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Real-Time Gait Analysis Algorithm for Patient Activity Detection to Understand and Respond to the Movements

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ABSTRACT

Context: Most of the patients suffering from any neurological disorder pose ambulatory disturbance at any stage of disease which may result in falling without showing any warning sign and every patient is different from another. So there is a need to develop a mechanism to detect shaky motion.

Objectives: The major objectives are: (i) To check different gait parameters in walking disorders using Shimmer platform(R). (ii) Wearing SHIMMER wireless sensors on hip, waist and chest, to check which one is the most suitable. (iii) To draw effective conclusion/results based on calibrated data in real time and offline processing in EyesWeb/Matlab.To develop an effective mechanism/algorithm for security warning and activating alarm systems.

Methods: Our thesis project is related to analyze real-time gait of the patient suffering from Parkinson's disease for actively responding to the shaky movements. Based on real world data, we have developed a mechanism to monitor a real time gait analysis algorithm to detect any gait deviation. This algorithm is efficient, sensitive to detect miner deviation and not hard coded i.e. user can set Sampling Rate & Threshold values to analyze motion. Researchers can directly use this algorithm in their study without need to implement themselves. It works on pre-calculated threshold values while initial sampling rate is set to 100MHz.

Results: Accelerometers putting on the chest shows high unnecessary acceleration during fall, suggest putting on waist position. Also, if a patient initiates steps with energy, his/her gait may become more stable as shown in the conscious gait. Results show that after DBS surgical procedure, the patient still experiences postural instability with fall. So it is evident to show that such patients may have reduced cognition even after surgery. Another finding is that such patients may lean left or right during turning.

Conclusions: We have presented a real time gait analysis algorithm, capable of detecting the motion of the patient with PD to actively respond to the shakier motion setting threshold values. Our proposed algorithm is easy to implement, reusable and can affectively generate healthcare alarms. Additionally, this system might be used by other researchers without the need to implement by themselves. The proposed method is sensitive to detect fall therefore objectively can be used for fall risk assessment as well .The same algorithm with minor modifications can be used for seizure detection in other disorders mainly epileptic seizers to alert health providers for emergency.

Keywords: Gait Analysis, Parkinson's disease, Wireless Sensors, Fall Risk Assessment, Aging, Wellness and Gait Event Detection.

TABLE OF CONTENTS

Contents

List of Figures

List of Graphs (Plots)

List of Tables

List of Appendices

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Inam-ul-Haq & **M. Adnan Jalil**
Ronneby, September 2012

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Ronneby, September 2012

Aim & Objectives

The Overall goal of this thesis work is to study different gait parameters to detect gait disturbance in the patients with Parkinson's disease, by exploiting wireless sensor technology (i.e. Shimmer) to actively respond to patient's movements through implementation of algorithm.

Objectives

- To check gait related parameters in walking disorders using *Shimmer platform*[(R)]
- Wearing *SHIMMER* wireless sensors on hip, waist and chest to check which one is the most suitable place
- To draw effective conclusion/results in both real time and offline processing in *EyesWeb* and *MATLAB*
- To develop effective mechanism for security warning and activating alarm systems (Algorithm)

1 INTRODUCTION

1.1 Gait

The way how a person walks is called gait. Another good definition can be “a coordinated action of neuromuscular and skeletomuscular systems. Gait disorders resulting in uncontrollable walking patterns may be due to diseases such as Parkinson, Epilepsy, Arthritis, Fracture, Injuries, Collision and many other diseases can cause neurological disorder or motor paralysis. These disorders can be either in one body part or throughout the body without confining to any specific age group.

1.2 Neurological Disorder

Any malfunctioning of neurons in the nervous system is called a Neurological disorder. Over 100 neurological disorders have been discovered throughout the world. In our study, we have chosen one disorder: Parkinson’s disease for falling. Etiology of many disorders is still unknown although a lot of research has been performed. Parkinson’s disease is a neurodegenerative disorder in the central nervous system. Three most common Parkinson symptoms are resting Tremor, Slowness of Movements and Rigidity. A Tremor is one of the [1] most common types of Parkinson’s disorder which can be monitored using inertial sensors. Epilepsy is an electrical storm in the brain producing set of seizures. So only one seizure is not an epileptic seizure rather it is combined effect of many seizures. Almost 1/4th of epileptic disorders cannot be treated using available therapies [2]. The modern advanced world is suffering more with Parkinson’s disease as compared to developing countries.

1.3 Gait Parameters

Experiments can be performed on different gait parameters like body velocity, time ratio, ground slope, stance/swing, body gestures and gait patterns. Sensors can be put on hips, knees, thighs, limbs, neck, head, chest or any other suitable body part to capture motion data for further pre-and post-processing.

1.4 Pre and Post Processing

Preprocessing is real time gait analysis through time and frequency domain to trigger various security steps and messages for patient care. Post-processing is offline analysis of motion data in different tools such as EyesWeb, BioMOBIUS and Matlab for calculations, analysis and plotting of motion to take decisions to formulate a mechanism for patient activity detection and monitoring.

1.5 Area of Study

The area which we choose is pretty interesting, pertaining to rehabilitation, wellness and healthcare for older people. If a research string or query is formulated then following keywords may be helpful using one or combination of more than one. WSN, BAN or WBAN, biosensors, neurological disorders, gait analysis, fall detection, fall avoidance, Parkinson's disease, wireless accelerometer, ambulatory monitoring, freezing of gait, wearable sensors, real time gait analysis, remote data acquisition, health monitoring, monitoring motor fluctuation, gait fluctuation, shaky gait, gait disorder, gait event detection, wearable embedded sensors, movement disorders, neurodegenerative disorders, fall risk assessment, technology for elderly.

1.6 Scope of Study

Wireless Sensor Network (WSN) technologies, has become business of billions of dollars ($25 Billion in 2012) for healthcare services for indoor patients, monitoring chronic disease and elderly persons. Few in such applications are wireless ambulatory cardiac & diabetic monitoring systems, and tracking different neurological disorders. These applications are increasing during the past few years for improving daily life health facilities and wellness solutions.

1.7 Problem Statement

Most of the patients suffering from any neurological disorder at their later stages of disease pose ambulatory disturbance. Such patients may even fall without showing any warning sign. Falls are considered one of the major causes of injury, disability, cost and mortality. For above, different gait related parameters need to study. There may need a systematic tool to take measurements as well.

Finally, there is a need to develop a mechanism to detect any gait deviation notifying 3rd party in the form of security alarms.

1.8 Research Questions

So particular research questions may be formulated as:

Q.1: What are / how to use gait parameters for gait analysis?

Q.2: Based on specific parameters how to
a) Formulate effective mechanism to monitor movements?
b) Trigger messages/alarms/button for patient care?

1.9 Evaluation of Gait Analysis

In order to assess & evaluate gait analysis, accurate, reliable & consistent measurement tools need to be utilized. Even slight deviation in data monitoring through measurement tools, is not encouraged to use [3]. Gait disturbance can be measured using 3 axis accelerometers like SHIMMER(R) for real time motion analysis. In the wireless sensor network, SHIMMER platform provides wireless Body Area Network (BAN) to capture motion data. This data can be saved in CSV (Comma Separated Version) file for post processing or a 2 GB MicroSD card can be used to capture data in the SHIMMER accelerometer itself. The use of accelerometer is more suitable due to the fact that we are capturing data from postural instability. One, two or combinations of more accelerometers can be put on different body parts. While SHIMMER Gyroscope may be more suitable for jerky motion for diseases such as epilepsy. Mostly, accelerometers and gyroscopes are used for gait analysis [4].

1.10 Short Description of Study

Defining our research work, this study is carried out on a patient with Parkinson's disease (PD), to study various gait parameters, test wireless accelerometers on different body parts and implementing an algorithm to trigger a security alarm system by setting a threshold value. Criteria for setting threshold value are calculating standard deviation and employed by different researchers like [5].

1.11 Motivation

Actually there is not such a smooth mechanism to monitor human gait. We need to develop such an efficient and adaptive method so that a user can set own sampling rate and thresholds. The main motivation to perform this experimental research work is to detect any gait deviation for the patient with PD. Security alarms can be activated whenever a patient poses shakier gait. Two types of alarms or sirens can be activated in the algorithm, first to activate Warning Alarms when the value from motion data exceeds minimum threshold value and second to activate Emergency Alarms when value from motion data exceeds maximum threshold value.

1.12 Methodology

Our research methodology is experimental in connection with literature review process. RQ 1 is based on finding and exploring the related base papers and pilot experimentations. Research question 2 is totally experimental starting from designing protocol in the form of 4GB Test, flowcharts of Algorithm (offline and real-time), Gait analysis tables 1 & 2. Then, finally implementation is done for real-time in MATLAB. Some detail about the flow of research process is given by the figure 1 below.

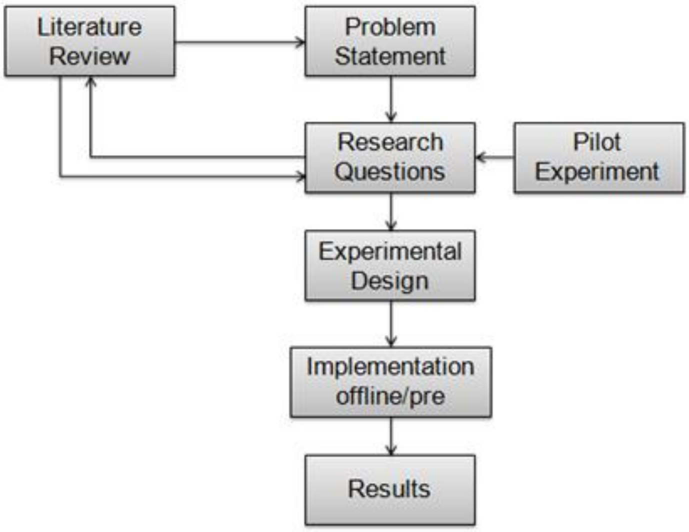

Figure 1 Research Methodology

1.13 Results

As shown in the gait assessment tables 6.2, 6.3 below, results show that the proposed system is fairly simple to use in real time situations, flexible to adjust to any necessary change in the future. In GUI environment, the concept of slider seems fairly suitable to control min/max thresholds for warning and emergency alarms, plotting real time motion and saving file with name. Threshold can be set between 200-300 in test-retest process.

1.14 Technical Description

Technically wearable wireless sensors provided by the SHIMMER can be put on the different body parts to remotely track the information about the movement of the patient with PD. This information is captured and saved into the PC through a data acquisition system for interpretation and offline processing. Depending on different requirements, real time implementation through algorithm can be performed on real time motion analysis to trigger different healthcare facilities such as emergency alarms, automated SOS calls and messages, nursing or health givers an alertness etc. The schema of our acquisition system is presented through the following figure.

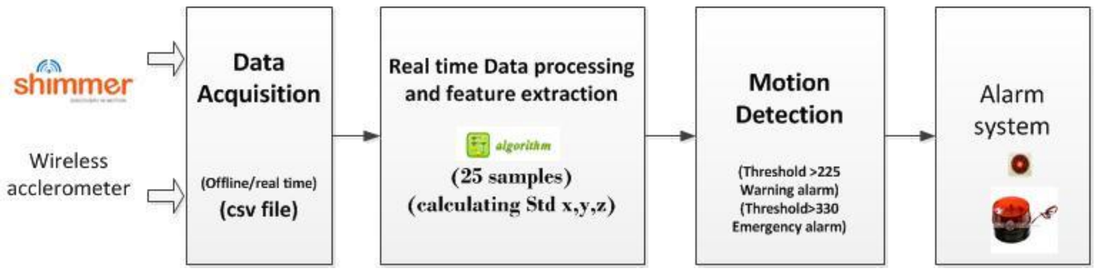

Figure 2 Data Acquisition to Track Motion

1.15 Advantage and Future Prospect

The major advantage of this algorithm is its reusability. Algorithm is not hard coded because a user can set his own sampling rate and threshold value and check the results. Specially minimum and maximum threshold values can be set through a GUI slider as shown in the Figure 18. This algorithm is further modifiable to trigger an airbag, a security push button, SOS calls, messages, a siren activation system, automatic email forwarding, health care alert system and many more. The same algorithm with minor modifications can be used for seizure detection in other disorders mainly in epileptic seizers to alert health providers in case of emergency.

1.16 Overall

Overall, this report presents the analysis of the experiment to measure the usability of wireless accelerometer data to monitor patient activity suffering from Parkinson disease. Our research and experimental work can be quoted towards fall risk assessment.

1.17 Organization of Chapters

The rest of the report is organized as: Chapter 1 gives a basic introductory description of the work, Chapter 2 discusses symptoms of PD and Gait Parameters, Chapter 3, 4 deals with software and hardware involved in this experiment, Chapter 5 discusses some existing tools and methods while Chapter 6 discusses our actual experimental environment with a result interpretation.

1.18 Major Achievements

- Real time algorithm implementation
- Detail Description of Gait Parameters
- 4GB Test

1.19 Related Work

A US patent device for monitoring real time deviations in the patients' gait is proposed. This device is useful to wear partially inside the auditory canal equipped with accelerometer and gyroscope. Subsequent current gait features are extracted continuously to compare with accumulated gait statistics to find the deviation in gait patterns. Functioning of this device is based on some important facts. One such fact is that neurological disorders possess unique identifiable characteristics. For example, small shuffling steps can be detected from forward velocity, vertical acceleration and step frequency. These authors also describe that small rapid stepping (Festination) and backward steps can be detectable by signature identifier. Vertical acceleration can be detected through 3-axis accelerometer which should be sensitive to low frequency, low amplitude motion and low energy consumable. They also stress to use a gyroscope in combination with accelerometer for accurate horizontal movement of the individual's head. Above authors suggest to use predefined gait features for an indication that a person is falling or prone to fall. If an individual is about to fall then system is configured to notify a third party and warn individual with postural instability as well [6].

Another related work is done by Toshiyo et al [23] in which a wearable automatic airbag opens when a fall occurs based on acceleration and angular velocity. They incorporate a fall-sensing algorithm in the form of a wearable smart jacket to protect head and hip, when value exceeds to the threshold limit. So this algorithm is proved helpful to avoid fall injuries thus saves lives at construction sites and other locations. The authors have used accelerometers and gyroscope in their studies.

Our proposed method works on some of features mentioned above. Some of these characteristics are as given: Our efficient and sensitive algorithm can be used to detect a small deviation in the gait in all three axis setting threshold values using wireless triaxial accelerometers. Step counts, vertical acceleration to detect fall, notifying a third party & individual itself are features described in our proposed system as well.

Another step detection algorithm for PD is implemented. This method is based on calculating standard deviation as the basic parameter which will be lower in case of shuffling gait. In the post-processing environment, the threshold value is calculated to be 25% of total standard deviation while it is 20% after trying different values in range 20-33% in real-time scenario. In order to track the motion initially for 60 seconds, a concept of rotating windows is used to make the calculation light. This rotating window uses array to hold 100 values to take next action and for each specific second 200 new values are received. Thus for each 60 second of the period, 12,000 values are received [5].

Our method is also based on calculating standard deviations at different time periods during each gait in order to set the threshold values in post-processing as shown in tables 6.2 & 6.3. Here, it is observed that a patient may fall during 1/4th of a second, thus algorithm will take every 25 values to take next action as shown in the Appendix F. Sampling rate 100 Hz means 100 sample values in each second. A 3-d array for holding 25 values is declared in the code for this purpose, as shown in Appendix G.

An activity recognition system based on neural networks for mobile phones is presented [31] that recognizes and records motional activities of a person. For this, MotionBand sensors are attached to the smart phone to capture accelerometry data. Among six activities to be detected are running, walking and cycling. The authors suggest that this idea of activity recognition can be applicable to other applications such as harmonizing the music with the activity we are engaged in for example: low music at rest and fast music during running. Another interesting application can be to automatically learn personal habits, such as disturbance can be reduced in the office using the concept of "Polite Calling" in which system redirects phone calls to voice mail showing the person is busy.

THE END OF CHAPTER

2 PARKINSON'S DISEASE

2.1 Introduction

Parkinson's disease is a progressive, incurable, most commonly observed in elderly population above 50. The patients with Parkinson's disease show a reduced, unbalanced and robot-like walking pattern. While other results show that PD patients keep 29% slower velocity and nearly 20% reduced stride length than the Healthy Elders, while all PD [7] subjects show abnormal gait patterns. In Genetic [8]PD, there can be more than ten genes associated with PD. In Sweden, out of 14000 PD patients, 550-700 have inherited background.

