Master Thesis
Implementation of the Kinect sensor and Leap motion for distance study of motor skills in Parkinson's disease

ICT in Health-Care

Nastaran Hosseinpour

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CHALMERS

Department of Signal and Systems
Chalmers University of Technology
Sweden, Gothenburg
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Abstract

Monitoring the progression of patients, in this case Parkinson's patients, and their response to treatment is really important both for patients and health-care professionals. Traditional assessment is done sporadically by trained clinicians. Developing technologies to assess symptoms in a cheaper and more frequent way is an important factor that would considerably improve treatment and follow-up for these patients.

Depth cameras are a good way to provide such tools. The Kinect device is mostly used for video-games, but it can also be used for serious purposes. The Kinect sensor provides 3D position of body joints, which can be used to determine how a person moves. The Leap motion is another type of technology, which represents an entirely new way to interact with computers to assess fine scale movements of the hands and fingers. This thesis investigates the potential of the Kinect and Leap motion sensors for measuring and assessing movement information. This information will be used for developing and testing an ICT tool for both assessment and rehabilitation of motor skills in Parkinson's patients.

The system was tested with real patients to demonstrate to what extent this technology is applicable for providing useful information for both assessment and rehabilitation. Results show that the version of the Kinect sensor used in this study can monitor whole-body movement, but it is not appropriate for monitoring hand movements. The Leap motion sensor can be used to complement some limitations of the Kinect sensor.

Preface

This study was performed as a master thesis project supported by grants to professor Martin Rydmark by Center for Person-Centred Care at University of Gothenburg (GPCC), Sweden and was mainly carried out during spring 2015. GPCC is funded by the Swedish Government's grant for Strategic Research Areas, Care Sciences (Application to Swedish Research Council nr 2009-1088) and co-funded by University of Gothenburg, Sweden.

The results from this project as a master thesis project for Chalmers University of Technology, carried out at Alkit Communication AB are going to be used for future investigations in ICT industry.

A special thanks to professor Martin Rydmark for supervision the project and medical advising, Lars-Åke Johansson's company for continuous support and technical supervision, Anita Sant'Anna for distance technical supervision, professor Bengt Arne Sjöqvist for examining the project, Dr. Bo Johnels for neurology consultation and Jurgen Broeren for occupational therapy advices.

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1 INTRODUCTION

Neurological disease and damage cause profound alteration of a person's life. The conditions are often life long and demand continuous treatment and rehabilitation, as well as support in the activities of daily life. Managing daily treatment as well as regular activities of daily living often becomes unmanageable, and travels to and from doctors for rehabilitation and being under control regularly are tiresome [1], [2], [3], [4].

It is important to monitor motor skills in Parkinson's patients to be able to quantify symptoms such as; bradykinesia (slow movement), and hypokinesia (decreased bodily movement) as parameters for clinicians and scientists in order to gauge disease severity, optimize medication schedules, and determine the effectiveness of intervention approaches. For this kind of disease, development of tools for remote assessment of motor function together with experts in clinical care and ICT can make a big difference for studying the progression of the disease [1], [2], [3], [4] .

The Unified Parkinson's Disease Rating Scale (UPDRS) is an overall assessment scale that quantifies the signs and symptoms of Parkinson's disease. The UPDRS is made up of several sections, which are evaluated by interview and clinical observation. These sections require multiple grades, related to symptom severity, assigned to each extremity such as; each hand and each foot. Following the UPDRS scores over time provides insight into the patients' disease progression. There is also a designed clinical test that evaluates the severity of Parkinson's symptoms, which is called Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS). This system provides features such as; process, format, and clinometric testing plan for study of the patients' status. This test works similarly to the UPDRS, while highlights the limitations of the original UPDRS such as; lack of information regarding additional non-motor elements [5], [6], [7], [8].

Developing services working remotely for monitoring motor skills of the Parkinson's disease patients at home is beneficial for patients, health-care systems and also society for so many reasons, such as reducing costs, making the most of the limited available time of therapists, and also possibility of repetitive practice of movements for better rehabilitation. Taking the patients to health-care centers or having doctors and therapists at home, generates large amounts of costs, while home-based ICT tools work much cheaper in so many cases. The concept of therapy at the home can be interpreted more flexible and convenient for the patient and also provides the possibility of repetition of exercises in frequent way. Sometimes for stimulating the neural reactivation in some regions of the brain controlling movements, and exercises must be repeated so many times in a day [9]. This goal can not be achieved by therapy sessions alone since fulfilling the required frequency of practice is almost impossible at the health care professionals sides. It is also impossible to meet therapists and neurologists continuously for unlimited numbers of practices, while by utilizing ICT systems data can be stored and be checked at another convenient time.

The high-tech tools and technologies as medical devices at a doctor's office are mostly too expensive to be implemented at home, while the Kinect is low-cost and easily accessible. Developed software for use with the Kinect can track patients' movements. The program could also provide positive feedback to encourage a patient to do exercises. Studies have shown that only a few people with motor disabilities do the exercises as they should.[5] This might cause some difficulty and the system won't be able to work properly. While positive feedback from a home rehabilitation program the therapy exercises will be more encouraging and engaging, and the results will be more reliable [9].

A proposed solution is using depth cameras such as the Kinect sensor, which is a good help to the diagnosis and monitoring of motor skills objectively and on a daily basis. By developing a system based on utilizing the Kinect sensor, it is possible to make multiple continuous tests over long periods of time, compare data and alert to irregular behavior [9].

1.1 Problem formulation

After a diagnosis of Parkinson's disease, patients usually experience a loss of coordination, balance, and mobility that can be improved by physical therapies including a range of exercise to regain the coordination and the balance to some extend. ICT tools for monitoring Parkinson's Disease symptoms need to be able to acquire and assess movement information with high accuracy and precision. New technologies such as Kinect and Leap motion need to be evaluated in order to determine if their use is appropriate and advised for such clinical applications [10].

1.2 Task

In this thesis work the limitations and capabilities of the Kinect sensor have been studied, and some clinometric experiments have been done based on the processed output data from the Kinect sensor. Different methods have been investigated to extract some useful motor features related to the disease in different patients. These methods are able to assess different parameters of the patients' movement disorders, such as; level of bradykinesia, tremors, instability, and the leg agility, while doing specific exercises. These methods will be used for developing a validated ICT tool for monitoring disease progression. For studying a more fine scale hand and finger's movements, Leap motion controller has been utilized in part of the study.

2 BACKGROUND

2.1 Parkinson's Disease

Parkinson Disease (PD) is a chronic degenerative disease of the central nervous system that produces movement disorders and changes in cognition and mood. Most patients report gradual onset of aching, fatigue, or malaise, followed by tremor in one or more extremities, typically a hand when it is at rest. Other

Figure 1: Parkinson's disease

common symptoms include difficulty getting up from a chair or turning over in bed; a change in vocal quality (a softer, less audible voice); shuffling gait that becomes faster after a few steps (festination); and a stooped posture. As the years pass, frequent falls may occur. Occasionally a tendency to fall backward (retropulsion) replaces festination. Facial expressiveness may diminish, and the handwriting may become smaller or more cramped (micrographia). Generally it can be said that Parkinson's disease (PD) is a multi-system neuro-degenerative disorder, which damages motor coordination and gait. Consequently, people with Parkinson's disease have reduced mobility and increased risk of slips, trips and falls.

2.2 Patient care

The concept of cooperation between health care institutes is a process where different care and nursing units and actors can participate. The focus is the patient's overall clinical situation and needs. All actors involved in different types of activities can access selected information in a distributed unit service structure based on the roles that they have related to the individuals. All activities are structured into activity types and activity instances. Some activities are aimed for assessment of conditions and some of activities are aimed for interventions related to goals that change. The health plan is an important concept keeping all assessment activities, goals and intervention activities together. The plan can contain prevention as well as assessment and intervention activities. The individuals and relatives are heavily involved in helping the patients to complete the performance of the activities. For advanced home rehabilitation, the frontiers in this field could be for example:

- Powered exoskeletons
- Various tele-medicine applications for communication between a live or a virtual physiotherapist and the patient.
- Tools to improve the patient-machine interface, like 3D stereoscopic visualization, haptics(sensory/motor), tools like a glove or a stylus giving the sense of touch and proprioception and audio/video communication [9].
- Serious games for rehabilitation of movement disorders.

Teamwork benefits the Parkinson's disease patient, who may require a social worker, nurses, primary care providers, and a neurologist, the efforts of a registered dietitian, physical therapist, occupational therapist, speech therapist, social worker, primary care providers, and a neurologist. If patients have periods of immobility alternating with periods when their mobility is severely impaired, they may need changes in their medication schedule or addition of new medications. The patient and family are taught safety measures to prevent injury caused by falling and swallowing techniques to deal with dysphagia. Prescribed drugs are administered and evaluated for desired effects and any adverse reactions, and the patient is instructed in their use and potential side effects so that the dosage can be adjusted to minimize these effects. The nurse, physician, or occupational or physical therapist teaches the patient and family about safety measures to prevent injury; about drug-related dietary restrictions; and about the need for frequent small feedings, to provide needed fluids, calories, and dietary bulk. The patient should plan daily activities to occur when he or she feels rested to prevent fatigue, but the patient needs to exercise regularly to prevent contractures and muscle atrophy. The ability to measure activities of daily living (ADL) for people with Parkinson's disease via an e-health system would have a significant impact on the equity, accessibility, and management of the condition for patients who live in rural and remote communities. A computer-based e-health system should incorporate videoconferencing with calibrated assessment tools [9].

2.3 Clinical Assessment of PD(UPDRS)

The UPDRS, Undefined Parkinson's Disease Rating Scale, has long been the major rating scale that is used to assess severity of symptoms of Parkinson's disease. The original form of the scale assessed daily life activities, motor skills as well as mental capacities such as; behavior and mood. By implementing the scale, a neurologist observes the performance of the patient when moving the arms, legs and body and then assigns a score to the performance from 0 (normal) to 4 (severe). Consequently, the higher score in this system, the more serious disability from PD. A new updated version of the scale has also been developed by the professionals of Movement Disorder Society, which adds new assessments of non-motor symptoms of PD. This new system is called MDS-UPDRS, Movement Disorder Society-UPDRS, as a revision of the UPDRS with sound clinimetric properties.

2.4 Problems with clinical assessment

For regularly supporting the daily life of patients or elderly people, who are suffering from a chronic disease, different issues should be considered. Study of the symptoms and the rate of the progression, are always sporadic, expensive and time consuming. A proposed solution for helping patients stay longer at their home is utilizing tele-home-care devices, which are able to monitor the patients conditions round-the-clock and eliminate some of the high costs, time, and barriers. Some of the common problems of specific type of patients can be controlled at home for saving financial resources as well as time. In this practice by putting the patient or assistant as a leader of their own health in a team with health-care professionals, health result and the quality of life can be improved.

2.5 Information and communication technology(ICT) in health-care

For improving services in health-care, implementing the capabilities of Information and Communication Technology can make a big difference. By evaluating ICT tools in health-care, factors such as; improvement of the clinical decision making, communication, costs, information management, and access to care can be done in a more frequent way. These ICT solutions, make all patients and health-care professional to have access to technologies that improve safety and quality of care, while generating smart solutions to monitor different circumstances of the patients when necessary, while ignores a large amount of the problems mentioned before regarding time and costs .

2.6 Previous works on instrumentation for PD assessment

In order to reduce cost for visiting medical facility and continues monitoring of the patient suffering from Parkinson disease researcher at Georgia Tech Research Institute (GTRI) has developed an iPhone application. This application will also help other neurological conditions to be monitored and relay the collected data to the medical personal.

Computer vision (CV) could have been useful in such assessment, so gait disorder assessment methods were developed using this technology. In order to find method several papers has been reviewed which can be helpful by using only one personal web camera for self treatment of Parkinson patient.

The technique used for such assessment is analyzing image. A video frames giving an image, which can be analyzing gait through video frames. By using efficient image segmentation algorithm the system gives severity level of the symptoms. And making cost effective solution is the main concern.

