Towards remote monitoring of Parkinson’s disease tremor using wearable motion capture systems

Mehdi Delrobaei\textsuperscript{a,\ast}, Sara Memar\textsuperscript{b,1}, Marcus Pieterman\textsuperscript{b,1}, Tyler W. Stratton\textsuperscript{c,d}, Kenneth McIsaac\textsuperscript{e}, Mandar Jog\textsuperscript{b,f,2}

\textsuperscript{a} Center for Research and Technology (CREATECH), Faculty of Electrical Engineering, K. N. Toosi University of Technology, Tehran, Iran
\textsuperscript{b} Lawson Health Research Institute, London, ON, Canada
\textsuperscript{c} Laboratory of Medicine and Pathobiology, University of Toronto, Toronto, ON, Canada
\textsuperscript{d} St. Michael’s Hospital, Toronto, ON, Canada
\textsuperscript{e} Department of Electrical and Computer Engineering, Western University, London, ON, Canada
\textsuperscript{f} Department of Clinical Neurological Sciences, Western University, London, ON, Canada

ARTICLE INFO
Keywords:
Inertial sensing
Wearable technologies
Remote monitoring
Whole-body tremor
Parkinson’s disease

ABSTRACT
The management of movement disorders is shifting from a centralized-clinical assessment towards remote monitoring and individualized therapy. While a variety of treatment options are available, ranging from pharmaceutical drugs to invasive neuromodulation, the clinical effects are inconsistent and often poorly measured. For instance, the lack of remote monitoring has been a major limitation to optimize therapeutic interventions for patients with Parkinson’s Disease (PD). In this work, we focus on the assessment of full-body tremor as the most recognized PD symptom. Forty PD and twenty two healthy participants were recruited. The main assessment tool was an inertial measurement unit (IMU)-based motion capture system to quantify full-body tremor and to separate tremor-dominant from non-tremor-dominant PD patients as well as from healthy controls. We developed a new measure and evaluated its clinical utility by correlating the results with the Unified Parkinson’s Disease Rating Scale (UPDRS) scores as the gold standard. Significant correlation was observed between the UPDRS and the tremor severity scores for the selected tasks. The results suggest that it is feasible and clinically meaningful to utilize the suggested objective tremor score for the assessment of PD patients. Furthermore, this portable assessment tool could potentially be used in the home environment to monitor PD tremor and facilitate optimizing therapeutic interventions.

1. Introduction
The healthcare system is experiencing a paradigm shift from standard clinical procedures to individualized assessment and treatment. This change is accompanied by emerging technologies such as wearables and the Internet of Things (IoT) \cite{1}. In this new paradigm, physicians can quantify the dynamics of disease progress, predict health risks, tailor individualized therapeutic protocols, and in doing so, effectively reduce costs that are burdening health care systems globally \cite{2}. Treatment of movement disorders, especially those related to Parkinson’s disease (PD), could greatly benefit from such efficient and affordable approaches \cite{1,3-6}.

Tremor is the most recognized symptom of PD, characterized by involuntary and approximately rhythmic shaking of a limb, head, or the entire body \cite{7-10}. PD tremor is not life-threatening, but it often reduces quality of life by affecting patients’ ability to perform certain daily living activities. Traditionally, tremor has been assessed using human observer-based PD rating scales, primarily the Unified Parkinson’s Disease Rating Scale (UPDRS) \cite{11}. Recently, advances in technology have allowed for more quantitative measures of tremor. Various sensor systems have been developed to objectively measure PD tremor. These sensor systems include: electromyography (EMG), accelerometers, gyroscopes, goniometers, and optical motion capture systems. However, the main drawback of these methods is that they are generally limited to the quantification of tremor severity for an individual limb, failing to provide a comprehensive, full-body assessment of tremor \cite{7,9,12-15}.

