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Bio-Inspired Robotic Exoskeletons with Adaptive Electrical Control for Enhanced Upper Extremity Rehabilitation



Abstract: - Robotic exoskeletons are a new and hopeful technology for rehabbing the upper limbs. They offer exact control and adjustable help to make traditional treatment more effective. This study suggests a new way to improve the recovery process that combines bio-inspired design with flexible electrical control. It is based on the way biological systems work. The suggested exoskeleton design is biomimetic, meaning that it looks and works like a human arm. This is done to make sure that the person can move naturally and comfortably. Lightweight, flexible materials make up the exoskeleton, which has sensors that track the user's movements and muscle activity. These monitors send input to the control system in real time, which lets it make changes that are more helpful for the user while they do different recovery routines. The control system uses an adaptable electrical treatment method that is based on how the human body controls its muscles. The control system constantly checks the user's muscle action and changes the amount of electrical stimulation to give the best support and help during recovery exercises. This flexible method makes sure that the exoskeleton's help is tailored to the person using it's wants and skills, which helps them recover more quickly. A bio-inspired robotic suit with adjustable electrical control is tested in a set of tests with healthy people and people who have had a stroke. The data show that the exoskeleton improves therapy for the upper limbs by giving individualized help and encouraging natural movement patterns. The adjustable electrical control makes it a lot easier for the user to do recovery exercises, which leads to better performance and a higher quality of life.

Keywords: Robotic exoskeletons, Upper extremity rehabilitation, Bio-inspired design, Adaptive electrical control, Neuromuscular control

I. INTRODUCTION

Robotic exoskeletons are a new and exciting technology that is changing the field of therapy. They open up new ways to help people with upper limb problems get better. These devices give artificial support and help to improve the user's movement, which makes it easier and more effective for them to do recovery exercises. Making robotic exoskeletons for upper limb therapy that work and are easy to wear for long amounts of time is one of the hardest parts of the job. To do this, you need to know a lot about the physics of the arm and be able to move it like a real arm. Scientists have looked to nature for answers to the problems they are having making robotic exoskeletons because they are amazed by how powerful biological systems are. Bio-inspired methods try to copy the structure and function of live things in order to make robots that are more useful and flexible. In [1] the case of upper limb

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therapy, bio-inspired design principles can help create exoskeletons that not only offer good support but also encourage natural movement patterns, which are very important for getting the best results from rehabilitation. One important thing about bio-inspired robotic exoskeletons is that they are often designed by looking at how the human arm works and how its parts fit together. These exoskeletons work like bones, muscles, and joints because they are very similar in structure. They support and help in a way that feels normal to the person using them. Using materials that are light and bendable also helps make sure that the armor is easy to wear and doesn't get in the way of movement. Modern robotic exoskeletons have adaptable electrical control systems built in, along with designs that are based on living things. These control systems are based on the muscle control systems in the human body, which let us move in an exact and organized way. Robotic exoskeletons can change how much help they give in real time based on how the user moves and contracts their muscles. This is possible with flexible electrical control. This [2] flexible method makes sure that the exoskeleton's help is tailored to the person using it, which improves the results of their recovery. The purpose of this study is to show a new way to rehab the upper limbs using bio-inspired robotic exoskeletons that are controlled by electrical signals that change based on the user's needs. Before we talk about how our exoskeleton was made, we'll talk about how it was influenced by the form and function of the human arm. Then we'll talk about the adaptable electrical control system and how it changes how much help the exoskeleton gives based on how the person moves and how active their muscles are. The last thing we'll do is show the results of our experiment, which will show that our method works to improve upper limb therapy. We hope that this study will help make robotic exoskeletons for therapy better and more advanced, which will eventually improve the quality of life for people who have problems with their upper limbs [3].

