Real-Time Error Analysis of Exercise Posture for Musculoskeletal Disorder – A Machine Vision Approach

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Abstract

Occupational diseases have been a significant cause of organ harm in the developed world in recent decades. The loss of motion is a major symptom and may also affect people's elbows, wrists, neck, knees, and other joints. It is preferable to treat work-related illnesses with exercise treatment. Recent advances in computer vision and machine learning have led to the suggestion of computationally more affordable alternatives. However, it is still difficult and insufficiently researched in the scientific-technical literature for a health professional to use artificial intelligence to monitor a patient while engaging in physical rehabilitation exercises. The contribution of this study aids humans by providing a visual system to analyze exercise posture and provide feedback on how to improve it. A human's stance is evaluated with an AI-based pose estimation method. It helps the user determine what kind of exercise they are doing by providing information like "Degree of Motion Required" for each move they make. To perform a posture analysis, this system uses OpenCV written in Python. Posture analysis is performed here on the live video feed. As the user exercises, this device analyzes their upper extremity posture in real-time and delivers feedback.

Keywords

Artificial Intelligence (AI), Computer vision, Work-related musculoskeletal disorders, home-based recuperation training, upper limb exercise, Pose estimation technique

1. Introduction

In 2020, 21% of all injuries and diseases inciting days from work resulted from Work-related Musculoskeletal Disorders (WMSD), with a center of 14 days from work differentiated and 12 days for any excess nonfatal injury and affliction cases. In Malaysia, 61% of laborers rely on a PC-based working environment. The side effects of outer muscle issues have multifactorial gamble factors like decision scope, mental interest, social assistance, work flimsiness, and so forth., Musculoskeletal disorders emerge in offices, farming, study halls, businesspeople, and so on [1, 2]. As a well-known saying goes, "Exercise not just changes our body, it alters our perspective, demeanor, and mindset." Wellness is a pattern today. Everybody needs to be fit, lovely, and solid [3]. The justification behind having Musculoskeletal Disorder like the absence of body movements, more static workspace in sitting/standing positions, inconvenience of work environment, shift example of working, additional time obligation, and so on; exercise treatment is the most recommended method for recuperating from the outer muscle issues.

The specialists like modelers, engineers, engineers, creators, and even analysts need to invest more energy in PCs. A few laborers must spend a similar stance over a longer term of more than 10 hrs. It is because of high work pressure; that work environment design doesn't meet the prerequisite for the idea of the work; in the late days, more specialists are required to do ShiftWise design because of the excellent efficiency. These issues make the issue in the human body parts like muscles, tendons, joints, bones, ligaments, ligaments, and nerves [4].

Vision-based sensors have recently been implemented in the field of activity monitoring. They can collect reliable skeletal data. There have also been major developments in the fields of Computer Vision (CV) and Deep Learning (DL). Because of these causes [5, 6], there has been a rise in interest in

