DE-42 (DC & SE)

NUST COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING

JetLance - Realtime Balance Assessment using Computer Vision and Pose Estimation

A PROJECT REPORT

DE-42 (DC & SE)

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YEAR

2024

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YEAR 2024

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Certification

This is to certify that Junaid Khan - 336226, Saad Rasheed - 337909, Shadab Zahra - 334728 and Omar Sibghat - 348458 have successfully completed the final project Jet-Lance: Realtime Balance Assessment using Computer Vision and Pose Estimation, at the National University of Sciences and Technology, to fulfill the partial requirement of the degree Bachelors of Computer Engineering.

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Sustainable Development Goals (SDGs)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	**Good Health and Well Being**	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Sustainable Development Goals

Complex Engineering Problem

Range of Complex Problem Solving

	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	X
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	X
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	X
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	X

Range of Complex Problem Activities

	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	X
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	X
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	X
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Acknowledgment

First and foremost, we express our deepest gratitude to ALLAH Almighty, the most merciful and beneficent, for His blessings and for granting us the strength to accomplish this work.

We sincerely appreciate our supervisor, Dr. Ali Hassan, for his invaluable intellectual support and guidance. As an inspirational mentor, he has provided both technical and moral assistance throughout this project. His insightful feedback and encouragement have enhanced our skills and critical thinking, enabling us to achieve our project goals. Without his unwavering support, completing this project would not have been possible. We are truly grateful for his guidance and expertise.

We also thank our peers and fellow students for their valuable insights and feedback during the development of this project. Their input has been essential in refining our ideas and improving the overall quality of our work.

Furthermore, we express our gratitude to our friends and family for their unwavering support and encouragement. Their belief in our abilities and constant motivation have been a source of inspiration throughout this journey.

Finally, we acknowledge the efforts of all those who have directly or indirectly contributed to the completion of this project. Your contributions, whether big or small, have played a significant role in our success.

JetLance Team

Abstract

Balance assessment is crucial in physical therapy for patients with stability and mobility issues. Traditional assessments like the Berg Balance Scale (BBS) require trained physiotherapists, making the process time-consuming and prone to variability in scoring. This thesis presents Jet-Lance, a system that automates the BBS using advanced computer vision and pose estimation technologies. Jet-Lance captures real-time video of patients performing BBS tasks and employs pose estimation to accurately identify body movements. An automated scoring algorithm then evaluates performance against BBS criteria, ensuring consistent and objective scores. The system reduces the subjectivity and variability associated with human assessors and features a user-friendly interface, increasing accessibility for patients with mobility limitations. By automating the assessment, Jet-Lance significantly reduces the time burden on physiotherapists and allows for more frequent evaluations, providing continuous monitoring of patient progress. This thesis demonstrates that Jet-Lance enhances the precision, reliability, and efficiency of balance assessments, offering a consistent and objective tool for improving patient care in physical therapy.

Keywords: Balance Assessment, Pose Estimation

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Chapter 1

Introduction

1.1 Background

Balance is an important requirement for carrying out activities of daily living smoothly. Age and certain other health issues can deteriorate body balance which can ultimately increase the fall risk and other related injuries. Regular Balance assessment can help to prevent falls by early detection of balance problems and developing the most effective rehabilitation strategy. There are multiple tests for assessing body balance. The Berg Balance Scale (BBS) is one of the most widely used tests for measuring balance in clinical health settings. BBS has fourteen sets of activities that need to be performed in the presence of a trained clinician who then grades the activity.

The traditional approach of scoring in BBS is effective yet this method has some drawbacks: scoring of this method is subjective; passing the test requires special training; this method is time-consuming. Recent technological advancements in pose estimation show great promise to be used for different applications. This technique uses computer vision to analyze human posture and movement, providing objective and accurate assessments of physical activities. Pose estimation algorithms can track key body points by capturing and analyzing video footage. Numerous studies have demonstrated the potential of pose estimation in healthcare applications. However, there is a lack of research applying pose estimation to automate the BBS assessment process.

This research aims to develop algorithms utilizing pose estimation to automate the grading of the fourteen BBS activities. By doing so, the objectivity and efficiency of balance assessments can be enhanced, providing more consistent and accurate results.

The automation of the BBS using pose estimation technology has the potential to revolutionize clinical practice. By offering more precise balance assessments, reducing the workload on healthcare professionals, and enabling remote patient monitoring, this research could lead to improved patient outcomes and tailored rehabilitation programs. In conclusion, the integration of pose estimation algorithms for automating the Berg Balance Scale assessment holds great promise for advancing balance assessment in healthcare settings.

1.2 Problem Statement

Balance assessment is a crucial component in clinical and rehabilitation contexts where the current approaches, especially the BBS, have several drawbacks. The conventional methods of administering the BBS involve rating by trained clinicians, which is subjective and may lead to variability and bias. Furthermore, these methods are slow and costly, and they need the involvement of specialized healthcare workers.

In addition, the absence of automation in balance assessment processes limits the availability of timely and accurate evaluations for people with mobility issues. The lack of objective, technology-based approaches to address these issues further complicates the situation. This shows a notable gap in the field of balance assessment.

The current limitations of balance assessment can be overcome by the pose estimation and computer vision technologies that have recently appeared. With these advancements, it is possible to design systems that can automatically and accurately assess human posture and movements, and therefore, balance and stability.

Nevertheless, there is a lack of research on the use of pose estimation technology to automate the Berg Balance Scale despite the technology's potential. Previous research has investigated different approaches to balance assessment and the use of pose estimation for other applications in healthcare settings, but none of them has been dedicated to the combination of pose estimation algorithms with the BBS.

Thus, the first question of this study is the absence of an automated, objective, and efficient method for Berg Balance Scale assessment using pose estimation technology. This project intends to address this gap by establishing and verifying algorithms for grading each of the fourteen BBS activities, thus offering healthcare professionals a valuable tool for balance assessment and improving patient care and outcomes.

1.3 Motivation

Berg Balance Scale BBS, a widely used balance assessment method to detect fall risk among people with balance disorder is conducted traditionally by a physiotherapist. This traditional method holds some challenges such as subjectivity. The current advancements in technology especially in pose estimation and computer vision provide potential solutions to these challenges. Thus, it is possible to create systems that provide accurate and consistent assessments with the help of these technologies.

The use of pose estimation to automate the BBS has several advantages. It can help to reduce the pressure on healthcare workers by automating the scoring process and allowing for remote evaluations. Furthermore, objective and precise assessments can help in making more accurate clinical decisions and enhance the quality of patient care.

Also, there is a significant lack of research on the automation of the BBS using pose estimation. Previous research has examined the application of accelerometers and pressure platforms for the automation of balance assessment and the use of pose estimation for various other healthcare fields but there is no current research that employs pose estimation for the automation of berg balance. We aim to fill this gap by creating and testing algorithms for grading each of the fourteen BBS activities.

On a personal level, our motivation comes from the desire to play our role for the betterment of humanity by using our engineering skills. With the help of this project, people with balance disorders can significantly benefit. We hope that this project will prove to be a massive success in the healthcare sector.

1.4 Aims and Objectives

The key objectives of this project are to develop and validate an automatic, custom application system, which would be focused on the assessment of Berg Balance Scale using pose estimation techniques with MediaPipe. This would represent an extremely accurate, reliable, and most effective balance assessment that would go a long way in improving clinical practice and care of patients. The project intends to achieve the following:

1. Utilize MediaPipe for Pose Estimation:
    - Integrate MediaPipe's pose estimation capabilities to accurately capture and analyze human movements and postures during each of the fourteen BBS activities.
2. Automate BBS Activity Grading:
    - Design and implement algorithms to automatically grade each of the fourteen

BBS activities based on the pose estimation data provided by MediaPipe.

- Validate the accuracy and reliability of these automated grading algorithms compared to traditional clinician-based assessments.

3. Deploy Algorithms on Jetson Platform:
   - Optimize and deploy the grading algorithms on the Jetson platform to enable real-time processing and analysis of pose estimation data.
   - Ensure the system is capable of running efficiently on the hardware with minimal latency.
4. Develop an Intuitive User Interface:
   - Design and implement a user-friendly interface for patients and clinicians to interact with the automated BBS assessment system.
   - Ensure the interface provides clear instructions and results, enhancing the overall user experience.
5. Create a MATLAB Application for Data Collection:
   - Develop a MATLAB application to facilitate the systematic collection, storage, and management of data from patient assessments.
6. Conduct Data Collection and Validation:
   - Recruit a diverse sample of patients and conduct balance assessments.
   - Collect comprehensive data to validate the accuracy, consistency, and usability of the automated BBS assessment system.
7. Evaluate System Performance and Usability Feedback:
   - Collect and analyze users—both patients and clinicians—responses to ensure the system meets clinical needs.

8. Identify and Address Limitations:
    - Recognize any limitations or challenges encountered during the development and validation process.
    - Propose solutions or future research directions to address these limitations and enhance the system's capabilities.

By achieving these objectives, the project aims to advance the field of balance assessment through the development of a reliable and efficient automated system using Pose estimation, ultimately improving patient health and clinical workflows.

1.5 Report Organization

The thesis is structured in the following manner: Chapter 2 is a literature review that offers an overview of the Berg Balance Scale and standard balance evaluation methods. It also highlights current advancements in pose estimation, its application in healthcare, and related work in the field. In Chapter 3 we describe the data collection process, including patient recruitment and data collection protocols. It also covers the development of an intuitive user interface for patient interaction and the use of MATLAB for data collection.

We are covering the main methodology and working of our system in chapter 4 this includes the system architecture, the choice of the model we used, the algorithms developed for grading each activity of the Berg Balance Scale, and the use of Nvidia Jetson.

In Chapter 5, we cover the integration of these algorithms on Jetson and the implementation of the user interface. Chapter 6 discusses the created system's performance metrics, focusing on the accuracy of activity grading and user experience. Chapter 7 concludes the thesis by discussing the limitations of the project and suggests steps that can be taken in the future to improve this project.

Chapter 2

Literature Review

2.1 Traditional Methods for Balance Assessment

Traditionally, balance is defined by clinical tests that assess an individual's capability of maintaining equilibrium during static or dynamic movements. These assessments frequently entail observer-assessed quantification of stability in prescribed tasks, yielding an objective numeric value for balance status and possible falls.

- Berg Balance Scale [1]: BBS is a widely recognized and used objective tool that assesses an individual's balance level by making them complete 14 activities of different complexity. This variation spans from such simple tasks as sitting to standing to rather difficult "standing on one's foot". Each of the BBS test activities is rated on a scale from 1 to 5, unveiling the patient's risk of falling and other balance impairments.
- Timed Up and Go (TUG) Test [2]: A simple yet effective test that measures the time required to perform five tasks, chair-stand rise, walking 3 meters, executing a turn, walking back 3 meters, and sitting down. It is most effective in estimating the patient's ability to move around, maintain equilibrium, and risk of falling especially in the elderly or those who experience difficulty in moving. Likewise in men where

the time < 11 seconds was associated with better performance; times more than 12 seconds suggested increased risk of falls among the elderly.

- Functional Reach Test (FRT) [3]: This Test evaluates a patient's steadiness by checking the range of the individual's motion in the form of forward reach when standing still. Importantly, it can help define the limits of stability and the possibility of a fall in a person. A reach of less than 6 inches is a marker that points to a high likelihood of the patient falling, while a distance of more than 10 inches is deemed suitable for most adults.

- Dynamic Gait Index (DGI) [4]: The Dynamic Gait Index measures the subject's capacity to adapt to balance during walking when exposed to particular demands. It consists of eight elements walking on straight and curved surfaces, turning the head while walking, and sidestepping obstructions. Each task is assigned up to 4 points based on participants' dynamic balance and gait adaptability; higher scores are more favorable.

- Tinetti Performance-Oriented Mobility Assessment (POMA) [5]: The Tinetti POMA is a 19-item test of postural stability, balance, and gait with items addressing both postural control and mobility. The balance portion involves both static and dynamic balance by means of exercises such as sitting balance, standing from a sitting position, spinning with the eyes closed, and turning in a circle for 360 degrees. The gait section measures the initiation of gait, an individual's step length and height, and the degree of symmetry in the steps. To conclude the results of the two segments are summed to know individuals who are at risk of falling.

- Balance Error Scoring System (BESS) [6]: The BESS subtests entail several stances: double-leg stance, single-leg stance, and tandem stance; they are done on both a firm and a foam platform. Each movement mistake, for example, stepping, stumbling, or opening the eyes, is equal to something and gives information about the person's balance and proprioceptive control. Contrary to the old version, it is frequently utilized in sports to confirm a concussion.

- Four Square Step Test (FSST) [7]: The FSST measures an individual's agility while stepping and requires one to change direction. A pattern where an individual has to move in four squares; forward, sideways, and backward in different steps at a given period. Regarding direct analysis, it evaluates mobility and stability in basic movements and object avoidance which is significant for independent movement and fall prevention.
- Mini-BESTest (Mini Balance Evaluation Systems Test) [8]: The Mini-BESTest is the shortened version of the Balance Evaluation Systems Test and is composed of 14 items that target anticipatory postural adjustments, reactive postural response, sensory integration, and dynamic balance during walking. This test is therefore useful in making assessments on specific balance deficits and using the assessment to plan correctly the right interventions.
- Posturography (Balance Platform Test) [9]: Posturography is the process of standing on a force platform which is used to determine the forces that the feet exert to remain balanced. It gives quantitative data regarding balance and can be used in various scenarios, for example, when the eyes are open or closed, as well as when on firm or shaky substance. This test is highly sensitive and is mostly practiced in research and advanced clinical cases.
- Romberg Test [10]: The four steps that are involved in the Romberg Test are; Having the feet of the patient aligned to the direction of the feet of the tester, placing the arms of the patient across the chest, and lastly shutting the eyes of the patient. Other minor alterations comprise of gait ataxia and sensory axia specifically when the affected patient is asked to shut his/her eyes since it indicates proprioceptive/vestibular disorder. It is one of the fastest ways to screen for balance disorders.

2.2 Overview of the Berg Balance Scale

2.2.1 Fourteen Exercises

The Berg Balance Scale is one of the most widely clinical measurements designed to assess the multiple dimensions of postural control and balance in a person. In total, the task includes 14 items, each specially designed to test various aspects of the individual's balance function, which gives a comprehensive insight into his or her ability to maintain balance and possible deficiencies.

1. Sitting to Standing: This test, where a patient is made to rise from sitting to a standing position without using the upper extremities, is an index for lower extremity strength and coordination. The ability to perform the task is a reflection of dynamic strength in the lower extremities and the ease of performing it.

2. Standing Unsupported: This exercise assesses the individual's ability to maintain the standing position unsupervised for a specified amount of time and is employed to test static balance. This task simulates demands on the lower extremity musculature that are required to achieve static upright equilibrium.

