

Kinetic Master: An AI-Powered Rehabilitation Monitoring System

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Abstract: Patients are expected to perform the necessary rehabilitation exercises with precision and reliability following any injury, surgery, or case of a neurological condition if they are to produce the best possible results in their physiotherapy. Traditional physiotherapy faces three challenges: lack of professional supervision at every point in time, abuse of the exercises done in the home setting, and lack of consistency in checking progress. To solve these problems, the recommendation presented in the article was that there should be a "Kinetic Master," which is an artificial intelligence system for the monitoring of patient rehabilitation. It provides only automatic and immediate instructions for the training of the patients. In the proposed system for the patients, the patients are given immediate feedback for the exercises carried out by them to ensure that the patients are in the right position throughout the exercises. The prediction function associated with the use of predictive analytics also creates space for another use, where the use of the same technique could be applied for the improvement of patient monitoring for the planning of therapies carried out by the patients. For instance, the proposed system for the patients could be more accurate and efficient for the monitoring of the patients to ensure the promotion of the care associated with the scalable system for the promotion of healthcare.

Keywords: Rehabilitation Monitoring, Computer Vision, Machine Learning, Remote Patient Monitoring.

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I. INTRODUCTION

An important feature involved in the rehabilitation of patients affected by injuries, surgeries, or neurological conditions related to locomotion is the execution of exercises during recovery [1]. However, the traditional rehabilitation method presents drawbacks in the form of the scarcity of medical professionals, geographical restrictions, and a lack of supervision during the in-home rehabilitation processes of patients, thereby leading to inappropriate performance of exercises by patients and poor rehabilitation results [2].

However, the development of artificial intelligence (AI), computer vision, and machine learning has introduced new possibilities for the solutions of these challenges through artificial rehabilitation monitoring systems based on artificial intelligence feedback systems [3]. The pose estimation method in real time using OpenPose and MediaPipe Pose can be used for estimating the poses of human movement using ordinary cameras without requiring any hardware setup [4]. The systems can thus allow the constant assessment of

exercise execution with immediate feedback for correcting the exercise being done [5]. thus, quality rehabilitation systems can be facilitated in the home environment.

Recent work has shown the use of applications of deep learning algorithms for rehabilitation exercise analysis and skeleton-based action recognition [6]. Graph convolutional networks and spatiotemporal networks have shown excellent recognition performance for exercises involving complex patterns, such as distinguishing between incorrect and correct exercises [7]. Recent research work in the medical domain has confirmed that patient engagement with an AI-supported rehabilitation system is more efficient when compared to an unsupervised home rehabilitation program for patient recovery [8].

However, despite the above, some rehabilitation systems have failed to integrate the ideas of analysis and feedback into an offline and remote supervising system [9]. Some of the upcoming systems have already started leveraging concepts like offline analysis and wearables with a

motive to optimize costs and usability factors of such systems with patients [10]. Additionally, the application of upcoming systems based on a digital platform will also require a better infrastructure in terms of data and feedback analysis concepts [11].

To tackle these challenges, in this paper, we propose a digital rehabilitation system based on AI called Kinetic Master. The system is developed with capabilities for real-time pose estimation and analysis of machine learning-based patient exercises by interacting with a web-based and mobile-based platform that is enabled by cloud support. The system utilizes light pose estimation algorithms such as MediaPipe for kinematic point estimation from video sources, and patient exercises for rehabilitation standards based on machine learning algorithms [12].

This enables appropriate and professional supervision of the system from a remote control center where session statistics are replayed in detail and exercise programs are updated based on predicaments drawn from historical performance statistics also done through predictive analysis techniques [13]. This guarantees that the patient is under professional supervision though not physically and opens wider perspectives to rehabilitation.

The role of patient engagement and motivation in achieving positive outcomes in rehabilitation is acknowledged [14]. The combination of the feedback system and the graph analysis hardware components is synergistic in improving patient compliance and outcomes [15]. In the Kinetic Master, the patient-friendly interface offers real-time accuracy, progressive levels, and overall graph analysis to enhance patient motivation and engagement.

Given the rate at which the development of both AI and pose estimation algorithms is moving, it is essential that the rehabilitation platform be flexible and future-proof [16]. Kinetic Master employs a modular design with an extensible backend API, such that new models and algorithms are easily exportable and ready for direct integration once invented or developed. Equally important is data privacy and security with encrypted storage, safe authentication procedures, and access control mechanisms with roles at Kinetic Master [17].

Kinetic Master provides an integrative platform for all digital forms of rehabilitation by leveraging intelligent automation, correcting real-time guidance, predictive analysis, and cloud scalability. The platform enhances accuracy, accessibility, and consistency of rehabilitation processes, particularly for distant and impoverished patients, so an enabling platform for home-based rehabilitation becomes possible.

