Parkinson's Disease Predictive Analytics through a Pad Game Based on Personal Data

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Abstract

Games for disease diagnosis and rehabilitation are developing rapidly in recent years. Pioneer research has shown that video games can contribute to improving the patients' physical and mental conditions. However, to this day the available playable games for Parkinson's disease (PD) patients have the disadvantages of costing expensively, setting up complicatedly, requiring accompany, and more importantly, lacking automatic and systematic personal data analysis. Therefore, in this paper, we present a predictive PD analytics through pad game. We first introduce the criteria and details of game design and implementation, which is tailored for the PD diagnosis and patients rehabilitation on pad technology platform. Then we introduce the analysis approach for personal data to detect the potential PD symptoms and monitor the progression of the PD patients.

Keyword: Parkinson’s Disease, Pad Game, Data Analysis.

I. Introduction

Background

The world population is ageing at an alarming rate. As the most serious example, the proportion of the elderly in Japan, who are defined as people aged 65 or older, has increased from 12.0% in 1990 to 23.3% in 2011, and is projected to reach 38.8% in 2050 [1]. In Singapore, the proportion of the elderly has risen from 7.7% in 2001 to 11.1% in 2012 [2]. In 30 years, 5.2% has been noticed for the proportion of the elderly in Canada, and it is foreseen that the total number of the elderly will be more than doubled [3]. In 2050, it is estimated that 22% of the entire global population is projected to be aged 60 or older [4]. Therefore, to improve the quality of life of the elderly has become unprecedentedly important.

Parkinson's disease (PD) is one kind of disease that seriously threatens and decreases the quality of life of the elderly. It affects about 1% of the elderly population [5]. PD may evolve in five stages. The most common early symptoms include akineisa (problems in initiating movement), bradykinesia (reduced amplitude and speed), abnormal facial expressions and postural instability [6] [7]. The current standard treatment is L-3, 4-dihydroxyphenylalanine therapy. Due to the negative side effects of the medication (e.g., destroying a small portion of the brain), physical therapy plays an important role in treating PD and delaying the need for drug interventions, especially at an early stage.

However, the physical exercises need to be done at an intensive daily basis to be effective [8] [9]. The intensive daily training not only poses economic problems for most patients [10] [11] but also makes patients feel mentally bored and physically tired [12] resulting in losing their motivations. To help diagnose PD at an early stage and to motivate the patients to exercise repetitively, video games for diagnosis and rehabilitation are developing rapidly in recent years. Some previous work has been done and shown that video games contribute to motivating patients to exercise more and providing additional instructions and feedbacks [13].

Despite of the benefits, the existing work [12] [14] [15] [16] [17] [18] [19] [20] has the following disadvantages. First, most of them depend on the complicated devices or platforms (e.g., GestureTek and IREX) to capture and track player motions, which are expensive and require system setup from experts. Second, most of them are designed for the rehabilitation purpose instead of diagnosis. However, as with any disease, an early detection of PD will significantly enhance patient's quality of life. Third, most of them require guidance from instructors, which make them difficult for the elderly to play alone due to the lack of computer knowledge. More importantly, they depend on the doctors or the therapists to subjectively monitor the progression of the PD patients rather than collecting the large amount number of the player playing games to conduct automatic and systematic data analysis, which actually contributes to improving the effectiveness of the doctors and therapists making decisions.

In recent years, the emergence of pad technology based devices (e.g., iPad, Nexus, and Galaxy, we will use iPad to refer to the devices based on pad technology in the rest of the paper) has brought the opportunity to overcome these disadvantages. The iPad has the virtues of being taken anywhere and installing applications easily. The age-friendly operations in iPad require little expert knowledge to play games installed on it. Therefore, in this paper, we introduce a PD diagnosis analytics through pad game, which is specially designed for both PD patients and doctors. The game has the following advantages. First, the patients can play the game anytime and anywhere without special requirement for setting up or instructor accompany. Second, the game is particularly tailored for PD prediction. The risk of a player having PD can be real-time calculated after the player completing the game and an alert will be sent to doctor in case that a high risk of the player having PD is predicted. Third, the collected data and the data analysis results can be visually shown to the doctors to facilitate them to make a decision on whether the player having PD and analyze the disease progression according to the recorded historical personal data involving in continuously playing games during a long time. Through these advantages, the elderly are encouraged to play the designed game more often. The potential possibility of having PD can be predicted at an earlier stage. And the collected data can further contribute to track the player's health condition.