3. Sitting with Back Unsupported but Feet supported on Floor or Stool: The subject is asked to sit for 2 minutes with arms folded, unsupported by the backrest. This task assess core stability and postural control. The ability to sit for 2 minutes upright shows trunk muscle strength and endurance.

4. Standing to Sitting: The task assesses the control and coordination needed to lower one's body from the standing to sitting position. The manner in which a person ascends, mostly without excessive use of his or her hands, shows lower extremities strength and his or her balance control during dynamic motion.

5. Transfers: This task, in which one is made to produce pivot transfers between two or more surfaces, instructs the individual to transfer from one level surface to another.

It necessitates the organization of coordination, strength, and balance—especially while changing over from surfaces with armrests to those without.

6. Standing Unsupported with Eyes Closed: Deprivation of visual information when performing this balance test will challenge your reliance on the proprioceptive and vestibular systems to maintain balance. Standing unsupported with your eyes closed is a measure of the robustness of these sensory systems with respect to their contribution to postural control.

7. Standing Unsupported with Feet Together: Standing with your feet together further reduces your base of support, and this tests your static balance. This position will continue to provide information into the postural control mechanisms under conditions of increased postural demands.

8. Reaching Forward with Outstretched Arm While Standing: The very act of reaching forward with an outstretched arm requires the CoG to be shifted anteriorly–this tests the ability to manage balance during forward lean activities.

9. Picking Up Object from the Floor from a Standing Position: The ability to pick an object up from the floor supported on one leg reflects the combination and functioning of several components: dynamic balance, strength, and flexibility. This exercise reflects the individual's ability to engage in stability while performing a reach or low-level activity demanded in everyday life.

10. Turning to Look Behind Over Left and Right Shoulders While Standing: This activity requires trunk and head rotation to look over the left and right shoulder. This activity tests balance during dynamic head movements, and, therefore, gives information about the subject in interaction of coordination and balance to walk within his/her environment in a safe and aware manner.

11. Turning 360 Degree: A full 360-degree turn tests dynamic balance and individual coordination. The ability to perform the task at a safe, but reasonable, rate demon-

strates the proficiency of the individual in conducting the rotational movements without the loss of balance.

12. Stand on Alternate Foot on Step or Stool: Stair climbing tests the person's dynamic balance and coordination. Alternating foot placement on a step tests lower limb strength and the ability to maintain balance while making repetitive, shifting movements.

13. Stand on One Foot in Front: Placing one foot directly in front of the other narrows the base of support. Static and dynamic balance are therefore challenged in the tandem stance. This checks the ability to maintain stability in linearly constrained positions, which would equate to the motions of balance required in activities such as walking or pivoting.

14. Stand on One Leg: Standing on one leg tests unilateral balance and lower limb strength. The ability to sustain this position without support speaks to the stability and control of the associated musculature upon one leg, a key component for activities that include single-leg stance phases.

Each of these tasks on the Berg Balance Scale observes balance from a different perspective. By systematically addressing these various tasks, the clinician can develop a better view of postural control capabilities, thereby informing intervention and rehabilitation strategies with an individual.

2.2.2 Grading Criteria for the Berg Balance Scale

The following shows the grading criteria used by clinicians to assess body balance score.

1. Sitting to Standing

    - (4) Demonstrates the ability to rise to a standing position without the necessity of utilizing hands for support and achieves immediate stability.

    - (3) Manages to stand independently, albeit with the assistance of hands.

- (2) Achieves a standing posture using hands after multiple attempts.
- (1) Requires minimal aid to attain a standing position or maintain stability.
- (0) Necessitates moderate to maximal assistance to stand.

2. Standing Unsupported
    - (4) Maintains an upright stance for a full 2 minutes without external support.
    - (3) Stands for 2 minutes under supervision.
    - (2) Sustains an unsupported stance for 30 seconds.
    - (1) Needs several attempts to maintain a 30-second unsupported stance.
    - (0) Unable to stand unsupported for 30 seconds.
3. Sitting with Back Unsupported but Feet Supported on Floor or on a Stool
    - (4) Sits securely without back support for 2 minutes.
    - (3) Maintains the position for 2 minutes under supervision.
    - (2) Manages to sit unsupported for 30 seconds.
    - (1) Able to sit unsupported for 10 seconds.
    - (0) Unable to sit without support for 10 seconds.
4. Standing to Sitting
    - (4) Sits down with minimal hand use, displaying controlled movement.
    - (3) Uses hands to control the descent into a sitting position.
    - (2) Leans against the chair's back to control descent.
    - (1) Sits independently but experiences an uncontrolled descent.
    - (0) Requires assistance to sit down.
5. Transfers

- (4) Executes a transfer with minor use of hands, ensuring safety.
- (3) Transfers safely but necessitates definite use of hands.
- (2) Completes the transfer with verbal cuing and/or supervision.
- (1) Needs the assistance of one person to transfer.
- (0) Requires the assistance of two people to transfer safely.

6. Standing Unsupported with Eyes Closed
    - (4) Stands with eyes closed for 10 seconds without compromising safety.
    - (3) Maintains stance for 10 seconds under supervision.
    - (2) Stands with eyes closed for 3 seconds.
    - (1) Unable to keep eyes closed for 3 seconds but remains standing safely.
    - (0) Needs assistance to prevent a fall.
7. Standing Unsupported with Feet Together
    - (4) Independently places feet together and stands for 1 minute without support.
    - (3) Stands for 1 minute with supervision after placing feet together.
    - (2) Positions feet together independently but fails to hold the stance for 30 seconds.
    - (1) Requires help to achieve the position but stands for 15 seconds.
    - (0) Needs assistance to both attain and hold the position for 15 seconds.
8. Reaching Forward with Outstretched Arm While Standing
    - (4) Confidently reaches forward 25 cm (10 inches) without losing balance.
    - (3) Extends arm forward 12 cm (5 inches) with stability.
    - (2) Manages to reach forward 5 cm (2 inches) while maintaining balance.

- (1) Reaches forward but requires supervision to ensure safety.
- (0) Loses balance while reaching or needs external support.

9. Pick Up Object from the Floor from a Standing Position
    - (4) Picks up an object from the floor effortlessly while standing.
    - (3) Needs supervision while picking up an object but does so safely.
    - (2) Reaches close to the object (2-5 cm) and maintains balance independently.
    - (1) Attempts to pick up an object but requires supervision.
    - (0) Unable to pick up the object and needs assistance to prevent a fall.
10. Turning to Look Behind Over Left and Right Shoulders While Standing
    - (4) Turns to look behind on both sides with effective weight shifting.
    - (3) Looks behind on one side with proper weight shift, but less so on the other side.
    - (2) Turns sideways to look behind, maintaining balance.
    - (1) Requires supervision to perform the task safely.
    - (0) Needs assistance to prevent losing balance or falling.
11. Turn 360 Degrees
    - (4) Completes a full 360-degree turn safely within 4 seconds.
    - (3) Safely turns 360 degrees in one direction within 4 seconds.
    - (2) Performs a 360-degree turn safely but at a slower pace.
    - (1) Needs close supervision or verbal guidance to turn.
    - (0) Requires assistance to turn safely.
12. Place Alternate Foot on Step or Stool While Standing Unsupported

- (4) Completes 8 steps independently and safely within 20 seconds.
- (3) Completes 8 steps independently but takes more than 20 seconds.
- (2) Performs 4 steps without aid under supervision.
- (1) Manages more than 2 steps but needs minimal assistance.
- (0) Needs assistance to perform the task or prevent falling.

13. Standing Unsupported One Foot in Front

- (4) Independently places one foot in front of the other and holds the position for 30 seconds.
- (3) Places one foot ahead independently and holds for 30 seconds.
- (2) Takes a small step independently and holds for 30 seconds.
- (1) Requires assistance to step but can hold the position for 15 seconds.
- (0) Loses balance while stepping or standing.

14. Standing on One Leg

- (4) Stands on one leg independently for more than 10 seconds.
- (3) Lifts leg and stands independently for 5-10 seconds.
- (2) Stands on one leg independently for at least 3 seconds.
- (1) Attempts to stand on one leg but cannot hold for 3 seconds, remaining stable.
- (0) Unable to attempt or requires assistance to prevent a fall.

2.3 Advances in Pose Estimation

Pose estimation, one of the subfields of computer vision has yet enjoyed much progress in the recent past. The field has grown making use of algorithms and techniques for improving the existing problems related to pose estimation. Here, we will discuss some of the key advancements in pose estimation:

- Deep Learning-based Pose Estimation: In the recent past, an emerging field in computer vision has demonstrated the capability of utilizing deep learning for pose estimation. These models utilize the use of CNNs and RNNs which are used for learning complex patterns in the images and the videos. They have particularly found application in estimating human poses from monocular images and videos
- Bottom-Up and Top-Down: The two generic ways for pose estimation are top-down or bottom-up methods. The top-down approach follows a two-step manner where the upper level detects the body in the image and the lower level finds the joints in the bounding box. Bottom-up approaches, on the other hand, begin with the estimation of simple parts of the human body and then use them to estimate a complete human pose.
- 2D and 3D Pose Estimation: The pose estimation problem is divided into two categories they are 2D pose estimation and 3D pose estimation. This is particularly defined as the task of estimating the 2D location of all the points of interest of a human body from image or video data. This task is easier and is generally applied in fields like human-computer interaction, security, or intelligent video surveillance. It is important to emphasize that 3D pose estimation is a more complex problem than 2D pose estimation since the former requires not only determining translation and rotation but also the depth of key point coordinates.
- Recent Advances: Consequently, there has been recent research to increase the model's precision as well as the speed at which it works. For example, paying

more attention to certain areas using attention mechanisms or capturing more spatial pyramid pooling features and regressing over them have also been used to enhance the performance of pose estimation models. Also, refining the models with less weight and complexity helps in integrating pose estimation for real-time uses.

2.3.1 Pose Estimation in Health Care

Here are some key uses of pose estimation in healthcare, along with a brief description of the problem, method, and solution for each:

1. **General Motor Development**:
    - Problem: Supervision of the overall motor progression in children to detect possible developmental issues.
    - Method: Develop a tracking framework that can estimate the pose of children from video data and monitor their motor-skill progression over time.
    - Solution: The method was thus useful in generally mapping the child's motor development and detecting emergent signs of a developmental disability.
2. **Clinical Motor Assessment in Adults with Neurologic Conditions**:
    - Problem: Measuring and comparing motor skills in adults with neurologic disorders like stroke and Parkinson's disease.
    - Solution: Motor skills in adults with neurologic conditions can be evaluated using pose estimation assessment, and may enhance the validity and reliability of clinical evaluations.
3. **Markerless Human Pose Estimation in Biomedical Fields**:
    - Problem: Diagnosing motor skills and defining developmental disorders in the biomedical sciences.

- Solution: The current study demonstrates that markerless human pose estimation is a useful method for the analysis of motor proficiency and identification of abnormalities in biomedical applications, and can potentially enhance the specificity and time efficiency of clinical evaluations.

4. **Improved Ability to Monitor Patients Remotely**:

   - Problem: Gaining therapeutic insight from treating a patient over a long distance.

   - Solution: This innovative method of pose estimation will enable healthcare professionals to get accurate and verified data on the patient's movement and positioning, no matter their current location.

5. **Faster Response Times for Detecting Distress in Patients**:

   - Problem: Being able to identify if a while-label patient or any elderly people within a hospital are feeling distressed promptly.

   - Solution: Several Real-time pose estimation technologies can aid healthcare providers in effectively managing distressed patients in a bid to enhance their recovery outcomes and minimize possible further manifestations of distress or severity of distress.

These are only a couple representative of the vast applications of pose estimation in the healthcare field. As technology progresses further, the world is likely to notice additional uses for this type of technology in offering better patient treatment.

2.4 Related Work

In recent years, several studies have been conducted to automate the BBS test. On analysis, it could be concluded that these studies can be divided into three categories.

The first category of studies used pressure platforms for determining BBS scores. In 2012, Brassard et al [11] proposed a serious game running on the Android OS that uses an augmented sole to measure movements realized by the user for the estimation of BBS score. For this evaluation, exercises are done by the user as actions to be performed in game [12]. In 2017, Bacciu et al [13] proposed a system that uses the Wii balance board (WBB) with a neural network designed by them to predict BBS scores. Individuals are only required to perform only one test task (stand and turn their heads backward while standing) to obtain their BBS scores. The process is completed in approximately 10s. An MAE of 3.80 was obtained for this system.

The second category of studies used imaging equipment for obtaining BBS scores. In 2019, Johnson et al [14]. used Microsoft Kinect 2 (MK2) with a feedforward neural network to predict BBS scores. MK2 collects data when the individual performs the two BBS test tasks (Pick an object up off of the floor, sit unsupported). This system has an MAE of 1.16. It takes approx. 5 minutes to complete the BBS test. In 2023, Ali proposed a web application that uses web cams to capture users performing five of the fourteen tasks and then traditional image processing techniques are performed to estimate the BBS score.

The third category of studies used wearable inertial measurement units (IMUs) to determine BBS scores. In 2014, Simila et al [15] proposed a system that uses an IMU and machine learning to automatically evaluate BBS scores. Accelerations of the lower back were measured during execution of the BBS test (timed up-and-go (TUG)) and corridor walking by wearing an IMU on backside of waist. Then k -nearest neighbor (KNN) algorithm was used to predict the BBS score based on the collected IMU data. They obtained a mean absolute error (MAE) of 3.53 for their system. In 2016, Badura et al [16] proposed an automatic system in which the BBS score of a subject is estimated by summing up the output of 14 multilayer perceptron. This system uses feature-based data from 5 inertial body-fixed sensors and requires the subject to execute the complete BBS test. They obtained an MAE of 1.47 for their system. In 2017, Shahzad et al [17] used an IMU to predict BBS scores. Their system only requires one IMU (attached on the lower back between the L3-L5 vertebrae) to be used and three test tasks (timed-up and go (TUG), Sit-to-Stand test (FTSS) and Alternate Step Test (AST)) to be conducted for obtaining BBS scores. Their system uses Lasso model for score prediction. They obtained an MAE of 1.44 for their system. In 2022, Bor-Shing Lee et al [18] proposed a system that requires users to wear an IMU device on their left thigh and perform two test tasks (placing alternate foot on stool and standing on one foot (right foot)) to predict their BBS scores using RF model. An MAE of 1.27 was obtained for this system. It takes 2 minutes to conduct the BBS test.

Chapter 3

Data Collection

3.1 Data Collection

Data collection was a meticulous process designed to gather a comprehensive dataset for automated Berg Balance Score (BBS) calculations. This section provides an overview of the data collection process, including the recruitment of participants and the protocols followed during data collection.

