Free hand interaction therapy for Parkinson's disease using leap motion

A dissertation submitted for the Degree of Master of Computer Science

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Declaration

The thesis is my original work and has not been submitted previously for a degree at this or any other university/institute.

To the best of my knowledge it does not contain any material published or written by another person, except as acknowledged in the text.

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This is to certify that this thesis is based on the work of

Mr./Ms.

under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

Certified by:

Supervisor Name: Dr. G. D. S. P. Wimalaratne

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Signature: Date:

ABSTRACT

This project is based on developing a system for Parkinson’s disease patients to give them free hand interaction therapies using the leap motion controller. Increasing demand for health applications for the more helpless people like Parkinson’s patients has led to develop an important system of this nature. Primary signs of Parkinson’s disease include tremor of hands, arms, legs, jaw and face. Physical therapies and exercise programs are recommended in people with Parkinson's disease to control the disease and to give them a better life. Rehabilitation methods using serious game without any device attached to the body is proposed for Parkinson's patients with limited mobility in order to restore their ability to independently perform the basic activities of daily living or to recover a lost or diminished function by performing exercises on a regular basis.

Leap Motion is an optical sensor specially designed for acquisition of 3D positions and orientations of hands and fingers. The main purpose of the sensor was to extend current input devices with 3D control for VR environments. The Leap Motion Controller is capable of detecting and tracking hands, fingers, and tools in its field of view. The device captures data one frame at a time and the rate at which this occurs, or frame-rate, can vary based on the lighting conditions, but typically occurs at approximately 100 frames per second (fps). The device is capable of recording the three dimensional fingertip positions, which is done in millimeters relative to the device’s origin. The Leap Motion Controller follows a right-handed Cartesian coordinate system, with the origin centered at the top and middle of the Leap Motion Controller

In this project, the Leap Motion sensor is used to give hand and finger therapies for Parkinson's patients using serious game application developed using three js. The scope of this project is to track the motion of the fingers of the hand and to exercise the fingers of the hand. Further to track the progress of the patient by giving an analysis of the output. Each patient should use a separate login and it will help to keep the records and analyze to monitor the progression of the Parkinson’s patient.

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CHAPTER 01

1.1 INTRODUCTION

Parkinson's disease is a progressive disorder of the nervous system that affects movement. It affects the nerve cells in the brain. A brain chemical called dopamine acts as a messenger between two brain areas; the substantia nigra and the corpus striatum to produce controlled and smooth movements. Most of the movement related symptoms of Parkinson's disease are caused by a lack of dopamine due to the loss of dopamine producing cells in the brain. When the amount of dopamine is too low, communication between the substantia nigra and corpus striatum becomes ineffective, and movement becomes impaired.

The cause of this disease is unknown, but it may involve both genetic and environmental factors. A small proportion of cases can be attributed to known genetic factors. Other factors have been associated with the risk of developing Parkinson's disease, but no causal relationships have been proven. There is an increased risk in people exposed to certain pesticides and among those who have had prior head injuries while the risk is reduced in tobacco smokers and those who drink coffee or tea. Around 15% of individuals with Parkinson's disease have a first-degree relative who has the disease and 5-10% of people[1] with Parkinson's disease are known to have forms of the disease that occur because of a mutation in one of several specific genes.

Parkinson's disease develops gradually, sometimes starting with a barely noticeable tremor in just one hand. But while a tremor may be the most well-known sign of Parkinson's disease, the disorder also commonly causes muscle rigidity, stiffness, slowing of movement or Poor balance and coordination. Primary signs of Parkinson's disease include tremor of hands, arms, legs, jaw and face. As symptoms get worse, people with the disease may have trouble walking, talking, or doing simple tasks. They may also have problems such as depression, sleep problems, or trouble chewing, swallowing, or speaking.

1.2 PHYSIOTHERAPY AND PARKINSON DISEASE

Physiotherapy is a medical science which is gaining rapid popularity. It does not make the use of a lot of medicines, injections or surgeries. It is a therapy which makes use of mechanical force. Sometimes the patient's own strength to cure their conditions. People commonly have a myth that only those patients who have a muscular or bone related problems can go to a physiotherapist. This is not completely true. Physiotherapy has many types and there are several disorders which can be treated to a vital extend with the help of physiotherapy. Physiotherapy makes use of exercises, muscle stretches, fraction, hot and cold applications, electrical stimulation and many such therapies to treat patient’s conditions. Pain is the most common symptom with which patient really present to a physiotherapist. Muscular disorders and bony disorders have very good spoke of treatment if physiotherapy treats.

Physiotherapy can also successfully used in patients having cardiac disorders or neurological disorders. Conditions like Parkinson, loss of balance can be treated very efficiently if the patient visits their physiotherapist regularly. With the help of proper exercises, stretches, massages, tractions and other things prescribed by the physiotherapist patient's condition can improve significantly. Physiotherapy can be used as a main stream treatment or even an association with the other therapies which the patient might be undergoing for their disorders. That is a separate category of physiotherapy which caters only to elderly people. Elderly people tend to use their balance due to degeneration of central nervous system. They tend to develop disorders like Parkinson. This condition can be controlled very well if the elderly people are offered physiotherapy services.

Physiotherapy is considered as a part of paramedical science but which is highly advanced. Great researches take place in physiotherapy, and new and advanced techniques developed every day. It is a very useful branch of medicine which can take care of all your health problems which are associated with pain. If someone has any neuromuscular complication, any bony complications or Parkinson symptoms then they have to attend for a physiotherapist without hesitation.

While medication has long been the most promising treatment available for Parkinson’s disease, a regular exercise program should always be part of managing Parkinson’s disease. In fact, many movement disorder neurologists say that exercise is as important as any one of your medications. Though exercise is not a cure, it may help slow the progression of symptoms.

Parkinson’s is a neurodegenerative disorder that affects about one million people in the United States and 10 million people worldwide. It is called a movement disorder because of the tremors, slowing, and stiffening movements it can cause, but its symptoms are diverse and usually develop slowly over time. Parkinson’s disease is not diagnosed with a test or a scan; instead it is diagnosed by the doctors, who asks questions about health and medical history and observes the movement. The goal of treatment is to help you manage your symptoms. Good symptom management can help you to stay healthy, exercise, and keep yourself in tip-top shape. Although there is no way now to correct the brain changes that cause Parkinson’s, we know that exercise can help patients to fight the disease and that staying healthy can prevent setbacks that make Parkinson’s disease progress faster.

Parkinson's disease is a Movement and Sensory Disorder. People with Parkinson's disease have difficulty regulating the size or speed of their movements. Movements are bradykinetic and hyopkinetic.

Changes in the movement system (muscles) lead to challenges controlling movements, including the following:

• Starting and stopping movements

• Automatically controlling muscles

• Linking different movements to accomplish one task (e.g., moving from sitting to standing)

• Finishing one movement before beginning the next (e.g., not completely turning around before sitting down)

Changes in the sensory system also lead to challenges, particularly noticing and correcting movement and voice issues. Here are some other examples:

• Slowness or smallness of movements (e.g., when told to make the movement bigger, a person with PD may feel the movement is now “too big”)

• Lack of movement (e.g., an arm that does not swing during walking)

• Changes in posture

• Changes in voice volume (e.g., when told to speak louder, a person with PD may feel they are shouting)

Licensed physical therapists (PT) and occupational therapists (OT) work in a variety of healthcare settings. Physical therapists address balance, strength, and range of motion related to a person's functional mobility (e.g., walking, getting in and out of chairs and changing position in bed). They can also design a personalized exercise routine. Occupational therapists address performance skills related to tasks that occupy a person's time, such as activities of daily living (e.g., dressing, bathing, cooking), work, school, social/communication and leisure activities.

There are two main reasons that exercise is important when you have Parkinson's disease.

1. Your body is coping with Parkinson's disease and the general effects of aging. As we age, certain changes occur in our bodies:
   • Loss of tissue elasticity (skin wrinkles, muscles can tighten)
   • Mineral loss in bones (fractures can occur more readily)
   • Loss of muscle mass (muscles are not as toned): We lose 1% of muscle mass per year over the age of 60
   If you combine normal, age-related changes with a sedentary lifestyle, you could end up with an increased risk of developing cardiovascular disease, osteoporosis, diabetes and cognitive impairment. Without regular exercise, our bodies and minds become weaker, stiffer and more likely to suffer an injury.
2. Research has shown that exercise benefits those with Parkinson's disease. Studies in both animals and humans have demonstrated the brain and body benefits of exercise.

In the last decade, studies and ongoing research have clearly shown us that exercise and physical therapy can help restore lost behaviors and function in people with Parkinson's. In total these studies have shown that physical therapy and exercise can improve many diverse aspects of Parkinson's by incorporating feedback, repetition, challenge, problem solving, engagement and motivation. In addition to improving symptoms, scientists are increasingly convinced that exercise may slow disease progression. Reported benefits of exercise include: Improved gait and balance, Reduced falls, Increased flexibility and posture, Improved endurance, Reduced freezing of gait, Improved working memory and decision making, Improved attention/concentration, Reduced depression and anxiety and Improved quality of sleep.

