From Controlled to Free-Living Contexts: Expanding the Monitoring of Motor Symptoms in Parkinson's Disease with Wearable *mHealth* Technologies

María Centeno-Cerrato[1][a], Carlos Polvorinos-Fernández[1][b], Luis Sigcha[2][c], Guillermo de Arcas[1][d], César Asensio[3][e], Juan Manuel López[4][f] and Ignacio Pavón[1][g]

[1] *Instrumentation and Applied Acoustics Research Group, Mechanical Engineering Department, ETS Ingenieros Industriales, Universidad Politécnica de Madrid, Madrid, Spain*

[2] *Department of Physical Education and Sports Science, Health Research Institute, & Data-Driven Computer Engineering (D2iCE) Group, University of Limerick, Limerick, Ireland*

[3] *Instrumentation and Applied Acoustics Research Group, Department of Audiovisual Engineering and Communications, ETS. de Ingeniería y Sistemas de Telecomunicación, Universidad Politécnica de Madrid, Madrid, Spain*

[4] *Instrumentation and Applied Acoustics Research Group, Department of Physical Electronics, Electrical Engineering and Applied Physics, ETS. de Ingeniería y Sistemas de Telecomunicación, Universidad Politécnica de Madrid, Madrid, Spain*

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Abstract: This study examines the application of wearable mobile health (*mHealth*) technologies, specifically smartwatches equipped with inertial sensors, for the monitoring of Parkinson's disease (PD). The aim is to investigate how the integration of the Monipar tool, designed to monitor supervised exercises, with the BioCliTe system, which continuously collects data during free-living activities, can improve the assessment of motor fluctuations and disease progression. The study proposes a set of free-living activities which can serve as characteristic indicators for assessing motor symptoms. By combining structured exercises with everyday tasks, this approach provides a more comprehensive evaluation of PD, capturing motor symptoms in both controlled and real-world environments. The research seeks to advance disease monitoring and patient care through more accurate tracking and the development of personalized treatment strategies.

1 INTRODUCTION

Parkinson's disease (PD) is a chronic, progressive neurological disorder caused by the loss of dopaminergic neurons, resulting in a significant reduction in the production of dopamine —a key neurotransmitter involved in the regulation of movement and motor control. PD manifests through a wide range of symptoms, categorized into two main groups: motor symptoms (e.g., resting tremor, bradykinesia, muscle rigidity, postural and gait disturbances or dyskinesias) and non-motor symptoms (e.g., sleep disorders, depression, cognitive impairment, and dementia in advanced stages). Despite advances in research, PD remains incurable, and its progression is inevitable. (Armstrong & Okun, 2020).

The most used scale to measure PD progression is the Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS), which evaluates symptoms and mental health through questionnaires and clinician-scored tests (Goetz et al., 2008).

[a] https://orcid.org/0009-0007-0113-3007
[b] https://orcid.org/0000-0002-4594-9477
[c] https://orcid.org/0000-0002-9968-5024
[d] https://orcid.org/0000-0003-1699-7389
[e] https://orcid.org/0000-0003-3265-3244
[f] https://orcid.org/0000-0001-7847-8707
[g] https://orcid.org/0000-0003-0970-0452

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The clinical management of PD presents a significant challenge due to the fluctuating nature of its symptoms. Medical consultations are commonly scheduled at intervals of six to twelve months, resulting in long gaps without detailed patient evaluation and treatment adjustment. Consequently, many patients can experience a deterioration of symptoms before their next clinical appointment (Rodríguez-Martín et al., 2022). There is a growing need for objective and continuous monitoring systems to assess disease progression and refine treatment strategies. This has led to the integration of technological tools aimed at improving both short- and long-term monitoring, as well as optimizing overall disease management.

Mobile health (*mHealth*) technologies and wearable devices allow continuous, accurate data collection in a simple manner without causing discomfort to the user. These devices, often equipped with sensors (typically inertial or bioelectrical), enhance monitoring quality while offering patients an accessible and convenient solution (Polvorinos-Fernández et al., 2024).

It is essential to ensure these sensors reliably operate within the relevant amplitude and frequency ranges for accurate treatment evaluation of the patients (Ru et al., 2022).

To obtain a more comprehensive and objective view, it is important to collect data from patients in a wide range of environments: during the performance of pre-defined guided exercises and during the execution of activities of daily living. Furthermore, these data can be used to develop digital biomarkers that facilitate the quantification of patients' motor status (Polvorinos-Fernández et al., 2024).

