Development of a Webcam-Based Program for Forearm Physical Therapy

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Received 19 Mar 2024; Revised 6 Jun 2025

Accepted 17 Jun 2025; Available online 30 Jun 2025

Abstract

The increasing number of stroke patients worldwide has highlighted the urgent need for accessible and effective rehabilitation solutions [1-2]. This research presents the development of a webcam-based physical therapy program aimed at supporting forearm rehabilitation for stroke patients. The system utilizes the MediaPipe framework to detect key anatomical landmarks, the shoulder, elbow, and wrist in real time and calculate the angle of arm flexion during therapeutic exercises. The program includes features for repetition counting, patient data management, and exercise history logging. Experimental evaluations were conducted to examine the impact of camera angle and body posture on detection accuracy. Results indicate that side and straight-on views at 45° and 90° camera angles yield optimal accuracy for detecting arm elevation, while oblique angles result in reduced performance. The system exhibited the highest reliability in detecting and counting exercise repetitions at lower arm elevation angles, particularly within the 0–30° range. In contrast, detection accuracy significantly declined at higher angles (40°, 60°, and 90°), especially when the camera was positioned directly in front of the user. This research contributes to the advancement of computer-assisted physical therapy by offering an affordable and practical tool to assist healthcare professionals in monitoring and guiding patient recovery.

Keywords: MediaPipe, Computer Vision, Stroke recovery, Physical therapy, Forearm rehabilitation.

1. Introduction

In recent years, the rising number of stroke patients has placed increasing demands on healthcare systems to provide effective and accessible rehabilitation solutions [1-4]. To address this challenge, there has been a significant increase in the development of computer-based systems designed to augment the capabilities of healthcare professionals, particularly physical therapists. One such advancement involves the implementation of webcam-based physical therapy programs, which aim to support the therapeutic and physical activity needs of stroke patients [5–21].

This study focuses on the design and evaluation of a prototype program for arm rehabilitation using webcam-based physical therapy. The methodology incorporates the MediaPipe framework, which applies machine learning models for real-time analysis of video frames captured via webcam. The program identifies key anatomical points, specifically the shoulder, elbow, and wrist, to calculate the angle of arm flexion during simulated lifting exercises.

A key component of this research involves evaluating the program under varying conditions, including different camera angles, stretching postures, and arm elevation angles. The findings from these experiments provide insights into the effectiveness and limitations of webcam-based physical therapy systems. These results underscore the importance of understanding the specific conditions and viewing angles that contribute to accurate and effective motion detection. Considering these findings, this study aims to develop a practical and efficient tool to support stroke rehabilitation by enabling real-time monitoring, repetition counting, and data recording, thereby assisting physical therapists in delivering personalized and effective care.

2. EXPERIMENTAL SETUP

2.1 MediaPipe Pose

MediaPipe is a framework that enables developers for building multi-modal (video, audio, any times series data) cross-platform applied ML pipelines. MediaPipe has a large collection of human body detection and tracking models which are trained on a massive and diverse dataset of Google.

MediaPipe uses a detector and a tracker in its framework to detect human skeletal main points. The detector is used to find the area of interest in the image, whereas the tracker tries to identify the posture landmarks. The framework by Google can detect 33 distinct points on the human body (shown in Fig. 1). There are alternatives to MediaPipe available like OpenPose, and Blaze poses. However, compared to others, MediaPipe, a cross-platform solution, is much faster in the face, hand, and pose detection. It is ideally suited for complex perception pipelines leveraging accelerated inference. We used 6 landmarks to estimate arbitrary poses and motions, which indices are 11, 12, 13, 14, 15, and 16 as shown in Figure 1. To analyze arm articulation, we calculate the angle formed at the left elbow using landmarks 11 (left shoulder), 13 (left elbow), and 15 (left wrist) and landmarks of 12(right shoulder), 14 (right elbow), and 16(right wrist) for the right arm articulation. This angle helps quantify the bending of the left arm, which is critical for evaluating motion range and detecting specific gestures or poses.

