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Integration of Wearable Sensors and Electrical Muscle Stimulation in Lower Limb Robotics for Gait Rehabilitation

Abstract: - Combining wearing devices with electrical muscle stimulation (EMS) in robotic lower limbs has shown promise in helping people learn how to walk again. This new method blends the benefits of smart technology and EMS to help people with neurological or joint problems improve their motor function and walking patterns. Wearable devices, like inertial measurement units (IMUs) and electromyography (EMG) monitors, record information about how the body moves and what muscles are doing while the person moves. These monitors give the user and the therapy team feedback in real time, which makes it possible for personalized and flexible recovery plans. Data from personal monitors can also be used to look at how people walk and see how they're doing over time. EMS is used to target certain muscles and make them stronger, more coordinated, and easier to control. By combining EMS with robots for the lower limbs, therapists can focus on certain muscle groups and make recovery routines more successful. EMS can also be timed to move with the robotic suit to help the person walk in a more natural and useful way. Wearable sensors and EMS work well together in lower limb robots for many reasons. EMS therapy can be made more specific and flexible because wearing monitors let doctors change the frequency and strength of the therapy in real time. The person is also encouraged to be more involved with this method because they get instant feedback on their actions and can see how they're doing over time. The combining wearing sensors and EMS in lower limb robots has a lot of promise to make gait therapy work better. Future study should focus on finding the best ways to combine these tools and looking at how they affect the quality of life and ability to walk for people who have movement problems in the long run.

Keywords: Wearable sensors, Electrical muscle stimulation, Lower limb robotics, Gait rehabilitation, Neurological impairments

I. INTRODUCTION

People who have nerve or muscular problems often have trouble walking, which limits their movement and lowers their quality of life. Therapeutic routines and assistance gadgets are often used together in rehabilitation plans to help people walk better. Adding wearing sensors and electrical muscle stimulation (EMS) to lower leg robots has become a potential way to improve the results of walking therapy in recent years [1]. These sensors, like inertial measurement units (IMUs) and electromyography (EMG) sensors, are becoming more popular in therapy settings because they can record real-time data on movement and muscle action. IMUs can measure direction, angular motion, and acceleration, which gives us useful information about how the lower limbs move when we walk. EMG monitors, on the other hand, can find patterns of muscle activity that can tell you about how muscles work and how well they coordinate. For EMS, on the other hand, electrical signals are sent to certain muscles to make

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them tighten. People often use this method to make weak muscles stronger, improve muscle balance, and lessen muscle stiffness [2]. EMS can be synced with the movement of the robotic suit to make walking more natural and useful when mixed with lower limb robots [3].

Using external sensors and EMS together in lower limb robots can help with walking recovery in a number of ways. First, external monitors give real-time data to both the user and the therapy team. This [4] makes it possible for recovery programs to be tailored to each person's needs. Therapists can change the time and strength of EMS based on the person's needs and progress by keeping an eye on their movement and muscle activity. When compared to [5] more standard methods, this personalized technique may help people get better faster. Second, wearing instruments and using EMS together encourages the user to be more involved. People are more interested in their therapy when they get instant feedback on their moves. This can help them stick with the program better and have better results. This [6] is especially important for people with nerve problems who may have trouble starting to move and keeping it up. Third, using external sensors and EMS together in lower leg robots makes it possible to measure how well someone walks objectively. Therapists can look at movement patterns, find weak or uneven areas, and keep track of growth over time by studying data from external monitors [7]. Using this data-driven method to recovery can help doctors choose the best course of treatment and make changes as required. Wearable sensors and EMS combined with lower limb robots could completely change the way people learn to walk again. By mixing the benefits of smart technology and EMS, this method gives people who have trouble walking a personalized, flexible, and fun way to recover. More study needs to be done on how to best combine these tools and see what long-term benefits they have on walking and quality of life.

