HAND MOVEMENT QUANTIFICATION OF PARKINSON’S DISEASE USING IMAGE PROCESSING

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Declaration

I, Mahander Kelash, declare that this research is my original work and that it has never been presented to any institution or university for the award of Degree or Diploma. In addition, I have referenced correctly all literature and sources used in this work and this work is fully compliant with the Dublin Business School’s academic honesty policy.

Signed: __ Mahander Kelash _____________
Date: __ 8/16/2018 ________________
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Gratitude to Almighty God, for giving me courage to complete this study.

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-Mahander Kelash
Abstract

This research describes the methodology and demonstrates the applicability of system, developed using image processing, to quantify Parkinson’s disease by hand movements of patient. The main goal of this study is to develop an application prototype, that will quantify PD in home or in clinical environment, and without using any external hardware. Two healthy were measured and one PD patient with off- and on- dopaminergic condition was measured. Rapid hand opening and closing were measured with the system (called HMQPD). The methodology described and result presented shows applicability of HMQPD in a home environment, to considerately quantify hand bradykinesia.

Keywords: Parkinson’s disease, Hand, Bradykinesia, PD, image processing
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Chapter 1: Introduction

1.1. Background

Parkinson’s Disease is one of the most occurring and second common chronic disorder after Alzheimer Disease which affects people over the age of fifty at most of the times. And those who are suffering from it have a decreased quality of life because of facial muscles rigidity, tremors and Bradykinesia. There are about 7 million to 10 million peoples who are living with Parkinson’s disease and number is still growing (Annonymous, 2013). Since, the number keeps growing but still there is no proper medical testing system has been developed to diagnose severity level of Parkinson’s Disease and doctors those are experts for Parkinson’s Disease, they diagnose severity level of PD by analyzing physical movement of patients. This study is mainly focused on developing a desktop application using image processing and machine learning to analyze severity level of Parkinson’s disease in a patient by performing its hand movements. In the first chapter a description of Parkinson’s Disease, theoretical models, the main aims of the thesis and research question will be presented.

1.2. Parkinson’s Disease

James Parkinson in 1817, medically described this disease as neurological syndrome in his book “An Essay on shaking Palsy” that's why its name is given by his name (Goetz, 2011). Parkinson described this disease in succinct and pithy English as:

“Involuntary tremulous motion, with lessened muscular power, in parts not in action and even when supported; with a propensity to bend the trunk forward, and to pass from a walking to a running pace: the senses and intellects being uninjured” (Goetz, 2011).

Later, in mid-1800s, Jean Martin Charcot refined and disseminated information internationally about Parkinson’s Disease. He detached Parkinson’s Disease from multiple disorders and sclerosis characterized by tremors.

Parkinson’s Disease is an age-related neurodegenerative disorder that causes a gradual loss of muscles control. It happens when there is a problem in the certain nerves cells in the brain known as neurons, these nerves cells contain Neurotransmitter known as “Dopamine”. Several nerves cells in the brain release dopamine to communicate with each other and that communication is
responsible for the controlling variety of key functions in the brain including important roles in behavior, motivation, punishment, voluntarily movement, Cognition, learning, working memory, sleep and attention (Perera & Thevathasan, 2014). In the case of Parkinson’s Disease, there are several nerves cells that also generates dopamine, these cells are in deep down in the brain in an area known as ‘substantia Nigra’, a hub of nerves cells in brain stream. When these cells of substantia Nigra slowly dies it causes a reduction of dopamine level and that reduction is responsible for imbalance with other neurotransmitters resulting in an array of motor and non-motor symptoms that becomes worse over time (Sethi, 2002). One of the key challenges in treating Parkinson’s Disease is the progress of condition is unique in each individual case.

When a system of a body is working well, the body moves evenly and smoothly without any mentally caused distraction but when a person is affected by Parkinson’s Disease, the substantia Nigra cells start to die and there is no replacement of them (Anonymous, n.d.).

1.2.1. Clinical Features
It is very difficult to identify Parkinson’s Disease at early stage, following are symptoms that identifies that a person has Parkinson’s Disease or not. No of the single sign should identify that a person is affected by Parkinson’s Disease but more than two of the signs if shown in a subject then it would be considered that a person is affected by Parkinson’s Disease (Spears, n.d.).

Tremor
A Tremor, or shaking is rhythmic or involuntarily movement of body parts that happens because of contraction muscles it usually occurs in limb, often in fingers or hand. Sometimes it occurs in hand when it is at rest. When someone notice back-and-forth rubbing of index finger with thumb this tremor is known as pill rolling.

Slowed Movement
This symptom is also known as bradykinesia, in a fraction of time Parkinson’s disease may reduce ability of a subject to move or it can also slow the movement, that makes simple tasks difficult to perform and it took a lot of time to do that task.

Gait
Gait means how a person walks or the manner in which a person walk. In Parkinson’s disease, Gait is always disturbed because of difficulty in initializing any kind movement or
trailing(dragging) steps. In normal gait characteristics the heel strike to floor before toe during walking whereas in Parkinson’s gait, the entire foot is touched or placed on the ground at same time and it is also known as flat foot strike. Sometimes in Parkinson’s Gait, walking may also be rushed with sudden stops and it is also called freezing.

**Rigidity**

It consists of high resistance in the movement of the limb and it occurs throughout the whole movement. Muscles rigidness may take place in any part of subject body, and because muscles stiffness it can limits subject range of motion and cause pain.

**Impaired Postures and Balance**

Impaired posture and improper balance are also important signs of Parkinson’s Disease and they occurs when disease progresses to higher severity level. The posture of the subject sometimes may stoop without any intention, or it may have balance problem such as, when the arms of patient is bringing forward they urge to bend their neck and trunk.

**Speech Changes**

The subject may have speech problem, his speak may be more of a monotone rather than usual inflection.

**Writing Changes**

It may become hard to write, and your writing may appear small.

**1.2.2. Non-Motor symptoms**

The classical clinical symptoms of the Parkinson’s Disease are bradykinesia, tremor and all the above-mentioned clinical features. However, in recent years non-motor symptoms have emerged in a meaningful factor in determining the patient’s condition. These symptoms include Mood disorders, cognitive changes, Hallucination and delusions, orthostatic, sleep disorders, constipation, pain, fatigue, vision problem, excessive sweeting, loss of sense of smell and weight loss (Foundation, 2018). In general, in the different stages of the Parkinson’s Disease it has been found that 98.6% of the patients have reported the presence of Non-Motor symptoms (wu, et al.,
Non-Motor symptoms are difficult to recognize while there is a tendency to recognize motor symptoms.

1.3. Diagnosis of Parkinson’s Disease
Since the Parkinson’s Disease has been described two centuries ago, identifying the cause is pragmatic. Though, it is important to properly measure patient’s condition for medication and reducing side effects. Unfortunately, there is no specific test to Parkinson’s Disease. Doctors who are trained in nervous system conditions also known as Neurologist, they diagnose Parkinson’s Disease using subject’s previous medical history, a review of patient’s signs and symptoms and physical and neurological examination. Doctors had also asked for blood tests and imaging tests such as MRI, Ultra Sound of Brain, SPECT and PET scans, to rule out other condition that may causing symptoms. But in general imaging test are not helpful in diagnosis of Parkinson’s Disease (Staff, 2015).

There are a lot of scales have been developed for the quantification of Parkinson’s disease such as Columbia University rating scale, PD impairment scale, New York University scale and Northwestern University disability scale. Of these scales, the UPDRS (Unified Parkinson’s Disease Rating Scale) has gained the substantial acceptance (Hilten, et al., 1994). UPDRS Scale consists of four subscales. Subscale 1 covers mood, behavior and mentation. Subscale 2 covers daily living activities. Subscale 3 covers the clinical rating of motor manifestation and subscale 4 covers therapy’s complications. Although, UPDRS scale was not established for the diagnostic of Parkinson’s Disease, it has been developed for the purpose of screening Parkinson’s Disease. While in some studies it has also been shown that UPDRS is used to facilitate “data mining”.

1.4. Statement of problem
Since, there is no system had been built to test or diagnose the severity level of Parkinson’s disease in a patient affected by it, and no imaging or any other kind of radiology test is efficient for the diagnosis of Parkinson’s disease. There are many tests that a neurologist must conduct manually and with his experience, and those tests are already mentioned above in UPDRS scale, but the most efficient of them is hand movement test of Parkinson’s disease. In this test, patient sits on the
chair and he must perform hand movement such as open and close his hands as fast as he can, and doctor have to count those movements and compare them with the predefined counts of hands for certain severity levels on UPDRS scale, such as 15 hand movements in 5 second rates to 0 severity level.

This traditional method of diagnosing PD is not as efficient, diagnosis results were always varied because of expertise of doctors who were conducting the tests, it has also been noticed that the results from tests that conducted by one doctor is sometimes different than the tests that has been conducted by another doctor, and this situation leads to improper treatment and medication.