2.7 Kinect in clinical applications

In recent years, the availability of inexpensive depth cameras, such as the Microsoft Kinect, has boosted the research in monocular full body skeletal pose tracking. From previous experiences of stroke rehabilitation it is known that the Kinect tool works well in an interactive situation in assessing kinematic information of motor function of the trunk, arm and leg. The advent of affordable depth imaging technology has made an enormous impact on motion capture in rehabilitation; ever since Microsoft Kinect has become available to developers, many papers have been published on rehabilitation using the Kinect sensor. The current section discuss the developed systems using Kinect that targeted assessment of post-stroke physical disability and rehabilitation. It separates the clinically-evaluated systems from the systems with no evidence of clinical experiments and reviews both.

2.8 Previous work on Kinect for PD assessment

Before introducing the technology of the Kinect, motion capture was used for rehabilitation exercises to provide tools for physical therapist. Some of them has been studied at the beginning of this work to realize how the systems really work. For instance, a virtual environment for stroke rehabilitation that tracks patients' arm movements during reaching exercises was developed by White et al. [6]. Other studies have also been done to identify the Kinect's capabilities for being used in physical therapy. Another Kinect-based rehabilitation system was developed by Chang et al. for assisting therapists while working with students suffering from motor disabilities [7]. At Clemson University, a 3D virtual environment using the Kinect is under development, in which a virtual arm mimics a patient's arm movements for interacting with virtual objects in the game [4] etc. The Kinect has been also used for some other medical purposes outside of physical therapy.

Parkinson's Disease Rating Scale (URSDRS) is a tool developed for assessing Parkinson patients and this application assess all of five movements based on it combining with some useful feature of Kinect sensor including depth sensing, skeletal tracking and high definition video. Kinect sensor measure the movement of body parts for example hand or arm rotation, tapping by hand etc. and it relays the data for physician's analysis. This application allows patient to reduce hospital visits as physicians can monitor the data remotely and can focus on the patient behavior. They can get data much more frequently and can suggest medication or visits. Being low cost also gives this system an advantage to be used, as Kinect sensor is quite cheap. Tests and development of the system are being made in Sweden currently and it is still under clinical trial. It is also suggested to be used for gamification and other forms of rehabilitation exercise to make this more fun.

It is often to use prerecorded machine standard from an examiner for interaction/instruction purpose. But it is seen that patient still need some interaction or individual assessment during this process. This is a drawback, which leads to a conclusion either such practice should be omitted or an alternative should be suggested [5]. Studies on Kinect sensor shows that it is not capable of detecting body movement finely. It can give good estimation of overall body movement but for the movement of human hand, it will not be able to give us accurate movement. Constructing a model of body parts based on the high definition video recording will be helpful. Alternatively leap motion can also be used, which is able to compute exoskeleton of human hand.

2.9 The Kinect sensor and tools

In today's life, detection technology is used in appliances, entertainment and safety but it is also aiding medical diagnostic. Detection can be achieved in many ways using infrared, microwave, optics and magnetics. Kinect sensor is one of the peripheral developed by Microsoft for the purpose of entertainment for its gaming platform Xbox360. But Kinect sensor for the Xbox 360 video game system has also potential applications in the physics laboratory especially for the medical purpose. Microsoft introduced Kinect sensor in November 2010. The combination of the peripheral is that the sensor unit is connected to a base with a motorized pivot. In order to track player body, it was designed to be positioned above or below a video display and for hand movements in 3D space, which allows users to interact with the Xbox 360. The Kinect contains a RGB camera, depth sensor, IR light source, three-axis accelerometer and multi-array microphone, as well as supporting hardware that allow the unit to output sensor information to an external device. In this thesis, the capabilities of the Kinect sensor as a data acquisition platform for use in movement disorders analysis in Parkinson's disease is evaluated. Several sample experiments demonstrating the sensor's use in acquiring positional data are provided. Two sensors make up the depth component of the Kinect: an infrared projector and a monochrome CMOS sensor.

This combination work together and make the basis for gesture recognition and skeleton tracking. The infrared light projector shines a grid of infrared light on the field of view, and a depth map is created based on the rays that the sensor receives from reflections of the light off of objects in the scene. The depth map specifies the distance of the surfaces of objects from the viewpoint of the Kinect. Many other depth sensing systems similar to this determine the depth map of the scene based on the time it takes the light to return to the source after bouncing off objects in the sensor's view (termed the time of flight method). In addition to this, however, the Kinect encodes data in the infrared light as it is sent and analyzes the distortions in the signal after it returns in order to get a more detailed 3-dimensional picture of the scene This 3-D depth image is then processed in software to perform skeleton tracking.

The Kinect output naturally lends itself to the use of a 3D rectangular coordinate system.

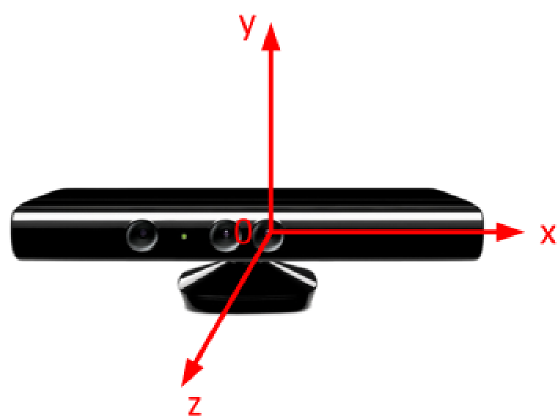


Figure 2: The Kinect sensor and coordinates

Given the aforementioned depth range of 0-10 m and a sensor field view of 57° horizontally and 43° vertically, this naturally defines an experimental space of 12 m in the x-direction, 9 m in the y direction, 10 m in the negative z direction. In order to acquire real-time data using a PC can be problematic. Usually data acquisition tools/devices are typically implemented using dedicated real-time processors that have been designed to acquire data in a loss less fashion based on the desired rate of data capture. Operating systems of the PC on the other hand were not designed to minimize timing variability (timing jitter) with respect to completing tasks. From a typical PC users' perspective, variations in timing of multiple milliseconds are not of great concern. However, timing variations in data acquisition in real-time may have a significant effect on the interpretation of results. Main purpose of Kinect sensor was for use with the Xbox 360 and the games developed by Microsoft for this platform.

For medical purpose and especially therapy facilities it is not likely to have an Xbox at disposal. For the purpose an application developed for a computer was much more practical. Drivers and APIs were needed to allow this program to interface with a computer instead of an Xbox. The software developed for this project had two main purposes. The first of these was to demonstrate that it would be possible to develop useful rehabilitation software tools with the Kinect, another was to collect data for analysis. The software written using

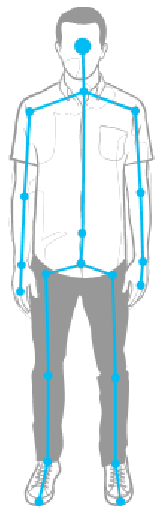


Figure 3: Whole body view

the Microsoft SDK provides similar functionality to give additional information about a patient's movements [10], [11].

2.9.1 Skeleton tracking with OpenNI

Compared with an RGB image, a depth image contains information relating to the distance of the 3D objects surfaces from the camera. Depth image reveals extra information about 3D position of pixels. Extracting depth information from an RGB image is not trivial and is computationally expensive. Also, with depth information, segmentation and background subtraction becomes considerably easier and more accurate; these encourages RE developers to prefer depth sensors over RGB cameras in motion capture applications. An important feature of the available depth sensors is skeleton tracking systems such as OpenNI that they provide some information and code similar to Software Development Kit(SDK). In June 2011 the developers accessed body joint positions and orientations.

The OpenNI enables tracking for 20 joints, shown in the figure X, Y, and Z coordinates are given in number of pixels for X and Y of each joint and Z in millimeter as the distance between joint and the sensor, according to the axes shown in the figure.

Microsoft's joint tracking algorithm identifies joint positions by processing a depth image. The algorithm first comes up with a joint guess for each pixel in a depth image, along with a confidence level for each pixel. After this, it chooses the skeleton that is most likely given those joint labels and confidence levels.

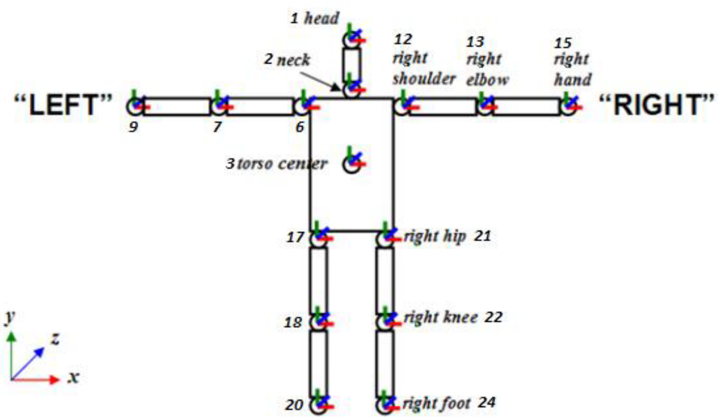


Figure 4: Whole body view

But before this could be done, the algorithm can also be changed in a way to know how to make accurate guesses for joint positions [10], [11].

2.10 The Leap motion and tools

Leap is another motion sensing device by Leap Motion. The main motivation behind building Leap was to alleviate 3D modeling which used to be accomplished using conventional human computer input devices such as mouse and keyboard. Leap Motion has partnered with both Asus and Hewlett Packard to embed its technology within future Asus/HP notebook/PCs. The leap unit is a 3" x 1.2" x 0.5" USB peripheral device. It is designed to be positioned in front of the screen (of a notebook or PC) on the table. The device consists of 3 infrared LEDs and 2 cameras. Leap's field of view is a hemisphere above the device with radius between 25 to 600 millimeters. The leap detects and tracks both fingers and tools (with similar shape of fingers such as pen). It provides developers with hand and fingers information such as finger tip position, hand velocity, hand/finger direction, etc. As stated in Leap Motion's web-page, the skeletal model of the hand will be released in the near future. But Leap Motion has not announced any decision on giving developers access to raw data (by the date of this article). In terms of gesture recognition, so far, Leap's SDK provided four gestures of key tap, screen tap, swipe, and circle. Leap's SDK is available for Windows, Linux, and OSX platforms and programming languages of C++, C#, Unity, Java, Java-script, and Python. Examples of clinical studies that have used Leap Motion controller are [15], [16].

Figure 5: Leap motion

3 Methods

The aim of this project is to study the accuracy of the Microsoft Kinect sensor for analysis and monitoring of movement disorders in Parkinson's patients by processing the data to gain smooth 3D position and velocity estimations of body joints. The output raw position data of the Kinect sensor are treated as signals to be precessed with signal processing methods for gaining 3D smooth and processed position data and consequently linear velocity estimations in a way for quantifying body posture, bradykinesia (slow movement), and hypokinesia (decreased bodily movement), as parameters for clinicians and scientists. These results will be used to gauge disease severity, optimize medication schedules, and determine the effectiveness of intervention approaches.

3.1 Data and noise from the Kinect sensor

Related to the patients with Parkinson's disease, their motor performance will be remotely registered with the Kinect sensor, connected to a lap-top computer or pad. Some features of MDS-UPDRS procedure can be extracted and tested interactively with doctors and patients by using the processed signals. The processed signals; such as position and velocity are extracted from raw position data of this sensor and the results from these signals will be used to design models for having a system, which is able to record data remotely from the patients for further study [10], [11], [12].

3.2 Data Acquisition

The data from Kinect sensor is a set of raw data of positions, while calculating velocity characteristics from this data needs a lot of filtering. A possible solution could be using Kalman filter as a technique for model based signal processing and estimation. The data obtained with Kinect normally cannot be directly fed into the designed computer vision algorithms. Most of the algorithms take advantage of rich information (RGB and depth) attached to a point. In order to correctly combine the RGB image with the depth data, it is necessary to spatially align the RGB camera output and the depth camera output. In addition, the raw depth data are very noisy and many pixels in the image may have no depth due to multiple reflections, transparent objects or scattering in certain surfaces (such as human tissue and hair). Those inaccurate/missing depth data (holes) need to be recovered prior to being used. Therefore, many systems based on Kinect start with a pre-processing module, which conducts application-specific camera recalibration and/or depth data filtering [10], [11], [12], [13].