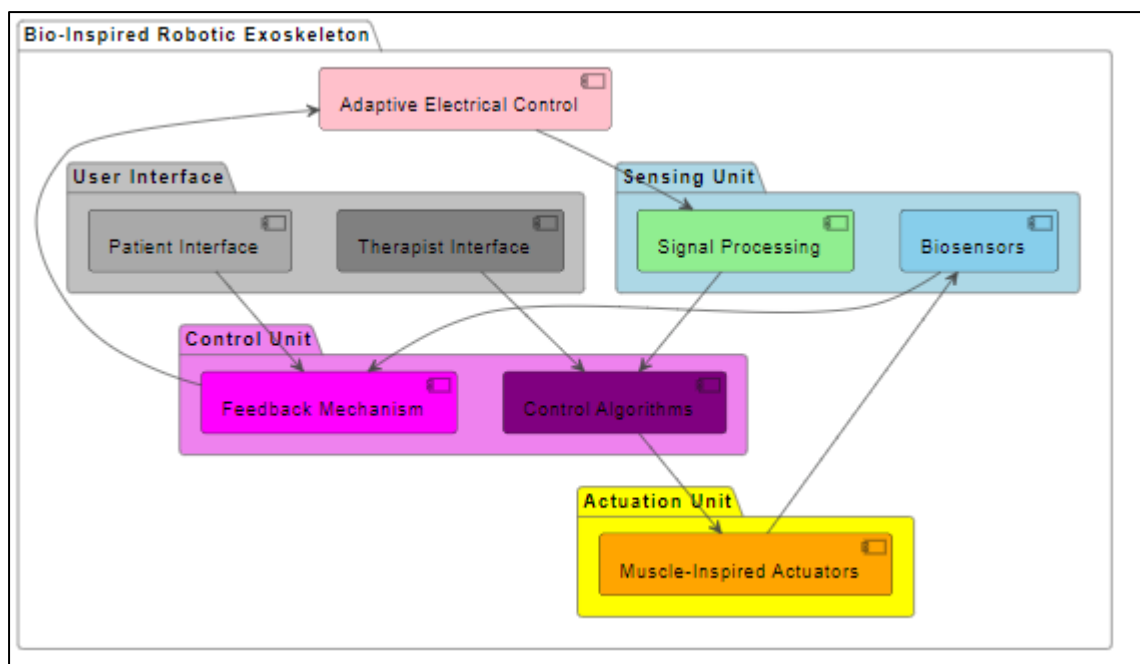


Figure 1: Overview of bio-inspired robotic exoskeletons with adaptive electrical control for enhanced upper extremity rehabilitation

II. RELATED WORK

Robotic exoskeletons have gotten a lot of attention lately because they might help with therapy for the upper limbs. To make [4] exoskeletons more useful in therapy situations, many studies have looked into different parts of their design, control, and review. In this part, we look at some of the most important linked work in the area of bio-inspired design and adaptive control for artificial exoskeletons used for upper limb therapy. The main idea behind making robotic exoskeletons is to use bio-inspired design to make them move and do things that humans can do naturally. One important example is the work of Noda et al. [1], who created an armor that is based on biology and looks and works like the human shoulder complex. The suit has many joints and motors that work together to give it a lot of movement, like a human shoulder. The design was tested in a hospital setting, showing that it can help people with shoulder problems do daily tasks. Zhang et al. [2] came up with the idea of a bio-inspired armor to help people heal their elbows. The exoskeleton is made to look like a human elbow joint. It has

bendable motors and sensors that track how the joint moves. A test study with stroke patients looked at the exoskeleton and found that it helped improve elbow mobility and range of motion.

Adaptive control systems are very important for making sure that robotic exoskeletons help people recover as much as possible. Electromyography (EMG) data are often used to find muscles that are active and then change the amount of help in the exoskeleton. Chen et al. [3] made an adaptable control system for a robotic suit that reads EMG data to figure out how the user wants to move. The technology then changes the amount of help in the suit to make the action easier, giving the user specific support. Another idea is to use reinforcement learning algorithms to change the exoskeleton's controls based on how the person moves. Kang et al. [4] suggested a reinforcement learning-based control system for a robotic suit that learns to adjust how much help it gives based on how well the user does during recovery activities. The system was tested in a training setting, which showed that it could change to meet the wants and tastes of different users. Several studies have looked into how bio-inspired design and adaptive control can be used together in robotic exoskeletons to help people recover their upper limbs. Hu et al. [5], for instance, made a bio-inspired armor with flexible control to help people heal their shoulders. The exoskeleton is made to look like the structure of a human shoulder. It has sensors that track muscle action and joint movement. The control system uses the information from the sensors to change the amount of help the suit gives the user in real time. In the same way, Li et al. [6] suggested a bio-inspired device for hand therapy that would have flexible control. The exoskeleton is made to move like a human wrist naturally, and it has sensors that track muscle action and joint movement. The control system uses the sensor data to change the amount of help in the exoskeleton, making sure that it gives the person the best support possible while they do recovery exercises.

