Intelligent Fall Prevention for Parkinson's Disease Patients based on Detecting Posture Instabilily and Freezing of Gait

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Keywords: Sensor Network, Parkinson's Disease, Freezing of Gait, Derivative Dynamic Time Warping Algorithm, Accelerometer.

Abstract: Parkinson's disease (PD) is a disorder that affects nerve cells in a part of the brain, and results from a progressive loss of dopaminergic and other sub-cortical neurons. Symptoms of Parkinson's disease may include resting tremor, bradykinesia, rigidity, a forward stooped posture, postural instability, and freezing of gait. As reported by several researchers, the forward stooped posture and freezing of gait are the most critical reasons to make the Parkinson's disease patients fall. The main objective of this research is to develop a fall prevention system for Parkinson's disease patients. There are two phases in the fall prevention protocol. The first phase is to detect and recognize the stooped posture and freezing of gait symptoms from the patient's movement activities. The next phase is to alarm an audio cue to break the block of freezing. An accelerometer based sensor network is designed to sense the movement information. The recorded data are transferred to the smartphone, which served as the core calculator unit, by Bluetooth communication protocol. The input signals are recognized and classified into the target symptoms. The main advantages of this proposed approach includes: (1) the safety: to detect the stooped posture and freezing of gait and to produce audio cue to help the patients to break the block; (2) the portability: not limited at specific locations; and (3) the expendability: easy to update or upgrade by using app install online.

1 INTRODUCTION

Parkinson's disease (PD) is a chronic, progressive neurodegenerative disease, usually occurs in the elderly population. The average age of onset is approximately 60 years old (Bloem, et al, 2004). Clinical symptoms of Parkinson's disease include tremor, rigidity, akinesia, bradykinesia, postural instability, gait blocking, etc. (Voss, et al., 2012). Parkinson's patients exhibit mainly autonomous action problems, such as akinesia, be referring to the difficult initial action, and gait block, means action to freeze or stop suddenly (which also called freezing of gait, FOG). According to statistics, with the progress of disease, almost all patients with Parkinson's disease are being impact by FOG (Giladi and Balash, 2005). As studied by (Bloem, et al, 2004), blocking gait and postural instability are the main reasons for caused fall by Parkinson's disease patients. The proportion of patients with Parkinson's disease had a fall of about 38% to 68% (Balash, et al, 2005) (Hiorth, et al., 2013). Therefore, the falls are such an important risk of Parkinson's disease patient groups. So how to avoid patient falls is a very important research issue. Currently in the field of prevention of falls mostly based health education, changing the factors will cause the fall in life-environment of ways to promote (Sherrington, et al., 2008) (Doughty, 2000) (Duncan, et al., 2012), have less of information technology (IT) aspects participated. Most of IT-based approaches are focus on fall detection while fall event happened. This result is reasonable because of there are too complex situations to made the fall unpredictable. It is difficult to recognize all prognostic fall situations. In order to make the fall prevention feasible, we focus on two most important situations to be monitored, that are gait of freezing and from sit to stand and walk (short as sit-stand-walk). On the other hand, according to the clinical studies of (Mak and Hui-Chan, 2004) (McIntoch, et al., 1997) (Powell et al., 2010), when Parkinson's disease patients in gait of freezing, can give visual or auditory stimuli so as to help the patient break the freezing status.

As mentioned above, the objective of this research is to develop a fall prevention system for

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Parkinson's disease patients. There are two phases in the fall prevention. The first phase is to detect patients with gait freezing and posture instability caused by sitting to standing posture forward bending. The second phase is using voice instructions (audio cue) to get patient attention for breaking the freezing gait. In this system, an accelerometer-based module is used to detect the patterns of sit-stand-walk and gait of freezing, and communicated with the smart phone by blue-tooth. The prognostic fall patterns are recognized by Derivative Dynamic Time Warping (DDEW)(Keogh and Pazzani, 2001) algorithm, and trigger an audio cue (sound as tick-tack) to break the freezing.

