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HOPE: Technology-Assisted Home Rehabilitation for Post-Stroke Motor Recovery

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Abstract— **Home-based Physiotherapy; Stroke Rehabilitation; Internet of Medical Things (IoMT); Real-time Monitoring Stroke is one of the diseases that causes long-term disability all over the world, because motor weakness in the upper extremities affects a large percentage of stroke survivors. This project presents the HOPE system, which is a smart, task-oriented system for rehabilitation and evaluation of the upper extremities, especially the hand, designed to support recovery after stroke and monitor the patient's condition. The system integrates a smart glove with all existing sensors, manufactured using 3D printing technology The rule-based assessment framework translates raw sensor data into clinically meaningful performance indicators using pre-defined thresholds based on rehabilitation principles. This framework bases the assessment on measuring actual movement time, coordination, range of motion, grip strength, force modulation, and bilateral symmetry during task-oriented exercises. The system is supported by a phone application that provides instant feedback, session summaries, progress tracking, and remote monitoring by therapists. By integrating assessment directly into functional training assignments, the HOPE program bridges the gap between patient assessment and traditional assessment methods, enhances patient monitoring, and supports longitudinal monitoring in both clinical and home settings.**

Keywords—Stroke rehabilitation, home-based physiotherapy, wearable sensors, smart glove, Internet of Medical Things (IoMT), real-time monitoring

I. INTRODUCTION

Stroke represents a major global health challenge, as it is classified as the third leading cause of death and disability worldwide, especially in elderly patients, with an estimated 93.8 million people affected globally in 2021 and approximately 12 million new cases each year.

It is expected that approximately one in four adults will suffer a stroke in their lifetime, and this is reflected in the impact of many in their daily lives and the activities they need to practice, which reflects the great impact of this condition on individuals and health care systems, especially their need for rehabilitation after the injury and their need to practice physical therapy exercises.

Despite advances in acute care, stroke still causes long-term disabilities among survivors because it affects all limbs associated with the affected part. A large proportion of stroke survivors have persistent motor deficits, with upper extremity weakness occurring in approximately 50-80% of survivors, many of whom continue to have motor deficits six months or more after the event. Weakness of the upper extremities and loss of fine motor control led to a significant reduction in independence in daily life, and this affects the daily life of the affected person, especially since he faces difficulty in returning to normal life, which contributes to the global burden of disability.

Brain tumors are one of the biggest health challenges facing the world in neurology, as they contribute significantly to morbidity, disability, and mortality around the world. According to global cancer statistics, brain and central nervous system tumors affect hundreds of thousands of new cases annually, and their occurrence represents more than 300,000 new cases annually throughout the world. Although less common than other types of cancer, brain tumors are associated with disproportionately high levels of functional impairment and neurological disability due to their direct impact on vital brain structures.

Analysis indicates that millions of individuals live with brain tumors or long-term consequences of surgical interventions, radiation, and chemotherapy. This effect goes beyond survival rates, as many patients suffer significant limitations in daily performance, mobility, coordination, and cognitive performance, in short, in carrying out daily tasks in their lives. This places a significant burden on individuals, families and healthcare systems, and of course the need for prolonged neurological rehabilitation and structured physical therapy programmers.

Despite advances in neurosurgical techniques, radiation therapy, and oncology care, many brain tumor survivors are at risk of developing persistent motor deficits, especially when tumors affect areas of the motor cortex, cerebellar pathways, or corticospinal tract. Frequent complaints of weakness in the upper extremities, poor coordination, constant tremors, and loss of fine motor control, all of which are a reason for not performing activities of daily living. These disabilities may continue for several months or years after the tumor is removed or treated, all of which cause long-term disability.

Traditional clinical assessments rely heavily on observation and self-recording by the practicing physical therapist, which limits the ability to detect subtle changes and track the patient's improvement in each session over the previous but functionally important session in movement quality, coordination, and control. The patient needs to practice a lot of exercises continuously, not only at the time of the designated session, but also his need to practice them at home. The therapist needs to follow him and monitor his movement to monitor the patient whether he is doing the correct exercise and progressing or not. This is not a part that traditional treatment misses, despite its importance for improving the patient’s condition in a faster period. These assessments are usually conducted in controlled clinical environments and capture only short snapshots of performance and are likely to ignore important aspects of daily motor function.

To overcome these limitations, this project proposes a complete assessment framework that includes task-specific condition assessment to determine the patient's stage and the exercise he or she needs to perform. Function-oriented and activity-based reflect real-world tasks and combines them with objective sensor measurement. The assessment focuses on five major functions of the upper extremities reaching, grasping, manipulating, releasing, and manual activities each of which plays a central role in functional independence and performance of activities of daily living.

The key feature of this framework is the integration of smart gloves equipped with wearable sensors, including inertial measurement units (IMUs), elastic sensors, force sensors, and encoders. IMUs are deployed to capture movement kinematics and joint dynamics; Flexible sensors and encoders precisely measure finger and wrist joint angles; Force sensors determine grip force and adjust force. The combination of these sensing modalities allows for a comprehensive quantitative measurement of the motor performance of all movements that help in the improvement and improvement of the affected limb. The use of sensors here, each type of them measures a different movement of a different joint because the improvement is on more than one scale rather than a single scale, capturing parameters such as range of motion, smoothness of movement, force control, and bilateral coordination - aspects that are crucial for effective rehabilitation but are difficult to observe clinically.