These biomarkers could play a crucial role in personalizing treatment and improving patients' quality of life (Mahadevan et al., 2020). The acquisition of data under both laboratory and free-living conditions is crucial for evaluating the validity and utility of novel biomarkers. Controlled laboratory environments enable the generation of robust and reliable biomarkers, whereas data collected in free-living settings are indispensable for determining whether these biomarkers retain their reliability and relevance in real-world contexts.

This study explores the use of inertial sensors to monitor patients with PD. All smartwatches employed for the measurements conducted in the study are equipped with an LSM6DS0 sensor, which incorporates a triaxial accelerometer and a triaxial gyroscope. The sampling frequency was configured in every device at 50 Hz.

The precise number and placement of sensors on the body remain subjects of debate; however, it is generally recommended to minimize the number of sensors to optimize usability and comfort, while ensuring the integrity of the data (Monje et al., 2019). In accordance with this, a decision was made to sacrifice some data quantity to enhance usability by placing the smartwatch on only one hand, specifically on the wrist most affected by symptoms. This approach ensures the capture of data related to motor performance and physical activity, while prioritizing user comfort and ease of use.

The study highlights the importance of collecting movement data in both supervised and unsupervised contexts. For this purpose, the *mHealth* tool BioCliTe (Digital **Bio**markers for Motor Status Assessment of Parkinson's Disease Patients for **Cli**nical and **The**rapeutic Application) was used to continuously capture motion signals during free-living activities and guided exercises. The guided exercises were performed using the Monipar tool (Sigcha et al., 2023), which provides instructions via a smartphone, while the smartwatch synchronously records data from the embedded inertial sensors.

2 MONITORING GUIDED ACTIVITIES: Monipar

Monipar is a technological solution developed as part of the TECAPARK project (TECAPARK), specifically designed to monitor the execution of specific guided activities selected from the MDS-UPDRS. These activities are intended to be performed in supervised contexts, ensuring controlled and accurate execution.

Monipar consists of two modules: a smartphone application that guides the user, and a wearable module in the form of a smartwatch, designed for real-time data collection. The mobile application, which uses an interactive interface, provides comprehensive guidance through both visual elements and audio prompts. This approach ensures that users execute the exercises accurately, reducing performance variability.

In addition, the application transmits activation and status data from the smartphone to the smartwatch, facilitating the automatic labelling of the recorded signals. Simultaneously, the smartwatch collects data via the integrated inertial sensors during each exercise, which is then stored in the device's local database. (Sigcha et al., 2023).

Monipar is structured around a set of exercises based on Part III of the MDS-UPDRS scale (Goetz et al., 2008), which assess different aspects of motor function. These exercises are strategically sequenced to ensure a comprehensive assessment (Sigcha et al., 2023). Figure 1 illustrates the instructions displayed in Monipar's exercise routine.

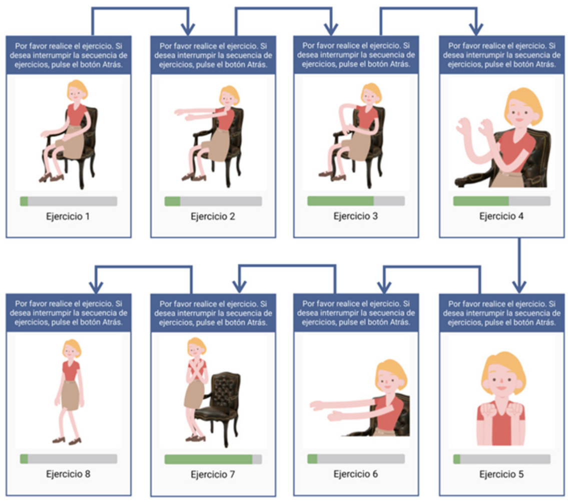

Figure 1: Visual Instructions for Monipar's exercise routine.