2 RELATED WORK

Bloem et al. (Bloem, et al., 2004) resulting the postural instability and gait impairment are the most common posture problems in a fall survey. Postural instability generally refers to the process of unstable posture. Especially, stooped posture and from sit to stand and begin to walk are the most prone to fall; on the other hand, in respect of gait impairment, freeing the gait is the most directly relevant with falls. Parkinson Disease Foundation made a similar recommends to patients with Parkinson's disease when changing from a sitting position to stand up and move forward should pay special attention to avoid out of balance and fall. Freezing of gait is particularly likely to occur in the beginning from sit to stand and to walk.

Morris et al. (Morris et al., 1996) found that using a metronome or a fixed beat music as the auditory stimulation on gait parameters in patients with PD has overall improvement. For examples, in gait frequency and stride length increased by 10% to 20%, further walking speed is increased to 35% to 40%. Mak et al. (Mak and Hui-Chan, 2004) prove that such feed-forward signals improving the PD patients impaired nervous system stimulation with enhanced effect.

In typically, there are four sensor-based methods to detect the early of freezing and the onset of freezing. The first method is to use a video camera to do image analysis (Chen et al., 2011) (Hubble et al., 1993) (Lozano, et al., 1995). This approach analysis the body posture of the patient, leg bending amplitude, and the pace length. The second method is to measure the lower extremity muscle strength (Bovi et al., 2011) (Nieuwboer, et al., 2004). This approach uses EMG Chart to analysis lower limb muscles condition of the patient. The third method is to measure foot pressure, using special trail of sensing foot trampling pressure (Leddy, et al., 2011). This approach allows patients to walk on the trail, and execute gait analysis based on the pressure distribution. Hardware devices and equipment required for the above-mentioned three methods have a certain volume and cannot be moved, and thus limiting the range of motion of subjects and testing time. The fourth method is to use wireless sensor (three-axis accelerometer, gyroscope) worn on patients in different locations (Sant'Anna, et al., 2011) (Bächlin, et al., 2010) (Godfrey et al., 2011) (Lee et al., 2010). The collected data is transmitted to the computing unit processing. This method is relatively unrestricted in the practice, because the hardware device is lightweight and easy to wear off.

With MEMS technology matures, wireless sensors including accelerometers, gyroscopes, instruments, has been widely used in research of body movement detection, gait analysis. Sensor measurement accuracy often depends on the location and number of worn, configure the location more, larger sensor number is used, its data will be more and more accurate. However, the effectiveness and cost considerations in the central processor, the number of sensors must be maintained at a certain amount and the most critical position. Participants usually placed the triaxial-accelerometer sensors around the right and left thigh and wrist, and/or placed triaxial-accelerometers and gyroscopes at waist and chest.

3 MATERIAL

The purpose of this research is to detect the imbalanced posture and gait freezing occurs as early as possible for Parkinson's patients, and then use audio cues to break the freezing to achieve the goal of prevention of falls. Although fall is a very complex behaviour, it is difficult to define all possible situations. Not all causes of falling can clearly identify their model (patterns), but if the results of this research can reduce the risk of falls in patients with Parkinson's, patients, it can have an important contribution to patients, their families and society.

Figure 1shows the proposed system architecture. The patient's activity acceleration data are collected by the sensor which communicated with smartphone by Bluetooth. The smartphone is used to collect part of activity data but also play the main processing work to recognize the freezing pattern and trigger an alarm.

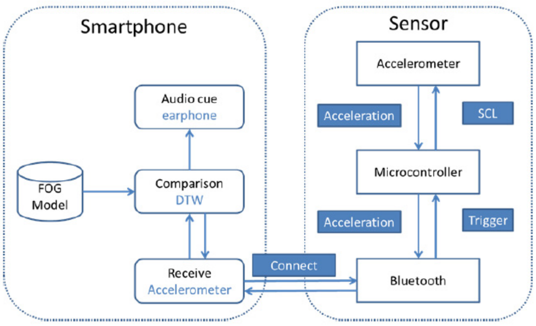

Figure 1: The proposed system architecture.

3.1 Gait Analysis

In this experiment, a gait unit is defined as a gait cycle which contains space and time parameters. In a normal gait cycle is started from a referenced supporting heel touching the ground, and terminated by the same referenced heel touches the ground again. In some abnormal gait, the heel may not be the first part of the foot touches the ground. Therefore, this type of gait cycle should be considered to refer to some part of the foot touches the ground start, until the same part again touching the ground for termination.