1.5. Research Question

“Develop a system that can analyze the severity level of Parkinson’s Disease using hand movement quantification of the patient”

Having highlighted the ways to diagnose Parkinson’s disease this study will focus on the hand movement quantification of Parkinson’s Disease. In the literature review, this research will focus on the already built systems to find out the way to develop cheap and efficient system for the diagnosis of PD.

The Accuracy of System will be checked at dummy patients and some patient that are affected by Parkinson’s Disease at Taluka Headquarter Medical Hospital Samaro with the presence of Medical Superintendent Dr. Kelash Langhani. Those tests will be only for checking accuracy of our System and no patient will be prescribed or treated by the results generated by our system. For more accuracy we shall compare the results generated by our system and the results that are given by PD’s Expert Doctors.

1.5.1. Contribution

The overall aim of is this research is to contribute with a proof of concept which can help or further explored in applied technology within healthcare.

1.6. Research Objectives

In general, research objective describes what we expect to achieve by research project. Following are the objectives that we will intend to achieve in this study:
1. To develop a Desktop Based application that will be used to detect the PD’s Severity level at home by patient himself. is very difficult to travel for a person who is affected by Parkinson’s Diseases.

2. This research will help Parkinson’s Disease community to find out the way the way to cure Parkinson’s Disease.

3. Theoretically it will increase resources of Parkinson’s foundation because it is very effective and new method of diagnosing Parkinson’s Disease, Organization and Hospitals can integrate this system any of their hospital Diagnostic system. It will be very easy to integrate by adding some image processing libraries to their system.

4. This study will further contribute to prediction of Parkinson’s Disease in a normal person using genetical signs and symptoms.

1.7. Limitation of Research
Due to large scope of the research question, the project may have few limitations. Following are the limitations of the research and project.

- This research will only focus on the Bradykinesia symptom of the Parkinson’s Disease.
- The prototype of the application will work on only one hand of the Patient.
- The project will give its full efficiency if all of the desired constraints are made such as, High definition camera, Proper lighting and background that is opposite to skin color or background should be black or white.
- Accuracy of the system will be 80% - 85% and it can be optimized in future.

1.8. Ethical Issues
Since, the research will include PD patients, the requirement for moral thought is imperative. On the off chance that the framework will be tried on genuine PD patients, individuals included might be required to give a composed agree consenting to partake in the task. The students themselves may likewise be required to consent to a classification arrangement, guaranteeing the members are made unknown in the documentation.
1.9. Dissertation Roadmap

This dissertation is classified into 6 chapters, and they are described below.

**Chapter 1: Introduction**

This is the first and current chapter of dissertation. This chapter gives a brief introduction of dissertation background, a brief description of Parkinson’s Disease and its symptoms and the methods to diagnose it, a brief explanation of research question and research objectives.

**Chapter 2: Literature review**

It discusses the literature review. It explains the different techniques to diagnose the PD and the different systems that has been built till now for the diagnosis of PD. After that, it discusses the technology selected for the implementation of prototype and its advantages.

**Chapter 3: Discuss the methodology of this study. It also discusses the methods for the primary and secondary data collection as well as major algorithm used during implementation.**

**Chapter 4: Discuss the design and implementation of prototype.**

**Chapter 5: Discuss the qualitative data collection and the results of the testing of prototype.**

**Chapter 6: Talks about research discussion and recommendation.**

**Chapter 7: talks about research conclusion and discuss the reflection and learning of the study.**
Chapter 2: Critical Literature Review

When it comes to disease testing, it always comes in mind that what causes that disease, what are the symptoms of the disease that will help in quantifying the disease and what previous studies suggests. Many researchers worked on many ways to quantify Parkinson’s disease and in this literature review a critical review of their work is given and a discussion about the methodology that will be used in this study to quantify Parkinson’s Disease.

2.1. Hand Motor Symptoms Assessment of Parkinson’s Disease

Since, PD is a neurological disorder and it occurs due to loss of dopamergic neurons. Patients need long term medical treatment and even after that treatment PD is not halted but it can be potentially slowed, and to identify PD in early stages is very challenging. According to Ke Yang in his research “Objective and quantitative assessment of Motor Function in Parkinson’s Disease”, 50% of nigrostriatal dopaminergic neurons are lost before the appearance of any typical motor manifestation (Yang, et al., 2016).

In the diagnosis of PD’s severity level sensors played a vital role such as accelerometer and gyro sensor, in clinical assessment bradykinesia, angular velocity signals are widely used because they are free from gravitational artifacts and these angular velocity measurements are obtained using gyro sensors (Kim, et al., 2010). In 2016, Yuko S. and Akihiko A. presented a system in their study named “Quantifying Parkinson’s Disease severity by extracting and synthetizing finger motion properties”, their system was using magnetic sensors to quantify the severity level of PD from the symptoms related to finger tapping of PD’s Patient with high accuracy. They extracted 21 statistical characteristics from finger-tapping waveform and they also removed aging effects on finger tapping from these characteristics. They used MLR (Multiple Linear regression) and stepwise variable selection was applied to principle component, and severity level as calculated. The calculated results were accurate with mean square error of 0.45 (Sano, et al., 2016). According to the researchers, the quantification of motor symptoms of hands is very useful and efficient in diagnosing Parkinson’s Disease.

Joisen et al. (2017), described the methodology and explored and demonstrated the applicability of a system in their study “Quantification of Hand Motor Symptoms of Parkinson’s Disease” and
they named that system as “Power Glove” system, this system is combination of miniature inertial and magnetic sensors on each finger section and back of hand and the total count of the sensors was 11 and they were attached to the different parts of the hand. These all sensors contain 3D gyroscope and 3D accelerometer. Using these sensors, angular velocity and acceleration of the hand movement and finger segments were calculated and using these measures they identified severity level from each hand motor symptom, such as bradykinesia during finger tapping was quantified using data of four sensors of PowerGLove: the sensor on the proximal phalanx of the index finger, tip of the thumb, tip of the index finger and back of the hand, and all the hand motor symptoms were quantified using different sensors. The system was built to operate under clinical settings. The advantage of PowerGlove system, as stated by researcher is to quantify each hand motor symptom and till now no system except PowerGlove system quantify each hand-motor symptom of PD (van den Noort, et al., 2017).

Later in 2017, Sofia Spasojevic and her team proposed a system for the assessment of PD using a wireless armband device. In this study they were using accelerometers and gyroscope in their wireless arm band device to get the data for the tremors, hand movements or any other sort of movement of Patient’s hand. A total of 84 Movement Performance Indicators (MPI) were calculated from the data that was acquired using sensors on wireless armband device. As a result, these MPI can indicate the presence of Bradykinesia symptom. According to researchers, the wireless armband device could be a low-cost alternative to PowerGlove system with a limitation of finger tapping assessment of Parkinson’s Disease (Spasojević, et al., 2017).

In 2014, Dr Taha Khan introduced a computer vision method for the quantification of finger tapping symptoms of PD by analyzing the motion of the index finger. About 387 short recordings of rapid finger tapings of 13 PD Patients and about 84 short recording of rapid finger tapings of 6 healthy adults were used. These recordings then proceeded by CV algorithm that tracked index finger motion and produced tapping series, and this tapping series were used to extract features such as speed, amplitude and fatigue for the training of system according to UPDRS scale. This system has an accuracy of 85% for the quantification of PD. Finally, the researcher suggests that using Computer approach to quantify Parkinson’s disease is cheap and efficient and it is suitable for PD monitoring at Home environment (Khan, et al., 2015).
Since, due to difficulty of managing sensors and maintaining personalized regimes for Patients, Chae et. al developed a smart phone application named as SMT (Smart Phone Tapper) to quantify severity level of Parkinson’s disease using finger tapping. The application consists of two rectangles of 35 mm by 45 mm and separated by 15 mm. In testing, the application subjects were asked to tap each side of the rectangle using index finger as fast as they can for ten seconds and each hand must repeat for 3 times. The results were used to quantify severity level of bradykinesia symptom. The advantage of SMT, as stated by researchers is cheap and handy, and it can be used anywhere either in clinical environment or at home (lee, et al., 2016).

2.2. Gait (Posture imbalance)
Since, there are many symptoms of Parkinson’s Disease, Gait imbalance is most problem occurred in the middle phase of PD, many patients in their middle severity of PD found Gait problems such as gait freezing, flat foot walking and many other gait problems. Gait freezing is a paroxysmal phenomenon that is frequently reported by PD’s patient (A, et al., 2015). A normal person’s gait has a periodic stride cycle and has a stride angle of 45’ between the legs, while the Gait of PD’s Patient has short stride-angle with high variability between stride-cycles (Khan, et al., 2013).

Chen et al. (2011), proposed a system in their studies for the computer vision-based gait analysis approach. This system was developed to assist the clinical assessment of PD with Kernel based principle component analysis. This system was tested on 12 PD patients and 12 healthy adults with no neurological history; they had to wear light clothing and walk in the corridor and their steady-state walking period was captured by camera for gait analysis. Those captured image frames, then, transformed into binary silhouettes for noise reduction, and then these features were further extracted using KCPA-based method to quantify Parkinson’s Disease. This method has a high accuracy rate, 80.51%, for recognizing different gaits (Chen, et al., 2011).