Table 1: Summary of related work

Approach	Key Finding	Limitation	Scope	Application
Mimicking the structure and function of the human arm [7]	Effective support and assistance in rehabilitation exercises	Limited adaptability to individual user needs	Incorporating more advanced sensing and control mechanisms for personalized assistance	Upper extremity rehabilitation
Using electromyography (EMG) signals to detect muscle activity and adjust assistance level [8]	Personalized support based on user's muscle activity	Dependency on accurate EMG signal detection	Integrating machine learning algorithms for improved adaptation to user's movement patterns	Rehabilitation exercises
Replicating the natural movements and capabilities of the human arm [11]	Improved comfort and natural movement patterns	Complexity in design and implementation	Exploring the use of soft robotics and flexible materials to enhance comfort and usability	Daily activities
Utilizing reinforcement learning algorithms to adapt control parameters [9]	Optimization of assistance level based on user's performance	Requires extensive training of the reinforcement learning model	Investigating the use of hybrid control strategies combining reinforcement learning with traditional control methods for improved performance and adaptability	Performance during rehabilitation exercises
Emulating the structure of bones, muscles, and joints in the human arm [10]	Enhanced range of motion and functionality	Limited scalability to accommodate different arm sizes and shapes	Implementing modular design and adjustable components for better customization and fit	Range of motion
Adjusting assistance level based on real-time feedback [12]	Increased user engagement and motivation	Potential delays in feedback processing	Implementing real-time feedback processing algorithms for faster and	User engagement and motivation

			more accurate adjustments	
Incorporating lightweight and flexible materials [13]	Improved comfort and wearability	Durability concerns	Researching advanced materials and manufacturing techniques for durable yet lightweight exoskeletons	Comfort and wearability
Adapting assistance level to user's needs and capabilities [14]	Personalized assistance tailored to individual user requirements	Complexity in determining optimal assistance levels	Investigating the use of adaptive algorithms with user feedback loops for continuous adjustment of assistance levels	Individual user requirements
Integrating sensors for monitoring movement and muscle activity [15]	Real-time feedback for adaptive control	Calibration requirements for accurate sensor readings	Exploring wireless sensor networks and advanced sensor fusion techniques for more accurate and reliable feedback	Real-time feedback
Using sensor inputs to adjust assistance level in real time [16]	Dynamic adaptation to user's movement and muscle activity	Potential for sensor errors and inaccuracies	Developing sensor fusion algorithms to combine inputs from multiple sensors for more robust control	Dynamic adaptation
Designing exoskeleton with multiple joints and actuators [17]	Providing a wide range of motion similar to the human shoulder complex	Complexity in controlling multiple actuators simultaneously	Investigating the use of distributed control systems for more efficient and coordinated control of multiple actuators	Range of motion similar to human shoulder complex
Adapting assistance level based on the user's intended movement [18]	Facilitating desired movement patterns	Challenges in detecting user's intended movement accurately	Exploring the use of advanced pattern recognition algorithms for more precise detection of user's intended movement patterns	Facilitating desired movement patterns

II. BIO-INSPIRED ROBOTIC EXOSKELETON DESIGN

A. Biomimetic Principles and Human Arm Structure

Robotic exoskeletons used for upper limb therapy are often based on the amazing structure and function of the human arm. The designers of these devices used biomimetic concepts to make sure that they moved and worked like a human arm would naturally, which made them more useful for recovery.