3.3 Data Analysis and Data processing

To be able to test the sensor abilities, a control subject performed a series of clinically functional movements whilst being concurrently monitored with the Kinect sensor. The subject stood directly facing the Kinect sensor at a distance of 3 m, which was estimated as adequate distance to collect accurate data. The Kinect sensor was positioned 1 m from the ground, with the lens perpendicular to the floor and pointing towards the subject. The whole test was done during 60 seconds and the control subject was asked to have a smooth and continuous simulated tremor in order to simulate the movement of a patient. The mentioned test included standing still for 20 seconds, and then being softly pushed by a researcher forward, and then recording for 40 more seconds.

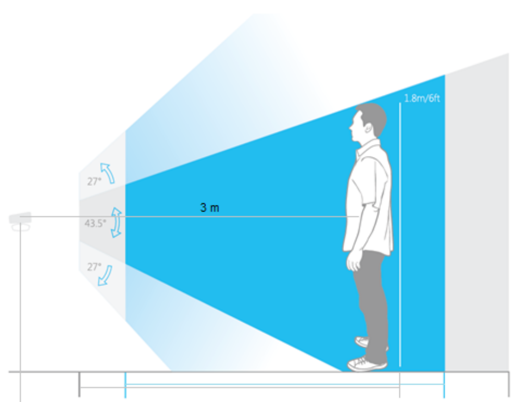


Figure 6: Whole body view detected by Kinect from 3 meters

A third test followed the same procedure, while the control subject stood on one leg. The result from this test was studied at different levels to be able to understand the abilities and disabilities of the sensor to prepare useful information. The data was studied carefully and different methods were tested to study the noise and analyzing the data. Finally useful information such as; smooth position data and linear velocity estimation were gained, which were the input data for further study.

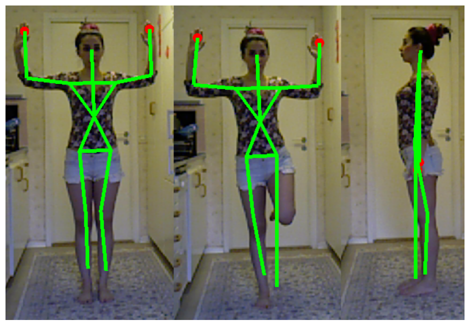


Figure 7: Whole body view

The data from Kinect sensor is a set of raw position data of joints in 3D, over the test time. Sample data of a frame, collected from a test is shown in the below table. The order of the joints is also following the order of the joints in openNI.

Skeleton Joint	**Raw x (Pixel)**	**Raw y (Pixel)**	**Raw z (mm)**
SkeletonJoint HEAD	x=334.9017	y=107.64891	z=2961.8127
SkeletonJoint NECK	x=331.56174	y=143.52585	z=3004.7502
SkeletonJoint LEFT SHOULDER	x=304.6082	y=142.91408	z=3008.0527
SkeletonJoint LEFT ELBOW	x=266.6375	y=145.11893	z=3056.0273
SkeletonJoint LEFT HAND	x=262.2248	y=88.76047	z=2863.1848
SkeletonJoint RIGHT SHOULDER	x=358.57462	y=144.13896	z=3001.4478
SkeletonJoint RIGHT ELBOW	x=399.36163	y=145.71465	z=3018.7385
SkeletonJoint RIGHT HAND	x=404.9462	y=83.62843	z=2933.0369
SkeletonJoint TORSO	x=330.5683	y=180.1799	z=2992.8123
SkeletonJoint LEFT HIP	x=311.21054	y=216.65582	z=2983.105
SkeletonJoint LEFT KNEE	x=311.40433	y=298.26187	z=2937.6355
SkeletonJoint LEFT FOOT	x=313.6207	y=365.4688	z=3073.3027
SkeletonJoint RIGHT HIP	x=347.95078	y=217.59993	z=2978.6436
SkeletonJoint RIGHT KNEE	x=342.7443	y=296.8623	z=2983.0737
SkeletonJoint RIGHT FOOT	x=332.18808	y=366.6301	z=3074.6077

Table 1: Sample data collected at distance of 3m from sensor

3.4 Calibration the sensor

3.4.1 RGB camera calibration

For analyzing the depth values, for instance taken of a flat wall, a distortion in z direction could be observed. To analyze the distortion, number of depth values at different distances from Kinect, were captured. After capturing depth values perpendicular to a flat wall, at different distances with 50 cm increments, the distance dependence of the depth map distortion was studied. By comparing z values of different tests with the true distances, the best distance for getting minimum distortion of depth map was chosen as the optimized distance for the tests. To be able to detect the whole body with reliable z values, the distance of 3 meters was chosen for the tests, even though this distance is only the optimized distance and some tests should be done nearer to the sensor to gain fine resolution.

3.4.2 Depth map calibration

By studying the output data of Kinect and comparing the data with true values, it was concluded that the joint positions in x-y plane, from Kinect are noisy and unstable. Some kind of filtering must be performed in order to smooth the position data. For the error detection in x-y plane, a ruler with 1 meter long was used in the experiment. Ruler was held by two hands, perpendicular to the sensor, at the distance of 150 cm from the ground. The next experiment was done at the height of 200 cm from the sensor, while the distance between two hands was 60 cm. The difference between hands was supposed to be 40 cm while the output data from Kinect was not showing the same distance. There are available mathematical formulas, for calculating the true distances from the pixel output values of the sensor. A similar error was also recorded in y direction. By knowing different parameters of the calculated error, possible characteristics of filtering will be considered.

3.5 Noise Analysis

To be able to study the movement of the head, in the performed exercises, plots of x, y and z of the head are shown in the below picture. X, y and z over different frames captured by Kinect are plotted respectively, in blue, red and green. This sample data is showing the head position data over samples for the control subject while doing defined control test.

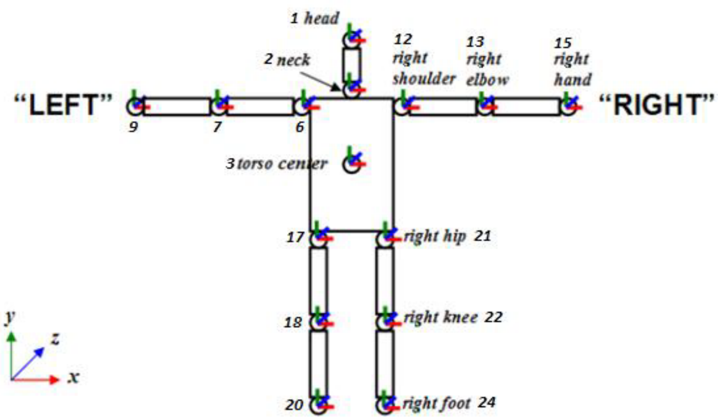


Figure 8: Whole body view

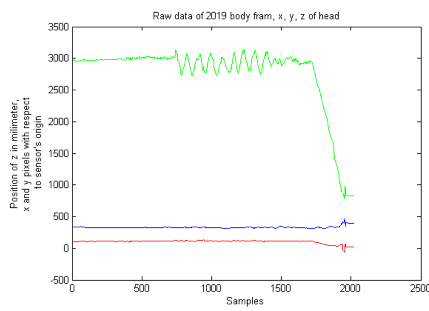


Figure 9: 3D position data of x_{head} for the whole test

By definition, the speed is the derivative of the position, so a natural estimate is Euler approximation. In Matlab, this is done using the command diff. By applying the Euler approximation to the measured signals, the output is as below:

Apparently, differentiation is an extremely noise-sensitive task. To be able to design the filter, it is necessary to study the characteristics of the signal in the frequency domain. The sampling frequency of the test was estimated as the number of samples over the test duration, which had an average of 30 for different tests. It is almost the same as the ability of Kinect for collecting 30 body positions per second. The position signal of the head in the frequency domain is shown in figure 10.

The output of the velocity estimation of this method is shown in figure 9, which contains some delay. The reason is that the original design of the filter is not causal. It is centered around time 0. So, in practice there is a need to shift it to become causal. In other word, it is impossible to have a good low-pass design without sufficient amount of delay. As a sanity check, it can be verified

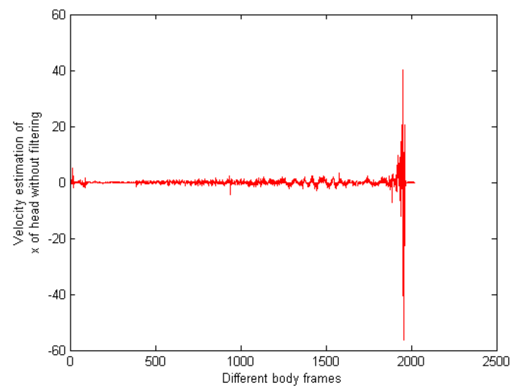


Figure 10: Raw velocity estimation of x_{head} for the whole test

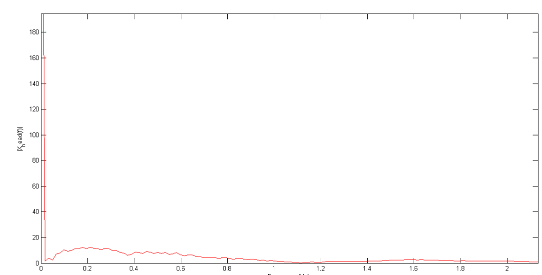


Figure 11: Single-Sided Amplitude Spectrum of x_{head} for the whole test

that the delay is equal to half of the designed filter length.

By comparing the output of the filter at this stage, with the velocity estimation of diff command, the delay could be measured and removed.

Velocity values for x of head, for the 11th to 20th frames are listed in the below table, which also contains some negative velocity values. This test was modeled with visible amounts of tremors to be more realistic, and these negative values are corresponding to the back and force movements, in x-y plane while shaking.

Frame 11	**Frame 12**	**Frame 13**	**Frame 14**
-4,25187968299454	-4,46106232957516	-3,58706177798682	-2,11642335121850
Frame 15	**Frame 16**	**Frame 17**	**Frame 18**
-0,514336401986843	0,851875242695703	1,75710179099708	2,12742232179720
Frame 19	**Frame 20**		
2,01731364289197	1,56804570163012		

3.6 Filtering the Noise

Designing the filter depends on some different parameters; such as the cut-off frequencies. Usually deciding on parameters is not automatic and needs some judgment. There are many works on estimating these parameters but they are not totally accurate. At this stage of the design, a value was fixed like some available examples. By reading the frequencies from a FFT plot and knowing the frequency of sampling, an estimate was made. By checking it for different data from different tests, a good estimation was done. For making sure that it is a reasonable number, looking at the FFT of the signal and making a rough estimate of the design is a good way to make the design finished. Finally, they can be tuned for the best final result. Two different methods were used to filter the raw position data of the Kinect sensor, to be able to get a smooth position data. With a smooth position data, linear velocity estimation of joint while doing the exercises can be done mathematics formulas.

3.6.1 Low-pass filtering FIRPM filter

As it was discussed above, for the joint positions to be useful and smooth enough for velocity computation, different filtering methods should be implemented. The output data of velocity after filtering with two different methods will be compared by each other. The most reliable velocity estimation will be chosen for further study. By comparing the frequency of the data for special type of exercises and the frequency of the noise, the possible solution of the filtering will be found. By comparing the results from Fourier transforms of position signals, it is obvious that the frequency of the noise is much higher than the frequency of the joints position data, then a low pass filter is adequate. Since some spikes of the real patients are also interesting, for different exercises, characteristics of the filters might differ.