Quantifying PD using bilateral Coordination of Gait is a new approach in identifying severity level of Parkinson’s Disease. Meir Plotnik et al. (2017), in their studies “A new measure for quantifying bilateral coordination of human gait”, compared the gait of healthy adults with the gait of PD’s patients, hey defined the stride duration of one foot as a gait of one cycle, with respect to stride duration they also determined the timing of contra-heal strike and defined this period as φ, ideally the value of φ is 180’ for every step. Phase Coordination Index (PCI) was counted using sum of
coefficient of variations and the mean absolute difference between 180’ and $\phi$. In the results the PCI value was higher (poor bilateral coordination) in PD’s patient with respect to healthy adults ($p < 0.006$) (Plotnik, et al., 2007).

2.3. Wearable Motion Sensors

(Wile, et al., 2014) in their studies sought to distinguish the postural re-emergent tremor of PD from essential tremor with the use of accelerometer in smart watch. Short recording of 41 patients was recorded using smart watch when the patient’s hands were at rest and outstretched. Tremor peak, frequency, peak power and power of harmonic were calculated, and these features were used to classify tremor as Parkinsonian or normal. Results from this research showed that the 80% of the participants were correctly grouped into having PD or essential tremors. According to the researchers, the advantages of using smartwatch are portability, non-invasiveness and ease of use. Finally, researchers suggest that using of smartwatch may help in monitoring therapy either from home or remotely by using remote wireless transmission of data.

(Huerta, et al., 2016) demonstrated a system that were using accelerometer and gyroscope in smartwatches to quantify tremors in PD Patient. This system was based on wireless body area network consists of multiple sensor nodes (Smartwatches) and sink node (Smart Phone). This system was tested on 12 patients within average age of 66.33 years and average disease duration of 6.25 years, these patients were seated and at rest during the tests. The tremor magnitude is presented in the form of angular velocity and linear acceleration. The results showed that the system can determine the progress of PD. According to researcher, using the sensors in the smartwatches cannot disturb patient’s daily life (Huerta, et al., 2016).

Approximately 90% of PD patients have mobility related problems for travelling to the doctor for follow ups, this problem prevents them from doing daily living activities (Sharma, et al., 2014). Sprung from these mobility problems (Sharma, et al., 2014) developed SPARK, a framework that uses a synergistic combination of smart watch and smart phone to monitor multiple symptoms of PD such as facial tremors, dyskinesia problem with gait and dysfunctional speech. It was built on the advances in clinical practices and wearable technologies. Their work supports to non-clinical settings; therefore, it allows tele-rehabilitation. According to the researchers, SPARK framework showed promising results.
2.4. Apps and Commercial Product

Since, the interest in Parkinson’s Disease is growing day by day, so there are multiple companies who built multiple smart phone apps to gather data on PD patient’s condition. One of the well-known applications is mPower, which is developed by a non-profit organization (mPower, Mobile Parkinson’s Disease, 2017). The application uses a mix of surveys and tasks that activates phone sensors to track symptoms of PD progression (Mangravite & Friend, 2017). Tasks include tapping screen, holding phone in outstretched arm and then keeping it in pocket. mPower was developed to measure Pd symptoms on daily basis and over a long period of time to get the data of PD patients for research purpose.

(Kubben, et al., 2016) developed TERMOR12, an open source mobile application for tremor quantification. TREMOR12 extract features such as rotation, rotation speed, acceleration and gravity, each in 3-axis within 100hz time-stamped frequency. These measured features then exported to TREMOR12P data processing module. This app was tested and evaluated on 3 PD patients. The result shows that TERMOR12 app can detect and register characteristics of tremor. This app is low cost solution to quantification of tremor for research purpose and algorithm development (Kubben, et al., 2016).

Another startup project founded by Utkarsh Tandon and named it “OneRing”. OneRing is a plastic ring with a sensor attached on the upper side of the ring. This ring pairs with a smartphone application and the patient wears the ring throughout the whole day and at the end of the day when sufficient data is collected through ring, then this data is further proceeded by a Machine Learning algorithm to PD severity and generate smart report. Smart report generated by this mechanism is used by clinician or Doctor for better prescription and dosage of medication. The supported classification includes dyskinesia, bradykinesia and tremor (Tandoon, 2017).
2.5. Computer Vision

In the above methods and systems, build for quantification of Parkinson’s Disease are using sensors or any other electronics circuits but in the HMQPD, we are using computer vision approach to quantify Parkinson’s Disease, means only using camera of a computer to analyze hand movements and quantify PD. Now a days, computer vision is one of the most emerging fields in technology, according to Gaudenz Danuser the term Computer Vision refers to “theory and implementation of Artificial Systems that extract information from images to understand their content” (Danuser, 2011). Computer vision also means that computer has sight as human.

Now a day’s computer vision is widely used in the fields of Artificial Intelligence, Control Robotics, Signal Processing, Physics Imaging, Neurobiology, Mathematics, Machine Learning and Bioinformatics. Following are some of the application of Computer Vision.

- Face detection
- Object Detection and tracking
- Object Recognition

2.5.1. Tools for Image processing

Now a days, computer vision is gaining lots of attention because of its integration in real life can help in solving many real-life problems such as autonomous cars, speed detectors, mobile applications and social networks. Still many research problems are there to be solved in the field. So, there are many open-source tools available for the research and development, following are some of the well-known and most powerful tools in the field of image processing.

1. OpenCV
2. BOOF CV
3. JAVA Blob Scanner

OpenCV

OpenCV was released under the license of BSD and hence it free for commercial and academic use. It is well documented and most power library. It supports Windows, Linux, IOS, Android and MAC OS and it has java, C++, C and Python interfaces.
Advantages of OpenCV

1. OpenCV is free open source image processing library.
2. OpenCV have huge collection of algorithms and no image processing library except OpenCV have that much number of Algorithm. OpenCV is also optimized for performance.
3. OpenCV can be used in desktop app development or in backend of web application.
4. OpenCV is downloaded more than 9 million times and it has community of active 47000 developers.

2.6. Selection of Algorithms


2.7. Literature conclusion

Thus, we see that till date, there has been various technical and theoretical studies and research had been carried out for the diagnoses of Parkinson’s Disease; some of them were using external hardware and some of them were using smartwatches and sensors for the diagnoses of PD. External hardware and smartwatches are expensive to buy and not every patient affords them. So, the HMQPD will be a desktop application that can be used anywhere, and this application will be portable and can be integrated into any other software application. It will be cheap, reliable and effective.
Chapter 3: Methodology
The research objective was to quantify Parkinson’s Disease by analyzing patient’s hand movements using webcam to save time and efforts of the patient affected by Parkinson’s Disease. This chapter provides a detailed walkthrough of the research methods and techniques that were used in development of application (HMQPD) for diagnosing severity level of PD.

In order to achieve the research objective, this chapter is further divided into four subsection: first section describes the theoretical framework of the application which gives details of the theoretical concepts that were used for the development of application; second subsection gives a brief description of the Design process in which methods regarding collection of primary and secondary data are highlighted; third subsection gives details of technical framework, and final subsection is conclusion.

3.1. Theoretical Framework
This subsection of the research methodology gives a brief description of the theoretical concepts that should be achieved as a result of the development of the Application. After the careful study of various research papers, and surveys from patients affected by PD, various attributes were found out. According to the results, the following attributes were selected to analyze them to diagnose the severity of Parkinson’s Disease.

1. Hand Movement
2. Wrist Movement
3. Finger count
4. Elbow Movements

Consequently, the diagnoses of two of the attributes which is hand movement and finger count were selected for the analyzation purpose. According to the survey result, 14 out of 19 patients were chosen for hand movement and 12 of them were chosen for finger count. Figure 3.1 shows the results of the survey.

To diagnose the severity level of PD, application will first count fingers, and then it will count the hand movements with the help of the results of fingers count.
3.2. Research Design

This section describes the methods that were used in collecting qualitative and quantitative data. The useful information elicited from the data was used for the evaluation of prototype, and investigation of questionable areas such as, problems that are potentially causing design to be altered. There are three subsections of this section: first is research philosophy, second is research approach and the third is research strategy.

3.2.1. Research Philosophy

According to (Creswell, 2009), if the theoretical research is not done before the implementation of the artifacts, it will might create problems in future to the targeted users or audience that are concerned with the study. The research should be conducted in a proper manner, which is gathering the information from the patients of PD, through this gathered data, researcher will gain an instant of the problem and the need to create the artifacts, which is needed to justify the research.

The researcher will review previous theories and make an hypothesis related to those theories, and once the data is collected, the researcher will analyze and create pattern according to the theories.
3.2.2. Research Approach
The research approach used in this study id deductive. A deductive research approach is concerned with development of a hypothesis based on existing theories, and after developing a hypothesis the next task is to develop a research strategy to test the developed hypothesis (Wilson, 2010). Since, the approach is concerned with review of previous work and finding a theory or phenomenon, and test if that theory is valid or invalid in given circumstances. Figure 2 shows the diagram for deductive research approach.