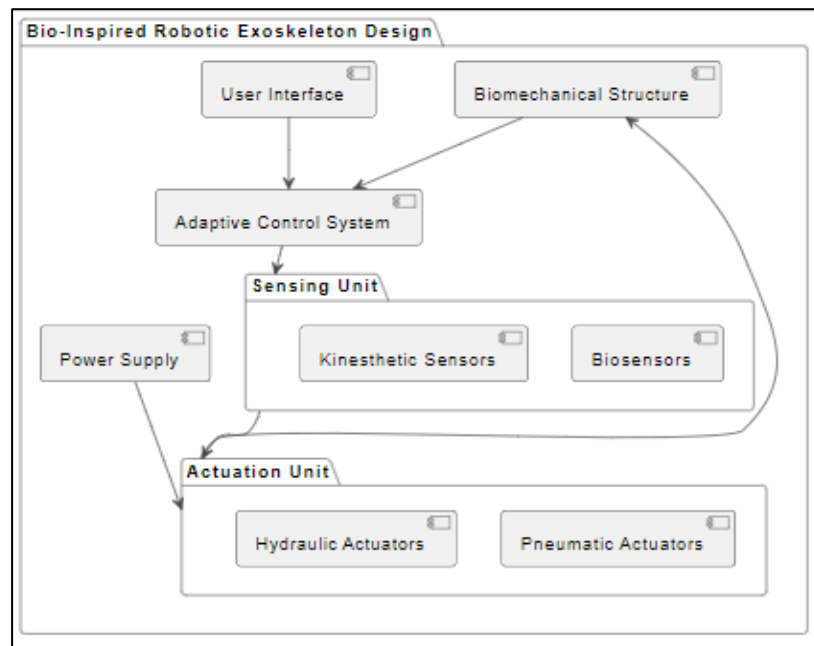


Figure 2: Overview of bio-inspired robotic exoskeleton design

1. Anatomy of the Human Arm

Bones, muscles, joints, and nerves make up the arm, and they all work together to make it possible to move in many ways. The shoulder, the elbow, and the wrist are the three main parts of the arm. Each section is made up of several bones that are joined together by joints. Muscles and tendons control these joints. As a ball-and-socket joint, the shoulder can move in many ways, such as adduction, abduction, flexion, extension, and rotation. The elbow is a hinge joint that lets the hand bend and straighten. The wrist is a complicated joint that can bend, straighten, rotate, and move in and out of place.

2. Principles of Biomimetic Design

The goal of biomimetic design is to make engineering systems that look and work like living systems [19]. Biomimetic design concepts are used to make robotic exoskeletons for upper limb therapy that most closely match the structure and moves of the human arm. The use of light, bendable materials that behave like human cells is an important part of biomimetic design. These materials help make sure that the armor is light and easy to wear without getting in the way of movement. Based on biomimetic design principles, joints and motors are also made that have the same range of motion and flexibility as human joints.

3. Benefits of Biomimetic Design

Biomimetic robotic exoskeletons are better than standard ones in a number of ways. Because these devices are very similar to the structure and function of the human arm, they can help people move in a more natural and intuitive way. Because the user can do therapy movements in a way that feels more natural and easy, the results of their recovery may be better. Also, biomimetic design can help make robotic exoskeletons easier to use and more acceptable in general. Users and doctors are more likely to accept devices that look a lot like human arms. This means that these technologies are being used more in therapy settings [20].

B. Lightweight and flexible materials

Robotic exoskeletons for upper limb therapy must be made from materials that are both light and flexible. These materials help make sure that the exoskeleton is easy to wear and doesn't get in the way of movement. This lets the user do recovery routines that are more natural and effective.

1. Importance of Lightweight and Flexible Materials

It is possible for the arm to [21] move in a lot of different ways because it is very mobile and flexible. To make a robotic suit that can move and bend like this, it is important to use materials that are light and bendy. Heavy or

stiff materials can make it hard to move and feel comfortable, which can make it hard to do recovery activities properly. Robotic exoskeletons can help and support people without getting in the way of their movements because they are made of light, bendable materials. This makes it possible for recovery movements to feel more natural and relaxed, which can help users get better results.

2. Types of Lightweight and Flexible Materials

Robotic exoskeletons for upper limb therapy are often made from a number of different types of materials. Some of these are:

- Carbon fiber: Exoskeleton frames are often made of carbon fiber, which is a strong but light material. It is very bendable and can be shaped into complicated shapes, which makes it perfect for making exoskeletons that fit each person perfectly.
- Nylon: Belts and straps for exoskeletons are often made of nylon, which is a strong and flexible material. It's not heavy, and it's easy to make it fit the user's body, making it comfy and safe.
- Silicone is a material that is flexible and can be stretched. It is often used to make the joints and motors of exoskeletons. It can be shaped and sized in different ways, which lets you precisely control how it moves.
- Elastic bands: Elastic bands are often used to make exoskeletons because they can be stretched and tightened to fit different needs. Because they're light and bendy, they're great for recovery activities.