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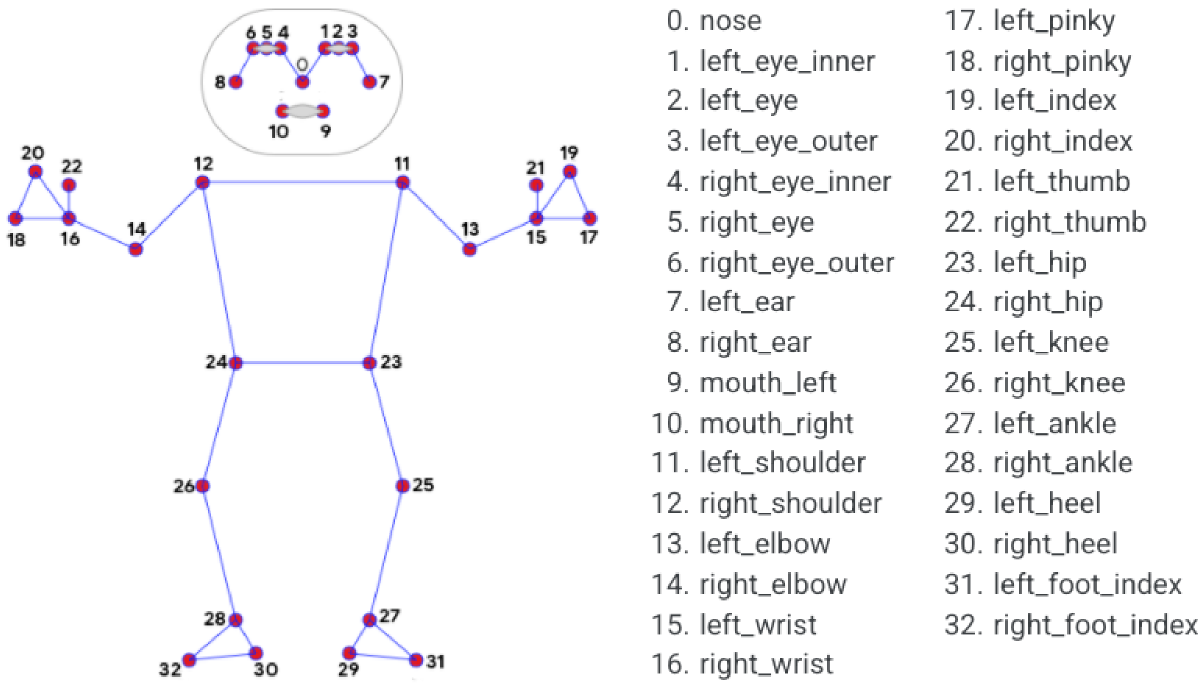


Figure 1: Landmarks used for estimating pose.

developing models for autonomous patient activity monitoring. Typically, patients receive help from trained therapists who keep tabs on their development and assess the efficacy of the treatment plan. A lack of trained therapists has made rehabilitation centers both costly and insufficient. In addition, assessments are prone to subjectivity and mistakes [7]. The scientific community is very interested in finding ways to enhance the performance of such systems to aid patients and physiotherapists.

Musculoskeletal disorders primarily influence the two pieces of our entire body. One is chest area parts like the Shoulder, Neck, Wrist, Fingers, and Joints in the hand, and the other is lower body parts like the Hip, Leg, knee joints, Ankle, and foot. In keeping an eye on the hardships of human oversight and evaluation of proactive errands, we base on the innate issue of a human stance appraisal that recognizes the spots of human body key joint centers (shoulder, elbow, wrists, etc.) from a lone picture, a movement of images by a singular camera, or different pictures from various cameras [8]. The fundamental commitment of our work depends on foreseeing the activity treatment pose that the physiotherapist recommends for outer muscle problems and giving remarks in light of the entertainer's activities continuously. The forecast of activity present is done through 33 central issues of milestones in the human body. Feedback about rectifying the stance is constantly given through our framework.

Our contributions to this article are deliberated as follows:

- Predicting the upper limb exercise pose without any pre-trained model. Generation of exercise pose from real-time video feed with the help of MediaPipe pose estimation library and computer vision method.
- Generation of real-time feedback on the degree of angle required for the particular body part. This ensures that the users do the exercise correctly.

An overview of the paper's structure is provided below. In Section 2, we'll talk about the research that's been published on the subject of AI-powered exercise therapy systems. Section 3 will dive deeper into the proposed methodology, covering pre-processing, the pose estimate concept, angular determination from participants, and corrective feedback during exercise. The analytic results and discussion of various upper extremity rehabilitation exercises are presented in the fourth section, and our conclusion and suggestions for future research are shown in the final section.

2. Related Works

Computer vision methods show promising answers for human posture assessment with the help of Android handsets [9]. Nowadays there are many exercise recordings accessible on the web. Samsung Health2 gives a committed area called programs containing short exercise recordings for different activities. The objective is to help individuals play out these exercises autonomously all alone. A typical perception is that even individuals who visit exercise centers routinely find it hard to play out all means (body present arrangements) in an exercise precisely. Constantly doing an activity inaccurately may ultimately cause extreme long-haul wounds [10]. With the new upgraded strategies using Artificial Intelligence (AI), cutting-edge computer vision has empowered to quantify body joints in 2D using a single camera to assess the angle deflection in the human body parts. Upgraded computer vision methods empower the mechanized estimation of head and body presence. A solitary camera can be utilized to gauge head repositioning precision to determine whether individuals have neck problems [11].