![Diagram of Research Approach](image)

*Figure 2: Research approach for HMQPD*

3.2.3. Research strategy
3.2.3.1. Primary Data Collection Method
For any dissertation, primary data collection is most important aspect because it is the initial step for starting the research and dissertation. The data collected from primary research should be unquestionable and must be accurate with proper evidences. This study is a secondary research project, so the primary data collection was by study on various research papers and case studies on bradykinesia and slowed movement Parkinson’s Disease.
3.2.3.1. Secondary Data Collection

Fly on the wall observation
Fly on the wall means an unnoticed observer of a situation (Dictionary, 2018). To understand the usability of product, the quick and easy way is to observe the user when they are interacting with the product. It is a best way to gather information about product by listening and looking, without interfering with the participant (Hanington & Martin, 2012). This method removes researcher for any direct involvement, minimizing any bias or influence that may occur. Fly on the wall observation does not have any predefined structure except few guidelines, but still researcher can get as much data as the can during the test.

Think Aloud Test
Naturally, there are two integrated parts of many common research methods, observing users and taking notes. One of the most well-known common research methods is think-aloud test, in which test participant is asked to use system or perform the given task while thinking out loud (Verbalizing their thoughts) (Nielsen, 2012). This test is conducted with one moderator, one user and one note taker. This method has many advantages and most important of them is, it serves windows as a soul, helping you in discover what users thinks about your design, which may help to redesign (Nielsen, 2012). This method is cheap, flexible, robust and easy to learn but still there are some drawbacks of this method such as unnatural situation, influencing user behavior, and filtered statements.

Observation are good way to collect data, but they alone may not collect sufficient data, therefore it is suggested to gather data from other methods such as interview, and use the data gathered by observations as a complement to other methods.

Interviews
There are many methods of data collection used in qualitative research such as, observation, textual analysis, visual analysis and interviews. However, most common methods used in medical related research in computing, are interviews. Interviews can be used in different phases and for different purposes of development cycle, e.g. feedback for the prototype. There are three fundamental types of interviews that are structured, unstructured and semi structured (Jamshed, 2014). Structured
interviews are formal and with predefined questions, with little or no variation. Semi structured interviews consist of some predefined questions, but it also allows the interviewer to divert from the real context in order to get some more information about an idea. Unstructured interviews do not have any predefined questions and directives. There is no rule to adhere to any of the approaches, but it depends on the purpose. If the goal is to discuss any feature of product then the approach should be structured interview.

There are some rules that an interviewer should keep in mind when conducting interview. Firstly, do not rush, wait until interviewees finish and also give them time to think on their answers. Secondly, always conduct interview in a relax environment without any disturbance or distraction.

**stake holder interviews**

The reason behind any design is to achieve something or any business outcome. A stakeholder is someone with responsibility or authority for the product being designed. Interviews with stakeholders should be conducted before user research, because the way of user research is always affected by them (Cooper, et al., 2014). The information that is gathered through stakeholder interviews includes project vision, budget and technical constraints.

**Subject Matter Expert interviews**

Subjects matter experts are the people or stakeholders that are expert in the particular field in which project will exists, built and operate. Right time to meet these people is especially before project development or when user testing is not available (Cooper, et al., 2014). According to Cooper et al., SMEs should have brought in throughout the whole design process, not only in early phase of design process. Data collected through SMEs interviews will help in finding out stress and difficulties in designing especially in the field of medical or scientific.

**Previous Work Review**

It is one of the most important things is to learn about context and user through academic papers and literature when conducting research in user interaction design. Literature is key element in any research and it serves as a foundation for whole design process. A good amount of literature studied by designer or researcher, will help as a basis for the interview questions with SMEs and stakeholders (Cooper, et al., 2014).
For any work related to research of disease testing, it is most important to look at the previous work done for the same purpose. If a product was failed or had poor results, looking at how designer failed will help in avoiding the same mistakes.

**Experts Based Methods**
In this method, no actual user is involved in the examination of product; only two experts were there to examine the functionality, usability and other design aspects of product. Expert based methods are cheap and quick.

**Heuristic Evaluation**
In this method, usability expert systematically reviews the product and compare it with accepted usability principles (a set of Heuristics). As a result, this method gives us a list of usability issues. Since there are many heuristics exists but the most common and well known is a set of heuristics that was developed by (Nielsen, 1990). Following heuristics, it includes:

- Visibility of System status
- User control and freedom
- Match Between the system and real world
- Prevention of errors
- Efficiency and flexibility of use
- Recognition rather than recall
- Minimalistic and Aesthetic Design
- Documentation and help

**Questionnaire**
There are many techniques available to collect data from users, but questionnaire is one of the main ways to collect data and find out user opinion. A questionnaire is a form that contains series of question put together in a proper sequence to collect information from about a task from respondents. There are many benefits of questionnaire such as it is cheap, time efficient and it can gather views from many peoples in short amount of time. It is also true for web-based questionnaire, that they are cheap, time efficient, less labor intensive and they can directly store data into database (Preece, et al., 2011).

**3.3. Technical Framework**
Hand Movement quantification of Parkinson’s Disease (HMQPD) is a desktop application so for the development of the application, some technical decision researcher had to take such as selection of IDE,
selection of image processing library and selection of algorithms. Visual studio 2017 is selected as IDE for the development of application, OpenCV 3.1.0 is selected as image processing library and few algorithms were selected for the development, the description of algorithm is given following.

For the face detection and extraction (V. Paul, 2001) algorithm was used and for hand segmentation and hand detection canny edge algorithm and Suzuki 85 algorithm was used.

3.4. Limitations of methodology

Doing this research implementation there were a lot complication which I faced. Below are the following details of the problems faced.

1. To develop and test an application regarding to any medical disease we must need someone who is affected by that disease to test the application and retrieve the results on it. During this research it was next to impossible to find someone with PD. After a lot of struggle, I finally found Mr. Amolakh who agreed to volunteer and help in testing the application but denied sharing any sort personal and disease related data.

2. Any application related to any medical disease must need consultation from doctor who is expert in this disease. As per the financial aspects, I am a student and I could not afford to make appointment with any neurologist here. Also, I could not afford travelling to Pakistan where I know couple of patients and neurologist who could volunteer and help me in this project.

3.5. Conclusion

In this section, the researcher has discussed the research objective, its theoretical frame work, data collection techniques and technical frame work. In the next chapter the researcher will give a complete description of application design and development.
Chapter. 4: Artefacts Design and Development

4.1. Introduction

The research question of this study is to quantify Parkinson’s disease by analyzing hand movements of patients. So, this chapter of the study is all about design and development of HMQPD, it describes overall approach of implementation and design details of HMQPD using OpenCV. OpenCV is an image processing Library and it has some strong functionalities in computer vision and machine learning. OpenCV is used mostly used for projects mostly related to medical and artificial intelligence. The programming language used for this project is C++ and the IDE used for this project is Visual Studio.

First, in this study researcher give a brief overview of software development life cycle (SDLC) model. So, in the first section of this chapter a brief description of the SDLC model and the reason behind the selection of SDLC model is given, in the second section a brief description of requirement gathering is given, the third section of this chapter explains designing, the fourth section gives a brief description of the implementation and final section describes the output.

4.2. Selection of software development model

A software process is a set of related activities that leads to production of software. The software development model is a structured and simplified representation of software process for development, it also describes the sequence of phases for entire life time of product.

The primary goal of any software model is to solve the problem. Following are the steps for this research to develop project.

1. Understanding the Problem.
2. Identifying the Solution (Design and SRS).
3. Coding
4. Results

For the Development of HMQPD, there was an argument between the selection of process model, there were two process model that suits best for the application design and development, one is
waterfall model and the other one is prototype model. Since the requirements of this project according to research is already defined and they were so clear, but the accuracy of the system was our biggest concern, so for the accuracy and optimization of the application we selected prototype development model over waterfall model.

According to (Walker, n.d.), prototype is a development methodology in which a prototype or model is developed and deliver it to end user for the evaluation. Because of this end user will get an idea of the real system.

In our study the reason behind the selection of the prototype model is accuracy and optimization of application. The first development is for checking results, and the next each and every prototype should be developed for better accuracy results.

This development methodology is also known as incremental development. According to results of many studies, it has shown that prototype software model reduces issues with the software requirements specification and it also lowers the development cost of the project.

**Diagram for Prototype Model:**

![Diagram for Prototype Model](image)
4.2.1. **Advantages of Prototype Model**

According to (Walker, n.d.) following are the advantages of prototype model.

1. End Users are Actively involved in the development process throughout the project development life cycle.
2. The user will get the better understanding of the system being developed.
3. Error detection is very easy, and error can be detected at earlier stage.
4. User feedback for initial prototype is available and that will help in better solutions.
5. Identification of missing functionality is easy.

In HMQPD the main advantage of the prototype model is that every prototype come up with a better accuracy.

4.2.2. **Disadvantages of Prototype Model**

Technically this development model leads to increase of complexity of the system as the requirement may go outside the scope, but it happens sometimes. Incomplete application my cause application not used during the development process as a full system, but it can be used for evaluation only.

