33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

WiiPD - An Approach for the Objective Home Assessment of Parkinson's Disease

J. Synnott, L. Chen, C.D. Nugent, *Member, IEEE* and G. Moore, *Member, IEEE*

Abstract— **This paper introduces WiiPD, an approach to home-based objective assessment of Parkinson's disease. WiiPD aims to make use of the many capabilities of the Nintendo Wii Remote in combination with a number of bespoke data gathering methods to provide a rich and engaging user experience that can capture a wide range of motor and non-motor metrics. In this paper we discuss the architecture of the approach, and provide details of the implementation and testing of the motor-assessment component of the system. Initial results of testing on 6 users indicate that the system is able to differentiate between normal and abnormal motor performance, suggesting that the system has the potential to monitor the motor fluctuations associated with Parkinson's disease.**

I. Introduction

Parkinson's disease (PD) is a neurodegenerative disease caused by the reduction of dopamine producing cells in the substantia nigra region of the brain. This manifests itself as a number of characteristic motor and non-motor symptoms. Motor symptoms include tremor, a rapid oscillating motion most noticeable in the distal regions of the body, bradykinesia which is slowness in movement, akinesia which is an unintentional freezing of movement, rigidity, and postural instability [1]. These debilitating motor symptoms can have a significant impact on the performance of activities of daily living (ADLs). Non-motor symptoms include anxiety, fatigue, depression, pain, issues with speech and can have a similarly debilitating effect on quality of life [2].

The Unified Parkinson's Disease Rating Scale (UPDRS) [3] is the primary clinical scale for the assessment of PD in which 42 aspects of the condition are assessed on a scale from 0 (not present) to 4 (severe) through a combination of patient questioning and monitoring. Patients are typically required to travel to a clinic to undergo assessment, and the NICE guidelines [4] recommend that these assessments are carried out every 6-12 months for those with early stage PD displaying mild symptoms, and every 2-3 months for those who are undergoing medication adjustments or have more complex issues. This current clinical practice is not ideal, however, as assessment is subjective, potentially resulting in inconsistencies in assessment results. Additionally, the assessments only provide a snapshot of a patient's condition at one point in time, and are carried out far less frequently than the potential rate of fluctuation in a patient's symptoms which can occur as medication wears off or reaches its peak effect.

One current focus of research in the area of PD patient assessment is to provide a means of gathering detailed objective information about a patient's condition over extended periods of time. Our work proposes an approach which uses low-cost, off the shelf consumer technology to provide an intuitive means of interaction with an engaging software package capable of capturing, analyzing, and visualizing a wide range of motor and non-motor metrics which can augment and reduce the subjectivity of UPDRS assessment. Such an approach has the potential for application in clinical decision support and disease management, with the possibility of providing clinicians with suggestions for medication or therapy adjustment.

The remainder of the paper is structured as follows. Section 2 provides a review of related research in the area of at-home assessment of PD, Section 3 provides an overview of the proposed architecture for WiiPD and details the motor analysis aspect of the approach. Section 4 details the implementation of the motor analysis component in the form of a series of mini-games. Section 5 discusses the results gathered from initial testing of the motor analysis aspect of the approach, and Section 6 provides a conclusion and discussion of the future direction of WiiPD.

II. Related Research

Existing studies into longitudinal at-home monitoring of PD have incorporated a range of approaches using various technologies.

Goetz *et al.* [5] investigated manual remote assessment of PD patients through the analysis of self-recorded video tapes of PD patients performing various motor tasks. This study demonstrated that video-recordings of motor tasks facilitate accurate assessment of ON/OFF state, but that these assessments are time consuming, highlighting the need for automated assessment using sensor technology.

Synnott *et al.* [6] investigated the automation of PD motor analysis using video capture technology. In this study, motion tracking technology was used to assess tremor amplitude during interaction with objects used in the performance of ADLs. Results from an initial assessment of

Manuscript received April 15, 2011. This work was funded by the Department of Employment and Learning Higher Education Innovation Fund.

