AI and RIoT for Rehabilitation: Advancing Hand Gesture Recognition and Voice Assistance

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Abstract. After a heart attack or a stroke, the patient needs rehabilitation; nevertheless, obviously, conventional approaches are costly, time-consuming, and need a highly qualified staff, which excludes the majority of patients. As part of the proposed solution, this research incorporates Rehabilitation Internet-of-Things (RIoT) that uses Mediapipe for hand gesture detection and voice to guide the exercises. The culmination of the system is to offer availability of computer vision coupled with speech recognition to evaluate the performance during the exercise and to report the extent of rehabilitation within the shortest time. In particular, these movements include flexion, extension of fingers, pinch using the thumb index finger, and opening/closing of the hand and full hand movement that helps in determining the degree of motion for performing movements during the rehabilitation exercises. The RIoT system acts as a voice-activated, on-the-body graphical display that helps the partly mobile users as they obtain real-time feedback from their hand gestures. The sensitivity of the deep learning-based gesture recognition and the speech synthesized is then tested and practiced on recovering patients before testing on the system platform. Thus, the system, in the framework of utilizing assistive automation for rehabilitation, releases the necessity to use human observers while still keeping the overall control by doctors or other healthcare managers. and enables the access to the high-quality rehabilitation therapy for patients, contributes to the decreased healthcare expenditures, and improve the outcomes of the overall patient rehabilitation.

Keywords: Stroke Rehabilitation · Rehabilitation Internet-of-Things (RIoT) · Voice AI · 4D Skeletal-Based Gesture Recognition · Machine Learning

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1 Introduction

The global health issue of stroke leads to continuous motor disabilities which demand extensive rehabilitation programs [1]. Limited therapy access exists mostly because of financial restrictions and inadequate numbers of specialized medical professionals, especially in remote locations [2]. Older adult stroke survivors and their caregivers face challenges in accessing rehabilitation and long-term care, including difficulties in accessing medical services, daily life challenges, and lack of awareness of available community services [3]. Machines along with computer systems exhibit artificial intelligence (AI) when they carry out tasks that demand human-level intellectual abilities like learning from experience and problem-solving and decision-making [4]. The application of intelligent systems together with algorithms in rehabilitation enables patient therapeutic processes to recover through assisted monitoring and process optimization [5]. Academic research about RIoT platforms was initially documented in [6] and expanded in [7, 8]. The studies established fundamental knowledge about RIoT development and its practical implementations. This research creates a fresh rehabilitation system that unites Rehabilitation Internet-of-Things (RIoT) technology with Voice AI and 4D Skeletal-Based Gesture Recognition to advance recovery results after stroke. The RIoT system achieves movement data collection through wearable sensors that report ongoing information to enable healthcare providers for patient-specific treatment plan adjustments. Through voice AI automation patients become more independent to use rehabilitation tools without needing caregivers to operate on them. The 4D Skeletal-Based Gesture Recognition system improves both exercise precision and effectiveness for patients to execute movements properly. This system generated through the combination of RIoT with Voice AI and gesture recognition technology enables rehabilitation treatment that is both accessible and demonstrates enhanced efficiency and patient engagement. Machine learning optimizes patient recovery through its delivery of real-time therapy feedback to achieve enhanced treatment results. Section I establishes the value of RIoT as it applies to medical information systems. Research background information and applicable studies appear in Section II of this piece. The study implements its materials and methods description within Section III. This study shows the analysis next followed by results in Section IV that leads to a discussion of findings in Section V. The paper concludes with Section VI by delivering a summary of the major findings from this research work.

2 Literature Review

These new innovations have made rehabilitation procedures more efficient over the recent past as per the integration of hand gesture recognition and voice control. These innovations are designed to deliver effectual, patient-specific, engaging, and time-effective treatment for people with motor disabilities.