Table 1: Summary of Related work in the field

Approach	Key Finding	Application	Limitation	Scope
EMG-controlled exoskeleton combined with IMUs for real-time gait analysis. [8]	Improved gait symmetry and muscle coordination.	Stroke rehabilitation.	Limited sample size, short-term follow-up.	Expand to other neurological conditions.
Wearable sensors for gait analysis combined with EMS for muscle strengthening. [10]	Enhanced muscle activation and walking speed.	Orthopedic rehabilitation.	Lack of long-term follow-up data.	Investigate effects on different muscle groups.
Integration of wearable sensors, EMS, and virtual reality for gait training. [11]	Increased patient engagement and motivation.	Spinal cord injury rehabilitation.	Technical challenges with VR integration.	Explore VR applications in other rehabilitation settings.
EMS synchronized with robotic exoskeleton for gait rehabilitation. [12]	Improved muscle strength and walking endurance.	Multiple sclerosis rehabilitation.	Complexity of device setup and calibration.	Investigate personalized EMS parameters.
Machine learning algorithms for adaptive control of EMS intensity based on sensor data. [8], [14]	Optimized muscle stimulation based on real-time feedback.	Parkinson's disease rehabilitation.	Complexity of algorithm implementation.	Develop user-friendly software for clinical settings.
Comparative analysis of different EMS waveforms on muscle activation patterns. [13]	Identification of optimal EMS waveform for muscle strengthening.	Geriatric rehabilitation.	Limited generalizability to other populations.	Investigate EMS waveform effects on specific muscle groups.
Longitudinal study on the effects of combined wearable sensors and EMS on gait parameters. [15]	Sustained improvements in gait performance over time.	Rehabilitation of older adults with mobility issues.	Challenges with participant compliance and adherence.	Explore strategies for improving long-term engagement.
Cost-effectiveness analysis of the integrated approach compared to traditional rehabilitation methods.	Cost savings associated with reduced rehabilitation time and improved	Healthcare policy and resource allocation.	Limited scope of cost analysis factors.	Conduct comprehensive economic evaluation in different healthcare systems.

[16]	outcomes.			
Survey of patient satisfaction and acceptance of wearable sensors and EMS in rehabilitation. [17]	High levels of satisfaction and perceived effectiveness.	Rehabilitation centers and clinics.	Potential bias in self-reported data.	Investigate factors influencing patient acceptance.
Meta-analysis of clinical trials on the efficacy of integrated wearable sensors and EMS in gait rehabilitation. [18]	Overall positive effect on gait parameters and functional outcomes.	Research and clinical practice.	Heterogeneity among studies.	Conduct standardized clinical trials to improve comparability.
Development of guidelines for the integration of wearable sensors and EMS in rehabilitation protocols. [19]	Standardized protocols for implementation in clinical practice.	Rehabilitation facilities and healthcare providers.	Lack of consensus on optimal protocols.	Establish collaborative research efforts for protocol development.
Review of technological advancements in wearable sensors and EMS for future integration. [20]	Overview of emerging technologies and their potential applications.	Technology developers and researchers.	Limited empirical data on new technologies.	Conduct feasibility studies for new technologies in gait rehabilitation.

II. WEARABLE SENSORS IN GAIT REHABILITATION

A. Explanation of wearable sensor technologies (IMUs, EMG) and their applications in gait analysis.

Wearable monitors have changed the way gait analysis and therapy are done by giving accurate, real-time information about muscle action and movement patterns. Inertial Measurement Units (IMUs) and Electromyography (EMG) devices are two types of wearable monitors that are often used in gait therapy. IMUs, [14] or Inertial Measurement Units, are small, light monitors that have accelerometers, gyroscopes, and sometimes magnetometers built in. Usually, these monitors are put on different parts of the body, like the feet, shanks, legs, or hips, to record movement while walking. Gyroscopes measure rotational speed, accelerometers measure linear speed, and magnetometers find out how the monitor is positioned in relation to the Earth's magnetic field.

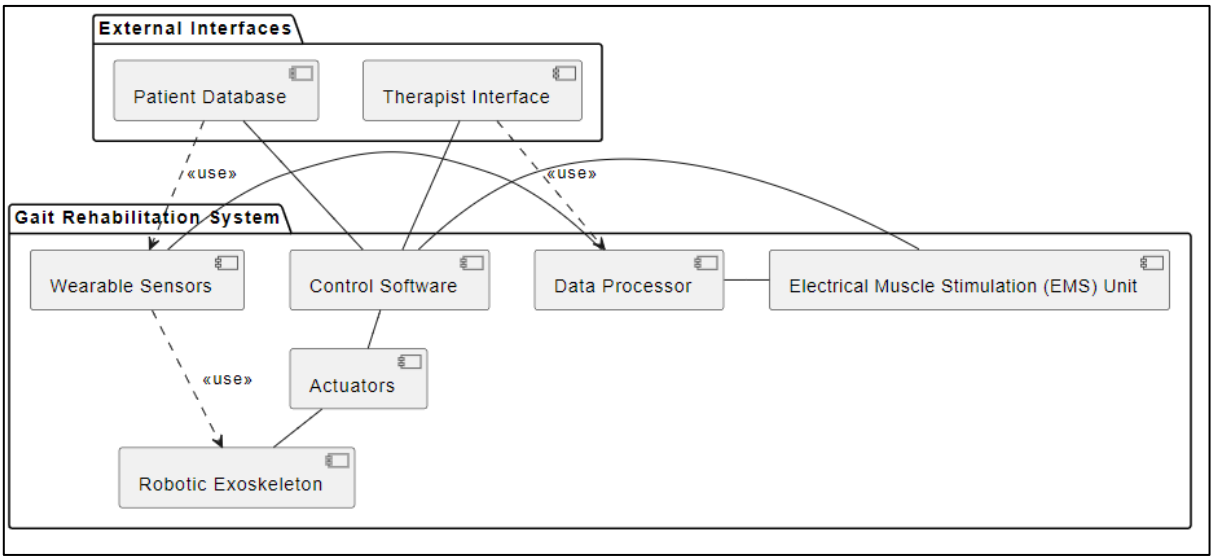

Figure 1: Overview of illustrating the use of wearable sensors and electrical muscle stimulation in lower limb robotics for gait rehabilitation