\ast This study was supported in part by a grant from the Academic Medical Organization of Southwestern Ontario (AMOSO).
\ast Corresponding author.
E-mail addresses: delrobaei@kntu.ac.ir (M. Delrobaei), sara.memar@lhsc.on.ca (S. Memar), mpieterm@uwo.ca (M. Pieterman), stratton@smh.ca (T.W. Stratton), kmcisac@uwo.ca (K. McIsaac), mandar.jog@lhsc.on.ca (M. Jog).
1 Equally contributed as the second author.
2 The authors have no conflicts of interests.

https://doi.org/10.1016/j.jns.2017.11.004
Received 16 August 2017; Received in revised form 10 October 2017; Accepted 2 November 2017
Available online 08 November 2017
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The vast number of tremor-measuring systems offer a wide range of assessment mechanisms. Surface EMG technique involves fixing electrode sensors on the skin which measure muscular contraction [3,12,16]. Accelerometers function by combining linear acceleration data, which may include gravity and additive noise, to measure the amplitude of oscillations of individual body segments [3,13,14]. Lastly, gyroscopes are commonly used to measure angular velocity [5,14,15]. These types of sensors are often attached in close proximity to body joints in order to measure rate of change, and consequently, tremor amplitude [3]. Joint angles can be directly measured using goniometers, which can be placed across a body joint to provide measures of rapid movements [3,9,18]. Numerically commercially available devices (APDM [19], REMPARK [20], Kinesia [21], PERFORM [5], Motus [22], Lift Labs [5], Physilog [23]) are able to track tremor in a single joint or body part. Although the tracking is available for longer periods, it does not provide a comprehensive picture of tremor in the patient.

Recently, camera-based systems (optical 3D motion trackers) have been widely used to assess movement disorders, including tremor. To perform this assessment, multiple cameras are set up to detect markers (either active or passive) placed on body parts of participants, and compute joint movements [3,9,24,25]. However, the camera-based technology’s elaborate set-up renders the recording system stationary, restricting its use to a controlled lab environment [26]. Inertial measurement units (IMUs) combine accelerometers, gyroscopes, and magnetometers (which measure the local magnetic field vector) to offer a novel approach in quantifying movement disorder symptoms. The significance of IMU sensors is that they can be serially attached to body parts to give a full-body description of body motion [27]. IMUs have allowed for the development of wearable technologies that are accurate, portable, easy-to-use, and can efficiently assess a variety of movement disorders [20,21].

In early stages of disease, PD tremor often begins with occasional tremor in the fingers, eventually progressing towards involvement of the entire arm and in some cases, the entire body. Therefore, full-body assessment of tremor becomes critical as the disease progresses. Such assessment aids clinicians in developing a more comprehensive treatment protocol. Whole-body tremor is a topic less explored in the literature, compared to the local assessment of tremor. Hence, the first motivation of this research is to reveal the importance whole-body tremor and select the best data collection and analysis approach. This research is also motivated by the idea of remote motor symptom monitoring for follow-up of PD patients. At times, it may be unreasonable to frequently ask a PD patient to make it to the clinic due to the weather, distance, or physical inability. Remote patient monitoring would reduce the need for patients to come to clinic for their tremor to be assessed [20].

In this framework, a set of clinically relevant standardized tasks could be defined for the patients to accomplish while wearing a safe and reliable data collection (i.e., motion capture) system. Information from the data collection system could then be sent directly to their physician. This method needs to be simple enough to set up in the home environment. Therefore, the main purpose of this study is to: (1) investigate the applicability of using an IMU-based full-body motion capture system in PD participants to track the biomechanics of tremor in all body segments; (2) develop standard motor tasks and algorithms that can detect, segment, and comprehensively output a clinically meaningful tremor score; (3) evaluate the clinical utility of the kinematic measure by correlating this new score with the UPDRS scores during the proposed standard tasks; (4) demonstrate the ability of this method to clearly separate tremor dominant from non-tremor dominant PD, as well as from healthy participants.

The final goal of this study is to introduce an objective framework in which whole-body tremor severity could be clinically quantified and analyzed reliably following remote monitoring of PD patients. Additionally, we hope to apply a similar framework to aid in the optimization of more invasive treatments for PD such as deep brain stimulation (DBS), wherein setting adjustments for the implanted device often require months of fine-tuning.

