BE018

Gait Monitoring and Analysis of Parkinson’s Disease Patients

RESEARCH PLAN

A) RATIONALE

This project is useful and relevant as Parkinson's Disease is becoming more and more prevalent amongst the elderly population in Singapore, and this means that more elderlies are at a risk of falling due to the symptoms of Parkinson's Gait. Moreover, many elderly citizens in Singapore live in HDBs where due to cramped spaces, they may have a higher risk of severe injuries upon falling. Research has also shown that walking in cramped spaces can trigger the worsening of Freezing of Gait. Thus, we feel it is of utmost importance to try to understand more about the parameters that could possibly measure Freezing of Gait and how we could analyse these parameters to create a simple gait monitoring device. In the future, we hope that this device could help medical researchers identify Freezing of Gait easily for a more effective diagnosis of Parkinson's Disease and also aid elderly caregivers in their day-to-day lives.

B) RESEARCH QUESTION

Is it possible to make use of signal processing algorithms in extracting gait parameters from motion sensors and identifying most suitable parameters for classification of Freezing of Gait in Parkinson's Disease Patients?

HYPOTHESIS

Whether gait parameters can be derived from Inertia Motion Units, to classify freezing of gait (e.g. Accelerometers, Gyroscope)

ENGINEERING GOALS

- Monitor gait patterns for parkisons disease patients
- Analyse gait during freezing and non freezing events
- Investigating gait parameters to understand what is most suitable for classification for freezing of gait in PD patients.
- Create a prototype of the gait monitoring device

C) PROCEDURE

- Review and understand how to extract gait parameters from motion sensors.
- Investigate which algorithm is most suitable from different algorithms present in literature
- Make use of a PD patient public dataset and create a prototype to test out the algorithms

RISK ASSESSMENT

1. Usage of Soldering Iron to solder Arduino board
    a. *Risks Involved:* Risk of Burn, Risk of Inhaling Toxic Gases
    b. *Safety Precautions:* Wear gloves and goggles at all times when handling soldering equipment and use a fume fan to capture toxic gases released.

LITERATURE REVIEW

Utilisation of IMUs in analysis

This section reports previous studies which have explored the application of motion sensors on PD patients to accurately predict FOG. Ferster et al. [1] placed 9-axis IMUs (comprising 3D accelerometers, 3D gyroscopes and 3D magnetometers) on both ankles of the subjects to extract gait features such as stride length and stride duration. Moreover, as FOG exhibits unique frequency ranges, they introduce and discuss frequency features such as dominant frequency, dominant frequency amplitude and the inverse of the dominant frequency slope of the acceleration data to quantify changes in gait quality. Ferster was able to show specific changes in the stride duration, stride length, dominant frequency and the inverse of the dominant frequency slope with up to four seconds prior to FoG on all subjects.

Baechlin et al. [2] proposed placing accelerometers at three different parts of the body: the shank, thigh and lower back, where the wearable computer is attached to.