2.1 AI-Driven Hand Gesture Recognition in Rehabilitation

Hand gesture recognition has emerged as a pivotal component in developing intuitive human-computer interfaces for rehabilitation. A deep learning-based system has been introduced to facilitate real-time control of applications through hand gestures, benefiting individuals with physical disabilities [9]. Similarly, a real-time gesture recognition tool employing virtual glove markers has been developed to enhance natural user interaction in rehabilitation contexts [10]. Furthermore, a study presented a hand gesture-based artificial neural network-trained hybrid human-machine interface system designed to navigate powered wheelchairs, demonstrating significant potential in assisting individuals with neuromuscular disabilities [11]. Another approach proposed is an electromyography (EMG)-based hand gesture recognition system that utilizes diverse domain feature enhancement and machine learning approaches, achieving high accuracy in gesture classification [12]. Additionally, an agile gesture recognition system for capacitive sensing devices has been introduced, emphasizing on-the-job adaptability, which is crucial for personalized rehabilitation applications [13]. The MediaPipe framework and Artificial Neural Networks effectively recognize hand gestures with 99.34% accuracy, improving communication for individuals using American Sign Language and benefiting those who are deaf or mute [14]. Hand gesture recognition using MediaPipe in user guide applications improves convenience and interactivity, making manual applications more engaging [15].

2.2 Voice-Assisted Rehabilitation Technologies

These technologies have also provided significant support for rehabilitation, particularly in speech-related aspects of voice assistance systems. In a more specific field, an adaptive interactive social robot has been introduced to assist in post-stroke rehabilitation by supervising exercise completion and offering real-time correction and encouragement [16]. Voice cloning technologies for speech disorder patients have been developed possible through AI assistance. The application of AI-based technology allows patients with ALS to produce synthetic versions of their voice so they can communicate their preferences [16]. Technology aids people with ALS to preserve their speech capabilities and professional participation by employing AI-based applications. Genetic speech synthesis systems together with voice cloning tools serve as technologies that help people with speech problems generate authentic vocal simulation with full personalization features [17]. The system combines real-time vocal responses with hand recognition technology to enable caregivers to assist paralyzed hand patients with their care routine as part of improving self-care abilities and life quality [18]. A conversational agent helps stroke patients with rehabilitation through interactive digital tools for unsupervised therapy while promoting their participation in therapy [19]. The implementation of a voice-based AI chatbot system enables physical activity promotion for elderly individuals to establish better lifestyle habits [20].

2.3 Integration of AI in Rehabilitation Robotics

The system ties together real-time vocal interaction and hand acknowledge technology to enable caregivers to support paralyzed hand patients using their care routines for enhancing self-care capabilities and life quality [18]. A conversational agent uses digital interactive tools to create self-directed therapy treatments of stroke patients who simultaneously gain better participation in their therapy experience [19]. A voice-based AI chatbot system represents a tool that promotes physical activity for elderly people to help them develop better lifestyle patterns [20].

2.4 Emerging AI Applications in Rehabilitation

AI applications in modern times revolutionized the operational methods used in rehabilitation services. Hand signal detection together with movement identification and voice recognition technology have been integrated by research to boost robotic tool delivery support while also making it suitable for rehabilitation purposes [21]. AI applications now enable the conversion of whispering and hoarse speech into audio with natural speech quality thus offering immediate help to people who have severe stuttering or vocal disabilities [22]. Kirsty represented the first AI technology-based physiotherapist system launched for NHS Lothian back pain patients in Scotland. The healthcare virtual practitioner utilizes application software for delivering personalized care to patients through a process that eliminates regular NHS staff waiting times [21]. Altogether, these studies provide a favorable outlook into the role of AI-based systems in rehabilitation. These advancements in hand gesture recognition and voice assisted innovations provide excellent and engaging self-therapeutic interphase to the patients.

Current rehabilitation environments mainly entail gesture identification, sensors or a robotic system to facilitate motor biofeedback. The real-time interaction needs of people with physical disabilities benefit from a gesture control system that uses deep learning [22] and an EMG-based approach using machine learning achieves high hand gesture classification accuracy at [23]. Patients can operate motorized devices better using the rehabilitation robot GC-Rebot by controlling it with hand gestures which enhance their interaction quality [24]. The game-based therapy system Hand Rehab depends on gesture identification for interactive recovery activities without active tracking features. The RIoT system brings Voice AI together with 4D Skeletal-Based Gesture Recognition and IoT-based monitoring which creates a new rehabilitation framework that is personalized and accessible to more users. Real-time biomechanical feedback defines RIoT beyond MediaPipe recognition systems that maintain high (99.34%) accuracy levels but focus on communication [25]. The implementation of sEMG-based rehabilitation gloves depends on specialized hardware components which reduce their potential for wide-scale home-based therapy applications. In this aspect, the application of the proposed RIoT framework of using AI-driven rehabilitation intersected with the use of monitoring introduces the ability for enhanced patient-automation and reduced dependence on the caregivers in addition to being economical for a remote rehabilitation solution.