2. Methods

2.1. Participants

Forty PD participants and twenty two healthy controls participated in the study. The PD participants were recruited from the Movement Disorders Center in London Health Sciences Center (London, ON, Canada). Participant demographics are listed in Table 1. In this table, LED denotes levodopa equivalency dosage, a measure which combines the contribution made by each PD medication into a single dosage, based on a standardized formula [28].

\begin{table}
\centering
\begin{tabular}{lcc}
\hline
& Controls (n = 22) & PD (n = 22) \\
\hline
Age (years), mean (SD) & 64.90 (3.91) & 65.28 (7.49) \\
Males, n (%) & 11 (50%) & 34 (85%) \\
PD duration (years), mean (SD) & – & 8.8 (4.33) \\
L-Dopa duration(years), mean (SD) & – & 7.1 (4.36) \\
LED* (mg/day), mean (SD) & – & 1082 (473) \\
\hline
\end{tabular}
\caption{Participants demographics.}
\end{table}

\* Levodopa equivalency dosage; calculation for LED was based on a standardized formula from literature by Tomlinson et al. [28].

Inclusion criteria for PD participants were: (1) idiopathic Parkinson’s disease, (2) males or females of 45 to 85 years of age, (3) have been on stable doses of anti-Parkinson medication, including any levodopa preparation, (4) no dementia or psychiatric abnormalities, (5) able to walk without any walking aids, (6) able to provide informed consent. Control participants were healthy and age-matched with no dementia or psychiatric abnormalities. The study was approved by the Human Subjects Research Ethics Board (REB # 107253) at Western University (London, ON, Canada) and all participants provided their written informed consent prior to participation.

2.2. Assessment tools

Tremor severity was measured using UPDRS as well as a full body, IMU-based, wearable motion capture system (IGS-180 – Synertial Ltd., UK). This system includes 17 embedded IMUs and the placement of each sensor is illustrated in Fig. 1. Each IMU includes three accelerometers, three gyroscopes, and three magnetometers that measure linear accelerations, angular velocities, and magnetic forces in all directions (3-axis each). The relative position and orientation between adjacent sensor units enable a fusion software (using quaternion method [40,41] — developed commercially available by Inertial Labs Inc., Virginia, USA) to identify body joint angles. The fusion software is implemented on a main processing unit (MPU) and communicates wirelessly to a receiver linked to a personal computer. Data acquisition was performed at 60 Hz sampling rate using IGS-Bio software Version 2.56 (Synertial Ltd., UK), configured for full-body human motion. The complete list of measured joint angles can be seen in the Appendix.

The system is also capable of generating a real-time 3-D animation based on the recorded joint angle data. The animation can be easily replayed at any time from the recorded data. A snapshot of the animation is illustrated in Fig. 2 b).

A specific, minimal set of instructions were given to all participants. These instructions were standardized and simple enough that participants could don the suit system with no or minimal spousal assistance. This was done in an effort to judge the technology’s ease of use.

Throughout this manuscript, the upper-extremity UPDRS means the sum of the UPDRS-Part III tremor scores (either rest or postural) for right arm and left arm. The upper-extremity UPDRS score for both arms together ranges from 0 = Normal to 8 = Severe. Hence, total UPDRS
means the sum of UPDRS-Part III rest tremor scores for head, right arm, left arm, right leg, and left leg. Total UPDRS ranges from 0 = Normal to 20 = Severe. It is noted that the UPDRS-Part III does not include the assessment of full-body postural tremor. While the UPDRS includes chin/jaw tremor, the kinematic recordings do not measure this tremor. However, head tremor is measured and included in the analysis.

2.3. Clinical tasks and procedure

Tremor can be assessed during a variety of different tasks; however, for remote monitoring, the selected task needs to be simple, clinically valid, and long enough for data analysis. In clinic, tremor is mainly assessed while sitting at rest (referred to as rest tremor) and sitting while performing a posture (referred to as postural tremor) — Fig. 2.