3.6.2 Linear velocity computations by designing FIR differentiators

A possible solution for filtering and velocity estimation is using FIRPM filter as a technique for model based signal processing and estimation. Other techniques; such as Kalman filtering will be tested to be able to control the results. This method is applied to remove the high frequency noise form the noisy position data, by designing a FIR filter, to be able to get an estimation of velocity. Since differentiation is an extremely noise-sensitive task, to be able to improve the estimator, the fact that the signal is low-pass, whereas the noise is mostly high-pass is considered. The purpose of this part of the study is to design a FIR filter that performs approximate differentiation for low frequencies, while blocking the higher frequency band. Using FIRPM to design a 10th order FIR filter that performs differentiation in the frequency interval, where f is normalized frequency, i.e. f = 1 corresponds to the Nyquist frequency is the first step. Then designing a 50th order low-pass filter with pass-band and stop-band is the second step of this filter design. Finally, the final low-pass differentiators will be designed by convolution the above filters. By definition, the speed is the derivative of the position, so a natural estimate is:

$$\hat{v}(n) = \frac{p(n) - p(n-1)}{T} \tag{1}$$

where T is the sampling interval and p(n) is the sampled position. In Matlab, this is done using the command diff.

Obviously, the filter could have been designed in one step, but this requires assigning appropriate weights to the different frequency bands. A filter such this introduces a delay and for the final results of velocity this delay should be compensated. The result from this part is compared with the results from Kalman filter, and the one which is more similar to the directly derivation with out filtering will be chosen as the adequate filter design.

3.6.3 Kalman filtering

Kalman filtering is a commonly used technique for model based signal processing and estimation since it was presented around 1960. The technique is named after one of the key inventors Rudolf Kalman. Kalman filtering is part of the class of linear filtering techniques which are based on time domain design criteria. First consider a simple filtering example to introduce the basic concept of Kalman filtering. Assume an airplane is moving along a straight line. The position of the airplane in some coordinate system is p(t) [m]. The speed of the airplane is s(t) = dp(t)/dt [m/s]. A discrete time model of the movement of the airplane is then:

$$p(t+T) = p(t) + Ts(t) \tag{2}$$

$$s(t+T) = s(t) \tag{3}$$

where T is the sampling interval. In the model above the speed is assumed to be constant. This assumption is in practice not realistic. The airplane could be subject to turbulence etc. and the pilot will most likely also change the speed of the airplane over time. These changes can also be incorporated into the model by adding two extra inputs w1(t) and w2(t) and we obtain:

$$p(t+T) = p(t) + Ts(t) + w_1(t) \tag{4}$$

$$s(t+T) = s(t) + w_2(t) \tag{5}$$

It is natural to regard the extra inputs $w_1(t)$ and w_2(t) as small perturbations which over time has a zero average. The model above is called a constant speed model and describes how the position of the airplane changes over time. A radar station can measure the position p(t) of the airplane. However all measurements are subject to noise so a natural model of the measurement is:

$$y(t) = p(t) + v(t) \tag{6}$$

where v(t) is the measurement noise. An air track controller need to know the speed and position of all airplanes in the airspace so the core signal processing problem is how to provide him with the best estimates of the position and speed of the airplane given only noisy measurements of the position obtained from the radar sensor.
In principle there are two sources of information involved in this estimation problem.

- The equations which describes the movement of the airplane assuming constant speed (1, 2)
- The measurement of the position of the airplane(3)

A Kalman filter is an algorithm which in an optimal way combines these two sources of information. It provides an estimate of both the speed and position of the airplane. To derive the Kalman filtering equations we will use a probabilistic view of the problem using multivariate random variables.

3.6.4 Linear velocity computations by designing KALMAN FILTER

The Kalman filter can be used for many estimation tasks. A classical "Wiener-filter type" example is to recover a distorted and/or disturbed random signal. The difference to the Wiener filter is that the Kalman filter is time-varying. This means that it can take initial uncertainty into account in an optimal way, and also that the dynamics describing the signal do not have to be stationary. Like the Wiener filter, the Kalman filter gives an LMMSE (Linear Minimum Mean Square Error) estimate of a signal. In some cases there are better non-linear filters, but not if the signal and noise are jointly Gaussian distributed. The Kalman filter has therefore found a wide use in applications such as adaptive filtering, calibration and target tracking. In this thesis the Kalman filter was applied to track moving joints using 3D Kinect measurements. The joints are assumed to move freely in the xy-plane, and the position at each time stamp is described by the variables x and y for type of measurements. It is assumed that the joints are nominally moving along a xy-plane, which means $\Delta Z = 0$. However, to allow for random changes in the movement, the following model is used:
$\ddot{x} = w_x$
$\ddot{y} = w_y$
Where w_x and w_y are zero-mean white noise terms. The state vectors are also introduced as below:

$$s(t) = \begin{bmatrix} s_1(t) \\ s_2(t) \\ s_3(t) \\ s_4(t) \end{bmatrix} = \begin{bmatrix} x(t) \\ \dot{x}(t) \\ y(t) \\ \dot{y}(t) \end{bmatrix} \tag{7}$$

The name s(t) for the state vector is unusual, but is used because x(t) denotes the x- coordinate. The state equations are then:

$$\begin{array}{c} \dot{s_1}(t) \\ \dot{s_2}(t) \\ \dot{s_2}(t) \\ \dot{s_4}(t) \end{array} = \begin{array}{c} s_2(t) \\ w_x(t) \\ s_4(t) \\ w_y(t) \end{array} \tag{8}$$

Now, measurements usually come in discrete-time. It is then more practical to use a discrete-time model of the target motion.

3.6.5 Theory

Finite-difference approximation is applied as below:

$$\dot{x}(t)|_{t=kT} \approx \frac{x(kT+T) - x(kT)}{T} \tag{9}$$

Where T is the sampling time, to the continuous-time state equations. Thus, derive a discrete-time state-space model of the form:

$$s(k+1) = As(k) + w(k) \tag{10}$$

Where A is a 4×4 matrix (from now on s(k) is used to denote discrete time, corresponding to t = kT). By Assumption that a camera-based sensor measures the xy-position of the target at discrete time k, with additive noise $v_x(k)$ and $v_y(k)$ respectively. The measurement equation is derived as below:

$$z(k) = Cs(k) + v(k) \tag{11}$$

Where z(k) is a 2×1 vector and C is 2×4.

A real-world target will of course not behave exactly according to our model. The usefulness of the Kalman filter stems from that it can give useful results even when the model is not perfect. By applying the Matlab-implementation of the Kalman filter to the joint tracking data, he input to the Kalman filter is the noisy measurements in each direction. By figuring out suitable values for T, Q and R from how the true data are generated, a good estimate of position data and velocity are accessible. By using the zero vector as initial state vector, and $100 \times I$ as initial state covariance matrix, how the algorithm behavior changes will be investigated. For instance by increase/decrease R by a factor of 10. For fine-tuning the performance of the algorithm testing different scaling of R (increasing R by a factor of 10 has the same effect as decreasing Q by the same factor) can be done.

Below pictures are showing the raw noisy position data of head joint, the filtered position data, velocity estimation before filtering and after filtering in z direction. Results are checked in z direction for a better estimate of filter since the output data in this direction is in mm. The sample test is from a control subject with specific rate of tremors, who is trying to fluctuate perpendicular to the sensor like the below picture while feet are on the ground in distance of 3 meters from sensor:

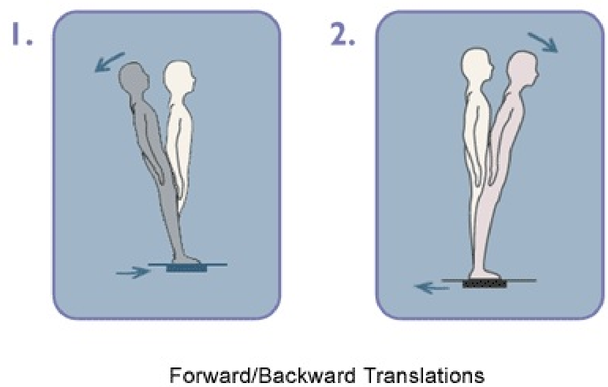


Figure 12: Whole body view, feet on the ground, forward and backward fluctuations

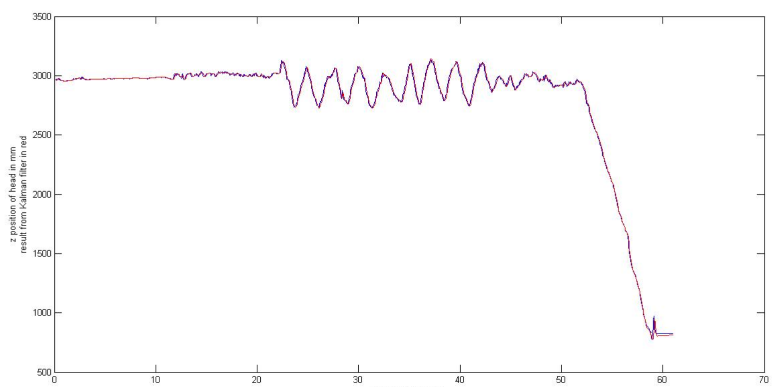


Figure 13: Estimation by Kalman filter vs unprocessed position

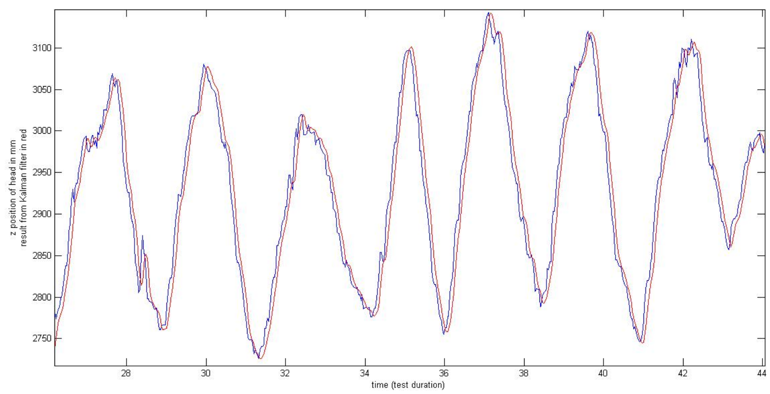


Figure 14: Estimation by Kalman filter vs unprocessed position

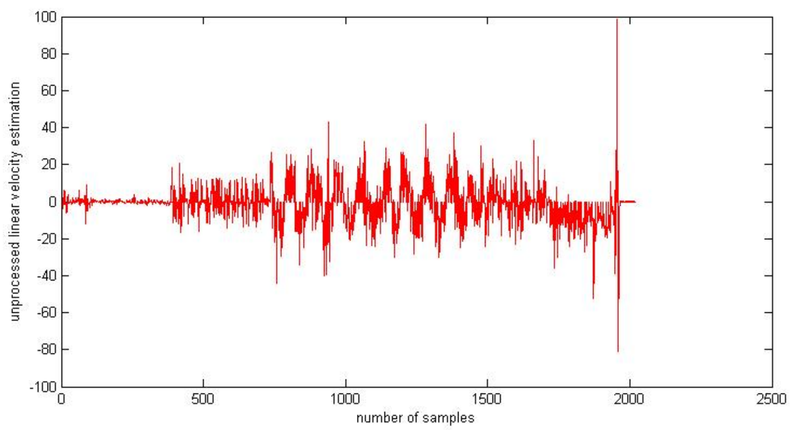


Figure 15: Unprocessed linear velocity estimation

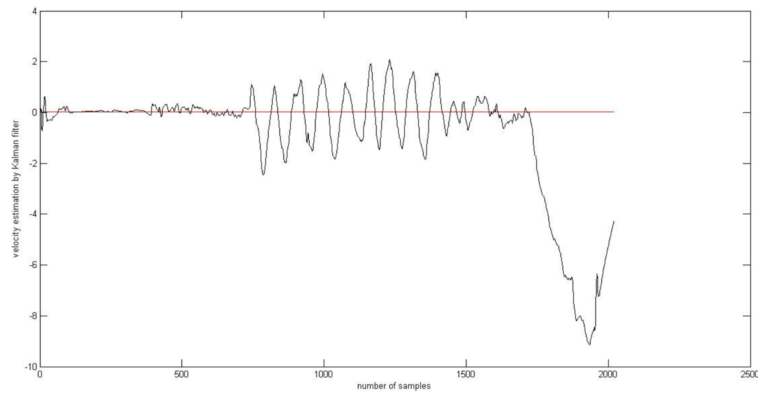


Figure 16: Estimation by Kalman filter

3.7 Possible assessment to be done by utilizing Leap Motion

Since the Kinect sensor was not able to detect the small movements of the hands and fingers, Leap motion has been utilized to be able to do a complementary study of the hand movements of PD patients. A Java code was written in Eclipse in a way to screen the hand movement of the patient while he/she is following a straight line shown on the screen. That is, if there is a line on the screen, it could be possible to see how well he/she can trace the line with moving the hand in the air. By comparing the line on the screen and the result from the patient exercise the relevant physician is able to see how shaky is the hand and study the rate of the tremors. Although the tremors of PD patients' hands are occurred at rest but this tool is showing the capabilities of the Leap motion for being implemented for further studies of the hand movements. The result from this assessment is discussed in chapter 4.

