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PAPER

Gait Analysis—A Tool for Medical Inferences

Sindhu K(✉), A Nidhi Uday, Abhishek S J, Anjali S

Department of Information Science and Engineering, BMS College of Engineering, Bengaluru, Karnataka, India

ksindhu.ise@bmsce.ac.in

ABSTRACT

Gait analysis is a valuable tool for making medical inferences and improving the diagnosis and treatment of mobility issues. This project aims to leverage gait analysis in addressing two important challenges: detecting knock knees and monitoring patients with Parkinson's disease for falls. The project proposes the integration of gait analysis with yoga therapy to provide a unique and effective approach for correcting knock knees. A web user interface is developed to enable individuals to access the system, receive accurate feedback on their gait, and access yoga postures tailored to target knock knees. Additionally, a fall detection system is designed to monitor patients with Parkinson's disease and notify caregivers or guardians in case of a fall. The implementation involves utilizing deep learning models, such as OpenPose model, a widely adopted deep learning framework for pose estimation and MediaPipe, another recognized framework used for building multimodal applied machine learning pipelines, to analyze gait patterns and detect knock knees and falls. The project aims to empower individuals in improving their gait, correcting knock knees, and enhancing their physical health, ultimately improving their quality of life and well-being.

KEYWORDS

gait analysis, knock knee, therapy, Parkinson, fall detection

1 INTRODUCTION

The field of gait analysis and its application in healthcare has gained significant attention in recent years. Gait analysis offers valuable insights into various musculoskeletal and neurological conditions that affect an individual's walking pattern [1]. It plays a crucial role in assessing and diagnosing various mobility-related disorders, enabling healthcare professionals to design targeted interventions and therapies. It serves as a valuable tool in orthopedics, rehabilitation, and sports medicine, helping to optimize performance, prevent injuries, and enhance overall functional outcomes [2, 19]. In this paper, a comprehensive system for gait analysis and yoga therapy, aimed at addressing two specific challenges: knock knee detection and fall detection in Parkinson's patients, is discussed.

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Knock knees, or genu valgum, is a condition where the knees angle inward, potentially causing discomfort, pain, and long-term complications. In mild cases, there may be minimal discomfort or impact on daily activities. However, more severe knock knees can lead to various issues. The misalignment places increased stress on the inner knee joint, which can lead to joint pain, instability, and wear and tear over time. Knock knees occur for various reasons and can be identified under specific conditions. Knock knees are relatively common in children as their bodies are growing and the alignment of the legs is still developing. Sometimes, knock knees persist beyond childhood due to underlying bone issues or abnormalities in the growth plates. Excess weight can affect the alignment of the legs, leading to knock knees [3].

Incorporating alternative and complementary approaches, such as yoga therapy, has shown promising results in improving balance, strength, and overall well-being in individuals with mobility issues. It targets specific muscle groups, promoting muscular balance, and enhancing body alignment as yoga is a holistic practice that focuses on physical postures (asanas) [10]. Parkinson's disease is a progressive neurological disorder that affects movement control. As the disease progresses, individuals may have trouble with everyday activities such as walking, getting up from a chair, or maintaining balance [14]. This can lead to an increased risk of falls and a decline in overall mobility and independence. Fall detection is a critical concern for individuals with Parkinson's disease, who are prone to sudden falls due to motor impairments. Factors related to the body's condition, such as muscle weakness, impaired balance, cognitive impairments, obstacles in the environment, can cause falls in Parkinson's disease patients [20].

The primary objective of this project is to develop an integrated system that combines computer vision techniques, machine learning algorithms, and yoga therapy programs to provide a holistic approach to gait analysis and mobility issue management. By leveraging the advancements in computer vision and deep learning, the project aims to accurately detect knock knees and provide real-time fall detection capabilities to enhance the safety and well-being of individuals with Parkinson's disease. The research work contributes to the existing body of research in several ways. Firstly, the project proposes an innovative algorithm for knock knee detection that utilizes image processing techniques and machine learning models to accurately identify and quantify the severity of knock knees. This algorithm offers a non-invasive and accessible solution that can assist orthopedic specialists in diagnosing and monitoring knock knee patients.