Movement boundary estimation is fundamental for grasping creature conduct, investigating the laws of item movement, and concentrating on control techniques. These days, high-level computer vision because of AI innovation upholds markerless articles following 2D recordings [12]. AI is a well-known approach and it decides the position and direction of the human body. This approach produces central issues on the human body and in light of that, it makes a virtual skeleton in a 2D aspect. The information is the live video which is taken from an individual's webcam and the result is catching tourist spots or central issues on the human body. The AI Trainer determines the count and season of the settings the individual requires to perform. It additionally determines missteps and criticism if any [3]. Human pose assessment or location in computer vision/designs is the investigation of calculations, frameworks, and pre-prepared models that recuperate the posture of an explained body, which comprises joints and inflexible parts utilizing picture-based perceptions [13]. it's one of the longest-enduring pervasive issues in PC vision the explanation being the intricacy of the models that relate perception with the posture, and since of the inconstancy of circumstances during which it'd be helpful [14]. Table 1 shows the existing methodologies, inferences, parameters measured, and research findings.

This framework is very simple and easy to use. The feedback for the exercises is given to the users in real-time. They can correct the pose instantly and perform the exercise perfectly. This model can be utilized in exercise centers as they have enrollment plans which the clients at that point pay. therefore, the model can be given to the participating clients.

The model gives live visuals during the whole exercise which prompts an autonomous excursion accordingly diminishing general cost. In this work, we focus on the solutions for the following important challenges in AI-based exercise pose analysis of existing systems.

- The process of gathering and annotating a lot of data is necessary to train and test AI models, but it may be time-consuming and expensive [8].
- People move in various ways, and there can be a lot of variation in how an exercise is carried out. Because of this, creating models that can precisely analyze a variety of exercises is challenging [1].
- Exercise real-time analysis might be difficult since it calls for high-performance computers and low-latency processing [9].
- Deep learning models are ineffective in real-time situations and might not be appropriate for use cases requiring low-latency processing [15].
- Deep learning models require much computing, so they might be prohibitively expensive for some applications and require high-end hardware and substantial computational resources [10].

3. Methodology

Upper extremity exercise poses datasets were collected from more than 200 samples from the 12 various healthy subjects. We gathered the exercise pose images from the humans concentrating on the Wrist,

Table 1
Existing methodologies, inferences, parameters measured, and research findings.

Reference	Inferences	Methodology	Parameters Measured	Results Achieved	Findings
[1]	3D Automated Joint Assessment (3D AJA) and Kinect Software Development Kit (SDK) performance are compared in this literature	Random Forest (RF) with Open-source Computer vision algorithm	Shoulder Flexion, Shoulder abduction, and elbow flexion upper limb exercise poses	Achieved F1-score of 0.759 and G-mean score of 0.811	The investigation in this literature of human body positions is only shoulder and arms. Further development is needed for other body parts.
[3]	OpenCV-based AI trainer model for bicep curl fitness exercise	cv2, Media pipe, numpy, and OpenCV is a cross-platform module which used in this work	Bicep curl counting for fitness exercise.	The prediction accuracy of this framework is 91%	These exercise poses for fitness applications only not applicable for rehabilitation training.
[8]	Performance comparisons of CNN, CNN-LSTM, and CNN GRU have been done in this work	Hybrid Deep Learning used to train the model	Shoulder abduction, adduction, internal rotation, Elbow flexion, and extension exercise poses	CNN GRU achieved 100% accuracy in classifying the exercise pose	Classification of exercise pose is only done in this work; No feedback in any term about the correctness of exercise pose is done.
[9]	Two modules are the main parts of this system. They are, Pre-processing and Native part systems to find the correctness of exercise pose.	PoseNet Model to predict the classification result.	Yoga pose Datasets	Android App with GUI to show the prediction result	Android App captures the exercise pose image and provides comments like "Correct" or "Wrong". This system fails to provide progress tracking and comment.
[10]	Overlay user pose on trainer pose to assess the quality of exercise pose correctness	CNN with affine transformation in pose estimation	COCO Human pose estimation Dataset used	Prediction of the wrong pose through the overlay of the standard pose with a timing duration of 10 seconds	This system can perform the correctness of exercise pose visualization through an overlay process in a limited duration of 10 seconds only.
[11]	Kinect and Camera based pose estimation through openpose	OpenPose technique to represent the human pose in 3D	User-generated poses observed by clinicians through IoT.	Provides an accuracy of 90% for predicting the pose without noise equivalent to a Kinect-based system.	No feedback is provided through this system in real time. The video should be monitored by the clinician and provide feedback.