Figure 3 Parkinson's disease World Map with Courtesy Wikipedia

Mainly Parkinson's disease can cause an effect on both **motor** and **non-motor** movements. Five most common symptoms related to Motor movements include Tremor, Bradykinesia, Rigidity, Festination and Postural Instability. While in non-motor movements, autonomic malfunction and neuropsychiatric problems are common as shown in the Figure 4. At advanced stages of PD, patients have more slowness and stiffness in walking and reduced muscle movements. As rigidity increases and mobility decreases, patients feel more pains during motion. In normal gait, heel strikes the ground before toe, but in case of Parkinson's disease, flat foot strikes with small stepping during the stance phase and reduced lifting of feet during swing phase.

In general, a patient with PD has an unstable stooped walking pattern, tends to lean right or left during turning, head-down, small-stepping and reducing arm swing.

2.2 Etiology of Parkinson’s disease

The exact cause of the disease is still ***unknown*** or idiopathic, yet there may be some other factors which somewhat can contribute toward the disease. These factors can be genetic, environmental (toxins) or low Dopamine level in the brain. These and some other factors that can constitute toward happening of the motor symptoms of the disease are stated below:

- Abnormal collections of tiny microscopic proteins inside nerve cells of the brain are called ***Lewy bodies***. Researchers believe these bodies to be one of the reasons for causing Parkinson’s disease.
- A patient with PD has impaired neurons in the brain area called substantia nigra. These neurons produce a chemical called Dopamine, and due to its reduced level, it affects smooth communication between muscles for movements. The result is a loss in the ability to control the proper functioning of body movements.

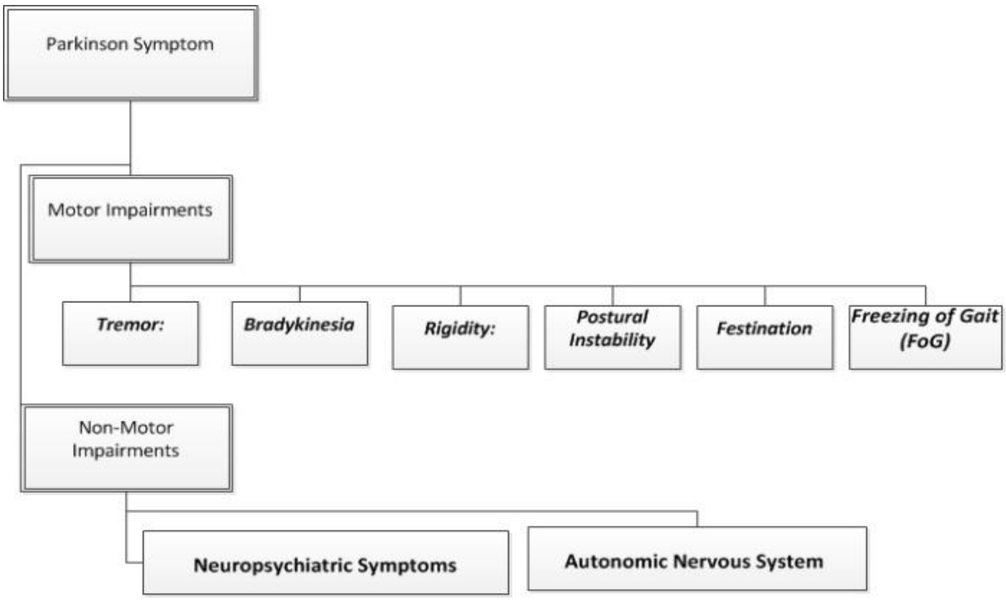

Figure 4 Primary Symptoms in Parkinson’s disease

- Why level of Dopamine is reduced is still ***unknown*** without any doubt.
- PD may be inherited although controversies exist.
- Some evidence shows that certain toxins in the environment such as manganese, carbon monoxide, carbon disulfide and some pesticides/herbicides may cause PD.

- Oxidation is thought to damage neurons.

- Some other drugs can cause symptoms similar to Parkinson's disease.

It is still an open research problem to solve the exact cause of PD. In fact, Dopamine is a chemical in the brain responsible for functioning as neurotransmitter among the neurons. Its reduced level causes different neurological and physiological disorders. Released by nerve cells Dopamine is a transporter of electrical signals from one neuron to another. In the brain, there are five known dopamine receptors D1-D5. Men have 2 times more chances than women for getting the disease.

2.3 Parkinson's Disease Symptoms

2.3.1 Primary Symptoms (Motor Impairments)

Tremor

The Tremor is 2nd most apparent symptom after [9]Bradykinesia in PD. Resting tremor is also common in which body part continuously shake when at rest. In tremor one or more body parts continuously move round a fixed pattern (3-6Hz, depending upon the severity). Majority studies do not focus to differentiate between action and resting tremor. The Tremor usually [10] starts shaking limbs on either side (3rd out of every four subjects) of the body and spreads all over the body in severe cases affecting jaws, lips, tongue. Severe tremors in legs are the great cause of gait shuffling. (***Details on Appendix D.***

Bradykinesia

Brady means slow and Kinesis means movement is the failure of basal ganglia which affects commands to move, sometimes shuffling or sliding of feet on the ground. Bradykinesia is the most common symptom in PD. Other name for Bradykinesia is ***motion slowness***. Opening & closing of hands can be used to estimate the severity of Bradykinesia. It is the slowness of movements both spontaneous and automatic making simple or routine tasks bit more difficult to perform [11]. In the early stages of Bradykinesia, signs of slow motion may not appear or less prominent. But individual body movements become gradually slower with aging in the disease and muscles start to freeze. ***(Detail on Appendix D)***

Rigidity

Rigidity is muscle ***stiffness***, muscle *inflexibility* or movement inflexibility, muscle tiredness or muscles ache. In fact, Rigidity is the change of tone in muscle movement or a sense of resistance to limb motion. Rigidity may occur in shoulders, hip, neck and can reduce range of motion. All muscles have opposing muscles and during rigidity these opposing muscles relax to pose hindrance to the movements. Even some patients may not find signs of rigidity in the early stages, but can be detected on physical examination. On later stages, it becomes uncontrollable and more reoccurring. ***(Details on Appendix D)***

Postural Instability (PI)

Other name is the ***loss of body balance***. The way of standing is called posture. It is losing of body balance leading to fall. It is the 4^{th} most common symptom in PD and can be examined by a test called "pull-test" for watching the behavior when a patient is pulled backward by the shoulders. PI is the most common symptom of fall. The patients with PD often fall left, right or backward during standing or turning. These patients behave PI even they are on medication, have undergone some surgery, exercising or therapies. It is reduced or nominal loss of maintaining body equilibrium that may become severe at later stage.

Festination

This word has Latin background meaning "***Too Hurry***". Sudden rapid shuffling of small steps or hurrying in walking is called Festination. Opposite to FoG, a motor uncontrollable symptom, Festination may lead to fall. Festination is caused due to hyper tonicity of the muscles. So in this way it is more dangerous as compared to PI and FoG. Festination can be observed in gait, speech and the handwriting etc. Some patients feel disturbance during speaking called Oral Festination. "Festination Gait is clearly associated with longer duration of PD symptoms, not with disease severity as reflected in the motor part of the UPDRS". So a change of gait and [12] physical therapy may help in controlling the conditions of Festination. Other name for Festination is Parkinsonian Gait.

Freezing of Gait (FoG)

Walking inactivity is called freezing of the gait. FoG is one of the most disturbing symptoms of Parkinson's disease. Freezing can also occur during speaking, arm swing or head nodding. Among these, freezing of legs is most distressing and annoying which may result in falling and injury. It is an episodic inability of taking step. It is [13]one of the most disturbing problems in which patients observe "*feet get glued*" [14], frozen or stuck to the ground, stoop forward and likely to fall. Nearly 30% within 5 years and 60% within 10 years experience FoG, more often at later stages. It may happen not only during walking, but also during sit-stand from the chair, getting out for water or taking clothes from laundry. Patients cannot completely avoid freezing but can adopt certain strategies, medications, therapies, nutrition and exercises to help controlling freezing. About 50% patients with advanced PD experience FoG, more in men, 10% in mild PD and 80% in severe PD [14]. ***(Detail on Appendix D)***

2.3.2 Secondary Symptoms (Non-Motor Impairments)

Patient has not control over few symptoms such as impairment of cognition, behavior, voice and brain and these are commonly included in non-motor disorders. Brain disorders include weakness of thoughts and dementia.

Neuropsychiatric Symptoms

It deals with all those symptoms that are related to Neurology and Psychiatry. It involves change in mood, thinking, behavior, reasoning, perception, judgment.

Depression

Depression is one of the main problems faced by almost all the patients. It is estimated that nearly half of patients with PD experience depression due to one or many reasons such as losing hope, lesser interest and little enjoyment in life. Re-occurring of disease after medication with Levodopa is another cause of anxiety.

Mild Cognition Loss

Some patients experience mild cognition loss at early stages, especially it affects the sense of self- planning and management. On later stages, these patient experience a severe condition known as dementia. Other cognition related symptoms in patients with Parkinson's disease include:

- Short period memory loss, forgetting and revising things
- Quick change in emotions such as anger, sadness and excitement
- Hallucinations & Delusion

- One of the earliest signs of PD is losing some or all of sense of smell. Sometimes it can occur many years before disease is diagnosed.

Autonomic Nervous System

It is an automatic nervous system which is not under control of any person. It is the nervous system that controls your autonomic functions such as heart, breathing, muscles, glands & urination etc. Patients with PD may experience some or any of these disorders. Other autonomic problems are constipation, erectile dysfunction in men, reduced sexual interest in women, and low blood pressure with dizziness, becoming fainting, profuse sweating, swallowing disorder and drooling (excessive saliva).

2.4 Treatments

There is not an absolute cure for the patient with PD but treatment through some medication, surgery, therapies and multidisciplinary actions can be given to slow down its progression or may help to control symptoms.

2.4.1 Therapeutics

Most of the medicines are used to treat the patient with PD by increasing Dopamine level in the brain in order to reduce the progression and / or controlling symptoms of the disease.

i. One such famous medicine is **Levodopa** or L-DOPA which is converted into Dopamine to treat the motor symptoms somehow. L-DOPA is extremely useful in Bradykinesia.
ii. **Carbidopa** or Lodosyn is another medicine used for peripheral metabolism of Levodopa and it allows crossing the blood-brain barrier. So Carbidopa is used instead of Benserazide in the US, while both have same function in treating Parkinson's disease. Entacapone has almost the same effects.
iii. Other Dopamine **agonists** include bromocriptine, pergolide, pramipexole, ropinirole, piribedil, cabergoline, apomorphine, bromocriptine and lisuride. Agonist is a medicine chemical that can combine with a receptor on a cell to produce a physiologic response. ***(Detail on Appendix D)***

2.4.2 Surgical Treatment

Surgical treatment is prescribed by physicians when effect of medications is greatly reduced or no effect at all. For treating rigidity there is a surgical method called Pallitomy. It is also to note that Thalamotomy is used for treating the symptoms of tremor. There is another surgical technique with the name Deep Brain Stimulation, which will also be discussed later on down in the report in chapter 6.

Deep Brain Stimulation: During this surgery, special electrodes are inserted into the targeted place in the brain. This complex surgical procedure is performed using MRI and neurophysiologic to make sure that electrodes are implanted in the right place. After that a special device called an impulse generator is used in order to provide electrical impulse to the part of the brain involved in motor function. A controller to ON / OFF and battery with timing 3-5 years are provided with the device. ***(Detail on Appendix D)***

2.4.3 Therapies

Speech Therapy

In order to improve speech and voice impairment, LSVT (Lee Silverman Voice Treatment) is most commonly and widely used speech therapy. This therapy is also proved good for improvement in facial expression, swallowing and talking.

Neuroprotective Therapy

Based on the theory that 300-400 thousands dopaminergic neurons can be protected somehow from early death using some potential Neuroprotective agents if identified in time. Research is being carried out to get better suitable results.

Gene Therapy

Recent clinical successes have opened chances to replace or correct infected / mutated genes in different diseases including PD for a cure. Another good option is Fetal cell transplantation.

There are some other therapies such as speech therapy, occupational therapy that are also helpful for independence, mobility and improved motor symptoms.

2.4.4 Diet & Nutrition

i. Parkinson's disease can have negative impact on digestive track due to the reduced strength of associated muscles. Gastroparesis is one such symptom in which food stays in the stomach for more than two hours. So a light, balanced, nutritional, easily digestible, small frequent meals, walk after each meal is recommended to take without causing any stomach disorder. Mediterranean diet can be introduced in the patients with PD.

ii. Excessive and combining two different types of proteins need to be discouraged because it may have negative effects on medicines.
iii. If the patient feels swallowing impairment (dysphagia), changes in eatable are recommended. Levodopa is a type of protein so two types of proteins should not be taken in one meal as it reduces the effect of the drug. So Levodopa is recommended to take 30 minutes before meal.

2.4.5 Lifestyle Modification

Rehabilitation also helps to decrease the progression of the disease. Proper education and awareness provided by different private and public bodies can help to fight with the disease in an effective way. Regular daily exercise to increase flexibility and moveability can be beneficial.

Rehabilitation through life-style modification can enhance the lives of people with Parkinson's disease. Special therapies can also contribute to gain a goal of rehabilitation. Such as physical therapy and occupational therapy can guide people to behave better in daily life. For independent living, certain necessary initiatives and precautionary measures can be adopted such as:

- How to sit / stand on the chair, bending, circling
- How to get out of bed more easily
- How to grip things, books, glass, stationary, mobile etc
- How to be conscious during turning
- What stuff is needed to be removed in the way
- What and how to eat, drink, dress using special utensils such as spoon or fork

Patients with PD are more prone towards falling in the wash rooms. Special devices and facilities can be used such as shower stools, grabbing sticks and wall handles.

2.5 Falling in Older Persons

Falls [11],[15]are considered one of the major causes of injury, disability, cost and mortality. Half of the PD population aging more than 65 has a tendency to fall and nearly 80% patients need hospitalization in this age group. Fall prevention can be achieved to some extent if a patient is analyzed with his gait pattern. Studies show that the reduced walking rate and weak grip are two other contributing factors towards falling. Normally, falling can happen during Festination and Postural Instability. The patients are also likely to fall during freezing in their gait.

Psychologically, these patients are prone to low fall rate and feel fear of falling. Both low fall efficacy and fear of falling are correlated yet have different dimensions. Keeping a diary for fall happening [16] during FoG is another good idea given by Albert et al and this record keeping [13]can be proved helpful for doctors, researchers and therapists.

The patients suffering from osteoporosis are more likely to get their hips fractured after fall, so studies suggest these patients to build strong muscles and bones through exercise; protein enriched nutrition along with medication and undergo fall-risk assessment.

Statistics projects that the population of age group 65+ is growing up to 4.3% during 2050 according to US Bureau of Census even then the cost of falling is estimated $28.2 billion during 2010. Attaining one of the goals of wellness, older people should be avoided from falling through proper in time planning.

2.5.1 Factors Responsible for Falling

Despite Parkinson’s disease, there are some other factors responsible for falling:

1. Weak muscles and bones
2. Week vision
3. Getting aged
4. Environmental factors (hurry, slippery)
5. Drug addiction
6. Back bone diseases,

2.5.2 Fall Detection

Fall could be characterized as a potential change in the horizontal movement of the patient. A phenomenon of unintentionally falling is caused due to different movement disturbances of gait.

Technologically fall detection can be divided into three main categories [17].

Fall Detection Techniques

2.5.2.1.1 Vision based Fall Detection

It includes different types of fix **cameras** which can continuously record the patient's activity. A Vision based fall detection system contains data acquisition system to collect images, implementing different algorithms that can recognize fall patterns and may trigger alarms. An advantage of vision based fall detection technique is the patient has no need to additionally wear anything. However, there are some privacy concerns, and probably difficult to use outdoors. Few of these methods are:

1- A 3D Centroid Position system for fall detection with the detection of inactivity [18].

2- An Automatic Detection of human fall in video [19].

2.5.2.1.2 Environmental

This approach is based on the installation of devices such as sensors in a certain area that monitor the patient's activity. Such environmental approach has some benefits such as patient do not need to wear anything. However, that approach may confine to limited range and difficult to use in outdoors. Few of these methods are:

(i) A Floor Vibration-based Fall Detector [20].

(ii) A Slip-fall Detection System, using the sliding linear investigative platform [21].

2.5.2.1.3 Wearable

These devices usually contain motion detectors called **sensors** such as gyroscopes and accelerometers. One such platform is provided by SHIMMER technologies. Using such systems, sensors can transmit data to the Data Acquisition System, apply different fall detection algorithms and then may trigger alarm. Wearable approach has some advantages such as it can be used both in indoor and outdoor, easy installation, smaller and light weight. Few of these method methods are:

(i) An Integrated Approach of Waist-mounted Accelerometry [22].

(ii) A Wearable Airbag to Prevent Fall Injuries [23].

Which technique is better?