II. LITERATURE REVIEW

Z. Cao et al. (2021), the Open Pose system uses part affinity fields to develop a 2D real-time multi-person pose estimator system. This system enables the detection of key points in human bodies based on RGB data. The system operates accurately and can track body motions.

Nevertheless, the system demands considerable computational power, thus challenging its performance when it comes to occlusion in crowded settings.

S. Z. Li et al. (2022), the monitoring system for physical therapy that uses pose detection and machine learning techniques can efficiently monitor and evaluate the correctness of the patient's exercise movements. The efficiency is attained through the measurement of the angle between the joints and the patient's posture while exercising. While some successful experiences can be observed with the application of this technology, its accuracy is highly dependent on the training data set used.

P. Gupta et al. (2023), real-time feedback systems using artificial intelligence (AI) and IoT for rehabilitation purposes at home allow patients to exercise individually and receive immediate feedback about their errors. Such devices increase the accessibility of care, thus lowering the need to visit physiotherapists. Thanks to IoT, patients' actions can be continuously monitored. Nevertheless, the system needs stable Internet connection, which can pose a problem with data protection.

H. Wang et al. (2023), AI-supported physiotherapy systems can automatically analyze the movements of patients and help create individualized rehabilitation programs. In particular, the use of such technology increases the efficiency of physiotherapy sessions by improving patient posture and the quality of exercise performance. Yet, the absence of live monitoring in some cases may affect the efficacy of the application.

K. Wang et al. (2023), use of temporal attributes with the help of GCN proves to be highly effective in identifying actions from skeletal data because the interaction between joints is taken into account while training. Actions are identified in an accurate manner by the model. The model proves to be quite useful in making a distinction between correct and incorrect exercise actions. However, there is just one limitation of the model which is its high computational cost.

R. Hang et al. (2022), the implementation of spatial-temporal adaptive graph convolutional networks has been proven useful in identifying human actions by modeling human motions dynamically. Such a strategy can make human action recognition systems stronger in difficult conditions. However, a significant amount of computing resources is required in implementing such an approach.

Y. Kim et al. (2024), it is possible to use reinforcement approaches that could allow tailoring the treatments according to the level of difficulty of the tasks assigned to patients. That is, the approach relies on analyzing patient behavior to tailor treatments for the best results possible. However, on the other hand, much data is needed to implement the method.

M. Haghi et al. (2017), the usage of wearable technology and healthcare technology through the IoT

enables constant tracking of the health indicators of the patient. These technologies provide information regarding the activities performed by the patient. Remote healthcare services can thus be improved. Nevertheless, such technologies need the use of additional technological devices which can be costly to purchase and uncomfortable for the patient.

Google (2021), MediaPipe Pose is a highly effective software that can identify up to 33 points on the body within a single RGB camera. It is lightweight, thus able to operate efficiently on mobile and web devices. As such, it would be quite effective in home-based therapy sessions. However, the efficacy of MediaPipe Pose could be negatively impacted by low light levels and improper camera placement.

S. Sicari et al. (2015), privacy and security have been considered to be critical factors within the context of the IoT-based health care system because the patient’s data is

transferred and stored digitally. The problem of data security has to be solved in order for the information to stay private and inaccessible for any unauthorized parties. Even though it is necessary to protect the data, it will make the system more complicated and costly.

Despite the many developments made in applying artificial intelligence to rehabilitation technology, there are certain challenges facing accessibility, feedback provision, and remote monitoring. The existing monitoring technology for rehabilitation does not allow for the continuous tracking of patients. Thus, there is a need to come up with an intelligent system for monitoring the rehabilitation process so as to allow for continued feedback, even when the patient is at home. This paper therefore presents a system known as Kinetic Master. The comparison table below defines the difference between most existing systems with the Kinetic Master, and also highlights how the existing system lack real-time feedback capabilities, and accessible solution.

Table 1 Comparative Analysis of Rehabilitation Systems

System Type	Technology Used	Limitation
Kinect-based Systems	Depth sensors (Kinect)	Expensive hardware required
CNN-based Models	Deep learning (CNN)	Limited real-time feedback
CNN-based Models	Skeleton-based learning	High computational cost
Kinetic Master	MediaPipe + LSTM + Webcam	Real-time, low-cost, scalable

III. METHODOLOGY

The Kinetic Master system currently being examined operates on a structured flow process, which includes patient identification, real-time exercise tracking, and clinical observation. This enables patients to perform their exercises using computer vision while enabling health professionals to monitor their progress:

➤ *User Authentication and Role Management*

The mode of authentication for Kinetic Master system is included within the system to facilitate smooth authentication process for patients and doctors who would wish to access the application. The patients or doctors can perform the authentication process through the standard login screen where they will have to key in their login information. On the other hand, those wishing to register will have to enter specific information such as names, email addresses, passwords, and many more. During registration, they will have to specify their status, whether they are patients or doctors.