3 Methodology

3.1 Use case diagram

Figure 1 shows that AI defines the ability of machines to replicate human intelligence which enables them to improve rehabilitation by using adaptive technologies along with smart systems for monitoring purposes. Assistance, hand tracking features, and feedback are additional features that help patients, whereas professionals supervise the treatment process and modify it if necessary. This involves the delivery of rehabilitation in a manner that is suited just for the person suffering from the disability, and based on data, not guesswork.

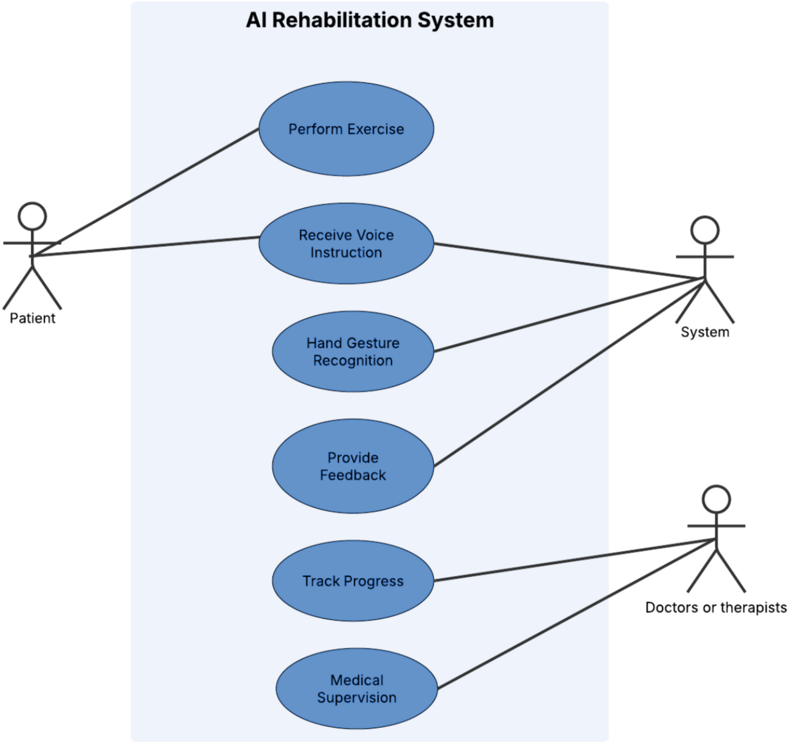

Fig. 1. URL use case.

3.2 Flowchart: System & User Interaction

Figure 2 explains the system's user interaction throughout rehabilitation by presenting exercise instructions and immediate movement-based feedback to users. It also gives voice instructions for the exercises and records and analyzes hand gestures and provides feedback. If the session is incomplete, the patient goes on, if it is complete the results are stored, and the session terminates. Here it is ensured that an adaptive and AI based approach is used to support the recovery process.