Gait cycle can be divided into two phases, the stance phase and the swing phase. In normal gait, the stance phase accounts for the 60% of entire gait cycle, which is defined as a referenced limb foot ground contact period. On the other hands, swing phase accounts for the 40% in the gait cycle, which is defined as the referenced limb foot without touching the ground during this time. For example, when the right (left) leg is in the stance phase, the left (right) leg will be in the swing phase. Therefore, a gait cycle includes right and left of the stage. A single swing phase of gait cycle includes the right side and the left side.

The double support time refers the time of the body weight is transferred from one foot to another foot, i.e. both left and right foot during ground contact simultaneously in one gait cycle. These variables can be used to measure a gait cycle: the time of standing (right and left), the time of leaving the ground (right and left), the time of double support, and the whole gait time.

3.2 Accelerometer-based Sensor

An accelerometer-based sensor was designed to capture body acceleration data. The sensor comprises the following components: (1) a LIS3LV02DQ triaxial-acceleration sensing unit, (2) a MSP430F169 microcontroller processing unit, (3) a BTM-112 Bluetooth module wireless transmission unit, and (4) a lightweight rechargeable lithium battery as the power supply unit. The sensor dimensions are 40 mm * 28 mm * 18 mm (see Figure 2). The sampling frequency was set as 32 Hz.

Figure 2: The accelerometer-based sensor.

3.3 Placement of Sensors and Smartphone

The accelerometer-based sensors are placed on the left and right ankle (as the Figure 3 shown), and smartphone is placed on the waist (as the Figure 4 shown).

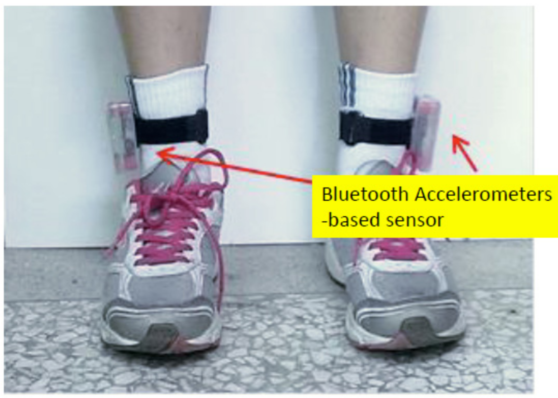

Figure 3: The accelerometer-based sensors are placed on the left and right ankle.

Figure 5 shows a sample acceleration data of a patient from sit to stand and walk which captured by the smartphone (HTC Desire A8181, Android-based smartphone).

Figure 6 shows part of the 3-axis acceleration data of freezing of gait from ((Bächlin, et al., 2010).

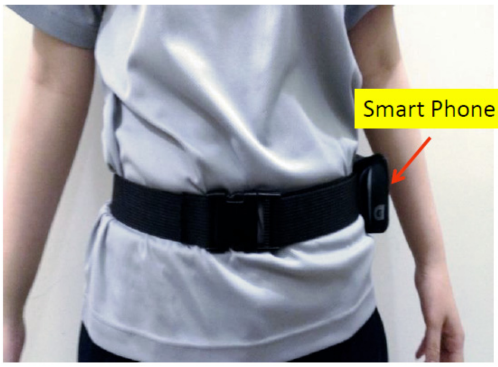

Figure 4: The smartphone is placed on the waist.

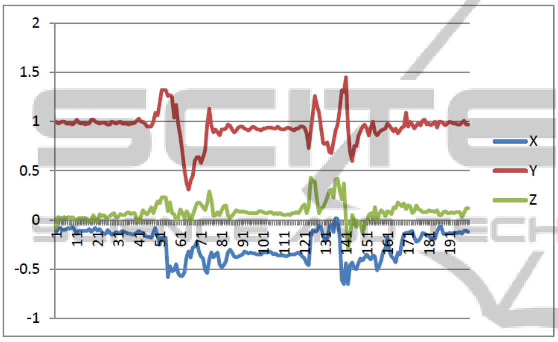

Figure 5: An acceleration data of sit-stand-walk activity captured from the smartphone.