Existing Games for Parkinson's Disease

Some pioneer studies regarding the application of games in the rehabilitation for PD patients have been conducted in [14] [15]. In [14], the authors tested the adaptation of PD patients in a virtual reality (VR) environment for the purpose of exploring whether VR can give more information to support clinical and neuropsychological approaches. In the study, a VR environment that is related to common daily activities at home (e.g., eating or using the bathroom) was employed. The test conducted on 2 female with PD and 10 normal control subjects showed that VR could help to improve the quality of life through cognitive rehabilitation.

In [15], the authors developed a computational architecture based on the EyesWeb open software platform [21]. The architecture integrates the modules for analyzing and recognizing gestures, generating real-time multimedia feedbacks, designing therapeutic exercises which can be performed in real time, and allowing the therapist to evaluate the progression of the therapy. A number of EyesWeb based exercises (e.g., asking the player to paint using his or her body) were developed for experiments. A preliminary study was conducted on 1 male and 1 female PD patient to evaluate whether such kind of systems are able to generate aesthetically resonant feedbacks in PD patients and provide them emotional and motivational involvement for the purpose of rehabilitation.

In [12], the authors developed an interactive multimedia system for the rehabilitation of PD patients to fulfill the needs of the physical therapist and the patients. The system integrates two physical therapy techniques -- multimodal sensory cueing [22] [23] and BIG protocol [24], and provide visual and auditory feedbacks. In the system, the patients are asked to control their avatars to complete movement related tasks. The avatars are mapped in the screen through capturing the location of the patient's hands, feet, and torso by a 10 near-infrared camera Motion Analysis System. Feedbacks are given based on the accuracy and timing of the movement.

In [17], the authors designed and implemented a collection of five mini-games (WuppDi!) for PD patients to train their memory and motor skills. The games are based on well-known fairy tales and cover different complexity levels. Visual and auditory feedbacks are provided to guide the players. The game can be setup up at both home and clinics. But the system requires a complicated setup. It is also recommended to provide assistance of a healthy person to assure balance and stability of the player. A field study was conducted on 13 PD patients (38% female and 62% male) to investigate how PD patients feel the games regarding game contents, game play, and motion. In [18], the authors improved WuppDi! by integrating the feature of tuning game difficulty by automatically adapting to the patients' individual differences.

In [16], the authors developed a medical gaming system for PD patients to measure their steadiness during the movements when traversing through the game environment and their tremors in the steady states. The system employs the Novint Falcon Human Interface Device to record the players' movements and provides force feedbacks to guide them. But the system implementation is difficult due to the strain of Novint Falcon on hardware and other issues (e.g., accurate measurement is difficult to be achieved).

A pilot study for the commercialized games based on Wii fit with balance board for PD was conducted in [19]. The study suggests a positive result that the home-based training programme with visual feedbacks could contribute to improving the static and dynamic balance, global mobility and functional abilities of PD patients.

In [20], the authors developed an exertion game to study the influence of music on player performance for PD patients. During the game, the player is asked to grab a worm and feed the moles appearing from the holes repetitively. An evaluation was conducted on 24 participants (37.5% female and 62.5% male). The evaluation results show that music indeed has positive effects on the player performance, even if no specific instructions are provided to the players to follow the auditory clues.

Through the existing work, it can be noticed that games really contribute to the aspects of the diagnosis and rehabilitation of PD patients. But it also can be noticed that most systems require complicated setups, expensive devices, and accompaniment from healthy persons. In addition, most work focuses on designing games to facilitate PD patients to practice more instead of collecting the personal data to conduct automatic and systematic analysis, which is actually important to help the doctors and therapists to make decisions. To address these disadvantages, we design and implement a game on iPad platform. The game has the features of installing easily, playing anytime and anywhere, and conducting personal data collection and real-time data anslysis, which is a major limitation of the existing works.