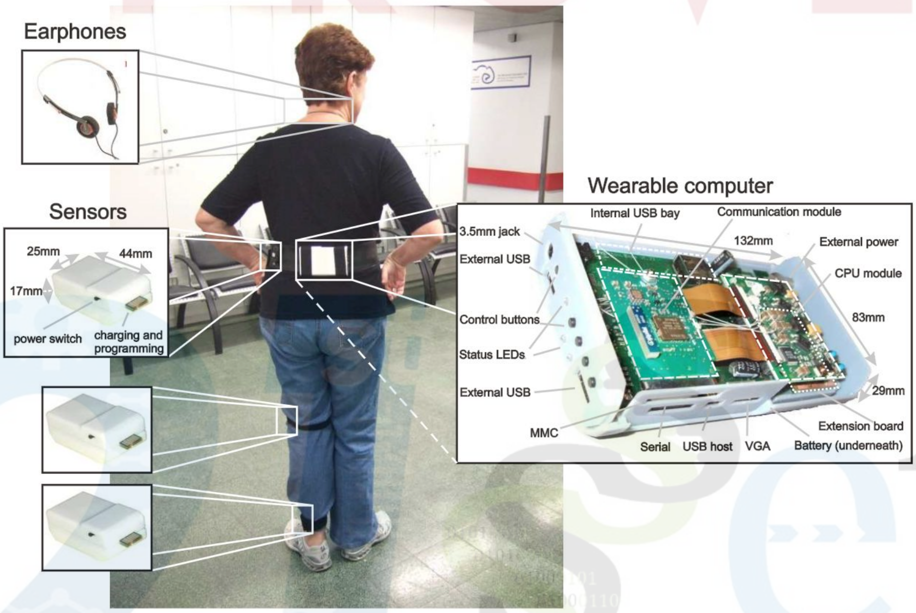

Figure 1: The Baechlin et al. 3-axial Accelerometer Wearable System

Alam et al. [3] analyzed the vertical ground reaction force using force insoles in patients' shoes to display gait cycles. Pinto et al. [4] again utilised accelerometers and gyroscopes to determine stride time, this time placing the accelerometer at the shank. In summary, a consolidated list of the main IMUs that were considered in this study is provided in Table 1.

Table 1: Table of possible IMUs

IMU	Purpose	Measured Parameter
Accelerometer	Measuring acceleration	Stride Length, Stride Duration
Gyroscope	Measuring angular velocity	Step Festination, Gait Asymmetry
Flexible Goniometer	Measuring body joint angles	Flat Foot Strike
Force- sensitive Insole	Measuring the tension and compression forces that act on the sensor	Gait Cycle (not accurate for PD patients who suffer from flat footedness)

Many works have utilised motion capture systems to annotate FOG events, synchronising sensor data and computer analysis to make way for machine learning algorithms. Kuhner et al. [5] performed this experiment, setting up 12 cameras as well as utilising an inertial measurement suit to create a 'live' system that reduces the latency of data processing.

The above literature confirms the success of utilising accelerometers, gyroscopes and force insoles to effectively differentiate FOG from normal gait and has greatly helped in designing the proposed approach for this study.

Gait parameters to be analysed

The frequency-based features discussed by Baechlin et al [2] are reliable, but they have one major drawback. The large amount of calculations required to perform the Fast Fourier Transform (FFT) algorithm needed to analyse frequency-based data means that a digital signal processing chip is required, making it impossible to fit in a small, lightweight unobtrusive system. This would make it impractical for real life detection. For the patients with gait problems, a bulky and obtrusive system may worsen the gait disturbances. Additionally, most experiments utilised a relatively long window length (4 seconds [2], 6 seconds [7], and 10 seconds [8]) for detection, leading to a long delay in FOG detection. Eom et al. [6] suggested a simple and fast time-domain method for FOG detection that was comparable to the traditional frequency-domain method with a calculation load of 1,154 times less. This has practical clinical applications.

Previous researchers also have reported the importance of five parameters for the detection of PD. Most notably, Hollman et al.[9] have proposed five major domains of gait based on factor analysis:

1. Rhythm - step and stride time
2. Phase - gait cycle
3. Variability - step-to-step variability
4. Pace - gait speed, stride and step length
5. Base of support - step width

Others have confirmed the importance of determining the spatiotemporal parameters. Alcock et al.[10], Coste et al.[11] and Schlachetzki et al.[12] have all discussed the importance of stride length, stride time and gait velocity in distinguishing PD patients from healthy older adults. Overall, a summary of gait parameters found in this research is shown below. In this study, the focus will be on gait velocity, stride time and gait cycle.

Table 2: Summary of Gait parameters found in this research

Gait abnormalities	Definition
Step Festination	Shortening of steps
Decrease in Stride Duration	Decrease in the time difference between two consecutive detected acceleration peaks of the same leg
Postural Instability	Loss of balance
Increase in step-to-step time variability	Difference in time taken between each stride
Stride Length Reduction	Reduction in distance between each stride/step
Decreased Cadence	Decrease in number of steps taken per unit time
Gait Asymmetry	Difference in gait between the two legs of patient

Bibliography for Literature Review

[1] Ferster, M. L., Mazilu, S., & Tröster, G. (2015). Gait Parameters Change Prior to Freezing in Parkinson's Disease: A Data-Driven Study with Wearable Inertial Units. Proceedings of the 10th EAI International Conference on Body Area Networks. https://doi.org/10.4108/eai.28-9-2015.2261411