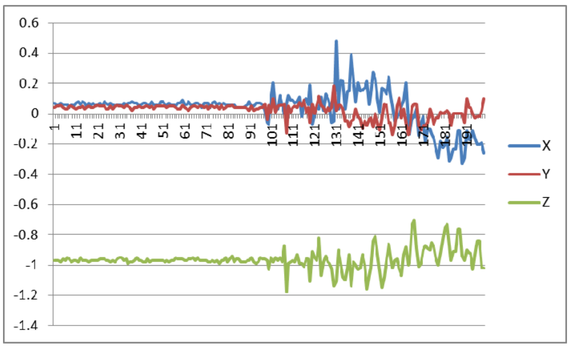

Figure 6: Part of tri-axis acceleration data of freezing of gait.

3.4 System Flow

The smartphone plays the fall prevention decision centre, which receives the tri-axial acceleration data from ankle sensors and smartphone built-in accelerometer. Figure 7 presents the system flow of fall prevention process.

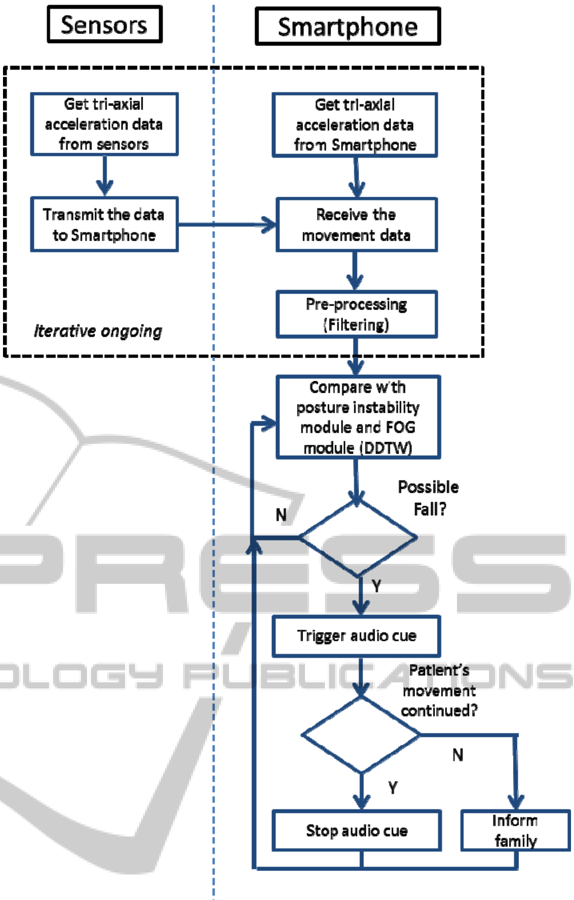

Figure 7: The system flow.

There are four phases in the proposed approach. First, the captured three-axis acceleration sensor data from the ankle transmitted via wireless Bluetooth to smartphone, and integrated with the acceleration data captured by the waist smartphone built-in accelerometer. In the next phase, according to the triaxial accelerometer signals probably mixed some noise. Therefore, a nonlinear median signal filter is used to filter noise. As a sliding window by capturing the odd samples, select the sort to replace the original value in the middle of the sample values. The filtering effect is related with the window size used. In preliminary analysis of this study, window size is set as 7.

In the third phase, the derivative DTW algorithm (DDTW) is adapted as the primary algorithm for determining the fall auspice. The DDTW is extended from classical DTW. DTW is a conventional method of alignment similarity of two time series, commonly used in speech recognition and action recognition. Since the length ratio of the two time series may be inconsistent, the use of Euclidean distance cannot correctly calculate the distance between the two sequences (and similarity). As such, DTW algorithm calculates the sequence similarity by extending or shortening the sequence length. For this purpose, the timeline sequence will exhibit the phenomenon of non-linear and warp, so that corresponding points of two sequences hold time consistency. That is, the best warp-path can be defined. However, the traditional DTW algorithm sometimes has misalignment results. When multiple points on a time series to the same single point, called singularities, or the two time series have large difference on Y axis are likely to make mistakes. Therefore, DDTW proposed amendment for modified X-axis before the Distance matrix calculated.