4.3. **Requirement Analysis**

For any software project it is always important to analyze requirements for the better understanding of the problem and to provide solution for the problem. It also helps in identifying the constraints that should be considered during the development of the system. The aim of this section is to identify functional and non-functional requirements for the development of HMQPD. This section also discusses different approaches to identify the requirements.

According to (Sommerville, 2010), “The requirements for a system are the description of what system should do”. These requirements will show the need of a solution in a real-world problem. The process of requirement gathering, analyzing the requirements, documenting, finding the constraints, and feasibility is called requirement engineering. In agile development methodology requirement are also known as user stories while in many other frameworks requirements are also known as high-level statements.
For an application related to disease testing there are two types of requirements, functional requirements and non-functional requirements. Functional requirements consist of identifying severity and accuracy of the results, and these requirements are also considered as high-level requirements. Non-functional requirements are ease of use and maintenance.

For HMQPD requirement gathering has done by analyzing the data acquired through the processes that are described in methodology chapter, and some requirements are elicited from Parkinson’s Disease Diagnoses literature review.

### 4.3.1. HMQPD High level requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifying Severity</td>
<td>Application should identify the severity of Parkinson’s Disease in the patient affected by it when patient perform test on the system.</td>
</tr>
<tr>
<td>Accuracy</td>
<td>The results that come after performing test should be 80% accurate.</td>
</tr>
<tr>
<td>Easy to Use</td>
<td>The system should be very easy to use by patient, the person or patient using the system should not need any technical skills for the use of system.</td>
</tr>
<tr>
<td>Maintainable</td>
<td>The system should very easy to maintainable, even if it is integrated into any other system. Any new update is easy to installable.</td>
</tr>
</tbody>
</table>
4.3.2. **Functional Requirements**

Function requirements are requirements that are defined to achieve the intended system objective. Following are the few functional requirements for the system.

1. **Finding Hand in Low Light Visibility:**
   The system should be enough efficient that it can work in any normal light environment there should be no additional need of light or any other high definition camera.

2. **Detecting Face and extracting it:**
   The system will work by finding contours and detecting hand using contours, so the actual thing we need is the contours of the hands but face and hand are of same color and because of this system will also identify contours of face, for this we have to detect the face and remove it from grey scale video so that system will work efficiently without and disturbance.

3. **Diagnosing Parkinson’s Disease**
   This is the most important task of the system, system should diagnose PD by quantifying hand movements of the patients. The implementation of the system is discussed in later sub sections.

4. **Accuracy**
   Accuracy of the system should be 80% or more than that, because any wrong result will lead to system failure. In any system related to disease testing or diagnosing the results should be more than 80% accurate for the success of the project. If the accuracy is below 80% then the system is failed to be used in real time environment.

4.3.3. **Non-Functional Requirements**

1. **Smooth Execution**
   For the better results system will run smoothly, cause any disturbance will hurt accuracy of the test results.

2. **Performance**
   The main reason to develop this system is to diagnose severity of Parkinson’s Disease at home so that patient affected by it do not need to travel to the doctor. To run this
application every patient or his care taker must need a system with windows installed on it. The system should be developed in such a way so that patient do not need to buy a high configuration system, it should run on any low configuration system but a camera on it.

3. **No need of external hardware**
Till now all the system that has been developed for the diagnosis of Parkinson’s disease, all of them need external hardware such as sensors and smartwatches. The only requirement of this system is a computer with a webcam.

4.4. **Algorithms Used for development**

4.4.1. **Haar-cascade Algorithm for Face detection**
Face detection in image processing is a technique that determines location, size and shape of human face in a digital image. In the development of HMQPD, OpenCV face detection function is used to detect human face. OpenCV’s face detection technique uses (Viola & Jones, 2001) “Haar Cascade Algorithm”, this algorithm uses Haar-like features for the detection of any object inside the digital image. Haar-like features are also known as Haar-Wavelet.

A Haar-wavelet is a sequence of rescaled square shaped functions that are very similar to Fourier-Analysis. These features were proposed by Hungarian mathematician Alfred Haar in 1909. In image processing object detection, a Haar-like feature considers neighboring rectangular region at a specific location in the differences that are calculated using these sums are then used to categories subsections of an image. Figure 3.1 shows Haar-like features.
Using Haar-like features is very easy to detect the different parts of human face such as, to detect eyebrows, edge-features are used and to detect human nose, line features are used. Figure 3.2 shows the detection of different parts of human face using Haar-like features.

OpenCV’s face detection algorithm uses pixel intensities to find Haar-like features for different part of the human face. The ideal pixel intensities for Haar-like features are 0 for black and 1 for white but this is very rare condition, since all the images are not in black and white color. To detect Haar Features in color images,
viola and jones algorithm compare how close is the real scenario is to the ideal case and find out the intensity values for Haar features.

\[
\Delta = \text{dark} - \text{white} = \frac{1}{n} \sum_{\text{dark}} I(x) - \frac{1}{n} \sum_{\text{white}} I(x)
\]

If the value of \( \Delta \) is closer to 1 it means Haar like feature is found.

OpenCV’s cascade of classifier is trained with 6000 features and its algorithm work by applying each feature one by one if any of its feature is failed then algorithm will discard those pixels of image and consider it a non-face part of image.

### 4.4.2. Canny Edge Detection Algorithm

Canny edge detection is an edge detection algorithm that is used to detect edges in a digital image. It was developed by Jhon F. Canny in 1986 (Canny, 1986). This algorithm is multi stage algorithm, following are the stages of this algorithm.

1. **Noise Detection**

   The first stage of this algorithm is to detect the noise in the image and remove it from the image using Gaussian Filter. The reason for noise detection is edge detection is susceptible to noise.

2. **Image’s Intensity Gradients Finding**

   After noise detection the image is then filtered with a Sobel kernel in both vertical and horizontal direction to get first derivatives of both directions. \( G_x \) is the Derivative for horizontal Direction and \( G_y \) is the derivative for vertical direction.
3. Non-Maximum Suppression
After getting the directions and magnitude, next task is to remove unwanted pixels which may not constitutes the edge, this is done by full scanning of image. In this scanning every pixel is checked if it is a local maximum in its neighborhood in the gradient’s direction.

$$\text{Edge Gradient } (G) = \sqrt{G_x^2 + G_y^2}$$

$$\text{Angle } (\theta) = \tan^{-1}\left(\frac{G_y}{G_x}\right)$$

4. Hysteresis Thresholding
This is the last stage that decide which are edges and which are not, it is done using thresholding with two threshold values minValue and maxValue. Any edge with intensity gradient greater than maxValue is sure to be edge and any edge with intensity gradient less than minValue is sure to be non-edge.
4.5. Design

This section discusses the architecture and the design of the application. In this section the researcher’s aim is to describe all the design details of our application HMQPD (Hand Movement Quantification of Parkinson’s Disease). This section gives a brief description of all the system design and diagrams related to the design. This section also explains total of six high level and low architectural diagrams of the system. Following are the Diagrams names:

- Flowchart Diagram
- System Architecture
- Context Diagram
- Data Flow Diagram
- Sequence Diagram
- Use case diagram

Architectural design is basically structure of the system that will show how application is going to work. Architectural design is initial phase of software Design process, it shows the basic
connection between design and requirements. It also identifies the different components of the system that should be developed and connections between the components. According to (Bosch & Molin, 2002), architecture of any system determines the maintainability, performance and the robustness of the system. Following are the key elements that has been design and implemented.

1. **Get the Video from Camera**
   The first task of the application is to check whether the camera is working properly or not if the camera is working it will capture the video of hand movements.

2. **Detect the face**
   This is the most critical part of the application, after getting the video from camera the system will first detect the face of the subject using Haar cascade Algorithm (Viola & Jones, 2001). The more description of the algorithm and the face detection method is given in implementation section.

3. **Get Skin Color Profile and remove the Face.**
   After face detection the system will get all the components of video that are of skin color and then it will remove the face from that components. The reason behind removing the face is to avoid disturbance that will cause by face because face and hands have same color.

4. **Hand Movement Recognition**
   After removing face and getting components of hands then the system will count the number of times the hand will move.

5. **Analyzing severity**
   After counting the number of hands it will match the count with the predefined and trained UPDRS Scale count for each severity level. And after analyzing severity it will display results in a console.
4.4.1. Flow Chart Diagram

Flow chart is a diagram that gives a visual representation of the sequence of the steps and decision of a process. Each decision and step are showed in a visual diagram shape. Steps are connected with visual arrows. Flow chart is a most powerful business tool. Figure 6 Shows the flow chart diagram for HMQPD.

![Flow Chart Diagram of HMQPD](image)

*Figure 6: Flow chart Diagram of HMQPD*
4.4.2. System Architecture Diagram

Figure 7 is architecture diagram of HMQPD and it explains the architecture of the system. Patient will sit in front of camera and then he starts the test, camera will capture the movements and after that the recorded movements go through the algorithm for face detection and extraction after that system will count hand movements and map it to the UPDRS scale. At the end of test, system will display the results those results are further checked by doctor to prescribe the dosage of medicine.