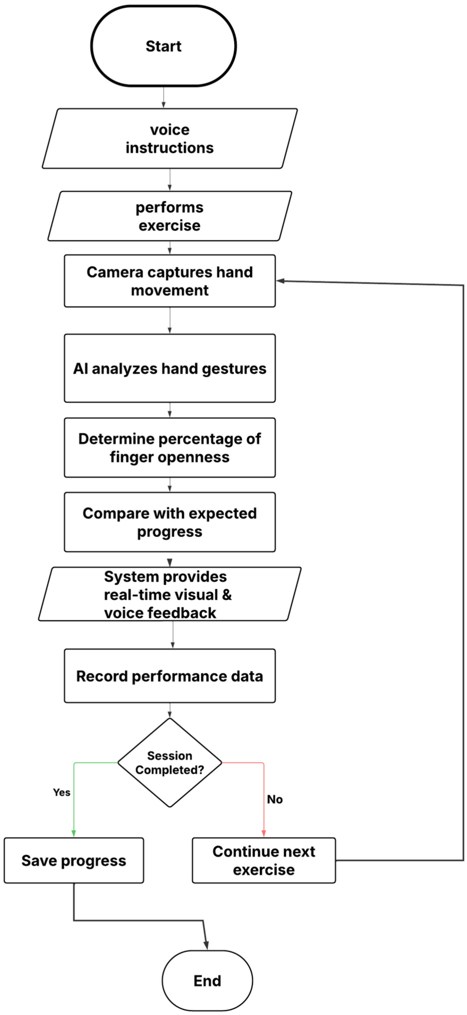

Fig. 2. Flowchart Explanation: System & User Interaction

3.3 System Architecture

Figure 3 depicts the system architecture and explains how Mediapipe partners with the deep learning models in the rehabilitation process.

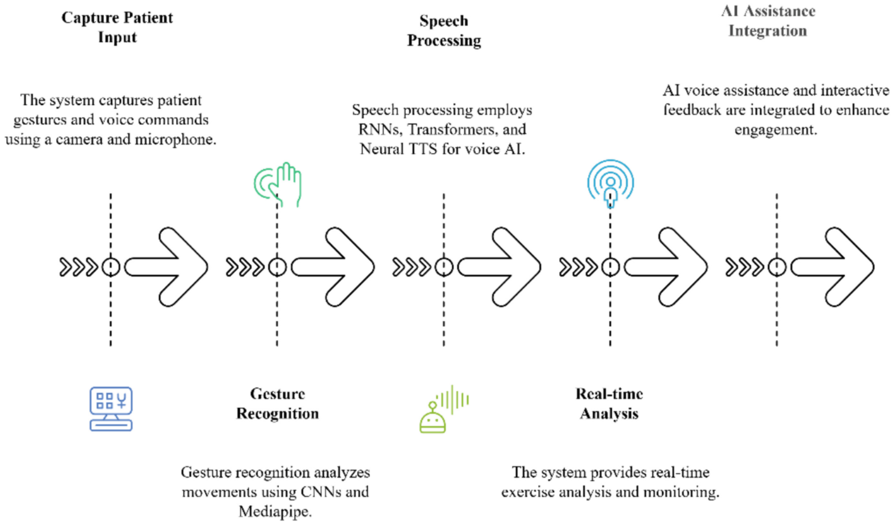

Fig. 3. System Architecture for gesture and speech interaction.

The key components include:

- Hand Pose Tacking: Mediapipe also allows performing accurate gesture tackling with real time detection of hand skeleton.
- AI Models: The computer incorporates CNNs, RNNs, and Transformers to study hand gestures as well as identify spoken language.
- Cloud-Based Processing System: A cloud computing component performs feedback evaluation and remotely monitors patient exercises.

3.4 AI Models and their Role

According to Fig. 4 is the combined workflow of the RIoT system. MediaPipe detects hand movements right in front of you, and CNNs identify what they are for accurate monitoring in rehabilitation. LSTM for dealing with the time aspect of hand movement and transformer for boosting NLP for voice user interface and for feedback. Together, these components are of an AI powered feedback loop to the patient through voice steering and gesture proficiency recognition. With this integrated approach, accessibility gets a boost, patient engagement is encouraged, and also, exact workout monitoring is assured.

