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Applications of AI in Prosthetics: A Critical Analysis

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ABSTRACT

Technological integration in prosthetics is great boon for a person with disabilities Artificial intelligence and Machine learning along with neural network can work simultaneously to provide the best results in for the real like motion and stability of prosthetics with right timing. Neural linkage and interaction with devices and software can be easy for the person and using bionic limbs .Using expertise and required knowledge of different field we can make prosthetics work as the normal limbs using right type of material can give it a feel of real human limbs , Machine learning Algorithms are used for the training purpose of prosthetics before using them practically in real life so they can predict what can be the next movement of the person using previous data that was provided during training and also using machine learning in real time to increase the accuracy along with neural network to let a person control prosthetics with brain only. ANN is used for the connection of prosthetics from human body like a brain and after integration of all the technology that we can use for the proper functioning of prosthetics we can use different types of network and ways for the different part of the body to act accordingly.

Keywords: Artificial Neural Network (ANN); Deep Learning; Myoelectric Control; Electromyography (EMG); Electroencephalogram (EEG).

1.0 Introduction

Humans have magnificent amount of brain power along with neural networks, having 85 billion plus neurons and trillions of connection it is extremely complex [1].Person with a disability use prosthetic but prosthetics are still not smart enough to act as they are real limbs but it can be achieved using advance technology that we have. We can use Artificial Intelligence to make it work from brain and we can train the model by using Machine Learning further we can use Artificial Neural networks to connect it by human brain . ANN (Artificial Neural network) have artificial neurons and they work as real human brain by receiving, processing and transferring signals from one neurons to another [2]. Further by using maths stats, create algorithm that can recognize patters that happen again and again and act accordingly. Unsupervised learning algorithm play big role to make it further better without interference of human.

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Reinforcement learning also work well as it works as trial and error and learning from it [3]. Deep Learning further consist of both supervised and unsupervised learning and using ANN which try to mimic as human brain using their layers input layer, output layer and hidden layer and it solve several types of problem that human brain process like pattern recognition matching, classification and input for the next layer can be the output layer of previous layer [4].

AI in prosthetic increased a lot but not much on the outer world it is still developing in laboratories and testing in laboratories but a implantation of chip in human mind that can send signal to prosthetics can be beneficial and will help patient to control the limbs directly from brain.AI in upper prosthetic limbs can be used as brain send two types of signals one work as involuntarily electroencephalogram (EEG) and other work as voluntary so it will work for signals that are voluntary to control limbs electromyography (EMG) [5] . Concept of AI that is use in lower limbs are based on all the different types of data such as the knee joint and at what length limbs need to be attached and on the movement off flow of limbs and at what angle sensor is connect on the knee itself [6].

Here are some of the key applications of AI in prosthetics [15]:

Pattern Recognition: AI algorithms can interpret signals from electromyography (EMG) sensors and other sensors to decode the user's intentions and translate them into precise movements of the prosthetic limb. This allows for more natural and intuitive control of the prosthetic.

Customization: AI can be used to design prosthetic devices tailored to an individual's unique anatomy and functional requirements. This includes optimizing the shape and size of the prosthesis to enhance comfort and functionality.

Tactile Feedback: AI can enable prosthetic limbs to provide sensory feedback to the user, allowing them to feel pressure, temperature, and texture. This feedback improves the user's ability to interact with objects and their environment.

Gait Analysis: AI can analyze a person's gait patterns and provide real-time feedback to optimize the prosthetic limb's movements. This helps improve walking efficiency and reduce the risk of musculoskeletal issues.

Machine Learning Predictive Models: AI can learn from the user's movements and adapt the prosthetic's behavior in real-time to better align with their needs and habits. For example, the prosthesis can adjust its behavior based on terrain or activity.

Voice Commands: AI-powered voice recognition can allow users to control their prosthetic limbs using natural language commands, making it easier to perform complex tasks.

Reinforcement Learning: Prosthetic limbs can use reinforcement learning algorithms to continuously improve their performance based on user feedback and real-world usage, becoming more adaptive over time.

Telehealth and Remote Updates: AI can enable remote monitoring of prosthetic users' health and usage patterns, allowing clinicians to provide timely support and updates to the prosthetic device without the need for frequent in-person visits.

Predictive Maintenance: AI can predict when a prosthetic device might require maintenance or replacement, reducing the risk of unexpected failures.