II. The Pad Game and Data Analysis Approach

Before coming into the details of the design and implementation of the proposed game, we generally introduce the criteria [11] [17] to design a game tailored for PD patients.

Designing Criteria

First, visual and auditory feedbacks need to be provided as they are an effective mechanism to support the players' perception of their progression and influence their actions during the game [11]. Furthermore, the importance of positive feedbacks needs to be emphasized in the games [11] [25]. To make players not feel frustrated when they do not achieve the task goals in the game, it is important to give players a feeling of success by rewarding them for their engagement and encourage them to continue playing [11] [25].

Second, the game needs to be designed simply for the players to avoid the feeling of frustration during game playing since many PD patients, as the elderly in general, have little experience with iPad though iPad is already comparatively simple to use. A study in [17] indicates that the patients feel difficult to coordinate moving a controller and pressing buttons at the same time for Wii. Therefore, it is better for the game design to avoid excessive demand. Built-in guidance and instructions will be beneficial to help first time using players [26].

Third, the game needs to be adaptable. When the players are novel to the game, they desire a low level of difficulty to meet their corresponding familiarity with the game. Furthermore, the PD patients have different cognitive abilities and motor skills as they have various disease symptoms, disease states, or even daily conditions. Therefore, the game needs to be designed to be adaptable to the player's different levels of abilities and skills to cover different degrees of complexity.

Fourth, music and rhythm need to be integrated in the game. The study in [12] [27] [28] shows that music contributes to training the PD patients regarding movement initialization and facilitation and therapy effectiveness enhancement. Therefore, music and rhythm should be considered as important elements in game design given these positive effects.

Besides, some other criteria need to be considered. For example, the game needs to be designed to appear familiar and appealing for the players through exploring the elderly's interests and avoiding negative and violent contents. Furthermore, designing a meaningful game is also important [29] (e.g., providing reasonable system outcome given the player's actions to make the player perceive the effects of their actions on the outcome).

The Pad game

By following the design criteria discussed above, we have designed and implemented a pad game – Pumpkin Garden. It is a virtual farming theme game integrated with particular components which are tailored for the purpose of possible PD symptom detection. The game currently is implemented for the iOS system. Figure 1(a) shows the interface of the Pumpkin Garden game. It includes three major components -- cropland, waterwheel, and animal fold. The player is asked to conduct four tasks on the three components to earn virtual rewards.

The first task is to clean the weeds on the cropland as shown in Figure 1(b). The small window on the top left corner is the visual instruction for this task. The player is asked to clean the weeds following the trails shown on the screen by using two fingers from each hand to slide on the screen simultaneously. After cleaning the weeds, virtual money will be rewarded to the player according to the degree of the task completion. The earned virtual money and the completion time are indicated in the top right corner and top central respectively as shown in Figure 1(c). As out of motion synchronization and tremor are possible PD symptoms, this task is designed to detect such symptoms to indicate the risk that the player may have PD. Currently, the task is designed with three difficulty levels.

The second task is to drive the waterwheel to water the cropland as shown in Figure 1(d). The player is asked to draw continuous circles to drive the waterwheel as the instruction indicates. As an obvious symptom of a PD patient is bradykinesia, e.g., drawing smaller circles, this task can help to detect such symptom.

Figure 1. The Pumpkin Garden Game

The third task is to drive the animals back to the fold as shown in Figure 1(e). When the task starts, some animals with sequence numbers are displayed on the boundary of the cropland. The player is asked to drive the animals back to the fold following the sequence numbers by tapping the animals. For example, the sequence numbers in Figure 1(e) are deer with 3, pig with 1 and rabbit with 2. Then the player needs to first tap the pig to drive it back, then the rabbit, and then the deer. If the player taps an animal correctly, a stripe of light will be shown at the tail of the animal with ``good" as encouragement as shown in Figure 1(f). Otherwise, ``Try again" will be popped up as an indication of incorrect tapping. Currently the task is designed to have three difficulty levels, and there are will be 3, 4, and 5 animals showing up for each level, respectively. As a PD patient may have problems with working memory and cognitive recognition, this task can help to detect these problems.