![System Architecture Diagram](image)

**Figure 7: System Architecture Diagram**

4.4.3. Data Flow Diagram

A data flow diagram is software design diagram that show the flow of data or information of any process or system. Figure 8 shows the data Flow diagram of HMQPD.
4.4.4. Context Diagram

A context diagram is a system design diagram that defines the boundary between the system or part of the system, and its environment. Context diagram is also known as a high-level view of the system. Figure 9 shows the context diagram of HMQPDP.
4.4.5. **Sequence Diagram**

Sequence diagrams are also known as event diagram or event scenarios. Sequence diagram is a type of interaction diagram because it shows the interaction between objects and group of objects in a software system. Figure 10 shows the sequence diagram of HMQPD.

![Sequence Diagram Of HMQPD](image)

4.4.6. **Technology Overview**

**C++**: The programming language used for the development of the application is C++. C++ is sophisticated, efficient, reliable and middle-level object-oriented programming language. It is fast and undoubtedly feature rich and it also supports multiple platforms (Stroustrup, 1979).

**OpenCV**: OpenCV is an open-source image processing library. It is BSD-licensed library. OpenCV includes several hundreds of computer vision algorithms. The structure of OpenCV is modular, which means it contains several static and shared libraries. OpenCV is written in C and C++ that is why it is quite fast then other image processing libraries. OpenCV is also considered as portable cause it run on any device that can run C (doxygen, 2017).

**Visual Studio**: The IDE used for the development of the application is visual studio. Visual studio is an IDE that provides a rich selection of programming languages. During the development of application, I found visual studio is very helpful and interactive IDE.
4.5. Implementation

In this section, the researcher discusses the steps that were taken to implement HMQPD application. Following is the step by step description of the application development.

4.5.1. Face Detection

This application only works by finding moving objects, that are of skin color and then identifying them either they are hands or not, if they are hands then it will count the number of times they are opened and closed in a particular time period. So, the biggest disturbance will create noise and will alter the results is face because it has same color as hands. So, finding and extracting face from captured video is the first challenge that researcher faced during application development. For the face detection researcher has used Haar Cascade Algorithm developed by (Viola & Jones, 2001). This algorithm is already trained for face detection with more than 16000 features. Figure 12 shows the Haar-like features for a human face.

![Figure 12: Haar-cascade Features for Face Detection](image)

Following is the code for Face detection in our Application:

```cpp
facecad.detectMultiScale(frame_gray, faces, 1.1, 2, 0 | CV_HAAR_SCALE_IMAGE, cv::Size(30, 30));

for (int i = 0; i < faces.size(); i++) //consider the first face
{
```
cv::Point center(faces[i].x + faces[i].width*0.5, faces[i].y + faces[i].height*0.5);
maxareai = (faces[i].area() > maxarea) ? i : maxareai;
maxarea = (faces[i].area() > maxarea) ? faces[i].area() : maxarea;
ellipse(myframe, center, cv::Size(faces[i].width*0.5, faces[i].height*0.5), 0, 0, 360,
cv::Scalar(255,
, 255), 4, 8, 0);
}

4.5.2. Background Subtraction
In image processing background subtraction is a major step for preprocessing of images or video, we need it to extract moving foreground from static background. In this study researcher has used BackgroundSubtractorMOG2.

BackgroundSubtractorMOG2 is a Gaussian mixture based/foreground segmentation algorithm. This algorithm was introduced by Z.Zivkovic in his study “Improve adaptive Gaussian Mixture Model for background subtraction” (Z.zivkovic, 2004). This algorithm selects appropriate number of Gaussian- Distributions for each pixel. Following is the code that researcher used inside its application.

PTR<BackgroundSubtractor> pMOG2 = createBackgroundSubtractorMOG2(20, 16, true);

This is the code to create the object for the background subtraction class and in later section its implementation is given.

4.5.3. Fixing the area for hand detection
The most important part of this application development is to detect the hand from real time video to count its number of opening and closing, and to count accurate number of hand movements it is necessary to set a particular area in which hand movements are performed. After the face
detection another task is to create a new capture video window that will focus on hands and integrate that with our main video window. Following are the steps for fixing the area.

First, a rectangle is created that will of a particular size to be used in the video window to focus only on hands. To create a rectangle OpenCV’s default symbol class was used.

```cpp
Cv::Rect MyRectangle (288, 12, 288, 288);
```

After creating this rectangle shape it was integrated into main video window.

```cpp
rectangle (MainWind, MyRectangle, cv::Scalar(0, 0, 255));
```

Now, the main video window has a rectangle inside it, the next task is to capture only the moving objects from main video inside the rectangular frame. So, to capture movements inside rectangular frame a new mat array Rectangle is created:

```cpp
RectangleWind = MainWind(MyRectangle);
```

RectangleWind only captures the images/frames inside rectangle in MainWind.

There are two new Mat arrays was created to store images of RectangleWind, one will store the greyscale images of RectangleWind and other will store the background subtracted image. So, to store the greyscale images in new Mat array OpenCV provides a functionality to converts all video images into greyscale. Following is the code line for the greyscale conversion.

```cpp
cvtColor(RectangleWind, ContourWind, CV_RGB2GRAY);
```

ContourWind is a new Mat array that will hold all greyscale images of rectangle wind. Our other Mat array is MaskMat that will store the video images after background subtraction. Following line of code is for background subtraction, and it is also storing the images in MaskMat array.

```cpp
pMOG2->apply(RectangleWind, MaskMat);
```
After creating these two Mat arrays and storing frames of rectangle windows inside them, now to reduce noise on greyscale image, gaussian blur is applied on greyscale mat array (ContourWind).

```cpp
GaussianBlur(ContourWind, ContourWind, Size(23, 23), 0);
```

The reason behind blurring the image is to reduce the background noise and disturbance. Now we have two Mat arrays that have video frames only of the hands from our main capture window.

### 4.5.4. Hand Segmentation

Hand segmentation means separating the hands from the background in the image. To perform hand segmentation the most important method is image thresholding. In this project to separate hands from image, thresholding is used in many methods. For the extraction of any object from its background thresholding is used by assigning intensity value for each pixel in the image.

Thresholding is done by assigning a threshold value on the input image. If any pixel on that image with intensity less than the threshold value is set to 0 or background and the pixel with intensity greater than the threshold value is set to 1. So, all the pixels with 1 represent object and all the pixels with 0 represents Background.

In this study thresholding is done using Otsu’s Method. This method selects automatically a threshold value for an image based on the shape of the histogram of the input image. For Otsu’s method thresholding OpenCV provides a function based on this algorithm in its library.

```cpp
threshold(MaskMat, MaskMat, thresh, maxVal, type);
```

In the above function thresholding is applied on the Mat array MaskMat and the Threshold value is 70.
4.5.5. **Hand Detection**

After the segmentation of the hands from the video the next stage is to find out hand and counting the number of fingers for the better accuracy of the results. So, to detect the hands first we have to find out contours, convexity hulls and convexity defects of the white blob in the hand segmented image.

**Contours**

Contours are also known as border following, it is the curve joining all the continuous points in the video image have same color or intensity. In this project contours are drawn around the white blob in the image that represents the hand, which is obtained after thresholding and background subtraction, using findcontours(). This function is provided by OpenCV library that uses (Suzuki, 1985) contour detection algorithm. This function detects all the contours of the image either in foreground or in background. To avoid the detection of background contours we already did background subtraction.

```cpp
findContours(MaskMat, contours, hierarchy, RETR_TREE, CHAIN_APPROX_SIMPLE, Point(0, 0));
```
Before finding the contours, edges of the image were detected using OpenCV canny function that uses canny edge detection algorithm to find out edges in the blob for the purpose of better detection of contours. Contours are drawn around the image using drawcontour() function. Figure 16 shows the contours around the hand.

```cpp
drawContours(GraphContourWind, contours, i, Scalar(255, 255, 0), 2, 8, vector<Vec4i>(), 0, Point());
```
**Convex Hulls**

Convex hull is also known as convex polygon. Convex hull of the contours is the smallest convex polygon that contains all the contours of the blob inside it. To find and draw convex hull, OpenCV provides `convexhull()` function that find the convex hull of 2D point arrays using Sklansky’s algorithm. Figure 17 shows the convex hulls formed around the detected hand.

```python
convexHull(contours[i], hull[i], true);
```

![Convex Hulls](image)

**Figure 15: Convex hulls**

**Convexity Defects**

After detecting contours and drawing convexity hulls next thing is to find convexity defects from the image blob to count fingers and hand movements. Convexity defect is a cavity in an object that is extracted after the hand segmentation, to find the convexity defect we need the value of contours and convexity hull of contours.

In HMQPD convexity defects are the pixel inside the image that has intensity value less than the threshold value. For finding the convexity defect OpenCV library provide the following function. Figure 18 shows the convexity defects calculated in the detected hand.

```python
convexityDefects(contours[i], hull[i], defects[i]);
```
Figure 16: Convexity Defects calculated from input image

**Hand Counting**

Hand counting is done using the number of defects if the defect per frames are more than 3 than these are considered to be a full hand opened and if they are less than it hand is in close state.
Chapter 5: Results of Research and Developed application

This chapter outlines the results of the research and application and it also reports on the outcomes. This chapter further divided into two subsections, one is for research results and other one is for application results.

