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Smart Remote Physical Therapy: Deep Learning-Based Patient Monitoring

Thirumangai S
B.E. Computer Science Engineering
Kumaraguru College of Technology
Coimbatore, India
thirumangai.22cs@kct.ac.in

Thilagan P
B.E. Mechatronics Engineering
Kumaraguru College of Technology
Coimbatore, India
thilagan.22mc@kct.ac.in

Anitha N
Assistant Professor of Mathematics
School of Foundational Sciences
Kumaraguru College of Technology
Coimbatore, India
anitha.n23@gmail.com

Abstract **This study is centred on the development of a methodology for remote health surveillance of patients undergoing physical therapy, employing pose detection technology. The approach utilizes advanced deep learning algorithms to assess patients' body positions during physical exercises, offering instantaneous feedback to both patients and therapists. This method of remote monitoring coupled with personalized feedback aims to enhance patient outcomes, decrease healthcare expenditures, and bolster patient engagement. By integrating pose detection technology, the system ensures precise tracking of patients' advancements, facilitating tailored therapy interventions and optimizing treatment effectiveness.**

Keywords: ***Deep Learning, Remote Health Monitoring, Physical Therapy, Rehabilitation, Healthcare Analytics, Telemedicine, Human Movement Analysis, Computer Vision, Physiotherapy, Feature Extraction.***

I. Introduction

Remote patient monitoring (RPM) represents an innovative healthcare technology facilitating healthcare providers to remotely observe and gather patient data beyond conventional clinical environments Through real-time data transmission, RPM allows continuous monitoring and timely interventions, enhancing patient care and outcomes. The relevance of RPM has surged due to factors such as the COVID-19 pandemic, which necessitated reduced in-person interactions to mitigate infection risks, the aging global population, rising healthcare costs, and the demand for more efficient and accessible healthcare services.

In physical therapy, RPM plays a vital role in monitoring patients with musculoskeletal disorders, neurological conditions, and in elderly rehabilitation. By tracking a patient's progress, offering feedback and support, and adjusting treatment plans remotely, RPM promotes adherence to home exercise programs and provides continuous education and support.

In India, RPM's potential in physical therapy is particularly significant. The country faces a high patient-to-physiotherapist ratio, with about one physiotherapist for every 53,000 people, as illustrated in Fig. 1, which references data from the World Physiotherapy Annual Membership Census 2020 [11]. This is starkly below the World Health Organization's (WHO) recommendation of one physiotherapist per 10,000 people to meet basic health needs. This shortage results in delayed diagnoses, prolonged wait times, and limited access to care, especially in remote or underserved areas. RPM can help bridge this gap by enabling physiotherapists to manage and monitor patients remotely, irrespective of location, thereby reducing treatment costs and minimizing the need for frequent, costly in-person visits.

Fig. 1

Remote patient monitoring (RPM) can be seamlessly integrated throughout different phases of physical therapy, contingent upon the patient's condition and therapeutic regimen:

- Prior to commencing physical therapy, RPM serves to evaluate the patient's baseline functional status and administer initial rehabilitative interventions.
- Throughout the active phase of physical therapy, RPM facilitates ongoing monitoring of the patient's progression, provision of feedback, and adjustment of treatment protocols as warranted.
- In the post-treatment phase, RPM plays a pivotal role in promoting sustained adherence to home exercise programs, vigilantly monitoring for potential relapses or complications and delivering continuous support and educational resources.

In physical therapy, computer vision and deep learning are pivotal for analyzing video recordings of patients' movements. By tracking specific body parts and employing sophisticated algorithms, these technologies can objectively measure range of motion, posture, and movement patterns. This precise data enables physical therapists to effectively monitor patient progress.

In this project, computer vision and deep learning technologies are harnessed to scrutinize video recordings of patients' movements. By tracking specific body parts, the algorithms generate objective measurements of range of motion, posture, and movement patterns. This detailed analysis assists physical therapists in monitoring patient progress and assessing improvements throughout therapy sessions. The integration of these advanced technologies not only enhances the precision of patient assessments but also streamlines the process, allowing for more targeted and effective physical therapy interventions.