J. Synnott is with the Computer Science Research Institute and the School of Computing and Mathematics, University of Ulster (synnott-j2@email.ulster.ac.uk)

L. Chen is with the Computer Science Research Institute and the School of Computing and Mathematics, University of Ulster (l.chen@ulster.ac.uk)

C.D. Nugent is with the Computer Science Research Institute and the School of Computing and Mathematics, University of Ulster (cd.nugent@ulster.ac.uk)

G. Moore is with the Computer Science Research Institute and the School of Computing and Mathematics, University of Ulster (g.moore@ulster.ac.uk)

this unobtrusive approach identified the ability for such a system to differentiate between activity performance with and without tremor.

While analysis of video data can have benefits in terms of unobtrusiveness and longevity, there are issues with privacy concerns and data sampling inconsistencies due to marker occlusions. An alternative approach involves direct user interaction with bespoke or off-the-shelf sensor equipment. One such approach by Cunningham *et al.* [7] involves the analysis of user interaction with a computer mouse while performing a target clicking exercise. This study identified differences between performance by users in "ON" or "OFF" states, and inconsistencies in results were indicative of issues with medication administration. While this approach has the advantage of using low-cost equipment which can be found in the majority of households, it may be the case that more advanced sensing equipment is required in order to capture the wide range of symptoms that can be present with PD.

Goetz *et al* [8] developed an at-home testing device that provided a range of tests within a small bespoke electronic device. The device included a two key keyboard for alternate finger tapping tests, an eight peg pegboard for fine motor function assessment, two buttons separated by 173mm for reaction time and movement time assessment, a docking station for an accelerometer device worn on the wrist and a microphone for speech assessment. The device was tested over a 6 month period, including a training period and was shown to detect worsening tremor, finger tapping and speech performance.

We aim to extend the existing research in the area by introducing WiiPD; an approach that uses the low cost, off-the-shelf Nintendo Wii Remote (NWR) with bespoke software to provide an intuitive user experience capable of monitoring a larger range of metrics than any currently available solutions.

III. PROPOSED APPROACH

We have proposed a general architecture that can be applied to the longitudinal analysis of PD and other chronic conditions with motor and non-motor components, such as with post-stroke rehabilitation. This approach involves the development of a system capable of capturing, analyzing and visualizing longitudinal changes in motor and non-motor conditions, and consists of several components:

- A *motor assessment* module which is capable of highlighting and capturing PD motor symptoms.
- A *non-motor assessment* module which collects data relating to other aspects of a patient's condition, including motor symptoms that cannot be detected through the motor assessment module, non-motor symptoms and medication compliance.
- A *metric analyzer* which analyzes data gathered from the motor and non-motor assessment modules, and directly from the NWR.
- A *visualization engine* which visualizes and summarizes the relationship between metrics in a technical manner for clinicians and a non-technical manner for patients and other stakeholders.

The relationship between these components is highlighted in Fig. 1.

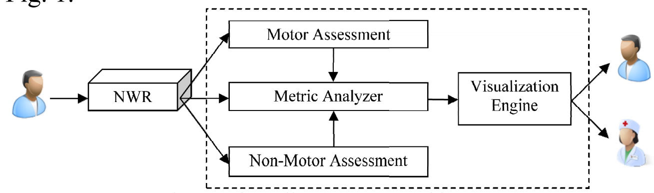

Fig. 1. The WiiPD System Architecture

The NWR was chosen as the main method of input as it is a low-cost, readily available, intuitive hardware device with a range of built-in sensor technology suited for upper-limb motion analysis. This device has shown promise in previous studies which have investigated the analysis of individual elements of motor function including tremor, fatigue, fall detection and range of motion [9-12]. In addition to 12 buttons for binary user input, the NWR also contains an ADXL330 3-axis linear accelerometer with a sampling rate of 100Hz and a measurement range of +/- 3 g. To provide device orientation information, a front-facing infrared camera with a refresh rate of 100Hz is provided, with the ability to track the movement of multiple IR sources emitted by a sensor bar typically placed above or below a display with which the user is interacting. The sample rates of both the accelerometer and IR camera are sufficient to capture the frequency components of Parkinsonian tremor.

The metric analyzer was designed to capture a number of metrics deemed indicative of a patient's condition. These metrics include: Reaction Time (T_r), Filtered / Unfiltered Movement Speed (M_s), Movement Accuracy (M_a), Click Accuracy (C_a), Completion Time (T_c), Tremor Amplitude ($Trem_a$), Tremor Frequency ($Trem_f$), Task Accuracy (TA), Fatigue Time (T_f), Error Time (T_e) Maximum Tap Rate (TR_{max}), and Mean Tap Rate (TR_{mean}). We propose that these metrics can be gathered during interaction with on-screen tasks with clear objectives.