- Exercise 1, Resting Tremor Assessment (Item 3.17), quantifies the amplitude of tremor when the limbs are at rest.
- Exercise 2, Postural Tremor Assessment (Item 3.15), assesses the presence of tremor when the patient maintains a fixed posture.
- Exercise 3, Repetitive Arm Extension Movement. To complement the items of the MDS-UPDRS scale, an additional exercise was incorporated, involving repeated forward arm extensions and bringing the hands to the chest.
- Exercise 4, Finger Tapping (Thumb-Index) (Item 3.4), assesses bradykinesia and fine motor coordination by repetitively tapping the thumb and index finger.
- Exercise 5, Rapid Hand Movements (Item 3.5), measures the patient's ability to perform rapid, repetitive hand movements, providing data on motor agility and bradykinesia.
- Exercise 6, Upper Limb Pronation-Supination (Item 3.6), assesses bradykinesia and motor symptoms, by measuring the pronation and supination movements of the hands.
- Exercise 7, Rising from a Chair (Item 3.9), assesses the patient's ability to rise from a seated position, reflecting postural control.
- Exercise 8, Gait Analysis (Item 3.10), assesses gait quality, enabling the identification of typical symptoms, such as freezing of gait.

Strategically timed rest periods were integrated between each exercise, ensuring optimal performance and minimizing the impact of fatigue on the data collected. The Monipar protocol has a total duration of 8 minutes. The duration of each exercise within the protocol varies, depending on factors such as the nature of the activity, its level of difficulty, and other relevant considerations, all aimed at achieving the most effective results for each specific task.

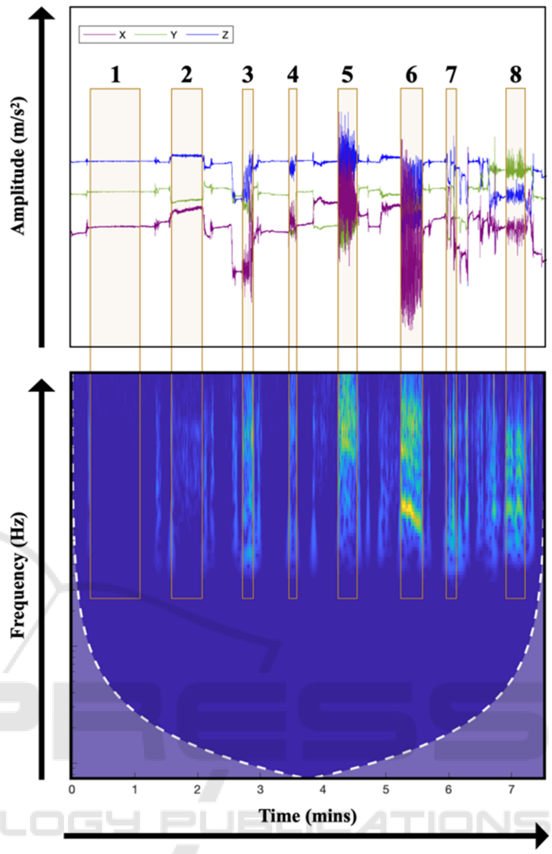

Figure 2: Example of an accelerometer signal recorded by Monipar, including labelled data. The upper section shows the temporal signal obtained from the three axes (time vs amplitude), while the lower section shows the scalogram of the combined signal from all three axes (time vs frequency) (Sigcha et al., 2023).

3 TRANSITION FROM Monipar TO BioCLiTe

Currently, Monipar provides valuable data on PD motor status in controlled, supervised environments. However, to ensure a comprehensive and precise evaluation of the disease progression and treatment efficacy, monitoring guided exercises must be combined with monitoring free-living activities, which do not require supervision. This integration offers several significant advantages:

- **More Realistic Representation of Motor Status.** Guided exercises in controlled environments, such as those performed with Monipar, allow for the evaluation of specific movements under standardized conditions, which is useful for measuring specific parameters of motor function. However, these exercises do not always reflect the demands and variations encountered in daily life. Free-living activities, such as walking, eating, or dressing, provide a more realistic perspective on how the disease affects functionality in everyday contexts. The integration of both types of monitoring can provide a holistic assessment of motor function, capturing both the accuracy of movements in defined exercises and the motor performance in real-life situations.

- **Detection of Motor Fluctuations and "Off" Periods.** PD is characterized by motor fluctuations, particularly in advanced stages, where patients experience "on" periods (with good motor control) and "off" periods (with significant impairment). Continuous monitoring during free-living activities permits the tracking of these fluctuations, information that may not be apparent during guided exercises. This allows for a more accurate assessment of motor function, facilitating better adjustment to medication and other treatments (Mantri et al., 2021).
- **More Comprehensive Data for Longitudinal Analysis.** Collecting data in different contexts (guided and free-living) provides a richer and more diverse dataset for longitudinal analysis. This allows the observation of long-term patterns, a more detailed assessment of disease progression, and the effectiveness of treatments. In addition, the diversity of data can help to develop more robust predictive models regarding disease progression.