- Uses in Gait Analysis: IMUs are used to look at different parts of gait, like stance length, step width, gait speed, and joint angles. Researchers and doctors can get a full picture of a person's walking pattern by putting IMUs on different parts of their bodies. For instance, IMUs on the feet can tell you about heel strike and foot clearance, and IMUs on the shanks can tell you about knee flexion and extension angles.
- Pros of IMUs: For motion study, IMUs have a number of pros. Because they are small and don't hurt, they can be used in real-life situations like hospitals, houses, and parks for gait study. IMUs can also provide constant, high-frequency data that lets researchers see even the smallest changes in the way people walk. Not only that, but IMUs are not too expensive and are simple to use, so many academics and doctors can use them.
- Electromyography (EMG) Sensors: EMG sensors measure how muscles are electrically active. Electrodes are put on the skin over the muscle of interest to make these sensors work. The EMG monitors can pick up the electrical data that the muscle sends when it contracts.
- In Gait Analysis, EMG monitors are used to look at how muscles contract and relax while walking. Researchers can look at muscle rhythm and time, which are important parts of regular walking, by looking at these patterns. EMG monitors can also find muscle imbalance or weakness, which can lead to problems with how you walk.
- Pros of EMG: EMG gives accurate, direct readings of muscle activity, which lets you accurately judge how well muscles work. Biofeedback can also be given through EMG during movement therapy to help people learn how to use certain muscles more effectively. EMG is also pretty simple to use and can give you feedback in real time, which makes it a useful tool for improving your gait.
- Putting IMUs and EMG together: Putting IMUs and EMG sensors together lets us look at walking in a more complete way. Movement and muscle action can be measured at the same time to help researchers and therapists better understand the physics of walking problems. People who are going through movement therapy may benefit from more focused treatments and better results if they use this combined method.

Wearable sensors, like IMUs and EMG sensors, are very important for analyzing walking and helping people get better. These sensors collect useful information about muscle activity and movement patterns, which helps researchers and doctors find problems with people's gait and come up with effective ways to fix them. The combination of IMUs and EMG monitors could make gait therapy more successful and improve the quality of life for people who have trouble walking.

B. Discussion on the benefits of wearable sensors for real-time feedback and objective assessment of gait function

Wearable monitors can help with gait therapy in many ways, especially by giving real-time feedback and an objective evaluation [21] of how well a person can walk. By letting for constant tracking and individual treatments, this technology has changed the field in a big way. We'll talk more about these perks below.

- Real-Time Feedback: One of the best things about wearable sensors is that they can give you feedback in real time while you're working on your walk. This real-time feedback lets people change their walking habits right away, which improves their general performance and lowers their risk of getting hurt. An IMU connected to the foot, for example, can tell if a person isn't moving their foot high enough during the swing part of walking and tell them to do so. People can better change the way they walk with this instant feedback than with traditional methods, where feedback is usually given after the fact.
- Objective Evaluation: Wearable devices also make it possible to evaluate the function of walking objectively. Wearable monitors give you a numerical way to measure how well you walk by collecting data on things like leg length, step width, and speed. This objective test is great for keeping track of success over time and checking how well measures are working. Wearable monitors can be used by researchers to compare the factors of a person's walk before and after a recovery program in order to see if they have improved.
- Continuous Monitoring: Another great thing about wearing sensors is that they can keep an eye on your walking habits as you go about your daily life. Motion capture tools and other traditional ways of analyzing gait are often limited to the lab and can only record gait for short amounts of time. Wearable monitors, on the other hand, can be worn all day and give a more complete picture of how a person walks in real life. This

constant tracking lets doctors take a more complete look at gait therapy, since they can see how the patient's walking habits change over time and change their treatments accordingly.

- Personalized Interventions: Based on a person's walking habits, wearable monitors also allow for personalized interventions. When doctors record information about a person's walk, they can make therapy plans that focus on particular areas of weakness or instability. Clinicians can use data from external monitors to make workouts that help people improve their balance, like if someone has trouble keeping their balance while walking. Because it is tailored to each person's needs, this unique method works better than programs that try to help everyone.