Well, it is observed that the third fall detection technique seems better than other two because it has more advantages such as light weight, smaller, compact, can record motion even for days, data acquisition in CSV files, enable any functionality like Gyroscope, Magnetometer etc with daughter board.

2.5.3 Fall Avoidance

Implementation of proper and timely intervention to decrease the fall risk is highly important and desirable. Following are some [24] of important fall avoidance / prevention techniques:

Fall Avoidance Techniques

Technology advancement in the field of electrical instrument has resulted in different reliable techniques to prevent fall. Some of the fall prevention techniques are given below:

(I) Intelligent Shoe System is designed to prevent slip during the walk using an enlarged sole area up to 7 cm comprising a parallel link with a servo motor. The degree of sole area changes with a real time analysis taken from the data acquisition system [24].

(II) Foot-Mat installed on the floor can be easily [25] applied at home. In foot mat, there is a triaxial accelerometer that measures low-high frequency and vibration in three dimensional, and a sensor that acts as a sensing resistor in the electrical circuit. Another advantage of using foot mat is that it has data acquisition system.

2.6 Gait Parameters

As this thesis project is directly related to Fall Detection, so FoG, fall risk assessment, postural instability and trembling of legs can also be included based on interested features to extract from. Generally different parameters or features related to gait have been described such as body velocity, time ratio, stride time and length, swing/stance phases, maximum acceleration at toe-off etc. Different researchers try to include or exclude different gait parameters depending upon their own specific requirements. However, the [26] article describes different combinations of gait parameters in its own style under the category of Gait Data.

Here, we try to present different gait parameters dividing into various categories. Some of these are listed below:

2.6.1 Step related Parameters

All parameters related to feet such as step length and time, frequency, maximum acceleration at toe-off or heel strike, an ankle swing rate and steps / unit time. A Sliding window method is [27] generally used to periodically measure gait parameters in the real-time environment. An algorithm based on Double Pendulum is employed to measure stride [28] length during walking.

2.6.2 Limbs related Parameters

Upper and lower limbs, thigh, shank, finger, hand, wrist mostly to detect and analyze tremors.

2.6.3 Body related Parameters

Sensing devices can be worn on different body areas to capture motion data. Some of these body areas are different positions on hip, belly, bellybutton, chest, trunk, waist and sternum. Higher acceleration has shown when wireless accelerometers are put on Chest as compared to using accelerometers on Hip or Waist during Freezing of Gait and falling.

Our subject was wearing a small wireless tri-axial accelerometer in her either sides of the waist as shown in the Figure 5.

Reason for choosing waist position is just in order to avoid tracking unnecessary motion data. In particular, accelerometers and gyroscopes are used for gait analysis [4].

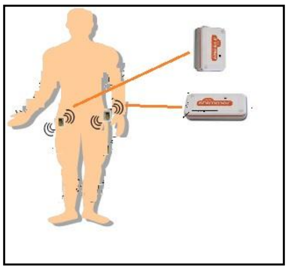

Figure 5 Gait Analysis

2.6.4 Constant Parameters

Some parameters are not directly related to gait and cannot be changed. Rather, these are to be kept under observation. These parameters include number of total participants (N), BMI, age, disease age, sex, the height, body physique, gait regularity, medicated, undergone surgery, therapy, disease condition (normal, moderate or severe) and the number of subjects. Other closely related disorders are also noted such as backbone disk slip, mentally retarded and similar. The detail description is given in the 4GB Test at the end of the report.

Our subject is 70 year old a healthy lady recently undergone medical surgery, reduced gait, small steps, no or minimum tremor.

2.6.5 Assumed Parameters

It is also assumed that no other impairments or disorders are present. These parameters are impairment during hearing, vision, cognition, memory loss, hallucinations, non-alcoholic and non-addicted and can be kept under exclusion criteria.

2.6.6 Special Parameters

There could be put some activity or induced patient to perform task such as to walk over a straight line, U-shaped, L-shaped, Sit-Stand, Stand-Go in the shape of different tests such as TUG (time up & go) test, 4GB (4 meter Go&Back), slow or fast gait and different scales such as ADL, holding something during walking etc can be used. Healthy subjects can also be included for comparison called control subjects. In our experiment, we encourage subject to walk 4-meters go and return fashion. We also observed that our subject poses shakier gait when holding glasses in both hands and she leans left or right during turning.

2.6.7 Universal Gait Parameters

Include body velocity, time ratio, distance range, session or repetition of gait if necessary and video recordings. We recorded all gait session with a high quality mobile for validation.

2.6.8 Features Extraction

Interested features from different gaits are extracted for further pre or post-processing for analysis. For example, in our experiments, we are more interested to extract the high acceleration features during the walk and capture more acceleration when the patient behaves above threshold value such as during turning, patient leans towards right or left. Analysis shows that patient with PD observes significantly longer turning duration [7].

Various methods and techniques are used for feature extraction. Some of them are Principle Component Analysis, high or low pass band filters, pattern recognition in Machine Learning and others.
Here we are giving some details about the purpose of using such techniques

2.6.9 Techniques Used for Feature Extraction

Time-Frequency Analysis technique is used for FOG detection, can be difficult to detect when the patient performs feet sliding gait [29]. Other techniques and methods are:

- MiMed-Pants algorithm [30]
- Online FOG Detection Algorithm based on Moore’s low latency principle [14]
- Berg Balance Score and TUG [15].

Names of related techniques for Fall Avoidance are described in section 2.5.3

END OF CHAPTER

2.7 Findings:

It is not necessary that every patient with PD possesses the same symptoms at different severity levels. But falling patterns somehow can be same either forward, side, backward. Symptoms of tremor or Bradykinesia may progress faster than rigidity. Also that every patient has a unique set of symptoms and this may trigger some researchers to work on FOG for fall detection or fall risk assessment. It is also to be noted that patients with PD lose their balance control and are more likely to fall.

During experimentation and measurement, it is also observed that falling might be more likely to happen during turning. Also wearing accelerometers on the chest gives unnecessary noise data as compared to waist or hip. As citizens at age 70+ are likely get ill soon or fall, so naturally there is a need to work on this group of people for their well-being. Detail description for Gait Parameters is introduced the first time in such way.

There does not exist an exact technical device to detection FoG [30]. Treating FoG can be done by involving brain to perform multiple actions such as singing, marching, ordering like get-set-go, etc. This deceiving therapy to the brain helps somehow for patients to unfreeze.

The loss of balance or postural instability cannot be treated with medicine. Problem with DBS is that it cannot decrease the progression of the disease. Other side effects may be brain bleeding, cognition decline, strokes, infection and minor symptoms of disease may last. However, it can relieve some symptoms and enhance wellness up to five years after surgery. Gastroparesis is one such symptom in which food stays in the stomach for more than two hours. Mediterranean diet can be introduced in the patients with PD.

3 HARDWARE

Wireless sensors such as accelerometers are used in this thesis project for providing sensing solutions to track motion data. As our thesis project is related to the area of the wireless sensor network and body area network, so brief description for these terms is given below.

Wireless Sensor Network: WSN is a low-cost, low-power; a scalable network of nodes that consists of spatially distributed sensors used to monitor physical conditions such as temperature, pressure, distance, etc. WSN has the ability to pass data to a central server or data acquisition system which can be further analyzed to take necessary measures.

Body Area Network: BAN is a group of tiny sensors wearable by an individual with some central unit to regulate communication. A wireless BAN uses PAN for scalability and the vital applications include logging information about cardiology, diabetes, neurological disorders, etc.

3.1 SHIMMER Platform

SHIMMER stands for Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability. Ireland based SHIMMER may help [40] researchers to use a core IT technology to create medical applications and devices for the full range of kinematic modules such as 3-axis Accelerometer, 6-axis (Accel/Gyro) and 9-degrees (Accel/Gyro/Magnetometer) for freedom of motion. It also includes wide range of sensing boards/devices such as ECG, GSR, Magnetometer, Stain Gauge, EMG, Heart Rate, etc. Some of important applications of using SHIMMER is given below:

- Motion tracking and streaming of biomechanical data
- Gestural computing and human-computer interface research

Figure 6 Shimmer XYZ

- Sport technique analysis and athlete development
- Rehabilitation assessment
- Motor disorder monitoring
- Gait analysis
- Navigation and tracking of objects or people

- Red light indication when going out of range is a unique feature.

NAME	PURPOSE	SPECIFICATION	PHOTO	APPLICATIONS
Accelerometer	Capture acceleration (xyz)	• 3-axis vibration, MSP430 microcontroller • 1.5- 6g sensitivity, Baseboard, 3 colors LEDs, reset button • 8Mhz, 10KB RAM, 48KB Flash, 2GB MicroSD • Can record .... • 802.15.4 Radio, Roving Networks RN-42 • Size: 53*32*15mm, weight: 22g, Sleep mode, • Battery life		• Realtime Data collection, storage and display • Measures tri-axial acceleration • Supports gyro, magneto, ECG, GSR etc. • Good for medical sensing applications
Gyroscope	Capture gyro data (xyz)	• Tri-axial angular sensing, Range = +/- 500 (°/sec) • Perpendicular z-axis, Daughter-board, reset button		• Complex motion tracking of biomechanical data
Magnetometer	Magnetic sensing (xyz)	• 3-axis digital compass IC for sensing slow motion • Gain = 390-1620 counts/milligauss, 15g, pinhole reset • 15 times less power as compared to gyro, Daughter-board		• Tracking objects, biomechanics, rehabilitation, sports training, healthcare
ECG	Electrical activity of heart	• 3-leads ECG/EKG digital signals, Daughter-board, 28g • Frequency range = .05Hz – 159Hz • Low offset precision amplification • Realtime Data collection, storage and display		• Collect and display electrical signal of heart
Stain Gauge	Stress measurement	• 28g, low/high gain output, Fall Risk Assessment • Frequency range: 1KHz, Excitation voltage: 2.8V ±5 • Connections: 3.5mm jack, daughter-board		• Pressure measurement, muscular-skeletal & sport research
EMG	Electrical activity of muscles	• Daughter-board, 28g, current: 180uA, Gain: 682 Frequency range: 5-482Hz		• Measures electrical activity of muscles, nerves, fatigue, tremor & Ergonomics
GSR	Stress Measurement	• Daughter-board, 28gFrequency range: DC-15.9Hz • Frequency range: 15.9Hz, Current: 60uA • Measurement range: 10K-470M Ω		• Stress Detection & Analysis
9DoF	Comprehensive Kinetic sensing solutions	• 9 Degree of Freedom daughter-board, 0.5-50Hz output, • Sensitivity: 2 (mV/°/sec) • Magneto range: 500, 25g, pinhole reset, • Gyro field range: 0.7-4.5Gauss, 390-1620 counts/mGa		• Provides gyro+magneto sensing, rehabilitation, object tracking, sports training,
GPS	Accurate time / location measurement	• Embedded GPS receiver, daughter-board • Pressure Range: 300-1100hPa, Temp Range: 0-65+/- 2° • Timing accuracy: <100ns, Position accuracy: <3m		• Environment/maritime sensing, tracking objects & people • Measures accurate location & time

Table 1 Description of SHIMMER Devices

3.1.1 SHIMMER Base-board

SHIMMER can be used as baseboard and can measure 3-axis acceleration independently. While all other circuit boards can be connected as daughter boards.

MSP430 Microcontroller: This main board has MSP430 Microcontroller which works as CPU and main parameters such as 8MHz, 10KB RAM, 48KB Flash memory for programming and debugging, an 8-channels integrated ADC / DAC analog signal to capture motion, 16-bit registers, 3-light emitting diodes, integrated Bluetooth radio module and a slot to hold 2GB MicroSD card. The main board is light weight 22g, compact 53*32*25 and highly configurable as shown in the Table3.1. It works on low level layers (Physical & MAC) and low-rate PAN standards on low power Bluetooth Roving Network (RN-42) at 3Mbps and up to 20 meters. Timestamps can be given to the signals due to the embedded clock in the Microcontroller. This clock is highly configurable to use an extremely low battery.

MMA7361 Accelerometer: The main board also contains Accelerometer MMA7361 with important features such as 3*5*1mm, current consumption 400uA, sleep mode 3uA, scalable sensitivity y (±1.5g, ±6g).

Important applications for Accelerometer MMA7361 are 3D Gaming, HD MP3, Pedometer & Robotics as motion sensing, Freefall detection through PC & Laptop.

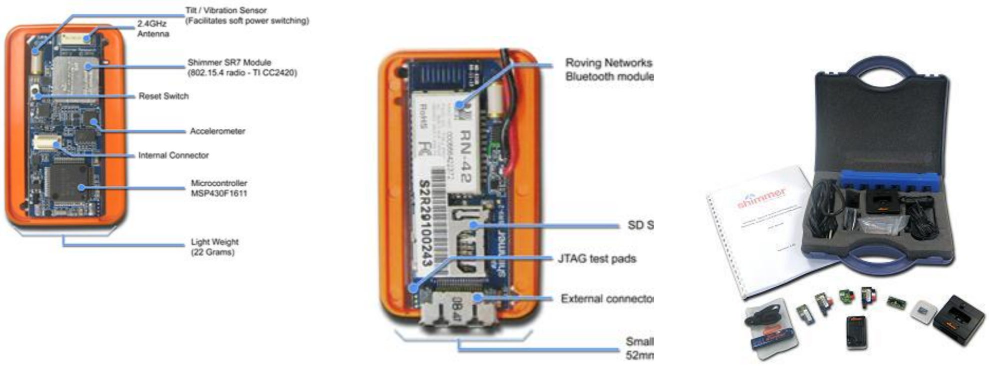

Figure 7 Internal Circuitry Parts of SHIMMER Accelerometer and Package Box

3.1.2 Daughter-board

Daughter-boards are relatively smaller circuit boards for 3rd party sensing which can be connected with base-board to function. It includes gyro, magneto, ECG, EMG, GSR and other circuit boards. Details can be read in the table 3.1.

3.1.3 MicroSD Card 2GB

Each base-board comes with a built-in MicroSD flash socket with 2GB card to record data for offline processing. Particularly useful to record data of experimentation for longer than a whole day [5].

3.1.4 Leads (ECG)

Cardio sensing to record electrical impulses of heart muscles are done through ECG leads.

3.1.5 Live USB

You can boot directly from the Live USB with TinyOS already installed on it. Other features and environments such as CYGWIN, TinyOS Source code, developing tools such as [28] BioMOBIUS can also be installed without any network access. Live USB can also be used in a virtual machine using VMware.

3.1.6 USB Dock

A USB cable is needed to connect the SHIMMER with PC through a docking station to program the shimmer. It can also charge the device but take more time. Green LED color shows that device is connected and fully charged while yellow shows not fully charged or during data transfer. This light becomes light-pink when device is being programmed.

3.1.7 6 Gang Multi Charger

This charger can hold up to six SHIMMERS to charge at a time. Green light shows fully charged while yellow light shows partially charged. SHIMMERS may not be configurable with low charging even connected with docking station to the PC.

3.1.8 Straps and bands

Wrist straps and chest or waist bands are used to put shimmer devices on these body parts.

3.1.9 Bluetooth

SHIMMER is used to communicate with PC or mobile devices through two radio communications such as Bluetooth and Roving Networks 802.15.4. Roving networks has bit a slow data rate as compared to Bluetooth but considered better with other performance parameters like it takes low power in sleep mode 26µA [5].

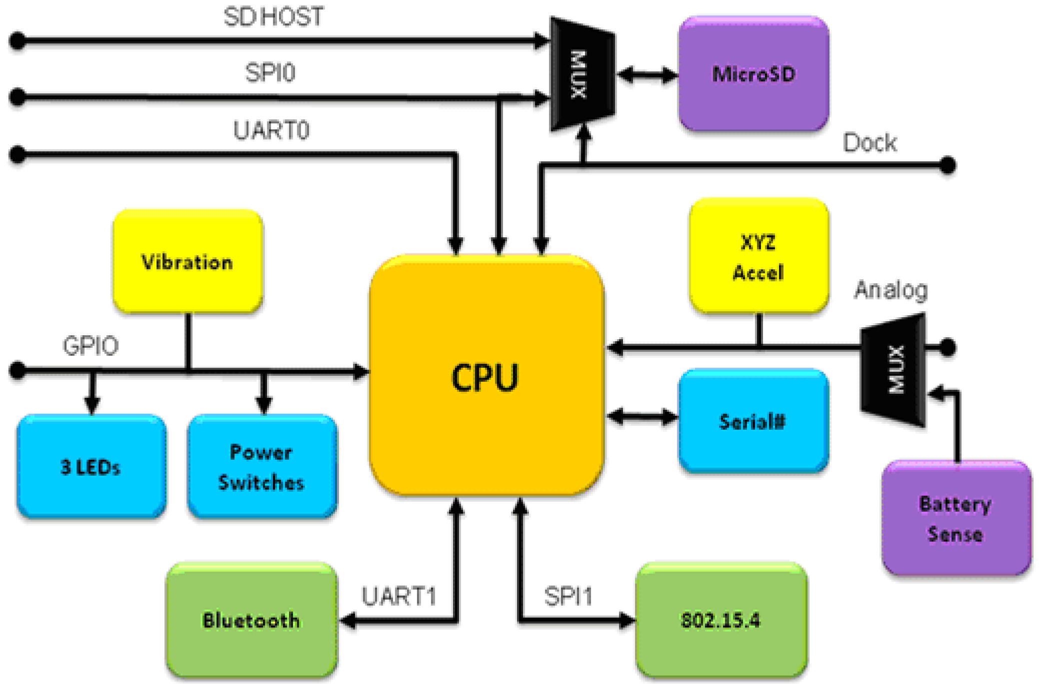

Figure 8 Shimmer Baseboard Interconnections and Integrated Devices

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END OF CHAPTER

3.2 Findings:

The detailed description about the SHIMMER platform devices has been presented into one Table 1.