3.1.1 Patient Recruitment

Patient recruitment for the project was conducted at Riphah University and Railway Hospital in Rawalpindi, Pakistan. These locations were chosen for their accessibility and the diverse range of individuals they cater to, ensuring a varied participant pool. Flyers and posters were prominently displayed at these locations to attract potential participants.

The recruitment process began with obtaining ethical approval from the relevant institutional review boards (IRBs) to ensure compliance with ethical guidelines for research involving human participants. Once approval was obtained, efforts were made to inform and educate potential participants about the study and its objectives.

Participants were selected based on specific inclusion criteria, including age, health status, and willingness to participate in the study. For the elderly group, individuals aged 40 to 68 years were recruited, while the control group consisted of healthy individuals aged 18 to 23 years. This age range was chosen to provide a diverse sample that could accurately represent the target population for the study.

In addition to age criteria, participants were also required to meet certain health criteria to ensure their safety during the balance assessment activities. Participants with pre-existing balance disorders or mobility issues were excluded from the study to prevent any adverse events during the data collection process.

Overall, the patient recruitment process for the project was conducted in a systematic and ethical manner, ensuring the selection of suitable participants for the study. The diverse sample of participants recruited from Riphah University and Railway Hospital provided valuable data for the automated Berg Balance Score (BBS) calculations, contributing to the success of the project.

3.1.2 Data Collection Protocol

The data collection protocols for the project were designed to ensure standardized procedures and accurate recording of the balance assessment activities. These protocols were crucial for maintaining consistency and reliability in the data collected, which was essential for the success of the project.

The data collection process involved recording videos of participants performing the fourteen activities of the Berg Balance Assessment. These activities were designed to assess various aspects of balance and mobility, such as standing, walking, and transferring. The videos were recorded in an isolated room to minimize distractions and ensure the focus of the participants.

As shown in Figure 3.1, four cameras were strategically placed at each corner of a square measuring 140 inches to capture different views of the same activity and the same participant. This setup allowed for comprehensive recording of the balance assessment activities, ensuring that all movements were captured from multiple angles.

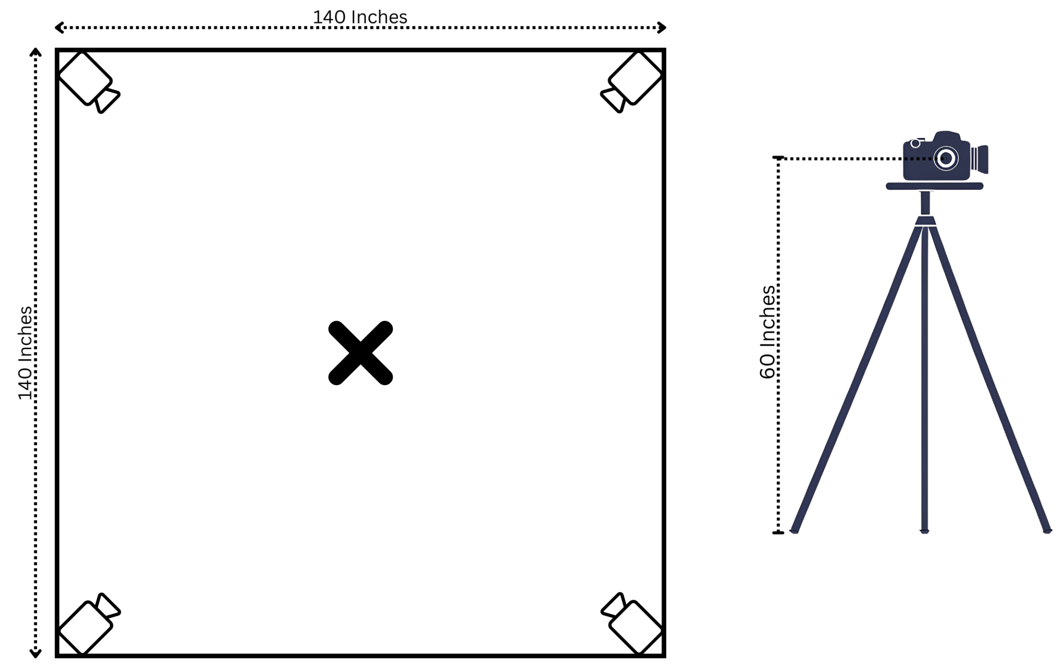

Figure 3.1: Camera Setup

During the recording sessions, only the participant was present in the room, performing the activities. The operator controlled the data collection process from outside the room using a custom-designed MATLAB application. This application provided real-time instructions and video guides to the participant, ensuring accurate performance of the activities.

After each activity, the operator entered the room to provide instructions for the next task. This protocol ensured standardized procedures for each activity and minimized errors in data collection. Additionally, the operator could pause, resume, or switch between activities as needed, ensuring flexibility in the data collection process.

The data collection protocols for the project were comprehensive and meticulously designed to ensure the accuracy and reliability of the collected data. These protocols were essential for the successful implementation of the automated Berg Balance Score (BBS) calculations using computer vision and machine learning algorithms.

3.1.3 Patient Confidentiality and Informed Consent

Ensuring patient confidentiality and obtaining informed consent were paramount in the data collection process. This section outlines the measures taken to protect patient privacy and ensure ethical conduct throughout the study.

Patient confidentiality was maintained by assigning each participant a unique identifier that was used to label all data collected during the study. This identifier was used in place of the participant's name or other identifying information in all documentation and analysis to protect their privacy.

Informed consent was obtained from each participant prior to their inclusion in the study. Participants were provided with detailed information about the study, including its purpose, procedures, potential risks and benefits, and their rights as participants. They were given ample time to ask questions and were informed that their participation was voluntary and could be withdrawn at any time without penalty.

Participants who agreed to take part in the study signed a consent form indicating their understanding of the study and their willingness to participate. For participants who were unable to provide consent themselves (e.g., due to cognitive impairment), consent was obtained from a legally authorized representative.

All data collected during the study was kept confidential and stored securely in compliance with relevant data protection regulations. Only authorized personnel involved in the study had access to the data, and all data was made anonymous prior to analysis to further protect patient confidentiality.

3.2 Data Collection Software

The data collection software played a crucial role in ensuring the smooth and efficient collection of data for automated Berg Balance Score (BBS) calculations. This section provides an overview of the software's design and functionality.

3.2.1 Intuitive User Interface for Patient Interaction

The user interface (UI) of the data collection software was designed to be intuitive and user-friendly, with a focus on enhancing the patient's interaction with the system. The UI consisted of three main components: a text box for displaying instructions, a video guide for demonstrating the activity, and controls for the operator.

The text box displayed instructions for the patient, guiding them through the performance of each balance assessment activity. The instructions were clear and easy to follow, ensuring that the patient could accurately perform the activity.

The video guide provided a visual demonstration of the activity, showing the patient exactly how to perform each movement. This visual aid was particularly helpful for patients who may have had difficulty understanding written instructions.

The controls for the operator allowed them to manage the data collection process efficiently. The operator could pause, resume, or stop the data collection process, as well as switch between activities. This flexibility ensured that the data collection process could be tailored to the needs of each patient.

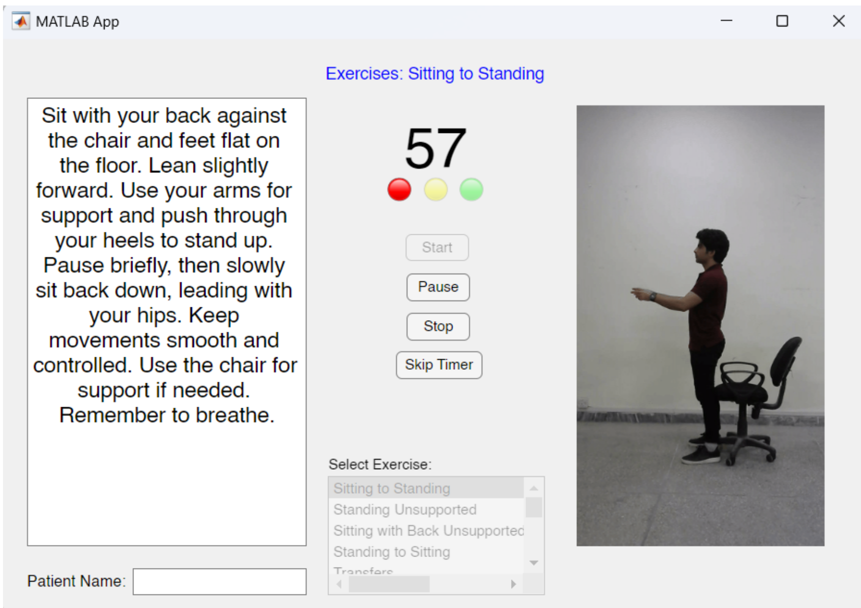

Figure 3.2: Recording Software

The intuitive user interface of the data collection software played a crucial role in ensuring the accurate and efficient collection of data for automated BBS calculations. The software's design and functionality were instrumental in enhancing the patient's interaction with the system, ultimately leading to more reliable and accurate results.

Chapter 4

Methodology

4.1 System Architecture

The system architecture of an automated assessment of the Berg balance scale (BBS) is designed to efficiently score a patient's balance. The process begins with a camera capturing a video of a patient performing 14 different exercises that are part of the BBS. The video is then processed by Mediapipe which analyses the video to extract key landmarks of the patient's body such as shoulders, elbows, knees, and ankles. After extracting the coordinates of these landmarks, algorithms process these coordinates and a score is assigned to the patient on a scale of 0 to 4 with 0 being the worst-performing score and 4 being the best-performing score. The scoring is in line with the BBS criteria. The scores are then displayed on a dashboard. The dashboard keeps a log of the patient's history and prepares a report of the exercises the patient has performed. The interface of the dashboard is designed to provide easy navigation and user-friendliness in addition to allowing patients and healthcare providers to easily review the patient's performances.

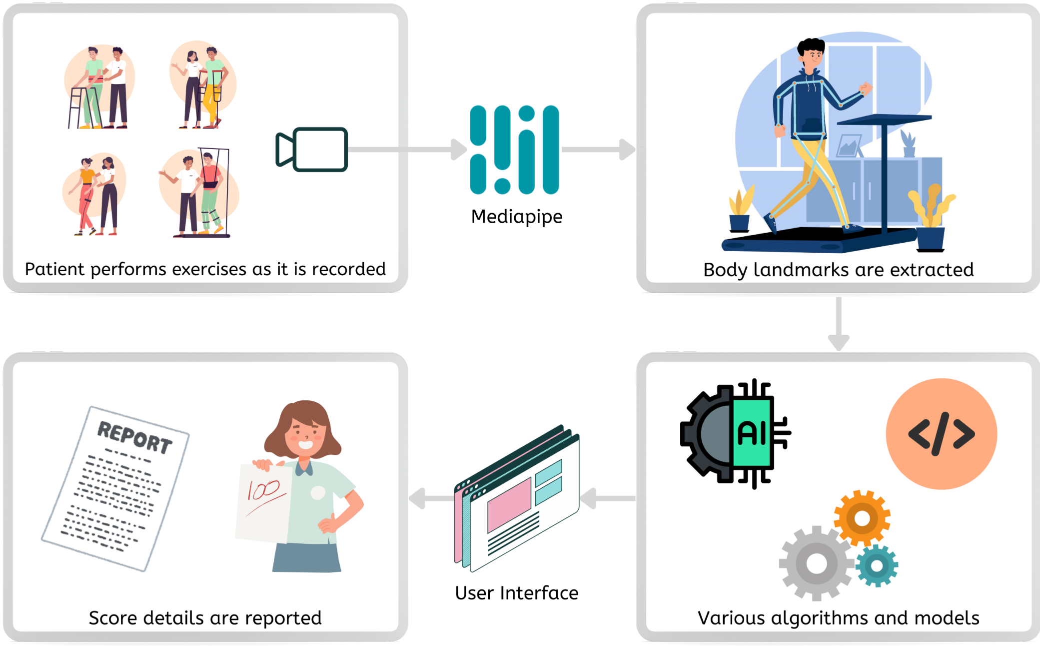

Figure 4.1: Flow Diagram

4.2 Algorithm Development

In this section, we will explain the details of algorithm development aimed at grading each of the fourteen activities outlined in the Berg Balance Scale. Each algorithm is designed to capture the variations in human movement, using a combination of rule-based logic and machine learning techniques. By dissecting the specific requirements and performance criteria of each activity, these algorithms provide a comprehensive framework for automating the assessment process. The detailed explanations will offer insights into the underlying methodologies and decision-making processes employed in grading individual tasks, by translating bio mechanical data into meaningful performance scores.

4.2.1 Grading Each of the Fourteen Activities

Within this subsection, we present detailed explanations of the algorithms devised to grade each of the fourteen activities of the Berg Balance Scale. Each algorithm is designed to evaluate specific aspects of balance and mobility, tailored to the unique requirements of the corresponding task. From simple tasks like sitting to more complex movements such as standing on one leg, our grading systems utilize a combination of criteria including joint coordination, stability, time factors, and task-specific considerations. Through a step-by-step breakdown, we will explain the underlying principles, rationale, and implementation details of each algorithm, providing a comprehensive understanding of how performance is assessed in the context of the BBS. These algorithms serve as the cornerstone of our automated assessment framework, offering healthcare professionals a reliable and efficient tool for evaluating balance deficits and tracking progress in clinical settings.

4.2.1.1 Sit to Stand

The grade of sitting to standing task performance can be evaluated based on multiple criteria, including displacement, hand usage, stability, and the time factor:

Displacement:

- Vertical displacement, calculated from hip positions, serves as the primary indicator of movement success.
- A positive displacement value indicates upward movement, signifying a successful transition from sitting to standing.
- If the displacement exceeds a predefined threshold (e.g., greater than 0.5 units), it is considered indicative of rising from a seated position.

Hand Usage: The use of hands, or lack of it, is determined from the positions of the wrists relative to hips and knees, reflecting the ability of the subject to perform the movement independently. Minimal or no hand usage indicates greater functional independence. If the hands are used during the transfer, the wrist positions will be relatively static. For example: the standard deviation of wrist positions is less than 0.01 indicates hand usage.

Stability: Sway, derived from hip positions, gives information about postural control and balance proficiency while transitioning. The lower sway scores indicate better stability and movement control. Standard deviation of hip positions will give information about the stability of the person doing the task. For example, the standard deviation of hip position less than 0.03 implies good stability.

Time Factor: Time taken to complete the transition is considered an added factor. A shorter time is associated with easier and more efficient movement execution, whereas a longer time is associated with difficulty or inefficiency in rising. For example: transition time is less than 2 seconds—that indicates efficient movement. Transition time exceeds 5 seconds—that indicates difficulty.