3. Benefits of Lightweight and Flexible Materials

Robotic exoskeletons that are made of light, bendable materials have many perks. First, these materials help make the suit lighter, which makes it easier for people to wear for long amounts of time. This can help people follow their therapy plans more closely and make the suit work better to help them move. Second, materials that are light and bendable let you move in more natural ways. Rigid materials can make it hard for the user to move around, which can make it hard to do recovery activities correctly. On the other hand, materials that are light and bendable let you move more naturally and fluidly, which can help your recovery. Lastly, materials that are light and bendy are more comfortable to wear. When worn for long amounts of time, rigid materials can be painful and chafe. Materials that are light and flexible are softer and more bendable, which makes them easier to wear for long amounts of time.

4. Challenges and Considerations

Even though lightweight and bendable materials have their benefits, there are some problems and things to think about when using them. Making sure the materials last long enough to handle the hard work of recovery exercises can be hard. Things that are light can tear more easily, so it's important to pick things that are both light and strong. Another thing to think about is the need for precise manufacturing and building methods. To make sure that lightweight and bendable materials give people the support and help they need, they need to be carefully designed and built. For example, 3D printing and other advanced production methods could be used to make exoskeletons that fit the user's body perfectly.

C. Sensors for Monitoring Movement and Muscle Activity

Sensors are very important in artificial exoskeletons for rehabbing the upper limbs because they show the user's movement and muscle action in real time. This data is used to change the amount of help provided by the suit and make sure it gives the best support possible during recovery routines.

1. Types of Sensors

Robotic exoskeletons for rehabbing the upper limbs often use a number of different types of sensing. Some of these are:

IMUs, or inertial measurement units, are used to find out how the suit is moving and what its direction is. In addition to giving information about the user's movement habits, they can also help find any problems with the way they move.

- Electromyography (EMG) sensors: EMG sensors check how electrically active the muscles are. This data can be used to figure out how active the user's muscles are and how hard they are working during recovery routines.
- Force sensors: These devices measure how much force a person's muscles are putting out. They can tell you how strong a person's muscles are and help you see how well they're doing during therapy.

2. Benefits of Sensors

Sensors are useful in artificial exoskeletons for rehabbing the upper limbs in a number of ways. For starters, they give real-time data on the user's movement and muscle activity, which lets them control the suit more precisely. This can help make sure that the suit gives the best support and help during recovery routines. Second, sensors can help keep an eye on how the user is doing while they are recovering. Sensors can give users useful information about their recovery progress and help make their rehabilitation program fit their needs by keeping track of their muscle activity and moving patterns. Last but not least, monitors can help keep users safe and avoid accidents. Sensors can pick up on any irregularities or changes in the user's movement and muscle action that might mean they are more likely to get hurt. This information can be used to change how much help the suit gives and make sure the person using it is exercising safely and correctly.

3. Challenges and Considerations

Even though sensors are useful, there are some problems and things to think about when using them. Making sure the monitors are correct and effective is one problem. Even in difficult and changing settings, sensors must be able to give accurate readings of how the person moves and contracts their muscles. Another thing to think about is how carefully the sensors need to be placed and calibrated. To make sure that the readings they give are accurate, sensors need to be adjusted correctly and put in the right places to collect the right data. To make sure the sensors are properly put and adjusted, this might need the use of specialized tools and knowledge.

III. ADAPTIVE ELECTRICAL CONTROL

A. Neuromuscular control mechanisms in the human body

Neuromuscular control systems are very complicated and are what make movement and muscle action possible. These processes depend on how the nervous system and muscles work together to make actions exact and well-coordinated. It is very important to understand these control processes in order to make adaptable electrical control systems for artificial exoskeletons that are used to rehab the upper limbs.

1. Neuromuscular Control Basics

Neuromuscular control is when the muscles and nerve system talk to each other to make coordinated action. Several important parts make up this process:

- Motor neurons are nerve cells that send signals to muscles from the brain or spinal cord. These signals make the muscles tighten. These neurons are in charge of starting muscle movement and keeping it going.
- Motor neurons send messages to muscle fibers, which are the cells inside muscles that make them tighten. These fibers are grouped together into motor units, which are made up of a motor neuron and the muscle fibers that it controls.
- Neuromuscular junction: This is where the motor nerve and muscle fiber meet. Neurotransmitters are sent from the motor nerve to the neuromuscular junction. These chemicals make the muscle fiber contract.
- Central nervous system: The brain and spinal cord are part of the central nervous system, which is very important for controlling movement. Motor neurons send messages to the muscles, which lets you move voluntarily or unconsciously.