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II. LITERATURE SURVEY

[1] Ferre et. al., Efficient Multi-axial Shoulder-Motion Tracking Based on Flexible Resistive Sensors Applied to Exosuits

- Based on the concept of Flexible Resistive Sensors Applied to Exo-suits.
- This Paper explains a way to track shoulder movements using a compressive seamless shirt that acts as a shoulder suit and has plastic brackets to hold ten flexible resistive sensors.
- To track shoulder movements we need to focus on three action support, stabilisation and force application.
- In this Construction the sensor performance depends on the Material and thickness of the suit.

[2] Zimmerman, Sensors and Technologies in RPM

- Optical sensors utilize flexible optical fibers, light sources, and photodetectors to measure joint angles through light attenuation.
- Cameras and video processing analyze video footage to track body motion, considering joint positions and physical limitations.
- Flex sensors detect resistance changes during joint flexion, easily integrating into tight fabrics.
- Sensor fusion enhances tracking accuracy by combining data from various sensors for different types of human movements.

[3] Pereira Et al., Joint angle estimation

- This study provides us two methods to track joint angles using image processing.
- Method 1 – The first method is very straight forward, it just measures angle between two 3D vectors. They do not require any calibration. However, unsigned angles are determined at the end.
- Method 2 – In this method, They are calibrated and knowledge of an axis is provided to them which is normal to the plane of movement. This enables them
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to estimate signed angles. It is assumed that the axis is known for every exercise.

[4] Uccheddu et. al., Automating physiotherapy exercise under the control of physiotherapy doctor, to improve the performance of the paralysis affected patient

- Home-based recovery aims to reduce healthcare costs but carries risks of adverse outcomes due to patient motivation and lack of strict doctor supervision, especially for knee arthroplasty patients.
- Tools for measuring joint recovery are crucial for patient motivation and remote doctor monitoring, with real-time pose monitoring being a recognized method.
- A new hybrid method using 2D body pose estimation and depth information overcomes limitations of relying solely on 3D skeleton tracking, benefiting physiotherapy rehabilitation.

[5] Faisal et. al., Monitoring methods of Human body joints

- An efficient joint monitoring system should accurately monitor physiological parameters such as joint angles, range of motion and joint posture.
- Sensors are Important components in the human body joint monitoring system. There are different methods to monitor one of the methods is using optical-based goniometer.
- It behaves like an optical flex sensor so by measuring attenuation of light, bending angle is calculated.
- The accuracy of them can be further increased by using IMUs they are placed on shank. Their data was used to estimate 3D lower limb joint kinematic quantities.
- It uses least-squares identification algorithm during this process.

[6] Seron et. al., Remote physiotherapy by telecommunications

- Using this approach can enhance efficiency for patients and reduce the burden on physiotherapy clinics.
- It eliminates the need for physical assistance from a therapist when demonstrating exercises.
- This solution is beneficial for patients with transportation challenges and specifically caters to those with musculoskeletal conditions, respiratory illnesses, orthopedic rehabilitation needs, and long-term conditions involving physical activity programs.

[7] Liao et. al., Deep Learning Framework for Assessing Physical Rehabilitation Exercises

- Physical therapy and rehabilitation programs are crucial for post-surgical recovery and musculoskeletal conditions but offering clinician access for every session is impractical and expensive. This lack of supervision leads to low compliance rates.
- Despite the availability and development of various devices like robotic assistive systems, virtual reality interfaces, and assistants utilizing Kinect-based technology, there still is a need for systems to monitor and assess patient performance effectively.
- The intended objective of the proposed model is to joint displacements of various body parts in a

hierarchical manner to leverage human body movements.

- It consists of two components: one focuses on discerning physical exercises, while the other assesses the precision of execution.
- The model was tested on gait data of healthy individuals using different classification techniques, including CNN, SVM, KNN, and LSTM neural networks.

[8] Chapple, Remote Patient Monitoring using Artificial Intelligence: current state, applications and challenges.

- The Region of Interest (ROI) on patients is identified using image processing ML techniques.

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Then the selected ROI is focused to estimate vital signs.