Rationale:

- **Score 4**: Optimal performance, minimal hand usage, low sway, and a short duration. This score reflects high functional independence and movement proficiency, with the individual easily transitioning from sitting to standing.
  - Displacement: Vertical displacement > 0.5 units
  - Hand usage: Wrist position standard deviation < 0.01
  - Stability: Hip position standard deviation < 0.03
  - Time: Transition time < 2 seconds
- **Score 3**: Satisfactory performance, occasional hand usage, acceptable stability, and a reasonable duration. This indicates adequate task execution with room for improvement, although the movement may not be as effortless as in the optimal scenario.
  - Displacement: Vertical displacement > 0.5 units
  - Hand Usage: Wrist position standard deviation > 0.01

  - Stability: Hip position standard deviation < 0.03
  - Time: Transition time between 2 and 5 seconds

- **Score 2**: Sub optimal performance, frequent hand usage, noticeable sway, and an extended duration. This score highlights potential assistance or balance challenges, with the individual experiencing difficulty in getting up within a reasonable time frame.
  - Displacement: Vertical displacement > 0.5 units
  - Hand usage: Wrist position standard deviation > 0.01
  - Stability: Hip position standard deviation > 0.03
  - Time: Transition time between 2 and 5 seconds

- **Score 0**: Failure to stand up within an extended duration, reflecting an inability to complete the task without substantial assistance or intervention. This score underscores the severity of movement limitations and the need for comprehensive rehabilitation strategies.
  - Displacement: Vertical displacement < 0.5 units
  - Hand usage: Wrist position standard deviation > 0.01
  - Stability: Hip position standard deviation > 0.03
  - Time: Transition time > 5 seconds

Joints Used: The function utilizes joint positions, particularly those of the hips, wrists, and knees, to assess task performance. Vertical displacement is calculated from hip positions, while hand usage is determined from wrist positions relative to hips and knees. Additionally, sway assessment relies on hip positions to quantify postural control and balance proficiency during the transition.

By integrating displacement, hand usage, stability, and the time factor, the grading system offers a comprehensive evaluation of sitting to standing movement.

4.2.1.2 Stand Unsupported

In this task, the person (subject) must stand for 2 minutes, and his score will be evaluated based on his stability. The grade of the Standing unsupported task is evaluated based on the following criteria, displacement of hips and shoulders in x-y direction and distance covered by ankles.

Stability: Sway, measured from hip and shoulder postures, gives information about postural control as well as balance proficiency during transitions. Lower sway scores suggest increased stability and movement control. The displacement of the hip and shoulder positions provides information about the person's stability while performing the task.
The total distance covered by both ankles in both x-y directions will be calculated to determine the score because the person must adjust his/her feet to stabilize himself/herself. The further the distance, the lower the score.

Graph:

Figure 4.2 demonstrates how the distance between the hips and shoulders influences the score. For example, the person with the highest score of 4 has covered the least total displacement.

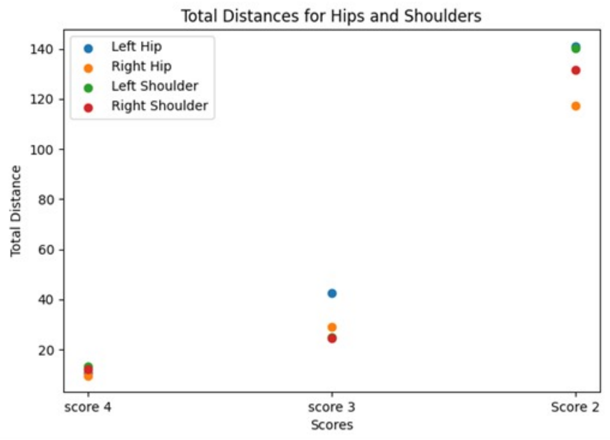

Figure 4.2: Total Distances for Hips and Shoulders

Figure 4.3 shows how ankle movement affects the score.

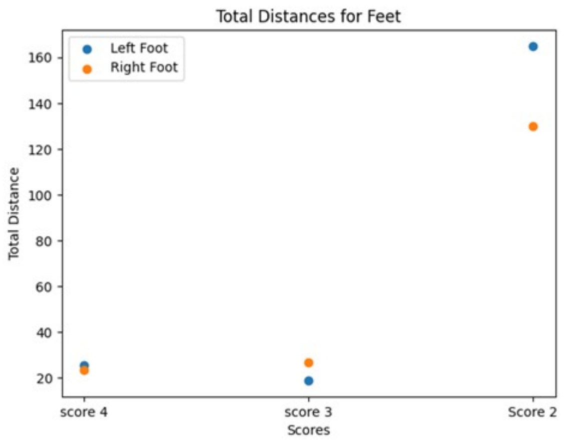

Figure 4.3: Total Distances covered by Feet

Figures 4.2 and 4.3 show that there are definite borders between distances. As a result, instead of applying the established thresholds, logistic regression was used for classification purposes.

Figure 4.4 is the graph that clearly defines boundaries between different scores. As there were 6 features resulting in the boundaries in 6-dimensional space, principal component analysis was utilized to visualize it in 2-dimensional space.

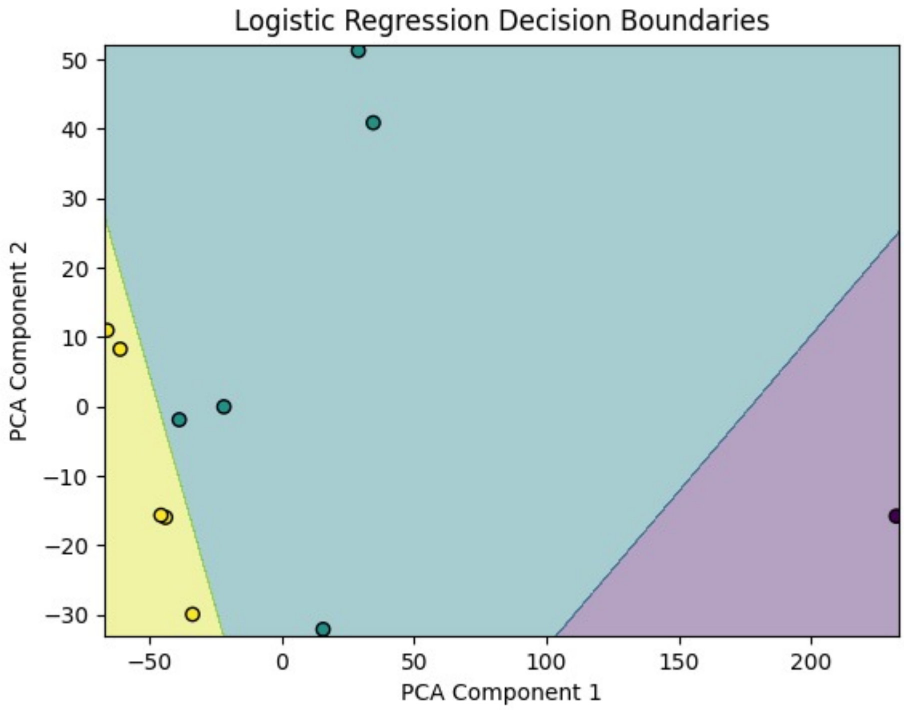

Figure 4.4: Logistic Regression Decision Boundaries

Limitations:

- Classes 0 and 1 comprised of subjects who couldn't stand hence the lack of availability of their data.
- Data points for the exercise were limited so no testing accuracy could be evaluated.

Joints Used: The function utilizes joint positions, particularly those of the hips, shoulders, and ankles to assess task performance. Sway is calculated from hip and shoulder positions, while the displacement of ankles tells if the patient has tried to stabilize himself.

4.2.1.3 Sit Unsupported

The score for this task can be calculated by looking at the criteria including hand support and stability.

Distance Calculation: For each frame, the Euclidean distance traveled by the left and right shoulder points from the previous frame is calculated. This distance is accumulated to get the total distance traveled by each shoulder over the entire duration.

Hand Support: The Euclidean distance between the left hand and the right shoulder, and between the right hand and the left shoulder, is calculated. These distances are averaged over the duration to determine if the hands are close to the shoulders. The person sitting in a position where he/she holds hands to opposite shoulders suggest that the hand is not being used for supporting the sitting position.

Rationale:

- **Score 4**: Able to sit safely and securely for 2 minutes.
  - Total shoulder distance: Very small (indicating minimal movement) < 0.1.
  - Hand-to-shoulder distance: Hands are close to the shoulders (indicating no use of hands for support) < 0.3.
- **Score 3**: Able to sit 2 minutes under supervision.
  - Total shoulder distance: Small (indicating some movement but still controlled) 0.1 - 0.5.
  - Hand-to-shoulder distance: Hands are close to the shoulders < 0.3.
- **Score 2**: Able to sit 30 seconds.
  - Total shoulder distance: Moderate (indicating noticeable movement) 0.5 - 1.0.
  - Hand-to-shoulder distance: May vary : 0.3 – 0.5.
- **Score 1**: Able to sit 10 seconds.
  - Total shoulder distance: High (indicating significant movement) > 1.0.
  - Hand-to-shoulder distance: Hands may be far from shoulders (indicating use of hands for support) > 0.5.

- **Score 0**: Unable to sit without support for 10 seconds.
  - Total shoulder distance: Very high (indicating very significant movement or inability to maintain position).
  - Hand-to-shoulder distance: Hands likely used for support.

Joints Used: The primary joints used include the left and right shoulders, and the left and right wrists. The shoulders' positions are critical for calculating the total shoulder distance, which indicates the degree of upper body movement. The wrists' positions relative to the opposite shoulders are used to determine the hand-to-shoulder distances, helping to assess whether the subject is using their hands for support. This combination of joints provides a comprehensive understanding of the subject's posture and stability, essential for evaluating their ability to sit unsupported.

4.2.1.4 Stand to Sit

The grade of standing to sitting task performance can be evaluated based on multiple criteria, including descent control, hand usage, the use of legs against the chair, stability, and the time factor:

Descent Control:

- Vertical displacement, calculated from hip positions, serves as the primary indicator of movement control during descent.
- A controlled and gradual descent signifies effective movement control and proficiency.
- For example, if the standard deviation of the hip descent rate (difference between consecutive hip positions) is less than 0.02, it indicates a controlled descent.

Use of Legs Against Chair:

- Monitoring knee and hip positions helps identify if the back of the legs is used against the chair to control the descent.

- This is indicated by a significant reduction in the hip-to-knee distance as the person approaches the chair.
- For example, if the hip-to-knee distance decreases by more than 20% as they sit down, it indicates the use of legs against the chair.

Hand Usage:

- The presence or absence of hand usage, determined from wrist positions relative to hips and knees, reflects the subject's ability to perform the movement independently.
- Minimal or no hand usage suggests greater functional independence.
- For instance, if the wrists remain above the hips and knees during descent, it is considered minimal hand usage. If the standard deviation of wrist positions is less than 0.01, it indicates static hand positions.

Stability:

- Sway assessment, derived from hip positions, provides insights into postural control and balance proficiency during the descent.
- Lower sway scores indicate better stability and movement control.
- For example, if the standard deviation of hip positions during descent is less than 0.03, it suggests good stability.

Time Factor:

- The time taken to complete the transition from standing to sitting is considered as an additional factor.
- A shorter duration suggests easier and more efficient movement execution, while a longer duration indicates difficulty or inefficiency in sitting down.
- For instance, if the transition time is less than 2 seconds, it indicates efficient movement. If it exceeds 5 seconds, it indicates difficulty.

Rationale:

- **Score 4**: Optimal performance, characterized by a controlled descent with minimal hand usage, low sway, and a short duration. This score reflects high functional independence and movement proficiency, with the individual easily transitioning from standing to sitting.
  - Controlled descent: Standard deviation of hip descent rate < 0.02
  - Minimal hand usage: Wrists above hips and knees, wrist position standard deviation < 0.01
  - Stability: Hip position standard deviation < 0.03
  - Time: Transition time < 2 seconds
- **Score 3**: Satisfactory performance, with controlled descent by using hands, acceptable stability, and a reasonable duration. This indicates adequate task execution with room for improvement, although the movement may not be as effortless as in the optimal scenario.
  - Controlled descent: Standard deviation of hip descent rate < 0.02
  - Hand usage: Wrists below hips and knees, wrist position standard deviation > 0.02
  - Stability: Hip position standard deviation < 0.03
  - Time: Transition time between 2 and 5 seconds
- **Score 2**: Sub-optimal performance, with the use of the back of the legs against the chair to control descent, suggesting potential balance or strength challenges.
  - Use of legs: Hip-to-knee distance reduction > 20
  - Controlled descent: Standard deviation of hip descent rate < 0.02
  - Stability: Hip position standard deviation < 0.03

  - Time: Transition time more than 5 seconds

- **Score 1**: Indicates that the individual sits independently but has uncontrolled descent, reflecting significant difficulty or reliance on external support to complete the task within an extended duration.

  - Uncontrolled descent: Standard deviation of hip descent rate > 0.02
  - Stability: Hip position standard deviation > 0.03
  - Time: Transition time > 5 seconds

- **Score 0**: Needs assistance to sit down, indicating an inability to complete the task without substantial assistance or intervention.

  - Significant hand usage: Wrists below hips and knees, wrist position standard deviation < 0.01
  - Uncontrolled descent: Standard deviation of hip descent rate > 0.03
  - Stability: Hip position standard deviation > 0.03
  - Time: Transition time > 5 seconds

Joints Used: The algorithm utilizes joint positions, particularly those of the hips, wrists, and knees, to assess task performance. Descent control is assessed by tracking vertical displacement of hip positions, while hand usage is determined from wrist positions relative to hips and knees. The use of legs against the chair is identified through the hip-to-knee distance. Additionally, sway assessment relies on hip positions to quantify postural control and balance proficiency during the transition.

By integrating descent control, hand usage, use of legs against the chair, stability, and the time factor, the grading system offers a comprehensive evaluation of standing to sitting movements. This enables targeted interventions and personalized rehabilitation strategies based on individual movement profiles and needs.

4.2.1.5 Transfers

The transfer task can be assessed with the help of our already developed algorithm for sitting to standing and standing to sitting. It is explained as follows:

Video Segmentation:

- Divide the video into two equal segments: one for the sitting to standing transfer and the other for the standing to sitting transfer.

Sitting to Standing Score Calculation:

- Extract joint positions, assess vertical displacement, hand usage, stability, and time taken during the sitting to standing transfer.
- Based on predefined criteria, assign a score (0 to 4) reflecting the individual's performance in this segment.

Standing to Sitting Score Calculation:

- Repeat the process for the standing to sitting transfer, evaluating descent control, use of legs against the chair, hand usage, stability, and time taken.
- Assign a score (0 to 4) for this segment according to the defined criteria.