Simulation and Testing: AI-driven simulations can help researchers and engineers design and test new prosthetic prototypes more efficiently, accelerating innovation in the field.

Data Encryption: AI can help protect the sensitive data collected by prosthetic devices, ensuring the privacy and security of users' personal information.

In summary, AI plays a pivotal role in advancing prosthetic technology by improving control, customization, sensory feedback, and overall user experience. These advancements not only enhance the quality of life for individuals with limb loss but also open up new possibilities for the future of prosthetic technology.

2.0 Literature Survey

A prosthesis is an artificial body limb that replaces a body part that has been cut due to accident, disease, or several medical conditions. Prosthetic plantation in the human body is performed by a prosthetist and highly trained team of medical professionals which have mental health counsellors, surgeons, physio therapists and specialized nurses. The functional loss of a limb is due to amputation, spinal cord damage by injury, heart problems, severe brain injury resulting disturbed neural network transport from brain to limbs of the body and those weak limbs than cannot perform as a healthy part of the body. The lost features and function of the bionic limbs can be restructured or regained by transplant of prosthetic limbs.[7]

2.1 Artificial neural network

ANN is a computing system that is caused by human nervous systems network or neural network that works with human brains. It is a collection of nodes called artificial neurons. This neuron receives signals, processes it and transfers it to other connected neurons just like the human neural system. These signals are real numbers. Each neuron output is computed by nonlinear function and addition of inputs. These connections are called edges. Neurons and edges have variable weight that increase or decrease as information it stores and depends on signal strength at a connection. These neurons have different layers and these layers perform distinct functions after travelling multiple layers.

2.2 AI (Artificial Intelligence) in prosthetics

The first intelligent prosthesis developed by Chas. A. Blatchford & Sons, Ltd. in 1993 and then a modified and better version came in 1995 which was called Intelligent Prosthesis Plus. After this a new modified prosthetic device was developed and it is a combination of three device mechanisms which have the following three mechanisms of hydraulic, pneumatic and microprocessor. The complete microprocessor developed by Otto bock is called C-leg. After that Rheo knee and power Knee came in the industry which completely uses onboard AI mechanism. [11].

Machine learning and AI concept use in prosthetics: Machine learning holds components of math’s, stats, and computer science, which is plateful to operate and make progress in the development of artificial intelligence. It is the learning of computer algorithms that can be better by itself through experiences and by using data. ML has two types of algorithms;

Supervised learning: algorithm uses a mathematical model of collection of data or collection of data that have the given input and required outputs. The data that is used is called as training data and it is made up of training examples. Every example has one or more than one input and required output which is called as supervised signal. Through recursive optimization technique supervised learning is used to make predictions of output from the inputs it has and its accuracy increases with time. Example 1: To predict in advance the model of knee joint that is trained with few inputs that are trained by identifying data such as text videos, this type of data called as labelled data, so we give the data of angle variation of knees in many different small phases of gait cycle and put on new cut body parts to predict the new data by the phase dependent pattern recognition technique.

Unsupervised learning: Unsupervised learning algorithms try to find a solution to anonymous or unnamed data which does not require any oversight by humans. It works by itself to collect information and allow performing more complicated work in comparison to supervised learning. Example: Intent detection algorithm with collection of samples of data that is called human artifacts or unlabeled data that is based on reference patterns it is an example of this kind of ML that can be used microprocessor knee.