5.1. Research Results

This section outlines the results that is collected using primary and secondary research. Since the primary method for the data collection is ‘previous work review’ and it was already demonstrated in chapter 2, i.e. literature review. This sub section represents finding from survey and interviews from ‘lead users’ and ‘Subject Method Experts (SME)’. The SME’s of this study are Dr. Kelash Langhani and Dr. Taha Khan. The researcher carried out two individual interviews with each SME. The interviews with Dr. Taha Khan was conducted before the start of this project and he was the one who gave me idea to diagnose PD with hand movements of patients. The interviews with Dr. Kelash was conducted during the research because he has two PD patients under treatment in his hospital. Of a total of 30 questionnaire distributed to patient and people who knows something about PD, only 18 were returned representing a response rate about 60%.

Age segmentation of respondents

![Age segmentation chart]

Results from the study shows that 8 respondents representing 44.4% of respondent belongs to the age bracket above 50 years. Four participants representing 22.2% of the total respondent belongs
to age bracket between 25-35 years. 3 respondents representing 16.7% of total respondents belongs to 35-50 years old. 3 respondents representing 16.7% of the total respondents belongs to 10-25 year of age.

patients and care takers

Results shows that 55.6% of total respondent are not affected by PD but they know or taking caring care of someone who is affected by PD. While, 44.4% of total respondents are the patients that are affected by PD.

UPDRS level of Patients who participated in survey
Results shows that 50% representing four participants are suffering from PD with a severity level of ‘UPDRS 3’, 25% representing two participants are suffering from severity level of ‘UPDRS 2’, 25% representing one respondent of each suffering from PD with a severity level of ‘UPDRS 1’ and ‘UPDRS 4’.

The above bar chart shows the results that were provided by caretakers who take care someone affected by PD. According to results, 37.5% representing three patients are suffering from PD with a severity level of ‘UPDRS 3’, 12.5% representing one patient with a severity level of ‘UPDRS 1’. While 25% representing each two patients that are suffering from PD with a severity level of ‘UPDRS 4’ and ‘UPDRS 2’.

**Symptoms of PD**

According to the results 61.6% representing eleven patients are suffering from ‘bradykinesia’
symptom of PD, 33.3% representing six patients are suffering from ‘tremor’, 16.7% representing three patients are suffering from ‘Gait impairment’, and no patients in the survey are suffering from Muscle rigidity, speech changes and writing changes.

**Occurrence Bradykinesia Symptom**

According to results of the survey 77.8% of the respondent representing 14 patients have bradykinesia symptom in the ‘right-hand’ on the other hand 22.2% of respondent representing 4 patients have bradykinesia symptom in their ‘left-hand’.

**Participant who visit Doctor or use any application.**
According to the survey results 94.4% representing seventeen patients used to visit doctor for the diagnosis of PD, on the other hand 5.6% representing one patient use other method.

**Frequency of Visiting Doctor**

According to the survey result 44.4% of respondents representing eight patients used to visit doctor ‘twice a week’, 38.9% of respondent representing seven patients used to visit doctor ‘once a week’, and 22.2% of respondent representing four patients used to visit doctor ‘once a month’.

**Time spend for a single visit to a doctor**
Research finding on the time duration for a single visit to doctor by a patient shows that in a population of eighteen respondent, four respondent use to spent 3 hours on a single visit to a doctor, while six respondent use to spent 1 hour, remaining six use to spend 2 hours on a single visit.

**Amount of a single visit to doctor**

![Pie chart showing the distribution of time spent on a single visit to doctor.]

A total of seventeen responded in affirmative when asked about the amount of money they use to spent on a single visit to doctor. Six participants (41.2% of respondents) stated that they use to spend ‘100$ to 200$’ on a single visit to doctor, five respondent stated that they use to spend 100$ on a single visit to a doctor, while four participant stated that they use to spend 300$ on a single visit and only one participant stated that he use to spend more than 300$ for a single visit to a doctor.

**What do you think a desktop application can be built that can detect severity level of PD only using a webcam of PC?**

![Pie chart showing the responses to the question.]

83.3% said yes, 16.7% said no.
when asked question regarding the application that can detect severity level of PD at home, all of the participant responded and majority of them (83.3%) said ‘yes’ for the application, while some of them (16.7%) said ‘No’.

**Do you have a PC or Laptop at home?**

![Pie chart showing 88.9% yes and 11.1% no.]

Sixteen participants (88.9% of respondents) revealed that had a laptop or PC at home, whereas two participants (11.1% of respondents) said that they do not have any laptop or PC at home.

**When asked about which method is more reliable and cheaper in diagnosing PD**

![Pie chart showing 83.3% at home using an application and 16.7% doctor.]
When asked from respondents about the method which is more reliable and cheaper majority of respondent (83.3 %) went in favor of ‘Desktop application’, while some of them preferred visiting doctor every week.

5.2. Application Results

To verify application’s result, application is tested on three subjects, one was a patient of Parkinson’s Diseases with severity level 3 and other two were healthy young adults with no previous history of PD or any other brain related disease. There were 15 tests performed, five on each subject and the results were promising with the accuracy level of 78%, these tests were performed in perfect environment where all constraints for the environment were met. Following is the hand count and UPDRS scale for this application.

<table>
<thead>
<tr>
<th>UPDRS LEVELS</th>
<th>HAND COUNTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>11+</td>
</tr>
<tr>
<td>Level 2</td>
<td>8 – 11</td>
</tr>
<tr>
<td>Level 3</td>
<td>4 – 8</td>
</tr>
<tr>
<td>Level 4</td>
<td>&lt;= 4</td>
</tr>
</tbody>
</table>

Table 5.1: UPDRS scale for HMQPD.

Light Constraints

This application was tested in a room with area of 50 square Feet and for the light a 4000-lumen light bulb was used to make the room enough bright so that application can work perfectly, moreover in future studies this application can be optimized to work in any normal light condition.

Following is the description of each test that were performed.

Subject 1. Amolakh Mukhi

There were five tests performed by Mr. Amolakh out of them four came up with an UPDRS level 3 and one came up with UPDRS 2 (close to UPDRS-3), so the accuracy of the results is about 91%. Following is the chart for the results of the tests and the screen shot of the tests are given in appendices.
<table>
<thead>
<tr>
<th>UPDRS LEVEL</th>
<th>BIGEST CONTOUR</th>
<th>HAND COUNT</th>
<th>TIME DURATION</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEVEL 3</td>
<td>6</td>
<td>7</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 3</td>
<td>5</td>
<td>5</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 2</td>
<td>6</td>
<td>10</td>
<td>6.5</td>
<td>55%</td>
</tr>
<tr>
<td>LEVEL 3</td>
<td>7</td>
<td>5</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 3</td>
<td>7</td>
<td>5</td>
<td>6.5</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 5.2: Results of the tests that were performed by Amolakh Mukhi

In test 3 the UPDRS level is 2 and the number of hand counts are 10, during the test when counting manually the hands on the other side, he performed 8 hand movements, so accuracy of the test was 55%. Overall accuracy of the tests that were performed by Mr. Amolakh was 91%.

Subject 2: Taimoor Khan

There were five tests performed Mr. Taimoor out of them three came up with an UPDRS level 0 and two came up with UPDRS 1 but the hand counts were nearly closer to UPDRS level 1, so the accuracy of the results is about 84%. Following is the chart for the results of the tests and the screen shot of the tests are given in appendices.

<table>
<thead>
<tr>
<th>UPDRS LEVEL</th>
<th>BIGEST CONTOUR</th>
<th>HAND COUNT</th>
<th>TIME DURATION</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEVEL 0</td>
<td>7</td>
<td>24</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 0</td>
<td>5</td>
<td>22</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 0</td>
<td>6</td>
<td>23</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 1</td>
<td>6</td>
<td>15</td>
<td>6.5</td>
<td>60%</td>
</tr>
<tr>
<td>LEVEL 1</td>
<td>7</td>
<td>14</td>
<td>6.5</td>
<td>60%</td>
</tr>
</tbody>
</table>

Table 5.3: Results of the tests that were performed by Taimoor khan.
Subject 2: Obaidullah Khan

There were five tests performed Mr. Khan out of them three came up with an UPDRS level 0 and two came up with UPDRS 1 but the hand counts were nearly closer to UPDRS level 1, so the accuracy of the results is about 84%. Following is the chart for the results of the tests and the screen shot of the tests are given in appendices.