In summary, the combination of guided exercises and free-living activities in the monitoring of PD patients provides a more comprehensive, accurate and personalized view of their motor status. Consequently, there is a need to move from Monipar (monitoring under controlled conditions) to BioCliTe (monitoring also under free-living conditions).

4 MONITORING OF FREE-LIVING AND GUIDED ACTIVITIES: BioCLiTe

BioCliTe provides a technological solution that evolves from the Monipar tool, adapting and extending its functionalities to increase both the scope and accuracy of monitoring in contexts beyond the clinical environment.

While Monipar was limited to recording data exclusively during guided exercises in a controlled environment, BioCliTe provides continuous movement data collection, extending monitoring throughout the entire day (without the need for supervision). This approach facilitates the collection of movement data while patients are performing tasks that reflect their daily routines.

In addition to providing data from the accelerometer and gyroscope, BioCliTe also supports the real-time tracking of the participant's physical activity, including total steps, walking steps, running steps, speed, distance, and calories burned.

BioCliTe not only focuses on monitoring free-living activities but also preserves the core functionality of Monipar by integrating guided exercises into daily tasks. This allows patients to carry out these exercises autonomously in their home environment, without the need for direct supervision.

Previously, the Monipar mobile application activated the smartwatch to initiate activity measurement; however, due to the transition to BioCliTe, this functionality has been updated. The mobile application now records the time intervals during which activities are performed, generating a time-stamped data file that tracks the signal's status throughout the activity, enabling the automatic labelling of movement data captured by the smartwatch.

The battery life of the smartwatch is a limitation to consider. Each smartwatch has a different battery capacity, making it necessary to evaluate how many hours of continuous data recording it can support. According to the studies conducted, the commercial smartwatches used in the experiments are capable of measuring acceleration and angular velocity for up to five consecutive hours. During the remaining hours of the day, the smartwatch only recorded data related to physical activity.

The system was designed to allow flexibility in the initiation and termination of measurements taken through the accelerometer and gyroscope, adapting to the individual needs of the patient. The recording period can be adjusted according to the patient's schedule, allowing guided activities to be performed at the most convenient times.

In Figure 3, acceleration data (recorded over a period longer than 1 hour) shows clear regions where tremor is present. This extended monitoring period allows for a more comprehensive assessment compared to the previous functionality of Monipar, which only evaluated movement during guided exercises. In addition to the Monipar exercises, the participant was asked to perform a free-living activity (cooking – beating a mixture).

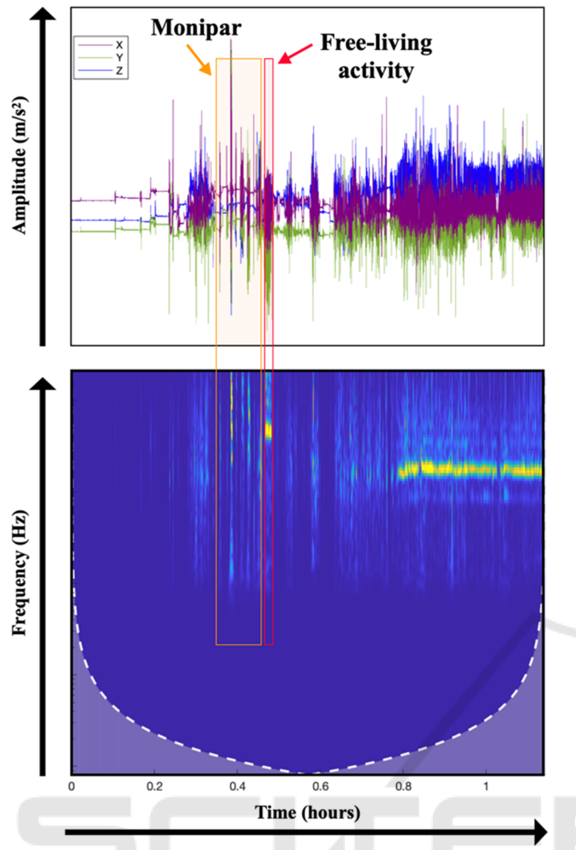

Figure 3: Example of an accelerometer signal recorded by BioCliTe, including labelled data.