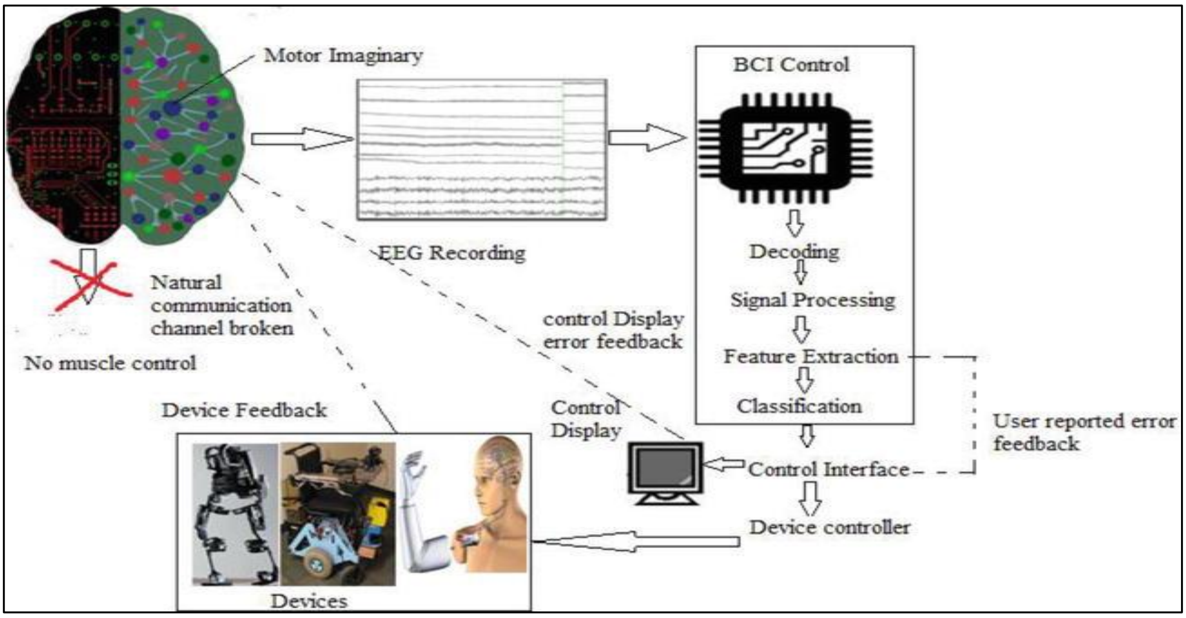
2.3 Reinforcement learning (RL)

It is related to how intelligent agent or software works. It gives us an idea of what steps we should take steps in a system to increase the chances of getting the desired result. The agent learns from the outcome of its steps it has taken and chooses the best feasible options from previous results and the new choices by trial-and-error learning. This is result driven learning process. It has agent and environment as its part.

Deep Learning: This kind of machine learning uses concept of supervised and unsupervised and smaller classes of ML, Deep learning uses the approach of artificial neural network (ANN) accompanied by creating image of 2-D or 3-d model by through a computer program this process is also known as rendering learning. ANN work like human brain neural network system. It can learn, memorize, generalize, like human brain. ANNs (Artificial Neural Network) we can achieve greater power to resolve problems connected to pattern recognition and matching, clustering, and classification. [20,21].

2.4 Uses of AI in prosthetics

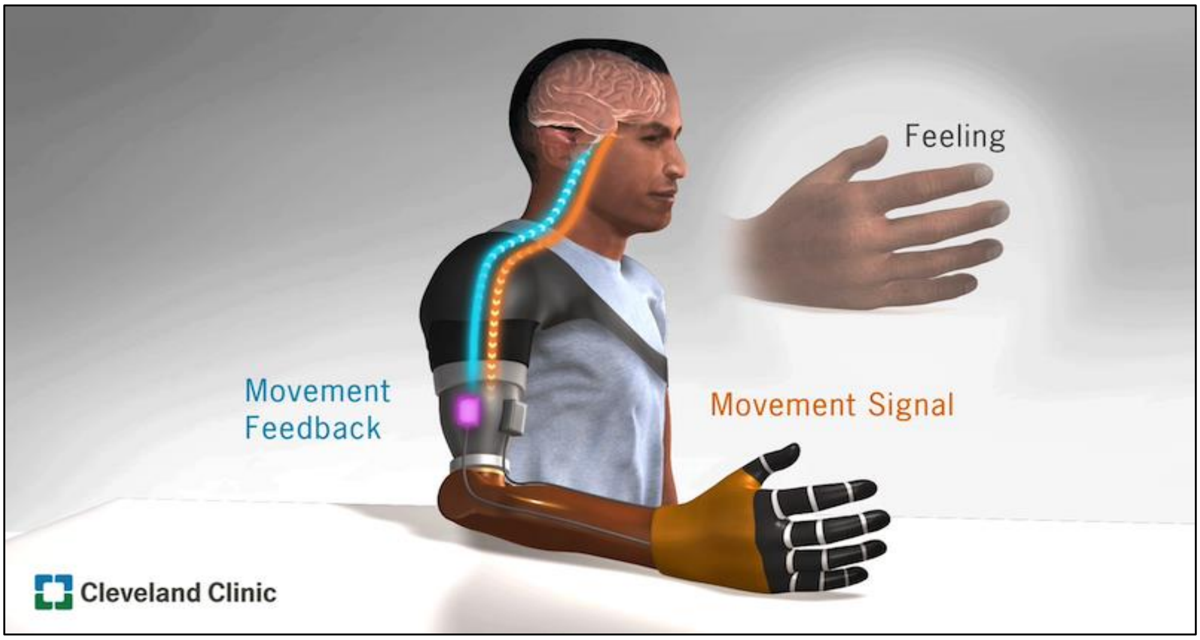
The application of AI prosthetic devices has been increasing day by day and can provide the opportunity to the patient to utilize the prosthesis in a much better way. Adjustable controlling could start a device that can work more precisely to the needed outcome by altering the input with a feedback method., a mind-controlled limb (type of myoelectric controlling) a limb which is fully automatic and works through the sensors that are planted in the Human brain cells, and that can regain the ability of transferring neurological e impulses from the limb back to the region of the cerebral region specifically to the sensory cortex [25].