Table 2
Summary of the pose, landmarks, Labels used, angle, and conditions

Name of the Pose	Landmarks Used	Labels Used	Angle Range	Condition
Right-hand Elbow Extension	12, 14, 16	Elbow Extension	$170°$˜$190°$	Between the angle range
Flexion of Wrist	14, 16, 18	Wrist Flexion	$140°$	Less than angle range
Extension of Wrist	14, 16, 18	Wrist Extension	$210°$	Greater than angle range
Flexion of Neck	0, 11, 7	NF	$280°$	Greater than angle range
Extension of Neck	0, 11, 7	NE	$230°$	Less than angle range
Right-hand Elbow Flexion	12, 14, 16	Elbow Flexion	$25°$˜$45°$ (or) $315°$˜$335°$	Two angles used to measure between the angle ranges

Neck, and Elbow joints. This section describes the methodology of our proposed system. Figure 2 shows the process flow of our system to estimate the pose for the various upper extremity body exercises.

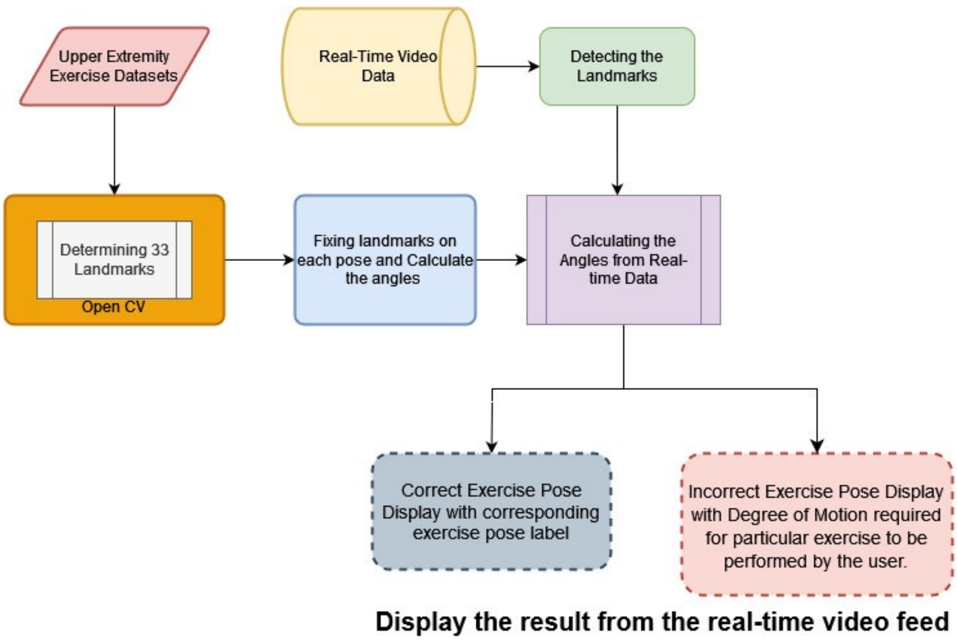


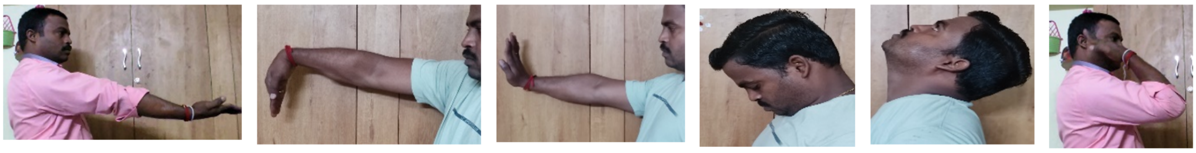
Figure 2: The process flow to Estimate the pose.

No standard procedure is followed to collect the datasets from the subjects with their own interest. Figure 3 shows the sample datasets collected from the subjects.