The main reason of using DDTW is to consider each gait in patients with symptoms of the freeze of its time series may not be the same, reliable assessment can be obtained through the DDTW algorithm. The captured three-axis acceleration serial signals are comparing with the postural instability and freezing of gait reference model established from the DDTW analysis. The three-axis acceleration data of postural instability and freezing of gait reference model is constructed from three sources: (1) Parkinson's patient gait freezing acceleration data set, built by the University of California (Bach and Lichman, 2011)(Bächlin, et al.,2010); (2) simulation data of posture and gait in patients with Parkinson's symptoms of the freeze by healthy subjects took the proposed accelerometer and smartphone; and (3) real acceleration data of posture and gait from 3-5 real Parkinson's patient.

The final phase is to trigger an audio cue using the build-in speaker in smartphone. The cue will terminate if the subject can move continued (i.e., return to normal gaits) after audio cue 10 seconds, or otherwise, the smartphone will contact the family or others.

3.5 Experiments

The experiment is currently in progressing, which approved by Research Ethic Committee of Hualien Tzu-Chi Hospital, Taiwan (IRB103-67-B).

Sample data category is expected to include the following categories: from sit to stand and walk stooped posture, FOG episodes precursor and FOG episodes (includes gait cycle disorder, such as split step, walking speed decreases, stop walking, etc.), and normal stop.

The evaluation of the proposed system will include the following three parts:

(1). evaluate the recognition rate: it is mainly to test the accuracy of identification of FOG and sit-stand-walk patterns, including the correct and incorrect classification.

(2). evaluate the audio cue issued latency: although there is no formal clinical empirical time analysis of fall events in the end occurs after the gait freeze happen. But the sooner the issue is better audio cue.

(3). verify that the overall accuracy of the system functionality, including follow audio cue termination, notify relatives and other functional requirements.

More detailed discussion will be given after the experiments completed.

4 CONCLUSIONS

The main objective of this research is to develop a fall prevention system for Parkinson's disease patients. There are two phases in the fall prevention protocol. The first phase is to detect and recognize the stooped posture and freezing of gait symptoms from the patient's movement activities. The next phase is to alarm an audio cue to break the block of freezing. An accelerometer based sensor network is designed to sense the movement information. The recorded data are transferred to the smartphone, which served as the core calculator unit, by Bluetooth communication protocol. The input signals are recognized and classified into the target symptoms. The main advantages of this proposed approach includes: (1) the safety: to detect the stooped posture and freezing of gait and to produce audio cue to help the patients to break the block; (2) the portability: not limited at specific locations; and (3) the expendability: easy to update or upgrade by using app install online.

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REFERENCES

Amboni, M., Barone, P., Iuppariello, L., et al, 2012. Gait Patterns in Parkinsonian Patients With or Without

Mild Cognitive Impairment, *Movement Disorders*, 27(12), pp.1536-1543.

Sant'Anna, A., Salarian, A., and Wickstrom, N., 2011. A New Measure of Movement Symmetry in Early Parkinson's Disease Patients Using Symbolic Processing of Inertial Sensor Data, *IEEE Transactions on Biomedical Engineering*, 58(7), JULY, pp.2127-2135.

Bache, K. and Lichman, M., 2013. UCI Machine Learning Repository [http://archive.ics.uci.edu/ml]. Irvine, CA: University of California, School of Information and Computer Science.

Bächlin, M., Plotnik, M., Roggen, D., Maidan, I., Hausdorff, J. M., Giladi, N. and Tröster G., 2010. Wearable Assistant for Parkinson's Disease Patients with the Freezing of Gait Symptom, *IEEE Transactions on Information Technology in Biomedicine*, 14(2), pp 436-446.

Balash, Y. et al. 2005. Falls in outpatients with Parkinson's disease. *Journal of Neurology* Vol.252, pp.1310-1315.

Bloem, B. R., Hausdorff, J. M., Visser, J. E., and Giladi, N. 2004. Falls and freezing of gait in Parkinson's disease: a review of two interconnected, episodic phenomena, *Movement Disorders* 19(8), August, pp.871–884.

Bovi, G., Rabuffetti, M., Mazzoleni, P., and Ferrarin,M. 2011. A multiple-task gait analysis approach: Kinematic, kinetic and EMG reference data for healthy young and adult subjects, *Gait & Posture* Vol.33, pp. 6–13.