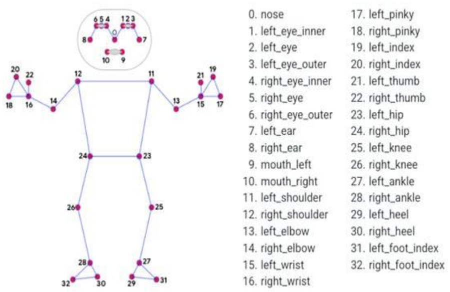
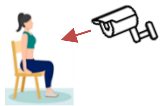
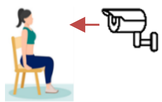
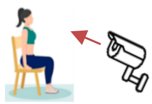


Figure 1 Definition of landmarks in MediaPipe

2.2. Camera Angles in Physical Therapy

This experiment investigates the influence of different laptop camera angles on the effectiveness of webcam-based physical therapy. Three camera angles 45°, 90°, and 135° were evaluated to determine their suitability for capturing the full range of motion during arm rehabilitation exercises. The experimental results indicate that the 135° angle is suboptimal, as it fails to capture the full image of the subject, potentially hindering accurate motion detection and analysis. In contrast, both the 45° and 90° angles successfully provide a complete view of the participants, making them more appropriate for use in webcam-based physical therapy applications.

Table 1 Camera Angles in Physical Therapy

Camera angle (degree)	Camera Installation Position	Result
45°		✓
90°		✓
135°		✕

2.3. Posture positions in physical therapy

This experiment investigates the impact of different body postures on the effectiveness of webcam-based physical therapy. Three posture positions straight, side, and oblique, were examined, as illustrated in Figure 2.

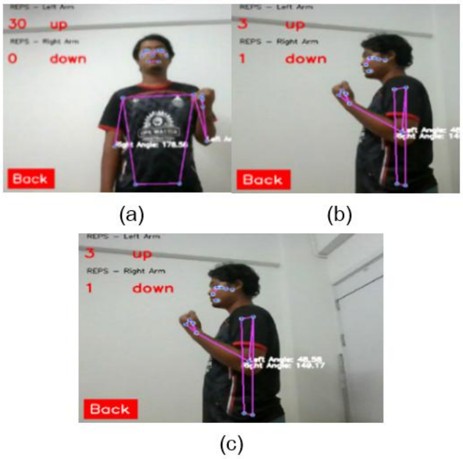


Figure 2 Posture positions: (a)straight Posture (b)Side Posture (c)Oblique Posture Respectively.

2.4. Arm Lifting Angles in Physical Therapy

This experiment examines the effect of various arm lifting angles on the accuracy of repetition counting during physical therapy exercises. Four elevation angles 30°, 40°, 60°, and 90°, were tested to evaluate their suitability for motion detection and performance tracking, as illustrated in Figure 3. The objective is to identify the optimal angle range that ensures reliable recognition of arm movements by the system.

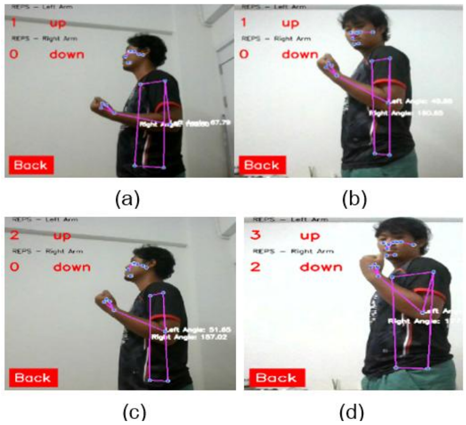


Figure 3 The arm lifting angles in physical therapy: (a) 90 angle (b) 60 angle (c) 40 angle (d) 30 angle, respectively

3. Software Design

3.1. Workflow of the System for Forearm Physical Therapy

The computational process for forearm physical therapy, comprising landmark detection, angle measurement using trigonometric functions, and repetition counting is summarized in the algorithm outlined below: Capture Video Frame: Acquire real-time video frames from the webcam. Landmark Detection: Apply the MediaPipe framework to detect key anatomical landmarks relevant to forearm motion. Angle Calculation: Using the identified landmarks (indices 11, 13, and 15 corresponding to the left shoulder, elbow, and wrist, respectively), compute the elbow joint angle via trigonometric functions.

1. **Real-Time Pose Display:** Visually present the forearm posture in real time to provide

immediate feedback to both the patient and the therapist.