4 RESULTS

The laboratory tool designed in this thesis is able to create an easy-to-use, affordable way to follow up remotely with Parkinson's patients. Taking advantage of Kinect's depth sensing, high-definition video, and skeletal tracking, the application can assess different movements based on the Unified Parkinson's Disease Rating Scale (URSDRS), a widely used tool for assessing the status of Parkinson patients. For example, the Kinect application measures different angles of between different parts of the body as well as the velocity of some joints while doing the exercises. The tool analyzes the movement data and presents the results for physician's assessment. The results from this tool can be interpreted as raw data for patients' different movements which needs physician's or therapist's judgment. The physicians can compare the data from different tests or days from a patient together, or comparing them with a reference data or even comparing the data from different patients together. By doing these comparisons and interpreting the output data they will be able to define the status of the patients.

4.1 Designed tests for measurement of physiotherapist variables

By capturing smooth three-dimensional movement patterns, some parameters such as pose, simple movements of legs and arms, as well as postural control, could be assessed. Even-though they are not completely accurate, but they might allow the clinicians to ensure their patients doing the movements correctly.

Assessing the progression of movements over time could be done by calibrating the program with an initial posture or natural pose and comparing their movements with this initial posture. Exercises for testing different movements such as flexing the knee and bringing it up or straighting the hands in the Sagittal plane and parallel with body, are examples for studying the bradykinesia or rigidity. The level of bradykinesia progression could also be achieved by joints velocity interpretation. These velocity estimations of body joints, while doing exercises provide useful information for studying the agility of the specific joints. This can provide a lot information regarding study the movement algorithms to show how the subjects do the exercises.

For developing such a tool for movement analysis in Parkinson's disease or any other type of disease which cause movement failure, different models are designed base on input processed data coming from previous steps. Models are designed in Matlab environment and there are some necessary conditions to be considered before performing the exercises. Different algorithms are modeled for different purposes and the results are shown as graphs, tables or written text on the screen as outputs of the software depending on the task.

By considering the results, the level of abilities and disabilities of the patient for performing a specific movement, as well as level of agility of specific limb by studying the velocity characteristics of the related joints, will be under control for further study. a limited number of test are collected which are discusses with neurologists and therapists to analyze to what extend Kinect sensor is able to prepare useful information for remote registration of movement disorders. In this project, three different subjects with moderate level of disease. The results of these subjects are also shown in the tables and by analyzing these results, further study regarding designing different parameters to be achieved by these results for the final setup will be discussed in the later sections.

4.2 Different definitions and body movement models to extract useful information in rehabilitation

Parkinson's patients are suffering from different problems, which are known as symptoms of this disease. Section 3 of UPDRS is about the motor examination of Parkinson's patients which are different issues to be studied at this section as listed below:

- Speech
- Facial Expression
- Tremor at rest
- Action or Postural tremor of hands
- Rigidity
- Finger Taps
- Hand Movements
- Rapid Alternating Movements of Hands
- Leg Agility
- Arising from Chair
- Posture
- Gait
- Postural Stability
- Body Bradykinesia and Hypokinesia

By considering the limitations of the Kinect sensor, some part of the above section have been chosen to be studied by the Kinect sensor, such as; Rigidity, Leg Agility, Arising from Chair, Postural Stability and Body Bradykinesia and Hypokinesia. Since the used Kinect sensor is not able to give a precise information of the hand and finger movements, the Leap motion has been implemented to compensate this specific limitation of the Kinect sensor. There have been different models developed for studying the mentioned factors, while a model has been also developed for study of the hand movement with output data of the Leap motion. The subjects were asked to do some exercises in front of the sensor over a specific time. There are some instructions which should be followed by the subject to gain a precise data from the sensor. To be able to study different movements in a convenient way, there are some definitions for different anatomical poses, planes and movements described below.

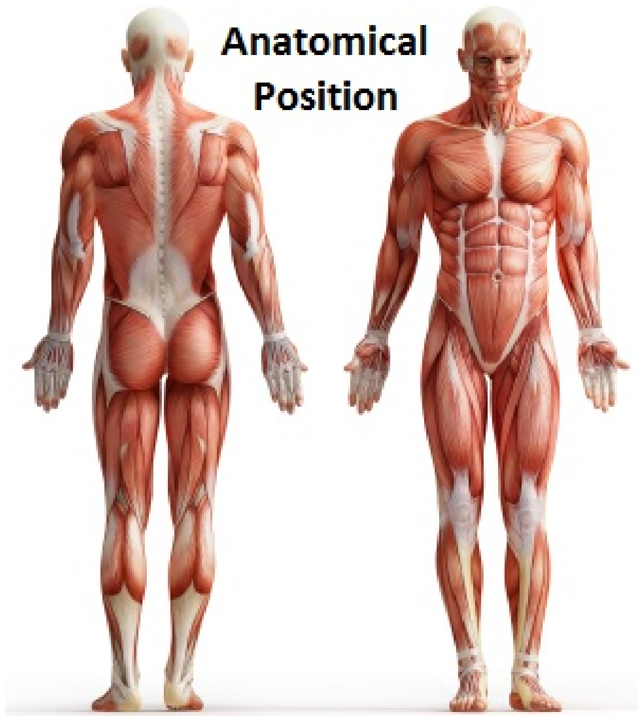


Figure 17: Anatomical position of standing

4.2.1 Standing

Standing, also referred to as orthostasis, is a human position in which the body is held in an upright ("orthostatic") position and supported only by the feet. Although seemingly static,the body rocks slightly back and forth from the ankle in the Sagittal plane. The sway of quiet standing is often likened to the motion of an inverted pendulum.[1] Briefly the Standard position can be interpreted as a reference position where the angel in all joints is $0°$.

4.2.2 Planes of Movement

- Sagittal Plane: Vertical plane of the body which passes from front to rear dividing the body into two symmetrical halves.
- Frontal Plane: Plane of the body which passes from side to side at right angles to the Sagittal plane; also called the Coronal plane.
- Transverse Plane: Any horizontal plane of the body which is parallel to the diaphragm; also called the horizontal plane.

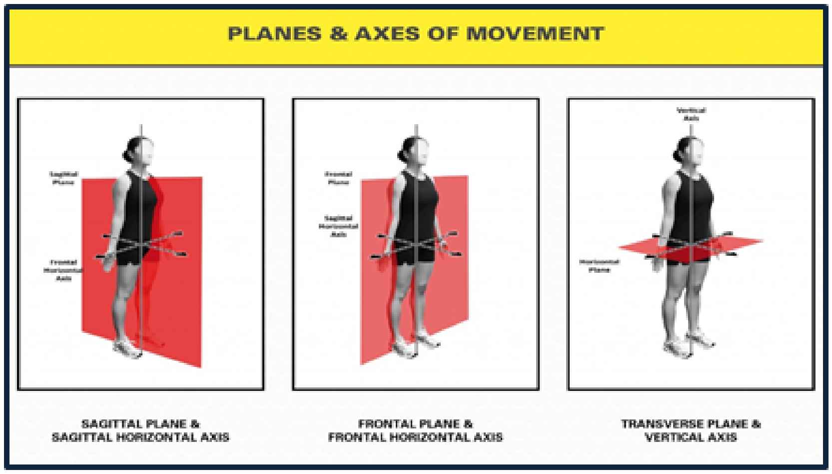


Figure 18: Planes and axes of movements

4.2.3 Axes of Movement

- Sagittal Horizontal Axis: Axis of the body that passes from front to rear lying at right angles to the frontal plane.
- Frontal Horizontal Axis: Axis of the body that passes horizontally from side to side at right angles to the Sagittal plane.
- Vertical Axis: Axis of the body that passes from head to foot at right angles to the transverse plane.

4.2.4 Types of Movement

This description of each movements with reference to planes is valid to the Standard position.

- Flexion and Extension:

  The most common type of motion occurs in the Sagittal plane and around a frontal horizontal axis. Flexion takes place when the angle decreases between the two bones attached to the joint being affected. When you flex your knee joint, the angle between your femur or upper leg and your tibia/fibula or lower leg decreases.

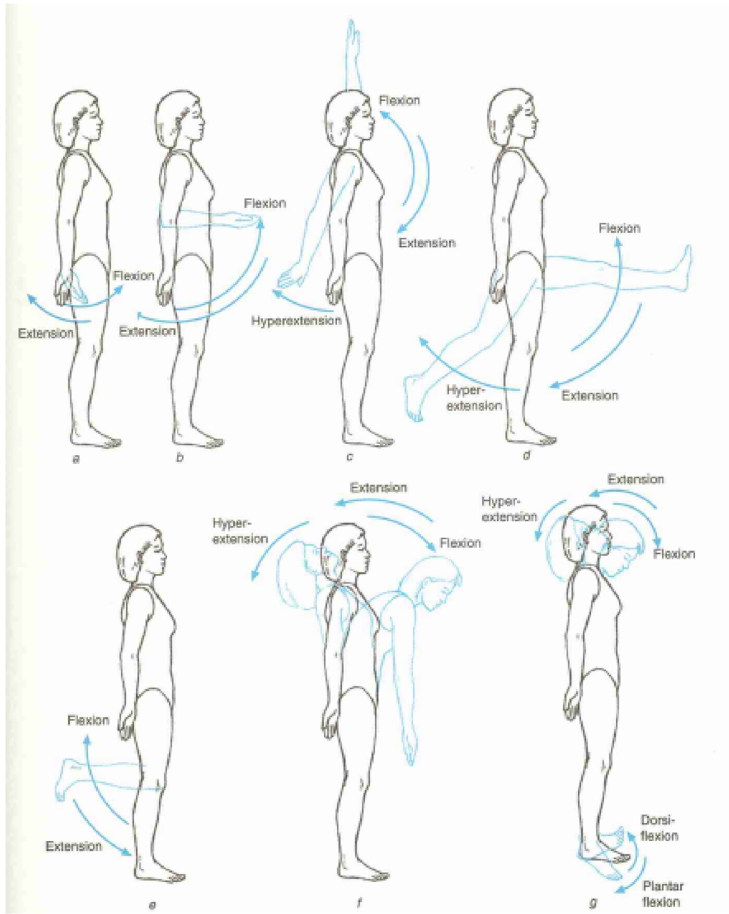


Figure 19: Flexion and Extension with reference to anatomical position

- Adduction and Abduction: These two movements are in the frontal plane and around a Sagittal horizontal axis. Adduction is movement in the opposite direction and toward the center of the body. When returning the leg from the abducted position back to a normal standing position adducting leg is occurred. Abduction is a movement laterally away from the middle of your body. From a standing position, when you move your leg to the side away from the middle of your body you are abducting your leg.
- Rotation: Rotation takes place in the horizontal plane. When you turn your head from side to side you are rotating your head in the horizontal plane around your spine which is acting as the vertical axis. With the head and torso there is only one type of rotation [14].