Mean Score Calculation:

- Calculate the mean of the scores obtained from the sitting to standing and standing to sitting transfers.
- This mean score represents the individual's overall performance in the transfer task.

Rationale: The combined score from both segments provides a holistic assessment of the individual's ability to perform transfer movements.

4.2.1.6 Stand with Eyes Closed

In this task, the person (subject) must stand for 10 seconds with their eyes closed and the score will be evaluated based on their stability. The grade of Standing unsupported with eyes closed task can be evaluated based on multiple criteria, including displacement of hips and shoulders in x-y direction and distance covered by ankles.

Stability: Sway, derived from hip and shoulder positions, gives information about postural control and balance proficiency while transitioning. The lower sway scores indicate better stability and movement control. Displacement of hip and shoulder positions will give information about the stability of the person doing the task. The total distance covered by both ankles in both x-y directions will be calculated in order to evaluate the score as the person will have to move his feet in order to stabilize himself/herself. The greater the distance, the lesser the score

Graph:

Figure 4.5 shows how the distance covered by both hips and shoulders affects the score. For E.g. the person with the highest score i.e. 4 has covered the least distance (for both hips and shoulders).

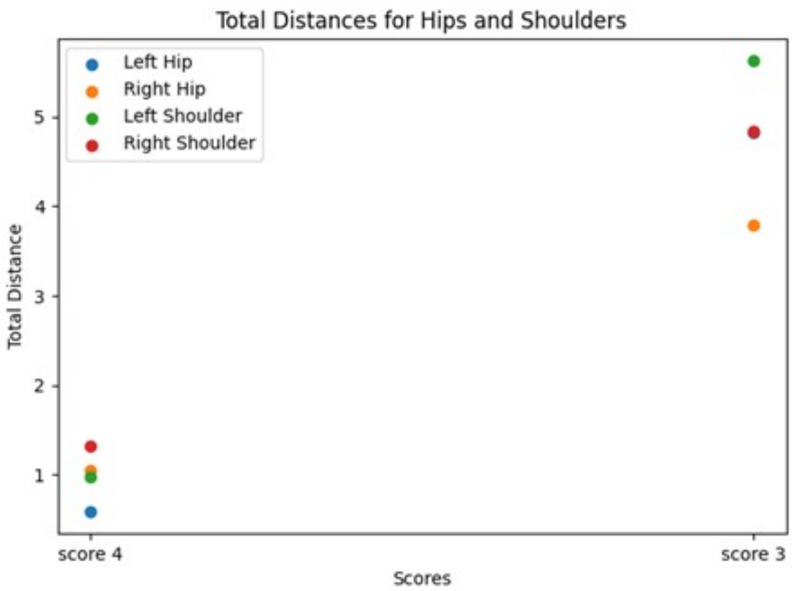

Figure 4.5: Total Distance for Hips and Shoulders

Figure 4.6 shows the score affected by the movement of the ankles. Since this task was executed for 10 sec, therefore, majority of the subjects were able to complete the task without moving their ankles.

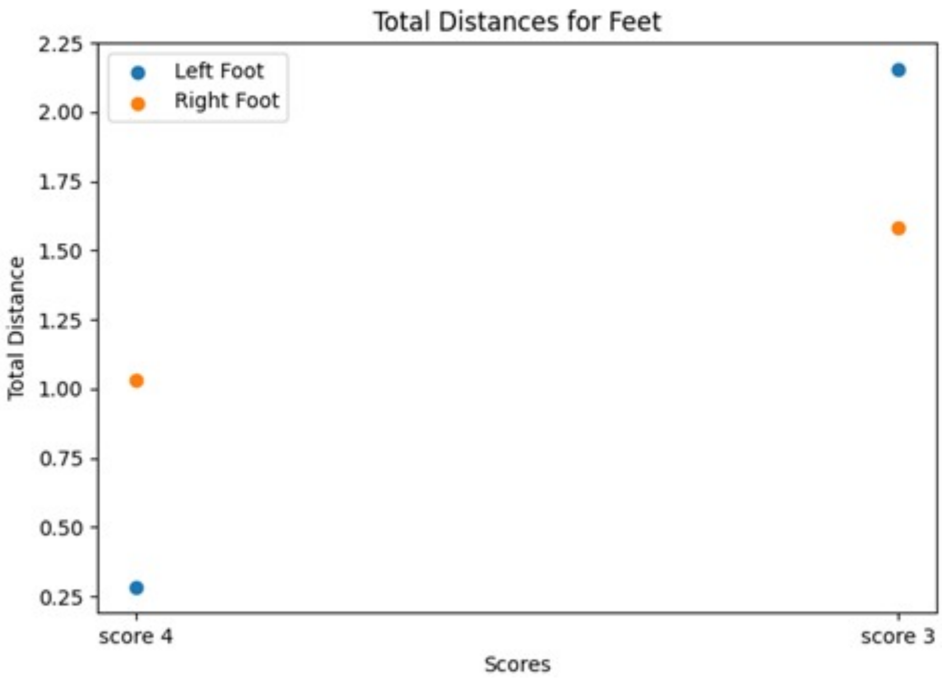

Figure 4.6: Total Distances for Feet

Limitations:

- Classes 0 and 1 comprised of subjects who couldn't stand hence the lack of availability of their data.
- Data for class 2 subjects was not available therefore class 2 thresholds were set on assumptions.

Rationale:

- **Score 4**: Optimal performance. The individual can balance them self with their eyes closed with little to no sway.
  - Sway: Displacement covered by Hip and shoulders < 3.5
  - Feet Movement for stabilization: Displacement covered by feet < 3.

- **Score 3**: Satisfactory performance the individual can balance them self with their eyes closed with a little sway.
  - Sway: Displacement covered by Hip and shoulder position < 9
  - Feet Movement for stabilization: Displacement covered by feet < 6.
- **Score 2**: Sub-optimal performance. The individual can not balance them self with their eyes closed and needs to readjust themselves once.
  - Sway: Displacement covered by Hip and shoulders < 15
  - Feet Movement for stabilization: Displacement covered by feet < 17.
- **Score 1**: Non-satisfactory performance: The individual can not balance them self with their eyes closed and needs to readjust themselves multiple times.
  - Sway: Displacement covered by Hip and shoulders > 15.
  - Feet Movement for stabilization: Displacement covered by feet > 17.
- **Score 0**: This score indicates that the patient can't perform the task.

Joints Used: The function utilizes joint positions, particularly those of the hips, shoulders, and ankles to assess task performance. Sway is calculated from hip and shoulder positions, while the foot coordinates tell if the person has lost his balance and needs to readjust themselves.

4.2.1.7 Stand with Feet Together

In this task, the person (subject) must stand for 1 minute with his feet closed and his score will be evaluated based on his stability. The grade of this task can be assessed by measuring the x-y displacement of the hips and shoulders, as well as the distance between two ankles.

Stability: Sway, measured by hip and shoulder positions, provides information about balance ability during transitions. Lower sway scores indicate improved stability and movement control. The displacement of hip and shoulder positions will provide information about the person's stability while performing the task.

Foot Position Deviation: The average deviation of foot positions from their initial average distance is calculated. This deviation indicates the subject's ability to maintain balance with feet closed. Lower deviations signify better balance control, resulting in higher scores.

Graphs: Figure 4.7 shows how the distance covered by both hips and shoulders affects the score. For example, the person with the highest score i.e. 4 has covered the least displacement in total (for both hips and shoulders)

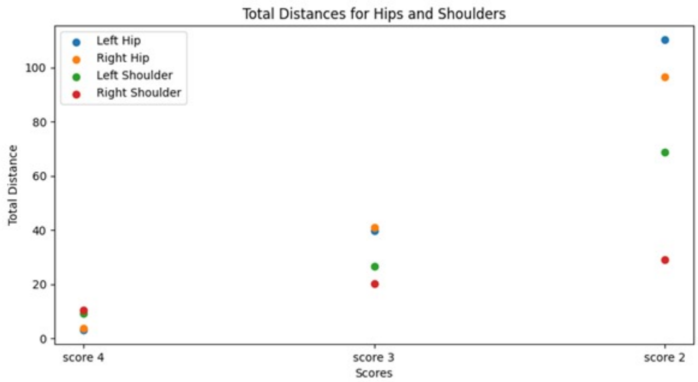

Figure 4.7: Total Distances for Hips and Shoulders

Figure 4.8 demonstrates how foot position deviation influences the score. Subjects with lower deviations receive higher scores, indicating better balance control with feet closed.

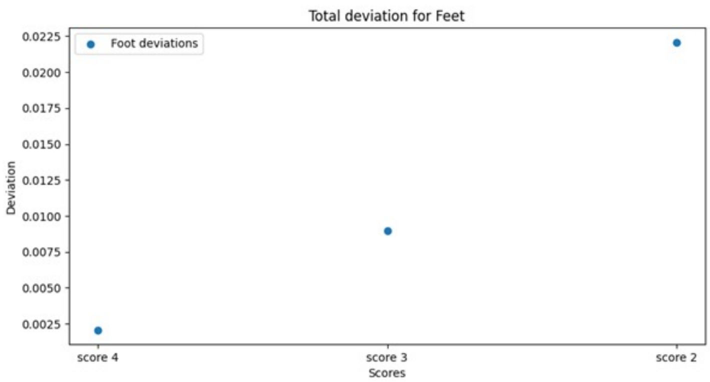

Figure 4.8: Total Deviation for Feet

Figures 4.7 and 4.8 show that there are definite borders between distances. As a result, instead of applying the established thresholds, the team used logistic regression

Figure 4.9 is the graph that clearly defines boundaries between different scores. As there were 5 features resulting in the boundaries in 5-dimensional space, principal component analysis was utilized to visualize it in 2-dimensional space.

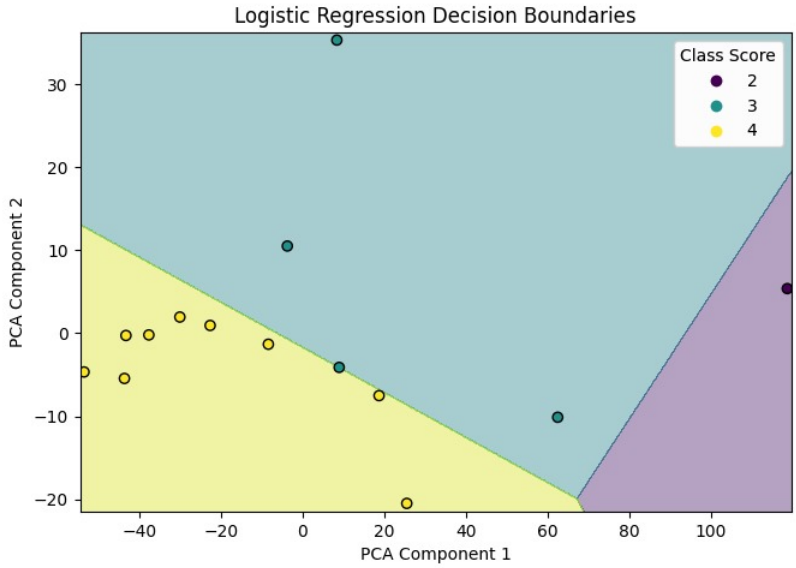

Figure 4.9: Logistic Regression Decision Boundaries

4.2.1.8 Reach Forward with Outstretched Arms

The score in this task can be assessed through arm extension and overall stability during the reaching movement. These criteria include:

Distance Measurement:

- The primary feature used in this task is the maximum forward distance reached by the fingertips during the reach.
- This distance is calculated by analyzing the difference between the initial position of the fingertips and their farthest position attained during the reach.

Stability During Reaching:

- The stability of the body, particularly the trunk and lower extremities, plays a significant role in executing a successful reaching movement.
- Lower sway scores, indicating minimal body sway or movement deviation, suggest better stability and balance control during the reach.
- For example, if the individual can maintain a stable trunk position while extending their arms forward, it reflects good stability during the reaching task.

Rationale:

- **Score 4**:
  - Optimal performance, characterized by a large forward reach distance (>= 0.4) and minimal body sway.
  - Distance measurements: Maximum forward distance >= 0.4
  - Stability: Standard deviation of shoulder positions < 0.10
- **Score 3**:
  - Satisfactory performance with a moderate forward reach distance (>= 0.3 and < 0.4) and minimal body sway.
  - Distance measurements: Maximum forward distance >= 0.3 and < 0.4
  - Stability: Standard deviation of shoulder positions < 0.10
- **Score 2**:
  - Sub-optimal performance with a smaller forward reach distance (>= 0.2 and < 0.3) and minimal body sway.
  - Distance measurements: Maximum forward distance >= 0.2 and < 0.3
  - Stability: Standard deviation of shoulder positions < 0.10
- **Score 1**:

- Indicates that the individual reaches forward but requires supervision, with a forward reach distance (>= 0.1 and < 0.2) or significant body sway.
- Distance measurements: Maximum forward distance >= 0.1 and < 0.2
- Stability: Standard deviation of shoulder positions >= 0.10

- **Score 0**:
  - Needs assistance to reach forward, indicating an inability to complete the task without substantial assistance or significant body sway.
  - Distance Measurements: Maximum forward distance < 0.1
  - Stability: Standard deviation of shoulder positions >= 0.10

Joints Used: The algorithm utilizes joint positions, particularly those of the index fingers and shoulders, to assess task performance. Arm extension control is assessed by tracking the horizontal displacement of the index finger positions, while stability is determined from the standard deviation of shoulder positions. By integrating arm extension control and stability, the grading system offers a comprehensive evaluation of the reaching forward movements.

4.2.1.9 Retrieve Object from Floor

In this task, the person (subject) must retrieve the object from the ground using little to no support. The grade Retrieving object from the ground task can be evaluated based on two main criteria: the closeness of wrist to foot index which means the wrist has reached the ground and the distance between the wrist and knee to see if the patient used support for stability.

Retrieval of Object:

The retrieval of the object is a crucial part of this task. The object is placed on the ground in front of the patient. The patient's wrists can be inspected to determine whether they have effectively grasped the object. The object's Y-position would be comparable to that

of the patient's foot. If the patient's wrist y-coordinate is close to their foot y-coordinate, we assume that they have successfully picked up the object.
The algorithm evaluates this by calculating the difference between the y coordinates of the feet and the wrist. If the difference is less than 0.055 units, it is considered that the object was picked up from the ground, if it is within 0.15 units, then the patient is trying to reach it but is unsuccessful.

Support and Stability:
The stability of patients can be measured by finding the difference between the user's wrist x coordinate and their knees x coordinate if the difference is small (< 0.00025 units) then they are using their knee for support which means they are less stable and need additional support.