Reaction Time (T_r) was defined as the mean time in milliseconds for a user to intersect with an on-screen target (*i*) after a change in target state (position or direction of movement).

$$T_r(i) = T_{cursorIntersection}(i) - T_{stateChange}(i) \quad (1)$$

Movement Speed (M_s) was defined as the mean rate of cursor movement (pixels/second) during task performance. Unfiltered M_s is calculated through analysis of the raw cursor movement data, whereas filtered M_s is calculated by analyzing the filtered gross motor movement data.

Gross motor movements were determined by processing unfiltered cursor movements using a moving average filter. This effectively removes any fine motor movements caused by tremor whilst maintaining the gross motor movements required for task completion.

Click Accuracy (C_a) was defined as the percentage of correct clicks detected during a task. A correct click is defined as a click performed when the cursor is over a target.

$$C_a = \frac{\text{TotalClicks} - \text{TotalIncorrectClicks}}{\text{TotalClicks}} \times 100 \quad (2)$$

Movement Accuracy (M_a) measures the user's ability to maintain a cursor position over a target. This was defined as the total time the cursor was held over the target as a percentage of the total possible time.

Movement Efficiency (M_e) was defined as the mean percentage difference between the cursor distances travelled (pixels) and the minimum distances required to move from the cursor's position to each target's (*i*) position upon target state change.

$$M_e(i) = \frac{Dist_{betweenTargets}(i,i-1)}{Dist_{cursorMoved}(i,i-1)} \, x \, 100 \quad (3)$$

Completion Time (T_c) was defined as the total time (milliseconds) between task start (T_{start} and task end (T_{end}).

Task Accuracy (TA) was defined as the percentage of correctly performed events within an activity. For T4, this is the percentage of button presses performed within a certain time period of the user being prompted to press a button. For T6 this is the percentage of blue and red targets correctly placed.

Fatigue Time (T_f) was defined as the amount of time (milliseconds) before a user's performance dropped below a fatigue threshold. For T4, this is when T_e exceeds a certain threshold, and for T5 this is when TR_{mean} for the previous *n* button taps falls below 50% of TR_{max}.

Tap Rate (TR_{max} and TR_{mean}) is calculated by analyzing the rate of button presses (Hz) detected over a period of 2 seconds. This time period is required in order to minimize the impact of unintentional button presses.

Error Time (T_e) is the total time delay between a user being prompted to press a button, and the button being pressed.

Metrics directly associated with tremor can be derived using accelerometer values obtained during task performance. The type of tremor detected (Kinetic, Postural, Rest) is dependent on the type of task being performed.

Tremor Amplitude ($Trem_a$) is calculated by taking the Root Mean Square value of the accelerometer values recorded during task completion.

Tremor Frequency ($Trem_f$) is calculated by performing an FFT analysis on the accelerometer data generated during task completion.

We propose that these metrics are capable of reflecting the severity of various PD motor symptoms as presented in Table I. Typically, metrics detailing fine motor movement (such as C_a, M_a, M_e) have the potential to reflect the severity of Parkinsonian tremor and dyskinesias. Metrics which detail gross motor movements (such as T_r, M_s, T_c, T_f, T_e, TR_{max}, TR_{mean}) may highlight the severity of bradykinesia and akinesia.

IV. Implementation

The motor assessment component of the approach was implemented in a mini-game format, which was chosen in order to provide a number of benefits. Firstly, this format has the potential to combine the fun, intuitive element of gaming with motion analysis, removing the monotony of repeated assessment tasks and adding a competitive edge to participation, potentially increasing compliance and acceptance of long-term participation. Secondly, the development of bespoke mini-games allows for the inclusion of tasks similar to those carried out during a clinical assessment. Finally, by including specific objectives in each mini-game, it is possible to constrain and guide the user's interaction in order to maximize the consistency of motor task performance, allowing results from repeat performances to be compared directly, minimizing subjectivity. Correct performance of activities can be encouraged through the use of on-screen prompts and the user can be rewarded with game progression or a higher score. For example, we can ensure a user maintains a horizontally extended arm posture for *n* seconds by requiring the user to hold the cursor over a target for *n* seconds, before proceeding to the next stage in the task. Several motor tasks were proposed in order to gather an overlapping subset of the proposed metrics. These tasks are described in Table I. The suite of motor tasks and metric analysis methods were implemented in C# using the XNA framework. Data collection from the NWR was