- This method of Remote Patient Monitoring saves time by cutting down frequent clinic visits.
- Even Though Telehealth has increased the accessibility in rural areas On the other hand, over utilization and misuse of Telehealth can increase cost to healthcare providers.
- Another important risk factor to consider here is patient data security.
- Patient data security is another challenge in tele-health monitoring.

[9] Ahmed Z, Mohamed K, Zeeshan S, Dong X, Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine

- This study aims to advance academic progress in healthcare by exploring different approaches in artificial intelligence and machine learning.
- By analyzing extensive patient data and considering broader factors, it becomes possible to identify biological markers that indicate changes in health, distinguishing between healthy and unwell individuals.
- It is important to enhance the integration of clinical, laboratory, and public health systems while addressing ethical concerns about healthcare data privacy.
- Creating flexible machine learning platforms can assist healthcare professionals in categorizing patients and improving decision-making.healthcare practitioners in categorizing subjects and optimizing decision-making processes.

[10] Mohammed, K.I., Zaidan, A.A., Zaidan et al. Real-Time Remote-Health Monitoring Systems: a Review on Patients Prioritisation for Multiple-Chronic Diseases, Taxonomy Analysis, Concerns and Solution Procedure

- The objective of RHMS is to deliver prompt medical services to remote regions by leveraging advancements within the domains of wireless networking, cloud computing, and data storage.
- Effectively prioritizing patients with multiple chronic diseases (MCDs) in telemedicine is pivotal to ensure the sustainable provision of high-quality healthcare and further exploration is necessary to tackle the constraints related to this prioritization.
- This study offers a thorough evaluation of patient prioritization in telemedicine applications, shedding light on the associated challenges and unresolved matters.
- The findings underscore the shortcomings of existing prioritization approaches for patients with MCDs and advocate the development of a fresh, multi-dimensional decision-making framework to address the prevailing issues.

III. OBJECTIVES

The objective of this study is to develop a deep learning-based framework specifically for remote patient monitoring in physical therapy. Key objectives include:

- **Develop a robust deep learning model**: Build a computer vision system capable of capturing and analyzing patient movement patterns using real-time video feeds.
- **Implement pose detection**: Integrate MoveNet and other computer vision models for detecting specific body joints and postures.
- **Create a lightweight solution**: Ensure that the framework can run on mobile devices efficiently, allowing patients and therapists to access and use the platform without heavy computational requirements.
- **Provide real-time feedback**: Offer immediate, personalized guidance based on movement assessments, improving the quality of physical therapy by ensuring exercises are performed correctly.
- **Establish patient-therapist communication**: Facilitate continuous interaction between patients and therapists for exercise adjustments, feedback, and progress tracking.

These objectives focus on delivering a scalable, mobile-friendly platform that enhances patient adherence and exercise precision while reducing healthcare costs

IV. SOLUTION

By integrating deep learning algorithms, the proposed method for Remote Patient Monitoring (RPM) offers real-time data analysis, allowing healthcare providers to effectively monitor patient progress and make necessary adjustments to treatment plans. The key components of the solution include:

- Patients receive timely reminders to perform their exercises according to the prescribed schedule, ensuring
- they maintain consistency in their physical therapy routines.
- Patients can engage in live conversations with their physiotherapists, receiving immediate feedback and addressing any concerns or questions during their therapy sessions.
- Patients have the ability to access and review records of their previous exercise sessions. This feature helps them track their progress over time and stay motivated to achieve their therapy goals.
- The system employs deep learning algorithms and pose detection technology to accurately track and evaluate patients' movements. This allows for precise feedback to both patients and physiotherapists regarding the correctness of exercise execution.

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- Health assessment data is collected and standardized, enabling patients to view progress reports that illustrate their improvement over time.
- Based on the analysis results, patients receive real-time feedback to ensure they are performing exercises correctly. This feedback can be delivered visually through on-screen animations or audibly through spoken instructions.

V. METHODOLOGY

The proposed method includes a detailed sequence of steps (Fig 2) as outlined below.