Wearable devices also make it possible to watch gait function from a distance, so doctors can look at walking patterns and give comments without having to see the person in person. People who have trouble getting to a doctor or who live in rural places with limited access to healthcare services will benefit the most from this. Even if a person can't make it to a clinic regularly, remote tracking can help make sure that they are getting the help and treatments they need to improve their walking function.

III. ELECTRICAL MUSCLE STIMULATION (EMS) IN GAIT REHABILITATION

A. Overview of EMS as a technique to improve muscle strength, coordination, and control.

Electrical Muscle Stimulation (EMS) is a way to improve muscle strength, balance, and control that is used in walking therapy. Electrical signals are sent to certain muscles during EMS, which makes them tighten. This contraction is like the natural firing of muscles that happens when you move your body on your own. This makes EMS a useful tool for building muscles and making motor skills better. EMS works by activating muscle fibers through probes that are put on top of the muscles being worked on. When the electrical signals are sent, they depolarize the motor neurons, which makes the muscles tighten. With EMS, you can focus on certain muscle groups, which lets you improve muscles that are weak or not used enough. EMS can help improve muscle balance and control by using muscles that aren't being used enough when you move voluntarily. EMS can help with movement therapy in a number of ways. One of the best things about it is that it can make muscles stronger without putting too much stress on the joints. This is especially important for people who have trouble walking because building muscle can help them stay stable and lower their risk of falling. EMS can also help build muscle stamina, which lets people keep their muscles properly activated throughout the walk cycle.

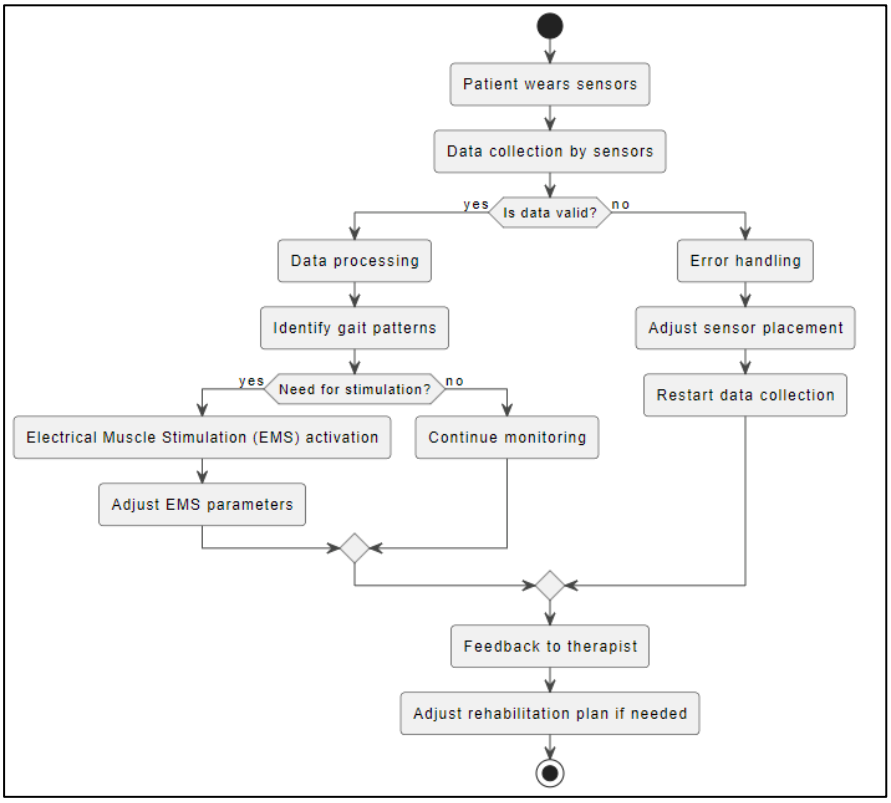

Figure 2: Process flow for the proposed System

EMS can also help muscles work together better, which is important for moving easily and smoothly. EMS can help teach the neuromuscular system to use muscles in the right order when walking by focusing on certain muscle groups. This can help improve the quality of your movement and the way your steps are balanced. EMS can also help loosen up tight muscles, which is another benefit. People who have nerve diseases like multiple sclerosis or a stroke often have muscle stiffness, which can make it hard to control their movements. By making muscles tighten, EMS can help reduce stiffness. This can help relax the muscles and increase their range of motion.

EMS can be used in a number of ways in gait rehabilitation. EMS is often used to improve muscles that are weak or have atrophyed because they haven't been used for a while. For example, EMS can be used to help people with knee osteoarthritis strengthen their thigh muscles, which can make them more stable and lessen the pain they feel when they walk. EMS can also help your muscles work together better and time their movements better. EMS can help encourage the right way for muscles to work by timing its movements with the movement of a robotic device or with certain gait training exercises. People with nerve problems may have trouble managing muscle activity while walking, so this can be especially helpful for them. EMS has many good points, but it also has some problems. One problem with EMS is that it's not right for everyone. For instance, people with certain heart conditions or skin conditions that might get worse from the wires might not be able to use EMS.