Source: Brain computer Interface (BCI), controlling prosthetic and orthotics devices.

2.5 AI in upper prosthetics limbs

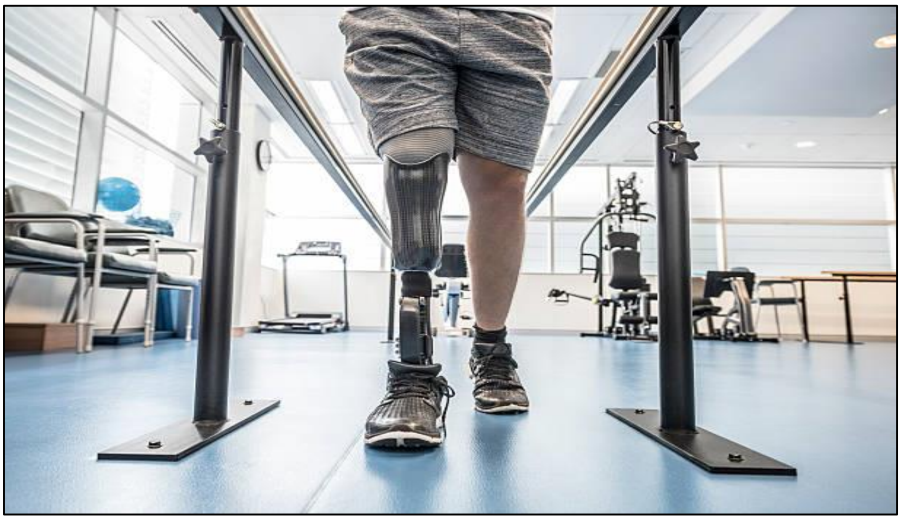
In upper limbs prosthesis Ai is used in direct and indirect form and is controlled by the neural network by many means and devices such as controller, signals, and algorithm. The electrical impulses that are coming from human brains are of two types. For operation of upper limbs prosthesis i.e., electromyography (EMG) and Electroencephalogram (EEG). Before that, attempts were made to command the muscles that are under control of Human beings. The prosthesis device is trying to concentrate more on the use of electromyography (EMG) signals that are under the control of Human beings or voluntary muscles. Much of the work could be finished on the control system of upper limb prosthesis. And this makes upper bionic limbs work to a greater extent like a natural upper limb but still it cannot perform like natural limbs.



Source: Scribd

2.6 Concept of AI that is used in lower limb prosthesis

First time when AI applications used in lower limb prosthesis that is a knee joint device that replaces the hydraulic mechanism through a mixture of microprocessor and servomotor.as suggested by the name of microprocessor it receives the signals from a sensor named as knee angle sensor. It gives the angle of knee flexion, its lateral velocity and angular movement. The flow or direction of movement is determined by the sensor because it has magnetic strips and weight information collected by the second sensor. Microprocessor receives the data and it detects and collect information produced by the cut or lost body part which and process the data and send the required information like how much extension, rotation and movement needed in the device for the proper bionic limb movement.