All participants were asked to perform the following standard tasks twice while seated:

(1) Rest: while sitting, the participants rested both of their forearms on the arms of a chair with hands hanging loosely off the edge. The participants were asked to hold this position for 20 seconds.

(2) Posture: while sitting, participants fully extended their arms forward with hands pronated at shoulder height level and asked to hold this position for 20 seconds.

The PD participants were assessed OFF and ON levodopa. In this study, a participant was considered OFF levodopa when it has been 12 or more hours since their last dose of levodopa medication has been taken. A participant was considered ON levodopa at approximately 45–60 minutes after taking their normal dose of levodopa.

2.4. Tremor severity score (TSS) calculation

A tremor severity score (TSS) was calculated at each body joint so tremor severity could be segmented based on the limb of interest. To calculate this score, signals containing angular displacement of all body joints were obtained from the motion capture system. The signals were band-pass filtered from 2 Hz to 20 Hz to eliminate non-tremor movements. The root-mean-square of each filtered signal (associated with each joint) was then considered as the TSS in that body joint. The root-mean-square of all joints associated with each body part’s (head, right arm, left arm, right leg, and left leg) TSS was calculated and called segmental TSS. Finally, the sum of all segmental TSS values were calculated and denoted as full-body TSS. Therefore, the total TSS (in degrees) can be calculated as

\[
TSS = \sum_{i=1}^{n} \text{RMS}[F_{2-20Hz}(J_i)]
\]

where \( J_i \) is the \( i^{th} \) body joint movement, \( n (= 47, \text{see Appendix}) \) is the maximum number of joint movements involved in the calculation, \( F_{2-20Hz}(\cdot) \) is the function which filters the signal from 2 Hz to 20 Hz, and \( \text{RMS}[\cdot] \) is a function to calculate the root-mean-square of all points forming the signal. This method was developed based on a review of the relevant literature (see section Section 4). Hence, it is always possible to either report a single full-body tremor severity score or present the decomposition of tremor severity per body segment or even per single joint movement (e.g., wrist flexion-extension, ulnar-radial, and pronation-supination – See Appendix).

2.5. Validation and statistical analysis

In order to verify the effectiveness of our method, we conducted...
relevant statistical analyses to mainly investigate the correlation between the UPDRS (as the gold standard) and the calculated tremor severity score results. The PD participants outcomes were also compared between OFF and ON medication states as well as to the control participants. Either parametric or non-parametric statistical tests were selected following Shapiro-Wilks test of normality. The results are reported with 95% confidence interval. The statistical analyses were carried out with SPSS software, version 22.0 (SPSS Inc., IL, USA).

3. Results

3.1. Upper-extremities rest TSS compared with UPDRS

In order to conduct a more thorough comparison, the PD participants were initially divided into two groups called tremor-dominant and non-tremor-dominant. This separation was made based on assessing PD participants OFF-medications and while sitting at rest using the UPDRS-Part III (motor examination). Any PD participant who had a total UPDRS score higher than two was marked tremor-dominant PD and the remainder of the PD participants were marked non-tremor-dominant PD (Table 2).

Figs. 3–5 show the results of the kinematic assessment compared with the UPDRS scores. Fig. 3 illustrates the upper-extremity TSS calculated for all participants while sitting at rest. It also compares the results with the sum of the upper extremity UPDRS scores (*Significance $p < 0.05$. Error bars represent the standard errors).