4.1 Proposed Free-Living Activities

Certain routine activities performed in daily living have been recognized as effective in the monitoring process, helping to characterize PD motor symptoms, such as tremor and bradykinesia.

Due to the current limitations in recognizing patterns associated with each specific free-living activity, the first stage is to manually label these exercises. To accomplish this, it is proposed to develop a mobile application like Monipar, where the user is guided through the task using visual and/or auditory instructions, while also marking the precise start and end points of each activity.

The data files would be stored locally on the mobile device, and by cross-referencing this information with the data recorded by the smartwatch, it will be possible to identify which sections of the signal correspond to each specific activity. After having gained a thorough understanding of the patterns and characteristics associated with the signals from each proposed free-living activity (using artificial intelligence techniques) the objective is to eliminate the need for manual labelling. In this context, the artificial intelligence system will autonomously recognize the activity occurring at any given moment.

Several daily activities have been identified as suitable for monitoring motor symptoms, including walking, standing up and sitting down, writing or drawing, cooking, typing and brushing teeth.

A series of controlled laboratory experiments were conducted, involving 20 healthy participants, to thoroughly evaluate each of the proposed activities. During these tests, participants performed the tasks while their movements were tracked by the inertial sensors embedded in a smartwatch. The data collected allowed an in-depth analysis of how these activities could function as reliable indicators of motor symptom progression when monitored over extended periods of time, in environments where constant supervision is not required.

It is noteworthy that the experiments involving patients with PD have not yet started, and the current findings provide a preliminary foundation for subsequent research involving PD individuals.

4.1.1 Standing up and Sitting down

Inertial sensors can capture the duration and fluidity of transitions from a seated to a standing position, providing valuable data to assess the impact of PD on functional mobility in daily activities. Figure 4 illustrates a significant amplitude increase in accelerometer and gyroscope signals corresponding to the participant's standing up activity.

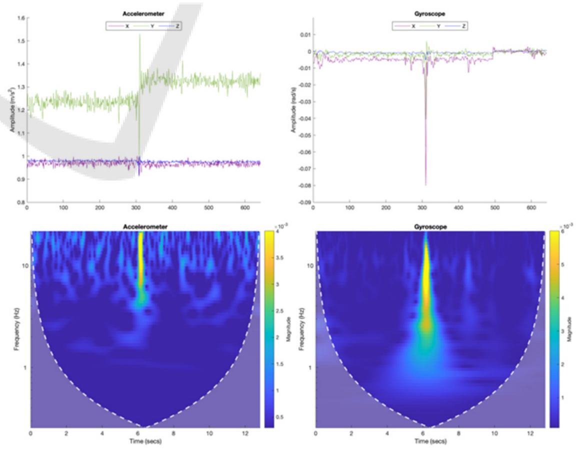

Figure 4: Signal recorded during the activity of standing up (healthy participant). Upper panels show the time-domain signals; lower panels the scalograms; left column corresponds to accelerometer data; right column to gyroscope data.

4.1.2 Gait

It is recommended to identify periods when the participant is walking during free-living activities for having observation in unsupervised environments. There is no need to develop a new tool to manually label walking events, as this can be achieved by cross-referencing physical activity data (steps or speed) with information from the accelerometer and gyroscope. Gait is a key indicator of PD progression, as difficulties such as "freezing of gait" can occur outside of controlled environments. Measurements taken during everyday activities like walking indoors or outdoors allow for the detection of subtle changes in mobility (Figure 5) (Borzì et al., 2023) (Polvorinos-Fernández et al., 2024).

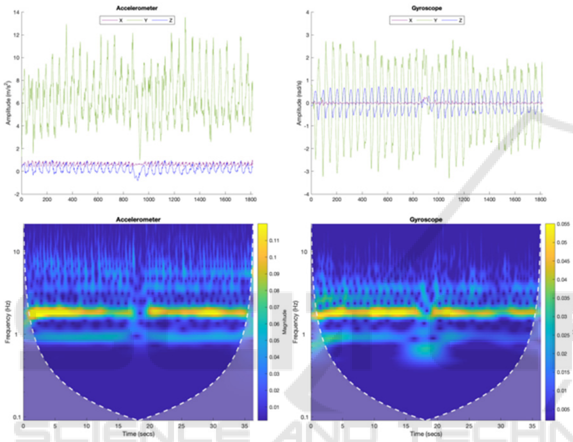

Figure 5: Signal recorded during the activity of gait (healthy participant).