TABLE I

An Overview of the Relationship between the Proposed Motor Tasks, Metrics, and Parkinsonian Symptoms

#	Task	Description	Metrics	Symptom
T1	Target Shooting	The user must move the cursor and click on *n* targets sequentially displayed in random locations.	T_r , M_s , M_e , C_a ,T_c , $Trem_a$, $Trem_f$	Kinetic Tremor, Bradykinesia
T2	Target Holding	Same as T1, however the user must hold the cursor over each target for *n* seconds before the next target will appear	T_r , M_s , M_e , T_c , $Trem_a$, $Trem_f$	Kinetic Tremor, Postural Tremor, Bradykinesia
T3	Target Following	The user must follow a moving target with the cursor for *n* seconds. The target will follow a random path with increasing speed.	T_r , M_a , $Trem_a$, $Trem_f$	Kinetic Tremor, Bradykinesia
T4	Button Tapping (prompted)	This is a prompted finger tapping exercise in which the user must press the 'A' button on the NWR each time a ball bounces.	T_r , T_e , TA , T_f	Bradykinesia
T5	Button Tapping (unprompted)	This is an unprompted finger tapping exercise in which a user must press the 'A' button on the NWR as quickly as possible to pump up and burst a balloon.	T_f , T_c , TR_{max} , TR_{mean}	Bradykinesia
T6	Target Sorting	A cognitive task in which users must click and drag a selection of blue and red targets to correct designated on-screen area.	T_c , TA , C_a , $Trem_a$, $Trem_f$	Cognitive Function, Kinetic Tremor, Bradykinesia

facilitated by using the WiimoteLib .NET library [13] which provides access to the data generated by the NWR's various sensors, including accelerometer sample values, IR source positions, and button presses. The software was installed on an Intel Classmate PC ECS E09. A USB Bluetooth dongle was used to facilitate communication between the NWR and the PC, and a wireless sensor bar was used to provide IR sources. Fig. 2 illustrates this hardware setup.

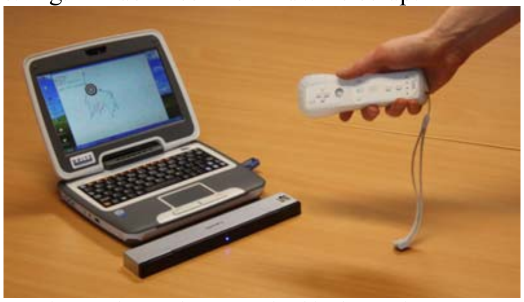

Fig. 2. The Hardware Involved in the Testing Stage

V. Testing and Evaluation

In order to demonstrate the potential of our approach, the target-based tasks were tested on 5 healthy individuals with no previously diagnosed motor conditions (Control Group). These participants had a wide range of previous experience with the NWR. As a comparison, the tasks were also run an additional 5 times with simulated Parkinsonian behavior including tremor, slowness of movement and reduced fine motor co-ordination. The mean metric values obtained from each group for each task are provided in Table II.

TABLE II
Mean Metric Values Obtained from the Control Group and Symptom Group for each Motor Task

	Control Group			Symptom Group		
Metric	T1	T2	T3	T1	T2	T3
T_r (millisec.)	529	642	-	1220	1794	-
Filtered M_s (pix./sec.)	290.55	139.66	186.63	264.07	181.97	246.14
Unfiltered M_s (pix./sec.)	397.43	200.85	254.24	1205.73	1153.1	1140.9
M_a	-	97.86%	82.71%	-	79.9%	53.5%
M_e	34.42%	49.35%	-	12.46%	6.4%	-
C_a	100%	-	-	72.17%	-	-
T_c (millisec.)	10996	26693	-	18196.7	42886	-

These results display a clear difference between each group, and are indicative of the behavioral variants performed in the symptom group. In particular, tremor can be detected through significantly higher unfiltered M_s values and significantly lower M_e and C_a values caused by the rapid oscillating cursor movements caused by the presence of tremor. Additionally, the M_a values in the symptom group are consistently lower due to the presence of tremor, and are lowest in T3 due to the addition of sustained target movement which also highlights slowness in movement. Slowness in movement, similar to that of bradykinesia, is further highlighted through T_r values, which are on average 157% higher in the symptom group, indicating slower performance while completing tasks. Finally, consistently and significantly higher T_c values in the symptom group highlight the overall negative impact of the symptoms on activity completion.