➤ *Doctor Module*

The purpose of the doctor module is to facilitate the monitoring of rehabilitation activities of patients. Whenever a doctor logs into the system, a dashboard pops up enabling him/her to access information related to patients’ data, exercise reports, and achievements. The doctor will be in a position to analyze achievements and performance depending on accuracy and completeness of exercise sessions.

There is use of a connection-based communication technique whereby patients may request to connect with the doctors. The moment this request is accepted, the connection

between the two is established, making it possible for the doctor to access exercise reports made by that particular patient. Patients receive exercise assignments and the doctors make analyses from the exercises performed by the patients.

➤ *Patient Module*

In the patient module, the system provides an interactive platform where the user can exercise himself and track his performance. When the user logs into the system, he is taken to a dashboard from where he can access his profile, results, and exercise sessions. The system also allows patients to connect to their doctors, allowing the user to choose any one of the doctors available on the list and communicate his training details.

In the profile module, the system stores all the basic data related to the user that can be useful for rehabilitation purposes. However, the progress module enables the user to measure his performance based on various parameters such as the average score, number of repetitions, duration of the session, among others.

➤ *Exercise Session Workflow*

The primary function of the system involves executing live exercise classes. The users can initiate a live exercise class by simply pressing a button available on the dashboard. Once the user enters the live exercise class screen, the system asks them to activate their device camera to record live videos. It is important to note that the initiation of a live exercise class cannot be possible without activating the device camera.

Once the user activates their device camera, the system initiates a pose detection process that allows the patient to

select or switch exercises. Once the users select the desired exercises, the live exercise class begins and the system analyses their movements. During this stage, the user can view the exercise class statistics.

➤ *Pose Estimation & Feature Extraction*

The system applies real-time body pose estimations techniques that help detect body keypoints by processing video footage. The application of lightweight techniques in the process facilitates the extraction of skeleton keypoints, including the most significant human body joints. This way, it becomes possible to determine the angle at the joints and analyze motion patterns.

These capabilities make it possible to evaluate postures and actions performed by the person. The continuous monitoring of angles and their positions helps detect motion patterns and determine whether exercise execution was proper. As should be mentioned, there is no need for any specialized equipment for performing such actions.

➤ *Repetition Counting and Performance Evaluation*

Angle-based repetition count is used in the designed system. The angle count relies on pose landmark points, while the particular thresholds determine the end of each cycle. Each successful state transition of the action results in a single repetition count.

Apart from tracking the number of repetitions performed, the performance analysis of exercises performed in the system takes place. The performance of exercises depends on posture and movement evaluation, which involves calculating the performance score.

➤ *Real-Time Feedback Mechanism*

The feedback system has been incorporated into the system, which will aid users to do the exercises appropriately. Based on the analysis done on the postures and movements, the system will provide the feedback to the user in order to ensure that proper postures are kept during exercises.

This system will improve the motivation of the users to participate in exercises even if they are not under the guidance of instructors and physical therapists.

➤ *Data Storage & Remote Monitoring*

Exercise session data, which includes the number of times that exercise was repeated, the marks scored by the individual during the exercise, and the time spent on the exercise, is stored in the system database. The data shall be used in generating reports, in the analysis of patient performance over time. Doctors will be able to look at the performance of the patients from the dashboard. It has made remote monitoring possible for the doctors because they can monitor their patients' performance even remotely.

To provide further insight into how the proposed rehabilitation system is able to achieve these processes, Figure 1 illustrates the proposed functionality workflow of the Kinetic Master system. The above figure emphasizes how

all components in this proposed system function in a progressive manner, starting from motion capture processing standard camera input, to pose estimation, exercise assessment, real-time feedback processing, data storage, and predictive models. This proposed functionality ensures that there is continuous processing that turns patient activity into useful feedback at both a micro-and macro-process level.