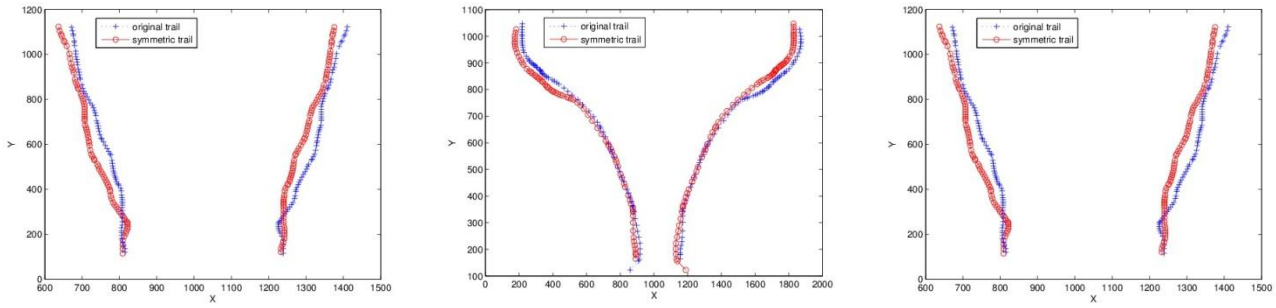
The fourth task is harvesting pumpkins as shown in Figure 1(g). When the task starts, some pumpkins are displayed one by one with intervals. The player is asked to remember the pumpkins displaying sequence and harvest them by sliding on the screen following the sequence as shown in 1(h). Currently the task is also designed to have three difficulty levels. The number of the pumpkins increases with the difficulty level. This task will help to detect the problems of tremor and working memory.

Besides the four tasks, music is also integrated into the game. For example, when the player completes a task, a piece of exciting music will start as encouragement. After a player completes the game, the related data (e.g., the sliding trails of removing the weeds and harvesting in the first and fourth task, each task completion time, the number of tapings to drive the animals back to the fold in the third task) will be analyzed real-time and recorded in database. If the analysis results suggest a high risk of having PD, an alert will be sent to the doctor. Furthermore, the long-term recorded data will help the doctor monitor the progression the PD patients.

Data Analysis Approaches

As we mentioned, one of the advantages of the designed pad game is that the player playing data is collected, real-time analyzed and kept as historical record for further personal data analysis. We propose the following real-time data analysis approaches corresponding to the four major tasks designed in the game, respectively.

For the weed cleaning task, we can collect the data regarding the trails of the player's fingers sliding on the screen. The example trails are shown in Figure 2.



(a) Easy (b) Medium (c) Hard

Figure 2. The example trails for weed cleaning task

Figure 2(a), (b) and (c) show the trails at the easy, medium and hard levels, respectively. To analyze the degree of the synchronization capability of the player, we calculate the difference between the left and right original trails. We first get the symmetry of the left or right trail regarding the central vertical line of the screen, and then calculate the difference between the symmetry of the left (or right) trail and the original right (or left) trail. In Figure 2(a), (b) and (c), the lines with circle are the collected data (original trails) during game playing, and the lines with plus sign are the symmetric trails. As the points will be captured only when two fingers touch the screen at the same time, the left and right trails will include the same number of points, the difference is calculated as follows.