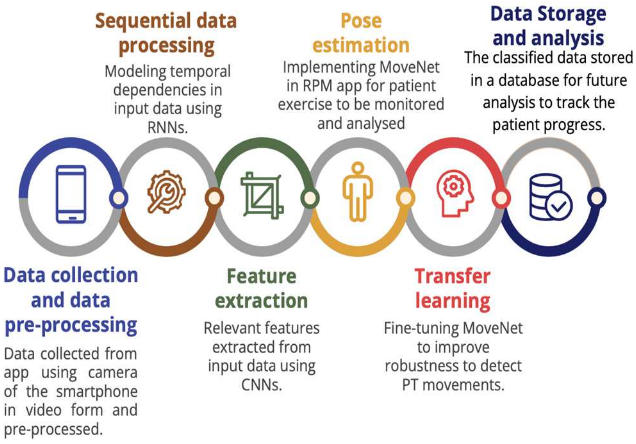

Fig. 2

A. Data Collection

The app collects data by recording videos of patients performing prescribed exercises using the camera on their smartphones as input. These videos are then uploaded to a server for pre-processing.

B. Data Pre-processing

The collected data is pre-processed to ensure consistency and accuracy. This step involves removing any noise or unwanted data from the videos and adjusting them to a standardized format for further analysis.

C. Pose Estimation using MoveNet

MoveNet is a computer vision architecture designed to perform real-time pose estimation, action recognition, and gesture detection from video feeds. Utilizing deep neural networks, MoveNet interprets video frames to extract detailed human pose and movement details. It identifies and maps out crucial body landmarks like the head, neck, shoulders, wrists, hips, knees, and ankles, visualizing these keypoints through a confidence map which visually represents the positions of each joint with a corresponding confidence level as depicted in Fig. 3.

The following is an outline of the technical aspects of implementing MoveNet for tracking and analysing patient movements: RPM App and Exercise Window: When the patient opens the RPM app and selects the exercise window, the smartphone's camera captures video footage of the patient performing exercises. This video is used as input data for the MoveNet model.

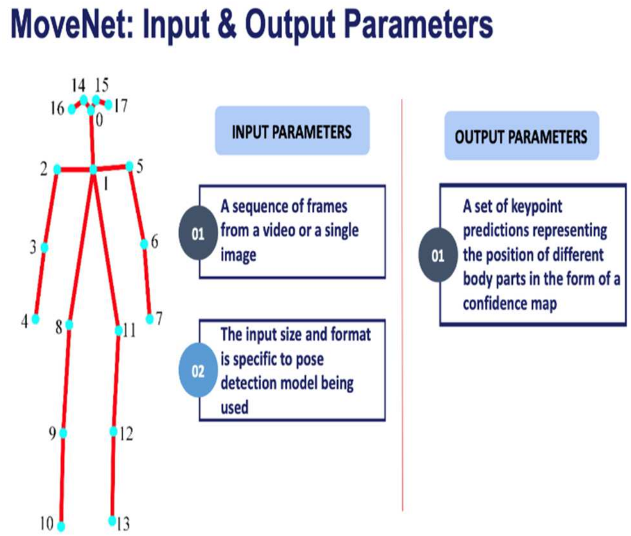

Fig. 3

1. MoveNet Implementation: MoveNet, using its CNN architecture, processes video frames in real-time to detect and track key body points. By analyzing spatial relationships between these keypoints, the model estimates the patient's body posture, joint angles, and movement patterns.
2. Pose Tracking and Analysis: The RPM app derives insightful health assessment data from the pose tracking information provided by MoveNet, such as exercise duration, range of motion, and pain scales.
3. Deriving Health Assessment data: Using the pose tracking information provided by MoveNet, the RPM app can be enabled to derive insightful health assessment data such as exercise duration, range of motion and pain scales.

MoveNet is optimized for lightweight, real-time performance on mobile and embedded devices. Its efficiency stems from:

- CNN-based architecture: MoveNet uses convolutional layers that are both accurate and computationally less demanding than some alternatives. CNNs are chosen for their effectiveness in image and video data analysis. They can detect spatial patterns, which makes them ideal for feature extraction from video frames, such as joint positions and body parts during physical therapy exercises.
- Low memory usage: The model architecture has been optimized to fit within the constraints of smartphones and small processors, without compromising accuracy

D. Sequential Movement Analysis with RNNs

Once the pose estimation is complete, the extracted body landmarks are processed over time using Recurrent Neural Networks (RNNs). While MoveNet handles the spatial aspect by identifying the position of joints in each frame, RNNs are used to handle the temporal dependencies between frames.