<table>
<thead>
<tr>
<th>Tremor dominant</th>
<th>Tremor non-dominant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient ID</td>
<td>Total UPDRS</td>
</tr>
<tr>
<td>PD-01</td>
<td>8</td>
</tr>
<tr>
<td>PD-02</td>
<td>4</td>
</tr>
<tr>
<td>PD-06</td>
<td>7</td>
</tr>
<tr>
<td>PD-09</td>
<td>4</td>
</tr>
<tr>
<td>PD-12</td>
<td>7</td>
</tr>
<tr>
<td>PD-13</td>
<td>5</td>
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<tr>
<td>PD-14</td>
<td>5</td>
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<tr>
<td>PD-15</td>
<td>4</td>
</tr>
<tr>
<td>PD-16</td>
<td>7</td>
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<tr>
<td>PD-17</td>
<td>3</td>
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<tr>
<td>PD-20</td>
<td>4</td>
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<tr>
<td>PD-22</td>
<td>4</td>
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<tr>
<td>PD-23</td>
<td>3</td>
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<tr>
<td>PD-25</td>
<td>4</td>
</tr>
<tr>
<td>PD-27</td>
<td>7</td>
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<tr>
<td>PD-31</td>
<td>8</td>
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<tr>
<td>PD-32</td>
<td>8</td>
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<td>3</td>
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<tr>
<td>PD-38</td>
<td>8</td>
</tr>
<tr>
<td>PD-39</td>
<td>1</td>
</tr>
</tbody>
</table>

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Table 2

Total UPDRS-Part III scores for PD participants OFF-medication and sitting at rest; the data were used to group PD participants into dominant and non-dominant tremor.

3.2. Full-body rest TSS compared with UPDRS

Fig. 4 presents the full-body TSS during sitting at rest task and compares the results with the total UPDRS. While sitting at rest, the TSS for tremor-dominant PD participants in their OFF state was significantly higher than the non-tremor-dominant PD in their OFF state ($p < 0.001$), as well as the tremor-dominant PD participants in their ON state ($p = 0.047$), and the healthy controls ($p = 0.003$). The TSS of the non-tremor-dominant PD participants in their ON state was also significantly higher than the healthy controls ($p = 0.014$). The same pattern of change was observed in the total UPDRS scores.

3.3. Upper-extremity posture TSS compared with UPDRS

Fig. 5 presents the results associated with the upper-extremity TSS while the participants were performing the posture task. The TSS of upper-extremity for tremor-dominant PD participants in their OFF state was significantly higher than the non-tremor-dominant PD in their OFF state ($p < 0.001$), as well as the healthy controls ($p = 0.008$). The TSS of the non-tremor-dominant PD participants in their ON state was also significantly higher than the healthy controls ($p = 0.001$). The same pattern of change was observed in the total UPDRS scores.

3.4. Correlation analysis

To further validate our findings, both Pearson product moment and Spearman rank-order correlations were calculated to identify both the linear and the monotonic relationships between the kinematically measured tremor (TSS) and the UPDRS results. Table 3 summarizes the correlation analysis results.

The average time to put on the suit took no more than 3 to
4 minutes min. Although the data was not specifically collected, most patients were noted to be able to put on the suit themselves. All patients kept the suit on for the entirety of the recording session with no discomfort reported. An animation showing the actual performance of the patient is generated for further clinical evaluation (Fig. 2 (c)). These animations can also be used by the clinician to rate the clinical state visually in addition to the kinematic sensor data.

4. Discussion

4.1. Limitations of UPDRS

The current standard of care in the management of movement disorders associated with PD includes subjective evaluation using the clinical gold standards such as the UPDRS [29]. In our previous work, we illustrated the subjective nature of the UPDRS motor score by revealing a weak correlation between four trained raters in scoring a randomized subset of PD participants [33].

Tremor in PD can occur in any body part. While upper extremity tremor is more visible, lower extremity tremor can occur with significant prevalence [29,30]. This is the reason why the UPDRS requires the measurement of tremor in all body segments. However, there are several limitations to the use of the UPDRS in this scenario. One of those limitations being that the UPDRS takes a single visual assessment of tremor. The severity of tremor in PD, however, varies over periods and longer assessment times can quantify this better.

Also, a change from rest to posture can produce a silent period termed latency where there is no tremor. This is followed by a re-emergence of the tremor which can be missed in visual assessments. Additionally, the measurement of tremor in the lower extremities is visually more difficult than in the upper extremities. Thus, the occurrence of tremor in all body parts, variability over time, latency, and difficulty in lower extremity visual evaluation are all reasons why a multi-sensor whole body quantitative tool is required.
4.2. Emerging technologies

No reproducible assessment tool has been widely accepted to be considered as the objective gold standard of tremor assessment. Kinematically recorded movements have a much higher resolution for measuring movements. Although not all aspects of such recordings are necessarily clinically useful, the reliability of an objective measure is inherent, over a subjective visual tool. Indeed, the UPDRS scores are dependent on the amplitude of the tremor and yet this judgement is inherent, over a subjective visual tool. Indeed, the UPDRS scores are measuring movements. Although not all aspects of such recordings are considered as the objective gold standard of tremor assessment.