In the following subsections, we deliberated the various operations involved in the process of pre-processing, pose estimation concept, **and** determination of angles from the subjects and provided feedback.

3.1. Data Pre-processing

In our work, we use the spyder (python 3.9) IDE to assess the pose. Firstly, data are called inside the process of operation with the help of the "cv2" module. Here, the "media pipe" module is used to find the landmarks in the human body. The input datasets are in the form of BGR (Blue, Green, Red), which needs to be converted into RGB using the "cv2.cvtColor" function for assessing the pose in real-time. The pixel size is fixed as 1280x720 using the function called "cv2.resize" to assess the pose angles clearly in the datasets.



(a) (b) (c) (d) (e) (f)

Figure 3: From left to right: (a) Right-hand Elbow Extension; (b) Flexion of Wrist; (c) Extension of Wrist; (d) Flexion of Neck; (e) Extension of Neck; (f) Right-hand Elbow Flexion.

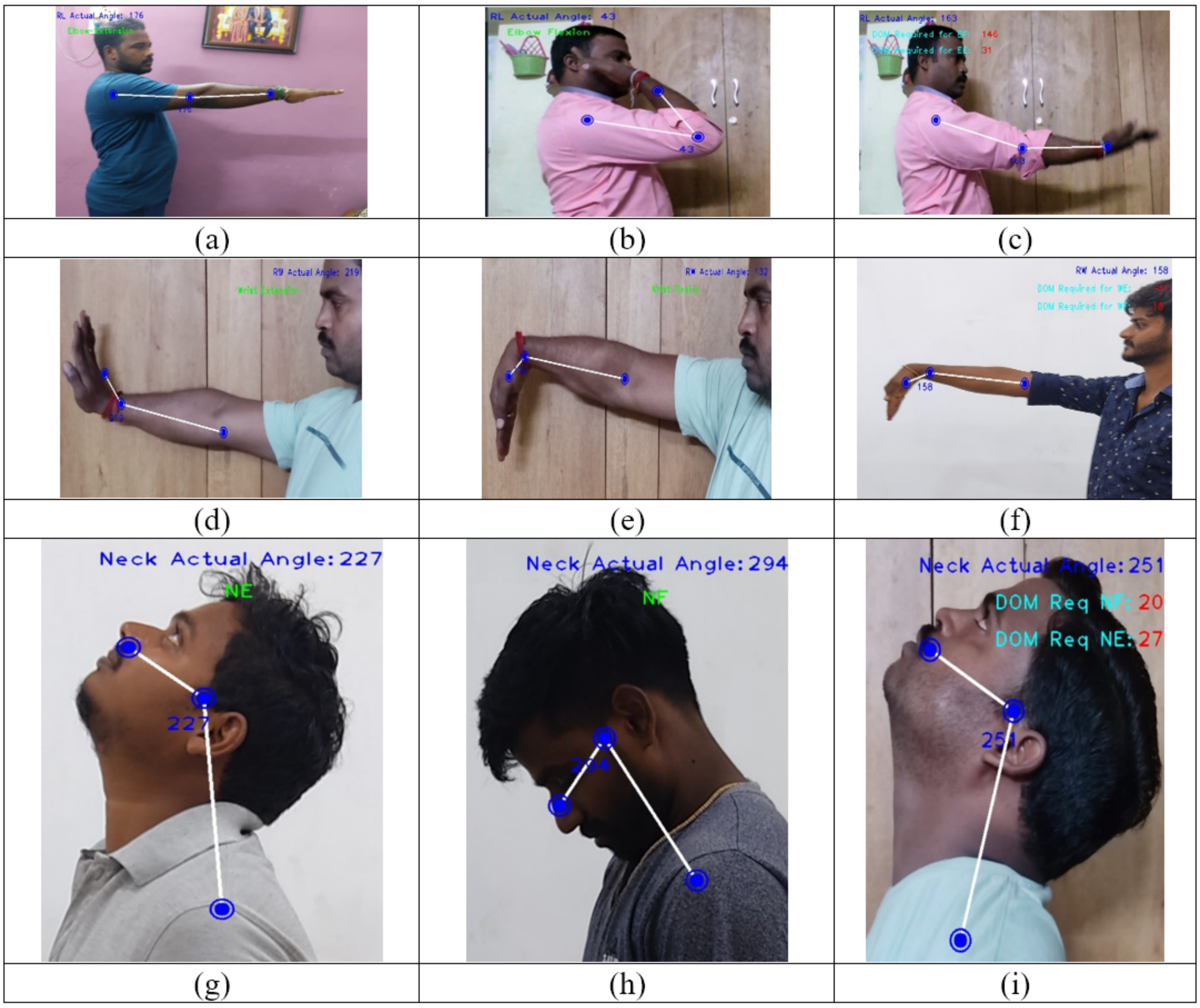


Figure 4: Sample outputs: (a) Correct Pose of Elbow Extension and its Angle; (b) Correct Pose of Elbow Flexion and its Angle; (c) Incorrect Pose of Elbow Extension or Flexion its Angle; (d) Correct Pose of Wrist Extension and its Angle; (e) Correct Pose of Wrist Flexion and its Angle; (f) Incorrect Pose of Wrist Extension or Flexion of its Angle; (g) Correct Pose of Neck Extension and its Angle; (h)Correct Pose of Neck Flexion and its Angle; (i) Incorrect Pose of Neck Extension or Flexion its Angle.

3.2. Pose Module

The pose module is the process that helps to detect the pose by using the 33 landmarks mentioned in Fig. 1. Here, we define the class called "poseDetector" to find Pose, Position, and Angle. This class is derived with the initialization of static image mode, model complexity, smooth landmarks, enable segmentation, detection confidence, and tracking confidence from the pose module to detect the pose accurately. Finding the pose can be done by fixing the landmarks in the dataset and connecting the landmarks with the attribute "POSE_CONNECTIONS". The position of the landmarks is determined by using the "list" variable in the form of an array. In real-time, the position of the landmarks is found by using the "list".

3.3. Angle Determination

To find the angle for the pose we used the 3 points namely, p_1, p_2, and p_3 from the “list” of the particular landmark for the particular pose. The angle measurement of these three points is calculated by using the following eq. 1 in the Python programming language.