One more problem is that EMS might not be as good for building muscle power as regular exercise training. EMS can help build muscle strength, but it might not work as well as lifting weights or doing other types of exercises that build muscle strength. EMS should not be used instead of physical therapy or other types of movement retraining. Instead, it should be used along with these treatments. Finally, EMS is an important part of movement therapy because it helps build muscle strength, balance, and control. EMS can help strengthen muscles, improve balance, and reduce stiffness by focusing on certain muscle groups. This can lead to better walking performance. Even though EMS has some problems, it can be a useful addition to a full program for movement therapy.

B. Explanation of how EMS can be synchronized with robotic exoskeletons to enhance gait rehabilitation

Electrical Muscle Stimulation (EMS) can be synced with artificial exoskeletons to improve gait therapy by activating specific muscles and helping the person walk. Putting these two things together makes walking therapy more complete and successful, especially for people with neurological or muscle problems. We will talk about how EMS and artificial exoskeletons can work together and the advantages of this method.

- Synchronization of EMS with Robotic Exoskeletons: To sync EMS with robotic exoskeletons, the movement of the exoskeleton must be coordinated with the electrical activation of certain muscles. Syncing can be done in a number of ways, such as by using sensors to track the user's movements or by using patterns that have already been set based on the user's desired gait parameters.
- Targeted Muscle Activation: One of the best things about combining EMS with robotic exoskeletons is that it lets you work on certain muscle groups while you walk. EMS can help improve muscle activation patterns and improve strength and balance by activating muscles at the right times during the walk cycle. EMS can be used to work the thigh muscles during the stance phase of walking, which helps the body stay stable and support its weight [22].
- Help with Movement: One more benefit of syncing EMS with electronic exoskeletons is that it can help people move around. The exoskeleton can provide artificial support for people who are weak or have restricted motion, and EMS can help trigger muscles to help with movement. This mixed method can help people walk better and with less effort, which is good for their general walking function.
- Better Gait Symmetry: This can also be achieved by synchronizing EMS with artificial exoskeletons. People who have trouble walking, like those who have hemiparesis after a stroke, can use EMS to work out the muscles on the affected side to make it more like the other side. This can help you walk in a more natural and efficient way, which can lower your risk of falling and make it easier to move around in general.
- Personalized therapy: When EMS is combined with artificial exoskeletons, it's possible to make therapy plans that are unique to each person. Clinicians can make the therapy program fit the person's needs and progress by changing the time and strength of EMS. This lets them focus on specific areas of weakness or instability. People who are going through movement therapy may have better results and heal faster with this personalized method.

Problems and Things to Think About: Synchronizing EMS with robotic exoskeletons has a lot of benefits, but there are also some problems and things to think about. The fact that the technology is so complicated and needs special training to be used well is a problem. The technology can also be too expensive for some hospital places to use, and it needs to be maintained all the time.

IV. INTEGRATION OF WEARABLE SENSORS AND EMS IN LOWER LIMB ROBOTICS

A. Description of the Integrated Approach:

Putting wearing sensors and Electrical Muscle Stimulation (EMS) into lower leg robots for walking therapy means mixing these technologies to make a complete and effective rehab plan.

- Wearable Sensors: Inertial Measurement Units (IMUs) and Electromyography (EMG) sensors are examples of wearable sensors that record real-time information about how people move and what muscles are working while they walk. To measure motion, IMUs are usually put on different parts of the body, like the feet, shanks, and hips. EMG monitors, on the other hand, find patterns of muscle activity.
- EMS: This method works by stimulating certain muscles to make them stronger, more coordinated, and easier to control. EMS works by sending electrical signals to muscles to help weak or underused muscles get stronger. This can improve muscle function and walking performance.
- Robotic Exoskeletons: Robotic exoskeletons are devices that a person wears that help them walk mechanically. People who have problems with their balance can walk better with the help of these gadgets, which support and help with movement.

B. Synchronization of Wearable Sensors and EMS with Robotic Exoskeletons:

For the combined method to work, personal monitors, EMS, and artificial exoskeletons must all work together in sync. This alignment can be done in a number of ways, including:

- Real-time Data Analysis: Movement patterns and muscle action are tracked by wearable sensors, which then study this data in real time. Based on this study, EMS can be used on certain muscles to improve how they are activated and how well they walk.
- Feedback Systems: Wearable monitors can let both the user and the robotic body know what's going on, so changes can be made right away. For instance, if the sensors pick up on a strange way of walking, EMS can be used on the muscles involved to fix the pattern.
- Adaptive Control: Adaptive control methods can change how often and how hard EMS is applied based on how the person walks. This adjustable control lets therapy plans be made just for each person, focusing on their unique weak or unbalanced areas.