Rationale:

- **Score 4**: Optimal performance. The individual can pick up an object from the ground with no support.
  - Wrist Reaching: Wrist Y-coordinate within 0.055 units of the foot Y-coordinate.
  - Support and Stability: Wrist X-coordinate difference from knee X-coordinate > 0.00025 units.
- **Score 3**: Satisfactory performance. The individual can pick up an object from the ground with a little support.
  - Wrist Reaching: Wrist Y-coordinate within 0.055 units of the foot Y-coordinate.
  - Support and Stability: Wrist X-coordinate difference from knee X-coordinate <= 0.00025 units.
- **Score 2**: Sub-optimal performance. The individual can't pick up an object from the ground but requires no support.
  - Wrist Reaching: Wrist Y-coordinate within 0.55 units of the foot Y-coordinate.

    - Support and Stability: Wrist X-coordinate difference from knee X-coordinate > 0.00025 units.

- **Score 1**: Non-satisfactory performance: The individual can't pick up an object from the ground and requires a little support.
    - Wrist Reaching: Wrist Y-coordinate within 0.15 units of the foot Y-coordinate.
    - Support and Stability: Wrist X-coordinate difference from knee X-coordinate <= 0.00015 units.

- **Score 0**: This score indicates that the patient can't perform the task.
    - o Wrist Reaching: Wrist Y-coordinate not within 0.15 units of the foot Y-coordinate.

Joints Used: The function utilizes the positions of the wrists, feet, and knees to assess task performance. The closeness of the wrist to the foot index indicates the ability to reach the object, while the difference of the wrist to knee indicates the use of support

4.2.1.10 Turn to Look Behind While Standing

The proficiency in this task can be assessed through various criteria, encompassing turn detection, angle measurement, and stability evaluation. These criteria include:

Turn Detection:

- The primary feature used in this task is the detection of significant angle changes to identify when the individual is turning.
- The start and end times of these turns are recorded to count the number of turns.

Angle Measurement:

- The extent of torso rotation is quantified by calculating the angle between vectors formed by the shoulder and hip joints.

- A larger angle indicates a more substantial turn, which reflects the individual's ability to turn effectively.

Stability During Turning:

- The stability of the body, particularly the shoulders, plays a significant role in executing a successful turn.
- Lower sway scores, indicating minimal shoulder movement deviation, suggest better stability and balance control during the turn.

Rationale:

- **Score 4**: The individual looks behind from both sides and weight shifts well.
  - Number of significant turns detected: 2
  - Maximum angle of rotation: > 35 degrees
  - Stability: Standard deviation of shoulder positions < 0.10
- **Score 3**: The individual looks behind on one side only; the other side shows less weight shift.
  - Number of significant turns detected: 1
  - Maximum angle of rotation: > 35 degrees
  - Stability: Standard deviation of shoulder positions < 0.10
- **Score 2**: The individual turns sideways only but maintains balance.
  - Number of significant turns detected: 2
  - Maximum angle of rotation: < 35 degrees
  - Stability: Standard deviation of shoulder positions < 0.10
- **Score 1**: The individual needs supervision when turning.
  - Stability: Standard deviation of shoulder positions >= 0.10

- **Score 0**: The individual needs assistance to keep from losing balance or falling.
  - Fewer than 2 significant turns detected
  - Stability: Standard deviation of shoulder positions >= 0.10

Joints Used: The algorithm utilizes joint positions, particularly those of the shoulders (left and right) and hips (left and right), to assess task performance. By integrating turn detection, angle measurement, and stability evaluation, the grading system offers a comprehensive assessment of the individual's ability to turn and look behind.

4.2.1.11 Turn 360 Degrees

This task can be assessed by using angle calculation, synchronization check, and time measurement. These criteria are explained as follows:

Angle Calculation:

- The primary feature used in this task is the angle of rotation calculated from the vectors formed by the shoulders i.e. left shoulder to the right shoulder and hips i.e. left hip to the right hip.
- The angle of rotation is calculated relative to the initial positions of these vectors. The calculation is done using the dot product and norms of these vectors to find the cosine of the angle, which is then converted to degrees.

Synchronization Check:

- Ensuring synchronization between the shoulder and hip vectors is crucial to determine coordinated body movement during the turn.
- The angles calculated for both vectors should change at similar rates, indicating that the upper and lower body are moving in unison.
- A threshold is set to detect significant desynchronization, where the difference between the shoulder and hip angles should be within 5 degrees.

Turn Detection:

- Significant angle changes are detected to identify when the individual is turning.
- The algorithm monitors the angles and detects when they increase from 0 to approximately 360 degrees, indicating a full turn.
- The initial and final positions are compared to confirm the completion of one full rotation.

Time Measurement:

- The time taken to complete the 360-degree turn is measured by storing timestamp when angle starts to change and then subtracting it from the time stamp when 360-degree angle is completed.

Rationale:

- **Score 4**:Able to turn 360 degrees safely in 4 seconds or less with synchronized shoulder and hip movements.
  - Angle Calculation: Full turn detected with angles increasing from 0 to approximately 360 degrees. And then again 0 to 360 degree showing rotation in both clockwise and anticlockwise direction.
  - Synchronization Check: Difference between shoulder and hip angles within the threshold.
  - Time Measurement: Each turn completed in <= 4 seconds.
- **Score 3**: Able to turn 360 degrees safely to one side only in 4 seconds or less.
  - Angle Calculation: Full turn detected to one side only.
  - Synchronization Check: Difference between shoulder and hip angles within the threshold.
  - Time Measurement: Turn completed in <= 4 seconds.

- **Score 2**: Able to turn 360 degrees safely but slowly, with possible desynchronization.
  - Angle Calculation: Full turn detected with angles increasing from 0 to approximately 360 degrees.
  - Synchronization Check: Possible desynchronization detected with angles outside the threshold.
  - Time Measurement: Turn completed in > 4 seconds.
- **Score 1**: Needs close supervision or verbal cuing to complete the turn.
  - Angle Calculation: Incomplete or inconsistent turn detected, angle not reaching to 360 degrees.
  - Synchronization Check: Significant desynchronization detected.
- **Score 0**: Needs assistance while turning, indicating an inability to complete the task without substantial assistance.
  - Angle Calculation: Incomplete or no significant turn detected.
  - Synchronization Check: Severe desynchronization detected.

Joints Used: The algorithm utilizes joint positions, particularly those of the shoulders and hips, to assess the task performance. The shoulder vector (left shoulder to right shoulder) and hip vector (left hip to right hip) are tracked to monitor the rotation angle and ensure synchronization. By integrating angle calculation, synchronization check, and time measurement, the grading system provides a comprehensive evaluation of the turning movement.

4.2.1.12 Place Alternate Foot on Stool

This task can be assessed through step count by using knee angle, and stability assessment. These criteria include:

Step Count:

- Monitor the knee angle to detect significant flexion (bending).
- Check for an increase in the knee angle indicating the foot is lifted to step.
- Count the step when the knee angle transitions from a bent position (<= 90 degrees) to a straight position (>= 100 degrees).

Knee Angle Calculation:

- Calculate the angle between the vectors formed by the hip to knee and knee to ankle for both legs.
- Use the dot product and norms of these vectors to find the cosine of the angle, which is then converted to degrees.

Stability Check:

- Calculate the overall stability score as the sum of ankle, knee, and hip stability scores.
- Calculate the standard deviation of ankle positions over time to assess stability of ankle.
- Calculate the standard deviation of knee positions over time to assess stability.
- The standard deviation of hip positions will give us the stability score of hips.

Rationale:

- **Score 4**:
  - Able to stand independently and safely and complete 8 steps in 20 seconds.
  - Stability Score is high (low standard deviation in ankle, knee, and hip positions).
- **Score 3**:

  - Able to stand independently and complete less than 8 and greater than 6 steps in 20 seconds.
  - Stability Score is moderately high.

- **Score 2**:
  - Able to complete 4 steps without aid with supervision.
  - Stability Score is moderate.

- **Score 2**:
  - Able to complete 4 steps without aid with supervision.
  - Stability Score is moderate.

- **Score 1**:
  - Able to complete > 2 steps needs minimal assist.
  - Stability Score is low.

- **Score 0**:
  - Needs assistance to keep from falling/unable to try.
  - Stability Score is very low.

Joints Used: The algorithm utilizes joint positions, particularly those of the ankles, knees, and hips, to assess the task performance. The integration of step count, knee angle calculations, and stability assessments helps in the grading of this task.

4.2.1.13 Stand with One Foot In-front

The score in this task can be assessed through various criteria, including foot placement accuracy, duration, and overall stability during the task.

Foot Placement Assessment: Determines whether the subject placed one foot directly in front of the other or ahead of the other foot. The distance between the opposite foot indices determine which foot is in front of the other.

Duration Tracking: Measures how long the subject can hold the stance without significant movement or loss of balance.

Stability Assessment: Assesses the subject's balance by analyzing the sway of key body joints, indicating postural control and balance proficiency. The standard deviation of the vertical positions (y-coordinates) of the left and right ankles, knees, and hips is used to assess sway and balance.

Rationale:

- **Score 4**: The subject places each foot directly in front of the other independently and holds each position for 30 seconds with minimal sway.
  - Foot in front distance is positive for both positions
  - Stability Score < 0.1
- **Score 3**: The subject places each foot ahead of the other independently and holds each position for 30 seconds with minimal sway.
  - Foot in front distance is positive but length of step exceeds length of the foot .
  - Stability Score < 0.1
- **Score 2**: The subject takes a small step independently and holds each position for 30 seconds with minimal sway.
  - Small step distance for both positions
  - Stability Score < 0.1
- **Score 1**: The subject needs help to step but can hold each position for 15 seconds with moderate sway.
  - Unable to maintain the required foot position independently

  - Stability Score < 0.2

- **Score 0**: The subject loses balance while stepping or standing.
  - Unable to maintain the required foot position
  - Stability Score >= 0.2

Joints Used: The algorithm utilizes joint positions, particularly those of the ankles, knees, hips, and feet, to assess task performance. Foot placement is assessed by tracking the forward and vertical displacement of the foot joint positions, while stability is determined from the standard deviation of knee, hip, and ankle joint positions. By integrating foot placement, balance stability, and duration tracking, the grading system scores the task.

4.2.1.14 Stand on One Foot

In this task, the person (subject) must stand on one foot for around 15 seconds and then switch to the other foot and stand on that for 15 seconds, and his score will be evaluated based on his stability. The grade of the Standing on one-foot task can be evaluated based on multiple criteria, including the duration for which the patient lifts his/her leg and the amount of sway.

Leg Lift Duration:
The duration for which the subject lifts each leg and maintains balance is a crucial factor in evaluating task performance. The lifting of each foot is determined by looking at the standard deviation of the foot index, the standard deviation is measured in two halves because one leg is lifted in one half of the video while the second leg is lifted in the other half. for example, if the deviation is more for the right foot in the first half it means the right leg is lifted in the first half and the left ankle is lifted in the other half.
Now to identify the lifting of the foot, A threshold is set which is the absolute difference between the current position of the foot and the initial position of the foot, if the threshold is greater than the standard deviation of the foot it means that the foot is lifted and vice

versa. It's important to note that a patient may alternate between lifting and placing down their foot multiple times during the task therefore we are measuring the longest lift only.

Figure 4.10 displays the y coordinate of the left and right foot, it can be seen when the foot was lifted and placed down.

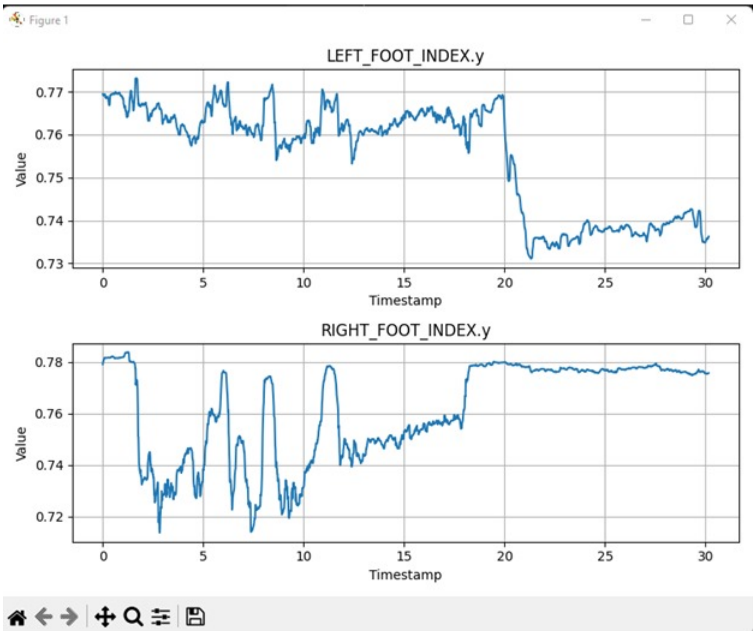

Figure 4.10: Y-Coordinate of the Left and Right Foot

In Figure 4.10 The sharp decrease in the graph (represented by the lower values) indicates a period when the foot is lifted.

Stability: Sway, evaluated by hip and shoulder positions, offers information about balance during transitions. Lower sway scores imply better stability and movement control. The movement of the hip and shoulder positions provides information about the person's stability while executing the task.

Rationale:

- **Score 4**: Optimal performance. The individual shows the ability to lift each leg for the entire duration with minimal sway.
  - Leg Lift Duration: > 10 seconds.

    - Stability: Displacement covered by Hip and shoulder position < 35.

- **Score 3**: Satisfactory performance. They can lift each leg for a significant duration but may show slight instability.
    - Leg Lift Duration: > 5 seconds.
    - Stability: Displacement covered by Hip and shoulder position < 35.
      OR
    - Leg Lift Duration: > 10 seconds.
    - Stability: Displacement covered by Hip and shoulder position < 80.

- **Score 2**: Sub optimal performance. The individual shows a lot of sway and can only lift their leg for a limited time.
    - Leg Lift Duration: > 3 seconds.
    - Stability: Displacement covered by Hip and shoulder position < 35.
      OR
    - Leg Lift Duration: > 5 seconds.
    - Stability: Displacement covered by Hip and shoulder position < 80.
      OR
    - Leg Lift Duration: > 10 seconds.
    - Stability: Displacement covered by Hip and shoulder position < 100.

- **Score 1**: This score indicates that the patient can only lift their leg for a couple of seconds.
    - Leg Lift Duration: > 1 second.

- **Score 0**: This score indicates that the patient can't lift their leg.
    - Leg Lift Duration: < 1 second.

Joints Used: The function utilizes joint positions, particularly those of the hips, shoulders, and foot index to assess task performance. Sway is calculated from hip and shoulder positions, while the lifting of the foot is determined by the foot index.