The role of RNNs here is to analyze how the body positions change sequentially across the video frames, which allows the model to evaluate the quality of the patient’s movements, consistency in performing exercises, and any deviations from the prescribed movement patterns. This sequence processing is crucial for understanding exercises like repetitions or sustained movements, where transitions between frames are just as important as the static positions.

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In physical therapy, movement patterns evolve over time, and RNNs are necessary to capture these dependencies and assess the quality of exercises by monitoring the progression of body positions across video frames. The two models complement each other, with CNNs focusing on extracting key features from individual frames and RNNs analyzing how those features change across time

E. Feature Extraction with CNN

In addition to pose estimation, CNNs are employed to detect and extract features like joint angles and movement patterns from individual video frames. These features provide detailed insights into the patient's range of motion and form during exercise, contributing to the overall evaluation of their progress.

F. Transfer Learning

Once features are extracted, machine learning techniques are used to classify the patient's movements. The algorithm is trained on a dataset of labeled examples of correct and incorrect movements, learning the patterns of correct movements and applying this knowledge to classify new data. Transfer learning techniques are implemented to fine-tune the pre-trained MoveNet model, enhancing its accuracy and robustness for physical therapy application

G. Data Storage and Analysis

All extracted data, including pose estimation, movement sequences, and patient feedback, is stored in a database for long-term tracking. This data is used to monitor the patient's progress over time, adjusting treatment plans as needed based on performance metrics such as range of motion, exercise duration, and pain levels.

H. Feedback Generation

Real-time feedback is generated, providing patients with corrective instructions as output. This feedback is based on the comparison between their movements and the ideal exercise form.

VI. Results and Findings

Various metrics are monitored to track patient advancement and gain valuable insights into their recovery journey, including exercise duration, range of motion, and pain intensity. These parameters are visualized through graphs to depict the patient's trajectory over time.

Fig. 4.a illustrates exercise duration as a time series graph, aiming to progressively increase the duration of each exercise session. This visualization aids in evaluating the patient's development in building strength and endurance, facilitating adjustments to their exercise regimen to ensure continued challenge and ongoing enhancement.

Fig.4.a

Fig. 4.b

Range of motion is represented in Fig. 4.b as a line graph, with the goal being to increase the patient's range of motion over time. This graph provides insight into the patient's progress in improving their flexibility and mobility to adjust their exercise program as needed to continue to target areas of weakness or limitation.

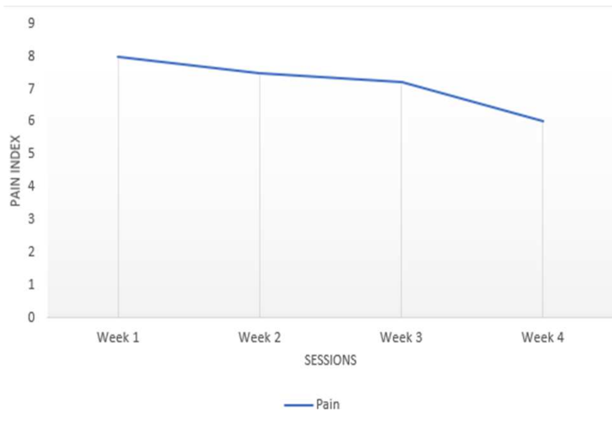

Fig. 4.c

Pain index is represented in Fig. 4.c as a line graph to provide insight into the patient's progress in managing their pain and improving their ability to perform everyday activities without discomfort or limitations.