4 SOFTWARE

Some software is required to program and connect to the SHIMMER. One such is BSL430 to burn program and second is ShimmerConnectV2.0 to connect with SHIMMER devices. There is also need to discuss some features related to EyesWeb and Matlab to make this device compatible to enable certain functionality like ECG, EMG, GSR, etc.

4.1 BSL430: BSL stands for bootstrap loader

It is the default set of open source program provided by the SHIMMER. It contains various samples to capture motion data with different combinations of sampling values and sensing parameters as shown in Figure 9. Mainly two of them are bootstraps and legacy bootstraps. Bootstraps contain 4 samples and each sample contains following set of programs:

1. AccessPointShimmer.ihex
2. BlinkShimmer.ihex
3. BoilerPlateShimmer.ihex (can be used as default)
4. HostTimeLogging_shimmer.ihex
5. JustFATLogging_shimmer.ihex
6. SixAxisTransmitter_shimmer.ihex
7. Sleep_shimmer.ihex

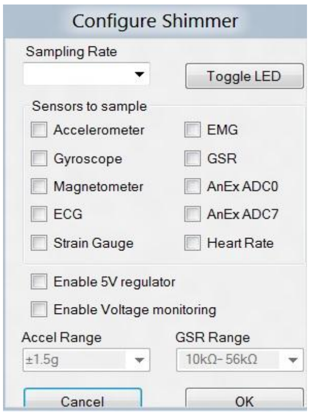


Figure 9 Shimmer Configurations

While legacy bootstraps contain three types of samples and each sample contains the following set of programs:

1. AccelECG_shimmer.ihex
2. AccelGyro_shimmer.ihex
3. AnEx_shimmer.ihex
4. ECG_shimmer.ihex
5. EMG_shimmer.ihex
6. GSR_shimmer.ihex

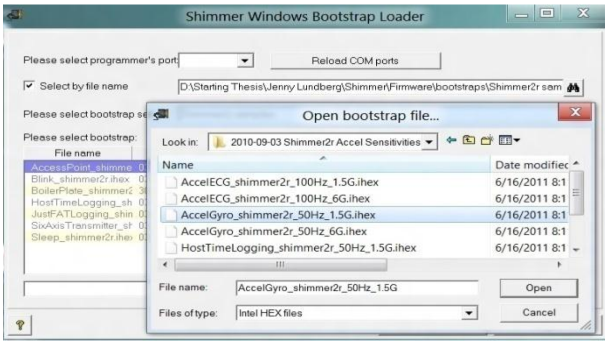


Figure 10 AccelGyro_shimmer2r_50Hz_1.5G

There are also special Shimmer Accel Sensitivities samples with most important are:

1. AccelECG_shimmer2r_100Hz_1.5G
2. AccelECG_shimmer2r_100Hz_6G
3. AccelGyro_shimmer2r_50Hz_1.5G
4. AccelGyro_shimmer2r_50Hz_6G
5. HostTimeLogging_shimmer2r_50Hz_1.5G
6. JustFATLogging_shimmer2r_50Hz_1.5G
7. JustFATLogging_shimmer2r_50Hz_6G

For our project, we used "**BoilerPlate_shimmer2r.ihex**" as default for ShimmerConnectV2.0 for fall detection in Parkinson disease. While for EyesWeb we developed customized application with "**AccelGyro_shimmer2r_50Hz_1.5G.ihex**" as shown in the Figure 10.

4.2 SHIMMER Connect

This software is used to connect SHIMMER with PC or mobile device. It contains shimmer configurations (sampling rate, sensors to sample, Accel range, GSR range), shows graphs/plot to see real-time motion data in time domain and Saves to CSV (an Excel extension).

4.3 Demo Applications and Samples

In order to check a device for the first time, it is a good idea to run with demo applications provided. Shimmer has provided different such demo applications as discussed above. We also tested demo programs on Matlab, BioMOBIUS and EyesWeb.

4.4 Mobile Symbian Application

World has changed towards handy wireless communication devices, such as smart phones. So Shimmer has provided a customized application for Symbian s60 mobile phones to store & display Accelerometer and ECG motion data. Future work could be to design customized applications for specific motion data on mobile phones.

4.5 EyesWeb

Developed by InfoMus Lab, EyesWeb is open source software to design real time applications for physiological, kinetic signals and Gesture Analysis. A user can develop his own application using EyesWeb Development Environment which gives the facility to create multi-model interactive programs. EyesWeb provides scientific research for developing industrial, educational, mathematical, engineering and biomedical applications. For this facility; Intel has chosen EyesWeb in its project “Independent Living” in 2008. Hundreds of applications can be designed for audio, video, media, math, 3D rendering and auditory.
Before proceeding with any new software, it is always good to start with its demo application. For EyesWeb, a demo application is SHIMMER_Demo_Patch.eywx.

4.5.1 GDE

(Graphical Development Environment) it provides the functionality to create EyesWeb blocks in Workspace as shown in the Figure 11.

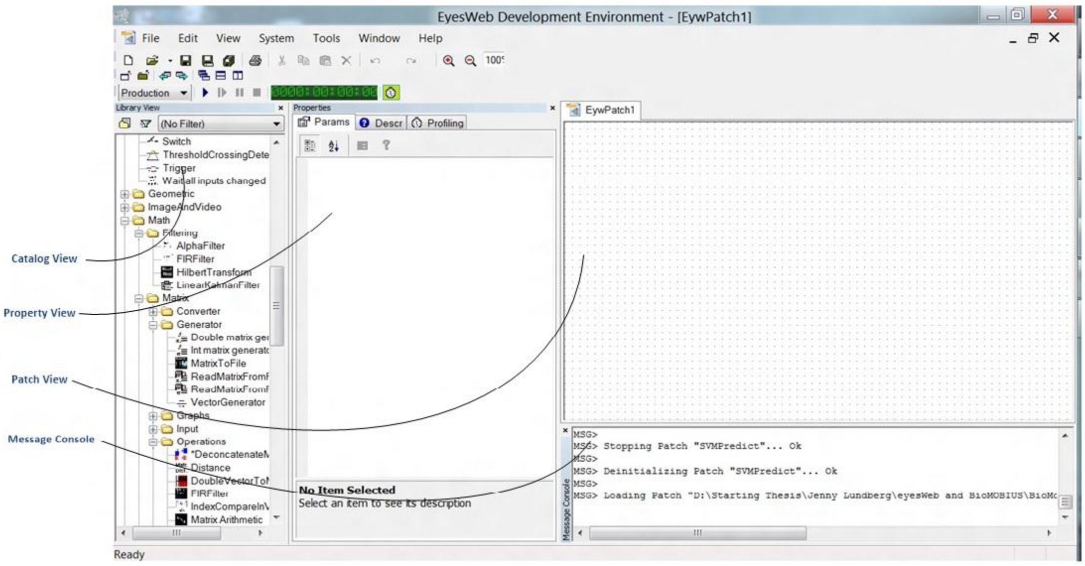


Figure 11 EyesWeb GDE Main View

4.5.2 EyesWeb Blocks & Patches

EyesWeb programs are developed to create Patches and can be saved as an extension test.eywx. Each patch consists of a set of Blocks and Functionality of EyesWeb is implemented through different types of blocks. These can be seen in Catalog view in Figure 12-13. Different blocks have different functions. In EyesWeb, GUI Objects contains basic functionality blocks while other main categories of blocks are:

Audio
BioMOBIUS

DataStructures
FileSystem
FlowAndControlStructure
Geometeric
ImageAndVideo
Math
Operations
Peripherals
Strings
TimeAndDate
TimeSeries

Talking about developing EyesWeb Patch, following blocks have been used:

I. **Bang Generator**: Bang Generator is a GUI object to trigger an action. It works like button: Connect Start, Stop, Disconnect, and Initialize. Start/Stop and Connect/Disconnect Bangs are used to control Shimmer while Initialize Bang is used to generate constant value to Constant Generator such as one Parameter Patch_Start = True.

II. **BioMOBIUS SHIMMER**: Main block is Shimmer block having 0 input and 16 outputs and 16 important parameters. Discussing these parameters, Serial Port = 11 depending upon Accel port, nSample = sampling rate such as 100 samples/sec, Dev Config = Accel, Accel Range = 1.5g

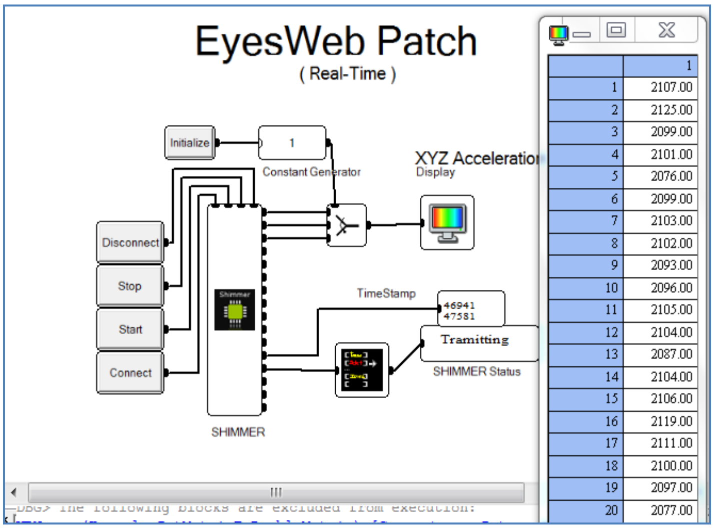


Figure 12 Real-time EyesWeb Patch (Display)

III. **Constant Generator:** Show SyncIn = True, Input Value = 0 for X-axis, 1 for Y-axis and 2 for Z-axis.

IV. **Input Selector:** 3 parameters used are number of input = 3, active input = 1(y-axis, checkbox is clicked),

Active on Select = False

V. **Matrix Display:** in order to see XYZ acceleration.

VI. **FastDataBufferMatrix**: From Input Selector to save csv files. **WriteMatrixToFile(int):** In order to save motion data into csv file.

VII. **Text Selector:** Important parameter is Docked = True.

VIII. **String Display:** Important parameter is Docked = False.

Another EyesWeb patch is also developed to save the CSV file for offline processing.

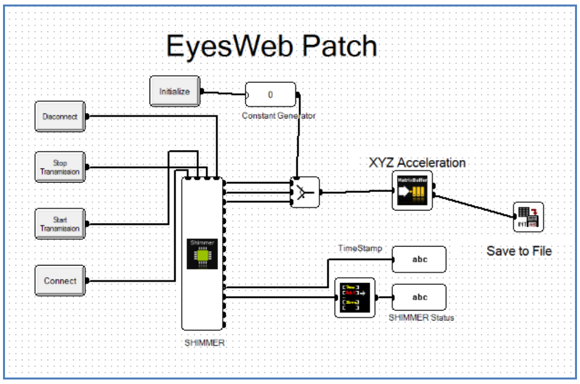


Figure 13 Real-time EyesWeb Patch (Save into file)

4.6 Matlab

Real time motion detection algorithm can be implemented in EyesWeb but we selected Matlab as a designing tool because it's signaling / data handling capabilities are more efficient. Shimmer Research has already provided "Shimmer Instrument Driver Rev0.4" for Matlab.

Once again, before proceeding with Matlab, demo applications for Shimmer need to be tested such as plotandwriteexample.m file. There are two other Matlab files:

1. ShimmerHandleClass.m
2. twoshimmerexample.m (to handle and use two SHIMMERS with different settings at a time)

It is also recommended to read Shimmer Matlab Instrument Driver User Manual.

MATLAB v9 is used to calculate mean, median, standard deviation and different types of plots to analyze the motion data shown in the Tables 6.2 & 6.3. Standard deviation, with different gait parameters (such as sampling rates, accel sensitivity, accel placement, gait types, time duration & distance) seems suitable for making it as the basis to find how far a value lies from mean value. Different researchers have used standard deviation as basic criteria to compare it with threshold values. It will be discussed in the later chapter in more detail.

Detail description about using Matlab will be discussed in Chapter 6.

THE END OF CHAPTER

4.7 Findings:

MATLAB tool has proved to be very efficient in dealing with calculations related to signals from the SHIMMER. So it is a signal processing tool which is easily be employed in such applications where there is a requirement to capture and track the real time motion as data acquisition.

5 GAIT ANALYSIS TOOLS & METHODS

Gait analysis is an important component of neurological examination after physical examination. During analysis, patient balance is checked as a part of Parkinson's disease standard measurement. Despite SHIMMER platform, there exist multiple instruments and tools of various complexities to [32] analyze the gait such as T&T *Medilogic®* Medizintechnik GmbH, measurement-device, marker-set, ©zebris Medical GmbH, an electronic controlled carpet with integrated pressure sensors, GAITRite ®-CIR Systems, Inc., a camera guided 3-D-kinematic-system (VICON Oxford Matrix) or a camera-operated video-system (Peak Performance 1.3).

Measurement-devices or marker-sets which are attached to body parts will affect the natural, undisturbed gait. A bit related work is done by Fei Yu et al [33] to develop wireless medical sensor devices for ECG, EMG, BST, eye movement and body motions continuously, while the software for signal processing and data recording is implemented in LabVIEW.

There can be a number of assessment methods for human motion and fall. Some of them are video capture, visual examination, interviews, keeping diaries, physical measurements, questionnaires and wearable sensors. In wearable sensors most common are accelerometers, gyroscopes, magnetometer, strain gauge, pedometer, actometer, etc [4].

The Difference between Gait Assessment & Gait Analysis

Gait Analysis can be defined as "Gait analysis is the study of the biomechanics of human movement aimed at quantifying factors governing the functionality of the lower extremities. This is crucial for the detection of gait disorders" [26]. Gait Analysis is the evaluation of walking style by observing human as he walks in a straight line [5]. In a broader sense, gait analysis includes assessment, planning and treating people with conditions affecting their gait. So gait analysis allows to assess the gait for different walking disorders.

Gait assessment is the evaluation of walking patterns in order to differentiate dysfunction. It includes different assessment tools and scales as mentioned below.

5.1 Existing Scales/Tests for Gait Assessment

Followings are some of standard scales and tests for measuring movability of persons who are able to walk, likely to fall, checking cognition level and related physical examinations.

5.1.1 Modified Fall Efficacy (MFE) Scale

MFE is a 14-questions one page form to know about daily routine life of a PD patient. Unlike Fall Efficacy Scale, MFE includes more questions related to outdoor activity range from 0-10 (not confident to completely confident). Some questions are related to know about the habit of meals, walking patterns, sit-stand up on chair and bed, dressing, bathing, light shopping n public transport.

5.1.2 Berg Balance Scale (BBS)

BBS is a 14-items scale of 15 feet walkway, scoring 0-4, time 15-20 minutes, to measure the balance of the patient while performing different tasks. A recent study conducted in Finland shows that a change of 8 points in the BBS is required for a genuine change in the balance between two assessments. Some of the items include sit-stand with and without arm support and turning 360 degrees, etc.

5.1.3 Unified Parkinson's Disease Rating Scale (UPDRS)

UPDRS is the most commonly used rating scale for clinical assessment based on an interview and clinical examination. It consists of 5 parts or sections such as:

- Section I: Assessment of Mentation, behavior, and mood
- Section II: Assessment of Activities of daily life (ADLs) including speech, swallowing, handwriting, dressing, hygiene, falling, salivating, turning in bed, walking, cutting food
- Section III: Evaluation of Motor Examination
- Section IV: Complications of Therapy
- Section V: Modified Hoehn & Yahr Staging
- Section VI: Schwab & England Activities of Daily Living Scale

5.1.4 Instrumental Activity of Daily Living Scale (IADL)

IADL is almost same as MFE scale with the difference between both is that, it is formulated to evaluate more complex daily routine tasks with detail interview based on a questionnaire. It contains 8-items, 10-15 minutes, 0-8 scoring. Some of required questions in detail are Mode of Transport, Food Preparation, Housekeeping and Ability to Handle Finance.