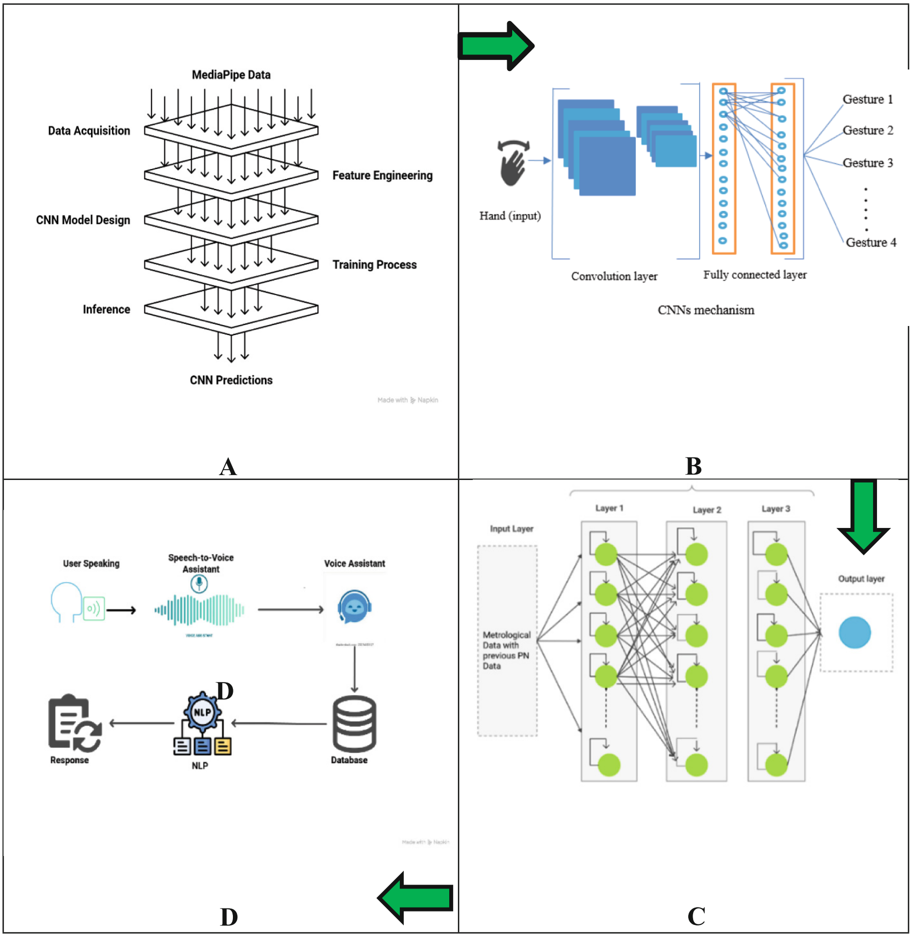

Fig. 4 **(A).** Mediapipe, **(B).** CNN, **(C).** LSTM, **(D).** NLP mechanism

MediaPipe:
The process of hand gesture registry via MediaPipe depicted in Fig. 4(A), is continuous video recording from camera of the patient hand movement. Each video frame is analyzed to get features such as finger, palm, wrist. MediaPipe presents 21 hand landmark locations in real time, while a CNN-based model examines the movements of the hand to determine the signals. The system gives immediate feedback to the patient to know when to do exercises and adjust movements for better results.

CNN Workflow in RIoT Gesture Recognition:
Figure 4(B) shows the CNN takes patient gestures during rehabilitation, trained by using google media pipe hand dataset. It changes video frames to pixel arrays to track hand gesture. where convolutional layer finds edges, curves and patterns and pooling layer sequences improve processing. The classification layer performs labeling of gestures as

open hand, fist or pointing position based on the detected position of the user and the output layer implements rehabilitation action as per the detected gesture.

LSTM Mechanism:
The Voice AI system employs LSTM for sequence decision-making, as presented in Fig. 4(C). The input layer Consume the data flowing in the current moment, beside of the data of previous iter. The beside data here includes the data of the moment (which is the past prediction), before it is changed in prediction. Key to the LSTM cells (colored circles) are input, forget and output gates that manage data flow while retaining most relevant information. The output of the model is determined by the time series properties in the data. LSTMs do better even in speech recognition and time-series because they have a good idea of temporal relationships.

NLP Mechanism:
Figure 4(D) shows that Voice AI system uses Transformer models to facilitate language communication through Natural Language Process (NLP). The system employs speech recognition to transform voice to text it as speech agency with the user. LSTM networks boost speech recognition, it enables a clearer audibility of the words that the patient buttresses and that lets better rehabilitation exercises. This NLP technology lets patients do rehabilitation without hands, providing added convenience for those who are not able to use their hands.

Implementation Steps
Data Descriptions:

Hand Gesture Recognition: The combination of MediaPipe and CNNs accesses hand landmarks through images and videos drawing their signals from Google MediaPipe Hand Dataset training. The accuracy of the system increases when preprocessing is combined with augmentation methods alongside model fine-tuning. The train-test split enables recognition of new gestures when applying sign language technology or touchless control systems.