By incorporating these assessments into functional tasks (eg, reaching for objects, grasping items of varying sizes, manipulating keys or tools, controlled release, and coordinated manual activities), this approach not only provides clinically meaningful measures but also supports longitudinal monitoring of recovery, both in the clinic and at home. The sensor-based assessment system was designed to enhance and develop traditional clinical assessments so that the physical therapist can monitor the patient from home and also save the patient instead of repeated visits by reducing them to the smallest possible number, and provide objective, continuous and detailed insights into the paths of motor recovery, as much of the recovery cannot be observed by the therapist because sometimes the improvement is relative, but the therapist does not notice and thinks that the condition is hopeless to treat, which can help guide personal rehabilitation strategies and improve long-term outcomes for survivors of the disease.

Stroke is a common cause of morbidity and mortality worldwide. Many patients suffer extended periods of recovery and insufficient functional restoration despite advancements in rehabilitation approaches. The total lifetime prevalence of stroke was 8.5/1,000 in the population aged 20 years and more. It increased with advancing age and was higher among males than females among all age groups except in the childbearing period (20 years to <40 years of age).

Lifetime prevalence of ischemic stroke (7.2/1,000) was higher than hemorrhagic stroke (1.1/1,000). Hemiparesis and hemiplegia were the most common presentations of stroke.

The total lifetime prevalence of stroke in the population aged 20 years and more in Upper Egypt (desert area) lies within the range that is recorded in developing countries. Clinical presentation and risk factors are like those recorded from developing and developed countries.

Conventional rehabilitation programs frequently need monotonous, time-intensive activities that may result in diminished patient motivation and compliance over time. Consequently, functional outcomes may remain inadequate, underscoring the necessity for more engaging, efficient, and patient-centered rehabilitation strategies.

Despite established clinical guidelines, a significant gap remains between recommended and actual rehabilitation practices. The National Clinical Guidelines advocate for at least 45 mins of therapy daily if there are rehabilitation goals (providing the patient tolerates this intensity), and recognition that high-intensity practice is better. However, there remains a big contrast between the recommended and actual applied therapy time.

Stroke leading to motor dysfunction and reduced functional independence being prominent challenges in post-stroke recovery. Rehabilitation strategies have traditionally relied on conventional physiotherapy.

An early and efficient rehabilitation routine is of utmost importance to improve the treatment outcomes and the quality of life of people who have a stroke. Current literature indicates that most of the post-stroke recovery occurs within the first weeks to months.

Although spontaneous neurological recovery is most rapid in the first 3–6 months after stroke, improvements in upper limb (including hand) motor function can continue for 12–24 months or longer, depending on individual factors and rehabilitation intensity, with some patients demonstrating even later gains.

The absence of accurate and real-time feedback during rehabilitation exercises constitutes a significant limitation of conventional upper limb therapy.

Rehabilitation assessments based on functional level, degree of impairment and recovery form the scientific basis for setting rehabilitation goals and formulating treatment programmers; However, traditional practice often performs assessment and treatment as two separate processes, which limits the ability to dynamically adjust treatment based on the patient's progress.

Patients often perform movements without immediate instruction on range of motion, precision, or muscle activation, potentially leading to improper execution. Physiotherapists frequently cannot monitor every movement, especially in unsupervised or home-based settings.

Traditional rehabilitation approaches often consider assessment and treatment to be separate processes, even though assessment is an essential and integral part of the treatment process. This aspect is missing in many traditional treatment methods, despite its importance, as the patient needs continuous follow-up to know his ability to perform specific tasks for which he has been trained. The therapist also needs to ensure that the patient has improved and is ready to move on to the next stage of rehabilitation. The lack of integration between assessment and treatment is one of the fundamental problems that limits the effectiveness of traditional rehabilitation methods and highlights the need for intelligent systems that provide continuous and objective assessment during training.

Brain tumors are considered one of the most important causes of neurological deaths worldwide. Although less common than stroke, brain and central nervous system tumors account for more than 300,000 new cases worldwide and are associated with significant rates of disability and mortality. The incidence of brain and central nervous system tumors varies around the world, depending on age, geographic region, and the technology used in the treatment stages. Higher rates have been observed in those aged 45 years and older. Unlike many systemic cancers.

The reason for the prevalence of brain tumors is improved diagnostic imaging techniques and longer survival rates after advances in neurosurgical procedures, radiotherapy, and chemotherapy. However, survival does not necessarily mean complete neurological recovery. A large percentage of brain tumor survivors suffer from persistent neurological disabilities after tumor growth or surgical removal. Motor weakness strongly affects the upper extremities.

Traditional rehabilitation programs for brain tumor patients should follow the general principles of neurological physical therapy; However, they may not adequately treat neurological fluctuations, fatigue fluctuations, or tumor-related progression. Similar to stroke rehabilitation, sometimes treatment programs may be repetitive and take a long time, which may affect the patient’s motivation and commitment. Stroke recovery is unlike recovery from brain cancer. Neurological function in brain tumor patients may improve, stabilize, or decrease depending on the tumor’s development, treatment response, or recurrence.

The absence of feedback during motor performance is considered one of the limitations in traditional rehabilitation methods for brain tumor survivors. Functional assessments are performed before treatment sessions, which limits the ability to adjust interventions by the clinician based on subtle neurological changes. Because neuro-oncology patients can experience rapid clinical changes, continuous data-driven monitoring becomes even more important.