VII. Discussions

A. *Proposed Solution- Identifying limitations along with mitigations*

- Privacy Concerns: The RPM app requires access to the patient's video footage, which raises privacy concerns. Patients may have reservations about their personal images and videos being stored or transmitted. Ensuring strict privacy protocols, encryption, and secure storage methods are crucial to protect patients' personal information.
- Data Security: The RPM app collects and stores sensitive health-related data, including exercise videos, movement analysis, and pain level assessments. To safeguard this data from unauthorized access, hacking, or data breaches, adequate measures must be in place. Implementing robust data encryption, secure servers, and strict access controls are vital for maintaining data security.
- Informed Consent and Transparency: Patients must provide informed consent before participating in RPM. They should be provided with comprehensive information regarding the nature of the collected data and its intended utilization and the security measures in place. Transparency about data handling practices and adherence to privacy regulations are essential to establish trust and ensure patient autonomy.
- Compliance with Regulations: The RPM app needs to comply with relevant data protection regulations, such as the General Data Protection Regulation (GDPR) or the Health Insurance Portability and Accountability Act (HIPAA), depending on the jurisdiction. Compliance helps protect patient rights and ensures ethical handling of sensitive health data.
- Secure Data Transmission: When transmitting data between the RPM app and servers or healthcare providers, secure communication channels, such as encryption protocols, should be implemented to prevent unauthorized interception or tampering of patient data during transit.
- User Education and Awareness: Patients should receive clear information and education regarding the privacy and security aspects of the RPM app. Providing guidance on maintaining strong passwords, identifying phishing attempts, and understanding the app's security features helps users actively participate in safeguarding their own data.
- Limited Detection of Specific Movements: The model may not accurately track certain movements, such as Forearm Pronation or Supination, and Wrist Abduction, which are crucial in some physical therapy exercises. These types of fine movements may fall outside the detection capability of the current pose estimation system.
- Occlusion Issues: The model may struggle to detect and track body parts when they are occluded or blocked from view by other body parts (e.g., when a hand is placed behind the body). This can result in inaccurate pose estimation or incomplete movement tracking, which could affect feedback quality during therapy sessions.

B. *Comparison with existing frameworks*

- Sensor-based Solutions: Although wearable sensors provide high accuracy, they can be intrusive and uncomfortable. MoveNet's contactless method ensures that patients can perform exercises without physical encumbrance while still receiving accurate feedback.
- Kinect-based Solutions: These require external hardware, limiting patient accessibility. In contrast, the proposed system uses a smartphone's built-in camera, making it far more accessible.

C. *Market for proposed solution*

1) *Hospitals and Physical therapy clinics*

The proposed model enables remote monitoring for discharged patients who require physical therapy. It allows hospital staff to remotely track patients' progress, create exercise plans, and monitor adherence. The model also facilitates virtual consultations for patients who cannot easily visit the clinic. This approach addresses challenges faced by hospitals, including limited access to therapy outside the hospital, adjusting treatment plans in real-time, and patients' difficulties in adhering to plans due to motivation or exercise performance issues.

Implementing the following plan for training therapists and patients will ensure that it is widely adopted and used in clinical practice.

1. Training Objectives: Stating the training objectives for therapists and patients such as understanding how to use the monitoring system, performing exercises correctly, and tracking progress.
2. Training Materials: Developing training materials, such as user manuals, video tutorials, and interactive software, that are accessible and easy to understand.
3. Monitoring and Evaluation: Monitoring and evaluating the effectiveness of the training program by collecting feedback from therapists and patients,
4. tracking progress, and making adjustments as needed.

2) *Individual Patients:*

Individual patients can use this proposed model to monitor their own progress and track their exercise plans. It will provide guidance and feedback on proper exercise technique and track progress over time. Patients can also use the app to schedule virtual consultations with their physical therapist. The goal is to provide patients with a clear understanding of how the system can help them manage their conditions and improve their overall health outcomes and addressing their concerns by providing information on the success rates of similar systems and the security measures in place.

VIII. Conclusion

The deep learning-based approach to remote health monitoring in physical therapy has shown promising results in the accurate and timely assessment of patient progress. The potential of this project can be further expanded by exploring the integration of deep learning analytics with wearable devices and gamification techniques. The use of wearable sensors can provide more accurate and real-time data on patient movements, which can be used to develop more personalized and effective treatment plans. Gamification techniques can further enhance patient engagement and motivation, leading to better adherence to the treatment plan. Overall, this project has highlighted the potential of deep learning-based approaches in the field of physical therapy and the potential for further research and development in this area.

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