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Wearable Technology Advancements Helping Amputees Regain Movement and Independence

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Abstract. Wearable devices have become more advanced in recent years, with scientists and engineers creating smart limbs, sensors, brain-computer interfaces (BCIs), and exoskeletons to help amputees move better. These tools are also used in hospitals and rehab centers for muscle training, motion analysis, and making therapy more engaging. While they have already helped many people walk again, hold objects, and even play rehab games, research is still working to improve their performance outside the lab by focusing on accuracy, battery life, comfort, and affordability. However, many devices remain expensive and hard to access, and some cannot yet work well in daily life, especially in busy or outdoor environments. This essay reviewed four main types of wearable devices, their real-life and rehab uses, and three cases where they restored movement and independence. These findings prove that wearable devices can change lives, and future research should make them smaller, stronger, and more affordable, with designs that work well at home so more people can benefit.

Keywords: Wearable device, inertial measurement unit, brain-computer interface.

1. Introduction

Wearable devices are new tools that help people who lost a leg or an arm. These people are called amputees. It is hard for them to move or do normal things, like walking, running, or even standing. In the past, prosthetic limbs were simple and didn't work well. But now, new technology like sensors and smart systems has made better devices. These tools can help amputees live better and move more easily.

Wearable devices can be worn on the body. Some of them are sensors that track how the body moves. Some are smart artificial limbs that move when the person tries to move. The most common sensors are called inertial measurement units (IMUs) and electromyography (EMG) sensors. IMUs can feel how the body moves. EMG can read signals from the muscles. Scientists can use these signals to make better prosthetic limbs that move in a smoother way [1]. Other new devices let people move their artificial limb using nerve signals or even their brain. This kind of tool is called a brain-computer interface (BCI). The goal is to help the prosthetic arm or leg move like a real one. Farina et al. said that muscle signals can now control smart arms with good results [2]. Some people can even pick things up or move fast using this type of tool.

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Still, there are some problems. These devices can be very expensive. Many hospitals don't have them yet, and some people cannot afford them. The battery life is short, and sometimes the device does not work well outside the lab. According to the World Health Organization, over 80% of people who need prosthetics worldwide still don't receive proper treatment [3]. This essay will talk about the types of wearable devices that help amputees. It will also explain how they work, how they are used in therapy and real life, and what still needs to improve. These new tools are not perfect, but they already help many people walk again and live more freely.

Wearable devices are tools that people wear on their bodies to help with health or movement. For amputees, these devices can help them move better and live more comfortably. In recent years, new wearable technologies have been used to help people who lost their arms or legs. These tools include smart prosthetic limbs, sensors, BCIs, and exoskeletons. Many of these devices are still being tested, but they have already changed the way doctors and scientists think about rehabilitation.

2. Types of wearable devices

One kind of wearable device is the smart prosthetic limb, like a robotic leg or arm. These are made to replace a missing body part and help the person walk, move, or do daily tasks. Unlike old prosthetics, smart limbs can move by using signals from the body or sensors. They are also built with motors and smart chips that let them copy the way humans move. Some can even connect to a smartphone app. In a review study, scientists explained how these new limbs can be adjusted to each person's needs and can even work on uneven ground [4].

Another kind of device is sensors, like IMUs and EMG (electromyography) sensors. IMUs are small devices that measure how the body moves. They can sense changes in speed, direction, or balance. They are usually placed inside a prosthetic limb or on the body. EMG sensors work by reading signals from a person's muscles. When you move a muscle, the EMG sensor reads the small electric signal, which can then be used to control a robotic hand or arm.

BCIs are also wearable devices. These tools let a person control a machine using only their brain signals. BCIs read signals from the brain using something like a cap with wires, called EEG (electroencephalography). These signals are then sent to a computer that understands what the person wants to do. Scientists say BCIs are helpful for people who can't move because of injuries. With a BCI, a person could think about moving a hand, and the machine would move it for them [5].

The last kind of device is called an exoskeleton. This is a wearable robot that goes over your arms or legs and helps you move. It is not used to replace a limb but to support it. Exoskeletons are helpful for people who are weak, injured, or older. Some exoskeletons are made to help people walk again after an accident. Others are used in the workplace to help workers lift heavy things. Exoskeletons are also controlled by sensors and AI, which makes the robot move naturally with the person [6].

3. Structure and working principles

Different wearable devices work in different ways. IMUs use small sensors like gyroscopes and accelerometers to measure how fast or in what direction someone moves. This helps the device know if a person is walking, sitting, or turning. The data is sent to a computer that figures out how to respond.

EMG sensors detect small electric signals from the muscles. When a person tries to move a finger, even if the finger is gone, the muscles still send a signal. The EMG sensor reads this signal

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and sends it to a motor in the prosthetic hand to make it move the way the person wanted. This makes the device feel more natural and easier to use.