Furthermore, A fall detection module based on video analysis techniques has been developed, utilizing the OpenPose model [4] and the MediaPipe [5] framework. This module leverages computer vision algorithms to detect falls in real-time, providing immediate alerts to caregivers or healthcare professionals for prompt intervention. In addition to the diagnostic and safety aspects, our system incorporates yoga therapy programs tailored specifically for individuals with knock knees and Parkinson's disease. These programs aim to improve strength, balance, and overall motor function through a combination of targeted asanas (postures), pranayama (breathing exercises), and meditation techniques.

The developed system is accessible through a user-friendly web interface, which allows easy access to the knock knee detection system and personalized yoga therapy programs. By integrating gait analysis and yoga therapy, a comprehensive solution to the unique needs of individuals with mobility issues and enhancing their overall quality of life is addressed.

2 RELATED WORK

In recent years, there have been several studies focusing on the recognition and analysis of abnormal gait patterns, detection of genu valgum (knock knees), quantification of lower extremity alignment, and analysis of yoga postures. These studies have utilized various approaches, including machine learning, deep learning, image processing, and wearable sensor technology. In this section, some of the notable related works in these areas are discussed. Kim et al. [6] proposed a method for detecting gait abnormalities by utilizing integrated gait features obtained from the Kinect depth camera. The study focused on differentiating between normal and abnormal gaits associated with conditions such as hemiparetic gait, Parkinson's disease, sciatic neuralgia gait, and myopathic gait. They used a k-NN classifier and SVM classifier to classify abnormal gaits with a high accuracy of 96.52%. Bakshi et al. [7] presented a deep learning-based approach for automated detection of genu valgum, a shape disorder characterized by knock knees. They employed a tuned CNN model that used image augmentation techniques to increase the number of training samples. The model achieved an accuracy of over 90% in detecting genu valgum from images. Tsai et al. [8] developed a convolutional neural network (CNN) to predict anatomical landmarks from radiographs, which were used to calculate hip-knee-ankle angles (HKAAs). The CNN model showed promising results in estimating HKAAs with minimal prediction errors, making it a potential computer-aided diagnostic tool for assessing lower extremity alignment in children. Saini et al. [9] conducted a clinical study to investigate the normal development of the knee angle in Indian children. They measured tibiofemoral angles in a cohort of 215 healthy Indian children and observed a progressive increase in knee valgus after the age of 2, peaking at around 6 years of age. The findings provided valuable insights into the physiological variations of knee angles specific to Indian children.

Chinnaiah et al. [10] introduced an embedded assistive system for analyzing yoga postures. Their system utilized image processing techniques and Kinect sensors to capture and analyze depth images of yoga postures. The system aimed to provide posture correction and guidance to individual practitioners, highlighting the potential benefits of technology in improving the practice of yoga. Nijjar et al. [11] proposed an image processing-based approach for valgus and varus disease detection by analyzing intermalleolar and intercondylar distances. Their system utilized the YOLOv3 algorithm for knee and ankle detection, followed by edge detection and thresholding techniques to calculate the distances. The system demonstrated accurate disease detection based on the calculated distances. Cao et al. [12] presented a remote gait monitoring mobile system enabled by wearable sensor technology. They collected gait data from healthy subjects and subjects with mobility impairments using inertial measurement units (IMUs) and accelerometers. A machine learning algorithm, specifically a random forest classifier, was trained to classify the subjects as healthy or impaired. The authors also developed a mobile app for remote gait monitoring and feedback. In addition to these studies, there have been investigations into the influence of knock knees on gait kinematics in children [13], providing insights into the relationship between knee alignment and gait patterns.

The existing systems for gait analysis use different techniques and technologies to measure and analyze gait. Some of the most common systems include optical systems, inertial measurement units (IMUs), and force platforms. The images or videos of a person walking that are captured by optical systems are processed to extract gait parameters like step length, step width, and stride time. IMUs can provide information about the acceleration, velocity, and orientation of movement and can be attached to various body parts, such as the foot, ankle, or shank. Systems known as force platforms can provide data on weight distribution, balance, and other aspects of gait by measuring the ground reaction force (GRF) generated [14]. In addition to these systems, computer simulations and models are available for analyzing gait and drawing conclusions about medical conditions.

The evaluation and management of knock knees (genu valgum) typically involve a combination of physical examination, imaging techniques, the use of wearable technology, and corrective measures.