4.1.3 Writing or Drawing

Activities related to writing and drawing, particularly the task of tracing a spiral, are common methods for assessing motor symptoms in patients with PD. These daily living tasks, which require continuous and fluid movements of the hands and wrists, are effective for detecting tremors, which appear as irregular or discontinuous strokes. Inertial sensors placed on the wrist can record deviations in acceleration and angular velocity, providing accurate data on the presence of tremors (Figure 6). Furthermore, these activities are well-suited for assessing bradykinesia symptoms, characterized by a progressive reduction in the size of letters or strokes when drawing. With these inertial sensors, it could be possible to capture the decrease in movement amplitude and the progressive slowing of motion of the upper limbs of the patients (Thomas Kollamkulam, 2017).

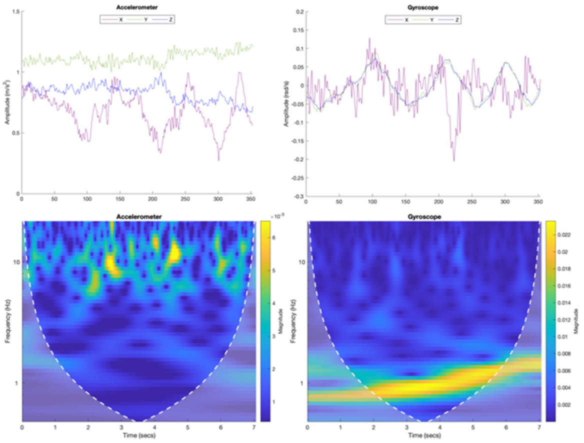

Figure 6: Signal recorded during the activity of drawing a spiral (healthy participant).

4.1.4 Brushing Teeth

Tooth brushing is a common daily activity that involves repetitive and structured movements. PD tremors may clearly manifest while holding the toothbrush, leading to irregular oscillations that can be detected by inertial sensors as fluctuations in acceleration and angular velocity. In addition, bradykinesia becomes evident in the reduced speed of tooth brushing, reflecting a decrease in the amplitude and speed of repetitive movements (Figure 7).

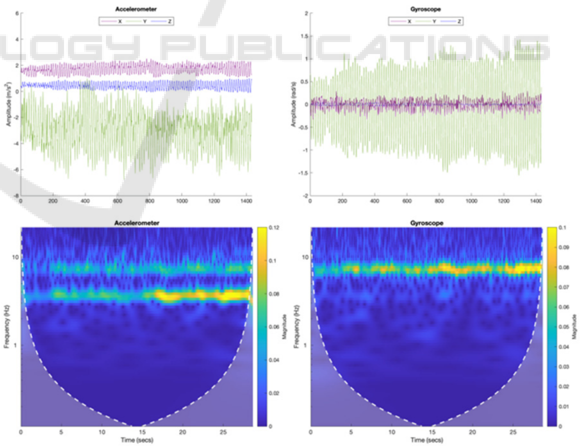

Figure 7: Signal recorded during the activity of brushing teeth (healthy participant).

4.1.5 Cooking

Cooking activities present a valuable framework for assessing motor function in people with PD because they replicate the complex, coordinated movements required in daily life. Routine tasks such as beating a mixture, stirring a pot or a cup of coffee, or cutting and chopping ingredients, involve rapid, repetitive, and synchronized movements of the arm and wrist (Figure 8). These tasks require controlled movements and precise regulation of force, making them particularly well-suited for assessing motor impairments (tremor, bradykinesia and rigidity).

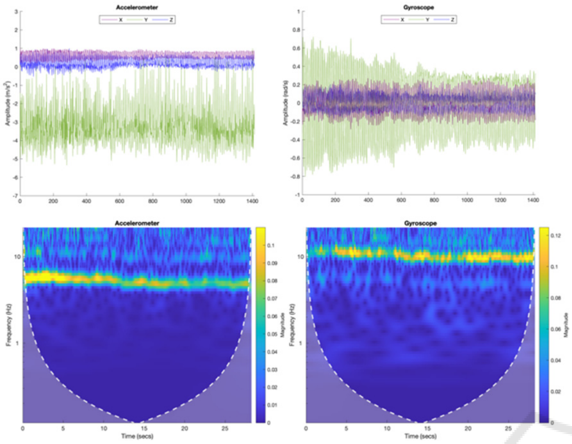

Figure 8: Signal recorded during the activity of beating a mixture (healthy participant).