BCIs work by reading brain waves, especially from the parts of the brain that control movement. For example, if a person thinks about lifting their arm, the brain sends out a signal. The BCI reads that signal and sends it to a machine to move the arm. But sometimes there is a lot of "noise" in the brain signals, especially if the person is moving around. That's why scientists are working hard to clean up the signal so the BCI can work better in real life [5].

Artificial Intelligence (AI) and machine learning play a big role in wearable devices. These systems learn from a person's movements and habits. Over time, they get better at predicting what the user wants to do. In exoskeletons, AI helps the robot guess what movement the person will make next. In prosthetic limbs, AI helps the device adjust to walking on stairs, ramps, or different ground types [6].

4. Applications and advancements

Wearable devices are not only made to replace a missing arm or leg. They are also used in hospitals. These tools help patients get better after injury, surgery, or stroke. In the last few years, wearable technology has made a big difference in medical care and training. Doctors and therapists now use these devices for walking practice, muscle training, and even fun rehab games. Some devices also track body movement to give better care [7].

4.1. Medical rehabilitation

One of the most common uses is in physical therapy. Many patients lose strength in their arms or legs after injury. It becomes hard for them to walk or move. A wearable robot called an exoskeleton can help. It supports the patient's legs during walking. In 2025, doctors tested an exoskeleton with patients who had a stroke. These patients trained with the robot suit in the hospital. The results were good. The patients walked better and had stronger leg muscles. The robot worked just as well as regular therapy [7].

Muscle training is also important. When a person cannot move part of their body, the muscles become weak. Some wearable tools help the muscles move. They also teach the body how to walk again. These tools are now part of daily therapy in some hospitals.

4.2. Motion analysis

Wearable devices can also be used to study how a person moves. This is called motion analysis. It means watching how a person walks or moves their body. Sensors on the device send the movement data to a computer. The doctor or therapist can then see the movement in real time. If something looks wrong, they can change the training right away. This is helpful because every patient is different. For example, some people walk slowly, while others lose their balance. The wearable device helps find these problems. Then the doctor can make a new plan. This gives better care and faster recovery. In the 2025 study, the exoskeleton also showed doctors how much the patients improved [7]. These tools are now helping many people around the world.

4.3. Rehabilitation training

Wearable devices are also used in rehab training. Some hospitals now use games to make therapy more fun. This is called gamification. It means turning hard exercises into simple games. In 2025,

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doctors studied stroke patients who played training games using wearable sensors. The patients felt happier. They also trained harder and recovered faster [8]. The games made therapy more fun and less boring.

Another study used virtual reality (VR) in rehab. The VR system used sensors on the arms and hands. Patients moved their arms to play a game on the screen. The system was called PABLO. In 2023, stroke patients used it to train their upper body. The results were good. Patients had better movement in their shoulders and elbows. They also had better control in their hands. Most patients said they liked the VR training better than regular therapy [9].

5. Case studies

Wearable devices have helped many people who lost part of their body or had trouble moving. This section shows three real examples where these tools gave people back some control.

5.1. Emg-controlled limb

One case is about a man who lost his arm. His arm was cut very high, so he had no hand and no elbow. The doctors gave him a smart robot hand that used something called EMG. EMG means electromyography. It is a tool that can read muscle signals. Even if the lower arm is gone, the upper arm still has muscles that try to move. That means the robot hand can read those signals and try to move like a real hand.

The robot hand also gave him feedback. That means it helped him learn how strong he was grabbing things (Figure 1). In the study, the hand could read his muscle signals with more than 90% accuracy. He could also do different types of grabs, like holding something big or pinching something small. He trained with it and got better. The signals stayed stable each time he trained, so the robot hand worked well every day. After some time, he could hold things without dropping them or squeezing too hard. The study showed that EMG-controlled limbs can give precise movements and even adapt to different tasks in daily life. This case shows that EMG-controlled hands can help amputees move again. Even when they lost most of their arm, the muscles can still work. That gives people hope to live better again [10].

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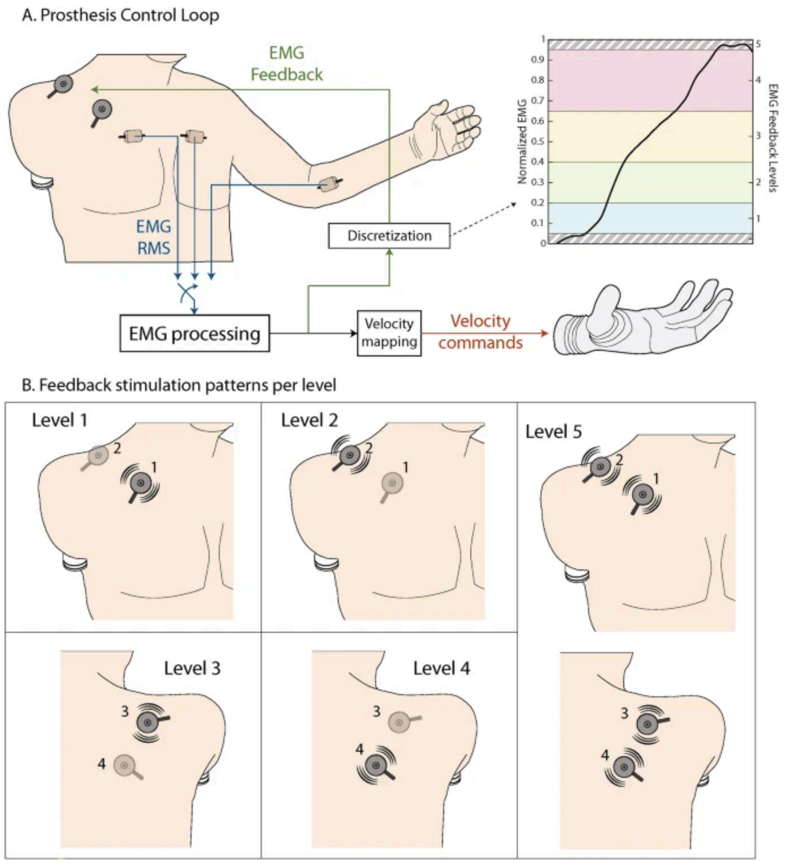