- Physical Examination: Visually assesses knee alignment, joint flexibility, muscle strength, and range of motion.
- Imaging Techniques: X-rays and Magnetic Resonance Imaging (MRI) scans to measure the angle between femur and tibia, determining severity [15].
- Wearable Technology: Smart insoles and depth-sensing cameras capture gait data and assess knee alignment.
- Corrective Measures: Treatment options include orthopedic braces, orthotics, physical therapy exercises, and surgery [16].

There are several existing systems and technologies for fall detection in Parkinson's patients. These systems aim to detect falls or abnormal movement patterns and provide timely alerts to caregivers or medical professionals. Here are some examples:

- Wearable Devices: Many wearable devices, such as smartwatches, wristbands, or pendants, incorporate fall detection features specifically designed for Parkinson's patients [17].
- Video-Based Systems: Video-based fall detection systems use cameras and computer vision algorithms to monitor the movements of Parkinson's patients [18].

The proposed system differs from the existing gait analysis systems by focusing on the specific issue of knock knees (genu valgum) and providing early detection and therapeutic solutions through a web interface. Unlike traditional gait analysis systems that mainly extract general gait parameters, the proposed system utilizes vision-based systems to assess knee alignment and provide yoga therapy programs to effectively manage knock knees. Furthermore, the proposed system is distinct from the existing fall detection systems for Parkinson's patients, as it utilizes MediaPipe, a multimodal applied Machine Learning (ML) pipeline, to provide real-time fall detection specifically tailored for individuals with Parkinson's disease.

In the domain of medical technology and healthcare innovation, various research papers have explored the realms of gait analysis, knee misalignment detection, and fall detection systems. Several of these studies have concentrated on devising computer vision-based methodologies to evaluate knee angles during gait, with the objective of identifying and quantifying knock knees. Nevertheless, many of these efforts have mainly focused on the detection aspect, without providing comprehensive therapeutic solutions. In contrast, the presented research paper introduces a comprehensive framework that encompasses both knock knee detection and tailored therapy. The research paper's approach leverages advanced deep learning models to accurately measure knee angles and differentiate between normal, mild, and severe knock knees. This distinctive fusion of detection and therapy distinguishes this research paper from prior studies, as it not only identifies the problem at hand but also offers an interactive and efficacious remedy for individuals afflicted by knock knees.

Furthermore, while certain studies have predominantly focused on knee misalignment detection, this research paper widens its purview to encompass fall detection for individuals grappling with diverse medical conditions. This is achieved through the utilization of state-of-the-art frameworks for real-time monitoring and prompt notifications. To conclude, the proposed work distinguishes itself by presenting a unique amalgamation of knock knee detection, individualized therapeutic interventions, and fall detection, effectively addressing critical gaps in the prevailing body of literature. By introducing an integrated solution that encompasses both assessment and intervention, this research paper endeavours to provide a more comprehensive and effective strategy for tackling knee misalignment and averting falls across diverse patient cohorts.

3 PROPOSED SYSTEM

Human gait varies depending on the movements made by the individual, making it possible to distinguish between normal and abnormal gaits based on their traits. This research work aims to address two important challenges related to human gait. Firstly, to develop a system that is capable of identifying the degree of knee misalignment and differentiating between normal gait and knock knees, allowing users to correct their posture through yoga therapy exercises. Secondly, to design s system to monitor patients diagnosed with Parkinson's disease and promptly notify their caregivers or guardians in the event of a fall, considering that Parkinson's disease is a neurodegenerative disorder that causes muscle stiffness, tremors, postural instability, which increase the risk of falling.

3.1 Knee misalignment detection for knock knees

The knock knee detection module utilizes the OpenPose model, a pre-trained deep learning model, to analyze the posture of a person and determine the presence of knock knees. The implementation of this module involves the following steps:

- Image as Input: The module takes an input image of the person to analyze the misalignment of ones' knees.
- OpenPose Skeletonization: OpenPose is employed to identify and mark key body joints on the person in the image. By analyzing the spatial relationships between these joints, the module constructs a skeletal representation of the person's posture.
- Angle Calculation: The module focuses on the knee joints and computes the angles formed between the thigh and lower leg bones. By setting angle threshold, where angle less than 7 is considered as normal knees, more than 11 as severe knock knees, and anything in between as mild knock knees, the module determines whether the person has knock knees.