Suppose each trail includes N points, for a particular point p_n $(1 \leq n \leq N)$ whose coordinate is $< x_n, y_n >$, we can get the coordinate of its symmetric point p_n' which is $< x_n', y_n' >$. The coordinate of p_n's corresponding point on the opposite trail is $< x_n'', y_n'' >$. Then the difference d between the two trails is calculated as:

$$d = \frac{\sum_{n=1}^{N} \sqrt{(x_n'' - x_n')^2 + (y_n'' - y_n')^2}}{N}$$

For the three levels, we can get the corresponding differences as d_{easy}, d_{medium} and d_{hard}. We also have the task completion time for the three levels, denoted as t_{easy}, t_{medium} and t_{hard}. Then we can have the following feature F_1:

$$F_1 = \begin{bmatrix} d_{easy} & t_{easy} \\ d_{medium} & t_{medium} \\ d_{hard} & t_{hard} \end{bmatrix}$$

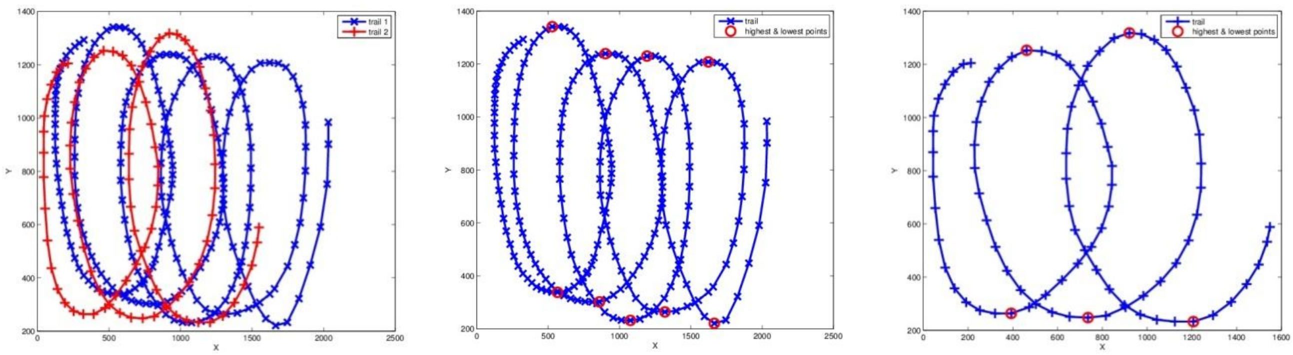
As an example, F_1 is calculated as

$$F_1 = \begin{bmatrix} 32.7426 & 2.82 \\ 59.3636 & 2.92 \\ 52.7903 & 5.46 \end{bmatrix}$$

for the trails shown in Figure 2.

A decision of high risk of having PD will be made if $d_i > \alpha_i$ or $t_i > \beta_i$ (i = *easy*, *medium*, *hard*), where α_i and β_i are predefined thresholds.

For the waterwheel driving task, we can collect the data regarding the player drawing circles to drive the waterwheel. Figure 3(a) shows an example of a player drawing circles. Due to the screen size limitation, the player can start drawing circles again after he/she reaches the boundary of the iPad screen. Therefore, we can see two trails overlapping with each other in Figure 3(a).



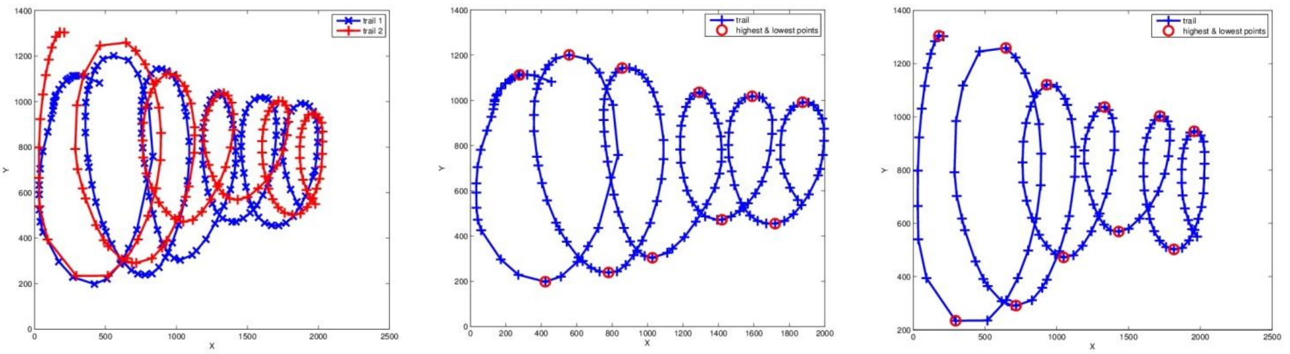
(a) (b) (c)