The general goal of exercise and physical therapy is to improve symptoms and help to do activities that patient enjoys. Physical therapist will recommend that patient to practice skills that are relevant to activities that patient have trouble with. If the patient has trouble getting out of a chair, then physical therapist might ask the patient to practice with seats at different heights and also to work on muscle strength.

Research has shown that people with Parkinson’s often need to work on the sequencing or timing of motions and on compensating for the effects of the disease (and the effects of aging) on the brain’s ability to accurately judge distances. Physical therapists commonly start you out with what the patient can do and then gradually make the activity more difficult. They will add new challenges and repetitions of a task to force the patient to problem solve and move better.

1.3 MOTIVATION

The hand therapies and rehabilitation methods using serious game without any device attached to the body is proposed for Parkinson's patients with limited mobility in order to restore their ability to independently perform the basic activities of daily living or to recover a lost or diminished function by performing exercises on a regular basis. To cover these specific objectives, several finger therapies have been created to exercise different purposes proposed by healthcare professionals.

Advantage of the three-dimensional cameras have allowed for more accurate recordings and can now be used to provide much more accurate measurements that are involved in movements such as resting tremor. The Leap Motion Controller capable of measuring changes in position of 0.2 mm for static setup and 1.2 mm for a dynamic setup produced by Leap Motion, Inc[14]. The Leap Motion Controller requires no external sensors or markers to be attached to the body, where without any device attached to your hand you can track your hands and fingers. One disadvantage of having sensors attached to the body is, for every gram of mass that is added by the sensor, the peak frequency of finger tremor decreases by approximately 0.85 Hz and also have an affect the acceleration amplitude[15]. Therefore the characteristics of the tremor can be change and alter the interpretation of tremor can be happen from the attached sensors. Another advantage of the Leap Motion Controller is it does not require calibration, eliminating possible errors caused by consistent recalibration. Also the Leap Motion Controller is not affected by interference from electrical sources, mechanical artifacts, stimulus artifacts, and the electrical activity of muscles that are not of interest. It is for these reasons that the Leap Motion Controller is of interest and may be a superior method for measuring tremor.

The activities in this serious game application not only are beneficial to recover physical mobility, but it favors the perception of visual acuity, whether the subject has it atrophied or not. This means that although the idea of these games is mainly to work at motor level, they also exercise the cognitive and perceptive capacities of the users. It has been determined that the activities are favorable for subjects with motor limitations due to suffering any of the following pathologies: Parkinson's Disease, people who have suffered a stroke, arthritis, osteoarthritis, manual stiffness, wrist and/or fingers fracture, tennis or golfer elbow, shoulder injuries, etc.

1.4 AIMS AND OBJECTIVES

- To give finger therapies for Parkinson’s patients using a serious game application to improve the motion of the affected hands of Parkinson’s patients.
- To track the progression of Parkinson’s patients with analysing and monitoring the records.
- To provide an environment for the Parkinson’s patients to do their daily therapies with high motivation (guiding the patients to do their therapies by their own without engaging another person for that).
- To improve the treatments of the patient where Doctors will be able to track the hand tremors progression and based on that feedback they can take necessary decisions to treat the patients.
- To evaluate the tremors progression over time by comparing the past tremor motion and present tremor motion.

1.5 SCOPE OF THE PROJECT

Leap Motion is an optical sensor specially designed for acquisition of 3D positions and orientations of hands and fingers. The main purpose of the sensor was to extend current input devices with 3D control for VR environments. In this project, the Leap Motion sensor is used to give hand and finger therapies for Parkinson's patients using serious game application developed using three js. The scope of this project is to track the motion of the fingers of the hand and to exercise the fingers of the hand. Further to track the progress of the patient by giving an analysis of the output. Each patient should use a separate login and it will help to keep the records and analyze to monitor the progression of the Parkinson’s patient.

PROJECT PLAN

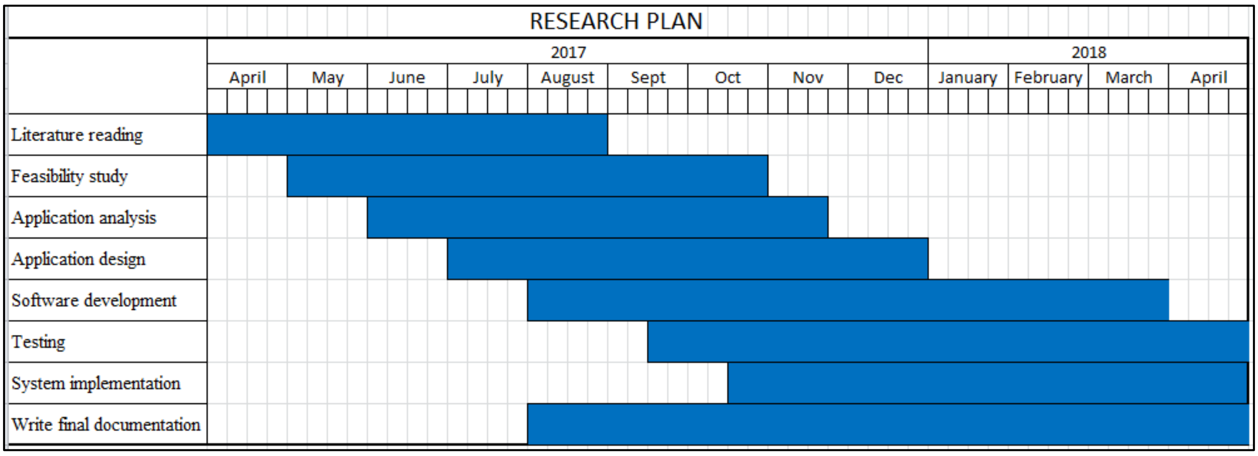

Figure 1.1: Project Plan

CHAPTER 02

2.1 LITERATURE REVIEW

2.1.1 PARKINSON'S DISEASE

Parkinson's disease is the most common serious movement disorder in the world, affecting about 1% of adults older than 60 years[8]. According to the research article "Parkinson's disease" [8], the prevalence of Parkinson's disease in industrialized countries is estimated at 0·3% of the general population and about 1% of the population older than age 60 years. People of all ethnic origins can be affected, and men are slightly more prone to the disorder. In one study, the annual incidence of Parkinson's disease was about 13 cases per 100 000. Mean age of onset of this disorder was estimated to be in the late 50s, but is now thought to be in the early-to-mid 60s. In people with young-onset Parkinson's disease, the initial symptom can arise between age 21 and 40 (sometimes 50) years, while the first symptom in juvenile-onset disease occurs before the age of 20 years.10 Young-onset Parkinson's disease affects 5–10% of patients.

Although symptoms can vary significantly between individuals[16], the primary motor symptoms involved with Parkinson Disease include: rigidity, postural instability, bradykinesia and tremor.

Bradykinesia

Bradykinesia refers to slowness of movement and initially manifests as slowness in performing activities associated with daily living, slow movement, and reaction times[16][17][18]. Similar to other parkinsonian symptoms, bradykinesia is dependent on the emotional state[16] of the patient and is the Parkinson characteristic that correlates best with the degree of dopamine deficiency.

Rigidity

Rigidity is described as an increase in resistance while passively stretching a muscle, causing a feeling of stiffness[19]. Rigidity is sometimes accompanied by the "cogwheel" phenomenon, which is the periodic interruption of rigidity on passive movement of the limbs[20]. Rigidity of the neck and trunk eventually leads to changes in posture and postural deformities.

Postural Instability

Postural instability usually occurs during the late stages of Parkinson Disease and typically after the onset of the other motor symptoms[16]. It is the most common cause of falls and the late onset of falls can differentiate Parkinson Disease from other neurodegenerative disorders like progressive supranuclear palsy (PSP) and multiple system atrophy (MSA).

Tremor

Tremor is defined as an involuntary rhythmic oscillation of a body part. The characteristic tremor of Parkinson Disease, is usually a 3-6 Hz distal resting tremor, but patients with Parkinson Disease may also exhibit postural and kinetic tremors[21][22][23]. Rest tremor occurs when a body part is at rest or relaxed while postural tremor occurs when a body part is maintained at a position against gravity, and kinetic tremor occurs during the movement of a body part. Rest tremor is such a characteristic feature of Parkinson's that it has been shown that the proportion of patients with resting tremor ranged from 69-100% in three series of autopsy proven Parkinson Disease[24][25]. In fact, rest tremor is the most common and most recognizable symptom[16] of Parkinson Disease, and is, by itself, a positive diagnostic criterion for Parkinson Disease.