4.3. Development of TSS measure

Two clinically applicable tasks were selected based upon the ease of administration and what is clinically useful in normal practice [23]. The sitting-at-rest task was intended to track resting tremor which is part of the UPDRS and measured simultaneously in all the segments. The posture task in the upper extremities was designed to capture action tremor.

Although PD tremor is classically a rest tremor, our prior work has shown that postural tremor is significant in PD [7, 18, 31]. The duration of this task was designed to include the re-emergent tremor. This is important as such postural tremor can be a significant component of the overall PD tremor and be responsible for an impairment of the quality of life of patients as it affects task performance. Thus, quantification of postural tremor in PD is as, if not more, important than rest tremor.

The method of calculating the tremor severity score - TSS was developed based on reviewing recent successful studies found in the literature [4,6,13-15,17,32]. For instance, Powell et al. [4] considered raw tremor acceleration waveforms and performed a time frequency analysis. A group of Gaussian bandpass filters, centred at 3 Hz, 4 Hz, 5 Hz, and 6 Hz with equal bandwidth of 1 Hz were then designed to calculate tremor severity.

Rigas et al. [6] also used accelerometric data and analyzed them using both a low-pass FIR filter with cut-off frequency of 3 Hz as well as a band-pass FIR filter with frequencies from 3 to 12 Hz to extract features corresponding to PD tremor severity. The frequency band was selected according to methods suggested by [7, 18]. Tracking below this band implies dyskinesia (uncontrolled twisting or jerking movements), a common side effect of levodopa seen in PD patients.

4.4. Evaluation of TSS measure

The proposed TSS was different between the healthy control and PD participants. As expected, the overall TSS was higher across all measures in PD. A small amount of tremor was recorded by the sensors in the control group as they are more sensitive than the visual assessment of the rater. Further, since the n value was large in this dataset, we could categorize patients into either tremor-dominant or non-dominant groups based on their total UPDRS tremor scores.

This separation showed the granularity of the kinematic system’s ability to further separate out differences in tremor quantity between these groups of participants. Once separated into groups, the correlation between the UPDRS and the kinematic rating was robust. This relationship is shown in both the linear and monotonic correlational analysis. The correlation for postural tremor is however only moderate. One possible reason for this is the fact that in PD, postural tremor can be delayed by a latency of up to 5 seconds after a change of position of the upper limbs from rest (Fig. 2 (a)) to arms outstretched (Fig. 2 (b)). If the postural visual rating is done immediately after this change in position, and latency occurs, then it might be scored a 0 or 1 (i.e. little to no tremor). The kinematic analysis technique measures tremor for a longer duration and this re-emergent tremor after the latency is more likely to be captured.

4.5. Logistics

Minimal assistance was given to the patients in putting on the suit. For each task, the patients were instructed with minimum details. This was done to determine if the participants would be able to set up the experiments in their home environment. The ease and speed of donning the suit with or without help is an important aspect of the technology-human interface. Therefore, although not specifically tested in this study, we anticipate that human instructions can reliably be replaced with either an animation or some audio cue based on a predetermined routine.

The relative ease of use of the technology encourages its use in the remote or home-based measurement scenarios. The home-based application of the proposed technology can make it a platform for remote assessment and be used for optimizing therapeutic medical and surgical interventions. The importance and applicability of these approaches have already been highlighted in the literature [36-38]. For instance, MercuryLive, a web-based integrated platform has recently been developed to enable clinicians to analyse wearable sensor data and interact remotely with PD patients in the home setting [36]. Sanchez-Ferro et al. [39] presented a systematic review on the new methods for the assessment of Parkinson’s disease, including tremor.