5.1.5 Activities of Daily Living (ADL)

ADL is actually an Index of Independence in Activities of Daily Living (IADL). It is designed to assess normal patient daily life activities based on dependence (1-point) / independence (0-point) with total 6-points means the patient is highly independent and 0-point means patient is highly dependent. Daily life activities include bathing, shopping, sit-stand patterns, housekeeping, cooking etc.

5.1.6 Timed Up & Go Test (TUG)

TUG is a famous time based test to assess patient's moveability. Normally, patient activity of sit-stand and vice versa on the chair with and without arm along with turning patterns is evaluated comparing with the criteria of time in the test.

5.1.7 Mini Mental State Examination (MMSE)

MMSE is a brief-questions' questionnaire to assess patient's level of cognition. It is normally used at the later stages of disease when the patient poses weaker mental status such as a short time memory loss and dementia. Some important brief questions are:

- What Is the Date Today? (Month > day, year, correct score=3)
- What Is this Called? (Watch)
- Please Repeat the Following: "No Ifs, Ands, or Buts." (Perfect= 1)
- Please copy this drawing (code 6 if low vision)

5.1.8 Hospital Anxiety & Depression Scale (HADS)

HADS is a 14-questions (7-anxiety and 7-depression) one page clinical scale to assess the level of anxiety and depression of a patient.

5.1.9 Fall Prevention Home Assessment Chart

It is a simple Yes/No questionnaire for fall prevention when the patient stays at home. Important parts include questions using Bathroom, Bedroom, Kitchen, Porch and Living Areas. An answer “No” means need improvement.

5.1.10 Personal Risk Factors Checklist

It is a simple 10-question Yes/No questionnaire to assess the risk of fall with recommendations to each “Yes” responses.

5.1.11 4-Meter Go & Back Test (4GB)

4GB is a 4-meter walkway designed by us to monitor the unbalanced gait of the patient with wearable sensors. Different types of gaits are formulated in order to give the patient more challenging environment during walking. Video is recorded for offline validation. Different types of gait parameters such as constant and assumed parameters are clearly mentioned along with special instructions to follow before taking measurements. Some important gaits are as follows:

- Sit_Stand_Chair (no arm support)
- Circle_Gait (with & without glasses in both hands)
- Simple, Slow and Fast Gait
- Pick_Both_Glasses Gait

Detail description is provided at the section 6.1, 6.2 & Appendix A.

5.2 Existing Gait Analysis Methods

Some of the existing gait analysis methods and techniques are presented here.

- A real-time gait event detector is proposed to automatically control FES (functional electrical stimulation) during paraplegic locomotion. The algorithm is based on fuzzy logic to estimate patient’s current state of gait. [34]
- The term “Gait Recognition” has recently gained significant attention which is strongly motivated by the need for automated person identification systems at a distance in visual surveillance and monitoring applications. The authors propose an efficient automatic gait recognition algorithm using statistical shape analysis. In this analysis, for each image sequence, an improved background subtraction procedure is used to extract a moving silhouettes of a walking figure from the background [35].

- A new method for viewpoint independent gait biometrics is proposed. In this method, the system relies on a single camera without camera calibration and works with a wide range of camera views [36].

Many other gait analysis methods and techniques with can be described.

5.3 Wireless Measurements

As the name "wireless" means no wires, so it means comparatively less burden as compared with Wired Measurements in which enormous quantities of wires are used. Wireless sensor network is good non-spatial method to use. Different types of gait of the patient with PD are tested using SHIMMER wireless sensor nodes.

SHIMMER: Shimmer provides an excellent platform for gait analysis as independent living technology [34]. Different daughter boards can be attached to the main board for motion detection and save the information into a central data acquisition system for later pre or post-processing. The features such as recording information for more than 24 hours in the form of CSV files into 2GB MicroSD card in one time full charge of the battery are quite efficient low power options. More over it provides the functionality to track information about ECG, EMG, GYRO, Strain Gauge, Heart Rate, GSR, Magnetometer, etc. So it gives the SHIMMER as good option to utilize it in the field of biomedical sensing, rehabilitation, gesture & posture tracking, gait analysis and motor disorder monitoring etc.

5.3.1 WISEPLA

A Short-range wireless sensor platform for gaits and it can be used in different implantable applications by Tekes. A 3-D packaging of electronics and biocompatible encapsulation technologies are likely to be developed under this project. Other services to track information are ECG/heart rate and different sensors. This project is cooperated with MIT, RGI, the BIOM Institutes of TUT and other companies.

5.3.2 Sensors™ for Medicine and Science

A concept of an integrated Glucose Monitoring System is given by the Sensors™ for Medicine and Science, Ins. Sensors for Medicine and Science is developing different glucose monitoring products in order to facilitate diabetic patients to regularly monitor their blood sugar with ease. This system provides highly accurate results with longer life along with analysis for O_2, CO_2, pH and Lactate.

5.3.3 ZigBee

It provides Certified Products for maintaining Health and Fitness of the patients. In this long list, some products in the Health & Fitness category include weight scales, BP monitors, in-home-displays, wireless watches, traffic management systems, different kinds of sensors and many more devices in order to help people live non-dependent. The importance of these ZigBee applications is that they require low data rate (250 Kbps), longer battery, and secure networks for periodic or continuous tracking of data.

5.3.4 PUHVI

A short-range PAN, well-being project for conducting research possibilities of applying wearable technology in wellness and healthcare providing long term health monitoring.

5.3.5 WIN Human Recorder Co. Ltd

In this system, the user can put on a portable sensor that is attached to the body as shown in the figure whereas information of its readings can be tracked through a computer. It can measure ECG signals, heart rate, brain signals, velocity, body temperature and respiration with a long life battery for up to four days. So this system provides a good and convenient service to remotely monitor the patient's health care activities, especially for the elder people.

5.4 Wired Measurements

It is a universal understanding over the fact that wired networks always provide fast and reliable communication of information. Yet these networks are becoming out dated due to the reason that these are expensive up to thousands of dollars [37],[38] and difficult to install, especially retroactively into an existing structure.

Some such wired systems are given below:

5.4.1 Nano17mm 6-axis Force/Torque Sensor

A novel protocol called Advanced Sensing for Assessment of Parkinson’s disease (ASAP) is used to [5] measure the patient’s grip force trying to follow a sinusoidal force target wave. For this purpose, a 9-gram 17 mm diameter measuring for all 6-axis force/torque is presented which is the smallest in the world. Some typical applications may include:

- Haptics, Rehabilitation
- Robotic Hand & Surgery, Telerobotics
- Finger-force research

This sensor contains an intelligent data acquisition system for data interpretation through the data acquisition card plug into the pc. It also provides high-signal-noise-ratio.

5.4.2 Digitising Tablet

Another measurement method is represented by a [5] digitizing tablet to analyze the Micrographia of PD patients. Micrographia is impairment in poor, small, shaky and abnormal handwriting. Another advantage is the facility to record the upper limbs’ tremor of PD patient in 2-D information at accuracy rate 200 lines per inch. Tremor rate cannot exceed 12 Hz while this tablet operates at a sampling rate of 50 Hz.

5.5 Our Gait Analysis Mechanism

Technically, wearable wireless sensors provided by the SHIMMER are put on the different areas of body to remotely track the information about the movement of the patient with PD. This information is captured and saved into the PC through the data acquisition system for interpretation and offline processing. Depending on different requirements, real-time implementation through algorithm can be performed on real time motion analysis to trigger different healthcare facilities such as emergency alarms, automated SOS calls, messages, health givers alertness, etc.

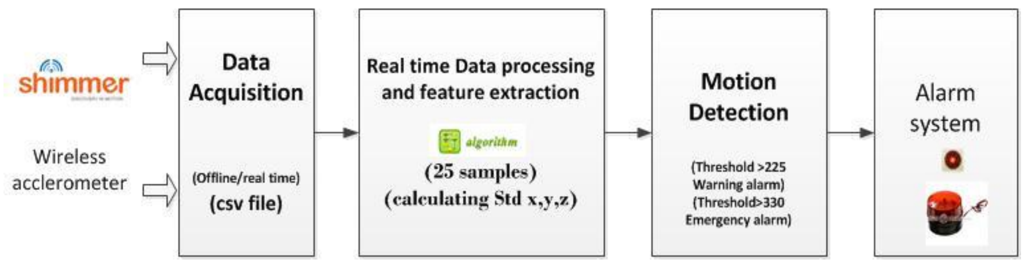


Figure 14 Data Acquisition to Track Motion

This study is carried out on a patient with Parkinson's disease, to observe various gait parameters, to test wireless accelerometers on different body parts and to implement an algorithm triggering security alarm system by setting threshold values. Criteria for setting threshold value are based on calculating standard deviation and finding two threshold values for warning and emergency alarm activation.

THE END OF CHAPTER

5.6 Findings:

4-Meter Go & Back (4GB) test has been designed and tested. This test may be good in planning and taking the measurements necessary for experiment. The different type of gaits, gait parameters and instructions are also provided in the test.

6 IMPLEMENTING ALGORITHM & RESULTS

In this chapter, we would document how we proceed in conducting experiments, taking measurements, calculating standard deviation and implementing the algorithm.

6.1 Experiment

6.1.1 Patient History (medical and fall history)

The lady with PD has undergone two surgeries during 2009. Subject is 70 years an old healthy patient with PD and has undergone Deep Brain Stimulation surgery. The detail about DBS is written in Chapter 2. The reason of DBS is that the patient is not feeling comfortable with medication and hence posing severe shaky motions which has reduced after surgery, but symptoms still exists. Perhaps the use of Levodopa has a low effect on her disease. But, after DBS surgical procedure, patient still experiences postural instability resulting in falls showing no sign specially when medication is not taken in time. Studies show that such patients after surgery may have reduced cognition. In an interview she tells that although falls rates are rare before surgery, but after surgical procedure, the fall rate increases significantly, varies day to day. When asked, replied that she falls early on the day before taking measurements in both experiments. Her fall history shows that she often falls backward pertaining to *Postural Instability*. Early in the day of measurement, she observes fall at right. Other constant parameters are:

Subject = 70 year
General physique = healthy
Gender = female

Support = walking sticks at both hands
Surgery history = recently undergone surgery (DBS)
Step related parameters = reduced gait, small steps

Medicated = yes
PD Symptoms = no or minimum tremor.

Assumed symptoms = Non-alcoholic, no backbone problem, no addicted

(MFE: this data was gathered through Modified Fall Efficacy (MFE) scale. It is a 14-questions assessment sheet to assess the patient's tendency to fall during daily life activities, while 4GB test designed by us may be helpful in taking measurements with gait parameters)

6.1.2 Method

Wearable waist-mounted tri-axial accelerometers are used to measure movement of human motion during walking under supervised conditions. In the first experiment, one accelerometer is used while two accelerometers are used on either sides of the waist in the second experiment. Right vertically positioned accelerometer is used to capture motion data for the EyesWeb patch, while left horizontal accelerometer is used to capture motion through "**Shimmer Connect**" default software. We also tested accelerometers putting on different body positions such as limbs, chest and waist. Results from pilot testing encourage putting accelerometer on waist in order to track motion more accurately and actively. When putting wireless sensors on chest & upper / lower limbs, unnecessary motions are captured which is not required. Another reason to put accelerometers on both waist positions is that it gives efficient information of the patient for falling [4]. Every patient with PD may be different in symptoms from another, but falling can have bit similar patterns.

SHIMMER tri-axial accelerometers with Sampling Rate 100Hz, 1.5g sensitivity and burn with "*BoilerPlate_Shimmer2r*" in BSL430. "*ShimmerConnect_V.2_Win*" software is used to capture the motion data.

We are interested to capture the higher acceleration above threshold value for fall risk assessment. To this contrast, FoG f_{max}=10Hz or even below [30].

(f_{max} = maximum frequency which is maximum standard deviation in a particular acceleration in xyz-axis)

6.1.3 Protocol

We conducted two series of experiments, 2nd experiment is conducted 3 weeks after the first experiment. In 2nd experiment, two readings were taken with a half hour pause. We may assume that the patient may perform the same as before. Subject underwent 6-7 types of gaits in 4-meter Go&Back (4GB) pattern to closely monitor and analyze the patient's gait. The pathway was clearly shown to the patient before taking measurements. The patient was instructed to walk at her normal, slow, fast, holding objects and circle gait and go back. This protocol is bit similar to [7]. One person was checking real-time gait through computer and saving files, the other person was recording the gait for validation later on. While another lady is there to assist the patient in the walkway. We changed the walkway from L-shaped to 4-meter Go&Back (4GB) fashion to give more challenges to induce patient to pose unbalanced gait perticularly during turning. Details of measurements of all gaits along with comments are shown in both gait tables. The 6 types of gait for the first experiment are as under:

a) 

Figure 15 Data Acquisition through WSN

b) SlowGait
c) NormalGait
d) FastGait
e) GlassBoth
f) Sit_Stand_GlassBoth
g) Pick_GlassBoth

The 7 types of gaits for the second experiment putting two accelerometers on either sides of waist are as under:

a) NormalGait
b) FastGait
c) BothGlass
d) FastBothGlass

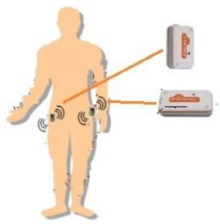


Figure 16 Two Accelerometers on Waist

e) SitChair2Chair
f) CircleGait
g) CircleGlassGait

These above activities are somewhat similar to [10].

6.1.4 Data Acquisition

Data acquisition can be pre-processing or post-processing. Pre-processing is a real time scenario to track the information related to the gait of the patient. While post-processing is an offline analysis of data saved into the computer (most commonly it is CSV file) to calculate the standard deviation at different points in the gait to set threshold values. We checked two software: "ShimmerConnect" and the EyesWeb patch. The parameters for configuring shimmer are:

Software burnt: **BoilerPlate_shimmer2r.ihex**

Software burnt for EyesWeb: **AccelGyro_shimmer2r_50Hz_1.5G.ihex**

Sampling Rate: **100 MHz**

Accel Range**: 1.5g**

Motion data is saved into CSV (Comma Separated Version) files with relevant gait names in all experiments for post-processing (offline) analysis to set threshold values based on the calculations of standard deviation at different points in each gait. This threshold value is used later on in the development of real-time gait analysis algorithm to detect and actively respond to the gait assessment process.

EyesWeb Patch

We have developed EyesWeb patch to capture motion data with a constant generator for particular axis motion with value 0,1,2 = x,y,z respectively. Hence experimental results are collected on different gait parameters to capture data on specific axis. This EyesWeb patch is developed to capture only one axis and we are interested in y-axis setting constant generator = 1 in experiment 01 and x-axis setting constant generator = 0 in experiment 02. So, when Constant Generator = 2, it means that we are capturing Z-axis motion. The XYZ acceleration in Real-time EyesWeb Patch has been shown above in the Figure 12-13 respectively. The purpose of using EyesWeb is that we want to validate our motion analysis results. So this tool is another method to verify the results in parallel to the ShimmerConnect default software.

Algorithm Implementation in MATLAB

Some important Matlab commands and features used in the gait assessment are as under:

M = csvread ("FILENAME.CSV", 1,1): This command is used to read CSV file leaving the first row and column and placing data into variable M for later use

Plot (M): Analyzing graph for variable M

Std (M): Std(m) shows how far data is distributed from mean such as if STD = 238 and maximum for x-axis then this shows that there is more deviation in this axis (more acceleration).

Plot (M(1200:1300,2:END)): Ploting for graph between samples 1200-1300 only

Std (M(500:600,2:END)): To see standard deviation between samples 500-600 only

Hist (M): Hist (m) command is used to see which axis has more acceleration in histogram through pictorial representation.

*Curve Fitting Toolbox™***:** This graphical tool is used for curve fitting and surface to data for the plots. This toolbox is important to use for post-processing of data, detailed exploratory data analysis, regression analysis using linear and non-linear models and providing custom equations.

Detail description about algorithm flow charts and code is available in the Appendix at the end of this report.

6.2 Gait Assessment

A wearable gait measurement system can be [27] successfully developed to perform gait analysis in neurological disorders specially fall risk estimation for the elderly population. Different measurements with standard deviations are calculated using Matlab tool as shown in the Table 6.1. Standard deviation is defined as the statistic used to measure how much variance from mean exists. The criterion based on calculating standard deviation seems good as different researchers [5][29][10] have employed it in their experimentation. Some other calculations, standards, rating scales, measurement tools and parameters are also used in the gait analysis procedure. So, spatiotemporal gait features are calibrated for offline processing to calculate and set threshold value which can be used for real time processing through algorithm implementation.