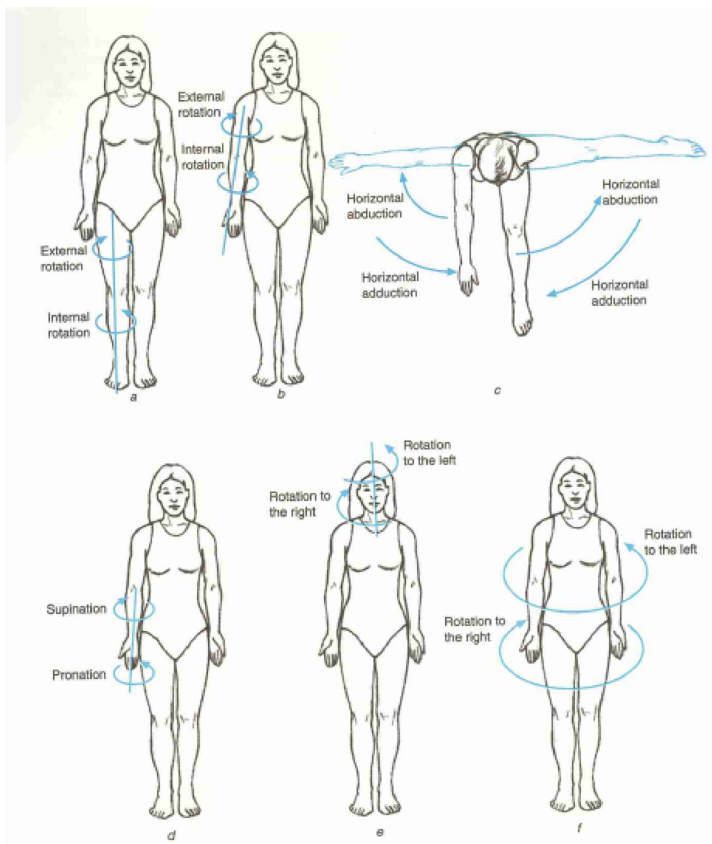


Figure 20: Adduction and abduction with reference to anatomical position

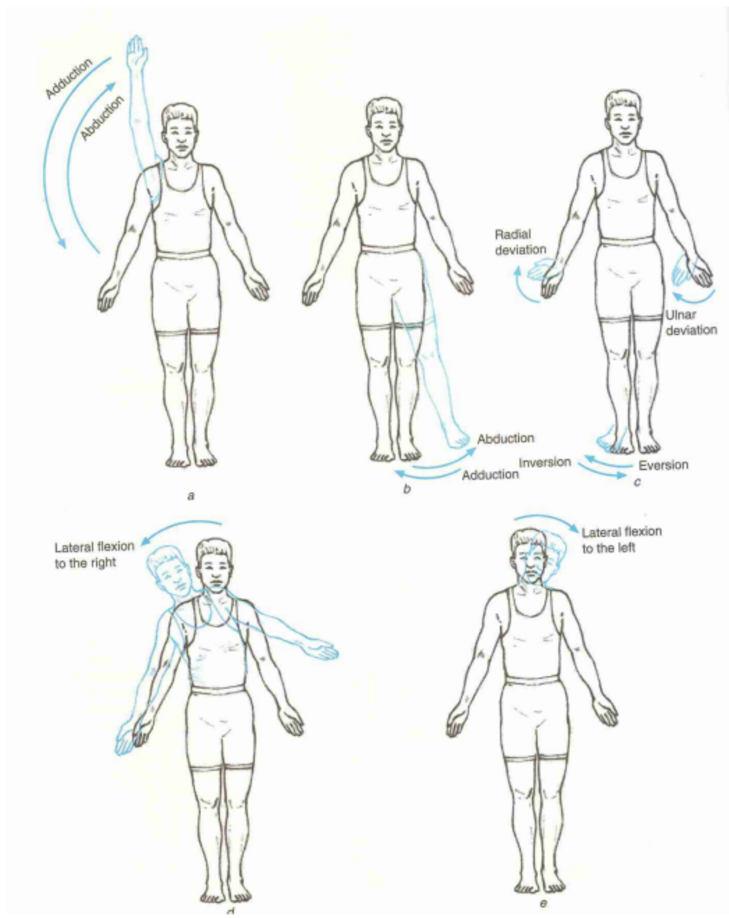


Figure 21: Rotation with reference to anatomical position

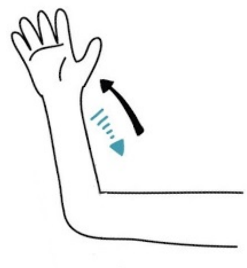


Figure 22: Whole body view, arm fluctuations

4.3 Designed mathematical models for motor examinations in PD patients

4.3.1 Arm fluctuations:

Arm fluctuations exercise is one of the exercises suggested by the neurologist. A proposed model for study the arm agility and rigidity and level of them is designed to see how rapid and flex is the patients' arm. The patients are asked to stand parallel with the sensor with a distance between 2 to 3 meters from the Kinect sensor. The whole body should be detected in the field of view. This test aims to assess the patients' ability to coordinate the arm to the tip of the fingers. The patient should do a regular cyclic motion as shown in the figure to open and close the arms simultaneously as fast as he/she can. Regularity in repeated cyclic movement of the patient shows how the nerves and muscles of the arm are acting. By considering limitations of the sensor, some times moving two arms simultaneously will cause more noise rather and moving them separately. In a optimized situation the patient can move both hands together and minimum angle between the lower arm and the upper arm can be calculated by the system to study the rate of rigidity in the patients arms. The velocity of the hand joint will also be calculated to see how fast the movement is. Theta calculation is as follows:

$$\theta_t = \tan^{-1}(\frac{\left|y_t^{hand} - y_t^{elbow}\right|}{\left|x_t^{hand} - x_t^{elbow}\right|}) \tag{12}$$

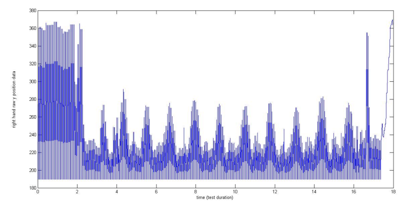


Figure 23: Unprocessed position data

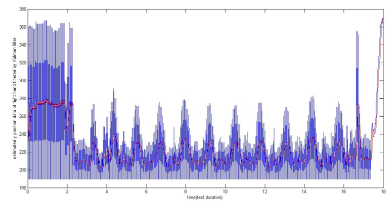


Figure 24: Estimation by Kalman filter in red

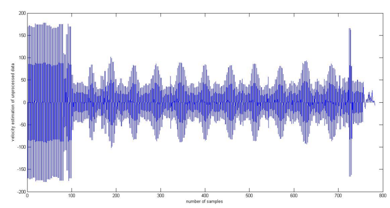


Figure 25: Unprocessed velocity data

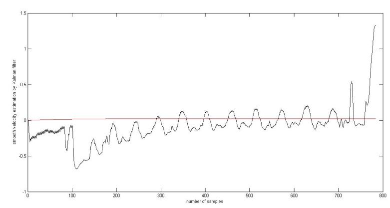


Figure 26: Estimation by Kalman filter

4.3.2 Leg agility(stand up mood):

In many patients with Parkinson's disease it can be seen that there are some problems in the knee joint, such as difficulty of stretching out the lower leg. In this test, the patient is asked to stand and keeping the thighs up, and his lower leg is moving like a pendulum around the knee joint to see to what extent this can be done by the patient as it is shown in the above picture.

In this cyclic motion the maximum angle at which the patient is able to stretch out the lower leg align with the thigh is measured by the program. The cyclic changes in this angle can also be show by the system in order to see how the nerves and muscles of the patient are properly controlled. This angle is measured base on the below formula:

$$\theta_t = \tan^{-1}\left(\frac{\left|x_t^{ankle} - x_t^{knee}\right|}{\left|y_t^{ankle} - y_t^{knee}\right|}\right) + 90 \tag{13}$$

When the angle between the lower leg and thigh is close to 180 this means the perfect ability of the patients' muscles for this exercise.

4.3.3 Leg agility(seated mood):

Another type of exercise suggested by neurologist is study the agility of the knee in patients while they are seated on a chair or table. The patient

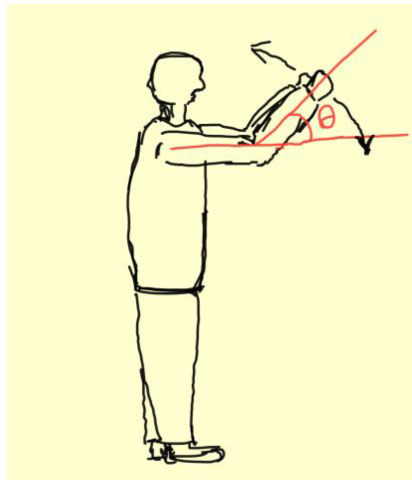


Figure 27: Whole body view, parallel to the sensor, arm fluctuations

Name	Average value of left hand's velocity	STD of left hand's velocity	Max hand angle (in degree)	UPDRS level
Linda	0.14	4.31	143.19	3
Eva	0.29	7.66	179.62	2
Bertil	-0.034	5.41	173.57	2

Figure 28: Left hand fluctuations test result

Name	Average value of left hand's velocity	STD of left hand's velocity	Max hand angle (in degree)	UPDRS level
Linda	-0.11	16.95	136.75	1
Eva	0.19	4.5	175..38	3
Bertil	-0.37	8.05	178.71	1

Figure 29: Right hand fluctuations test result

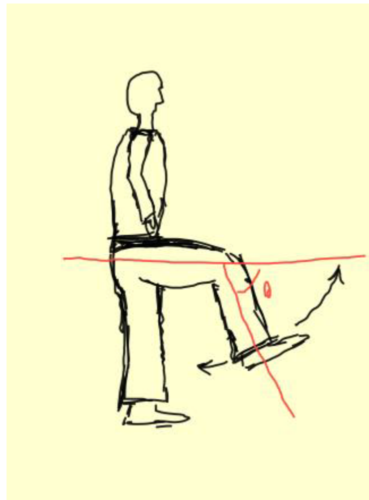


Figure 30: Whole body view, leg and knee agility(stand up mood)

Name	Average value of ankle's velocity	STD of ankle's velocity	Max knee angle (in degree)	UPDRS level
Linda	-0.037	1.01	164.26	1
Eva	1.26	5.10	177.97	1
Bertil	-0.036	1.17	169.93	1

Figure 31: Left leg agility test result

Name	Average value of ankle's velocity	STD of ankle's velocity	Max knee angle (in degree)	UPDRS level
Linda	0.018	3.78	143	2
Eva	0.072	4.44	159.23	1
Bertil	1.57	4.25	111.37	3

Figure 32: Right leg agility test result

Name	Average value of ankle's velocity	STD of ankle's velocity	Max knee angle (in degree)	UPDRS level
Linda	-0.31	15.14	157.60	1
Eva	-0.23	10.13	177.74	1
Bertil	0.21	25.56	125.44	2

Figure 33: Left knee agility test result

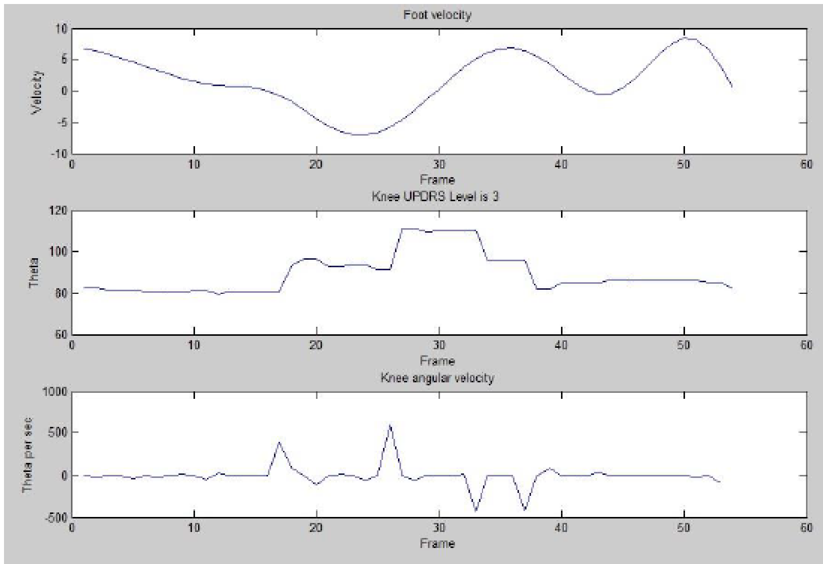


Figure 34: Right knee agility test result

will be asked to sit on a table and legs will fluctuate freely parallel with the sensor. Again the maximum angle between the lower leg and vertical axis of the body will be calculated by the system. Like the previous exercise, to be able to see how fast is the movement, the velocity of the foot joint is also calculated.