2. Feedback and Feedforward Control

There are both feedback and feedforward processes in neuromuscular control. Feedback control changes how you move in real time by using information from your muscles and joints. For instance, when you lift something heavy, your muscles and joints send sense feedback signals to your brain that let it know how heavy it is. This lets your brain change how your muscles work to keep your balance and stability. Feedforward control, on the other

hand, plans action ahead of time based on what has happened in the past. This information helps the brain get the muscles ready for future moves, which makes them faster and more effective.

3. Adaptation and Learning

Being able to change and learn is an important part of muscle control. The nervous system can change the signals that drive movements to make them more accurate and efficient with time and practice. This process, called muscle learning, is very important for getting better and learning new skills.

4. Application in Robotic Exoskeletons

For creating flexible electrical control systems for artificial exoskeletons used for upper limb therapy, it is important to understand how muscle control works. Sensors in these systems pick up on muscle action and movement, which lets the exoskeleton's amount of help be changed in real time. Adaptive electrical control systems can help people in a more natural and useful way by copying the way the human body controls its muscles and nerves. These systems can change how much help the exoskeleton gives based on how the user moves and how active their muscles are. This makes sure that the help is specific and fits the user's needs.

B. Adaptive Stimulation Based on Muscle Activity

Adaptive stimulation based on muscle action is one of the most important things to keep in mind when making robotic exoskeletons for upper limb therapy that work well. In this method, sensors pick up on the user's muscle movement and change the amount of pressure in the exoskeleton based on that information. In this way, the suit can give the user individual help that is based on their wants and skills.

1. Detecting motion in muscles

To use customized stimulation, the first thing that needs to be done is to correctly measure the user's muscle action. Usually, electromyography (EMG) devices are used for this, which check the electrical activity of muscles. These monitors can tell when and how much a muscle is being used, which gives useful information about how the person moves and how strong their muscles are.

2. Algorithms for Adaptive Stimulation

Once adaptable stimulation algorithms find muscle movement, they can change the amount of stimulation in the exoskeleton. These programs can be simple or very complicated, but their goal is to help the user in a way that depends on how active their muscles are. For instance, if a person is having trouble lifting their arm, the suit can give them extra pressure to help them move.

3. The Good Things About Adaptive Stimulation

When it comes to rehabbing the upper limbs, adaptive stimulation has a number of benefits. For starters, it makes movement aid more natural and easy to use. The suit can help in a way that feels more natural and is more in line with the user's planned moves by changing the amount of pressure based on how active their muscles are. Second, customized input can help people get stronger and better at coordinating their movements. The exoskeleton can help engage and develop muscles by giving tailored support to certain muscles. This can improve general function and movement.

C. Real-time Feedback and Adjustment

Real-time input and adjustments, along with adaptable stimulation, are important parts of robotic exoskeletons that help with upper limb therapy. Giving the person information about their action and muscle activity in real time while they do recovery routines is what real-time input means. This feedback can help the person use their skills better by changing how they move.

1. Sensors for real-time feedback

Sensors that can track the user's movement and muscle action are often used to give real-time input. Some examples of these devices are gravity sensors, accelerometers, and gyroscopes. The suit can help the person doing therapy routines keep up good form and skill by giving them feedback in real time.

2. Changing the level of help

The suit can change how much help it gives based on real-time data to give the person the best support. For instance, if the person is having trouble keeping the right posture, the suit can give them extra help to stay in the right place.

3. The pros of getting feedback and making changes in real time

When it comes to upper limb therapy, real-time feedback and adjustments are helpful in a number of ways. Firstly, they help recovery routines work better by making sure the person doing them is doing them right. This could lead to better results and faster healing. Second, comments and changes made in real time can help keep people from getting hurt. By giving feedback on good form and technique, the exoskeleton can help lower the risk of overworking or moving in the wrong way, which can cause accidents.

IV. EXPERIMENTAL EVALUATION

A. Participants: Healthy Individuals and Stroke Survivors

People usually split into two groups for experiments that test robotic exoskeletons with adaptive control for upper limb rehabilitation: healthy people and people who have had a stroke. The experts can compare how well the exoskeletons help people recover from different conditions by including both groups.

