacts can be detected whenever there is an acceleration peek before a change of polarity in the signal. After this detection most part of the lateral acceleration is opposite to the foot in contact with the floor, making it possible to determine if it was a left or right step. Toes off can be determined analyzing the vertical acceleration, already excluding the static gravity component, detecting minimums after each heel strike. Every event is recorded with a timestamp that allows determining gait phases [19].

The step length is calculated through the use of two pendulum models: the first relative to the swing phase and the second, with an unknown radius, to the double support phase [20]. The step duration was calculated computing the difference between each foot contact.

This algorithm is the final product of a Master Thesis done at Fraunhofer Portugal [19] and its final output are the following measures: walking distance, first leg in contact, mean steps duration, mean stride duration, mean stance phase, mean swing phase, mean double support phase, cadence, mean step length, walking speed, step duration and length asymmetry, stride time variability, step time and length variability, pelvic sway, lateral displacement and lateral peak velocity.

The final component that does not need the user's input are some simple questions to be filled by the health care professionals, concerning some visible symptoms the user may manifest (in this case tremors and instable posture).

IV. RESULTS

Before evaluating the results holistically, validation of the spiral analysis component was needed. Firstly, it was necessary to evaluate the performance of using or not using the stylus to draw the spiral. 5 healthy persons were recruited to draw the spiral with their index finger to compare to the rest of the control group gathered for the main problem. One of the complaints this small group had was the lack of vision available on the screen while drawing the spiral, due to the size of the finger. They felt as they didn't get the accuracy they know they have. This complaint was never mentioned in the control group (nor the PD patients) that used the stylus. It is to remember that a regular stylus replicates the index finger's size and have similar diameter so it is likely possible that the same complaint would occur in case of using it. The results obtained were the ones expected with the control group having 9.7 +- 4.66 pixels average error with the stylus and the small group without it had a 17.3 +- 4.33 pixels of average error.

For the main problem it was possible to gather data from 35 test subjects: a total of 17 PD patients - 12 male and 5 female - with an average age of 67.5 SD ± 3.97 and 18 healthy subjects: 14 male and 4 female with an average age of 72.1 SD ± 9.03. The PD group had the disease diagnosed for 8 SD ± 6.6 years. All the PD patients performed the tests in Hospital S. João, Oporto, Portugal, while they were waiting for the medical consult. Only the ones indicated by a neurologist helped in this project since a few requisites were necessary (motor capabilities and no medication related symptoms). The control group was assembled by visiting social centers or inviting seniors to Fraunhofer's facilities.

With several features gathered, it was necessary to reduce its number. With the help of a neurologist from Hospital S. João, it was possible to create a subset of features that may represent some relevance to diagnose and discard all the ones that didn't (age, gender, height, weight, features related to only one side of the body, i.e. the diagnostic relevance is in the ratio between both, not on one side alone).

Analyzing the data obtained in a simple statistical method, we obtained the result displayed in Table 1. Taking a wider look at all the results it is possible to see that the variability on the PD group is very high which means that the features do not represent the group in a consistent way. However some features in some components are not like this. In the spiral component, the cross feature shows a significant difference between both groups. The same happens in the simple questions and in the gait analysis (cadence, walking speed, pelvic sway and lateral displacement). The component regarding the tap analysis did no show any relevant feature due to high values of variability. These results can be justified with the medication the patients were taking that shadowed the symptoms. Also the tap analysis were analyzed to check for traces of bradykinesia, however the number of taps required for the tests were not enough to achieve any results.

TABLE I. ALL FEATURES GATHERED (AVERAGE ± STANDARD DEVIATION)

Feature	Parkinson Group	Control Group
Spiral Average Error (pixels)	21.66 ± 23.94	9.94 ± 4.14
Spiral Cross (%)	6.6 ± 3.7	11 ± 2.9
Spiral Pressure Ratio (%)	3.1 ± 3	3.3 ± 3.1
Spiral Side Ratio (%)	13.5 ± 10.9	16.3 ± 10.4
Tap Time Ratio (%)	33.5 ± 30.8	13.4 ± 9.9
Tap Pressure Ratio (%)	11.7 ± 8	13 ± 9.6
Water Time Ratio (%)	28 ± 19.7	10.4 ± 10.8
Water Pressure Ratio (%)	10 ± 14	6.6 ± 9.6
Water Speed Ratio (%)	27.8 ± 25.8	9.3 ±8.1
Flexed Posture (% Positive)	83.3	29.4
Rest Tremor (% Positive)	77.8	11.8
Mean Steps Duration (seconds)	0.58 ± 0.17	0.48 ± 0.07
Mean Stride Duration (seconds)	1.16 ± 0.35	0.95 ±0.14
Step Duration Asymmetry (%)	8.33 ± 9.17	4.87 ± 4.07
Step Time Variability (milliseconds)	79.45 ± 71.57	38.41 ±19.06
Cadence (steps per minute)	108.8 ± 19.23	130.6 ± 31.92