Parkinson's disease usually begins around age 60, but it can start earlier[1][2]. It is more common in men than in women. There is no cure for Parkinson's disease. A variety of medicines sometimes help symptoms dramatically. Surgery and deep brain stimulation can help severe cases. With deep brain stimulation, electrodes are surgically implanted in the brain. They send electrical pulses to stimulate the parts of the brain that control movement. There is no medical test that will clearly identify the disease, but brain scans are sometimes used to rule out disorders that could give rise to similar symptoms.

The stages of Parkinson's disease may be distinguished as; an initial stage in which the individual with Parkinson's disease has already developed some disability requiring pharmacological treatment, a second stage associated with the development of complications related to levodopa usage, and a third stage when symptoms unrelated to dopamine deficiency or levodopa treatment may predominate[3]. Treatment in the first stage aims for an optimal tradeoff between symptom control and treatment side effects. In the second stage the aim is to reduce Parkinson’s disease symptoms while controlling fluctuations in the effect of the medication. Sudden withdrawals from medication or overuse have to be managed[5].

Exercise programs are recommended in people with Parkinson's disease[4]. Exercise in middle age reduces the risk of Parkinson's disease later in life. When an exercise program is performed under the supervision of a physiotherapist, there are more improvements in motor symptoms of Parkinson’s patients. Regular physical exercise with or without physical therapy can be beneficial to maintain and improve flexibility and quality of life[6]. Medication may improve the symptoms and continually monitoring the progress of the patient may be helpful to manage the disease.

Research has shown that regular exercise benefits people with Parkinson’s disease. It can reduce stiffness and improves mobility, posture, balance and gait. Current pharmacological management is incompletely effective at controlling the symptoms of Parkinson’s disease and patients are often seeking complementary approaches. Exercise is a compelling strategy since recent evidence suggests both physical and cognitive benefits and, relative to many pharmacological therapies, it is inexpensive.

It is recommended that people with Parkinson’s disease should perform exercises 45 minutes to one hour after medications when the symptoms at their lowest level[7]. There aren’t many ways for patients and doctors to quickly and reliably track tremor progression over time. With better tracking of tremor measurement it could progress faster aiding in the treatment of tremors and doctors could have a more efficient tool for quantifying tremor. By doing this project I hope to develop a tool to monitor the tremor progression of the patient as well as to encourage patients to do simple interesting exercises to improve their motion of the affected hands.

Tremor is a primary symptom of Parkinson’s and it is shaking often in hand, arm or leg without control when you are awake and sitting or standing (resting tremor). There are lots of researches were done to identify and analyze these tremors. Among that, “ A software for recording and analysis of human tremor"[9] research paper describes how they develop an easy-to-use application for tremor-analysis and recording, running under MS-Windows, that allows us to investigate different forms of tremor by advanced mathematical methods of time series analysis. The application is also applicable for users who are not familiar with these kinds of advanced data analysis methods. It provides tools for the diagnosis and treatment monitoring under laboratory conditions, based on previously developed and established methods of spectral and cross spectral analysis of tremor and electromyography time series.

Another article of analyzing human tremor describes how they analyzed tremor for the purpose of recognition[10]. This research is based on recording and analysis system for human's tremor. The analysis was performed based on frequency and amplitude parameters. The fast Fourier transform (FFT) and higher-order spectra were used to extract frequency parameters (e.g., main peak frequency). In order to diagnose subjects' condition, classification was implemented by statistical significant tests (t-test). The goal was to compare different subject groups with Parkinson's disease. We recognized that other electrophysiological methods (e.g., digitizing tablets and video based methods) are available for the diagnosis of Parkinson's disease. Although using an electrophysiological approach was limited by accelerometer, we found that there was a high level of agreement between clinical and electrophysiological diagnosis of tremors. In this study, the examples have shown that for brief periods of time there can be a marked degree of correlation between frequency and amplitude parameters for two groups. Since the clinical and physiological interpretations of the results were complicated, this paper suggest to work on different approaches (e.g., other signal analysis methods) together with clinical staff to improve the presentation of results and to develop more easy to interpret values or graphs that can be calculated from tremor data.

2.1.1 REHABILITATION OF PARKINSON'S DISEASE

Exercises and physical therapies are necessary to rehabilitate Parkinson's patients since there is no cure for this disease. Physical therapies will be helpful to reduce stiffness and improves mobility, posture, balance and gait. A research article, "The Effectiveness of Exercise Interventions for People with Parkinson's disease: A Systematic Review and Meta-Analysis"[11] is describing how to systematically review randomized controlled trials (RCTs) reporting on the effectiveness of exercise interventions on outcomes (physical, psychological or social functioning, or quality of life) for people with Parkinson's disease. RCTs meeting the inclusion criteria were identified by systematic searching of electronic databases. Key data were extracted by two independent researchers. A mixed methods approach was undertaken using narrative, vote counting, and random effects meta-analysis methods. Fourteen RCTs were included and the methodological quality of most studies was moderate. Evidence supported exercise as being beneficial with regards to physical functioning, health-related quality of life, strength, balance and gait speed for people with Parkinson’s disease. There was insufficient evidence support or refute the value of exercise in reducing falls or depression. This review found evidence of the potential benefits of exercise for people with Parkinson’s disease, although further good quality research is needed. Questions remain around the optimal content of exercise interventions (dosing, component exercises) at different stages of the disease. The aim of this systematic review was to evaluate the effectiveness of exercise interventions in randomized controlled trials undertaken with people with Parkinson’s disease. This study supports and updates the findings of previous reviews, and, through refining our scope to one aspect of physiotherapy (i.e., exercise-based interventions) we have identified that exercise is of benefit to people with Parkinson’s disease in respect of physical functioning, strength, balance and gait speed. Findings add to the growing body of evidence regarding the effectiveness of physiotherapy for people with Parkinson’s disease. There is currently insufficient evidence to support or refute the value of exercise in reducing falls or depression, or its safety with people with Parkinson’s disease.

Among the research articles discussing the analysis of tremor of Parkinson’s patients, "Detection of Parkinson Disease Rest Tremor"[12] is measuring the rest tremor of 30 human subjects, consisting of 10 Parkinson’s subjects, 10 Essential Tremor subjects, and 10 healthy control subjects to classify test subjects as either Parkinson or non-Parkinson. The rest tremor was measured by recording the three-dimensional position and acceleration of their index finger while at rest over a set period of time using two devices. The first device, the TremorometerTM, has 510k clearance to measure and quantify tremor by measuring acceleration in human patients. The second device, the Leap MotionTM Controller, is a three-dimensional camera that uses two CCD (Charged Coupled Device) cameras, three infrared Light Emitting Diodes (LEDs), and preprocessing in order to obtain position data.

The study was split into two sections. The first section, involves comparing the Leap Motion Controller to the Tremorometer by calculating different tremor characteristics and comparing them to determine if the two devices are statistically similar. The second part of the study involves using those same characteristics in an attempt to classify subjects as either Parkinson or non-Parkinson subjects. This study was fairly successful in comparing the Leap Motion Controller to the Tremorometer. All eight characteristics were found to not be statistically different across trials for either device, suggesting that both devices may be repeatable.

This article suggested that rather than performing two separate trials with the two devices individually, to perform one trial with the two devices simultaneously as done in other similar studies. This would ensure that the same tremor was recorded rather than tremor from the same individual at two different points in time.

It is also recommended that postural tremor be recorded rather than rest tremor, since it is less likely that the Leap Motion Controller will incorrectly record the index finger. This is because if the hand is outstretched, fingers are more spread apart than they would be at rest. When the Leap Motion Controller can distinguish individual fingers as is the case when fingers are more spread apart, it is much more likely to obtain an accurate recording of the index finger. It is suggested that to improve the pre-processing of the data an alternative approach be taken to estimate the spectra on the data. One method is to blind the study to eliminate bias and pre-process each tremor signal individually, applying different filters and windowing to best estimate the power spectral density. It is also suggested that more subjects and possibly more trials be recorded in future works. This would increase the power of the study and add more validity to the results.

Leap motion is a cutting edge technology for hand tracking. Research article "Free-Hand Interaction with Leap Motion Controller for Stroke Rehabilitation"[13] describes how to use leap motion technology in rehabilitating stroke patients. In this paper, it leveraged the technology of free-hand interaction to rehabilitate patients with stroke. It modified the game of Fruit Ninja to use Leap Motion controller’s hand tracking data for stroke patients with arm and hand weakness to practice their finger individuation. In a pilot study, it recruited 14 patients with chronic stroke to play the game using natural interaction. This finding suggests that our freehand Fruit Ninja’s score is a good indicator of the patient’s hand function and therefore will be informative if used in their rehabilitation.