The angle calculation is focused on determining the angles related to the knee joint. Specifically, it calculates the angles for both the left and right knees. The angles are computed based on the detected key points representing specific joints. Here's a breakdown of the key angles:

1. Left Knee Angle (left_angle): calculated using key points for the left hip (lh), left knee (lk) and left ankle (la). The angles are determined using trigonometry based on the positions of these key points in the image.
2. Right Knee Angle (right_angle): similar to the left knee angle but involving key points for the right hip (rh), right knee (rk) and right ankle (ra).
3. Calculation Method: The script checks for the existence of key points to ensure they are detected in the image. Then angles are calculated based on the arctangent of the slope between relevant key points.
4. Severity Classification: after calculating the left and right knee angles, the script classifies the severity of the knock knees based on the angles. The severity is categorized as severe, mild, or normal.

- Quantitative Assessment: The module provides a quantitative assessment of knock knees based on the detected angles. It would classify the severity of knock knees into different categories, helping medical professionals make informed decisions regarding treatment.

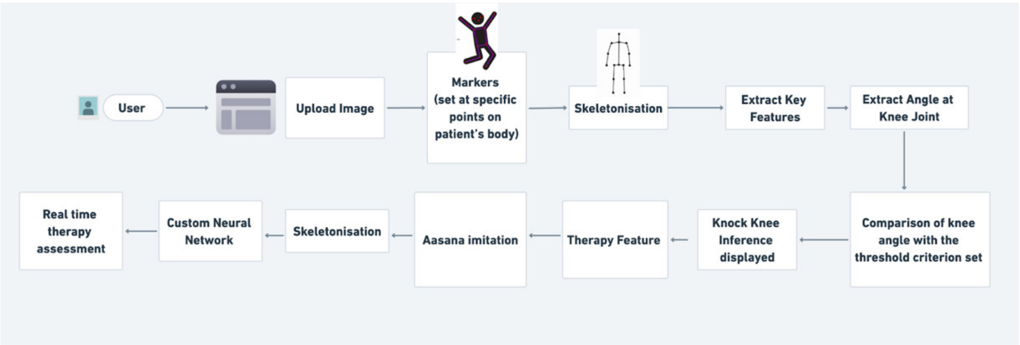

Fig. 1. Architecture of the proposed system

Figure 1 depicts Knock Knee Detection, Therapy and the flow of the proposed approach, which shows the clear methodology, also includes the glimpse of the implementation approach considered.

3.2 Therapy for knock knees using yoga poses

The therapy module aims to improve the alignment and strength of knees in individuals diagnosed with knock knees. It utilizes specific yoga poses tailored for this purpose. The implementation of this module involves the following steps:

- Pose Recommendation: After the knock knee analysis results, the module recommends a set of yoga poses that are most beneficial for improving knee alignment. These poses are selected to target the relevant muscles and promote correct posture.
- Pose Visualization: The module provides visual representations of the recommended yoga poses to guide the user. These images illustrate the correct alignment and posture for each pose.

- User Interaction: The user imitates the shown images of the yoga poses, following the instructions provided by the module. The user attempts to align their body and replicate the correct posture demonstrated in the images.
- Real-Time Feedback: The module utilizes computer vision techniques to analyze the user's posture while performing the yoga poses. If the user's alignment matches the correct posture, the skeleton overlay on the screen turns green, indicating proper alignment. If misalignment is detected, the module provides real-time feedback to help the user adjust their posture.
- Progress Tracking: The module keeps track of the user's performance and progress. It records metrics such as the duration of holding each pose, repetitions completed, or improvements in alignment over time. The module encourages users to surpass their previous performance, providing motivation for continued practice.
- Neural Network Model: To support the therapy module, custom neural network model is developed. Models like MoveNet Thunder, which are specifically designed for pose estimation and tracking, can be utilized to accurately detect and analyze the user's body movements during the yoga poses.

3.3 Fall detection for Parkinson's people using mediapipe

The fall detection module focuses on detecting falls in individuals with Parkinson's disease to ensure their safety and prompt assistance. The implementation of this module involves the following steps:

- Input Data Acquisition: The module acquires data from video streams capturing the user's movements and activities. The video can be from any source with good video quality, like a CCTV inside home or a public street camera. We have used pre-recorded videos to test the proposed approach for fall detection. We recommend using our algorithm in real-time for actual use of fall detection, to help get notified after fall. This data serves as the input for fall detection.