In the following table, step count is used as gait parameter to count the number of steps per seconds. It can also be called step frequency. All walks are 4-meter Go&Back (4GB) except circle gaits. Experiments A, B are conducted on same the day with half hour pause.

6.2.1 Step Count

Sr. No.	Gait Name	Experiment 01 (steps/sec)	Experiment A / B (steps/sec)	Experiment 02 Mean of (A, B)
1.	"NormalGait"	1.57	1.73/1.31	1.52
2.	"FastGait"	1.61	1.54/1.13	1.33

3.	"BothGlassGait"	1.41	1.3/1.3	1.30
4.	"Sit-Stand-Walk"	1.29		
5.	"Pick-up-Glass"	1.10		
6.	"FastBothGlass"		1.54/1.58	1.56
7.	"CircleGait"		1.15/1.45	1.30
8.	"CircleGlass"		1.48/1.47	1.47

Table 2: Step count, Number of steps taken by the Subject

We compare Experiment 01 (two weeks before) with Experiment 02.
Column-wise in the above table, it is clear that the patient looks healthier in experiment 01 as compared to experiment 02. This fact is also validated by matching the results with video recordings. Moreover, Experiment B yields reduced steps/sec because the patient becomes tired, less interested or loses concentration in taking measurements.

Row-wise in the table, when the patient is forced or have to do some extra task to perform like holding glasses in both hands in "**BothGlassGait**" and "**Pick-up-Glass**", then the number of steps per second decreases sharply. This suggests that hands of patients with PD are needed to be free for smooth walking. In the "**Sit-Stand-Walk**" gait, patient poses reduced walking patterns and same is the case with "**Pick-up-Glass**" gait as shown in the table above. Underlined "**CircleGait**" is matchless here because the patient is resistant to follow tags in the circle and she has to do extra hard work to concentrate. Comparing "**CircleGait**" and "**CircleGlass**" with other gaits, it is clear that the patient has overall good step count per unit time.

In short, if the patient has to do some extra work during the walk, it becomes problematic for her. It becomes a source of reduced walking patterns and lack of concentration, which later on may be a major reason for fall. So if both hands are set free, then probably patient will walk at normal speed with good meditation. Sometimes, fast but conscious gait with energetic stepping produces walking patterns better with low deviation in acceleration as shown in the following calculation in "**FastGait**" Exp B:

Std(xyz) = 124.55 122.88 97.43

Ignoring Std(z) = 97.43 because both values for x and y axis yield higher deviation. The subject leans right during turning back and gives higher deviation in "PickGlassBoth" gait as shown below:

$$f_{max} = \mathbf{417.38}$$

6.2.2 Gait Tables

Different values for standard deviation are calculated by putting one accelerometer on the right waist position in the experiment 01 and two accelerometers in both waist positions for experiment 02.

The positions where accelerometers are put on waist is another gait parameter.

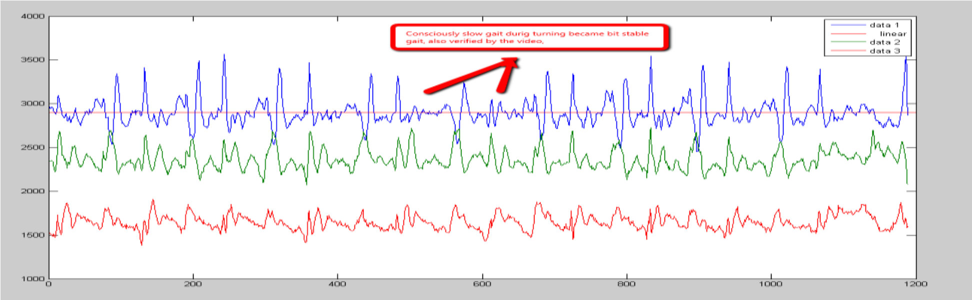
Experiment 01 - Standard Deviation of XYZ Acceleration - detail results in 4 meter Go&Back (4GB)

Sr. No.	GAIT	X-ACCELERATION	Y-ACCELERATION	Z-ACCELERATION	SAMPLES(taken)
1.	NormalGait	99.74	121.39	91.82	2298 total samples
2.		17.44	15.17	15.16	300 samples (at rest)
3.		193.37	328.58	183.37	426-450 samples
4.		126.06	224.84	133.40	501-525 samples
5.		148.38	<u>261.71</u>	156.91	626-650 samples
	Comments:		Slightly higher values show bit jumping gait		
1.	FastGait	117.58	152.21	102.49	1668 total samples
2.		79.70	152.06	72.50	126-150 samples
3.		226.32	<u>347.01</u>	206.56	301-325 samples
	Comments:		Slightly higher values show bit jumping gait		
1.	SlowGait	66.42	62.51	66.96	3516 total samples
2.		65.22	25.70	30.19	126-150 samples
3.		81.58	111.11	45.58	2676-2700 samples
4.		59.72	<u>154.64</u>	44.65	2726-2750 samples
	Comments:	Fairly balanced gait i.e. No.1,2 have all accelerations almost close	Slightly higher values show bit jumping gait		
1.	GlassBoth	88.51	109.10	86.11	2774 samples
2.		92.71	<u>138.99</u>	85.12	501-525 samples
	Comments:	No. 1.2.3 Fairly balanced gait			
1.	Sit_Stand_GlassBoth	140.82	118.37	107.20	2761 total
2.		41.34	34.87	32.02	351-375 (sit-stand)
3.		107.62	252.14	68.53	1001-1025 samples
4.		120.98	173.20	110.24	1776-1800 samples
5.		144.30	<u>551.31</u>	100.43	2626-2650 (stand-sit+jerk)
	Comments:		No.6: Value 551 suggests to have higher threshold i.e. > 551		
1.	Pick_GlassBoth	159.42	125.51	148.09	2493 total
2.		118.71	181.20	100.15	751-775 samples
3.		50.61	30.46	67.42	451-475 samples (1st glass pickup)
4.		295.02	<u>417.38</u>	251.86	1226-1250 samples (Leans right during turning)
5.		39.78	52.57	52.90	1476-1500 (2nd glass pickup)
	Comments:	Both glass picking up is fairly balanced	1st glass pickup = 1 second, bit smooth	417 shows risk to fall	

Note: 6 Gaits are given; No.1 is standard deviation of total samples for xyz-acceleration.
Majority of values of interest naturally fall under Y-acceleration column due to accelerometer orientation as shown in the Figure.
Maximum accelerations are underlined.

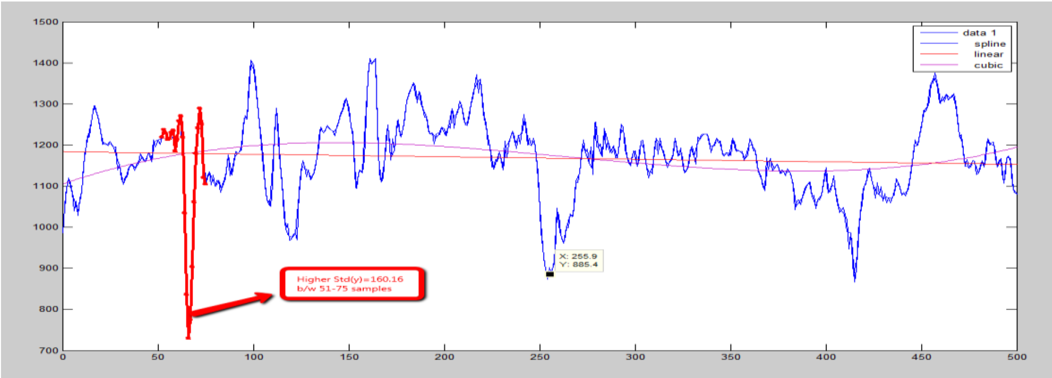
Table 3: Experiment 01 shows 6-different types of gaits with higher std deviations after each 25 samples

Consciously slow gait during turning makes the patient's gait bit stable, so it is suggested to be careful more during turning or circling in any case as shown in the Plot 1 below. Sometimes, slightly higher acceleration in "SlowGait" is due to jumping behavior.



Plot 1: Consciously slow gait during turning becomes more stable

Our studies also demonstrated that the induced small step gait has significantly lower acceleration resulting a more stable gait. So whenever a patient feels unstable, he/she can avoid postural instability during a shaky gait through small stepping.



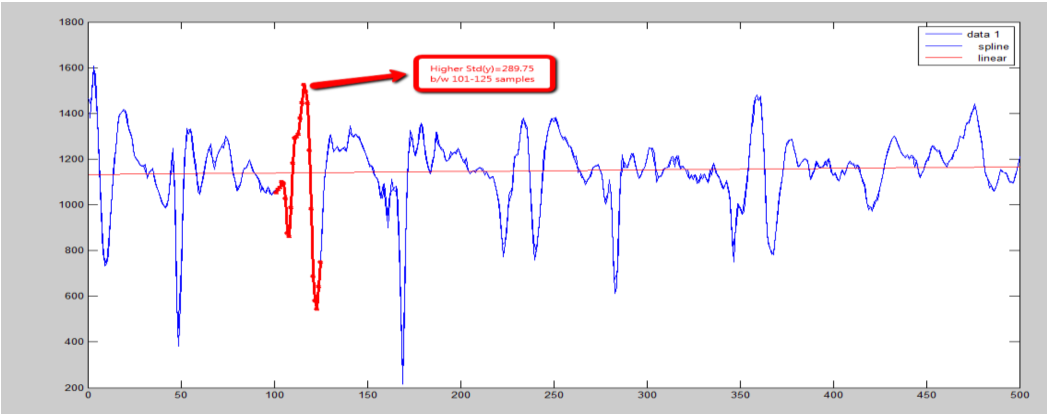
Plot 2 SitChair2Chair Gait Ploting in MATLAB

Patient takes turn before sitting on the chair each time in the gait "**SitChair2Chair**" holding glass in both hands, so threshold value should be set to discard unnecessary noise in the signal as shown in the Plot 2. Also, note that this gait is formulated to check the sitting patterns of patient holding glasses in both hands without arm support.

In "**CircleGait**" Accel(Y) becomes more sensitive due to change of orientation of shimmer accelerometer such as between samples 676-700

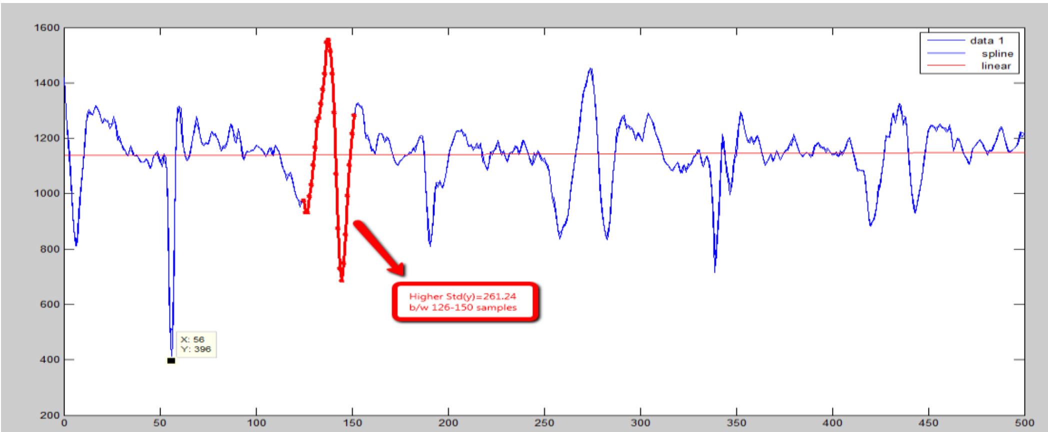
$$Accel(XYZ) = 213.83, \underline{\mathbf{237.77}}, 161.66$$

In "**FastGait**" higher acceleration to be noted is **289.75** captured through EyesWeb as shown in the plot 3 below. Data is captured for first 5 seconds to analyze the starting behavior. It is also observed that when the patient starts stepping with energy, her gait patterns are bit stable.



Plot 3: "FastGait" in EyesWeb showing higher acceleration

In "CircleGait", higher acceleration noted to be 261.24. This type of gait protocol is designed to give the patient some challenging environment as shown in the plot 4 below.



Plot 4 "CircleGait" in EyesWeb showing higher acceleration

6.3 Results & Discussion

Experiment 02 – Only Max. Standard Deviation of XYZ Acceleration - detail results in 4 meter Go&Back (4GB) and circling gaits

Sr. No.	GAIT	X-ACCELERATION	Y-ACCELERATION	Z-ACCELERATION	SAMPLES(taken)
1.	*NormalGait*				
1.1		<u>181.68/223.55</u>	134.42/77.12	105.28/79.68	151-175/1476-1500 samples
	Comments:				
2.	*FastGait*				
2.1		<u>216.56/232.34</u>	86.90/180.86	63.62/74.29	2601-2625/426-450 samples
	Comments:				
3.	*BothGlassGait*				
3.1		<u>242.85/217.93</u>	124.81/103.27	63.27/60.55	876-900/326-350 samples
	Comments:				
4.	*FastBothGlass*				
4.1		<u>272.92/236.26</u>	162.27/154.00	56.82/107.25	301-325/826-850 samples
	Comments:				
5.	*SitChair2Chair*				
5.1		<u>184.27/228.88</u>	178.02/93.89	107.42/115.29	1151-1175/2926-2950 samples
	Comments:	Std(xyz) for total samples = 98, 172, 119 Shows patient turns before sitting so gives more accel(y)	y-axis more sensitive		
6.	*CircleGait*	<u>111.89</u> <u>211.60</u>	93.73 193.96	72.16 116.82	Total Samples 4751-4775 samples
6.1		213.84/162.43	<u>237.77/186.15</u>	161.67/124.27	676-700/1351-1375 samples
	Comments:	Std(x)211 as patient takes a little jump	Here Y-axis becomes sensitive	Total Std(xyz) gives close values, this means stopping and fairly conscious walking pattern	
7.	*CircleGlassGait*				
7.1		<u>240.64/154.32</u>	170.16/154.19	147.72/108.60	51-75/2501-2525 samples
	Comments:				

Note: 7 Gaits are given; No.1 is standard deviation of total samples for xyz-acceleration.
Majority of values of interest naturally fall under Y-acceleration column due to accelerometer orientation
Maximum accelerations are underlined; X-axis is more sensitive i.e. it is verticular to the surface.

Exp A / Exp B, Exp A, B are conducted on same day with half hour pause. Both A, B are put into Experiment 02

Table 4: Experiment 02 shows 6-different types of gaits with higher std deviations after each 25 samples

In this chapter we propose a method for tracking the real time motion of the patient using wireless sensors. The method is based on analysis of calculating standard deviation on different gaits. The collected data is analyzed and various interesting features are extracted. Based on these features, algorithm with name GaitAnalyzer is implemented to track and monitor the gait of the patient. The algorithm has been evaluated with three experiments on different time slots. The good aspect of the method is that it contains a smooth slider for setting threshold values 1 and 2. Both these values can be set to different standard deviations to capture the motion and saving into the computer for later offline processing. Plotting in parallel and ON/OFF for alarms representing at the end are also good aspects of this algorithm. Results and simulation show that method is fairly simple and sensitive to track the real-time gait. In order to take the necessary measurements systematically, a test or scale was necessary. So 4-meter Go&Back test (4GB) is designed and it is observed that this test may provide help for future researchers to take the necessary measurements in their experiments to get expected results.

Some of the features described in Table 6.2, first three gait types show fairly healthy a little jumping fashion. When the patient is carrying two glasses in each hand in *GlassBoth* Gait, a fairly balanced gait is observed. But at 5th *Sit_Stand_GlassBoth* gait,

$$f_{max} = \mathbf{551.31}$$

is observed when the patient takes a jerk during sitting. This higher value of standard deviation also suggests setting threshold to higher values. But we need to analysis data captured during experiment 02.

In the table 6.3 experiment 02, again first three gait types are fairly balanced, however, "FastBothGlass" gait gives

$$f_{max} = \mathbf{272.92}$$

This is a bit higher acceleration. Two gaits "BothGlassGait" and "CircleGait" also yield higher acceleration.

"CircleGlassGait" however yields maximum acceleration i.e.

$$f_{max} = \mathbf{240.64}.$$

Above gait does not have higher acceleration as it was expected. It can be helpful in suggesting setting threshold value. While in physical examination, patient was observed losing concentration during circling.