The results demonstrated significant correlations between scores generated from the Fruit Ninja game and standard clinical outcome measures, such as the Fugl-Meyer Arm assessment and Box-and-Blocks Test. The qualitative evaluation of the system was also proved successful. To make the system more accurate and responsive, we also proposed a kinematic model of the hand. Using this model allows us to incorporate 3D parameters of the hand in tracking which in turn makes tracking more robust.

The use of the Leap Motion Controller (LMC) has been extended from its initial purpose in the entertainment industry, towards different applications based on gesture recognition such as remote control, sign language translation, augmented reality and also in health care. In healthcare applications, due to the ability to detect with high precision the finger joints and their movements, the leap motion controller has been used in systems oriented to the rehabilitation of fine and gross manual dexterity, enhanced by a virtual environment that stimulates to the patient.

On the one hand, several works focused on hand motor recovery using only the leap motion controller and a virtual environment are found. In the research paper[29], the prefrontal cortex hemodynamic responses during the executions of demanding manual tasks performed in a semi-immersive virtual reality environment is studied. The leap motion controller is used to track the hand movements and to enable subjects to transpose their hand movements within a virtual 3D task. In a research paper[30], the user-centered methodology for the design of serious game based on leap motion controller is presented. The implemented exercise game accomplishes with both the users and the therapists considerations for the hand rehabilitation. In the research paper[31], the leap motion controller as a gesture controlled input device for computer games was studied. The experience with the leap motion controller into two different game setups was evaluated, investigating differences between gamers and non-gamers with 15 participants. Results indicated the potential in terms of user engagement and training efforts for short time experiences. However, the study results also indicated that gesture-based controls are rated as exhausting after about 20 minutes. While the suitability for traditional video games was thus described as limited, users saw potential in gesture based controls as training and rehabilitation tools. Thanks to the portability and low cost of the sensor, the leap motion controller is appropriated to perform exercises at home and remotely supervised by clinicians. Thus for example, a tool for doctor on which they can prescribe patient to imitate standard exercise hand motion and get automatic feedback, such as score, is proposed in[32]. According to similarity in the scoring, the rehabilitation effect is enhanced. Other similar study, but focused on the cerebral palsy treatment is shown in[33]. Because the purpose of these systems is to measure the similarity between the standard gestures and those performed by the patient, an immersive virtual environment is not necessary. A study for the treatment of motor and cognitive impairments in children with cerebral palsy is addressed in[34]. Integration between patient and virtual environment occurs through the leap motion controller plus the electroencephalographic sensor Mind Wave, responsible for measuring attention levels during task execution. Based on results, the level of attention can be correlated with the evolution of the clinical condition. Besides, others studies integrate support devices in addition to the leap motion controller to assist the patient. In the research paper[35], the fusion of the leap motion controller and the Omega.7 haptic sensor with force feedback capabilities has enabled a bilateral rehabilitation training therapy. The leap motion controller tracks the healthy hand and the Omega.7 device haptic interacts with the impaired hand. It allows bilateral complementary tasks for the training of the coordinated cooperation of the paretic arm and intact arm. Other assisted rehabilitation systems is addressed in[36], using the leap motion controller to visualize in a virtual environment the feedback forces sent by a 3D-printed hand orthosis. The hand orthosis is also commanded by four servomotors that eases the full development of the proposed tasks.

On the other hand, the leap motion controller has not only been used as a rehabilitation tool, but has also been used to automate the assessment of the functionality of the hand. This issue is addressed in[37], where an automated system based on the Simple Test for Evaluating Hand Function (STEF) was implemented. In the case of the Parkinson treatment, a novel index of finger-tapping severity, called "PDFTsi", was introduced in[38]. This index quantifies the severity of symptoms related to the finger tapping of Parkinson's disease patients. Several works are focused on the use of leap motion controller to measure the hand tremor. In [39] study, the authors propose the implementation of a tremor detection system while gesture controlling service robots by the leap motion controller, and head tremor while using an augmented reality application running on the Vuzix M100 smart glasses. Similar work but using only the leap motion controller is studied in [40]. A novel approach of tremor quantification based on an open-source mobile app is presented in[41]. Due to the integration of leap motion controller technology into healthcare applications has begun to occur rapidly, the validation of the sensor data output [42] and the feasibility in neuro rehabilitation [44] are important research goals. The results of these studies provided a proof-of-concept that leap motion controller can be a suitable tool for videogame-based therapy in hand rehabilitation.

2.1.1 HEALTH IMPACT OF PARKINSON DISEASE IN SRI LANKA

The annual years of healthy life lost per 100,000 people from parkinson disease in Sri Lanka has decreased by 35.4% since 1990, an average of 1.5% a year.

Though this has been the trend overall, adjust the filters at the top of the visualization to see how the rate of annual years of healthy life lost due to parkinson disease has changed over time for men and women of specific age groups in Sri Lanka [26].

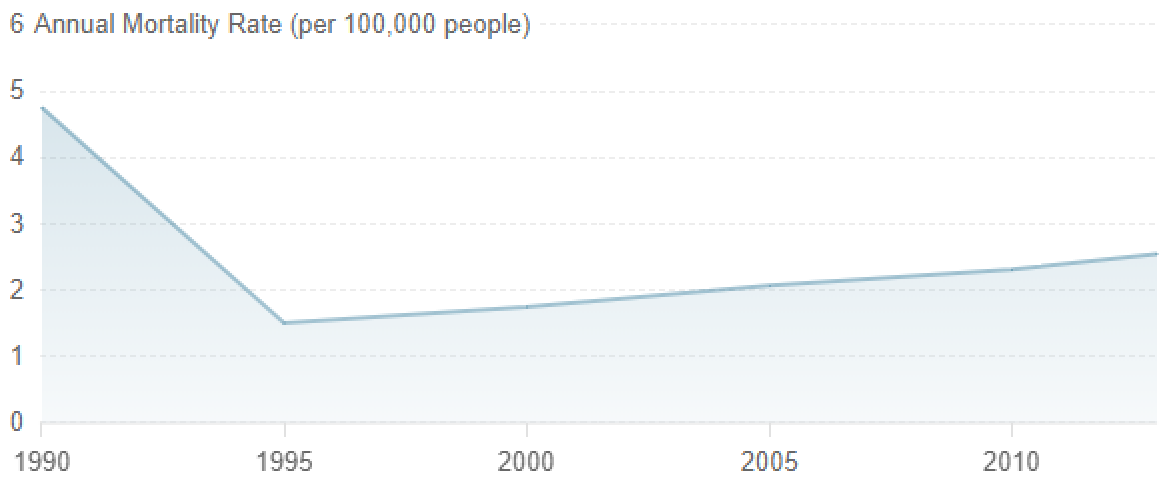

Figure 2.1: Year vs Annual Mortality Rate[26]

For men, the deadliness of parkinson disease in Sri Lanka peaks at age 80+. It kills men at the lowest rate at age 40-44. At 101.5 deaths per 100,000 men in 2013, the peak mortality rate for men was higher than that of women, which were 70.1 per 100,000 women.

Women are killed at the highest rate from parkinson disease in Sri Lanka at age 80+. It was least deadly to women at age 45-49.

For men, the health burden of parkinson disease in Sri Lanka, as measured in years of healthy life lost per 100,000 men, peaks at age 80+. It harms men at the lowest rate at age 25-29. At 796 years of healthy life lost per 100,000 men in 2013, the peak rate for men was higher than that of women, which were 507.8 per 100,000 women.

Women are harmed at the highest rate from parkinson disease in Sri Lanka at age 80+. It was least harmful to women at age 20-24.

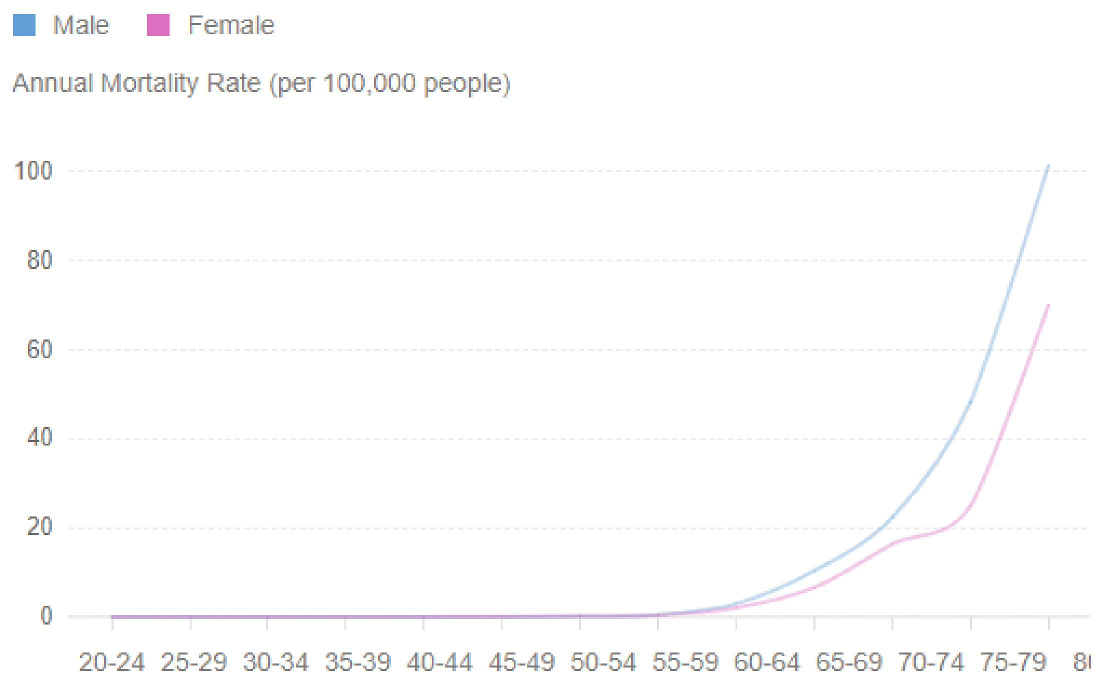

Figure 2.2: Gender and Age vs Annual Mortality Rate[26]