Feature	Parkinson Group	Control Group
Walking speed (meters per second)	1.25 ± 0.265	1.64 ±0.51
Mean Step Length (meters)	0.69 ± 0.07	0.75 ± 0.08
Step Length Variability (meters)	32.94 ± 16.14	29.68 ± 8.14
Step Length Asymmetry (%)	3.59 ± 3.03	2.36 ± 1.76
Pelvic Sway (meters per second	3.24 ±0.64	5.64 ± 1.63
Lateral Displacement (centimeters)	3.01 ± 1.6	2.12 ± 0.7
Lateral Peak Velocity (centimeters per second)	15.03 ± 4	15.61 ± 3.48

Due to the nature of this problem, the classification algorithms to be used were narrowed to decision trees, classification rules and Bayesian networks. These were the selected algorithms mainly because they allow verifying the steps taken to reach a decision (interpretability) and, in medical cases, this is one of the most important characteristics.

Firstly, some feature selection algorithms were used to verify which features or subset of features was most relevant for classification purposes. Using the Information Gain Attribute Evaluation method, that verifies which features give more information for classification purposes, six features showed some relevance (zero is non relevant, one most relevant):

- Pelvic Sway – 1.0
- Rest Tremor – 0.613
- Walking Speed – 0.580
- Spiral Cross – 0.476
- Posture – 0.388
- Tap Time Ration – 0.387

Using an algorithm that verifies the subsets of features like the Best first (greedy hill climbing) algorithm, the same features are selected. However with the Greedy Stepwise (SBE) only 4 features are selected (Tap Time Ratio, Posture, Rest Tremor and Pelvic Sway). All these results were obtained using the Attribute Selection algorithms implemented in the WEKA [21] package. The dataset used had all features considered as non relevant to diagnosis discarded as previously mentioned.

Given the low quantity of data, it was necessary to use a 10-Fold Cross Validation for each algorithm. The software used to test the different algorithms was the RapidMiner [22] with the package of WEKA algorithms. The results obtained are displayed in the Table II. The results obtained for each algorithm used are promising where the Decision Trees have the lower variability values meaning that between all the folds the differences were not very substantial.

TABLE II. COMPARISON BETWEEN THE ALGORITHMS USED (SINCE A 10-CROSS FOLD VALIDATION WAS USED THE VALUES ARE AVERAGE ± STANDARD DEVIATION

Measure	Decision Tree (C4.5)	Classification Rules (RipperK)	Bayesian Networks
Accuracy (%)	86.67 ± 13.54	80.83 ± 17.10	87.5 ± 23.05
Precision (%)	91.67 ± 17.08	80.83 ± 20.43	86.67 ± 30.55
Recall (%)	86.67 ± 20.82	90 ± 20	85 ± 32.02

V. CONCLUSION

Firstly, comparing the use of the stylus or not it got proven that with the stylus the subjects can perform the test to the extent of their capabilities. This way the results were not affected by environment related issues (vision) and only by the performance of the subject. Secondly, the main problem, some of the components didn't have the expected results (tap analysis mainly). We concluded that the tests were not long enough to gather symptom related data (like bradykinesia) and that the number of required taps to finish the test should be higher (at least 10 taps). In general the spiral analysis component had some interesting results, while the PD patients' group was much more heterogeneous (some had no difficulties while others just couldn't perform it), which implied a higher variability. For classification purposes this is not a good data characteristic. Finally, the last two components showed obvious differences in some features, mainly the rest tremor question and the pelvic sway feature in the gait analysis that were the ones often selected by the algorithms to make the necessary decisions to achieve a classification. For future work, collecting more data is one of the most important tasks, both control group and PD group and, if possible, try to gather data from patients that are not yet diagnosed but have a high likelihood of having PD and modify the data gathering application to try to detect more efficiently bradykinesia with the tap tests.

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