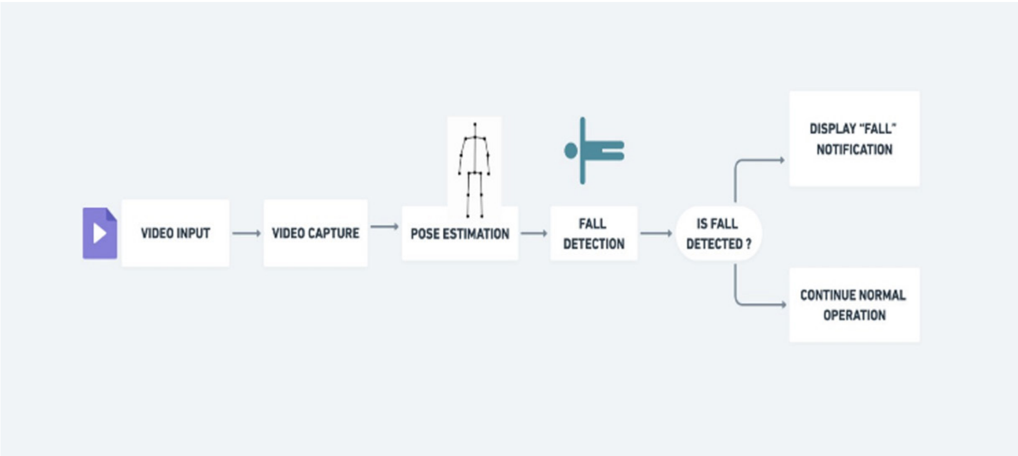

Fig. 2. Fall detection module

Figure 2 depicts the proposed approach for the Fall Detection, where video input is processed and analyzed, and further pose estimation is done and the fall detection algorithm classifies, if the subject under consideration has fallen.

- MediaPipe Integration: The module utilizes the MediaPipe framework, which offers prebuilt components for multimodal applied Machine Learning pipelines. MediaPipe provides ready-to-use models and tools for analyzing video streams, making it suitable for fall detection.
- Fall Detection Algorithm: The module employs a fall detection algorithm based on machine learning. This algorithm analyzes the relative position of pre-defined landmarks at hips and ankle, and continuously monitors any significant change in the coordinates of these landmarks, if the change exceeds the limit in cartesian plane, then the system infers it as fall, thus detecting the fall. So, to elaborate this, the algorithm utilizes the OpenCV and MediaPipe libraries to perform real-time pose estimation on video feed. It detects key landmarks on a person's body, focusing on leg motion and the position of the nose. The algorithm increments a counter when a significant leg motion, measured in y-axis, is detected. If this motion persists for a certain number of frames and nose's y-axis position indicates a potential fall, thresholds are set at leg_motion_threshold and nose_fall_threshold, the code annotates the video frame with a 'FALL' label in the proposed work, whereas in real-time, this algorithm can be used to send notification to caretakers. The thresholds set can be fine-tuned for precise fall detection and it can be applied to various scenarios, including both public street cameras and inside home. The algorithm mainly focuses on analyzing pose and movement patterns in the captured video frames rather than relying on the specific source of the video.

  The algorithm focuses primarily on 2D pose estimation, which involves tracking landmarks in the x and y coordinates of the image. In this context, variations in the cartesian referential are mainly associated with the x and y axis. The z-axis, representing depth, is typically not a significant factor in 2D pose estimation.
- Notification System: If a fall event is detected, the module triggers a notification to alert caregivers or medical professionals. The notification can be sent ensuring timely response and assistance.

  The notification is triggered under the following conditions:
  1. Significant leg motion: The code calculates the absolute difference in the y-coordinates of specific landmarks representing the left and right legs. If either leg exhibits motion exceeding the predefined threshold (leg_motion_threshold), a counter (j) is incremented.
  2. Sustained leg motion: The counter (j) is used to track the continuity of significant leg motion. If this counter surpasses a certain threshold (set at 5 frames), it suggests sustained leg motion.
  3. Nose Position Above Threshold: If sustained leg motion is detected, the code checks the vertical (y-axis) position of the nose landmark. If the nose is positioned above a specified threshold (nose_fall_threshold), it indicates a potential fall.
  4. Fall Confirmation: If the above conditions persist for a certain duration, the code annotates the video frame with a 'FALL' label and sets a flag (is_fall) to true.
- Continuous Monitoring: The module continuously monitors the user's movements and activities in real-time, allowing for immediate detection and response to fall events. This ensures the safety and well-being of individuals with Parkinson's disease, reducing the risk of injury.