2. **Repetition Counting:** Analyze the motion pattern to count completed exercise repetitions, supporting quantitative monitoring of rehabilitation progress.

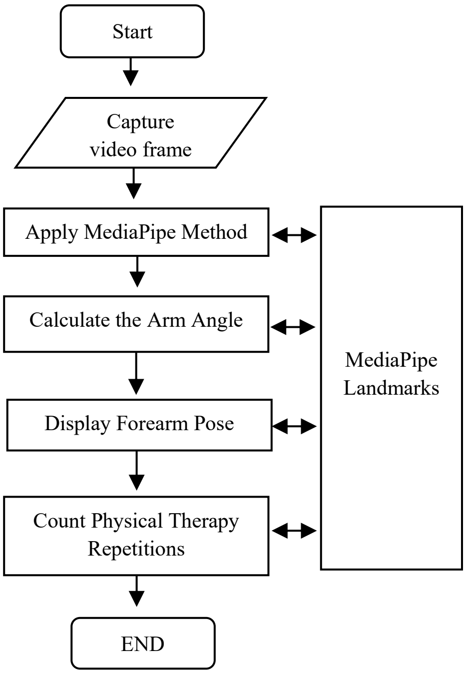


Figure 4 Flowchart of the Proposed Method

In summary, the system workflow begins with capturing video input, followed by landmark prediction and angle computation through the MediaPipe framework. The system then displays the current pose and counts the number of complete movements. This computer-assisted system is designed to support physical therapists in delivering effective forearm rehabilitation through webcam-based monitoring, as illustrated in Figure 4.

3.2. Calculate Measure of Angle

To analyze the flexion of the forearm during physical therapy exercises, the system calculates the angle formed at the elbow joint using three anatomical landmarks: the shoulder (point 11), elbow (point 13), and wrist (point 15), as detected by the MediaPipe framework, as illustrated in Figure 5.

The angle at the elbow is computed using the cosine rule derived from trigonometry, which is applied to the vectors formed by these three points. Given three points in a 2D or 3D coordinate system, the vectors from the elbow to the shoulder (vector A) and from the elbow to the wrist (vector B) are first determined. The angle θ between these two vectors is then calculated using the following formula:

$$\theta = \cos^{-1}\left(\frac{\vec{A}\cdot\vec{B}}{\|\vec{A}\|\cdot\|\vec{B}\|}\right) \quad , \qquad (1)$$

- Magnitudes:

$$\|\vec{A}\| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad , \qquad (2)$$

$$\|\vec{B}\| = \sqrt{(x_3 - x_2)^2 + (y_3 - y_2)^2} \quad , \qquad (3)$$

Where:

- $\vec{A}$=shoulder−elbow
- $\vec{B}$=wrist−elbow
- $\vec{A}\cdot\vec{B}$ is the dot product of vectors A and B
- $||\vec{A}||$ and $||\vec{B}||$ are the magnitudes (lengths) of vectors A and B
- θ is the elbow joint angle in radians (which can be converted to degrees)

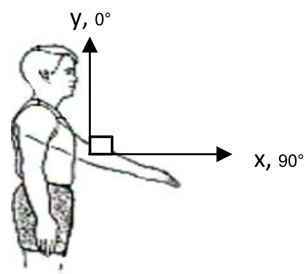


Figure 5 Measurement of Elbow Joint Angle

3.3. User Authentication System

Before accessing the program, users must authenticate by logging in with their registered email address and password. For first-time users, the system provides a registration module that enables account creation. These user authentication and registration interfaces are designed to ensure secure access and personalized tracking of therapy progress. The corresponding interface layouts are depicted in Figures 6 and 7.

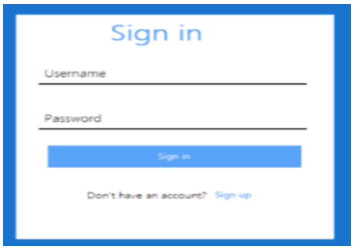


Figure 6 User Login Interface

Figure 7 User Registration Interface

The program includes a feature for reviewing historical records of physical therapy sessions. This function provides detailed information on each patient's therapy history, including the date and time of each session, as well as the number of exercise repetitions completed. An example of the historical record display is presented in Figure 8.