But after implementing the real time algorithm in Matlab, threshold1, 2 are changed with little difference. So it is up to the user to set the threshold values after calculating standard deviation at different maximum points. Algorithm suggests setting both threshold values as under:

$$\text{Threshold}_{value >} 240 \qquad (6.1)$$

Warning Alarm

$$\text{Threshold}_{value >} 320 \qquad (6.2)$$

Emergency Alarm

Both above 6.1 and 6.2 can be changed depending upon the movement of the patients. Algorithm is flexible, yet sensitive and can be validated through [4] i.e. can be adjustable to

take minimum allowed threshold value ranging 200-300. Some important parameters for the algorithm are given below:
Max/Min threshold values = 0 - 2000.
Capture duration = 120 seconds approx.
Saving file with name = "ShimmerData.dat"
"start" is basically similar to push button to be used in the future device
Maximum Distance range (good distance) = at 12-15 steps away
Maximum Distance range (in general) 25 steps
Simulation of algorithm is shown in the Figure 18 below

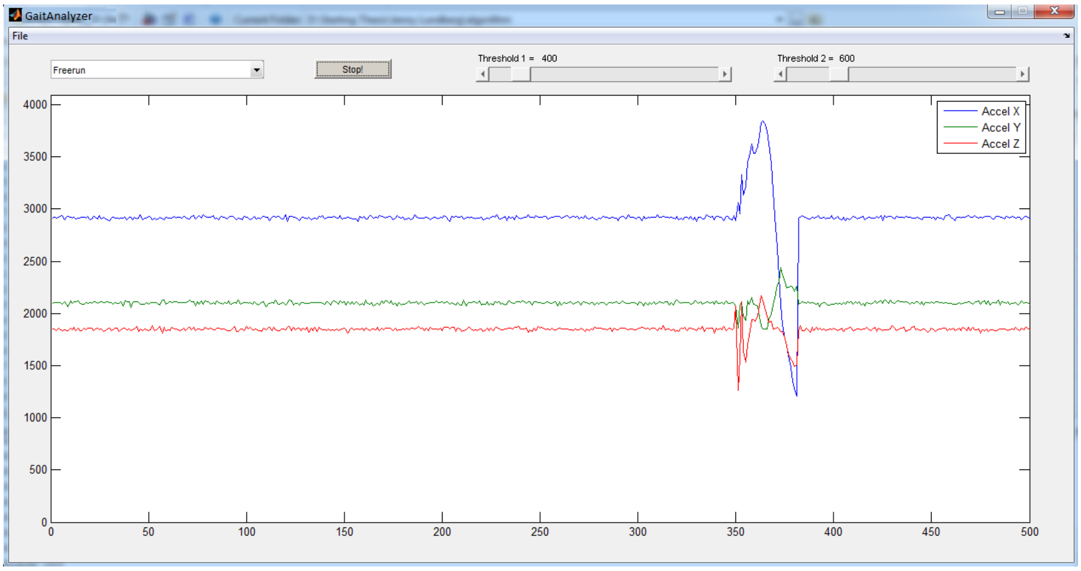


Figure 17: Real Time Algorithm (Simulation)

No hurdle in the path = no wall, no turning aside, line of sight is recommendable

The figure 18 is a simulation diagram of the real time gait analysis algorithm for tracking movement of patients. For example, if Threshold 1 = 400 and Threshold 2 = 600 are set, it means that an unbalanced movement with standard deviation 400-600 will be received and the corresponding warning / emergency alarms will be activated. In this way, practitioners, clinicians and health providers can employ this method to actively understand and respond to the movements of the patients.

The proposed system may generate a high rate of false alarms, in such condition push button can be designed to cancel false alarm as suggested by different authors and one such is [4].

The comparison between our proposed system and the results from other systems is bit difficult. One reason is that our study is based on the experimentation and calculation of one lady with PD. Secondly, 4GB test is designed the first time to fulfill our own specific requirements. This test can be helpful for similar method of taking measurements and open to the public, along with the MATLAB code to design and modify the system as required.

So, a practitioner or clinician may understand our method and he/she may need our test and results for his study somehow.

Internal Validity: Internal validity includes instrumentation & maturization which could have effect on casual link of outcome and treatment. It includes pilot experimentation for verifying WAIST position, 4GB test, Flow Charts of algorithm and Gait tables 1 & 2. A false positive alarm could have effect on internal validity, but if threshold is calculated and set accurately, these false alarms can be avoided.

External Validity: External validity is related to generalization. This proposed algorithm can be fairly used for other patients with PD. However, for seizure detection or gait analysis for some other neurological disorders, it may need test-retest reliability.

Construct Validity**:** Our 4GB test provides valid basis for motion data, after algorithm implementation, threshold is tested to set between 200-300 (+/- 30) in offline and real-time processing.

Conclusion validity: We have a valid 4GB test protocol to take measurements. We concluded that threshold value falls between 200-300 every time whenever algorithm is executed.

Reliability: Reliability means consistency in data collection and data analysis. We observed a bit consistent results in setting thresholds between 200-300 in offline and real time environments and it is proved in the test-retest process.

6.4 Conclusions

We have presented a real time gait analysis algorithm which is capable of detecting the motion of the patient with PD and to objectively achieving the goal of designing an effective technique to actively respond to the shakier motion setting threshold values. Our proposed algorithm is easy to implement, reusable and can affectively generate healthcare alarms. Additionally, the system might be used by other researchers in their studies for real time tracking of the motion of the patient with PD. The proposed method is sensitive to detect fall therefore objectively can be used for fall risk assessment as well. We have also validated that putting wireless accelerometers on waist position gives efficient result and this is performed through literature review/pilot experimentation.

The major advantage of this algorithm is its reusability. Algorithm is not hard coded because a user can set his own sampling rate and threshold value in order to check the results. More specifically minimum and maximum threshold values can be set through a GUI slider as shown in the figure 18.

6.5 Future Work

This algorithm is further adjustable to trigger an airbag, a security push button, SOS calls, messages, siren activation system, automatic email forwarding, health care alert, and many more. The same algorithm with minor modifications can be used for seizure detection in other disorders mainly epileptic seizers to alert health providers for emergency. In this way, in combination with Gyroscopes, related disorders and seizures can also be detected.

A market device can be equipped with button options on it, for fast, slow and other gaits setting threshold value to inform the patient about his postural instability.

Risks

1. Should also try other Shimmer firmware samples & battery time, gyroscope
2. Change of placement of accelerometer may change results (pilot study)
3. Algorithm may not give efficient results during *stop-restart* session same time (let the algorithm run smoothly), at a distance > 25 steps away (Blue Tooth range)

Admittance

We admit that patients with PD can also be treated more efficiently with Electroencephalography, diet, behavioral study, medication and therapies. However, our study can have benefit for individual researchers and industry to devise a tool to assist patients in postural instability suffering from different neurological disorders.

6.6 Summary

Any malfunctioning of neurons in the nervous system is called Neurological disorder. Over 100 neurological disorders have been discovered throughout the world. In our study, we have chosen one disorder: Falling in Parkinson's disease.

Experiments can be performed on different gait parameters like body velocity, time ratio, ground slope, stance/swing, body gestures and gait patterns. Sensors can be put on hips, knees, thighs, limbs, neck, head, chest or any other suitable body part to capture motion data for further pre-and post-processing.

Pre-processing is real time gait analysis through time domain and frequency domain to trigger various security steps and messages for patient care. Post-processing is offline analysis of motion data in different tools such as EyesWeb, BioMOBIUS and Matlab for calculations, analysis and plotting of motion to take decisions to formulate a mechanism for patient activity detection and monitoring.

The area which we choose is pretty interesting, pertaining to rehabilitation, wellness and healthcare for older people. Other related keywords may include keywords may be helpful using one or combination of more than one. WSN, BAN or WBAN, biosensors, neurological disorders, gait analysis, fall detection, fall avoidance, Parkinson's disease, wireless accelerometer, ambulatory monitoring, freezing of gait and fall risk assessment.

Most of the patients suffering from any neurological disorder in later stages of disease pose ambulatory disturbance especially falling. Such patients may fall without showing any warning sign and every patient is different from another. So there is a need to develop a mechanism to detect shaky motion to avoid such patients from falling. Therefore, a real time gait analysis algorithm is implemented to trigger security alarms.

In order to assess & evaluate gait analysis, accurate, reliable & consistent measurement tools need to be utilized. Even slight deviation in the data monitoring through measurement tools is not encouraged to use [21]. Gait disturbance can be measured using 3 axis accelerometers like SHIMMER(R) for real time motion analysis. In the wireless sensor network, SHIMMER platform provides wireless Body Area Network (BAN) to capture motion data. This data can be saved in CSV (Comma Separated Version) file for post processing or a 2 GB MicroSD card can be used to capture data in the SHIMMER accelerometer itself. The use of accelerometer is more suitable due to the fact that we are capturing data from postural instability. One two or combinations of accelerometers can be put on different body parts. SHIMMER Gyroscope is more suitable for jerky motion with disease such as epilepsy.

Mostly accelerometers and gyroscopes are used for gait analysis [4].

Defining our research work, this study is carried out on the patient with Parkinson's disease (PD), to study various gait parameters, test wireless accelerometers on different body parts, and implementing an algorithm to trigger a security alarm system by setting a threshold value. Criteria for setting threshold value are calculating standard deviation and employed by different researchers like [3].

The main motivation to perform this experimental research work is to avoid the patient with PD from falling during unstable shaky gait. Security alarms can be activated whenever a patient poses a shakier gait. Two types of alarms or sirens can be activated in the algorithm. First, to activate Warning Alarms when the value from motion data exceeds maximum threshold value 1 and second to activate Emergency Alarms when the value from motion data exceeds maximum threshold value 2. Later on airbag can be put on the patient's hip position to avoid him/her from injury and hip fracture.

The results show the proposed system is fairly simple to implement in the real time environment, flexible to adjust to any necessary change in the future.

The major advantage of this algorithm is its reusability. Algorithm is not hard coded because a user can set his own sampling rate or threshold value or both, and check results. This algorithm is further modifiable to trigger airbag, a security push button, SOS calls, messages, siren activation system, automatic email forwarding, health care alert, and many more. The same algorithm with minor modifications can be used for fall avoidance or health care assurance on other disorders mainly in epileptic seizers to alert health providers in case of emergency, can be used for other seizures and disorders such as epilepsy, etc.

Overall, this report presents the analysis of an experiment to measure the usability of wireless accelerometer data to monitor the activity of the patient suffering from Parkinson disease. Our research and experimental work can be quoted toward fall risk assessment.

THE END OF CHAPTER

6.7 Findings:

Although accelerometer on the chest shows higher acceleration during fall hence unnecessary body motion create more noise in the calibrated signals.

Also, if a patient initiates steps with energy, his/her gait may become more stable as in conscious gait Plot 1. From our visual examination and post processing analysis, results show that after DBS surgical procedure, the patient still experiences postural instability even she suddenly falls showing no sign specially when medication is not taken in time. So it is evident to show that such patients may have reduced cognition even after surgery.

6.8 Bibliography

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4-Meter Go & Back Test
(4GB)

There are 7-types of gaits which are monitored by the sensors and can be validated through video recording at the same time.

Gait Name	Gait Parameters				
	Body related parameter	Total No. of Steps	Total Time	Cadence (Steps/Sec)	Distance
a) Normal_Gait b) Slow_Gait c) Fast_Gait d) Fast_Both_Hands_Glass e) Sit_Chair2Chair_Glass f) Circle_Gait g) Circle_Glass_Gait h) Fast_Pick_Glass_Gait i) . j) .	e.g. Either sides of the waist	e.g. 18-19	e.g. 11 Seconds	e.g. 1.73	e.g. 8-Meters

Constant Parameters:

Age: ____________ **Height**: _______________ **BMI**: ____________ **Surgery** (date): ________
Disease (Age): ________ **Subjects** (Total): ________ **Gender**: ____________ **Medicated** (Y/N):______
Body (Physique): ___________ **Last Therapy** (Date) :_____________ **Disease** (Condition) :_____________

Assumed Parameters:

Non-addicted, no impairment in: any neurological disorder, backbone slip, vision, hearing, cognition, memory loss, hallucination, extremely tired etc can be put into Exclusion Criteria.

Instructions:

(i) Body Related Parameters can be anywhere such as upper and lower limbs, chest, ankle, belly, bellybutton, trunk, waist, etc.
(ii) If no. of subjects is more than one, separate test for each subject.
(iii) Any or all of "Gait Names" can be repeated depending upon specific requirements.
(iv) Other Special Parameters can be included/changed of walkway in Go & Back, L-Shaped, U-Shaped, depends on specific requirements.
(v) Circle_Gait in a 1-meter diameter with no hurdle.

Becareful:

(i) During Circle_Gait, subject may fall or feel dizzy or get tired
(ii) Good to perform trials before actual measurements
(iii) Save files immediate after each gait with same "Gait Name"
(iv) Person operating camera for video shall call names of each gait in case of repeating of gaits.

Note any sudden / uncertain condition during / after taking measurements: ______________
Comments / Recommendations / Feedback: ____

Appendix B

//**PSEUDO CODE** (Real-time)

```
1. Start
2. Set Std = 0;
3. Set Threshold1 = 250;
4. Set Threshold2 = 220
5. Initialize VAVLUE counter = 0;
6. Read acceleration (xyz);      //matlab
7. Load data into File (temp);
8. While VALUE counter = 24;
9.          Calculate std(temp);
10.         Save into file;
11.                 IF Std > Threshold2;
12.                         Activate Emergency Alarms;
13.                         Print "Patient is about to fall";
14.                         Set VALUE counter = 0;
15.                 ELSE
16.                 IF Std > Threshold1;
17.                         Activate Warning Alarms;
18.                         Print "Take Care!";
19.                         Set VALUE counter = 0;
20.                 ELSE
21.         Print "Device is not working!!";
22. End
```

// Temp is File = 3D array i.e. int temp[24]

// Sampling rate = 100Hz (100 values/sec)

// 25 values per 1/4th sec

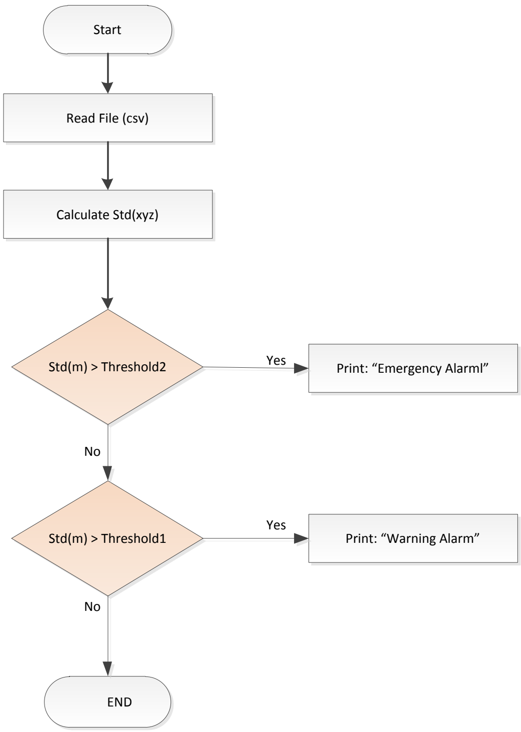
Emergency Alarms active = 10 seconds

Warning Alarms active = 5 seconds

Algorithm continues reading next 25 samples in either case.

Appendix C

Offline Gait Analysis



Comments:

Std=Standard Deviation
Threshold1 = 417
Threshold2 = 551
CSV File(m)

Note: Algorithm is flexible, It means that user can set Sampling rate and Threshold value

Appendix D

Parkinson's disease Symptoms

Tremor: There are many types of tremors and all cannot be associated with PD. Like an Essential tremor is wrongly associated with Parkinson's disease because it does not affect during the rest. The patients, who have a tremor, show less frequency in FOG. However, in some cases, tremor is never observed [14]. Mostly tremor develops later on when disease makes progress. Almost 30% PD has a tremor which causes trembling of limbs, jaws and uncontrollable movement of the body [39].

Bradykinesia: General muscle weakness, rigidity and tremor may contribute to but not necessarily. Sometimes slowness may occur during initiating movement, repeating of motion and rapid necessary fine actions such as writing. In short in Bradykinesia small stepping, shorter arm swing and stooped forward are general symptoms.

Rigidity: Freezing of gait is more complicated stages associated with rigidity. Bradykinesia, Resting Tremor and Rigidity are often visible. Muscle blocking is visible as tremor and Bradykinesia, while this blocking during muscle contraction and relaxation does not allow the smooth movement of elbow, knee joint and other body joints. So in a result muscle may freeze for up to a minute. In short Rigidity is the loss of arm swing and facial expression, [5] tiredness, freezing of limbs or shoulders and reduced initiating of muscle movement.