Figure 1. Application of EMG feedback for hand prosthesis control in high-level amputation: a case study [10]

5.2. Exoskeleton in stroke recovery

One case is a 57-year-old man who had a stroke. After the stroke, he could not move one side of his body and had very bad balance. The doctors looked at his medical records and checked if he could do a new training. Then, they gave him a special robot machine. It is called a wearable self-balancing exoskeleton robot. That robot helped him stand up and carry weight and train his upper body to stay straight. That training is called trunk control. It is very important to do that early after a stroke. It helps the legs move better again.

He did the training for 3 weeks. Every day the robot helped him walk, balance, and put weight on his weak leg. The study showed that his balance and leg movement got better after the training. He also followed the program well and never missed a session. The man said the robot made him feel more confident and happier during the training. The results also showed higher satisfaction and no bad side effects. This case shows that the robot can help stroke patients recover faster, especially when used early [11].

5.3. Use of bcis in prosthetic arm control

One case is from UC San Francisco. A man had a stroke a long time ago and lost the ability to move and speak. He could not move his arms or legs. But his brain could still think about moving. The doctors put small sensors on his brain that could read brain signals when he imagined moving his

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hand. The signals went to a computer. That computer used AI to help control a robotic arm. This tool is called BCI, which means brain-computer interface.

At first, the robot arm did not work very well. It was not very accurate. So the doctors let the man practice with a virtual robot arm. That helped him train his brain to send better signals. After that, when he used the real robot arm, he could pick up blocks, turn them, and move them. He also opened a cabinet, took a cup, and moved it to a water machine. The study showed the BCI worked for 7 months without needing a big reset, which is much longer than past devices that only worked for 1 or 2 days. This was possible because the AI could adjust when brain signals moved to a slightly different place. The doctor, Karunesh Ganguly, said this learning between humans and AI is the next big step for BCI. This case shows that even if someone can't move, the brain can still send signals, and BCI can help turn those signals into real actions (Figure 2) [12].

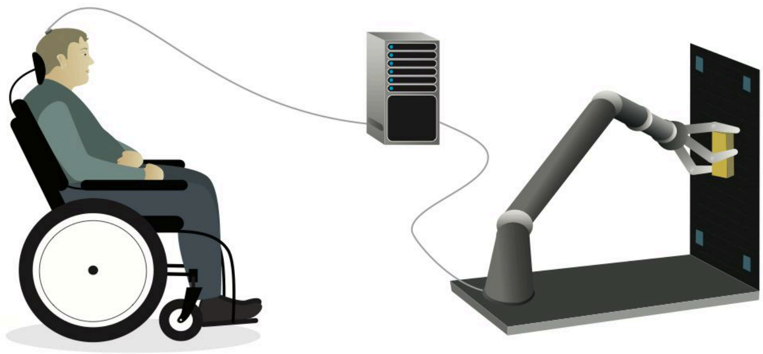

Figure 2. Schematic diagram of a paralyzed man moved a robotic arm with his thoughts [12]

6. Conclusion

This study reviewed the types, working principles, and applications of wearable devices for amputees and individuals with mobility impairments. These devices including smart prosthetic limbs, sensors such as IMUs and EMG, BCIs, and exoskeletons, have shown significant potential in improving mobility, independence, and quality of life. Smart prosthetic limbs and EMG sensors enable precise and natural control of artificial limbs by translating muscle signals into movement, while BCIs offer a direct link between brain activity and device control. Exoskeletons have proven valuable in rehabilitation, providing physical support, enhancing muscle strength, and facilitating balance training. Case studies demonstrated that EMG-controlled limbs can achieve over 90% movement accuracy, exoskeletons can accelerate stroke recovery, and BCIs can restore functional arm movements even in patients with severe paralysis. Future developments are expected to focus on improving affordability, portability, and signal stability, as well as integrating AI and adaptive algorithms to enhance device performance in daily life.

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