The primary goal of this project is to develop an objective, sensor-based assessment framework for assessing upper limb motor function in individuals with neurological disabilities, especially post-stroke patients. This framework aims to overcome the limitations imposed on traditional clinical self-evaluations and reduce the repeated visits of patients and follow up on the disease and their performance after each session or exercise they perform to ensure the improvement of patients. The most important goal is to follow the slight improvement that the doctor does not notice through the naked eye by providing quantitative, repeatable, and function-oriented measurements.

TABLE I COMPARISON BETWEEN STROKE AND BRAIN TUMOR

Aspect	Stroke	Brain Tumor
Cause	Interruption of blood supply (vascular event)	Abnormal tumor growth or post-surgica effects
Onset	Sudden	Often gradual or treatment-related
Motor Pattern	Frequently one-sided weakness (hemiparesis)	Depends on tumor location and surgical impact
Recovery Timeline	Most rapid recovery in first 3–6 months	Recovery depends on tumor type, treatment, and neurological damage
Condition Stability	Usually, non-progressive after event	May be progressive or influenced by ongoing treatment

II. RELATED WORK

A. Music Glove (Flint Rehab)

It's a hand rehabilitation device designed primarily for post-stroke patients. It focuses on improving finger coordination, grasp, and release through interactive, music-based exercises.

The glove contains touch and pressure sensors located on the fingers. Patients perform pinch and grasp movements in response to musical cues .Real-time feedback is provided to encourage correct timing and repetition.

Music glove is focusing in the following hand functions:

- Grasp
- Release
- Finger Coordination

Fig. 1. Music Glove (Flint Rehab)

B. Neofect Smart Glove

It’s a sensor-based rehabilitation glove designed to improve hand and finger motor function in stroke and neurological patients using gamified therapy.

Equipped with motion and flex sensors while Patients perform guided hand exercises through interactive games, Performance data is recorded and displayed for progress tracking

Neofect is focusing in the following hand functions:

- Grasp
- Release
- Fine Motor Control

Fig. 2. Neofect Smart Glove

C. SaeboGlove

a mechanical assistive glove, not a sensor-based system. It is designed to support finger extension in patients with neurological impairments, especially after stroke.

Uses elastic tension systems to assist finger opening, enables patients to perform functional grasping activities, No electronic sensors or digital feedback

Saebo glove is focusing in the following hand functions:

- Assisted Grasp

- Assisted Release

Fig. 3. SaeboGlove

D. Hand Tutor (MediTouch)

A sensor-based rehabilitation glove used for assessment and treatment of hand and finger motor impairments following stroke and neurological injuries.

Integrates motion and angle sensors, Measures range of motion, speed, and coordination. Data is visualized through therapeutic software and games.

Hand Tutor is focusing in the following hand functions:

- Assisted Grasp
- Assisted Release

Fig. 4. Hand Tutor (MediTouch)

TABLE II COMPARISON OF COMMERCIAL SOLUTIONS AND THE HOPE SYSTEM

Feature	Music Glove	Neofect	SaeboGlove	Hand Tutor	HOPE (Proposed)
Sensor-based assessment	No	Yes	No	Yes	Yes
IMUs for arm movement	No	No	No	No	Yes
Grip force measurement	No	No	No	No	Yes
Finger angle tracking	Limited	Limited	No	Yes	Yes
Task-oriented ADLs	Limited	Moderate	Moderate	Limited	Extensive
Bimanual activities	No	No	No	No	Yes
Home and clinic use	Yes	Yes	Yes	Clinic	Yes
Objective progress tracking	Limited	Moderate	No	Yes	Advanced
Customizable (3D-printed)	No	No	No	No	Yes
Research & scalability	No	No	No	Limited	High

III. SYSTEM OVERVIEW

The proposed system is an intelligent upper extremity rehabilitation platform based on Task-Oriented Rehabilitation, designed to deliver repetitive, goal-directed functional training, consistent with scientific evidence-based stroke rehabilitation guidelines. The system is based on a smart glove printed with 3D printing technology and supported by a group of sensors designed to measure the functional performance of the hand and fingers. These sensors measure several important functional elements, including the strength of the hand grip, the force of finger pressure, the speed of reaching a specific object, in addition to the ability to bend and straighten the fingers, and the force of releasing objects from the hand. The system also allows for evaluating the patient's ability to control the sliding or moving of small objects within the hand, which reflects the level of fine motor control (Manipulation). A suitable sensor is assigned to each function to ensure accurate and objective measurement of each element of motor performance.

The platform relies primarily on the assessment phase that the patient initially goes through, where his functional condition is precisely determined before starting the rehabilitation program, and then customized therapeutic exercises are designed that suit the patient’s abilities and functional goals. All data and results extracted from the sensors are combined to be displayed in an integrated manner on a smartphone application. The application allows the results of each rehabilitation session to be compared with previous sessions, which helps track the development of motor performance over time. This contributes to motivating the patient to adhere to the required exercises and clearly understand his level of progress. The system also allows the doctor or therapist to monitor the patient's condition remotely without the need for repeated visits, with the ability to modify the treatment plan based on the recorded objective data.

The system aims to :

- To design functional, activity-based assessment tasks that reflect real-life activities of daily living such as reaching, grasping, manipulation, release, and bimanual use.
- To integrate a smart glove equipped with IMUs, flex sensors, force sensors, and encoders for comprehensive monitoring of upper limb and hand movements.
- To objectively quantify key motor performance indicators including range of motion, movement smoothness, coordination, grip force, force modulation, timing, and bilateral symmetry.
- To enable detection of subtle motor deficits and compensatory strategies that are difficult to identify through clinical observation alone.
- To support longitudinal monitoring of patient progress and provide data-driven insights to assist clinicians in tailoring personalized rehabilitation programs.