C. Advantages and Challenges of Integration:

Advantages:

- Personalized Rehabilitation: Wearable sensors and EMS can be used together in lower limb robots to make individualized therapy routines. Clinicians can make treatments more successful by focusing on specific areas of weakness or instability by looking at real-time data.
- Improved Gait Function: Using EMS and artificial exoskeletons together can help improve walking by making muscles stronger, more coordinated, and easier to control. This can help people who have trouble walking get around and live a better life.
- Real-time data: Wearable sensors give the user and the therapy team data in real time, so changes can be made right away. People can better fix their walking routines and improve their general walking ability with this real-time feedback.

Challenges:

- When portable devices, EMS, and robotic exoskeletons are all used together, it can be hard to get everything to work right without the right tools and knowledge.
- For some healthcare situations, the cost of the tools needed for inclusion, like personal monitors, EMS devices, and robotic exoskeletons, can be too high.

- Some people might be hesitant to use robotic exoskeletons, portable monitors, or EMS because they are worried about their comfort, privacy, or how well they work. It's important to think about user acceptance and respect when putting this combined method into place.

V. CLINICAL APPLICATIONS AND CASE STUDIES

A. Case Reports Demonstrating the Effectiveness of the Integrated Approach in Gait Rehabilitation:

Case Report 1:

The patient is a man who is 55 years old and has had a stroke that left him hemiparesis.

Intervention: Wearable monitors, EMS, and an artificial device were used in a walking therapy program for the patient. Wearable devices were used to track the characteristics of the patient's gait. EMS was given to the muscles in the injured legs to improve their strength and balance, and the robotic suit helped them walk mechanically.

Results: The patient's gait speed, step length, and muscle power all got a lot better after 8 weeks of retraining. He was able to walk with less help from gadgets and more freedom.

Case Report No. 2:

Patient Profile: A 40-year-old woman with a partially damaged spinal cord that makes it hard for her to walk.

Intervention: Wearable monitors, EMS, and an artificial device were used in a walking therapy program for the patient. Wearable devices were used to track how the people walked, EMS was used on the muscles in the lower limbs to make them work better, and the robotic suit helped them walk by supporting and guiding them.

Results: The patient's gait alignment, muscle rhythm, and balance all got better after 12 weeks of therapy. She said she felt less tired and had more courage when walking.

Case Report 3:

Patient Profile: A man in his sixties who has Parkinson's disease and is having trouble walking.

Intervention: Wearable monitors, EMS, and an artificial device were used in a walking therapy program for the patient. Wearable devices were used to track the parameters of the walk, EMS was used on the leg muscles to make them work better, and the robotic suit helped and supported the person while they walked.

The patient's walk speed, step length, and balance all got better after 6 weeks of therapy. He said that he was cold less often and could move around better generally. These case studies show that the combined method works to improve movement and walking function in people with a range of neurological and physical problems. When portable devices, EMS, and artificial exoskeletons are used together, they create a complete and individualized therapy program that focuses on specific disabilities and helps people do better.

B. Discussion on Specific Clinical Applications and Outcomes:

Stroke Rehabilitation:

- Clinical Use: The combined method can help people who have had a stroke improve their general movement, muscle strength, and the way they walk. People can improve their walking routines and get back to walking on their own by using wearing monitors to give them real-time feedback and tailored muscle stimulation.
- Results: Research has shown that people who have had a stroke and go through the combined method have big changes in their quality of life, balance, and the way they walk. EMS and artificial exoskeletons can work together to help people recover lost functions and make it easier for them to do daily tasks.

Spinal Cord Injury Rehabilitation:

When someone has a spinal cord injury and is trying to get better, the combined method can help improve muscle balance, reduce stiffness, and make walking better overall. People can learn to use their muscles better and get better at walking by syncing EMS with the movement of a robotic device.

- Results: Studies have shown that people with spinal cord injuries who use the combined method have better muscle power, faster walking, and more movement. When used together, EMS and artificial exoskeletons can help people who have suffered a spinal cord injury become more independent and improve their quality of life.

Multiple Sclerosis Rehabilitation:

- Clinical Application: The combined method can be used to help people with multiple sclerosis get stronger, feel less tired, and walk better. People can improve their walking and quality of life by using EMS to target specific muscles and wearing devices to track their walking habits.
- Findings: The combined method has been shown to improve muscle strength, balance, and the speed at which people walk in people with multiple sclerosis. EMS and artificial exoskeletons can work together to help people with multiple sclerosis stay mobile and independent.