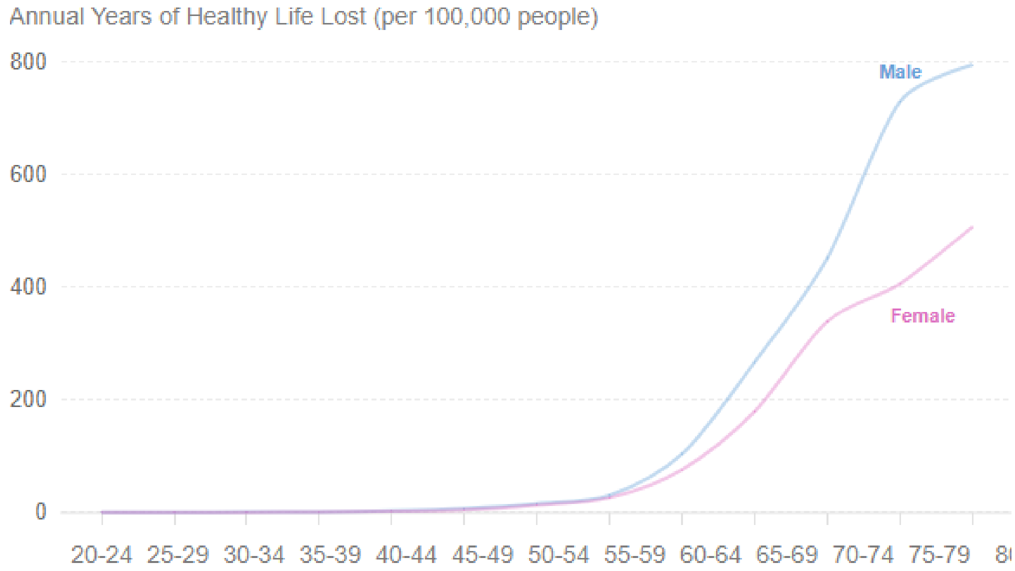

Figure 2.3: Gender and Age vs Annual Years of Healthy Life Lost[26]

2.1.2 PHYSICAL THERAPIES GIVEN TO PARKINSON'S PATIENTS

According to the clinical practice guidelines[44] for physical therapy in patients with Parkinson's disease, the physical therapies of Parkinson's disease divide into three phases; early phase, mid phase and late phase depending on the stage of the Parkinson's disease.

Early phase physical therapy goals are Prevention of inactivity, Prevention of fear to move or to fall, Preserving or improving physical capacity (aerobic capacity, muscle strength, and joint mobility). Information and advice, Exercise therapy (possibly in a group) and Balance are the physical therapies we can give to the patients at this stage. Mid phase physical therapy goals are Maintain or improve activities, especially Transfers, Body posture, Reaching/grasping, Balance, Gait. Cognitive movement strategies and cueing strategies, Balance and Gait training are the therapies we can follow at the mid phase. Maintain vital function and prevention of pressure sores are the late phase physical therapy goals.

As physical therapy treatments for the Parkinson's patients we can focus on Time of treatment, Contra-indications, Dual tasks, Treatment Strategies like Cognitive movement strategies and Cueing strategies and about Clinical guidelines. Patients with Parkinson's disease find it difficult to pay full attention to all tasks when they are performing more than one task at a time (dual tasking or multitasking). Avoiding performance of dual tasks increases the safety of patients with Parkinson's and decreases falls. In cognitive movement strategies Complex activities are transformed to a number of separate elements which are executed in a defined sequence, and which consist of relatively simple movement elements such as standing up from chair, moving chair backward, moving chair forward, lying or standing. In cueing strategies performance of automatic and repetitive movements is disturbed as a result of fundamental problems of internal control. Rhythmical recurring cues are given as a continuous rhythmical stimulus, which can serve as a control mechanism for walking. Other cues used are keep balance, for example when performing transfers, initiating activities of daily living and getting started again after a period of freezing. Cueing strategies (to initiate and continue the activity) and cognitive movement strategies, and also avoidance of dual tasking are important in improving the ability to reach, grasp and move objects.

There are indications that in patients with Parkinson's disease, exercise programs to improve coordination of muscle activity make the performance of activities easier. Change in posture towards flexion can often be corrected by applying feedback or verbal feedback. Exercise program consisting of exercising balance and training strength is effective in stimulating the balance in patients with Parkinson's disease. Exercise program focused on walking, mobility of the joints and muscle strength, decrease the number of falls. Exercise program focused on the improvement of joint mobility combined with activity related (e.g. gait or balance) exercises improves activities of daily living functioning. Program focused on the improvement of muscle strength increases muscle strength and the improvement of aerobic capacity improves motor skills.

Parkinson's disease and exercise guideline of Canada [45] is describing the exercises that the patients to follow to keep up their flexibility, stretching, posture, coordination and manual dexterity, walking, improve balance, strengthening, breathing and relaxation. According to this article, it is important to have good flexibility to be able to accomplish daily tasks. It is preferable to begin with movements that are not too intense, such as tilt head forward and backward, tilt head from left to right, move chin forward and backward, bend the arms while holding a stick, extend the arms while holding a stick, bend and extend the knees and point and flex the feet. The muscle relaxation that occurs after stretching is particularly beneficial for people with Parkinson's disease. Let arms fall by side, join hands together over the chest, raise arms over the head separate hands and hold this position for 10 seconds and bend upper body to the side while holding the same position exercises are recommended mainly for the flexor muscles of the upper body, arms and legs. Parkinson's patients should try exercises that require using the arms and legs at the same time in a series of alternating or opposed movements, gradually increasing the speed of execution. These exercises require a great deal of concentration. Simultaneously lift left arm to the side and raise right knee, simultaneously lift right arm to the side and raise left knee, place hands on thighs one palm up and one palm down and alternately switch the position of hands are some exercises that Parkinson's patients can practice to improve their coordination. To maintain dexterity and grip strength, patients should try wrist and finger movement exercises such as Touch each finger in turn to the thumb, alternate the left and right hands or do both hands at the same time, make a tight fist then open the hand and extend it completely and alternate the left and right hands or do both hands at the same time.

Balance depends on many physical components: Posture, muscle strength, mobility, vision, proprioception and the vestibular system, which is responsible for balance reflexes [45]. Several of these components are affected by Parkinson's disease and decrease the person's ability to keep the balance. When doing exercises to improve balance such as with feet slightly apart, shift your weight from one hip to the other and swing one leg back and forth then repeat with the other leg, make that there is a stable support nearby at all times. The goal of strengthening exercises is to promote greater range of movement and improve joint flexibility, as these both tend to decrease as the disease progresses. Repeating the exercises helps maintain strength. While sitting, with 1 to 3 kg weights on the wrists, extend then bend the left arm then repeat the exercise with the right arm and while sitting with 1 to 2 kg weights on the ankles, extend, then bend the left leg then repeat the exercise with the right leg are very beneficial for the extensor muscles of the arms and legs.

2.1.3 LEAP MOTION CONTROLLER

The Leap Motion Controller, shown in Figure 1, is a USB 3D camera that connects to a computer and is claimed to measure positional data accurate to within 0.01 mm. The device, made by Leap Motion, Inc., is very small with a height of 1.27 cm, a width of 3.05 cm, a depth of 7.62 cm, and only weighs 45.36 g. The Leap Motion Controller uses two CCD (Charged Coupled Device) cameras and three infrared LEDs to obtain depth information. As illustrated in Figure 2.6, on the following page, the device is capable of detecting a roughly hemispheric area of about 0.23 cubic meters[27].