Chen, S. W., Lin, S. H. Liao, L. D. et al., 2011. Quantification and recognition of parkinsonian gait from monocular video imaging using kernel based principal component analysis, *BioMedical Engineering OnLine*, 10:99.

Dibble L. E., Christensen J., Ballard D. J. and Foreman K. B., Diagnosis of Fall Risk in Parkinson Disease: An Analysis of Individual and Collective Clinical Balance Test Interpretation, PHYS THER. Vol.88, 2008, pp.323-332.

Doughty K., 2000. Fall prevention and management strategies based on intelligent detection, monitoring and assessment. Presented at New Technologies in Medicine for the Elderly, Charing Cross Hospital, 30th, Nov.

Duncan, R. P. Leddy A. L., Cavanaugh J. T., Dibble L. E., Ellis T. D., Ford M. P., Foreman K. B., and Earhart G.M., 2012. Accuracy of Fall Prediction in Parkinson Disease: Six-Month and 12-Month Prospective Analyses. Parkinson's Disease. Article ID 237673, doi:10.1155/2012/237673.

Giladi, N. and Balash, Y., 2005. "Treatment of Parkinsonian gait disturbances." Evaluation and management of gait disorders. Marcel Dekker Inc., pp. 273-83.

Godfrey A., Bourke, A. K., Olaighin, G. M., van de Vend, P., Nelsond, J., 2011. Activity classification using a single chest mounted tri-axial accelerometer, Medical Engineering & Physics Vol.33, pp. 1127– 1135.

Hiorth, Y. H., Lode, K. and Larsen, J. P., 2013. Frequencies of falls and associated features at different stages of Parkinson's disease. European Journal of Neurology Vol.20, pp.160–166.

Keogh, Eamonn J., and Michael J. Pazzani. "Derivative Dynamic Time Warping." SDM. Vol. 1. 2001.

Leddy, A. L., Crowner, B. E. and Earhart, G. M., 2011. Functional Gait Assessment and Balance Evaluation System Test: Reliability, Validity, Sensitivity, and Specificity for Identifying Individuals With Parkinson Disease Who Fall, Physical Therapy 91(1), January, pp.102-113.

Lee, J. A., Cho, S. H., Lee, Y. J., Yang, H. K., Lee, J. W., 2010. Portable, Portable Activity Monitoring System for Temporal Parameters of Gait Cycles, J Med Syst, Vol.34:959–966.

Mak, M. K. Y., Hui-Chan, C. W. Y., 2004. Audiovisual cues can enhance sit-to-stand in patients with Parkinson's disease, Movement Disorders, 19(9): 1012-1029.

McIntosh, G. C., Brown, S. H., Rice, R. R., Thaut, M. H., 1997. Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease, Journal of Neurology, Neurosurgery, and Psychiatry, Vol. 62:22-26.

Morris, M. E., Iansek, R., Matyas, T. A., Summers, J. J., 1996. Stride length regulation in Parkinson's disease normalization strategies and underlying mechanisms. Brain Vol.119, pp.551–568.

Nieuwboer, A., Dom, R., De Weerdt, W., et al., 2004. Electromyographic profiles of gait prior to onset of freezing episodes in patients with Parkinson's disease, Brain, vol.127, 1650b–1660b.

Powell, W., Stevens, B., Hand, S. and Simmonds, M., 2010. Sounding Better: Fast Audio Cues Increase Walk Speed in Treadmill-Mediated Virtual Rehabilitation Environments, School of Creative Technologies, University of Portsmouth, UK, School of Physical & Occupational Therapy, McGill University, CANADA.

Sherrington, C., Whitney, J. C., Lord, S. R., Herbert, R. D., Cumming, R. G., and Close, J. C. T., 2008. Effective Exercise for the Prevention of Falls: A Systematic Review and Meta-Analysis. Journal of the American Geriatrics Society 56(12): 2234-2243.

Voss, T.S., Elm, J. J., Wielinski, C. L., Aminoff, M. J., Bandyopadhyay, D., Chou, K. L., Sudarsky, L. R., Tilley, B. C., 2012. Fall frequency and risk assessment in early Parkinson's disease, Parkinsonism and Related Disorders 18, pp.837-841.