4.1.6 Typing

Patients with PD often experience motor symptoms when typing, which can affect both the accuracy and speed of their keystrokes. By analysing the variations in hand movement, the sensors detect patterns indicative of bradykinesia, such as reduced movement amplitude or slower motion, as well as tremor-related irregularities, like involuntary, rhythmic motions. The changes in acceleration and angular velocity can be valuable in assessing the severity and progression of PD symptoms (Figure 9).

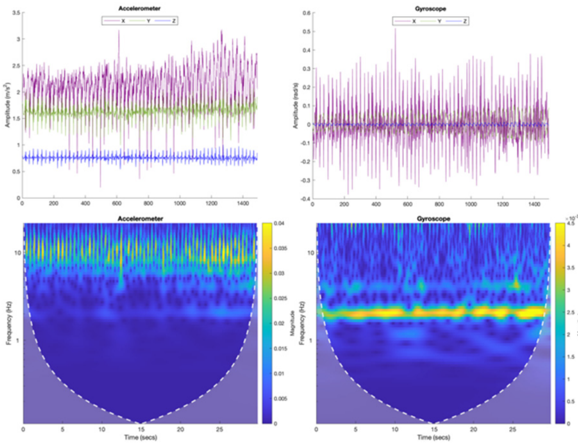

Figure 9: Signal recorded during the activity of typing (healthy participant).

5 CONCLUSIONS

This study highlights the critical role of *mHealth* technologies, such as Monipar and BioCliTe, in improving the assessment of PD. Using wearable devices, specifically smartwatches, can allow accurate, continuous, and non-invasive monitoring of motor symptoms, contributing to a deeper understanding of the disease's progression.

Monipar provides a structured framework for the guided execution of standardized exercises derived from the MDS-UPDRS scale, enabling controlled assessments in supervised settings. Building on this foundation, BioCliTe extends the monitoring capabilities to free-living activities, allowing for continuous data collection in unsupervised, real-world environments. This dual approach—combining guided exercises with daily activity monitoring—provides a comprehensive assessment of motor function, potentially bridging the gap between clinical assessments and the challenges patients face in their everyday lives.

To improve the understanding of motor impairments in unsupervised settings, several free-living activities have been proposed for analysis, including gait, standing up and sitting down, writing or drawing, cooking, typing, and brushing teeth. These activities replicate hand movements commonly performed in everyday life, allowing for the detection of tremor, bradykinesia, rigidity, and other motor symptoms under real life conditions (Polvorinos-Fernández, Sigcha, Pablo, et al., 2024). Incorporating data from these activities complements traditional guided exercises and enriches the dataset available for clinical evaluation. However, challenges remain in accurately recognizing patterns of free-living activities and ensuring reliable classification using smartwatch data alone. To perform automatic labeling effectively, a large and robust database is required. Additionally, the complexity of monitoring a wide range of daily activities necessitates the development of advanced analytical tools, including machine learning and data fusion techniques, to improve activity recognition and symptom detection.

One of the key limitations of this study is the absence of PD patients in the trial sample, which restricts the ability to directly evaluate the effectiveness of the technologies in monitoring PD-specific motor symptoms, particularly in relation to the proposed activities. Another limitation is the reliance on smartwatches for data collection, as factors such as device calibration, user behaviour, and environmental conditions can introduce variability and affect the accuracy of the measurements. Additionally, the battery life of the smartwatch may impact the continuous monitoring of motor symptoms, which could influence the completeness of the data collected throughout the day. These factors must be considered in future studies to improve the generalizability and applicability of the findings to the PD population.

The integration of wearable devices into these *mHealth* solutions can offer significant advantages, including real-time detection of motor fluctuations, improved tracking of disease progression, and more personalized treatment strategies. These technologies represent a transformative step in PD management, providing clinicians with detailed, patient-specific insights. Future research will focus on optimizing data analysis algorithms to enhance the accuracy and reliability of symptom detection in diverse real-world scenarios.