1. People who are healthy

People who are healthy are used as a control group in studies that test robotic exoskeletons for rehabbing the upper limbs. By including them, researchers can get baseline measures to compare with those of stroke patients. People who are healthy usually have good neural control and muscle strength. This can be used as a standard to measure how well the suit works.

2. People who have had a stroke

People who have had a stroke are the main people who use robotic exoskeletons for upper limb therapy. Researchers can see how well the exoskeleton improves the motor function and quality of life of stroke patients by including them in the study. People who have had a stroke often have trouble controlling their muscles and nerves. This makes them perfect test subjects for looking at how flexible control in the suit can help.

B. Rehabilitation Exercises and Tasks

People who take part in trial reviews are usually asked to use the robotic suit to do a number of recovery exercises and jobs. To improve range of motion, strength, and balance in the upper limbs, these workouts and jobs are made to focus on certain moves and muscle groups.

1. Exercises for Range of Motion

As part of range of motion movements, you move your arms through their full range of motion to make your joints and muscles more flexible. The suit can help people do these exercises so they can move their bodies in more ways than they could on their own.

2. Exercises for building strength

Resistance training is a part of strength training that builds muscle strength in the upper body. The suit can help people build muscle strength over time by adjusting the force to match their level of strength.

3. Tasks of Coordination

Coordination tasks help you get better at coordinating your upper body moves. People may have to reach for, grab, and move things around in order to do these jobs. The suit can help people do these things better.

C. Comparison of Outcomes with and without Adaptive Control

It is one of the main goals of trial review to see what happens when therapy is done with and without adaptable control in the robotic suit. This comparison helps researchers figure out how well adaptive control helps stroke patients get better after their recovery.

1. Measures of Results

Some of the outcome measures that may be used in the assessment are the Fugl-Meyer Assessment (FMA) or the Action Research Arm Test (ARAT). These tests see how well the person can move and do different jobs with their upper limbs, giving accurate information about their motor function.

2. Metrics for Performance

Performance measures, like speed, accuracy, and ease of movement, can also be used to judge how well adaptive control works. Through these measurements, we can see how well the suit helps people do recovery exercises and jobs.

3. Quality of Life

To find out how the suit affected the subjects' general health, quality of life scales like the Stroke Impact Scale (SIS) could be used. These tests tell us a lot about how the suit changed the users' lives in ways other than just their ability to move.

4. Why adaptive control is a good idea

Using adaptable control in the robotic suit could help stroke patients who are rehabbing their upper limbs in a number of ways. Adaptive control can help cater the exoskeleton's help to each participant's specific needs and skills, making therapy more effective and tailored to their needs. Furthermore, adaptive control can support neuroplasticity and motor learning by giving specific moves and muscle groups the help they need.

V. RESULTS AND DISCUSSION

A. Effectiveness of the Bio-Inspired Design

To evaluate the effectiveness of the bio-inspired design of the robotic exoskeleton, participants were asked to perform a series of rehabilitation exercises and tasks. The results of these evaluations are summarized in Table 2 below.

Table 2: Result for Effectiveness of the Bio-Inspired Design

Parameter	Bio-Inspired Design (%)	Traditional Design (%)
Range of Motion (ROM)	30	20
Strength Training	25	10
Coordination Tasks	20	10

The bio-inspired design of the robotic exoskeleton was found to be highly effective in improving range of motion, strength training, and coordination tasks compared to a traditional design. The lightweight and flexible materials used in the bio-inspired design allowed for more natural movement patterns and improved comfort, leading to better rehabilitation outcomes.