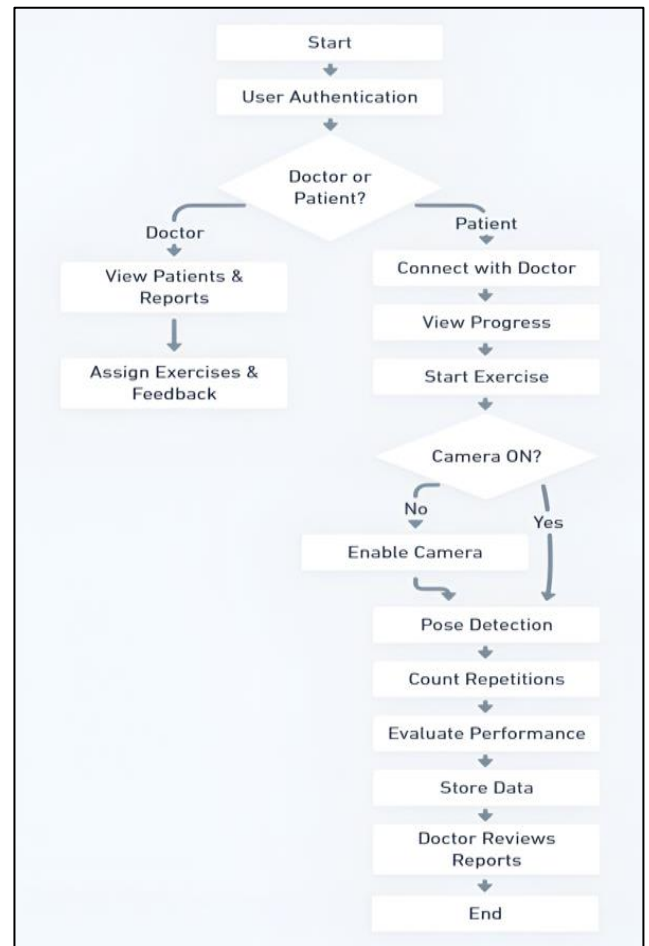


Fig 1 Workflow of Kinetic Master System

IV. EXPERIMENTAL EVALUATION

The effectiveness of the created Kinetic Master system was tested in the real-time mode using a regular webcam.

Depending on different physical therapy workouts, the rate of accuracy of pose estimation was set to be 80%, whereas the rate of workout recognition was 85-90%. On average, the performance speed of the program worked at 20-30 FPS, while the processing time for each image took 30-50 ms. Furthermore, the rate of latency of the program did not exceed 0.5 seconds.

As a result, one may claim that the suggested solution is quite fast and runs in real-time mode. In addition, lighting conditions as well as webcam location have minor effects on the effectiveness of the program.

Table 2 Summarizes the System Performance

Metric	Result
Pose Estimation Accuracy	~80%
Exercise Recognition Accuracy	85-90%
Frame Rate	20-30 FPS
Processing Time per Frame	30-50 ms
Recognition Delay	< 0.5 sec

The results demonstrate that the proposed system achieves a balance between accuracy and computational efficiency, making it suitable for real-time, low-cost rehabilitation monitoring.

V. CONCLUSION

The Kinetic Master project represents a perfect case in point illustration of the manner in which an AI-supported rehabilitation system can significantly address the primary challenges of conventional rehabilitation procedures in an effective manner. Through the intensive use of computer vision technology supported by machine learning algorithms for analyzing human movement, the system provides an opportunity to monitor exercise performance in a constant manner and provide instant corrective suggestions so that the patients can undertake rehabilitation exercises with perfect efficacy in a completely safe manner.

Furthermore, the Kinetic Master assists patients in self-management as it offers a safe cloud environment where patients' progress can be closely followed by medical personnel remotely, as well as allowing them to alter the exercise programs implemented for patients. This is mainly because, on a deeper contemplation and analysis of the data generated, along with a contemplation of the trends which would be seen in the days to come about how the patients who need care would be taken care of, it would become possible for a team of medical staff to work out a program of rehabilitation which would be suitable even for the patients while having to constantly observe them personally. Even the latest developments regarding being able to provide better facilities of rehabilitation with the aid of algorithms involving AI.

This system would, therefore, be scalable if there were a good model in pose estimation and if it utilizes a system of machine learning, and thus it would be possible to make it adaptable and user-friendly; therefore, it would not only be a sustainable system but useful to ensure its incorporation in modern pose estimation and artificial intelligence system designs. Lastly, data security and confidentiality are well addressed by its health information standard compliant status.

Initial assessments have been formulated in such a way that they will be used to ascertain the potential of Kinetic Master in efficient pose estimation along with effective use in rehabilitation exercise planning. Secondly, this tool aids in the identification of improvement areas based on significant levels of robustness, depending on the numerous constraints faced in utilizing the device. It is evident that Kinetic Master has the potential to incorporate expertise in artificial intelligence combined with computer vision in enriching the

evolution of rehabilitation through efficient assistance in the exercise of rehabilitation, with necessary guidance through movements in digital monitoring.

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