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REFERENCES

Armstrong, M., & Okun, M. (2020). Diagnosis and Treatment of Parkinson Disease: A Review. *Jama*, *323*, 548. https://doi.org/10.1001/jama.2019.22360

Borzì, L., Sigcha, L., & Olmo, G. (2023). Context Recognition Algorithms for Energy-Efficient Freezing-of-Gait Detection in Parkinson's Disease. *Sensors*, *23*(9), 4426.

Goetz, C. G., Tilley, B. C., Shaftman, S. R., Stebbins, G. T., Fahn, S., Martinez-Martin, P.,…LaPelle, N. (2008). Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale presentation and clinimetric testing results. *Movement Disorders*, *23*(15), 2129-2170. https://doi.org/https://doi.org/10.1002/mds.22340

Mahadevan, N., Demanuele, C., Zhang, H., Volfson, D., Ho, B., Erb, M., & Patel, S. (2020). Development of digital biomarkers for resting tremor and bradykinesia using a wrist-worn wearable device. *npj Digital Medicine*, *3*, 5. https://doi.org/10.1038/s41746-019-0217-7

Mantri, S., Lepore, M., Edison, B., Daeschler, M., Kopil, C., Marras, C., & Chahine, L. (2021). The Experience of OFF Periods in Parkinson's Disease: Descriptions, Triggers, and Alleviating Factors. *Journal of Patient-Centered Research and Reviews*, *8*, 232-238. https://doi.org/10.17294/2330-0698.1836

Monje, M., Foffani, G., Obeso, J., & Sánchez-Ferro, A. (2019). New Sensor and Wearable Technologies to Aid in the Diagnosis and Treatment Monitoring of Parkinson's Disease. *Annual Review of Biomedical Engineering*, *21*, 111-143. https://doi.org/10.1146/ annurev-bioeng-062117-121036

Polvorinos-Fernández, C., Pavón, I., & Sigcha, L. (2024). *Smartwatch gait dataset in simulated Parkinson's disease restricted arm swing conditions* (Zenodo. https://doi.org/10.5281/zenodo.13884808

Polvorinos-Fernández, C., Sigcha, L. F., Borzí, L., Olmo, G., Asensio, C., Lopez Navarro, J. M.,…Pavón, I. (2024). Evaluating Motor Symptoms in Parkinson's Disease Through Wearable Sensors: A Systematic Review of Digital Biomarkers. *Applied Sciences*, *14*, 10189. https://doi.org/10.3390/app142210189

Polvorinos-Fernández, C., Sigcha, L. F., Pablo, L., Borzí, L., Cardoso, P., Costa, N.,…Pavón, I. (2024, 01). *Evaluation of the Performance of Wearables' Inertial Sensors for the Diagnosis of Resting Tremor in Parkinson's Disease*

Rodríguez-Martín, D., Cabestany, J., Pérez, C., Pie, M., Calvet, J., Samà Monsonís, A.,…Rodríguez-Molinero, A. (2022). A New Paradigm in Parkinson's Disease Evaluation With Wearable Medical Devices: A Review of STAT-ON. *Frontiers in Neurology*, *13*, 912343. https://doi.org/10.3389/fneur.2022.912343

Ru, X., Gu, N., Shang, H., & Zhang, H. (2022). MEMS Inertial Sensor Calibration Technology: Current Status and Future Trends. *Micromachines*, *13*(6), 879.

Sigcha, L., Pavón, I., De Arcas, G., Costa, N., Costa, S., Arezes, P.,…Polvorinos, C. (2023). *Monipar Database: smartwatch movement data to monitor motor competency in subjects with Parkinson's disease* (Zenodo. https://doi.org/10.5281/zenodo.8104853

Sigcha, L., Polvorinos-Fernández, C., Costa, N., Costa, S., Arezes, P., Gago, M.,…Pavón, I. (2023). Monipar: movement data collection tool to monitor motor symptoms in Parkinson's disease using smartwatches and smartphones [Original Research]. *Frontiers in Neurology*, *14*. https://doi.org/10.3389/ fneur.2023.1326640

TECAPARK. https://www.i2a2.upm.es/tecapark/

Thomas Kollamkulam, M. a. L. A. a. P. P. (2017). Handwriting Analysis in Parkinson's Disease: Current Status and Future Directions. *Movement Disorders Clinical Practice*, *4*. https://doi.org/10.1002/ mdc3.12552