IV. HARDWARE DESIGN

This project uses an array of wearable sensors integrated into a smart rehabilitation glove to objectively assess upper limb motor function during activity-based functional tasks. Each tool is chosen according to all the measurements needed for each procedure that we follow in the school of physical therapy, as in every exercise that the patient performs, it is done through a specific exercise that the patient performs according to the stage that the patient has reached to capture a specific aspect of movement, strength, or coordination that is usually weak after neurological injuries such as a stroke.

A. Smart Glove Design and Fabrication

The smart glove is the main component that the patient wears while performing the exercises in the proposed rehabilitation and evaluation system. It is designed to integrate multiple sensors including IMUs, flex sensors, force sensors, and encoders into one lightweight, easy-to-use platform that patients can comfortably wear during functional hand and arm activities.

1) Smart Glove Design and Fabrication

Traditional clinical assessments rely heavily on observation and self-recording, which often fail to capture fine motor deficits in hand and finger movements. The smart glove allows continuous, objective, and quantitative assessment of upper extremity function while the patient performs task-oriented real-life activities. By integrating sensors directly on the hand and fingers, the glove allows precise measurement of movement, strength and coordination in a natural, environmental setting, whether in clinics or at home.

2) Fabrication Methodology: 3D Printing

a) Customization and Patient-Specific Fit

3D printing allows the glove structure and sensor mounts to be customized to different hand sizes and levels of impairment. This is especially important in stroke rehabilitation, where patients often present with spasticity, edema, or deformities that make standard-sized devices uncomfortable or unusable.

b) Accurate Sensor Placement

Precise positioning of sensors is critical for reliable data collection. 3D-printed holders and channels ensure stable and repeatable placement of IMUs, force sensors, and flex sensors on specific anatomical landmarks, reducing noise measurement and sensor drift.

c) Rapid Prototyping and Iteration

3D printing enables fast design modifications, allowing :

- Easy adjustment of sensor positions
- Iterative optimization based on clinical feedback
- Quick replacement of damaged components.

This significantly reduces development time and cost compared to traditional manufacturing methods.

d) Lightweight and Ergonomic Design

Using 3D printing, the glove can be designed to be:

- Lightweight
- Low-profile
- Non-restrictive to natural hand movement

This improves patient comfort and compliance during long assessment or therapy sessions.

e) Cost-Effectiveness

Compared to custom-molded or commercial wearable systems, 3D printing offers low cost solutions suitable for scaling in rehabilitation centers, research labs, and home-based programs.

B. Hardware Tools

1) Inertial Measurement Units (IMUs)

IMUs consist of accelerometers and gyroscopes (and sometimes magnetometers) that measure linear acceleration, angular velocity, and orientation of body segments.

a) Role :

IMUs are mounted on the upper limb (hand, wrist, forearm, and/or arm) to capture hand kinematics during reaching, manipulation, and bimanual activities.

b) What They Measure:

- Range of motion of shoulder, elbow, and wrist
- Trajectory and direction of movement
- Compensation strategies (e.g., trunk or shoulder substitution)
- Bilateral coordination and symmetry in bimanual tasks

Fig. 5. Inertial Measurement Unit

2) Flex sensors

Flex sensors change their electrical resistance according to the degree of bending, allowing estimation of joint angles.

a) Role:

Flex sensors are placed along the fingers to measure finger flexion and extension during grasping and release tasks.

b) What They Measure:

- Finger joint bending angles
- Timing and coordination of finger movements
- Completeness of hand opening and closing

Fig. 6. Flex Sensor

3) Force Sensors

Force sensors measure the amount of force applied between the hand and an object or surface.

a) Role:

Force sensors are embedded in the glove at the fingertips and palm to assess grip strength and force modulation.

b) What They Measure:

- Grip force magnitude
- Force variability and stability
- Gradual force reduction during release
- Force distribution across fingers

Fig. 7. Force Sensors

4) Encoders

Encoders provide precise measurements of angular position and movement of joints or mechanical elements.

a) Role:

Encoders are used to enhance the accuracy of finger joint movement tracking, particularly during grasping and manipulation tasks.

b) What They Measure:

- Precise finger joint angles
- Small changes in joint motion over time
- Consistency and repeatability of movements

Fig. 8. Encoder

5) Electromyography (EMG) Sensors

EMG sensors measure electrical activity produced by skeletal muscles during contraction. They detect muscle activation signals and translate them into measurable data reflecting neuromuscular performance.

a) Role:

EMG sensors are integrated into the glove or forearm band to monitor muscle activation patterns during task-oriented exercises.

They help assess muscle engagement, coordination, and timing during reach, grasp, manipulation, and release tasks.

b) What They Measure:

- Muscle activation intensity (signal amplitude)
- Timing of muscle contraction and relaxation
- Muscle coordination patterns
- Fatigue levels during repetitive tasks

Fig. 9. Electromyography (EMG) Sensors

Together, these tools form an integrated, sensor-based assessment system capable of capturing both gross and fine motor impairments. By combining motion, force, and finger posture measurements, the project delivers a comprehensive, objective evaluation of upper limb function aligned with real-life activities.