Freezing of Gait: Freezing is not necessarily associated with all patients, but there are more chances if the patient is older, remains depressed and is being medicated with Levodopa for a longer time. Sometimes, stepping becomes too fast which results in freezing or falling. So try to slow down stepping in a rhythmic pattern. But the biggest risk associated with falling is unpredictable. Somehow a patient can only be judged by examining his gait behavior, turning patterns and sit-stand positions. Chance of falling in elderly people > 60 is up to 30% and therefore associated injuries and cost of falls become high [15].

Nearly 8% patients observe frozen shoulders as early symptoms, sometimes feeling stiffed and painful. It is closely resembled with Postural Instability where a patient with a shuffling gait loses his balance and co-ordination. So due to poor coordination between reflexes, PD patients have an increase risk of falling especially in later stages. There does not exist an exact technical device to detection FoG [30]. Reason for freezing is yet not known.

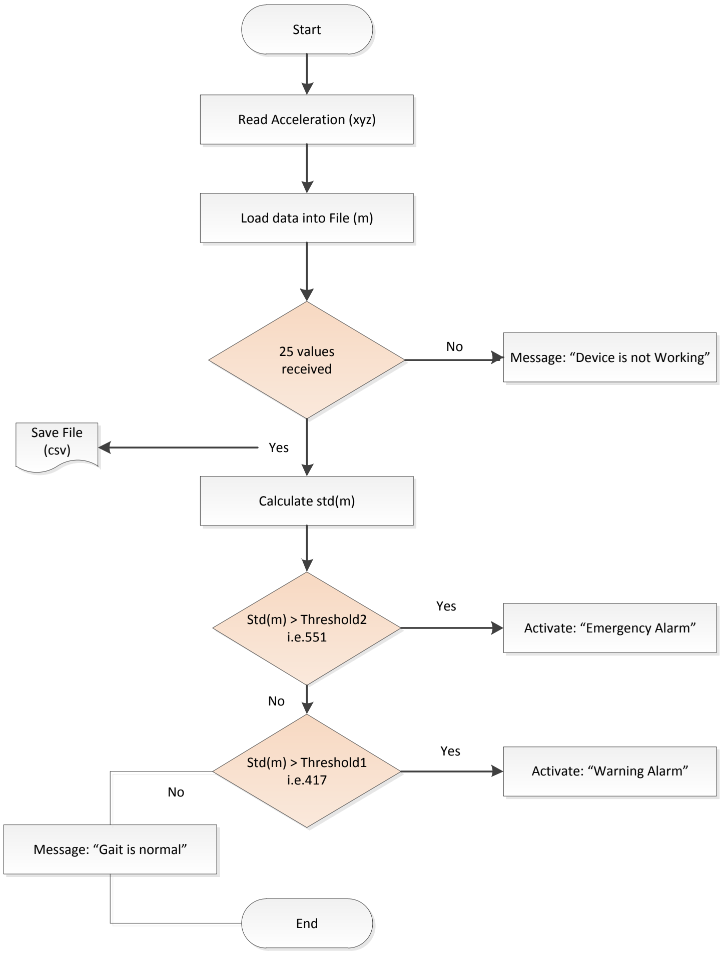
Treatment

i. **Rasagiline** and Selegiline basically belongs to MAO-B (a class of antidepressant drugs) are also used to increase Dopamine level in brain basal ganglia.
ii. Amantadine for treating early **tremors**.
iii. Antidepressants such as Duloxetine for **anxiety** and Gabapentin for neuropathic pains.
iv. Sildenafil for erectile dysfunction. It may have some negative impacts on kidneys.

Most common side effect of drugs is Hallucination. Especially 7-10 % L-DOPA is reached to the brain due to the fact that Benserazide cannot cross blood-brain barrier while remaining amount is assimilated into the other body parts causing nausea and dyskinesia. So Benserazide in combination with L-DOPA is used to treat Parkinson's disease.
Loss of balance or postural instability cannot be treated with medicine.

Deep Brain Stimulation: Generally DBS is recommended in those circumstances where use of Levodopa has reduced or no effect in the brain. So it is good option and sometimes gives good results. Problem with DBS is that it cannot decrease the progression of the disease. Other side effects may be brain bleeding, cognition decline, strokes, infection and minor symptoms of disease may last. However, it can relieve some symptoms and enhance wellness up to five years after surgery.

Appendix E



Comments:

Std=Standard Deviation
Threshold Value=200 (calculated during various measurements)
CSV File(m)
25 values, because when Sampling rate= 100, means getting 100 values/sec, whereas a patient falls $1/4^{th}$ of a second i.e. 25
File(m) = 3D Array i.e. int temp[25]

Best Feature : Algorithm is flexible, It means that user can set Sampling rate and Threshold value

Appendix F Code: Offline Gait Analysis

```
function void = offlineFallManag(fileName, Fs, Threshold1, Threshold2)

[siren,siren_fs] = wavread('SIREN 1.WAV');%'SIREN 2.WAV');
[siren2,siren_fs] = wavread('SIREN 2.WAV')
filedata = csvread('circlegait.csv',1,1);
arr_counter = 1;
Fs = 100;
processed_buff_size = round(Fs/4);
for(loop1=1:processed_buff_size:length(filedata)-processed_buff_size)
    x = filedata([loop1:loop1+processed_buff_size-1],1);
    y = filedata([loop1:loop1+processed_buff_size-1],2);
    z = filedata([loop1:loop1+processed_buff_size-1],3);

    std_x = std(x);
    std_y = std(y);
    std_z = std(z);

    std_arr(arr_counter,1) = std_x;
    std_arr(arr_counter,2) = std_y;
    std_arr(arr_counter,3) = std_z;
    arr_counter = arr_counter+1;

    Threshold1 = 250;
    Threshold2 = 270;

    if( (std_x > Threshold1) || (std_y > Threshold1) || (std_z > Threshold1) )
        display('Alarm ON');
        wavplay(siren, siren_fs);
        % break;
    end
        if( (std_x > Threshold2) || (std_y > Threshold2) || (std_z > Threshold2) )
        display('Alarm ON');
        wavplay(siren2, siren_fs);
        % break;
        else
        display('Alarm OFF');
    end
end
plot(std_arr(:,1));hold on;
plot(std_arr(:,2),'r');hold on;
plot(std_arr(:,3),'g')
```

Appendix G: Code: Real Time Gait Analysis

```
%%%%%%%%%%%%% Start %%%%%%%%%%%%%%%%%
clc
handles.NO_SAMPLES_IN_PLOT = 500;              % Number of samples that will
be

             displayed in the plot at any one time
handles.DELAY_PERIOD = 0.25;
                                                  % A delay period of time in
                                                seconds between data read
                                                operations
handles.comPort = '3';
handles.captureDuration = Inf;
handles.Threshold1 = 200;
handles.Threshold2 = 400;
handles.fileName = 'ShimmerData.dat';
handles.active = 0;
set(handles.pushbutton1,'String','Start!')
set(handles.slider1, 'Value', handles.Threshold1);
set(handles.slider2, 'Value', handles.Threshold2);

handles.shimmer = ShimmerHandleClass(handles.comPort);              % Define shimmer
as a
                                                    ShimmerHandle Class instance with
                                            comPort
if (handles.shimmer.connect)                  % TRUE if the shimmer connects
    % Define settings for shimmer
    handles.shimmer.setsamplingrate(100);      % Set the shimmer sampling rate to
51.2Hz
    handles.shimmer.setinternalboard('None');  % Set the shimmer internal daughter
board
                                                            to 'None'
    handles.shimmer.setenabledsensors('Accel',1);    % Enable the shimmer 1
accelerometer
    handles.shimmer.setaccelrange(0);                % Set the accelerometer range to
0
                                                            (+/- 1.5g)

    handles.iAccelXShimmer = handles.shimmer.getsignalindex('Accelerometer X');
                                                    % Determine the column index of
                                            the
                                                            Accelerometer X-axis
                                                    signal
    handles.iAccelYShimmer = handles.shimmer.getsignalindex('Accelerometer Y');
                                                    % Determine the column index of
                                            the
                                                            Accelerometer Y-axis
                                                    signal
    handles.iAccelZShimmer = handles.shimmer.getsignalindex('Accelerometer Z');
                                                    % Determine the column index of
                                            the
                                                            Accelerometer Z-axis
                                                    signal

    signalNameArray = handles.shimmer.getenabledsignalnames; % Get the list of
enabled
                                                                    signals
    signalNamesString = char(signalNameArray(1,1));          % Create a single
string,
                                                                    signalName
                                                            sString
    for i= 2:length(signalNameArray)           % which lists the names of the enabled
        tabbedNextSignalName = [char(9), char(signalNameArray(1,i))];
                                                    % Add tab delimiter before signal
                                            name
        signalNamesString = strcat(signalNamesString,tabbedNextSignalName);
                                            % Concatenate signal names delimited by
                                    a tab.
```

```
    end
    dlmwrite(handles.fileName, signalNamesString, '%s');     % Write the
signalNamesString
                                                                     as the first row
                                                             of the file
else
    delete(handles.figure1)
end
%%%%%%%%%%%%%% End %%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%% StartI %%%%%%%%%%%
if (handles.shimmer.start)                           % TRUE if the shimmer starts
streaming
            processed_buff_size = round(handles.shimmer.getsamplingrate/4);
            [siren_low, siren_low_fs] = wavread('SIREN1.WAV');
            [siren_high, siren_high_fs] = wavread('SIREN2.WAV');
            arr_counter = 1;
            plotDataBuffer = [];
            newData = [];
            elapsedTime = 0;                         % Reset to 0
            tic;                                     % Start timer
            while (elapsedTime < handles.captureDuration)
                  pause(handles.DELAY_PERIOD);         % Pause for this period of time
               on
                                                             each iteration to allow
                                                             data to arrive in the
                                                             buffer
                newData = handles.shimmer.getuncalibrateddata;
                                                           % Read the latest
                                                      uncalibrated data
                                                             from shimmer data buffer
                if ~isempty(newData)                  % TRUE if new data has arrived
                    dlmwrite(handles.fileName, newData, '-append', 'delimiter',
'\t');
                                                           % Append the new data to the
                                                file in
                                                             a tab delimited format

%%%%%%%%%%%% StartII %%%%%%%%%%
x = newData(:,handles.iAccelXShimmer);
y = newData(:,handles.iAccelYShimmer);
z = newData(:,handles.iAccelZShimmer);

         std_x = std(double(x));
        std_y = std(double(y));
        std_z = std(double(z));

        std_arr(arr_counter,1) = std_x;
        std_arr(arr_counter,2) = std_y;
        std_arr(arr_counter,3) = std_z;
        arr_counter = arr_counter+1;

        if( (std_x > handles.Threshold2) || (std_y > handles.Threshold2) || (std_z > handles.Threshold2) )
           handles.shimmer.stop;                          % Stop data streaming
           display('Alarm High ON');
           wavplay(siren_high, siren_high_fs);
           handles.shimmer.start;                         % Start data streaming
        elseif( (std_x > handles.Threshold1) || (std_y > handles.Threshold1) || (std_z > handles.Threshold1) )
           handles.shimmer.stop;                          % Stop data streaming
           display('Alarm Low ON');
           wavplay(siren_low, siren_low_fs);
           handles.shimmer.start;                         % Start data streaming
        else
           display('Alarm OFF');
        end
```

Appendix H: Scientific Discussion / Validation on Results

As our supervisor Dr. Jenny Lundberg directed to take input from the researchers in the field, we contacted different individuals and got following comments/feedbacks:

(Barry Greene, PhD)
Applied Technology & Design
Intel labs.

Greene says that "I think you are developing a potentially useful system. While it may be beyond the scope of your project, I would suggest testing your system on a target population, e.g. Parkinson's patients, older adults at risk of fall etc and using these data to further refine your methods"

(Fei Yu)
Alsion 2, 6400 Sønderborg,
Denmark.

Fei Yu suggested using Fourier Transform besides using STD to compare results. He also suggests using ROC and Classification Methods to evaluate result accuracy.

(Wouter Speybrouck)
Technology Consultant
Hewlett-Packard Belgium
Diegem, Machelen, Brussels, Belgium.

Wouter says that "observation you have made about the "steps with energy" is in my opinion very true. As long as the patient knows that you are testing his gait he will consciously or unconsciously pay attention to his steps. I guess this is worth mentioning in the report and in your findings". He also suggests taking 50-100 samples/second to avoid false positive alarms.

(Arash Salarian)
Department of Neurology,
Oregon Health & Science University,
Portland.

Arash suggests that "working directly on raw acceleration may give less accurate results. So there is a need to calibrate the signal before any processing because as variation between devices is very big. Also change in orientation (accelerometer) may change readings, so this issue also affects the test-retest reliability of the measurements. To have a robust outcome you either have to rely on features of the signal that are invariant to the orientation of the sensor (e.g. the norm of the acceleration vector) or develop a method to compute and compensate the orientation of the sensor in relation to the body (either automatically or using a protocol of functional tests)".

He quoted that idea of using the 4GB test for this purpose is good but is not enough. Such tests are good at assessing sensitivity of the detection method but are not enough to assess specificity or the positive predictive value. In other words, these protocols do not give you a reasonable estimate of false positive as well as true negative rates.

He also commented that "GaitAnalyzer may not be suitable for certain types of gait such as stumping gait. There are also possibilities that during gait analysis you might record very small variation of acceleration signal, e.g. when a PD subject is walking very slowing specially during OFF state. User selectable thresholds might appear to be a good idea but in fact are an important limitation. Who is going to set the thresholds? Patients? Clinicians? Also, depending on the type of activities, thresholds might need to be changed. Thus ideally, system should use adaptive thresholds that are automatically selected based on certain features of the system”.

(N. Gy˝orbíró,)
Spatial Media Group,
University of Aizu, Aizu-Wakamatsu,
Fukushima-ken 965-8580,
Japan.

According to Norbert, some possible mobile applications could be:

- GPS tracking in correlation with gait: finding out which places/routes cause most problems for patients. Suggesting alternative routes, e.g. gait analysis shows the route the patient takes to a shop is difficult.. Similar scenarios can be devised for in house, but you'd need indoor positioning for that.

- Emergency features: if a critical value is reached, the phone can automatically call / signal an emergency call.

- Collecting of long time statistics: tracking improvements / worsening condition

- Consider whether using any other phone's sensors, including camera and microphone could be beneficial

“I haven't done any work on gait analysis so not sure if these fit your interests but perhaps they can be adapted or could trigger other ideas”.

(Nigel Lovell)
UNSW Scientia Professor,
Graduate School of Biomedical Engineering,
University of New South Wales,
UNSW Sydney NSW 2052 Australia.

Nigel says that our research work sounds interesting but in terms of translating something that works in a lab to working in real life you would need to do quite a bit more work including clearly defining the clinical need for such a device. At the moment it seems to be trying to do everything from gait analysis to falls prediction and prevention.

“You need to simplify your research aims. As well look at such things as test-retest reliability studies to see if the algorithms work on the same subject when the device is attached in somewhat different positions and the likelihood of false positives from activities of daily living (if used for falls)”.

(Alan DeLaTorre)
Project Manager - Age-Friendly Portland
Institute on Aging | School of Community Health
Portland State University

Aland says: your work with accelerometers and movement disorders is very interesting and I would like to be of assistance. Please let me know if there are specific questions that I may be able to assist with.

I must admit that many of these questions are tough to answer as I am not an expert in the area that you are focusing on, nor do I understand the development of algorithms. Nonetheless, I've included responses to several of your questions here:

1. How can accuracy and specificity of algorithm be validated (as we have tested on one female with PD)?

   Regarding validity, I would assume that it is important to try and control for certain human variable. For instance, are you able to test with a person who has PD and someone who does not have PD? If you could control for physical characteristics and/or functional ability that would be helpful. Look to attachments (Lawton and ADL) for variables that you may be able to hold constant. Also, are there specific PD theories of previous research that you are testing against? If so, you should look to those findings as a marker for validation.

2. We have captured raw acceleration from the sensors (accelerometers) and devices may vary; will it be an issue?

   It sounds like a reliability issue. If two different people are taking measurements with two different devices on the same exact phenomenon, those data should match. If the devices vary, you MUST make sure that they are giving you reliable data. If they do, it is not a problem. If they do not, yes it will be an issue. You also want to determine that human error is eliminated. Are the instrument calibrated (if they can be)? Are the researchers trained in the same manner?

   I have looked at the attachments but would still like specifics on the type of input that you are looking for. It may help to know that I am a qualitative researcher who studies age-friendly cities and policies. I am not experienced in dealing with models or algorithms but would be more than happy to provide you with suggestions about housing and environments for older adults and people with disabilities.

3. You asked "are there characteristics of the built environment that are important to consider such as housing elements". What does this mean?
   If I have understood it, probably you are talking the possibility to build this algorithm in some wearable device? If so then I am happy that this can be possible. This algorithm can be housed in the dress to track the information for unbalance shaky gait for wellness. But for this, of course, need some funding opportunities to work further over it.