Figure 3. (a) The example circle trails drawn by a player; (b) Trail 1 with the highest and lowest points; (c) Trail 2 with the highest and lowest points

To analyze the circle trail data, we first separate the two trails. And for each individual trail, we find the highest and lowest points corresponding to a circle. Figure 3(b) and (c) show the separated trails with the identified highest and lowest points. Suppose for the trails, we find a total number of N pairs of highest and lowest points. Then we calculate the distance d_n ($1 \leq n \leq N$) for each pair of points. For the example shown in Figure 3, the calculated difference is $[1090.5,1022.1,974.2,987.9,1041.7,1122.1]$. We continue to calculate the difference between d_i and d_{i+1} $(i = 1, \dots, N-1)$, denoted as d'_i. Then we can get the feature F_2 as:

$$F_2 = [d'_1, \dots, d'_i, \dots, d'_{N-1}]$$

For the example shown in Figure 3, F_2 is calculated as $[-68.4, -47.9, 13.7, 53.8, 80.4]$. If there are γ consecutive d'_i smaller than ε (γ and ε are two thresholds), an alert will be triggered. As an example, Figure 4 shows a trail with smaller and smaller circles. F_2 is calculated as$[60.8, -131{,}2, -277.7, -0.5, -106.8, -310.9, -181.5, 32.3]$. If we set $\gamma = -100$ and $\varepsilon = 3$, an alert will be sent to the doctor.



(a) (b) (c)

Figure 4. (a) The captured data for the smaller circles drawn by a player; (b) Trail 1 with the highest and lowest points; (c) Trail 2 with the highest and lowest points

For the animal driving task, the player is asked to drive the animals back to the fold. The data is collected as the number of the times the player taps the screen. In the game, the player is asked to drive the animals back to the fold N times (currently, $N = 3$). Suppose for the nth time, the player uses k_n taps to drive all the animals back to fold and the completion time is t_n, and the minimum number of necessary tapings is a_n. Then we can get the task completing ability in the nth time as $^{a_n}/_{k_n}$. If $^{m_n}/_{k_n} < \zeta$ or $t_n > \eta$ (ζ and η are two thresholds), an alert will be sent to the doctor.

In the harvesting task, the player is asked to harvest pumpkins by memorizing a randomly generated sequence. Suppose the player is asked to harvest pumpkin *N* times. At the *n*th time, the player is asked to harvest pumpkins by memorizing a sequence with the length of l_n. Suppose the total length of the accurate sequence from the player is l'_n. Then we calculate the accurate rate for the *n*th time as ${l'_n}/{l_n}$. Suppose the completion time of the *n*th time is t_n. If ${l'_n}/{l_n} < \theta$ or $t_n > \lambda$ (θ and λ two thresholds), an alert will be sent to the doctor.

The above data analysis is performed real-time to facilitate an immediate alert to be sent to doctor for the diagnosis purpose. The game can also be played repetitively and the data will be recorded and analyzed using a similar way for the doctor to monitor the progression of the PD patients.

III. Conclusions

With the development of technology, video games have been adopted for PD diagnosis and rehabilitation. In this paper, we proposed a PD predictive analytics through pad game. The implemented game has the advantages of easy installing, playing anytime and anywhere, and detecting possible PD symptoms at an early stage. More importantly, the data of player playing game are collected and recorded. Real-time data analysis is performed and alerts will be sent to the doctors in case of high risk of having PD is detected. In the future, we will conduct evaluations on the elderly to study the threshold settings and the long-term influence of the game on the PD patients based on the collected personal historical data.

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