$$\begin{aligned} angle = math.degrees(math.atan2\,(y_3 - y_2, x_3 - x_2) \\ - (-math.atan2\,(y_1 - y_2, x_1 - x_2))) \end{aligned} \tag{1}$$

where, x_1, x_2, x_3, y_1, y_2, y_3 are the body joints points for different exercise poses.

3.4. Real-time Pose Assessment

Finally, the pose assessment in real-time can be achieved through the comparison of angles from the pose detector class displaying the type of exercise and providing the degree of motion required to perform the particular exercise properly in the heuristic method. We fixing the angle variation based on the reference gathered from the system execution. Reference angle values are taken by performing the execution on the dataset and measuring the angle through the display.

4. Results

This work utilizes the body landmarks with the help of the “media pipe” module which is shown in Fig. 1. The analysis of the pose can be achieved by finding the angle by using eq. 1. The following is Table 2. Shows the Poses and Parameters used to analyze the exercise pose in real-time.

Figure 4 shows the sample execution of our system’s output with its corresponding exercise pose label, if the exercise is performed by the user correctly.

5. Conclusion and Future Work

The main focus of this work is to provide real-time visual feedback on the correctness of exercise poses performed by the participants for the various upper limb exercise poses. The variation of angle deflection of body parts is also displayed for the clarification of angle deviation still to be done by the user. This system doesn’t require a specialized capture device like a Microsoft Kinect sensor, or RGB depth camera to analyze the correctness of exercise pose. Capturing of human action is done with the webcam on the desktop or laptop. Even though, it provides good results and guidance there are still some limitations to consider for future work.

1. Accuracy of the system needs to be analyzed to improve the quality exercise pose classification outcome of the system.
2. We plan an in-home lower body reclamation system that licenses patients to finish recuperation without assistance from any other person at home through Android mobile.
3. Occlusion of body parts during the real-time analysis is still a big challenge in the system.
4. Analysis of musculoskeletal patients’ exercise pose based on the American Academy of Orthopaedic Surgeons (AAOS) standard based on goniometer angle measurement for the prescribed exercises by the physiotherapist.