Figure 8 Historical Records Page of the Program

4. RESULTS

This section outlines the physical therapy postures utilized in the experiment, as illustrated in Figure 2. It then describes the arm elevation angles employed during the therapy sessions, as illustrated in Figure 3. The corresponding experimental results are subsequently analyzed and discussed.

4.1 Impact of Posture on Arm Elevation Detection Accuracy

The table demonstrates how posture direction affects the accuracy and consistency of arm elevation angle detection in a physical therapy monitoring system. For both straight and side views, the measured arm elevation angles are highly consistent and accurate, with means of 30.00° and 29.75°, and standard deviations of 0.00 and 0.50, respectively. These postures also yield high accuracy rates 100% for straight view and 99.2% for side view indicating that the system can reliably detect and track movements from these angles. In contrast, the oblique view shows a noticeable drop in performance, with a lower mean angle of 22.50°, higher variability (standard deviation of 1.91), and a reduced accuracy of 75%. This suggests that the oblique posture introduces challenges in angle estimation, likely due to reduced visibility or distortion of key joint positions. Overall, the data highlights the importance of camera placement and body orientation in achieving accurate motion detection for effective physical therapy monitoring, as illustrated in table 2.

Table 2 Impact of Posture on Arm Elevation Detection Accuracy

Posture direction	Arm Elevation Angles				Accuracy (%)	Mean	Standard Deviation
	90°	60°	40°	30°			
Straight	30	30	30	30	100	30.00	0.00
Side	30	30	30	29	99.2	29.75	0.50
oblique	24	22	24	20	75	22.50	1.91

4.2 Impact of Viewing Angle on Arm Movement Detection Accuracy

The highlights that the program's ability to detect and count arm-raising movements during physical therapy varies based on the viewing angle and degree of arm elevation. In the straight view, the program fails to recognize higher elevation angles (40 - 90°) but successfully detects lower angles (0 - 30°), indicating limited accuracy from this perspective, as illustrated in Figure 5. In contrast, the side view allows the program to detect all elevation angles reliably, demonstrating that side positioning provides better visibility for motion tracking. This suggests that for accurate movement monitoring, especially in rehabilitation settings, side view camera placement is more effective.

5. Summary

This study presents a comprehensive evaluation of a webcam-based physical therapy system designed for arm rehabilitation, emphasizing the impact of camera angles, posture direction, and arm lifting angles on exercise accuracy and system performance. The experimental results yield several key findings:

Camera Angle Testing: The results indicate that camera placements at 45° and 90° provide optimal visibility for capturing the patient's arm movements, enabling accurate pose estimation and real-time feedback. These angles allow the system to detect joint positions without significant occlusion. In contrast, a 135° camera angle fails to fully capture the arm's range of motion, thereby reducing system effectiveness and rendering it unsuitable for practical use.

Posture Direction (Stretching Positions): The system performs most effectively when the subject adopts either a straight (frontal) or side-facing posture. These positions enable high-accuracy detection of arm elevation angles, as evidenced by a mean of 30.00° and 29.75°, respectively, with minimal standard deviation. On the other hand, the oblique posture results in reduced accuracy and increased variability due to the partial obstruction of key landmarks, which complicates the angle estimation process.

Arm Lifting Angles: The analysis of different elevation levels shows that the system can most reliably detect and count repetitions at lower arm angles, specifically within the 0 – 30° range. At higher elevations (40°, 60°, and 90°), the accuracy drops, particularly when the camera is placed directly in front of the subject, suggesting that lower angles are more suitable for consistent and accurate repetition tracking in rehabilitation exercises.

Accuracy in Physical Therapy Execution: The system exhibits greater accuracy when monitoring the left arm compared to the right, though both arms demonstrate challenges when analyzed under oblique viewing conditions. This performance discrepancy highlights the importance of visibility and the need for optimal positioning of both the camera and the subject to ensure symmetrical and effective rehabilitation.

In conclusion, the findings from this study offer critical guidance for the implementation of webcam-based physical therapy systems. By identifying the most effective viewing angles, postures, and movement ranges, this research supports the development of systems that are both accurate and accessible. These insights contribute to enhancing remote rehabilitation practices and assisting physical therapists in delivering effective, technology-assisted care to stroke patients and individuals undergoing arm mobility therapy.

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