This angle is again calculated by the below formula:

$$\theta_t = \tan^{-1}\left(\frac{\left|x_t^{ankle} - x_t^{knee}\right|}{\left|y_t^{ankle} - y_t^{knee}\right|}\right) + 90 \tag{14}$$

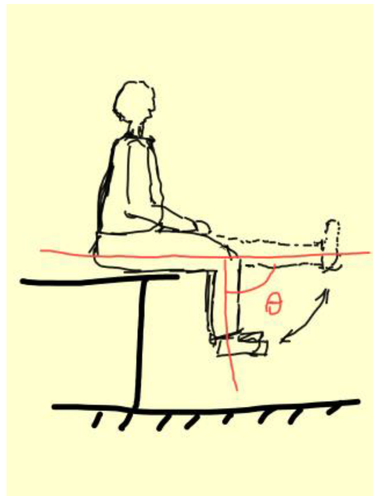


Figure 35: Whole body view, parallel to the sensor, leg and knee agility(seated mood)

4.3.4 Rising from chair (Sit-to-stand movement):

Rising from a chair is an objective measurement used to evaluate functional limitations and is suggested to be a major factor in independence and quality of life in individuals with PD.

Sit-to-stand performance in this population is impaired, particularly the time necessary to transition from forward flexion to an extension direction. Further, bio-mechanical analysis of this task reveals reduced torques and rate of force development at the hip, knee, and ankle as compared to controls.

A really common procedure for study the rate of progression of Parkinson's disease is to study the algorithm of rising from chair movement in the patients. Patients with high levels of the disease mostly tend to fall while doing this movement, while preparing some information like the angle between back of the patient and the chair while rising can prepare useful information for studying this movement in the patients. In this test the maximum angle between the back and the chair which should have a completely straight back is calculated by the below formula:

$$\theta_t = \tan^{-1}\left(\frac{\left|x_t^{neck} - x_t^{hip-center}\right|}{\left|y_t^{neck} - y_t^{hip-center}\right|}\right) \tag{15}$$

To be bale to calculate this angle this test should be done in different phase like the below picture:

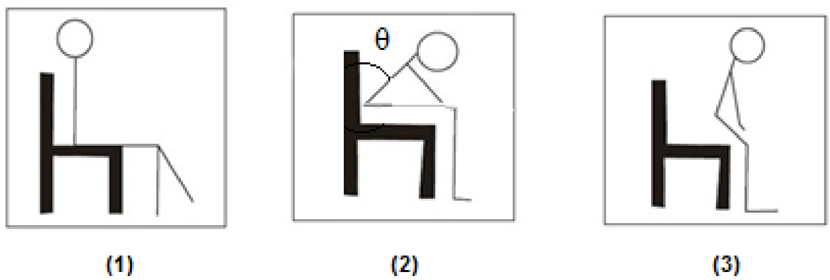


Figure 36: Different phases of rising from chair exercise

Name	Max Angle bended (degree)	Max velocity in Forward direction	Max velocity in Up direction
Linda	14.87	67.81	112.08
Eva			
Bertil	24.81	94.46	133.08

Figure 37: Rising from chair test result

4.3.5 Postural instability:

One of the most important signs of Parkinson's is postural instability, a tendency to be unstable when standing upright. A person with postural instability has lost some of the reflexes needed for maintaining an upright posture, and may topple backwards if jostled even slightly. Some develop a dangerous tendency to sway backwards when rising from a chair, standing or turning. This problem is called retropulsion and may result in a backwards fall. People with balance problems may have particular difficulty when pivoting or making turns or quick movements. To be able to study this issue, a model was designed like the below picture:

The maximum angle which the patient tends to fall is calculated by the below formula:

$$\theta_t = \tan^{-1}\left(\frac{\left|x_t^{neck} - x_t^{ankle}\right|}{\left|y_t^{neck} - y_t^{ankle}\right|}\right) \tag{16}$$

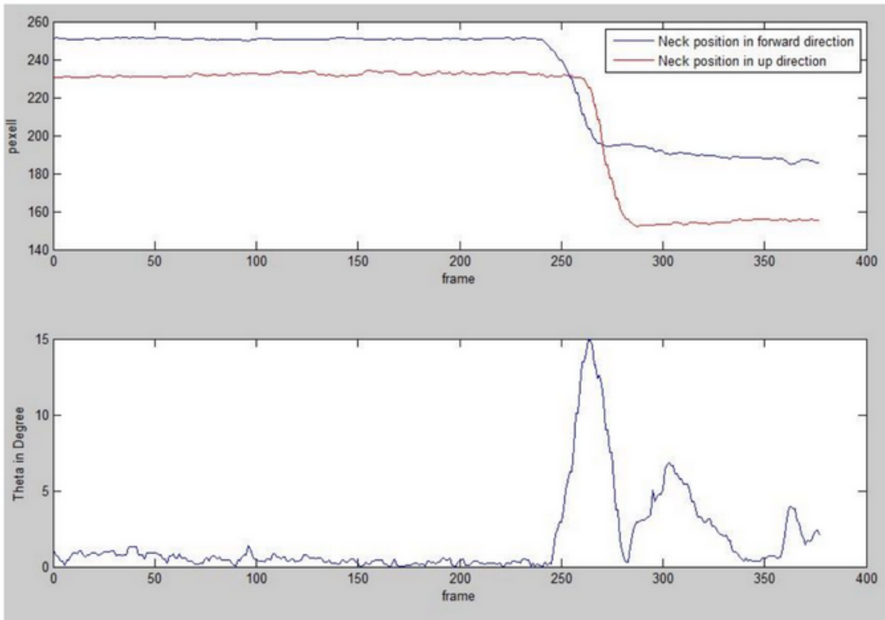


Figure 38: Neck position while rising from chair forward and upward for Linda

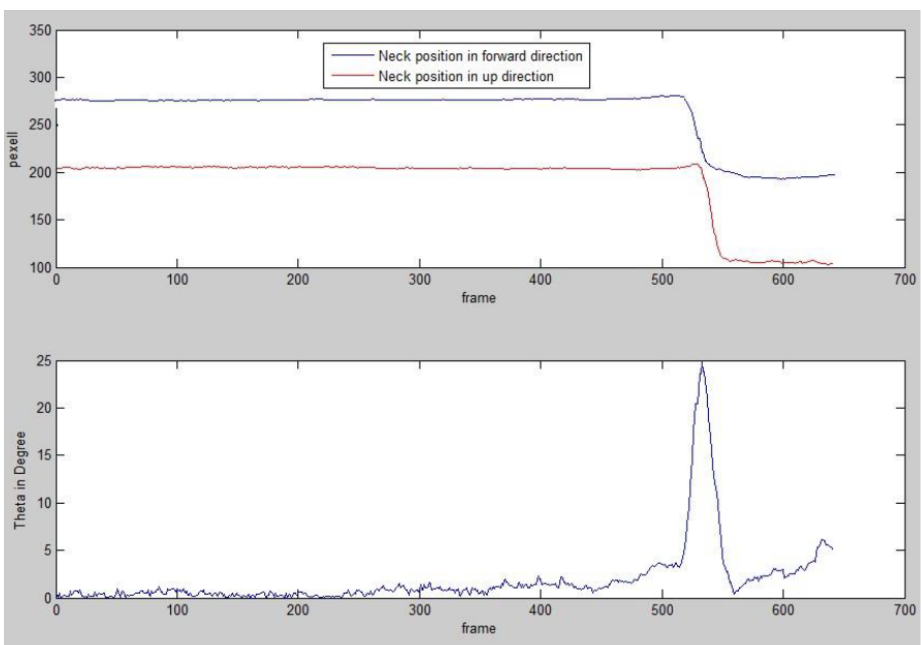


Figure 39: Neck position while rising from chair forward and upward for Bertil

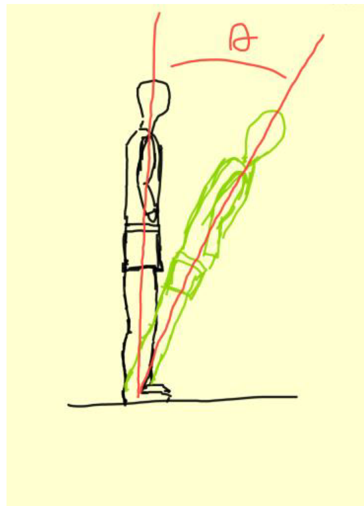


Figure 40: Whole body view, parallel to the sensor, fall threshold :

Name	Max theta bended	UPDRS Level	Description
Linda	1.31	4	Worrying
Eva	3.47	3	?
Bertil	3.32	3	?

Figure 41: Postural instability test result

4.3.6 Arms rigidity:

Some patients may describe stiffness in the limbs, but this may reflect bradykinesia more than rigidity. Occasionally, individuals may describe a feeling of stiffness when moving a limb, which may be a manifestation of cogwheel rigidity. While testing different patients, it was seen there are some subjects who are suffering from this issue more that others. It can be interpreted as lack of dynamic stretches. For instance a subject were asked to stand with feet together, bring both arms up the side with facing forward perpendicular to the sensor as is shown in picture 41.

The angle between the upper arm and the vertical axis of the body is calculated by the below formula:

$$\theta_t = \tan^{-1}\left(\frac{\left|x_t^{Rhand} - x_t^{Rshoulder}\right|}{\left|y_t^{Rhand} - y_t^{Rshoulder}\right|}\right) + 90 \tag{17}$$

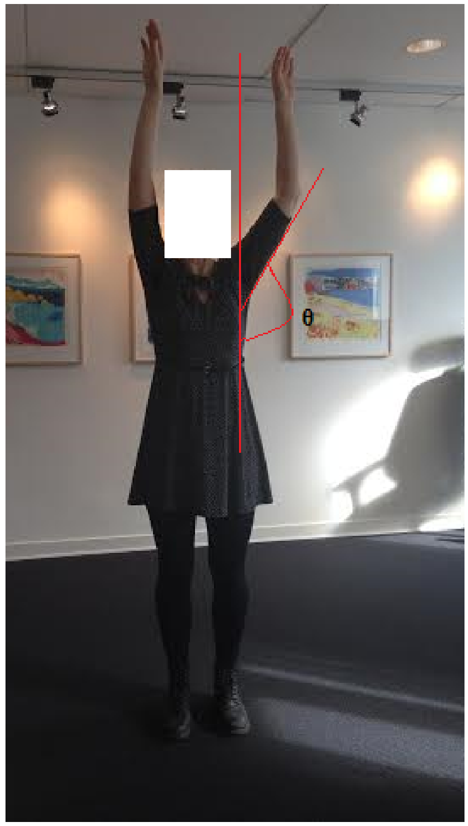


Figure 42: Whole body view, perpendicular to the sensor, stiffness

4.3.7 Marching exercise for study of leg agility:

The aim of this study was to examine of agility performances according to different velocity values of the patients' knee while doing the exercise. Average values of knee velocity was studied to analyze how agile the knees are. Patients suffering from disease such as PD are mostly having a slow knee movements comparing with healthy people. The values of standard deviation of the velocity could also provide some information for the physicians and therapist controlling the patients' symptoms.

Name	Max theta (degree)	UPDRS Level	Description
Linda	76	1	Normal
Eva	88	?	?
Bertil	85	?	?