While the home-based application of the proposed technology is encouraged in this research work, the system is simple enough to be used in the clinic to provide clinicians with objective measures which do not hinder their standard practice. The technology based objective measurements can be used to provide scores for tremor to the clinician.

If needed, the animation can also be used to perform a visual assessment without having to have an actual video of the patient. The animation can be created locally from de-identified raw data thereby protecting the confidentiality of the data during transmission from a remote site or in the clinic. As the system we used is wireless, this then becomes a standardized, portable comprehensive assessment tool for clinic and remote utilization. The system then allows the physician to have “smart” data that could not only expedite the assessment and improve access for patients but also help tailor therapy directly to the patient’s needs.

The proposed wearable technology in conjunction with the existing web-based platforms could assist in expanding the scope of PD telemedicine. Such future technologies would effectively enable the clinicians to make informed and rapid decisions regarding the state of the patient and then optimize the necessary therapeutic intervention.
Preliminary evidence also exists suggesting that wearable sensors could facilitate the process of optimizing stimulator settings in patients with Parkinson’s disease undergoing DBS [37].

5. Conclusion

The results showed that a simple measure defined as the full-body tremor severity score or TSS can help in assessing PD tremor using such multi-sensor wearable technology. The TSS correlated well with scores obtained from a gold standard clinical scale, the UPDRS. This quantitative approach reliably separated tremor-dominant PD participants versus non-tremor-dominant and healthy participants. The findings suggest that such portable wearable motion capture systems can be used for automatically detecting and reporting the severity of full-body PD tremor.

If the suggested method is implemented and applied, an accurate animation developed from the sensor data could be remotely generated and considered along with the calculated TSS. In conclusion, the animation combined with the calculated TSS provides physicians with a comprehensive objective assessment of their patients, allowing them to make medication adjustments accordingly. The physicians can review the actual movements with no need to transfer and watch the actual video of the patient.

An ideal movement disorders remote monitoring system would potentially include either wearable sensors or sensors embedded in the environment to collect, analyse, and transfer relevant data. Such a system could provide clinicians with real-time reporting of the severity of multiple symptoms to optimize both the dosing and timing of a suggested medical intervention. This work was an attempt, foremost, to introduce a new tool and analysis approach for tremor as a prototype to pave the way for further developments.

Acknowledgement

The authors appreciate the participation of Dr. Andrew Parrent, Dr. Matthew Hebb, and Dr. Keith MacDougall (Western University, London, ON, Canada). We also acknowledge the efforts of Mr. Greydon Gilmore (Lawson Health Research Institute, London, ON, Canada) and Dr. Fariborz Rahimi (Bonab University, East Azerbaijan, Iran).

Appendix A

Table 4

<table>
<thead>
<tr>
<th>Body part</th>
<th>Segment</th>
<th>Motion</th>
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</thead>
<tbody>
<tr>
<td>Head</td>
<td>Head</td>
<td>Flexion/extension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral tilt</td>
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<tr>
<td></td>
<td></td>
<td>Axial rotation</td>
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<tr>
<td>Trunk</td>
<td>Right clavicle</td>
<td>Axial rotation</td>
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<td></td>
<td></td>
<td>Depression/elevation</td>
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<td></td>
<td></td>
<td>Retraction/protraction</td>
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<td></td>
<td>Left clavicle</td>
<td>Axial rotation</td>
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<td></td>
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<td>Depression/elevation</td>
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<td>Right elbow</td>
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<td>Right shoulder</td>
<td>Flexion/extension</td>
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<td>Pronation/supination</td>
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<td>Abduction/adduction</td>
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<td>Left arm</td>
<td>Flexion/extension</td>
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<td>Left wrist</td>
<td>Ulnar/radial</td>
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<td>Left elbow</td>
<td>Pronation/supination</td>
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<td>Rotation</td>
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### References


30. A. Sánchez-Ferro, W. Maetzel, Advances in sensor and wearable technologies for Parkinson’s disease, Mov. Disord. 31 (9) (Sep. 2016) 1283–1292.