Rehabilitation for Parkinson's disease:

- Clinical Use: The combined method can help people with Parkinson's disease improve their balance, speed of walking, and general movement. With tailored muscle stimulation from EMS and real-time data from wearing devices, people can improve the way they walk and lower their risk of falling.
- Research has shown that people with Parkinson's disease who use the combined method have better quality of life, balance, and the characteristics of their walk. EMS and artificial exoskeletons can work together to help people with Parkinson's disease stay mobile and independent.
- Using portable devices, EMS, and artificial exoskeletons together seems like a good way to help people with a variety of neural and muscular problems walk better and move around more easily. More study and clinical studies are needed to make sure that these results are correct and to find the best ways to use these tools in clinical practice.

VI. FUTURE DIRECTIONS AND CHALLENGES

A. Potential Advancements in Technology for Better Integration:

- Advanced Wearable Sensors: In the future, wearable sensors may become lighter, more bendable, and more comfy, which will improve the user experience and obedience. They might also make it easier to get more accurate readings of muscle action and walking data.
- Better EMS Devices: EMS devices may get smarter, letting you finetune the activation of muscles. They might also have monitoring features that give users and doctors information in real time.
- Intelligent Robotic Exoskeletons: Some robotic exoskeletons may use artificial intelligence (AI) systems to learn how people walk and give them more personalized help. They might also get lighter and use less energy, which would let them be used for longer amounts of time.
- Integrated Systems: Wearable devices, EMS, and artificial exoskeletons may be able to work together seamlessly in future systems, giving users and doctors a complete and easy-to-use interface.

B. Addressing Challenges Such as Cost and Accessibility:

- Cost-effective Solutions: People should work on coming up with cost-effective solutions that are easy to add to recovery programs that are already in place. To cut down on development costs, this could mean using open-source hardware and software systems.
  Protection from Insurance: Pushing for protection from insurance for integrated recovery programs could help more people get access to them.
- Telehealth and Remote Monitoring: With telehealth and remote monitoring, people can get recovery services from the comfort of their own homes, which can help remove hurdles to entry.
- Training and Education: Giving healthcare workers training and education on the benefits and how to use integrated therapy programs can help get more people to use them and make them easier to find.

C. Importance of User Acceptance and Compliance

- User-Centered Design: To make sure that combined therapy programs are simple, comfy, and easy to use, users should be at the center of future improvements.

- Teaching and Learning: Teaching and learning users about the benefits and right way to use integrated therapy programs can help them accept and follow them more easily.
- Feedback Mechanisms: Adding feedback mechanisms to interactive systems can help users see how they're doing and keep them inspired to keep going with the rehab program.
- Continuous Improvement: Integrated therapy programs can better meet the needs and interests of users by always getting better based on comments from users and clinical results.

VII. CONCLUSION

Using portable sensors and Electrical Muscle Stimulation (EMS) in lower limb robots for gait therapy is a potential way to help people with a wide range of neurological and musculoskeletal problems walk better and move around more easily. Wearable monitors that give real-time feedback, EMS for focused muscle stimulation, and artificial exoskeletons for mechanical help are all used together in this combined method to make a complete and personalized recovery program. Several studies and case reports have shown that this combined method works, showing changes in walking measures, muscle strength, and general movement. Clinicians can make therapy programs more effective by focusing on specific areas of weakness or imbalance by coordinating personal monitors, EMS, and robotic exoskeletons. This helps patients have better results. There are, however, problems that need to be fixed in order to make the merging of these tools even better. These include how much the technology costs and how easy it is to get, how well users accept and follow the rules, and the need for technology and therapy procedures to keep getting better. Efforts to solve these problems and new developments in technology, like smarter personal monitors, EMS devices, and artificial exoskeletons, can help make combined therapy programs more useful and open to more people. Using external sensors and EMS together in lower limb robots for gait therapy has a lot of potential to make the lives of people who have trouble walking better. To move the field forward and give better care to people, more study and development must be done in this area.

REFERENCES

[1] Chen, G.; Qi, P.; Guo, Z.; Yu, H. Gait-Event-Based Synchronization Method for Gait Rehabilitation Robots via a Bioinspired Adaptive Oscillator. IEEE Trans. Biomed. Eng. 2017, 64, 1345–1356.

[2] Maqbool, H.F.; Husman, M.A.B.; Awad, M.I.; Abouhossein, A.; Iqbal, N.; Dehghani-Sanij, A.A. A real-time gait event detection for lower limb prosthesis control and evaluation. IEEE Trans. Neural Syst. Rehabil. Eng. 2017, 25, 1500–1509.