4.3 Pose Estimation Techniques

Pose estimation is a method used for determining a person's posture in a three-dimensional space from images or videos. To do this, the coordinates of important joints, such as the ankles, knees, shoulders, etc., are extracted. The selection of an adequate pose estimation model relies on specific factors and greatly influences the application of choice, for example in Berg Balance assessment the pose estimation should be fast and accurate.

4.3.1 Choice of Pose Estimation Models

There are several pose estimation models like media pipe, open pose, pose net, yolov7 pose. Depending on the device [CPU/GPU/TPU etc.] the performance of different frameworks varies. There are many 2-stage pose estimation models that perform well in benchmark tests. Alpha Pose, OpenPose, Deep Pose, to name a few. However, due to the relative complexity of 2-stage models, obtaining real-time performance is computationally expensive. These models run fast on GPUs but not so much on CPUs. In terms of efficiency and accuracy, MediaPipe is a well-balanced framework for pose estimation. It generates real-time detection on CPUs. [19]

For balance assessment using the berg balance scale media pipe was selected for pose estimation this was because of the following main key features.

3D Pose Estimation: One of MediaPipe's primary functions is its capacity to approximate the 3D coordinates of important body points. With the help of this feature, we can measure joint depth, which is useful for precise balancing assessments.

Real-Time Performance: MediaPipe is ideal for applications that need fast and precise perception processing since it is tuned for real-time performance. Applications in robots, augmented reality, and virtual reality are included in this. [20] The provision of a rapid score for the Berg balance assessment depends on this swift execution.

Single-Person Detection: During a balancing evaluation, the focus is primarily on one individual. By eliminating any potential interference from other people in the frame, MediaPipe's single-person recognition capabilities serve to ensure the correctness of the posture assessment.

4.4 Hardware Development

For our Berg Balance Assessment application, we have deployed the system on the NVIDIA Jetson Nano Developer Kit. The software stack includes:

- **Operating System**: Ubuntu 20.04
- **Node.js**: Version 20.12.2 with NPM (Node Package Manager) version 10.5.2
- **Python**: Version 3.8; **Pip**: Version 20.2
- **SQL**: Version 8.0
- **Camera**: USB Camera with 720p resolution

4.4.1 Utilization of Jetson for Processing

Our application involves several components working together seamlessly. A React application serves as the user interface, providing functionalities such as user authentication, a dashboard for displaying user scores for each exercise, and a recording modal that captures videos of patients performing Berg Balance exercises. These videos are then sent to an Express.js application.

The Express.js app processes the incoming videos by creating a child process to run Python scripts using the following code:

```
import { spawn } from 'child_process';
```

Implementation of this spawn:

```
const pythonProcess = spawn(
    pythonExecutable, [scriptPath, videoPath]);
let outputData;
pythonProcess.stdout.on('data', (data) => {
    outputData = data.toString()
    console.log(data.toString());
});
pythonProcess.stderr.on('data', (data) => {
    console.error(`stderr: ${data}`);
});
```

- **pythonExecutable**: Path to the Python interpreter in the virtual environment.
- **scriptPath**: Path to the exercise script.
- **videoPath**: Path to the video sent by the client-side application.

The server application not only processes the video to extract joint coordinates using MediaPipe and apply the Berg Balance algorithm but also saves the generated scores into a MySQL database.

4.4.2 Processes Running on Jetson Nano

The Jetson Nano is responsible for running four main processes, all on localhost:

1. React Application
    (a) Manages user authentication
    (b) Provides a dashboard for displaying user scores
    (c) Contains a recording modal for capturing exercise videos

2. Express.js Application
    (a) Handles various API routes
    (b) Initiates child processes using the spawn function to run Python scripts
3. Python Scripts
    (a) Extract joint coordinates using MediaPipe
    (b) Apply the Berg Balance algorithm to the captured video
4. MySQL Server
    (a) Stores the scores and other relevant data in the database schema

This integrated setup ensures efficient processing and storage, facilitating the automated Berg Balance assessment using computer vision.

Chapter 5

Deployment & Validation

5.1 System Integration

The successful development of the Berg Balance app required the seamless integration of various components, ensuring that each part works harmoniously within the system.

5.1.1 Integration of Algorithms with Jetson

To harness the computational power of the NVIDIA Jetson Nano Developer Kit, we integrated our computer vision algorithms directly onto the device. The integration process involved several key steps:

1. **Algorithm Development and Testing**: Initially, we developed and tested our computer vision algorithms, including the extraction of joint coordinates using MediaPipe and the application of the Berg Balance algorithm, in a standalone Python environment. This ensured that each algorithm functioned correctly before deployment.

2. **Environment Setup**: The Jetson Nano was configured with Ubuntu 20.04, Node.js version 20.12.2, Python version 3.8, and MySQL version 8.0. We also set up a

virtual environment to manage Python dependencies efficiently.

3. **Video Processing Pipeline**: The Express.js server, running on the Jetson Nano, receives videos from the React client application. Using the spawn function, the server initiates a child process to execute the Python scripts, passing the paths for the Python executable, the script, and the video as arguments. This pipeline ensures real-time processing and analysis of the video data.

4. **Data Management**: The results from the Python scripts, including the calculated Berg Balance scores, are captured by the Express.js server and stored in the MySQL database. This integration facilitates the continuous updating and retrieval of user data.

5.1.2 User Interface Implementation

The user interface, designed with React, serves as the primary point of interaction for users. The implementation involved the following steps:

1. **User Authentication**: A robust authentication system was implemented to secure user data. This system ensures that only authorized users can access the application, view their scores, and record new exercise sessions.

2. **Dashboard**: The user dashboard provides an intuitive overview of the user's performance across different exercises. It displays scores, trends, and other relevant metrics, allowing users to track their progress over time.

3. **Recording Modal**: The recording modal is a crucial component, enabling users to record their exercise sessions directly from the application. Once a session is recorded, the video is automatically uploaded to the server for processing.

4. **API Integration**: The React application communicates with the Express.js server through a series of API calls. These APIs handle tasks such as user authentication, video upload, score retrieval, and data visualization.

5. **Responsive Design**: Ensuring a seamless user experience across various devices, the interface was designed to be fully responsive. This design approach guarantees that users can interact with the application from desktops, tablets, and mobile devices without compromising functionality or usability.

By integrating these components effectively, we created a cohesive system that automates the Berg Balance assessment using computer vision, providing users with accurate and timely feedback on their performance.

Chapter 6

Results

6.1 Performance Metrics

In our study, we collected data from patients performing the Berg Balance Scale (BBS) exercises and had this data labeled by a trained physiotherapist to ensure accuracy and reliability. Subsequently, we generated our own scores using the developed algorithms. By recording videos of patients executing the BBS tasks, we were able to apply our automated scoring system to these recordings. This process allowed us to evaluate the performance of our algorithms against the expert-labeled data. The comparison revealed that our automated scoring system demonstrated high accuracy, closely mirroring the physiotherapist's assessments. This validation in a clinical setting underscores the effectiveness of our algorithms in providing objective, consistent, and reliable balance evaluations, thereby enhancing the efficiency and precision of patient assessments.

The performance metric for "Stand with Feet Together" and "Stand Unsupported" are different than the rest since they are trained on a Machine Learning model. Due to scarcity of data points the testing accuracy can't be computed instead of this we are using k-fold cross validation with k = 4. In our data there is a point right on the boundary line of class 3 and 4 which can be seen in graph 4.4 and 4.9 and when that is tested using k fold cross validation that boundary point is given the wrong label to counteract this that point is removed and then the model is tested but when we will deploy our model that data point will be used. In table 6.1 the accuracy measured are using k = 4 cross-validation and that data point is removed also since we only have 1 data point for the score 2 when that is tested there would be no boundary for score 2 so it will always predict it 3 which is being considered correct here. Without the removal of that data point we get accuracy of 92.3% for task standing with feet together and 80% accuracy for task standing unsupported.

6.2 Accuracy of Activity Grading

The project aimed to automate the calculation of the Berg Balance Score using computer vision and machine learning. The accuracy of the system was evaluated by comparing the predictions made by the algorithm against manually assessed scores for various balance exercises. The results are presented in the Table 6.1.

Exercise Name	Total Samples	Right Predictions	Accuracy (%)
Sit to Stand	14	11	78
Stand Unsupported	10	9	89
Sit Unsupported	14	12	85
Stand to Sit	14	12	85
Transfers	14	7	50
Stand with Eyes Closed	13	11	84.6
Stand with Feet Together	14	12	86.3
Reaching Forward with Outstretched Arm	14	10	71
Retrieve object from Floor	13	10	77
Turning to Look Behind while Standing	14	11	78
Turning 360 Degrees	13	10	76
Placing Alternate Foot on Stool	14	9	64
Standing with One Foot in Front	14	11	78
Standing on One Foot	15	13	86.6

Table 6.1: Results

Summary of the results:

- The overall accuracy of the system varied across different exercises.

- The highest accuracy was achieved in the "Stand Unsupported" (89%) and "Standing on One Foot" (86.6%) exercises, indicating the system's reliability in these scenarios.
- The "Transfers" exercise showed the lowest accuracy (50%), suggesting a need for further refinement in the algorithm for this specific activity.
- Most exercises achieved accuracy levels above 75%, demonstrating the potential effectiveness of the system in automating BBS calculations.

6.3 User Experience

User Interface is developed in ReactJS framework. Other third-party libraries are also used for the smooth implementation of the whole workflow.

6.3.1 Authentication

An authentication page is provided to the user so they can sign up for his/her account. This account is then used for the login and all the user data storage and retrieval.

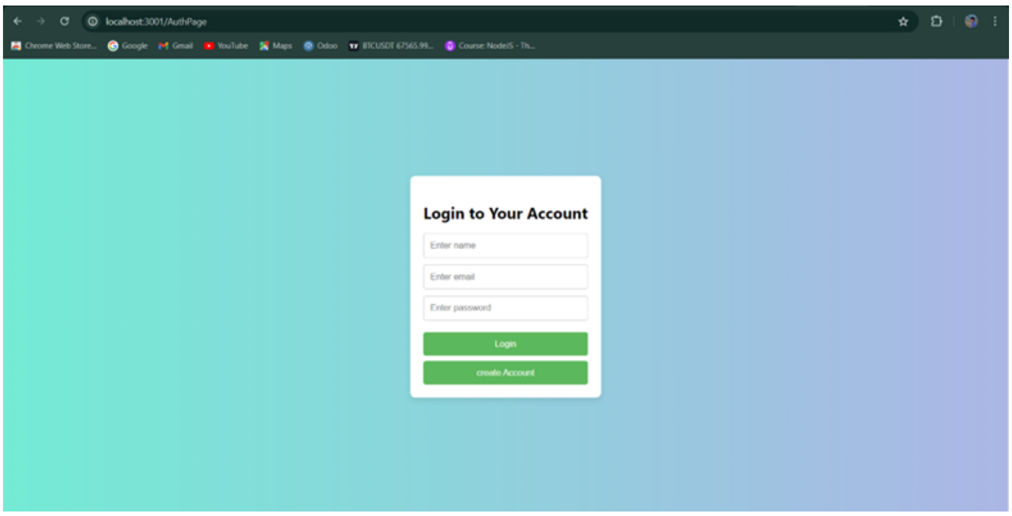

Figure 6.1: Authentication

6.3.2 Dashboard

Dashboard shows the logged-In user and all the exercises performed by the user in the past.

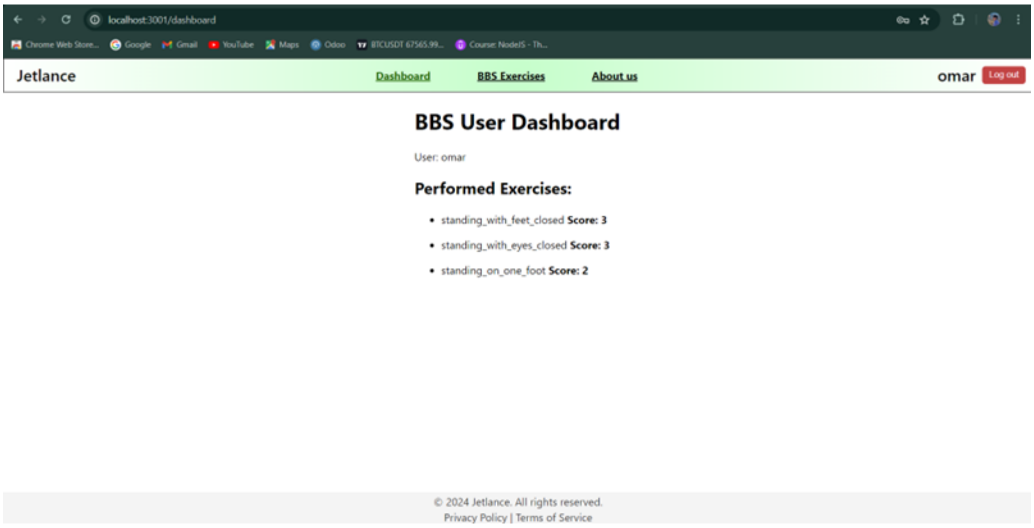

Figure 6.2: Dashboard

6.3.3 Exercises Page

This page lists all the 14 exercises of BERG BALANCE assessment. Two options are given to the user; upload a recorded video or record a live video.

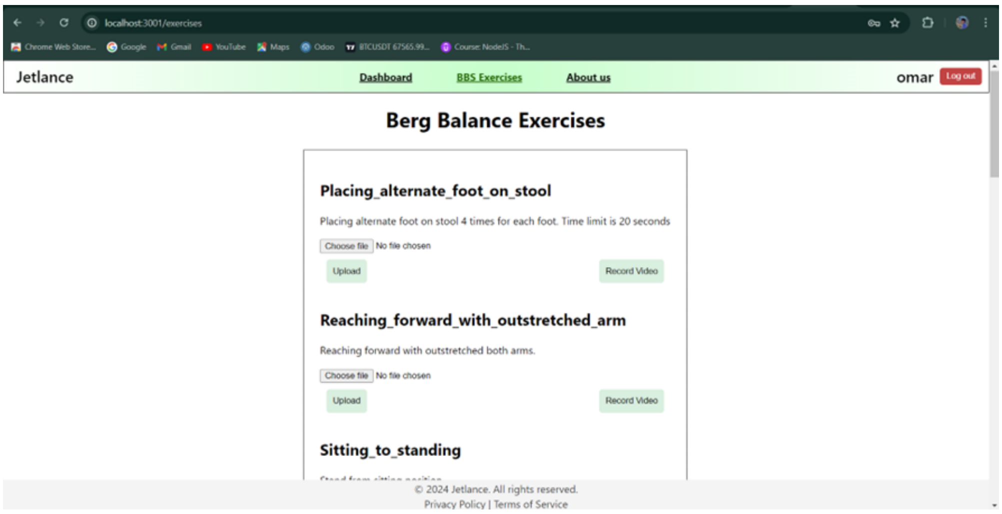

Figure 6.3: Exercises Page

6.3.3.1 Upload recorded video

User can select a recorded video from the directory. And upload it by clicking the upload button.