4 RESULTS

4.1 Knock Knee detection module results

a) Home Page Interface
The homepage of the proposed system shows an intuitive web interface. Users can access the knock knees detection and therapy modules from here. The interface allows users to input their gait images for analysis. The home page is the landing page to navigate to each module, The user gets options to choose Knock Knee Detection if he wishes to do a self-assessment; else, if he wishes to proceed with Knock Knee therapy, he can choose the Knock Knee Therapy option and continue doing therapy in his comfort zone (see Figure 3).

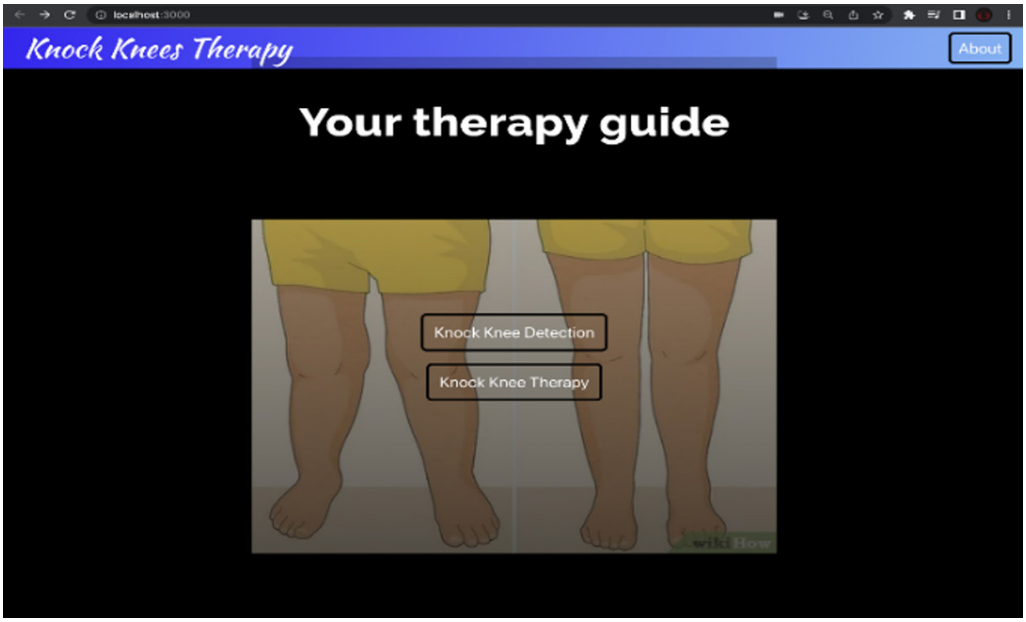

Fig. 3. The home page

b) Severe Knock Knees Detection
The knock knee detection module successfully identifies severe knock knees in a person's gait. The angle measurement indicates a significant deviation between the thigh and lower leg bones, confirming the presence of severe knock knees. Figure 4 is a skeletonized image of the subject and inferences made from detection, showing the subject with Severe Knock Knee.

c) Mild Knock Knees Detection
For individuals with mild knock knees, the detection module accurately quantifies the degree of knee misalignment. The angle measurement reflects a moderate deviation between the thigh and lower leg bones, confirming the presence of mild knock knees. Figure 5 is a skeletonized image of the subject and inferences made from detection, showing the subject with Mild Knock Knee.

d) Normal Gait Detection
The detection module properly identifies a normal gait with minimal knee misalignment. The angle measurement shows a negligible deviation between the thigh and lower leg bones, confirming a normal knee alignment. The images have to be provided in frontal/coronal plane 2D format. Figure 6 is the skeletonized image of the subject and inferences made from detection, showing the subject with Normal Knees.