V. Task-Oriented Rehabilitation Framework

Stroke can significantly impair upper limb function, which greatly affects a person's ability to perform everyday tasks. The task-oriented approach, based on occupational therapy principles, uses meaningful activities to help people recover functionally. This review examines how effective the task-oriented approach is in occupational therapy for upper extremity rehabilitation after a stroke. We conducted a thorough search of English-language research published between 2018 and 2023, using Medline, Scopus, and Google Scholar as additional sources. Following the PRISMA guidelines, a detailed screening process led to the inclusion of 16 relevant articles in this review. The quality of the studies was assessed using the Pero scale. A narrative synthesis was conducted to summarize and interpret the findings of the included studies, which consisted of controlled trials examining the effectiveness of task-oriented interventions delivered alone or in combination with other rehabilitative approaches. The task-oriented approach was studied alongside (a) assistive technology, (b) the Bobath method, (c) mirror therapy, (d) Botulinum Toxin injections, and(e) other therapeutic techniques. Findings indicate that these interventions effectively enhance motor function, self-perceived arm use, and performance in activities of daily living. Integrating task-oriented therapy with the aforementioned therapeutic techniques is effective in managing the hemiplegic upper extremity after stroke.

TABLE III. REHABILITATION APPROACHES BASED ON TASK-ORIENTED PRINCIPLES

Method	Main Goal	Mechanism	Patient Role	Task- Oriente
Assistive Technology	Improve functional performance	Smart gloves, sensors, robots	Active	Yes
Bobath Method	Facilitate normal movement patterns	Therapist hands-on to inhibit abnormal tone and facilitate correct movement	Semi-active	No
Mirror Therapy	Stimulate neural pathways via visual feedback	Reflection of unaffected limb	Active	Partial
Botulinum Toxin	Reduce spasticity	Pharmacological	Passive	No

VI. Functional Tasks

This section describes structured, task-oriented exercises designed to train and assess upper limb functions during stroke rehabilitation. Each exercise is function-specific, clinically relevant, and aligned with activities of daily living. Sensor-based measurements are integrated to provide objective and quantitative evaluation of motor performance.

A. Reach Function

1) Exercise 1: Forward Target Reach

a) Objective

This Improve shoulder–elbow coordination, active range of motion, and movement smoothness.

b) Description

The patient sits upright with the trunk supported. A target is placed at arm's length on a table directly in front of the patient. The patient is instructed to extend the affected arm to reach and touch the target, then return to the starting position. The task is repeated for 8–10 repetitions.

c) Progression

- Increase reaching distance

- Add multiple targets at different heights
- Introducing light objects to reach and touch

Fig. 9. Reach Function Exercise

B. Grasp Function

1) Exercise 1: Cylindrical Object Grasp

a) Objective

Improve grip strength and finger flexion coordination.

b) Description

The patient grasps a cylindrical object (e.g., bottle or foam roll), holds it for 3–5 seconds, and then relaxes.

c) Progression

- Vary object size and weight
- Increase holding duration.

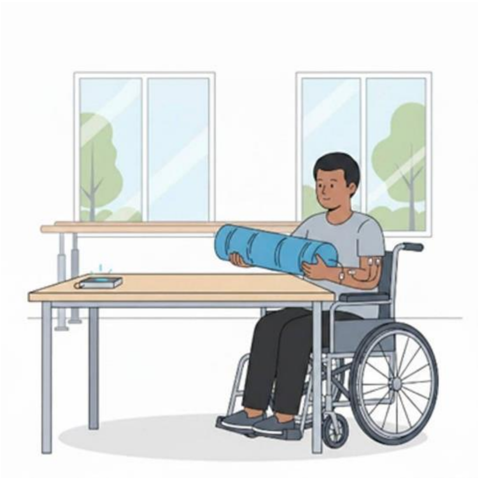

Fig. 10. Cylindrical Object Grasp Exercise

2) Exercise 2: Pinch Grasp Task

a) Objective

Enhance fine motor control and thumb–finger coordination.

b) Description

The patient performs pinch grasping using small objects such as coins or pegs and places them into a container.

c) Progression

- Vary object size and weight
- Increase holding duration.

Fig. 11. Pinch Grasp Exercise

C. Manipulation Function

1) Exercise 1: Object Rotation Task

a) Objective

Improve wrist control and in-hand manipulation.

b) Description

The patient grasps an object and rotates it clockwise and counterclockwise using wrist and finger movements.

c) Progression

- Reduce object size
- Increase rotation speed.

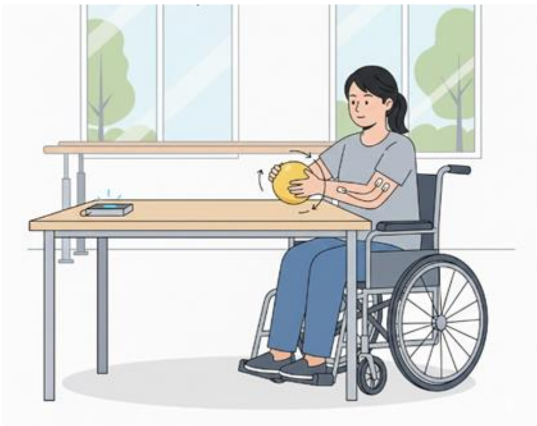

Fig. 12. Object Rotation Task

D. Release Function

1) Exercise 1: Controlled Object Release

a) Objective

Improve timing and completeness of finger extension.

b) Description

The patient grasps an object and places it gently on a surface, focusing on controlled finger opening.

Fig. 13. Controlled Object Release Exercise

2) Exercise 2: Repetitive Open–Close Task

a) Objective

Enhance finger extension speed and coordination.

b) Description

The patient repeatedly opens and closes the hand without objects.