Figure 2.4: Leap Motion Controller

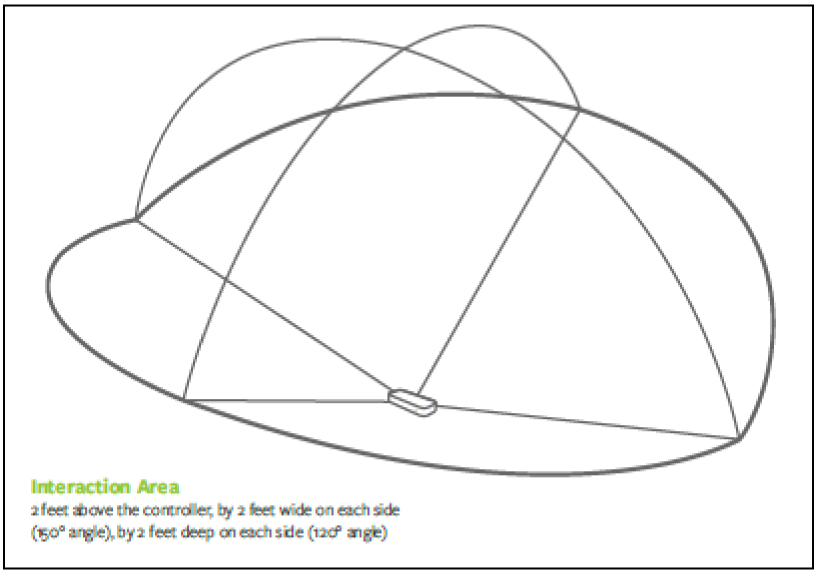

Figure 2.5: Interaction area of Leap Motion Controller

The Leap Motion Controller is capable of detecting and tracking hands, fingers, and tools in its field of view. The device captures data one frame at a time and the rate at which this occurs, or frame-rate, can vary based on the lighting conditions, but typically occurs at approximately 100 frames per second (fps). The device is capable of recording the three dimensional fingertip positions, which is done in millimeters relative to the device's origin. The Leap Motion Controller follows a right-handed Cartesian coordinate system, with the origin centered at the top and middle of the Leap Motion Controller as shown in Figure 3. The data from the Leap Motion Controller is accessible using the Leap SDK and a supported programming language such as C++, C#, Objective-C, Java, JavaScript, and Python.

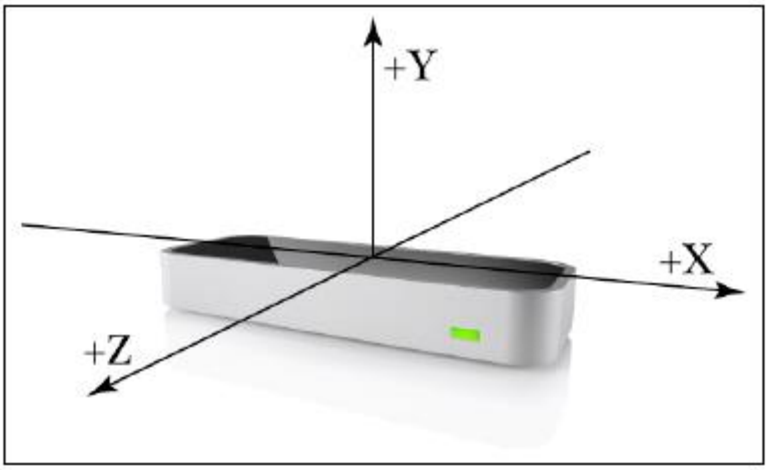

Figure 2.6: Leap Motion Controller Right-handed Coordinate system

The Leap Controller hardware itself is the center of this frame of reference. The origin is located at the top, center of the hardware. That is if you touch the middle of the Leap Motion controller (and were able to get data) the coordinates of your finger tip would be [0, 0, 0]. In its normal position, that is on a desk with the user on one side and the computer monitor on the other, the green LED is facing the user, then the user is "in front" (+z) of the controller and the monitor screen is "behind"(-z) the controller. If the user enables automatic orientation, the Leap Motion software adjusts the coordinate system if the controller is reversed (the green LED is facing away from the user).

<u>The Interaction Box</u>

The interaction box is an axis-aligned rectangular prism and provides normalized coordinates for hands, fingers, and tools within this box. The Interaction Box class can make it easier to map positions in the Leap Motion coordinate system to 2D or 3D coordinate systems used for application drawing.

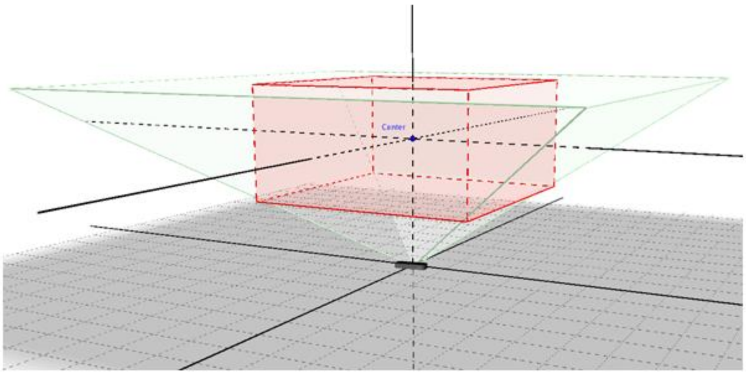

Figure 2.7: Interaction Box of the Leap Motion

When the user's hand or finger stays within this box, it is guaranteed to remain in the Leap Motion field of view. We can use this guarantee in the application by mapping the interaction area of the application to the area defined by the Interaction Box instead of mapping to the entire Leap Motion field of view [28].

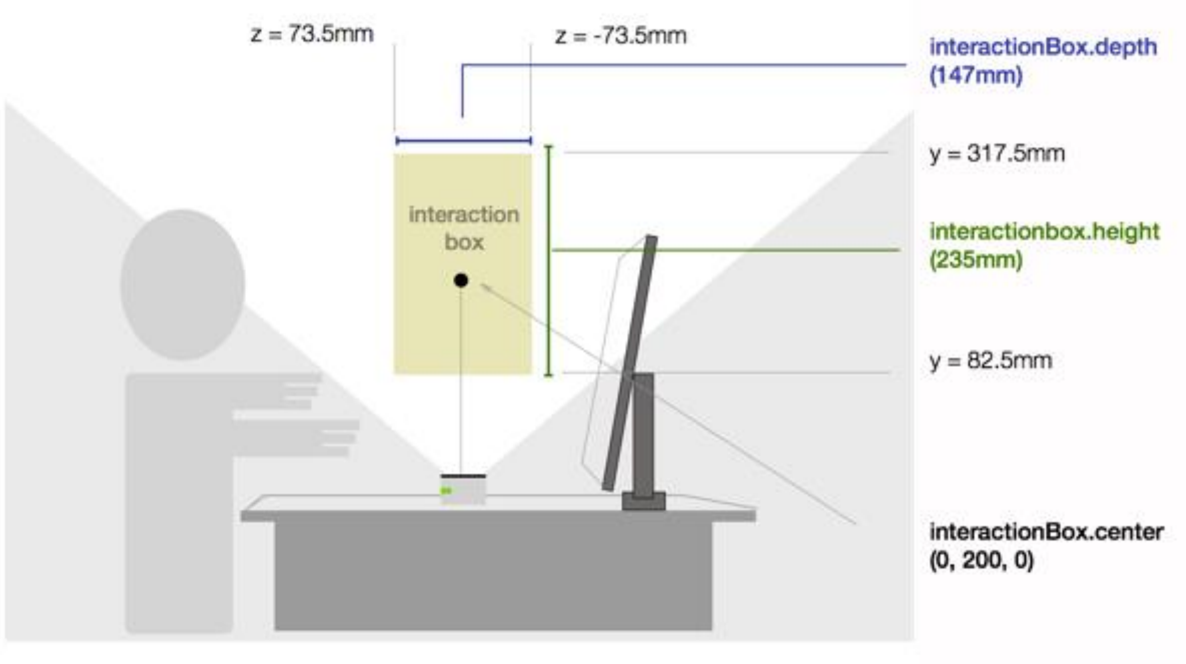

Figure 2.8: Measurements of the Interaction Box

CHAPTER 03

3.1 SYSTEM ANALYSIS AND DESIGN

The Serious Game developed for this study try to imitate exercises included on traditional physical therapy, with the added value that the immersive virtual environment tries to hook the patient to the point of not focusing on the fact of being in a rehabilitation session. Human movement is a complex behavior for Parkinson’s patients. Physical therapists maximize an individual’s ability to engage with and respond to his or her environment using movement-related interventions to optimize functional capacity and performance.

The physical therapist’s role is distinctive in that we are educated to systematically evaluate movement behavior and underlying impairments in the context of an individual’s function and performance. Physical therapy provides a customized and integrated plan of care to achieve the individual’s goal to reduce stiffness and improves mobility, posture, balance and gait. Exercises that require large, rhythmical movements through a full range of motion have been shown to decrease rigidity. Each day, patients should spend their time on strengthening, range of motion, task performance and coordination exercises of the more involved limb. Force them to do as many tasks as possible with the involved upper limb, using the other limb only to help stabilization.