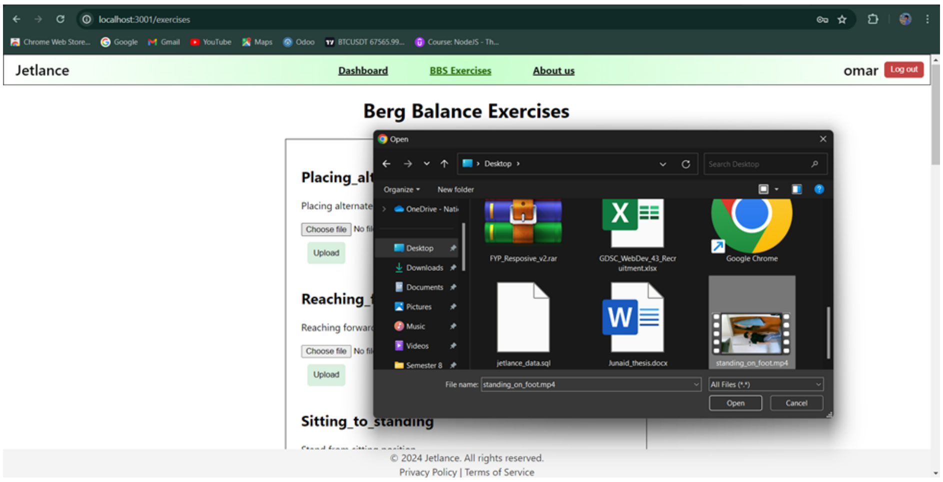

Figure 6.4: Uploading a recorded video

6.3.3.2 Record live video

When user click "record video" button a modal is opened for the user where user can live feed from the camera. When user clicks the start recording button the recording gets started.

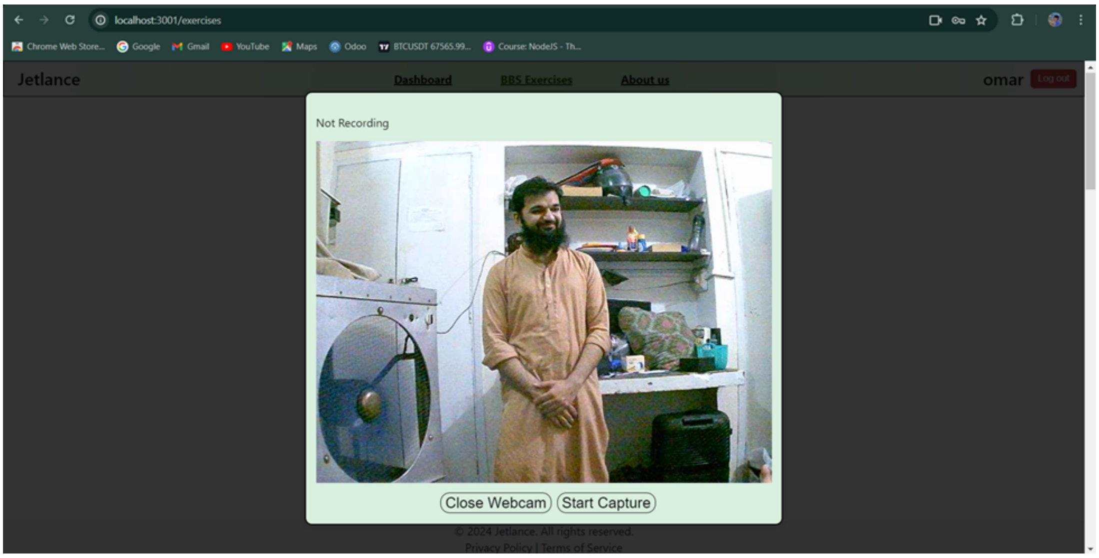

Figure 6.5: Recording Modal

After the allocated exercise time the user clicks the stop recording button. The video is now recorded.

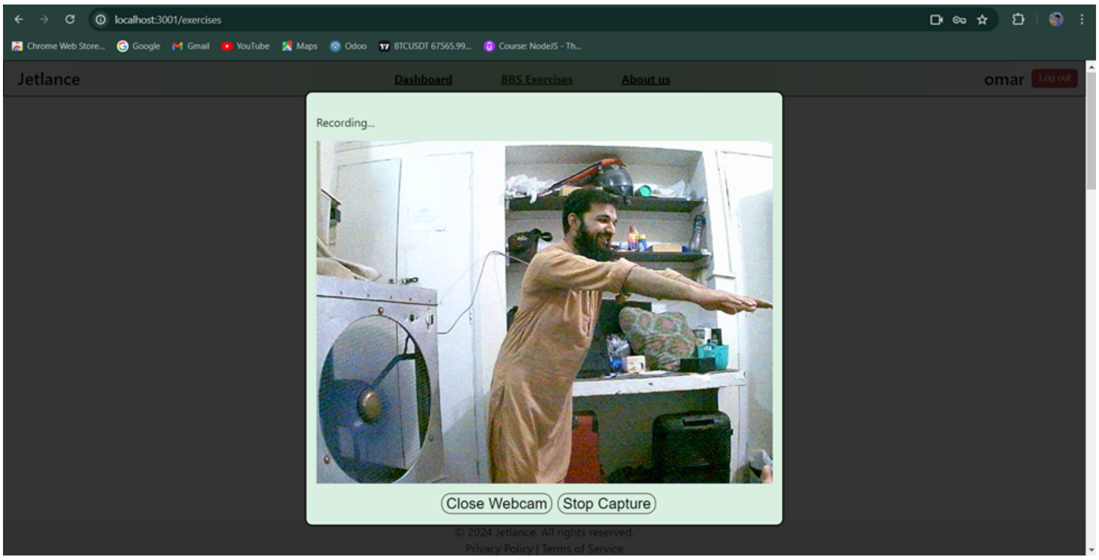

Figure 6.6: Recording Starts

When user clicks the “Get Score” button, the video is uploaded to the server for scoring.

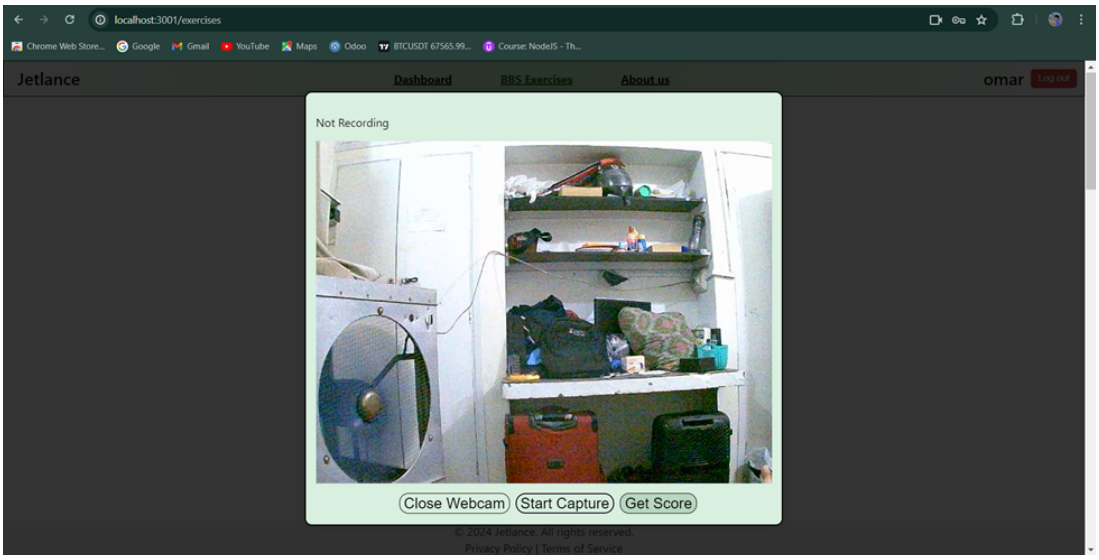

Figure 6.7: Recording Complete

After scoring, the score is displayed on the dashboard of the application.

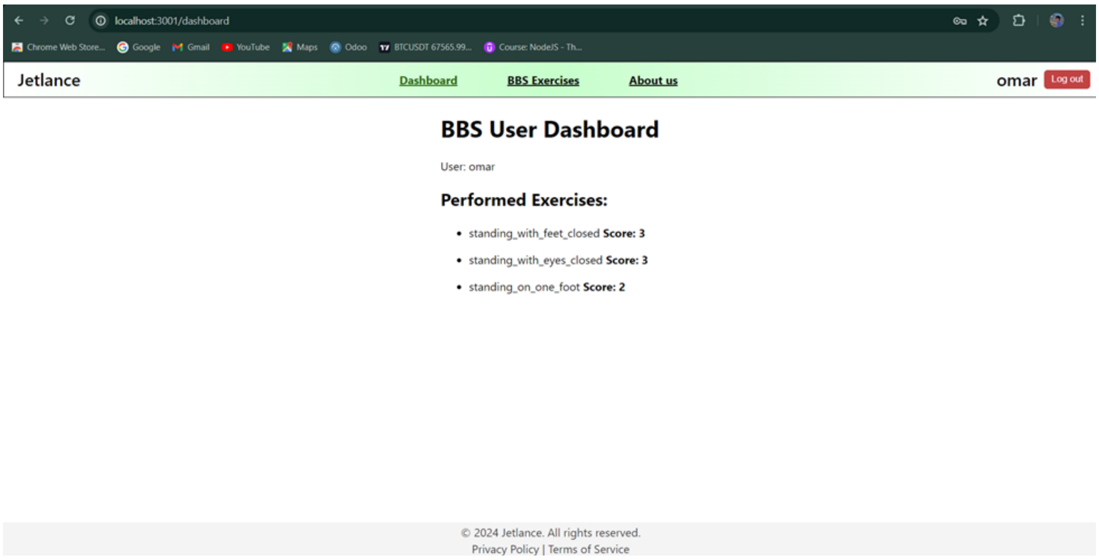

Figure 6.8: Recording is Scored

Chapter 7

Conclusion and Future Directions

7.1 Limitations

While the project demonstrated significant potential in automating the calculation of the Berg Balance Score using computer vision and machine learning, several limitations were identified during the course of the study. Addressing these limitations will be crucial for improving the system's accuracy and reliability in future iterations.

7.1.1 Sample Size and Diversity

One of the primary limitations of the project was the relatively small sample size. Although efforts were made to recruit a diverse group of participants, the total number of individuals involved in the study was limited. This may have affected the generalizability of the results, as the dataset may not fully represent the broader population, particularly those with varying degrees of balance impairment.

7.1.2 Accuracy Variations across Exercises

The accuracy of the system varied significantly across different exercises. While some activities, such as "Stand Unsupported" and "Standing on One Foot," achieved high accuracy levels, others, such as "Transfers," exhibited lower accuracy. These variations indicate that the algorithm may require further refinement and optimization to handle specific balance tasks more effectively.

7.1.3 Complexity of Movements

Certain balance assessment activities involve complex movements that can be challenging for computer vision algorithms to interpret accurately. Movements that involve multiple joints or rapid changes in posture may introduce errors in the analysis, affecting the reliability of the BBS calculations. Improving the algorithm's ability to capture and analyze complex movements remains a key area for development.

7.1.4 Ethical and Privacy Considerations

Ensuring patient confidentiality and obtaining informed consent were critical aspects of the study. However, the reliance on video recordings for data collection raises ethical and privacy concerns that must be carefully managed. Protecting participant data and ensuring compliance with data protection regulations will be essential for the wider adoption of the system in clinical settings.

7.1.5 Limited Real-time Capabilities

While the system aimed to provide real-time assessment of balance activities, the processing speed and response time may still require optimization. Delays in real-time analysis could impact the practical usability of the system in clinical practice, highlighting the need for further improvements in processing efficiency.

7.1.6 Dependence on Specific Technologies

The project relied on specific technologies, such as Mediapipe for computer vision, Jetson for real-time processing, and React for user interface development. Dependence on these technologies may limit the system's flexibility and adaptability to other platforms or environments. Exploring alternative technologies and ensuring cross-platform compatibility will be important for future scalability.

7.2 Future Work

Building on the foundation laid by the project, several avenues for future research and development can be pursued to enhance the system's functionality, accuracy, and usability. Addressing the current limitations and exploring new opportunities will be critical for the continued advancement of this technology in the field of balance assessment and healthcare.

7.2.1 Expanding the Dataset

To improve the generalizability and robustness of the system, future work should focus on expanding the dataset. This involves recruiting a larger and more diverse group of participants, including individuals with varying degrees of balance impairment and from different demographic backgrounds. A more comprehensive dataset will enable the development of more accurate and reliable algorithms capable of handling a wider range of scenarios.

7.2.2 Algorithm Refinement and Optimization

Enhancing the accuracy of the system across all balance assessment activities will require ongoing refinement and optimization of the algorithms. This includes improving the system's ability to interpret complex movements and minimizing errors in challenging tasks such as "Transfers." Leveraging advanced machine learning techniques, such as deep learning and ensemble methods, could further enhance the algorithm's performance.

7.2.3 Real-World Testing and Validation

To ensure the practical applicability of the system, extensive testing and validation in real-world settings are necessary. This involves deploying the system in various clinical environments, such as hospitals, rehabilitation centers, and elderly care facilities, to evaluate its performance under different conditions. Real-world testing will provide valuable insights into the system's strengths and areas for improvement.

7.2.4 Enhancing Real-Time Capabilities

Improving the real-time processing capabilities of the system is crucial for its usability in clinical practice. Future work should focus on optimizing the processing speed and response time to ensure seamless and efficient real-time assessments. This may involve leveraging more powerful hardware, optimizing software algorithms, and exploring parallel processing techniques.

7.2.5 User Interface and Experience Enhancements

Enhancing the user interface and overall user experience will be important for ensuring the system's accessibility and ease of use. Future developments should aim to create a more intuitive and user-friendly interface for both patients and operators. This includes incorporating feedback from users to make necessary adjustments and improvements.

7.2.6 Integration with Healthcare Systems

Integrating the system with existing healthcare systems and electronic health records will facilitate seamless data management and analysis. Future work should focus on developing interoperability standards and protocols to enable smooth integration with various healthcare platforms. This will enhance the system's utility in clinical workflows and decision-making processes.

7.2.7 Exploring Additional Applications

Beyond balance assessments, the system has the potential to be adapted for other healthcare applications, such as gait analysis, fall risk prediction, and physical therapy monitoring. Future research should explore these possibilities, expanding the scope of the system to address a wider range of healthcare challenges and needs.

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