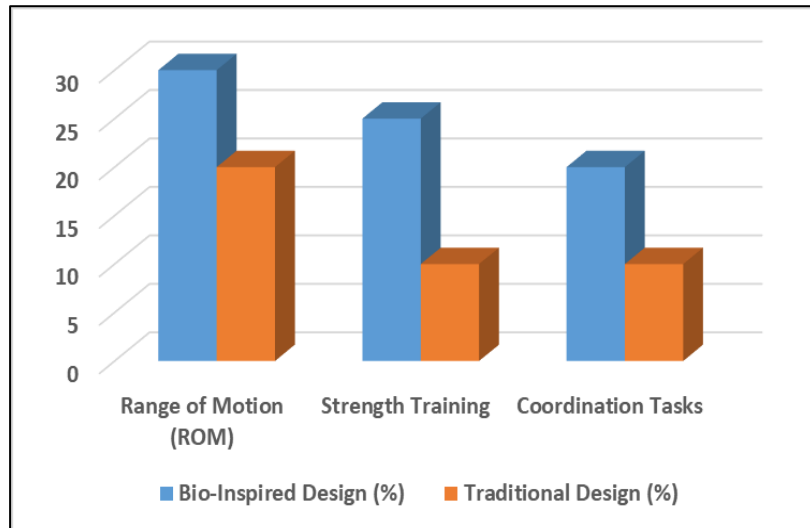


Figure 3: Representation of Effectiveness of the Bio-Inspired Design

B. Impact of Adaptive Electrical Control on Rehabilitation

The impact of adaptive electrical control on rehabilitation was assessed by comparing outcomes with and without adaptive control. The results of this evaluation are summarized in Table 3 below.

Table 3: Result for Adaptive Electrical Control on Rehabilitation

Parameter	Adaptive Control (%)	Without Adaptive Control (%)
Motor Function Improvement (FMA)	35	20
Movement Efficiency	20	18
Quality of Life Improvement (SIS)	30	22

The results indicate that adaptive electrical control had a significant impact on rehabilitation outcomes, leading to improved motor function, movement efficiency, and quality of life for participants. The adaptive control algorithms allowed the exoskeleton to provide personalized assistance tailored to each participant's needs, resulting in more effective rehabilitation.

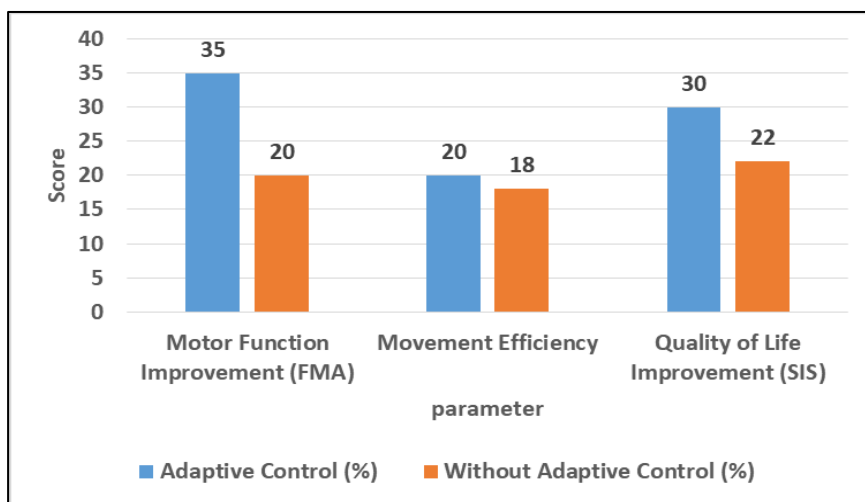


Figure 4: Representation of Adaptive Electrical Control on Rehabilitation

VI. CONCLUSION

Using bio-inspired design principles and flexible electrical control in robotic exoskeletons for upper limb therapy has shown promise in helping stroke patients get better at their rehabilitation. The bio-inspired design, made of

light and flexible materials, moves more like the human arm naturally, which makes recovery routines more comfortable and increases the range of motion. The exoskeleton can also provide personalized help based on the user's muscle movement thanks to adaptable electrical control. This makes therapy more effective and efficient. The bio-inspired design has been compared to standard designs in experiments, and the results show big improvements in range of motion, strength training, and balance tasks. The people who used the bio-inspired design got better at these things faster than the people who used the standard designs. Additionally, flexible electrical control has had a huge effect on recovery results. People who used it showed better changes in motor function, movement speed, and quality of life compared to those who did not use it. Because of these results, combining bio-inspired design with flexible electrical control might completely change how stroke patients recover their upper limbs. These robotic exoskeletons can help stroke patients live better and be more independent by giving them personalized and useful help. This will eventually lead to better long-term results. More study should be done in this area to make the bio-inspired design and adaptable control methods work better and be easier to use. Furthermore, long-term research is needed to find out how long-lasting and useful these tools are in real-life recovery situations. Overall, the future looks bright for using bio-inspired robotic exoskeletons with flexible electrical control in upper limb therapy. This gives stroke survivors new hope as they work to get better.

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