In addition, doing some drills like tap the fingers, tap the wrist and then tap the forearm moving from the elbow as fast as possible will improve the balance responses and postural alignment. They can also practice turning the palm up and down as fast as possible, throwing and catching balls, putting small objects in small containers, taking your index finger to quickly touch objects that are moving those that and still.

Main objective of the proposed research is to develop a system to give hand therapies like tapping fingers and squeezing and stretching the fingers of the hand. Such activities will overcome the broadness of doing exercises and make the hand therapies more interesting and fun. We are using the leap motion to track the finger movements, and then we record and analyse data of the patient to monitor the progression of the patient. This system will contain another option if the patient is willing to do a regular exercise session, then it will guide through the sequence of steps from warming up to cooling down. It will monitor the time and give instructions to the patient. All the exercises and physical therapies include in this system are recommended for the Parkinson's patients to improve their flexibility and body control.

3.1.1 THE SYSTEM HARDWARE

To conduct rehabilitation for hand/finger motion disabilities is an adequate hardware for virtual reality environment needs to be set up. Here, we are presenting Leap Motion + 2D display.

This combines 2D display and Leap Motion as input device, as shown in the following figure. 2D display is a standard part of every computer, and any kind of 2D display can be empowered for this task. However, limitations are obvious, as the conversion of real 3D hand/ finger motions to a 2D virtual world renders one dimension unavailable for preview. Losing this insight into the third (depth) dimension limits the set of applications.

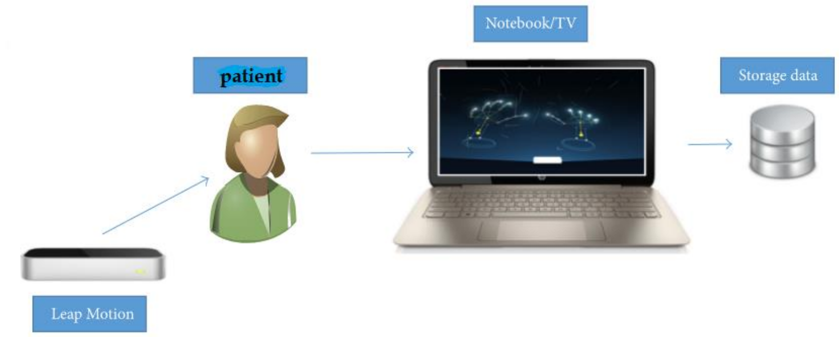

Figure 3.1: Interaction of patient/user with proposed virtual environment.

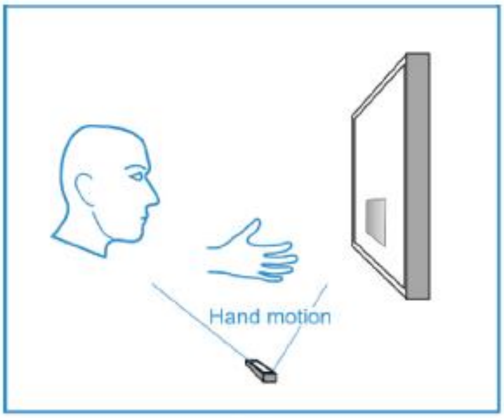

Figure 3.2: System hardware setup: Configuration with 2D display

3.1.2 THE SYSTEM SOFTWARE DESIGN

The present concept for the system software is designed by utilizing a database and activities which imitates physical therapies which developed using serious gaming concept. The database is a well-defined collection of data specific for a user. There will be User's personal information, Specialist medical reports and prescription data and Rehabilitation progress data stored in the database.

Personal information of the user should include sex, age, hereditary disease risk, and all other personal data which could influence the rehabilitation progress. Specialist medical reports and prescription data are the most valuable data for creating future exercise plans and prognosis of expected results. Rehabilitation progress data should contain all important data collected during exercises performance sorted by date.

The serious game developed in the virtual reality software part is responsible for all feedback from system to user, and should be implemented on the game software already supported by Leap Motion SDK and three js. Finally it will show guidance and results depending on the chosen analysis and monitor the progression of the disease.

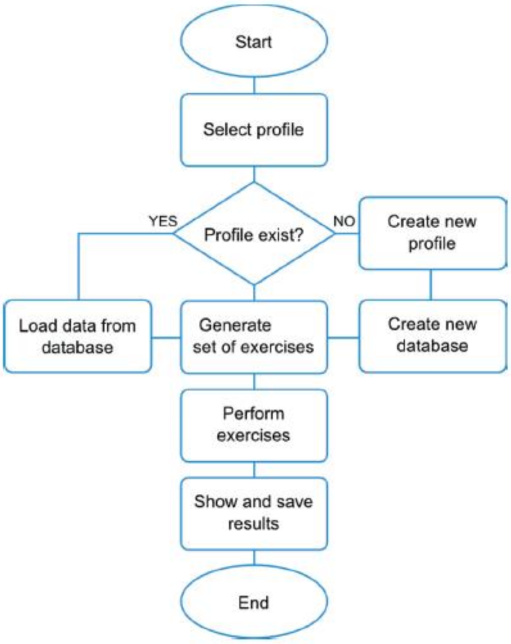

Figure 3.3: General workflow of the application

Database of the application is created as follows to record the details of the patient and the user who is using this system. The user may me a nurse or a physiotherapist who is login to the system and keeping the records of the personal information and progress data of the patient.

logindetails

UserId	FirstName	LastName	Email	Password	NIC

patient_register_info

UserId	PatientId	PatientName	NIC	Age	Address	Phone	RegDate	Reports	Prescription

progress_data

UserId	PatientId	Date	Test01	Test02	Test03	Test04

3.2 METHODOLOGY

As a result of the discussion between the physiotherapists who is working in the Physiotherapy unit at National Hospital of Sri Lanka (NHSL), I captured the physiotherapy treatments given to the Parkinson's patients. According to the information gathered from the physiotherapy unit, there is a wide range of exercises that is applicable to whole body that has been practicing to the patients for their rehabilitation. In order to narrow down the scope of the project and to focus on one specific area, I have chosen some finger therapies to implement in this system that will be very useful to improve their coordination.

We combined the physical therapies for fingers of the hand with the Leap sensor. Since our focus is finger individuation, we customized the therapy so that patients can do their own hand therapies without a physiotherapist. Using the hand tracking information of the Leap sensor, we are going to monitor the patient’s finger movement. The setup includes a PC/notebook and a Leap sensor that is plugged in via its USB. The physical therapies runs on a browser (e.g. Google Chrome) while the hand is monitored using our java API code which is written on top of the Leap sensor's SDK.

To determine the feasibility of free-hand interaction using Leap Motion controller for Parkinson's exercises, we are hoping to conduct a pilot study with Parkinson's patients. The participants should ask to play our free-hand finger therapy. We also wish to simplify the exercises so that patients with Parkinson's with different levels of hand deficits are able to do the finger therapy.

To avoid turning the rehabilitation exercises into boring and repetitive tasks, exercises are often interesting. The patients who are engaging in the proposed system can be keep a record of their improvement after doing these finger therapies regularly, which makes it appropriate for hand rehabilitation.

To track the finger motions of the patient, a stand-alone Java program was written in order to access and record the positions detected by the Leap Motion Controller. The Eclipse platform can be used to write the code necessary to access and record the data obtained from the device for thirty seconds. The stand-alone Java program that was written, recorded the position of each fingertip on the hand that exhibited the most tremor. The code was run twice for each patient and each time it was run, it saved a separate comma delimited CSV file and keeps the records. Then that data is used to analyze, compare and monitor the progression of the Parkinson's patients.

Figure 3.4: Leap Motion Application

The hand therapies for the patients created using three js and it is combined with the inputs of Leap Motion controller. After completing the implementation part of the system, it was tested for a set of Parkinson's patients. The potential risks that were determined for the participants were mild and considered unlikely. The predetermined potential risks are discomfort from attempting to hold one hand still, boredom or frustration during the recordings and stress if the patient exhibits too severe of upper limb tremor to record the data. In order to reduce the potential risk to the subjects, a physician was present throughout all studies.

Since we are considering the patients who are at the early stages of Parkinson’s disease, the implemented exercises will be helpful to rehabilitate the Parkinson’s patients according to the information provided by the Physiotherapist at National Hospital of Sri Lanka.

CHAPTER 04

4.1 IMPLEMENTATION

The most significant feature is the flexibility of the proposed activities of the application to define a specific therapy protocol that is easy to customize to the patients particularities. Another relevant characteristic, in addition to the capability to exercise, is the potential of the proposed system as an assessment tool. The decreasing times gathered in each session by the application, are coherent with the improvement of the physical condition of the patients, measured by the traditional tests.