Source: Kennedys on Twitter: "Following the third day of the @ACRMconference, @markb_kennedys discusses the human perspectives bought on by life-changing injuries, in addition to the way in which alternative medicines and increased family

3.0 Devices Used for AI in Prosthetics

S. No.	Topic	Objective	Conclusion
1.	limbU	Additive manufacturing is very fastly providing humans focus to create devices that can be wore by patients easily. Prosthetic limbs are created and developed by keeping in mind 3D printed prosthetics are a very beneficial option for limb replacement of an affected person. For adding new feature to it, Troy Baverstock, from Australia created prosthetic legs with the help of 3D printing. It was called limbU.	The smart electronics helps the artificial limb-user effectiveness for being attentive for any kind of stimuli. For example- limbU can receive body actions and also can do daily activities as well, also can perform difficult work like searching something on the phone and updating the doctor about the wearer's health information. We can change the outer cover to match it with any occasion.
2.	**Össur**	**Össur** is a start-up that is functioning along with the Alfred Mann Foundation, in United States it can create brain-controlling prosthetic limbs that are very light to hold and has a longer battery life. If the wearer go through an orthopedic surgery, it helps the patient collect data of the patient's daily activity and also the movement and help informing these to the doctor.	This facilitates extra care at the healing time. Its also a method to motivate the patient and his enthusiasm at the time of recovery.
3.	BPM pathway	**BPM pathway** is a technology that records the after surger condition of the patient. It contains a easy to wear without wire sensor which is linked to the main network so that the patients' healing process or recovery process is visible on a monitor.	**My mobility application** facilitates continuous information during the recovery as it records data of body of patients and sends it to their concerned physicians for better results unlike the traditional method.
4.	Avocado	**Avocado,** manufactured in india is an Artificial Intelligence based prosthesis which provides the patient regular as well as difficult activities. Avocado is wore on wrist and it has tiny electrical adapter and also a device whose function is to provide continuous updates about the battery life of machine.	Same as humans that can combine the concept of armchair and avocado and merge those concepts into one image, so can DALL-E.So it gives the patient better picture for his daily life work.

4.0 Methodology

There are in excess of 40 million handicapped people across the globe, as per the Wellbeing Association. Continuous advances in prosthetic hand and extremity development have altogether dealt with the individual fulfillment for upper-limb unfortunately impeded individuals. Regardless, openings stay in the control of prosthetic hands, expressly in using typically made electric signs from the patient's muscles. Materials and technique. Man-made intellectual prowess (PC based knowledge) makes it serviceable for machines to acquire actually, adjust to new data sources and perform human-like tasks. Using these advances, laptops can be ready to accomplish unequivocal tasks predominantly of data and seeing plans in the data.

One of the endeavors of PC based knowledge is the control of prosthetic hands. Nowadays there are several associations that use reproduced knowledge to do control of prosthetic hands. According to Robert Armiger, bioengineers are dynamically wanting to make "human-machine interfaces encapsulated by a prosthetic member that genuinely feel like an extension of the body." The not-for-benefit Unfortunately crippled individual Coalition assessments, and that number should practically twofold to 3.6 million by 2050. A normal 185,000 new lower-extremity expulsions happen consistently. So those people need clever prosthetic arms for a fantastic life. The most inciting in this work is to make improvement of mechanical hand as ordinary as a certified hand. Essential calculations are very inefficient for this present circumstance, so the prosthetic arm moves incredibly disproportionate and unnatural. Man-created insight can help with vitalizing the arm to move as close as it possible with the human one. At present there are several models that use the force of man-made intelligence to make a conventional prosthetic arm [12;13;14].

According to latest assessment, last preliminaries have shown a stunning advancement in the referred to above circle. Researchers make a novel prosthetic that license a patient to move all hands by his will, yet furthermore move his fingers freely. Mimicked insight gives the humanity this remarkable, astounding possibility. These days, this prosthetic hand is flawed at this point. Be that as it may, with the assistance of man-made intelligence the prosthetic hand gains a headway with each utilization [12;13]. Simulated intelligence is just on the beginning of its way however it has proactively made a leap forward in clinical exploration. It has been assigned to tackle a scope of medical conditions and to make individuals live better. The issue of prosthetic hands and their controls are at this point basic for PC trained professionals. With the help of man-created mental ability prosthetic hands can fulfill comparative capacities as ordinary ones.