Speech Recognition: Google Speech Commands is a tool for training deep recurrent neural network (RNN) and Transformer-based models for speech recognition from dated spoken word data. To begin with, the preprocessing of the audio signals involves spectrogram creation or MFCC where the input is fed into deep learning models. In the assessment of performance, Word Error Rate (WER) as well as accuracy figures are used. Splitting the data set to the left and right equally guarantees that the system adopts reliable generalization to perform well in voice-controlled aspects such as voice controlled smart assistants or else smart home automation systems. The integration of these technologies ensures that patients receive precise, personalized rehabilitation, improving adherence and recovery outcomes.

Accuracy measurement: The prevalence of Word Error Rate serves as the primary measurement for determining the precision of CNN-based recognition systems. WER evaluates the system accuracy through its comparison between predicted words and reference transcript words. The formula calculates WER measurement according to the following mathematical Eq. (1):

$$\mathrm{WER} = \frac{S + D + I}{N} \tag{1}$$

Where:

- S = Number of substitutions
- D = Number of deletions
- I= Number of insertions
- N = Total number of words in the reference

3.5 Overview of the RIoT

Medical rehabilitation using artificial intelligence features webcam recognition of hand gestures alongside Voice AI directional commands through an Internet of Things enabled system for stroke patient rehabilitation processes. The rehabilitation system uses various components which include a webcam and AI-based gesture recognition as well as RIoT Application (IoT) and database along with web server and voice AI feedback. Figure 5 illustrates the major parts and their interaction in the rehabilitation of patients by the RIoT system.

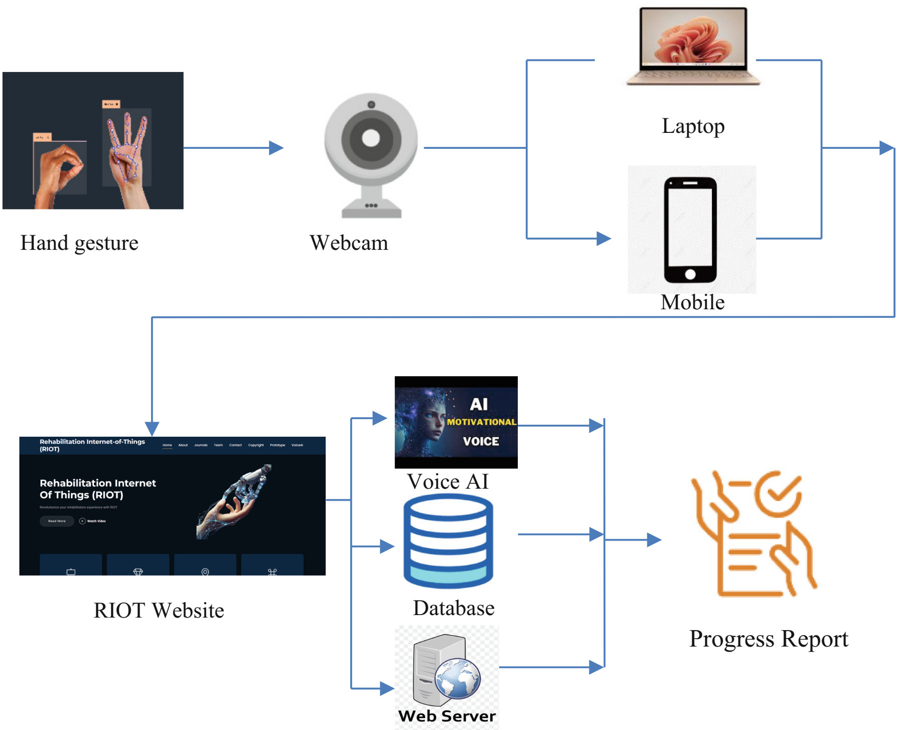

Fig. 5. RIoT with AI Overview

Step-by-Step Process:

- Patient inclusion: The patient can either use a tablet or a laptop to enter the system where the voice AI will guide him through the different exercises.
- Webcam-Based Hand Gesture Detection: The webcam records hand activities, licenses how far open the fingers are to interpret gestures.
- Transmission of Data: AI transmits the gesture data to the RIoT Application to analyze the outcome and response.
- SQL Database and Web Interaction: The data collected is saved into the database, and the client will be able to access the data through GUI web application by the healthcare providers and patients.
- Feedback & Motivation: Voice AI, in addition to guiding people's motions, gives encouragement or correction and teaches how to execute movements in a better way.
- Feedback Management: The system identifies whether exercises have been done and repeats the instructions, if not done the system retains the result of the exercise for consulting.