Filtered M_s is similar in both groups as the effect of the tremor component is reduced, however, the values for the symptom group are somewhat higher on average, indicating that further movement filtering is required to fully remove the effect of tremor oscillations.

VI. Conclusion and Future Work

We have proposed a novel approach to the longitudinal at-home assessment of PD which uses the NWR to gather user metrics during interaction with software. The software consists of a series of mini-games developed to capture a range of objective motor metrics that are indicative of PD severity. Initial trials of the software demonstrate that the approach has the ability to differentiate between users with no underlying motor conditions, and those who mimic Parkinsonian symptoms. It is, however, recognized that a lack of real user testing is a limitation of the work. Recruitment is currently ongoing for testing on patients with PD. In addition, future work will involve implementation of the non-motor assessment and visualization modules.

References

[1] J. Jankovic, "Parkinson's disease: clinical features and diagnosis", *J. Neurol. Neurosurg. Psychiatry*, vol. 79, no. 4, pp. 368-376, April, 2008.

[2] K. R. Chaudhuri *et al.* "The non-motor symptom complex of Parkinson's disease: A comprehensive assessment is essential", *Current Neurology and Neurosceince Reports*, vol. 5, no. 4, pp. 275-283, Aug., 2005.

[3] WE MOVE (2008, April 21). *Unified Parkinson's disease rating scale* [Online]. Available: http://www.mdvu.org/library/ratingscales/pd/updrs.pdf.

[4] National Collaborating Centre for Chronic Conditions, "Parkinson's disease: Diagnosis and management in primary and secondary care," Royal College of Physicians, London, England, 2006. [Online]. Available: http://www.nice.org.uk/CG035.

[5] C.G. Goetz *et al.*, "Evaluating Parkinson's disease patients at home: Utility of self-videotaping for objective motor, dyskinesia and ON-OFF assessments" *Mov. Disord.* vol. 23, no. 10, pp. 1479-1482, July, 2008.

[6] J. Synnott *et al*., "Assessment and visualization of Parkinson's disease tremor," in Proc. IEEE Int. Conf. on Inf. Technol. and Applications Biomed., Corfu, Greece.

[7] L. Cunningham *et al.*, "Home-based monitoring and assessment of Parkinson's disease", *IEEE Trans. Inf. Technol. in Biomed.*, vol. 15, no. 1, pp 47-53, Nov. 2010.

[8] C. G. Goetz *et al.*, "Testing objective measures of motor impairment in early Parkinson's disease: Feasibility study of an at-home testing device," *Mov. Disord.,* vol. 24, no. 4, pp. 551-556, Mar. 2009.

[9] A.J. Chambers *et al.,* "Use of the Nintendo Wii remote to quantify finger tapping in Parkinson's disease", *Mov. Disord.*, vol. 23, suppl. 1, May, 2008.

[10] R.D. Connors *et al.*, "Use of the Nintendo Wii remote to measure tremor in essential tremor"", *Mov. Disord.*, vol. 23, suppl. 1, May, 2008.

[11] N. Mamorita *et al.* "Development of a system for measurement and analysis of tremor using a three-axis accelerometer", *Methods Inf. Med.*, vol. 48, no. 6, pp. 582-588. 2009.

[12] M. Wierengin and J. M. Eklund, "Real-time signal processing of accelerometer data for wearable medical patient monitoring devices", in Proc. IEEE EMBS, Vancoover, British Columbia, Canada.

[13] B. Peek (2008, June 7). *WiimoteLib - .NET Managed Library for the Nintendo Wii Remote*. [Online] Available: http://www.brianpeek.com/blog/pages/wiimotelib.aspx