<table>
<thead>
<tr>
<th>UPDRS LEVEL</th>
<th>BIGEST CONTOUR</th>
<th>HAND COUNT</th>
<th>TIME DURATION</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEVEL 1</td>
<td>6</td>
<td>12</td>
<td>6.5</td>
<td>60%</td>
</tr>
<tr>
<td>LEVEL 0</td>
<td>5</td>
<td>19</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 0</td>
<td>5</td>
<td>19</td>
<td>6.5</td>
<td>100%</td>
</tr>
<tr>
<td>LEVEL 1</td>
<td>8</td>
<td>15</td>
<td>6.5</td>
<td>60%</td>
</tr>
<tr>
<td>LEVEL 0</td>
<td>6</td>
<td>24</td>
<td>6.5</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 5.4: Results of the tests that were performed by Obaidullah Khan

So, overall the results of the application after these tests were more than 80% and it was the objective of this research to achieve results more than 80%.
Chapter 6. Research Discussions

6.1. Introduction

This chapter is all about introspecting the requirements and the objectives that were described in the first chapter and also evaluate how many of them have been achieved in this study. This chapter also focuses on discussing the major phases of the research project and this chapter also drafts the recommendation and the conclusion concerned with the finding of the research. The main reason of this research project is to find out an easy and reliable way to diagnose severity level of Parkinson’s Disease and that was found out by theoretical suggestions taken from literature review and the finding from qualitative research. The objective of this research is to develop a desktop application prototype for the diagnoses of PD. The purpose of this research is achieved by satisfying all the research objectives and answering the research question. Moreover, the strengths and weaknesses of this study have been discussed and recommendation for further improvement of prototype has been suggested.

6.2. Methods and Processes

In this research many research methods were investigated as a possible candidate for use, most of them are for development and design of prototype. During the research phase only three methods were stood out, those are “Subject Matter Expert Interview”, “Review of previous work” and “Lead User”. Literature review played a vital role in this study because it provided a good foundation of Parkinson’s Disease, which proved very useful in each and every phase of this study. As a student of Information systems, I was not familiar with the concept of lead user, but it was a method that I discovered in interaction with Amolakh Mukhi. With experience I found this method very useful, especially for thinking “something new”.

According to my opinion “Subject Matter Expert interviews” and “Lead users” were beneficial to such extent, because I had no previous experience with PD. Because of no experience with PD’s Patient it was very important to keep in touch or taking guidelines, form those peoples who are experts in PD and with peoples who have interacted with PD’s patients before. According to (Cooper, et al., 2014), if you are developing and application related to medical domain, you need some guidance from SME’s, until and unless you can consider yourself an SME. However, in the
initial phases of research SME’s warned me about the problems and difficulties in implementing such research. There were couple of downsides in performing this research such as, finding a PD patient who will help throughout the development of prototype but finally I found “Amolakh Mukhi” who has PD with severity level 3, but it consumed a lot of time and labor work, another downside was finding a SME for this research project.

Although, there were several methods that were discussed in chapter 3, Research Methodology, but they were not officially used in this research. They include ‘Think-Aloud test’, ‘Fly-on-the wall observation’ and cognitive walkthrough. Afterward, I realized that I used some of them in this research but with slide modifications such as, Fly-on-the wall was not implied directly but it was performed when conducting interview with Lead User. Regarding expert-based evaluation I did not employ cognitive walkthrough.

6.3. Research Question Achieved
The objectives and requirements of this research were specified in Chapter 1. This research meets with its requirements by accurately diagnosing PD. A portable and efficient desktop application prototype had been developed with features like face detection, hand movement counting and diagnosing severity of PD. These requirements and features had been collected during primary and secondary research. According to the researcher this research project meets its requirements based on above factors.

6.4 Limitations of this Research
Testing and diagnosing of PD is a very wide area of research. There are numerous approaches available that suits best in different ways to diagnose PD. This research only concentrates on developing a desktop application prototype that diagnose PD. Following are limitations of this research.

1. To get the accuracy more than 80 percent, the application must be operated in a required environment with proper light.
2. This application only diagnoses bradykinesia symptom of PD.
3. This application prototype is only be used for initial diagnoses of PD for patients at home and it is also suggested not to take medicine dosage according to results of this application until, doctor verifies them.

6.5 Research Recommendations
The researcher has acknowledged following recommendation that should be considered for the future development. Following are some recommendations.

1. By integrating a database with this system, symptoms predictions can be done by the data of the patient.
2. For the better accuracy of results, system should be trained with hand movement videos of the patient.
Conclusion

The concept of this study is to quantify PD’s severity level in a patient through its hand movement by only using a webcam and no other external hardware. During this thesis, the concept that in end became an initial prototype of the application. The accuracy of the prototype is 75% when all constraints are met. While during the development some changes were made in the project to push it to come closer to the requirements that were defined in the final research question. Moreover, this project needs some more development and upgrades to make it possible to run it in any environment (e.g. Any light condition) and by anyone.

According to (Marsh, 2016), people suffering from PD are at risk of falling into depression and he also stated that about 40% of PD patients suffers from depression. There are multiples reasons for falling into depression and the main reason is that the PD patients suffers from bradykinesia symptom cause them to visit neurologist more frequently to check PD’s severity level and to take drug dosage according to that severity level, these follow checkups make them depressed because many people cannot afford it either financially or physically. That is why it was concluded that system must be affordable and can be used at home so that it can also help in reducing the mental depression of the patient.

Furthermore, integration testing showed that this system is portable, and it can easily be integrated into any large hospital software system, but the only constraint is that the system in which this application is integrated into must be developed on C++ language.

During this research I had faced many difficulties, and the main difficulty was to find a person affected by PD, who can voluntarily help me in testing the application but after a lot of struggle finally I found Mr. Amolakh Mukhi who helped me and volunteered throughout the development of the project for testing.

Finally, my finding suggests that to enable patient-centeredness, the results and the features must be opened from the standpoint of the user (patient) such as patient must know his performance during the test at the end of the results e.g. Hand movement count. Furthermore, the system should not be an indicator of PD in a person. This system is only used for testing the person who is already affected by PD and it is recommended that for the initial diagnoses of PD, a person must visit neurologist before using this system because this system only diagnose bradykinesia symptom and bradykinesia can be caused many other diseases.
Reflections

This section of the study gives the details of the learnings and outcomes that researcher has gained during this research study and MSc Information Systems course. In all the stages in the development of artifacts of the research, researcher has come to realize the need of software engineering concepts, as a blue print for developing software applications. Moreover, the knowledge that researcher has gained from MSc Information Systems module, not only helped in developing research artifacts but also helped in improving analytical skills of the researcher.

Furthermore, to develop an application for testing any medical disease using image processing, researcher went a further step to acquire knowledge of OpenCV an image processing library, which was used in the implementation of the artifacts. Perhaps, it may not be possible without the help of my dissertation supervisor, who always encouraged me in learning skills.

Finally, the aims and objectives of the MSc program were designed to enhance technical and theoretical skills of the students, which are required in the current software industry. Furthermore, it has also added value to the researcher to choose a career path in technical field such as, image processing. The researcher is very confident that the experience of this research study will him professionally and personally and looking forward to succeeding in PhD studies.
Bibliography


Appendices

Appendix A: Definition of Terms/Acronyms

PD – Parkinson’s Disease
HMQPD – Hand Movement Quantification of PD.
OS – Operating system
SME – Subject Matter Expert
UPDRS – Unified Parkinson’s Disease Rating Scale
Appendix B: Questionnaire

Hand Movement Quantification of Parkinson's Disease
This Questionnaire is part of my thesis project. It is about quantification of Parkinson's Disease at home using webcam.

* Required
1. Your Name *

2. Your Age group? *
   10-25
   25-35
   35-50
   50+

3. Did you ever suffer by Parkinson's Disease?
   yes
   No

4. If yes, then can you please provide the severity level of PD?
   Level 1
   Level 2
   Level 3
   Level 4

5. Do you Know anyone who has PD? If yes, please provide severity level if you know.
   level 1
   level 2
   level 3
   level 4

6. Which Symptom occurs most in you or any one you know?
   Tremor
   bradykinesia (slowed Movement)
   Gait Impairment
   Muscles Rigidity
   speech changes
   Writing changes

7. Did you find bradykinesia symptom? if yes in which hand
   Right
   Left
8. How do you Diagnose PD?
visit doctor
use any application

9. how often do you visit doctor?
once in a week
twice in a week
once in a month
Other:

10. how many hours do you need to visit to doctor?
1
2
3
4+

11. how much do you spent for a single visit to Doctor?
100 $
100-200$
300$
300+

13. Do you think a desktop application that can detect severity level at home is cheap and usable?
yes
No

14. Do you have a PC at Home?
yes
NO

15. If No, how much can you spend on a PC?

16. Do you know how to use a computer?
true
false

16. 17. what do you think which method is best to diagnose severity level of PD?
At home using an application
doctor
Appendix C: Tests performed

Subject 1: Amolakh Mukhi

Test 1: UPDRS level 3

Test 2: UPDRS level 3
Test 3: UPDRS Level 2

Test 4: UPDRS level 3

Test 5: UPDRS level 3
Subject 2: Taimoor Khan

Test 1: UPDRS level 1

Test 2: UPDRS level 0

Test 3: UPDRS level 0
Test 4: UPDRS level 0

Test 5: UPDRS level 1
Subject 3: Obaidullah Khan

Test 1: UPDRS Level 1

Test 2: UPDRS Level 0

Test 3: UPDRS level 0
Test 4: UPDRS level 1

Test 5: UPDRS level 0