Figure 43: Arm rigidity test results

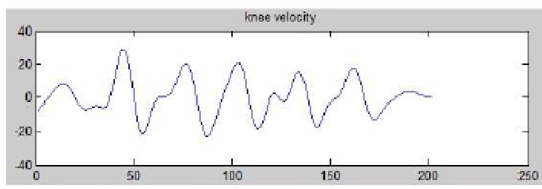
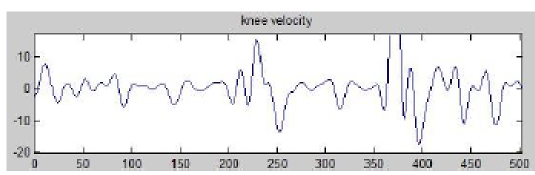
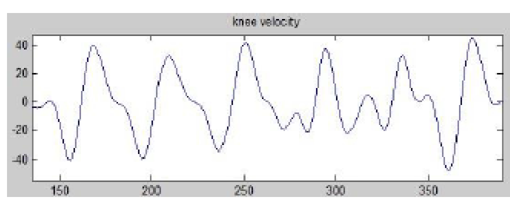
Name	Average value of knee velocity	STD of knee velocity	UPDRS level
Linda	0.39	10.92	
			
Eva	1.31	9.34	
			
Bertil	0.14	17.68	
			

Figure 44: March exercise test result

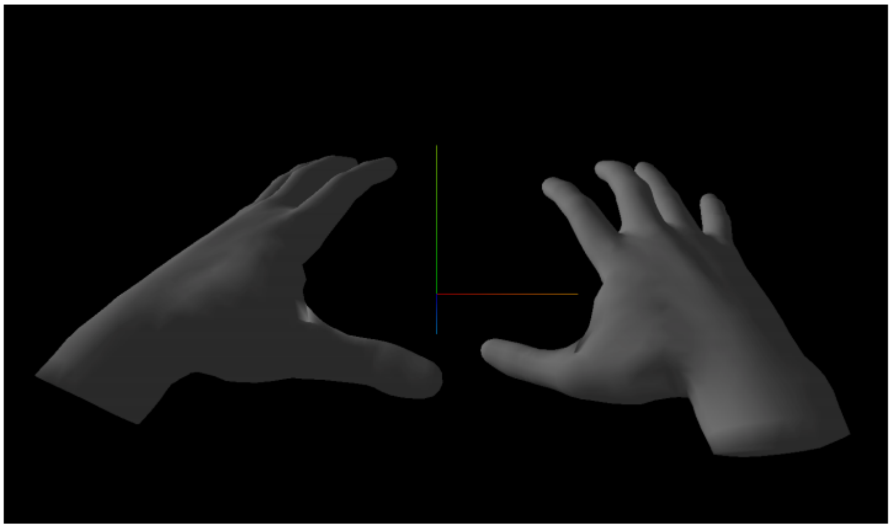


Figure 45: Hand detected by Leap motion

4.4 Limitation of the Kinect sensor

By doing different measurements, it is concluded that the Kinect system has potential to be a low-cost, home-based sensor to give reliable position data to measure movement velocities in people with PD. The Kinect can accurately measure the timing and gross spatial characteristics of clinically relevant movements but not with the same spatial accuracy for smaller movements, such as hand clasping or toe tapping, as well as really small tremors. Measurement of the timing of movement will provide the most accurate and stable outcomes, however the Kinect may also be useful in tracking the relative worsening or improvement for both the timing and size of movements over time. Further study will be done continuously to see how accurate this sensor is for tracking of smaller movements and developing user-friendly software to monitor PD, or stroke symptoms at the home.

4.5 Tracking Hand Tremors with Leap Motion

The idea behind studying the characteristics of hand's movement is to measure how well the subject follows a trajectory with his/her finger or hand to assign a status for hand capabilities while suffering from a disease affecting hands agility. Picture 46 is showing the test result from different subjects trying to follow the straight horizontal line on the screen above the sensor.

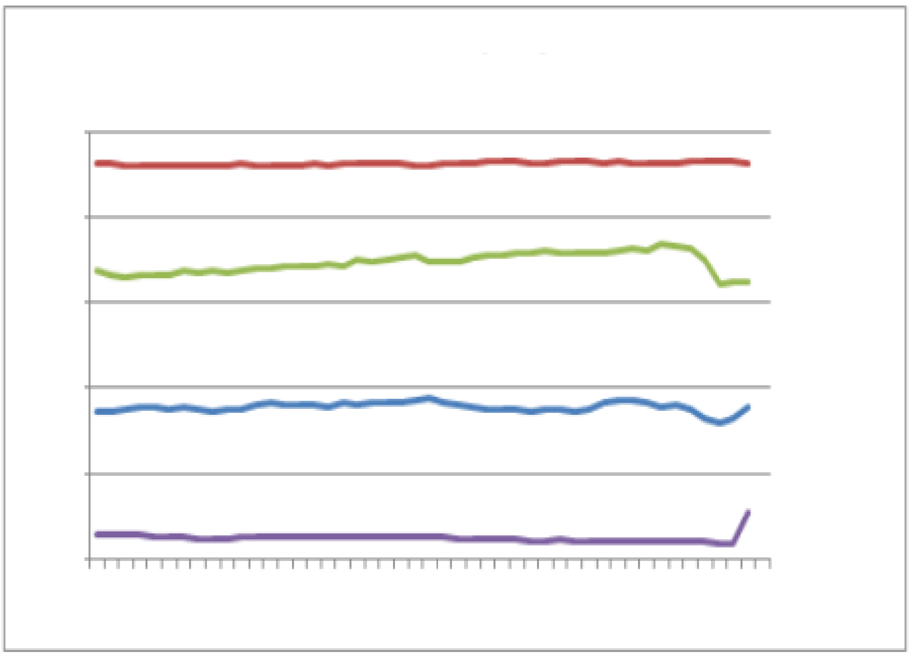


Figure 46: Different subject's results following a line on screen over Leap Motion

5 DISCUSSION

Evaluation of the Kinect sensor and Leap motion joint tracking for clinical and in-home Parkinson's rehabilitation tool was the purposed problem to be solved in this work. The Microsoft Kinect's ability to track joint positions could be utilized to provide a tool for rehabilitation of such patients, both in a clinical setting and as a tool to aid the patients at home. A possible solution for completion of the Kinect sensor limitations is to implement Leap motion tracking sensor for hand movement analysis, which is not possible to get from this type of sensor.

The result obtained from this thesis could be interpreted as a tool which can measure and calculate some clinometirc parameters from the collected data by the Kinect sensor of PD patients. These results and values can be studied by medical doctors and physiotherapist in a way to gauge disease severity as well as rate of progression of the patients under specific treatment plan. The results of such tools can also be interpreted by patients themselves at home in a cheaper and more convenient way. Not only for PD patients but also some other patients suffering from any kind of disabilities affecting the body same as PD can also benefit from such tools.

5.1 Contribution

This thesis implemented and evaluated tools for estimating Parkinson's symptoms, such as; bradykinesia in the legs and arms, postural instability, rising from chair problem, and some other movement disorders which might occur by Parkinson's or any other disease by using Kinect and Leap motion sensor. Different phases of this thesis work by using the Kinect sensor is listed as below:

- An available code in Eclipse/Java is modified for making the sensor to meet the purposed needs for working in an efficient way to follow openNI algorithms.
- Preparing a code in Java in a way to have the unprocessed output data in .txt format to be able to import them in MATLAB.
- The noise characteristics of the openNI joint tracking algorithm have been estimated.
- Two different filtering techniques are designed for filtering the joint tracking data.
- Specific exercises and features for estimating symptoms based on the UPDRS are tested by designing and modeling a tool in Matlab environment, which works in an automatic fashion.
- The proposed system is evaluated on a small number of patients and control subject.

Using the Leap motion sensor:

- Programming the sensor in Eclipse/Java in a way to collect the 3D position of the palm over time.
- Designing a line on the screen to be followed by a cursor, which is following the movements of each hand.
- Extracting different characteristics of the hand movements to study the tremors or abnormal hand movements (hypokinesia), while the trajectory itself is visible on the screen.

In general working with sensors such as Kinect and Leap motion are always a bit tricky when it comes to storing the big output data from the test results to be analyzed by the tool developed in this thesis or similar tools. On the other hand asking a patient to do the predefined exercises in a correct way in front of the sensors to not to have the possible errors or noises is also a bit hard as well. Some patient are old and they might find such technologies yo be implemented at home a bit confusing and expensive. Some exercises might also be dangerous for a group of patients having the stability problems. The tools similar to the one developed in this thesis are having both pros and cons that are briefly discussed in the introduction as benefits of distance study of the symptoms and cons like the factors mentioned above. In general this thesis studied the possibility of implementation of such tools which could be a useful help if updated and designed properly. The aim of the project was to test the Kinect sensor and Leap motion for the distance study of motor skills in lab environment and could proof that by a better and more proper installation of the device itself and noise filtration, this technology can bring a lot support to ICT.

6 CONCLUSION

This particular study focused on mobility therapy for Parkinson's patients, while most of the findings are equally applicable to other areas of therapeutics, including for neurological disorders that result in impaired movement, such as post-stroke movement disorders, multiple sclerosis, and cerebral palsy. Any realm of therapy that treats impaired balance and mobility could potentially benefit from the use of the Kinect to monitor patient movement. The built model is able to analyze the output data of the Kinect sensor, and by utilizing different mathematical models is able to provide useful information of the patient movement for further study of the movement disorders. The setup will located at the home of the patient and the patient will do different exercises at different times. The data of the Kinect sensor will be analyzed in the built model in Matlab environment and the results of the exercises will be provided both for the patient himself and also the health care professionals.

The software developed for this project are not in a form that would be useful for professional Parkinson's disease therapy. However, further work could easily be done to improve on these proof-of-concept applications to enable their use in rehabilitation facilities or patient homes. In this thesis the potential and limitations of the Kinect was explored to develop a model working as an ICT tool at-home rehabilitation of Parkinson's patients. The result of this tests can also be used for any kind of rehabilitation such as; stroke patients rehabilitation.

The overall lesson from these studies is that Kinect is an acceptable and affordable depth sensor for rehabilitation purposes. But developers should take note of problems with occlusions in the image and noises in skeleton tracking. To solve these problems, use of Kalman filter, sensor fusion and calibration were proposed.

The advent of affordable depth imaging technology has made an enormous impact on motion capture in rehabilitation; ever since Microsoft Kinect has become available to developers, many papers have been published on rehabilitation using the Kinect sensor. This project is also related to the development of systems using Kinect that targeted assessment of post-Parkinson's disease, physical disability and rehabilitation. The convenience and affordability of the Kinect sensor with its acceptable accuracy invited a lot of interest among Rehabilitation Engineering developers to propose stroke rehab frameworks based on Kinect.

6.1 Future work

Creating a user-friendly system which works in real-time that not only facilitates but also incentives data provision is the future work for this project. Gathering real-time data with such a system from patients' homes enable home care aides, family caregivers, and patients to enter real-time health data-covering variables from medication intake and vital signs to daily routines and even state of mind-regardless of computer skill or medical literacy. Physicians, nursing personnel, and other care coordinators can then easily review a patient's health information and care patterns simultaneously. This new digital tools captures comprehensive information from the home and process them in the built models in real time for effective care provision unlike any previously available method which were tested in this project.

The data in this project were imported manually from .txt format in Matlab and were processed there both for processing and filtering the data and also different mathematical calculations for different tests. By creating a systems which works in real-time, the data will be imported in the processed environment automatically and the results will be shown by just a click. There is no need for supervision the system at each time or maybe make some alterations on the system for a specific need. Even though the system is also working in an automatic fashion at the moment but there is still a lot work for collecting the data by patient and put them in a folder for further investigations by the system. Real-time data improve affordability and quality of care by enabling early intervention and improving monitoring of clinical status. Real-time information about a patient helps home-care providers monitor, communicate, and triage rapid changes in status to avoid preventable deterioration. Because Web-based care information is available instantaneously, significant events or trends can be spotted right away.

Analyzing data over days, weeks, or longer also allows providers to recognize patterns of decline and spot emerging problems earlier. While in-home caregivers may not notice or report small day-to-day changes, a digital patient care record helps visualize these patterns over time. For example, a geriatrician could see that a dementia patient is experiencing significant changes in sleep patterns, which can affect behavior and mood throughout the day.

Enhances care coordination efforts and enables better care transitions: The use of real-time data generated from a patients' home creates collaborative opportunities for health care providers. It bridges the gap in care coordination, creating an exchange of information among patients, caregivers, and health care providers that improves patient-doctor communication. Physicians, insurance caseworkers, nurses, and family caregivers can simultaneously work to make collective decisions about the care process.

7 References

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