Here's an overview of the methodologies used in applying AI to prosthetics:

Data Collection and Sensor Integration [15]:

- **Data Gathering**: The first step involves collecting data from various sensors, such as electromyography (EMG), accelerometers, gyroscopes, force sensors, and temperature sensors, which are often embedded in or around the prosthetic limb.
- **Data Preprocessing**: Raw sensor data must be preprocessed to remove noise, filter signals, and ensure data quality.

Feature Extraction [15]:

- **Feature Engineering**: Engineers and data scientists extract relevant features from the sensor data to represent the user's limb movement, muscle activity, and sensory input. This step often includes time-domain and frequency-domain analysis.

  Machine Learning Models [16]:

- **Classification and Regression**: Machine learning models, such as Support Vector Machines (SVM), Random Forests, and Neural Networks, are trained on the extracted features to classify user intent (e.g., grasping, walking) or predict continuous variables (e.g., joint angles).
- **Reinforcement Learning**: In some cases, reinforcement learning models are used to train prosthetic limbs to adapt and learn from user feedback over time, allowing for more natural control.

Pattern Recognition [17]:

- **Pattern Recognition Algorithms**: These algorithms are employed to interpret patterns in sensor data, allowing the prosthetic limb to recognize specific gestures, movements, or commands from the user.

Personalization and Customization [18]:

- **User Profiling**: AI methods are used to create user profiles, taking into account individual anatomy, preferences, and physical abilities to customize the prosthetic limb's behavior.
- **Model Fine-Tuning**: Machine learning models can be fine-tuned for individual users based on their unique patterns of use and feedback.

Sensory Feedback [19]:

- **Feedback Integration**: AI algorithms are used to process sensory input from the prosthetic limb's sensors and provide feedback to the user, simulating the sensation of touch or proprioception.

Real-time Control [20]:

- **Control Algorithms**: AI algorithms enable real-time control of the prosthetic limb by interpreting user intent and adjusting the limb's movements accordingly. This can involve inverse kinematics, forward kinematics, and control policies.

Continuous Learning and Adaptation [17]:

- **Online Learning**: Prosthetic systems can use online learning techniques to adapt and improve their performance based on user behavior and changing circumstances.

Human-Machine Interaction [17]:

- **Natural Language Processing (NLP)**: Natural language interfaces are developed to enable users to control their prosthetic limbs through voice commands.
- **Gesture Recognition**: AI is used to recognize and interpret gestures made by users to control the prosthetic limb.

Remote Monitoring and Support [18]:

- **Cloud-Based Solutions**: Data collected by prosthetic devices can be stored in the cloud, allowing for remote monitoring by clinicians and providing the opportunity for remote updates and troubleshooting.

Ethical Considerations [20]:

- **Privacy and Security**: AI methodologies should include robust security measures to protect user data and maintain privacy.
- **Bias Mitigation**: Efforts should be made to ensure that AI models are not biased and do not discriminate against users based on factors such as gender, age, or ethnicity.

Testing and Validation [20]:

- **Simulation and Testing Environments**: AI-driven simulations and virtual environments are used for testing prosthetic devices and algorithms before deployment.

User Training and Support [20]:

- **AI-Powered Training**: AI can assist in creating personalized training programs to help users adapt to and maximize the benefits of their prosthetic limbs.

The application of AI in prosthetics is an interdisciplinary field that involves collaboration between engineers, data scientists, clinicians, and users to develop and refine methodologies that enhance the functionality and usability of prosthetic devices. Continuous research and development in this area aim to improve the quality of life for individuals with limb loss.

5.0 Conclusion

Loss of body parts like limb is a huge loss for someone. It can affect any person physically as well as psychologically. However, the advancement of technology has given hope for millions that they can too have a normal life.AI in orthotics and prosthetics are not that much widely spread. But technology is something that always grows in forward direction even in small amount. But this service also has drawbacks like many people who have this problem can't afford the cost of this process. 3D Printing gave many contributions in the field of Prosthetics for growing nations and it facilitates people having less income that cannot afford advance technique can rely on it. Also, the government and funding agencies should come forward to make this available for larger population in affordable cost. In upcoming time due to presence of prosthetics a person's daily life can become better also the machine will be easily available in less amount. This technique is always researching on finding advancement that is best for the patients and most effective way. In the end it also matters to make wearer feel comfortable in those machines and not make it too heavy or noticeable, so technology is also working on it.

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