Fig. 14. Repetitive Open-Close Exercise

E. Bimanual Function

1) Exercise 1: Jar Opening Simulation

a) Objective

Improve bilateral coordination and force symmetry.

b) Description

The unaffected hand stabilizes the object while the affected hand performs rotational movement.

Fig. 15. Jar Opening Simulation for training bilateral coordination.

2) Exercise 2: Cloth Folding Task

a) Objective

Encourage functional use of the affected limb.

b) Description

The patient folds a towel using both hands in a coordinated manner.

Fig. 16. Cloth Folding Task to encourage functional use of the affected limb.

TABLE IV TASK-ORIENTED REHABILITATION

Functional	Stroke	Brain Tumor

Task		
Reach	Restore controlled arm movement	Re-establish motor pathways after surgery
Grasp	Improve grip strength & coordination	Enhance neuromuscular activation
Manipulation	Recover fine motor precision	Address coordination deficits or tremors
Bimanual Tasks	Reactivate affected limb	Restore bilateral balance and control

VII. ASSESMENT PROTOCOL

Evaluating the function of the upper extremity after a stroke is essential to understand the level of motor impairment, determine what level the patient has reached, track the progress of recovery, determine the required exercises, and direct rehabilitation interventions, because one person's injury differs from another person in the degree of injury. Some patients can perform some functions and others cannot. Traditional clinical assessments often rely on therapist observation and self-scoring, which may fail to capture subtle deficits in movement quality, coordination, and timing. In addition, these assessments are typically performed in clinical settings and at discrete time points, which limits their ability to reflect real-world performance.

To address these limitations, this project adopts an activity-based functional assessment approach. The assessment is designed around realistic activities of daily living (ADLs) that require reaching, grasping, manipulating, releasing, and hand coordination. Each exercise measures the patient's ability to perform a specific task, and they are fully detailed in measuring this. If the patient has the ability to do the task correctly, he has passed the test and will focus on the rest of the exercises until he passes the test. By performing these tasks while wearing a smart glove equipped with wearable sensors, objective kinematic and kinematic data can be collected continuously. This approach allows for quantitative assessment of movement quality, force modulation, coordination, and symmetry, providing a more accurate and comprehensive representation of upper limb functional capacity.

TABLE V ASSESSMENT ACTIVITIES FOR UPPER LIMB FUNCTIONAL TASKS

Function	Assessment Activity	Measured Parameters	Sensors Used
Reach	Reaching a cup on a table	Shoulder & elbow ROM, movement speed, trajectory deviation	IMU
	Pressing a wall-mounted button	Accuracy, joint coordination, compensatory movements	IMU
Grasp	Grasping bottles of different sizes	Grip force, finger flexion angles, force adaptation	Force, Flex, Encoder
	Picking up small objects (coins/blocks)	Precision grasp, thumb–finger coordination	Flex, Force, Encoder
Manipulation	Buttoning and unbuttoning a shirt	Fine finger coordination, task completion time	Flex, Encoder
	Turning a key in a lock	Wrist rotation, object manipulation control	IMU, Encoder
Release	Placing an object on a surface	Release timing, residual grip force, finger extension	Force, Flex
	Transferring objects between containers	Release accuracy, hand opening speed	Force, Flex
Bimanual Activities	Combing hair	Inter-limb coordination, movement symmetry	Dual IMU, Flex
	Opening a jar	Force distribution, timing synchronization between hands	Force, Dual IMU

VIII. RULE-BASED EVALUATION FRAMEWORK

The rule-based assessment logic used to evaluate upper limb functional performance during task-oriented rehabilitation exercises for stroke patients. All of this is done by collecting all measurements through primary sensors and translating them into clinically meaningful decisions using pre-defined thresholds derived from rehabilitation methods and the requirements of functional tasks that a person needs in his daily life. The goal is to provide new treatment methods that help patients and help us here in making decisions that benefit the treating physician to determine whether the patient has improved to move to the next stage or not based on the patient's sensor readings while he is doing the exercises. The assessment is organized by functional areas: reaching, grasping, manipulation, releasing, and manual activities. For each exercise, and the evaluated parameters.

A. Reach Function

The reaching task assesses the patient's ability to extend his arm toward the target and how quickly he reaches the target at the specified time, in a practical and controlled manner.

1) Measured Parameters

- Range of motion (ROM)
- Movement speed
- Presence of compensatory movements

2) Rule-Based Logic

Reaching task is considered functionally successful when the range of motion of the joint exceeds thresholds, the speed of movement remains within an acceptable range, and the hand follows a straight path without any deviation.

B. Grasp Function

This exercise evaluates the ability to understand the strength of the nerves in the injured hand, its ability to grasp, and coordinate finger flexion. Different object sizes challenge the patient's ability to adapt grip force appropriately.

1) Measured Parameters

- Grip force magnitude (measured using force sensors)
- Finger flexion angles (measured using flex sensors)
- Force stability and adaptation during object holding (measured using force sensors)

2) Rule-Based Logic

A grasping task is considered functionally successful when the generated grip force exceeds the predetermined minimum required to securely grip the object, the finger flexion angles reach the specified functional ranges, and the grip force remains stable without any escape for a specified time. Insufficient strength, or incomplete finger flexion, indicates that the patient's nerves are not improving and that he needs more training.