[3] Song, L.; Wang, Y.; Yang, J.J.; Li, J. Health sensing by wearable sensors and mobile phones: A survey. In Proceedings of the IEEE 16th International Conference on e-Health Networking, Applications and Services (Healthcom), Natal, Brazil, 15–18 October 2014; pp. 453–459.

[4] Derawi, M.; Bours, P. Gait and activity recognition using commercial phones. Comput. Secur. 2013, 39, 137–144.

[5] Schneider, O.S.; MacLean, K.E.; Altun, K.; Karuei, I.; Wu, M. Real-time gait classification for persuasive smartphone apps: Structuring the literature and pushing the limits. In Proceedings of the 2013 International Conference on Intelligent User Interfaces, Santa Monica, CA, USA, 19–22 March 2013; pp. 161–172.

[6] Skelly, M.M.; Chizeck, H.J. Real-time gait event detection for paraplegic FES walking. IEEE Trans. Neural Syst. Rehabil. Eng. 2001, 9, 59–68.

[7] Rueterbories, J.; Spaich, E.G.; Andersen, O.K. Gait event detection for use in FES rehabilitation by radial and tangential foot accelerations. Med. Eng. Phys. 2014, 36, 502–508.

[8] Salarian, A.; Russmann, H.; Vingerhoets, F.J.G.; Burkhard, P.R.; Aminian, K. Ambulatory monitoring of physical activities in patients with parkinsonapos's disease. IEEE Trans. Biomed. Eng 2007, 54, 2296–2299.

[9] Gavrila, D.M.; Davis, L.S. 3-D Model-based tracking of humans in action: A multi-view approach. Proceedings of the IEEE Computer Vision and Pattern Recognition, San Francisco, CA, USA, 18–20 June 1996; pp. 73–79.

[10] Ajani, S. N. ., Khobragade, P. ., Dhone, M. ., Ganguly, B. ., Shelke, N. ., & Parati, N. . (2023). Advancements in Computing: Emerging Trends in Computational Science with Next-Generation Computing. International Journal of Intelligent Systems and Applications in Engineering, 12(7s), 546–559

[11] Karaulovaa, I.A.; Hallb, P.M.; Marshall, A.D. Tracking people in three dimensions using a hierarchical model of dynamics. Image Vis. Comput 2002, 20, 691–700.

[12] Furnée, H. Real-time motion capture systems. In Three-Dimensional Analysis of Human Locomotion; Allard, P., Cappozzo, A., Lundberg, A., Vaughan, C.L., Eds.; John Wiley & Sons: Chichester, UK, 1997; pp. 85–108.

[13] Cappozzo, A.; Della Croce, U.; Leardini, A.; Chiari, L. Human movement analysis using stereophotogrammetry. Part 1: Theoretical background. Gait Posture 2005, 21, 186–196.

[14] Chiari, L.; Della Croce, U.; Leardini, A.; Cappozzo, A. Human movement analysis using stereophotogrammetry. Part 2: Instrumental errors. Gait Posture 2005, 21, 197–211.

[15] Anandpwar, W., Barhate, S., Limkar, S., Vyawahare, M., Ajani, S. N., & Borkar, P. (2023). Significance of Artificial Intelligence in the Production of Effective Output in Power Electronics. International Journal on Recent and Innovation Trends in Computing and Communication, 11(3s), 30–36.
[16] Casadio, M.; Morasso, P.G.; Sanguineti, V. Direct measurement of ankle stiffness during quiet standing: Implications for control modelling and clinical application. Gait Posture 2005, 21, 410–424.
[17] Bonato, P. Wearable sensors/systems and their impact on biomedical engineering. Eng. Med. Biol. Mag 2003, 22, 18–20.
[18] Engin, M.; Demirel, A.; Engin, E.Z.; Fedakar, M. Recent developments and trends in biomedical sensors. Measurement 2005, 37, 173–188.
[19] Bachmann, E.R. Inertial and Magnetic Tracking of Limb Segment Orientation for Inserting Humans into Synthetic Environments. Ph.D. Thesis,. Naval Postgraduate School, Monterey, CA, USA, 2000.
[20] Bamberg, S.J.M.; Benbasat, A.Y.; Scarborough, D.M.; Krebs, D.E.; Paradiso, J.A. Gait analysis using a shoe-integrated wireless sensor system. IEEE Trans. Inf. Technol. Biomed 2008, 12, 413–423.
[21] Liu, T.; Inoue, Y.; Shibata, K. A wearable ground reaction force sensor system and its application to the measurement of extrinsic gait variability. Sensors 2010, 10, 10240–10255.
[22] Jagos, H.; Oberzaucher, J.; Reichel, M.; Zagler, W.L.; Hlauschek, W. A multimodal approach for insole motion measurement and analysis. Procedia Eng 2010, 2, 3103–3108.