Fig. 4. Severe Knock Knee

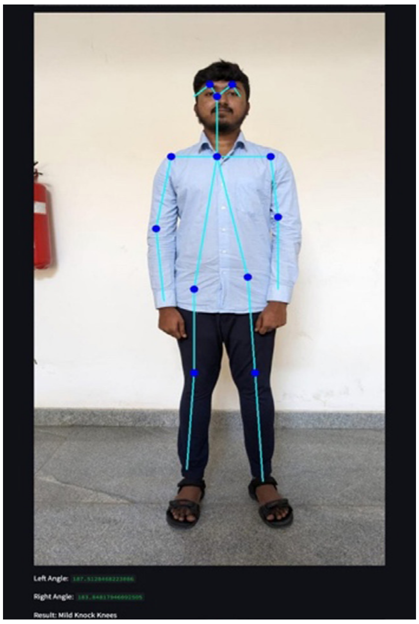

Fig. 5. Mild Knock Knee

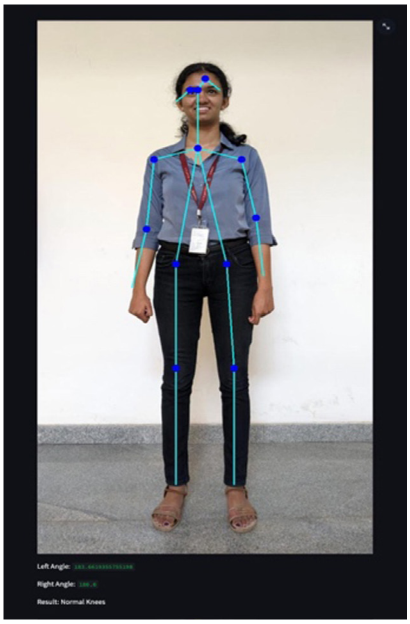

Fig. 6. Normal Knees

Figure 4 Source: Adapted from Choubisa, S.L. and Choubisa, D., 2019. Genu-valgum (knock-knee) syndrome in fluorosis-endemic Rajasthan and its status in India. Fluoride, 52(2), pp. 161–168.

4.2 Knock Knee Therapy module results

a) Knock Knee Therapy Before Correct Posture

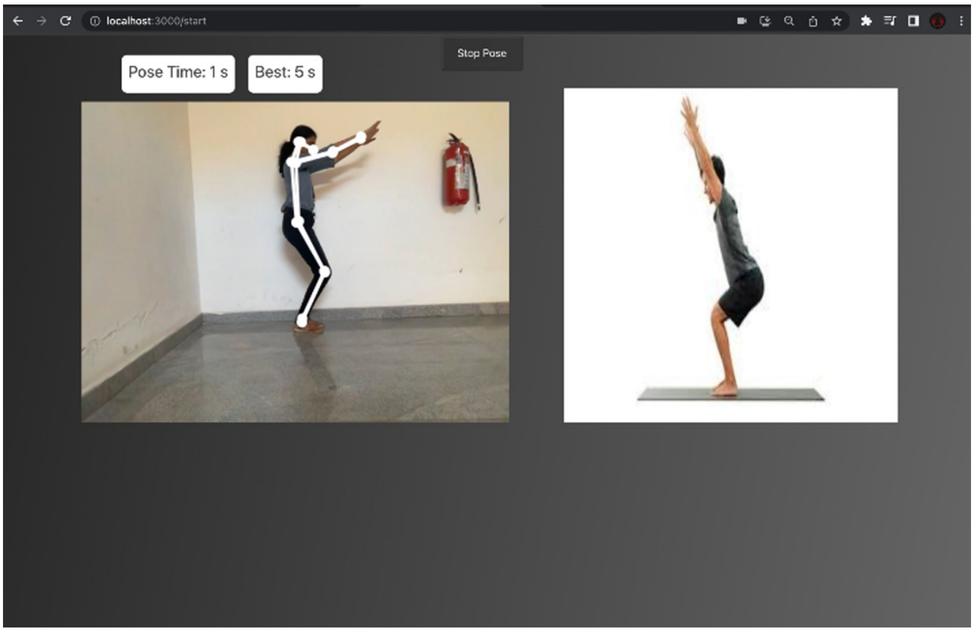

Fig. 7. Knock Knee therapy before correct posture

Figure 7 depicts the person trying to imitate the yoga pose visible on screen, before doing the correct posture.

b) Knock Knee Therapy with Correct Posture
Figure 8 depicts the person imitating the correct yoga pose visible on screen and then the skeleton turns green, and the timer begins.

4.3 Fall detection module results

a) Fall Detection of a Person
The fall detection module accurately detects a fall event in a person with Parkinson's disease. Using the MediaPipe framework, the system monitors the patient's movements and activities. Figure 9 depicts an instance of fall detection of the person, where the system detects that the subject has fallen.