C. Release Function

The release task depends on assessing the patient's ability to open his hand, touch it with the rest of the fingers, and release an object in a controlled manner and at the specified time. This task is one of the daily activities that the disease requires in its daily life, such as placing and leaving things safely and moving smoothly between grasping and other hand movements. This exercise improves finger movements and control of the affected hand.

1) Measured Parameters

- Release time (time from initiation of finger extension to full object release (
- Finger extension speed (measured using flex sensors over time)
- Smoothness and consistency of finger opening (derived from flex sensor signal patterns)

2) Rule-Based Logic

The release task is considered a decision that the task has been successfully completed when the object is released within a specified period and the finger release speed remains within the functional limits specified for a normal human. Opening the finger quietly and continuously without delay or slowness of movement is determined by the time it takes. A prolonged release time or slow extension of the finger indicates weakness in the nerves of the finger, or increased spasticity, and these are all reasons that indicate that the patient needs to retrain this part of the hand to strengthen and improve it before progressing to more advanced functional tasks.

D. Manipulation Function

Manipulation is an assessment of the patient's ability to control small objects inside the hand after holding them, as well as moving them inside the hand, and controlling finger movements. This function reflects an advanced level of motor control and the ability to perform daily activities.

1) Measured Parameters

- Finger coordination patterns (measured using flex sensors)
- Wrist rotation angle and orientation (measured using IMU)
- Task completion time (derived from sensor timestamps)

2) Rule-Based Logic

Limited wrist movement, poor finger coordination, or long task duration indicate poor manipulation ability.

E. Bimanual Activities Function

Manual activities evaluate the coordinated use of both upper extremities during daily living. These tasks are considered different and important, but they are in the advanced stages of rehabilitation for daily life because they train the patient in the daily activities that he performs.

1) Measured Parameters

- Inter-limb movement coordination and synchronization (measured using dual IMUs)
- Force contribution of each hand (measured using force sensors)
- Finger coordination patterns of both hands (measured using flex sensors)

2) Rule-Based Logic

Bimanual performance is considered functional when both hands contribute in a coordinated and synchronized manner, the distribution of force between the hands remains within acceptable limits, and finger movements are normal. This can be achieved through mirror therapy.

TABLE VI SENSORS USED FOR UPPER LIMB FUNCTIONAL TASKS AND THEIR PURPOSE

Function	Sensors Used	Why These Sensors Are Used
Reach	IMU	IMUs measure arm motion, enabling trajectory analysis, range of motion, and compensation detection.
Grasp	Force Sensors	Force sensors measure grip force, assessing strength, variability, and modulation.
	Flex Sensors	Flex sensors measure finger bending, evaluating flexion patterns and coordination.
	Encoders	Encoders measure finger joint angles, tracking grasp dynamics and subtle movements.
Manipulation	IMU	IMUs track wrist rotation, hand orientation, and movement smoothness during manipulation.
	Force Sensors	Force sensors monitor force distribution and adjustments, essential for precise manipulation control.
Release	Force Sensors	Force sensors track grip force reduction and residual force, ensuring safe, timely object release.
	Flex Sensors	Flex sensors track finger extension angles, allowing evaluation of release timing and completeness
Bimanual Activities	Dual IMUs	Dual IMUs are used to assess temporal and spatial coordination between both hands, movement symmetry, and synchronization during bimanual tasks.
	Force Sensors	Force sensors measure force contribution of each hand and assess force symmetry during cooperative tasks such as opening jars.
	Flex Sensors	Flex sensors capture finger coordination patterns in both hands, supporting evaluation of balanced hand usage and compensation strategies.

IX. Application Interface and Feedback

The Stroke rehabilitation requires consistent, supervised exercises and careful monitoring of the patient's progress Because it is like exercising the muscles in specific movements. Many patients face challenges adhering to their rehabilitation plan due to lack of motivation, feedback, or access to therapists. HOPE mobile application was designed to bridge this gap by providing a comprehensive, interactive, and patient-centered rehabilitation platform that connects patients and therapists. This is through the patient seeing the rehabilitation system that is required to be followed and the exercises required. This is determined after the patient passes the concrete required of him, and passing the cement is the main factor in determining the exercises required of him. As for the therapist, he is the one who reviews the report and the recorded video of the patient doing the exercise for continuous follow-up and sees the extent of the patient's improvement in each session. He wanted any modification or improvement of the treatment plan. The system aims to enhance motivation, and measurable recovery outcomes through personalized exercise, real-time monitoring, and feedback.

A. Patient Side

The mobile application provides patients with a personal and interactive rehabilitation platform. Patients can log in to see daily exercise programs and assessment tasks. Each exercise includes clear instructions and visual demonstrations to ensure proper execution. During exercises, the system uses the mobile phone's camera to record the patient's movements, allowing the session to be recorded for the therapist to evaluate the patient's condition during rehabilitation. By integrating sensors in a wearable glove with task-oriented functional exercises, the system provides objective, reproducible assessment and continuous monitoring and patient encouragement to maintain clinically meaningful exercises for motor performance in unsupervised home settings.

1) During a session

a) Assessment Phase

The Patient logs in to the application and Completes a functional assessment to evaluate current abilities Results are analyzed automatically to determine which exercises the patient needs in their personalized program.

b) Exercise Selection

Based on the assessment, the system generates a customized exercise list. Exercises are displayed clearly with:

- execution Visual demonstration or video
- Step-by-step instructions
- Recommended repetitions and duration

allowing the session to be recorded for the therapist to evaluate the patient's condition during rehabilitation. By integrating sensors in a wearable glove with task-oriented functional exercises,

the system provides objective, reproducible assessment and continuous monitoring and patient encouragement to maintain clinically meaningful exercises for motor performance in unsupervised home settings.

