Estimating Bradykinesia in Parkinson's Disease with a Minimum Number of Wearable Sensors

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***Abstract*— Monitoring motor function of patients with Parkinson's disease (PD) over long periods of time is essential in order to improve symptom management and avoid complications. Wearable technologies can be useful in this context as long as they do not unnecessarily increase patient and caregiver burden. The goal of the current study was to identify whether using more wearable sensors improved the estimation of whole-body bradykinesia scores. Ten patients diagnosed with idiopathic PD were recruited to take part in this study. Data was collected over 3 separate occasions using clinical evaluations and three-axis acceleration. In order to estimate the clinical scores associated with bradykinesia of the upper- and lower-limbs, a machine learning algorithm using a leave-one-subject-out cross-validation paradigm was implemented. Using two sensors per limb did not improve estimation error within the upper- or lower-limbs. Results demonstrate that the use of multiple sensors on a single limb does not significantly improve the estimation of clinical scores related to bradykinesia. However, in order to obtain whole-body limb-specific bradykinesia scores, a minimum of one wearable sensor per limb is required.**

Keywords—Parkinson's disease, wearable sensor, accelerometer, bradykinesia, sensor reduction.

I. Introduction

A major issue facing clinicians treating patients with Parkinson's disease (PD) is to monitor the motor function of patients over long periods of time in order to improve symptom management and avoid complications. As PD patients are faced with a multitude of motor impairments such as tremor, rigidity, bradykinesia, akinesia, gait disturbances, and postural instability [1], as well as motor complications [2] associated with treatment such as dyskinesia and wearing off, new tools and methods need to be developed. The advent of wearable technology allows for the quantitative evaluation of motor function over longer periods of time. A recent paper from the Movement Disorders Society Task Force on Technology highlighted potential opportunities that can arise from the use of wearable technology in PD [3]. For instance, several groups, including ourselves, have demonstrated that clinical scores of different motor symptoms and complications can be accurately estimated using wearable technologies [4, 5]. Despite the positive prospects that the use of wearable technology can bring about, several challenges remain [3]. One issue that has arisen is how to best use this technology in order to collect clinically relevant information without excessively increasing patient burden. The current study addresses one specific aspect of patient burden by identifying whether using more wearable sensors improves the estimation of whole-body limb-specific bradykinesia scores.

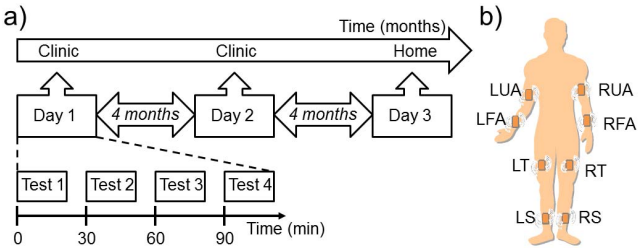

Fig. 1. a) data collection procedure. b) placement of wearable sensor on the human body.

II. Methods

Ten patients diagnosed with idiopathic PD were recruited to take part in this study (7 males; 61.2±9 years of age; Hoehn & Yahr range from 2 to 3). Data were collected over 3 separate occasions over an 8 months period (see Fig. 1a). During data collection, the motor function of patients was assessed clinically while wearable sensors were simultaneously placed on the patients' upper- and lower-limbs. Specifically, sensors were placed bilaterally on the upper-arm, forearm, thigh, and shank (see Fig. 1b). These sensors collected three-axis acceleration data. The data presented here pertains to bradykinesia, which was assessed while patients performed multiple repetitions of alternating hand movements and heel tapping tasks. Each test was repeated four times.

In order to estimate the clinical scores associated with bradykinesia, the acceleration data was first filtered between 0.5 and 12Hz in order to remove non-human generated noise. Then, the data was segmented into 30 overlapping epochs of 5s evenly distributed over each trial. From those epochs, a total of 60 features were extracted from the acceleration data of all axes. The features included the root mean square of the

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acceleration data, the peak frequency of the power spectrum, the ratio of the energy in the peak frequency to the total energy, the range of auto-covariance within the acceleration data, the correlation between acceleration of the upper- and lower-limbs, entropy of the acceleration data, and the range of the acceleration data. An additional 32 features were extracted from the envelop of the acceleration signal such as its variability, range, minimum value, as well as the ratio of its sum to its length. Then, a feature selection algorithm, which employed the ReliefF method to rank the features and Davies-Boulden index to select a feature subset, reduced the feature dimension. Finally, clinical scores for bradykinesia were estimated using a support vector machine (SVM) with a Pearson universal kernel (PUK). These clinical scores were estimated using features from each individual sensor on that given limb. A leave-one-subject-out cross-validation paradigm was used to estimate the bradykinesia scores. Average estimation errors obtained using 1 or 2 sensors on each limb were compared using a one-way repeated measures analysis of variance (ANOVA) for each condition.

III. Results

The method employed in the current study was able to yield estimated clinical scores of bradykinesia having a root mean square error (RMSE) of approximately 0.4 for the upper-limb during rapid alternating movements when utilizing data from 2 sensors (see Table I). This RMSE was approximately 0.5 when using only the upper-arm sensor while it was approximately 0.4 when using the forearm sensor. ANOVA did not reveal statistically significant differences between the RMSE, indicating that using two sensors did not improve estimation error within the upper-limb.

The RMSE of the estimated bradykinesia clinical score of the lower-limb was between 0.5 and 0.6 during leg agility when utilizing data from 2 sensors. This RMSE also ranged between 0.5 and 0.6 when using either the thigh or shank sensors. ANOVA did not reveal statistically significant differences between the RMSE, indicating again that using 2 sensors did not improve estimation error; this time within the lower-limb.

TABLE I. Root mean sqare error (RMSE) for the estimated clinical scores of bradykinesia

	UA + FA	UA	FA
AHM-R	0.37 (0.22)	0.49 (0.20)	0.35 (0.19)
AHM-L	0.39 (0.20)	0.50 (0.19)	0.41 (0.22)
	T+S	T	S
LA-R	0.59 (0.21)	0.56 (0.25)	0.60 (0.27)
LA-L	0.47 (0.20)	0.51 (0.24)	0.48 0.22)

Upper Arm (UA), Forearm (FA), Thigh (T), Shank (S)
Alternating Hand Movement (AHM), Leg Agility (LA), Right (R), Left (L)

IV. Discussion and Conclusions

The goal of utilizing wearable sensors in movement disorders is to collect data that would otherwise not be available to clinicians in order to improve the management of symptoms while minimizing complications. Since patients [6] and caregivers [7] already experience significant burden from the disease, there is a need to identify minimally invasive protocols using wearable technology in this population. Unfortunately, there is no universal solution to this issue as it needs to be addressed based on the clinical question being posited. On the other hand, the current study dealt with identifying the minimal number of sensors required to adequately estimate whole-body clinical bradykinesia scores. Results of the current study demonstrate that the use of multiple sensors on a single limb does not significantly improve the estimation of clinical scores related to bradykinesia. As such, in order to obtain limb-specific bradykinesia scores, a minimum of 4 wearable sensors is acquired (i.e. one on each limb). This is important information for the design of clinical trials examining the effect of an intervention on bradykinesia as well as for clinicians wanting to obtain a whole-body assessment of bradykinesia in their patients using wearable devices. Additionally, a clinician only concerned with the upper-limb may opt to use one sensor per arm thereby further minimizing patient burden. Future studies should examine whether the current results also apply to other symptoms of PD, such as tremor, as well as motor complications of treatment (i.e. dyskinesia).

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