Using this system, a Parkinson patient can do their therapies for hands without the guidance and instruction of a physiotherapist. Basically this system will keep the records of the registered patient output results. Then we can monitor the progress of the patients with respect to the time. Using a registered user name and password patient can login to the system. Patient can create a user name and a password when they first login.

After the patient successfully login to the system, patient can choose their hand therapies (in this system five hand therapies are available). Then they can proceed with their therapies, where the results will be recorded by the system.

Following is the user interface where you can enter your user name and password to login to the system. If the user is login to the system for the first time, then he/she has to create a new user login by clicking the "Create New Login" button.

Figure 4.1: Login page of the system

If you don't provide a valid user name and a password, then you will get the following message as shown in the following Figure 4.2.

Figure 4.2: Login Failed Dialog Box

After user is successfully logged into the system, the user can select the hand therapy that is suitable for the patient Figure 4.3.

Figure 4.3: Hand therapy selection page of the system

Patients can select various types of hand therapies as shown below, Figure 4.4, Figure 4.5, Figure 4.6.

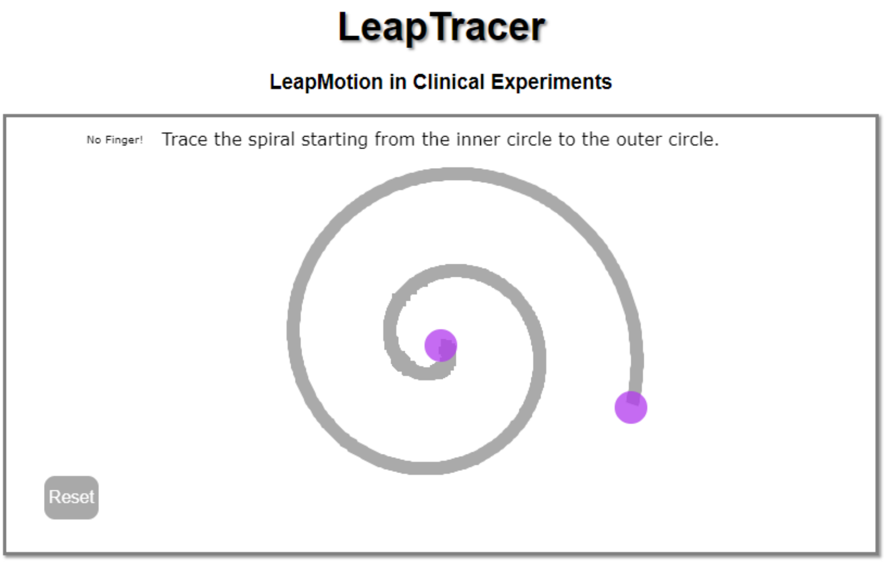

Figure 4.4: First Hand Therapy of the application

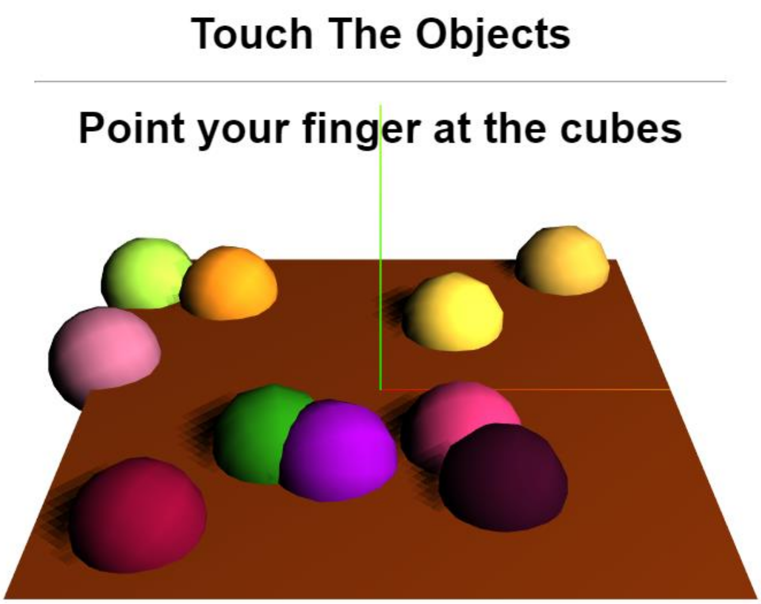

Figure 4.5: Second Hand Therapy of the application

Make a Tight Fist and Extend the Hand with the Object

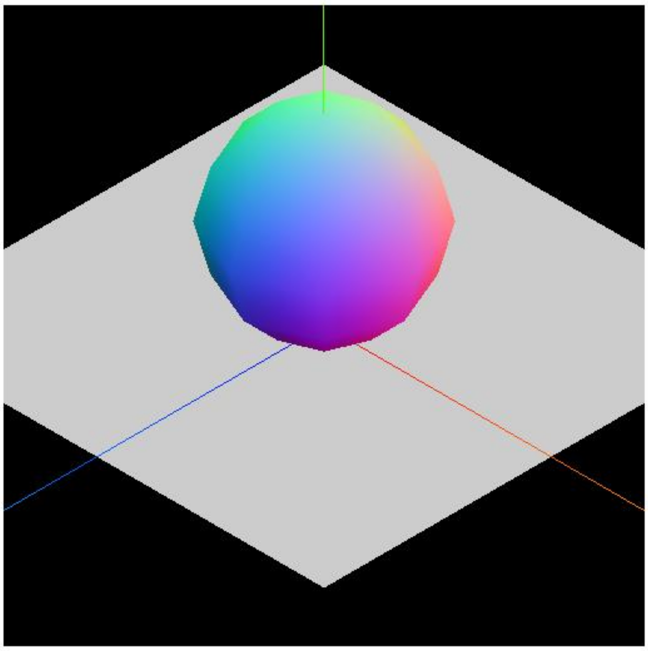

Figure 4.6: Third Hand Therapy of the application

CHAPTER 05

5.1 EVALUATION

After designing the framework, we conducted an extensive evaluation with real patients. For the design of the study, we collaborated with a therapist from National Hospital of Sri Lanka. The plan to evaluate this project is to use this system for patients who are suffering from Parkinson's disease. The aim is to keep the record of data of that specific set of Parkinson's patients. Participants are planning to recruit from National hospital clinic as well as the volunteers who wish to take part in this experiment.

Participants are planning to recruit in person during their clinic visits with their physician or nurse. If the potential participant expressed interest in the study and fit all inclusion/exclusion criteria, informed consent materials were provided. I will review the document with the potential participant, which give the participant an opportunity to ask questions. Potential participants will then give time to read the document in its entirety, ask questions, and speak with friends/family members if they desired. If the potential participants agreed to participate in the study, the user accounts will be created for each participant and keep the record of the results of each hand therapy. Each therapy is done twice or thrice a week and keep the record of data over the time.

This evaluation method is an experiment based evaluation since it is going test the system against a set of Parkinson's patients and record the relevant data over a period of time. There's no bench mark or a baseline to evaluate this approach. We are going to keep a track of the result values of each therapy and then monitor the progression over time.

This application was tested using two Parkinson's patients at NHSL physiotherapy unit and got the results as follows:

	Task 01	Task 02
Patient 01	Accuracy 9%	Time: 46.03 Seconds
Patient 02	Accuracy 12%	Time: 32.09 Seconds

To get the maximum benefit of this application, we should record the output data of each and every task of the patients for a period of time and then analyze it to monitor the progression of the patients.

CHAPTER 06

6.1 CONCLUSION

This system is based on the Leap Motion controller, which is an optical sensor based on stereo vision. The system incorporates the controller with advanced software, enabling rehabilitation progress monitoring and customization of the exercise program. The Leap Motion controller is a promising device for enabling user-friendly gesture recognition services. Based on this project, the Leap Motion device can be accurately classified by representing its 3D gesture paths as set of 2D image projections, which can then be used to do physical therapies for the Parkinson's patients.

The serious games implemented in this work, are a versatile tool in rehabilitation processes, since different functional problems can be treated according to the configuration defined by the therapist. Different treatment protocols can be created in an easy way. One of the applications is to use these gestures to navigations in the Virtual Reality Environment. In this research, we adopt four different gestures with hands to represent moving left/right, focusing a fingertip, tapping and stretching fingers. Using these gestures the patient could do the physical therapy that will be helpful to rehabilitate the patients. Based on the user experience, the use of the leap motion controller based serious game application in the treatment of Parkinson’s has been favorably accepted. The utility of the games has been highlighted by the users, however there are certain exercises that have been difficult to perform and required the help of the therapist.

The concept of the system can also be extended with a reminder, and a remote monitoring component. The reminder will ensure regular training, while the monitoring component will enable specialists to remotely check the progress of the rehabilitation.

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APPENDIX A

INTERFACES AND THE CODING OF THE THERAPIES