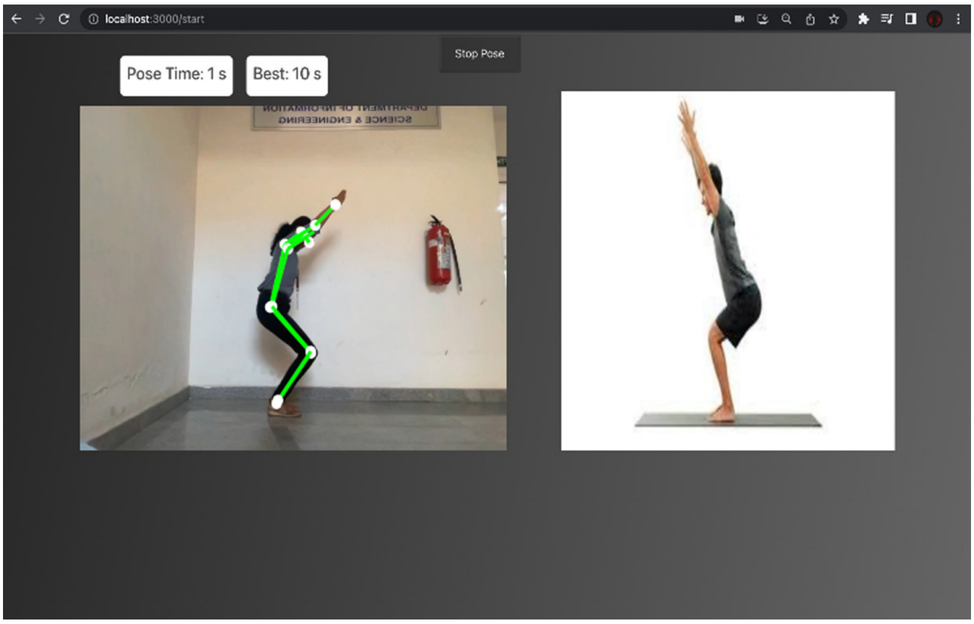

Fig. 8. Knock Knee therapy with correct posture

Fig. 9. Fall detection of a person and notification

Figure 9 Source: Adapted from a video on Shutterstock, Stock Video ID: 1030457330, uploaded by Chistropher Fertnig.

5 CONCLUSION

The proposed work implements a comprehensive system that integrates gait analysis, yoga therapy, and fall detection to address the challenges of detecting knock knees and monitoring patients with Parkinson's disease. By leveraging gait analysis techniques, the system aims to provide accurate assessments of knee misalignment and distinguish between normal gait and knock knees. The incorporation of yoga therapy recommendations tailored to target knock knees offers individuals an effective and holistic approach for correcting their condition.

The development of a user-friendly web interface allows individuals to easily access the system, receive feedback on their gait analysis, and access yoga postures with clear instructions to guide them in performing the exercises correctly and safely. Furthermore, the fall detection system provides continuous monitoring for patients with Parkinson's disease, ensuring their safety by promptly annotating video frames with "FALL" upon detection of a fall. As a future enhancement, we plan to implement a notification system that would instantly alert the caretakers or caregivers on their mobile phones in the event of a fall, enhancing the overall safety and responsiveness of the system.

By combining gait analysis, yoga therapy, and fall detection, this project strives to empower individuals to take an active role in improving their gait, addressing knock knees, and managing the challenges associated with Parkinson's disease. The proposed system offers a unique and integrated solution that has the potential to significantly enhance the diagnosis, treatment, and overall well-being of individuals affected by knock knees and Parkinson's disease.

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7 AUTHORS

Sindhu K is working as Assistant Professor in Department of Information Science and Engineering at BMS College of Engineering, Bengaluru, Karnataka, India (E-mail: ksindhu.ise@bmsce.ac.in).

A Nidhi Uday is student in Department of Information Science and Engineering at BMS College of Engineering, Bengaluru, Karnataka, India (E-mail: nidhiuday.is19@bmsce.ac.in).

Abhishek S J is student in Department of Information Science and Engineering at BMS College of Engineering, Bengaluru, Karnataka, India (E-mail: abhisheksj.is19@bmsce.ac.in).

Anjali S is student in Department of Information Science and Engineering at BMS College of Engineering, Bengaluru, Karnataka, India (E-mail: anjalis.is19@bmsce.ac.in).