The proposed system is very simple to use and provides good results to the performer. This framework provides precise results in the output to analyze the complex exercise pose concentrating on musculoskeletal disorder patients. Utilizing this system will provide good guidance to know about the user’s exercise pose.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

References

[1] P. B. Rodrigues, Y. Xiao, Y. E. Fukumura, M. Awada, A. Aryal, B. Becerik-Gerber, G. Lucas, S. C. Roll, Ergonomic assessment of office worker postures using 3d automated joint angle assessment, Advanced Engineering Informatics 52 (2022) 101596.

[2] P. Vinothini, I. Halim, R. R. Umar, Y. Too, I. Halim, A future framework for musculoskeletal disorders symptoms among computer office workers, International Journal of Physiotherapy 5 (2018).

[3] G. Samhitha, D. S. Rao, C. Rupa, Y. Ekshitha, R. Jaswanthi, Vyayam: Artificial intelligence based bicep curl workout tacking system, in: 2021 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES), IEEE, 2021, pp. 1–5.

[4] V. C. Chan, G. B. Ross, A. L. Clouthier, S. L. Fischer, R. B. Graham, The role of machine learning in the primary prevention of work-related musculoskeletal disorders: A scoping review, Applied Ergonomics 98 (2022) 103574.

[5] D. Ekambaram, V. Ponnusamy, S. T. Natarajan, M. F. S. F. Khan, Artificial intelligence (ai) powered precise classification of recuperation exercises for musculoskeletal disorders, Traitement du Signal 40 (2023) 767.

[6] S. Sardari, S. Sharifzadeh, A. Daneshkhah, B. Nakisa, S. W. Loke, V. Palade, M. J. Duncan, Artificial intelligence for skeleton-based physical rehabilitation action evaluation: A systematic review, Computers in Biology and Medicine 158 (2023) 106835.

[7] S. Rahman, S. Sarker, A. N. Haque, M. M. Uttsha, M. F. Islam, S. Deb, Ai-driven stroke rehabilitation systems and assessment: A systematic review, IEEE Transactions on Neural Systems and Rehabilitation Engineering 31 (2022) 192–207.

[8] V. Bijalwan, V. B. Semwal, G. Singh, T. K. Mandal, Hdl-psr: Modelling spatio-temporal features using hybrid deep learning approach for post-stroke rehabilitation, Neural processing letters 55 (2023) 279–298.

[9] G. G. Chiddarwar, A. Ranjane, M. Chindhe, R. Deodhar, P. Gangamwar, Ai-based yoga pose estimation for android application, Int J Inn Scien Res Tech 5 (2020) 1070–1073.

[10] A. Nagarkoti, R. Teotia, A. K. Mahale, P. K. Das, Realtime indoor workout analysis using machine learning & computer vision, in: 2019 41st Annual international conference of the IEEE engineering in medicine and biology society (EMBC), IEEE, 2019, pp. 1440–1443.

[11] O. D. A. Prima, T. Imabuchi, Y. Ono, Y. Murata, H. Ito, Y. Nishimura, Single camera 3d human pose estimation for tele-rehabilitation, Proceedings of the eTELEMED 2 (2019).

[12] X. Wu, Y. Wang, L. Chen, L. Zhang, L. Wang, Motion parameters measurement of user-defined key points using 3d pose estimation, Engineering Applications of Artificial Intelligence 110 (2022) 104667.

[13] G. Dsouza, D. Maurya, A. Patel, Smart gym trainer using human pose estimation, in: 2020 IEEE International conference for innovation in technology (INOCON), IEEE, 2020, pp. 1–4.

[14] B. Debnath, M. O'brien, M. Yamaguchi, A. Behera, A review of computer vision-based approaches for physical rehabilitation and assessment, Multimedia Systems 28 (2022) 209–239.

[15] L. Alzubaidi, J. Zhang, A. J. Humaidi, A. Al-Dujaili, Y. Duan, O. Al-Shamma, J. Santamaría, M. A. Fadhel, M. Al-Amidie, L. Farhan, Review of deep learning: concepts, cnn architectures, challenges, applications, future directions, Journal of big Data 8 (2021) 1–74.