2) After completing a session

patient performs exercises while Sensors track the performance and the app generates feedback:

a) Motivational Voice Note:

a short encouraging message from the system or therapist to reinforce engagement and boost confidence, simple encouragement during exercises: "Great! Keep going!

b) Session Summary:

- Improvement percentage compared to the previous session, highlighting progress in movement quality or repetitions.
- Total time spent on exercises throughout the week, helping patients track consistency.
- Number of exercises completed out of the total assigned, providing a clear view of adherence.

c) Visual Feedback:

simple charts and icons to indicate improvement, stability, or areas needing more focus.

3) Post-Session Guidance

- Recommendations for next session based on current performance
- Optional notes from therapist for tips or adjustments
- Patients can review recorded video to self-check movements if desired

B. Therapist Side

Therapists have access to a dedicated dashboard that allows them to effectively monitor and manage their patients' rehabilitation journey. Features include:

- Patient Profiles: containing demographic data, medical history, and rehabilitation progress.
- Rehabilitation History: detailed logs of completed exercises, performance metrics, and previous session summaries.
- Monitoring Dashboard: providing an overview of patient adherence, performance trends, and alerts for missed sessions or reported difficulties.
- Progress Reports automatically generated reports including:
  - Improvement over time (session-to-session comparison).
  - Weekly and monthly summaries of time spent, exercises completed, and progress percentage.
  - Objective analysis of movement quality captured via webcam recordings.

Therapists can adjust exercise plans, provide personalized guidance, and send feedback notes or voice messages directly through the platform. This ensures that interventions are data-driven and tailored to each patient's unique needs.

C. System Highlights

- Patient-centered design promotes motivation, engagement, and adherence.
- Sensor and Webcam-based assessment provide objective tracking of movement and performance.
- Immediate feedback supports patient progress and self-awareness.
- Comprehensive dashboards and reports enable therapists to make informed clinical decisions.
- Long-term tracking ensures measurable outcomes and continuous improvement in rehabilitation

X. Discussion

The proposed HOPE system demonstrates the potential of rule-based and sensor-based evaluation to address the major limitations of traditional upper limb rehabilitation after stroke, as they face many difficulties, especially while performing exercises alone at home and losing follow-up from home. By integrating sensors in a wearable glove with task-oriented functional exercises, the system provides objective, reproducible assessment and continuous monitoring and patient encouragement to maintain clinically meaningful exercises for motor performance in unsupervised home settings.

A. Clinical Relevance

Modern rehabilitation systems have increasingly relied on machine learning techniques to classify movement quality or predict clinical outcomes. While these methods may achieve high accuracy, the rule-based framework adopted in the HOPE system does not rely on large data sets. This makes it particularly suitable for early-stage deployment and personal rehabilitation. Furthermore, the rule-based approach ensures consistent behavior across patients and sessions.

B. Transparency of Rule-Based Logic

One of the main strengths of the proposed approach is the transparency of the existing decision logic. The classification of functional performance in HOPE is derived from pre-defined thresholds in the Menderes School of Physiotherapy and is already applied to clearly defined parameters that depend on the sensor used. Each of them measures a certain inviolability to provide new information, such as joint range of motion, grip strength, smoothness of movement, and time to complete the task. All of these outputs are useful and based on decisions by the doctor and also the system to determine the stage it has reached. The patient. This makes the system easily interpretable by doctors and therapists. This transparency enhances confidence in the system's output and facilitates clinical adoption, as therapists can understand, validate, and modify rules based on individual patient needs or clinical experience.

C. Suitability for Home-Based Rehabilitation

The design of the HOPE system is particularly suitable for home rehabilitation for patients who need to perform rehabilitation exercises continuously, as the therapist does not need to monitor the patient continuously. The use of wearable sensors embedded in a lightweight smart glove allows data to be collected comfortably for the patient during daily rehabilitation exercises. Rule-based assessment provides immediate and cumulative feedback on task performance, allowing patients to understand their progress, continually monitor their condition, and adhere more effectively to recommended treatment programs through patient encouragement. In addition, the system supports continuous follow-up of the disease and the continuous follow-up of their condition by doctors, which reduces the need for frequent personal visits and also encourages the patient to constantly perform the required exercises. This ability is especially valuable for long-term stroke recovery, especially because stroke patients need a long recovery period, as continuous practice and motivation are important for recovery.

XI. Conclusion

The limitations of traditional treatment methods, poor patient adherence, and the scarcity of objective and continuous assessment methods remain major obstacles to stroke rehabilitation, particularly the restoration of upper limb mobility. This project proposes an integrated rehabilitation framework based on activities and assessments, combining functional training with real-time, sensor-based assessment using a smart glove equipped with hand motion sensors. The system provides an assessment of movement quality, coordination, and force control which are aspects that cannot be accurately tracked through traditional observation alone. It's done by focusing on basic human hand activities such as reaching, grasping, manipulating, and releasing, as well as tasks requiring flexible use. Integrating assessment and treatment into a unified platform allows for monitoring improvements in mobility and progress in rehabilitation programs. In addition, while therapist supervision continues, periodic visits to physical therapy clinics and centers are no longer necessary thanks to remote monitoring capabilities. Overall, the proposed approach offers a patient-centered alternative that may improve functional outcomes for stroke patients by bridging the gap between anticipated rehabilitation techniques and their actual execution.

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