[1] Nutt, J. G., Bloem, B. R., Giladi, N., Hallett, M., Horak, F. B., & Nieuwboer, A. (2011). Freezing of gait: moving forward on a mysterious clinical phenomenon. The Lancet Neurology, 10(8), 734–744. https://doi.org/10.1016/s1474-4422(11)70143-0

[2] Bachlin, M., Plotnik, M., Roggen, D., Maidan, I., Hausdorff, J. M., Giladi, N., & Troster, G. (2010). Wearable Assistant for Parkinson's Disease Patients With the Freezing of Gait Symptom. IEEE Transactions on Information Technology in Biomedicine, 14(2), 436–446. https://doi.org/10.1109/titb.2009.2036165

[3] Alam, M. N., Garg, A., Munia, T. T. K., Fazel-Rezai, R., & Tavakolian, K. (2017). Vertical ground reaction force marker for Parkinson's disease. PLOS ONE, 12(5), e0175951. https://doi.org/10.1371/journal.pone.0175951

[4] Pinto, C., Schuch, C. P., Balbinot, G., Salazar, A. P., Hennig, E. M., Kleiner, A. F. R., & Pagnussat, A. S. (2019). Movement smoothness during a functional mobility task in subjects with Parkinson's disease and freezing of gait – an analysis using inertial measurement units. Journal of NeuroEngineering and Rehabilitation, 16(1). https://doi.org/10.1186/s12984-019-0579-8

[5] Kuhner, A., Schubert, T., Maurer, C., & Burgard, W. (2017). An online system for tracking the performance of Parkinson's patients. 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). https://doi.org/10.1109/iros.2017.8205977

[6] Eom, G.-M., Kwon, Y., Park, S. H., Kim, J.-W., Ho, Y., Jeon, H.-M., Bang, M.-J., Jung, G.-I., Lee, S.-M., Koh, S.-B., Lee, J.-W., & Jeon, H. S. (2014). A practical method for the detection of freezing of gait in patients with Parkinson's disease. Clinical Interventions in Aging, 1709. https://doi.org/10.2147/cia.s69773

[7] Moore, S. T., MacDougall, H. G., & Ondo, W. G. (2008). Ambulatory monitoring of freezing of gait in Parkinson's disease. Journal of Neuroscience Methods, 167(2), 340–348. https://doi.org/10.1016/j.jneumeth.2007.08.023

[8] Morris, T. R., Cho, C., Dilda, V., Shine, J. M., Naismith, S. L., Lewis, S. J. G., & Moore, S. T. (2012). A comparison of clinical and objective measures of freezing of gait in Parkinson's disease. Parkinsonism & Related Disorders, 18(5), 572–577. https://doi.org/10.1016/j.parkreldis.2012.03.001

[9] Hollman, J. H., McDade, E. M., & Petersen, R. C. (2011). Normative spatiotemporal gait parameters in older adults. Gait & Posture, 34(1), 111–118. https://doi.org/10.1016/j.gaitpost.2011.03.024

[10] Alcock, L., Galna, B., Perkins, R., Lord, S., & Rochester, L. (2018). Step length determines minimum toe clearance in older adults and people with Parkinson's disease. Journal of Biomechanics, 71, 30–36. https://doi.org/10.1016/j.jbiomech.2017.12.002

[11] Azevedo Coste, C., Sijobert, B., Pissard-Gibollet, R., Pasquier, M., Espiau, B., & Geny, C. (2014). Detection of Freezing of Gait in Parkinson Disease: Preliminary Results. Sensors, 14(4), 6819–6827. https://doi.org/10.3390/s140406819

[12] Morris, T. R., Cho, C., Dilda, V., Shine, J. M., Naismith, S. L., Lewis, S. J. G., & Moore, S. T. (2012). A comparison of clinical and objective measures of freezing of gait in Parkinson's disease. Parkinsonism & Related Disorders, 18(5), 572–577. https://doi.org/10.1016/j.parkreldis.2012.03.001