This system monitors and records the rate of rehabilitation exercises and applies AI motivation to encourage the patients including and especially stroke patients, to aid in their rehabilitation.

4 Results

The AI rehabilitation system makes use of hand gesture recognition then connects it with voice AI technology to enrich rehabilitation patient experiences. MediaPipe helps track hand movements in real-time with high precision through accurate monitoring of finger positions as well as movement patterns. Patients can have hand-free access to rehabilitation due to integrated voice AI technology.

Hand Gesture Recognition Performance
The system determines and evaluates hand motions during rehabilitation sessions to provide patients with effective tracking along with feedback. Two key exercises are included:

Open and Close Hand Exercise

- Through visual feedback the system presents finger openness amounts which show patients how their treatment is advancing.
- With its functionality the system tracks finger motions by measuring exact finger opening percentages (Fig. 6(A)).
- The system collects hand movement information for analyzing patient progress using.

Touch Finger Exercise

- Touch detection through the system enables users to gain better manual control and coordination (Fig. 6(B)).
- The system delivers specific feedback for recovery by tracking both left and right hands with high precision.
- The system provides real-time numerical together with visual feedback which enables patients to successfully accomplish their rehabilitation objectives.

The constant gesture surveillance enables doctors to obtain essential data regarding patient improvement levels which helps them adjust treatment plans effectively.

Voice AI Integration

Users receive audio instructions including exercise feedback and motivational feedback from the Voice AI module during rehabilitation programs.

- Users achieve correct exercise execution through verbal instructions.
- Users can modify their movements through immediate audio feedback provided by the system.
- The motivational aspects in speech help patients stay active throughout their rehabilitation activities.
- Through voice command features users can activate its functions without struggling because it includes accessibility for people with restricted movements.

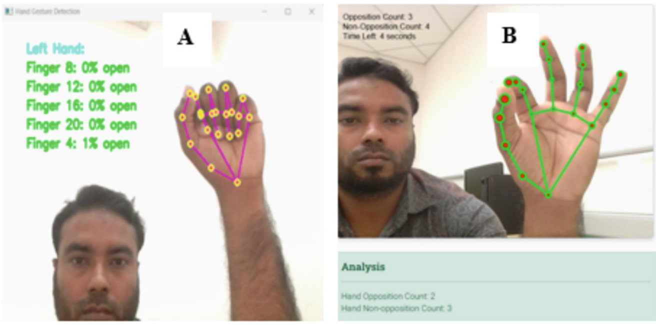

Fig. 6 **(A)**: Represents the percentage of closure for each finger. **(B)**: Counts the number of finger touches detected.

Voice artificial intelligence combined with gesture recognition improves both accuracy and creativity and independence during rehabilitation thus enabling better home-based therapy for heart attack and stroke patients. People find this system better than traditional rehab because it provides cost-efficient and user-friendly services that adapt treatment according to individual improvement metrics. Real-time voice feedback enables patients to learn and focus better thus speeding up the recovery process. Existing challenges to this system stem from unreliable gesture detection because patients perform different movements, technical upkeep requirements, unstable internet connectivity and obligations regarding data security and patient authorization. Upcoming technological developments in deep learning as well as wearable biosensors and reinforcement learning systems will improve the system. Medical engagement can improve through the combination of emotion recognition with facial monitoring systems. Ultimately, this AI-based method could change home-based rehab by connecting the patients to the healthcare professionals more efficiently.

5 Conclusion

This research demonstrates that input through hand gestures and voice with the help of Artificial Intelligence aid patients in making rehabilitation less laborious, tiresome, and monotonous. The system employs AI technology together with seeing and understanding systems to provide users with cost-effective therapeutic solutions. Patients demonstrate better treatment connection when they participate in recovery activities through both verbal communication and manual movements. The system requires full optimization because it requires solutions to accuracy problems and removal of barriers related to technology implementation and ethics. Additional research on wearable sensor devices along with AI-based adaptation systems will significantly enhance their total effectiveness. The system represents a decentralized healthcare rehabilitation method by both reducing healthcare expenditures while boosting patient outcome effectiveness alongside improved holistic health results.

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