Applications and Prospects of AI in Intelligent Artificial Limbs Design

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Abstract. In recent years, the rapid development of artificial intelligence (AI) has greatly promoted the design and manufacturing of intelligent medical devices. However, the system of AI, the variety of signals from sensors, and the cognition of bionic dynamic devices are too immature, and current research in this field is not systematic enough. The problems of them limit the advanced development of intelligent artificial limbs. This paper reviews the application of AI to intelligent artificial limbs in the medical field. The review involves three main sections: structure designs, signal recognition, processing, and motion control. The review adopts interdisciplinary and literature research methods to summarize the main problems and promising techniques. The review summarizes the motion controls and structure problems in intelligent artificial limbs. AI can provide all-time adjustment of intelligent artificial limbs to improve the patient's adaptation. The improvement of structure design and motion control can make intelligent artificial limbs able to help disabled people move again and even do some easy sports to accelerate the rehabilitation of motion ability This paper provides a review and analysis of the intelligent artificial limb. The advanced development of the intelligent artificial limb in AI is divided into several aspects. The analysis in this paper provides many advice for the product. The advice of the intelligent artificial limb can make it produced widely in the market.

Keywords: Artificial limbs, AI, Deep learning

1 Introduction

Intelligent artificial limbs are an emerging product in both the academic field and the medical prosthetic limb market. With the development of AI and bionics and the combination of interdisciplinary techniques, the intelligent artificial limb is the most promising product in the future. It is most likely to be a dominant technique for motion rehabilitation. There are many active-passive mixed types of artificial limbs.

Nowadays, the research on intelligent artificial limbs is mainly about the algorithms of AI, materials, and some signal recognition. The application of deep learning in AI has revealed its function successfully. Many materials, like artificial muscle and carbon fiber, are also used in a lot of ideal models to test their performance. For signal recognition, electromyography establishes the connection

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between the neural system and motion control. Nevertheless, there is a huge lack of contact between AI and artificial limb motion control. Although the algorithms and training models have matured, there are few studies to relate artificial limbs with AI models. AI can have an adaptive model to adjust the artificial limb under the current development of AI.

Moreover, portability and battery are also big puzzles for the product. Many researchers about this puzzle claim that the product can decrease its weight and dimensions to improve its mobility performance. The product can reduce the degree of freedom to be portable enough to reach the standard for daily use. For the structure and material of an intelligent artificial limb, it is essential to establish a complete system or model to take an assessment of a patient so that the intelligent artificial limb can adapt to a specific patient best. 3D scanning of the stump, body feature analysis, and service environment need to be considered as three main features to determine the material, structure, and degree of freedom.

The studies of intelligent artificial limbs in the future need to pay more attention to the connection between AI and limb motion control. The human-machine interface system is important for the use of intelligent artificial limbs. This research mainly reviews recent studies about the application of AI to intelligent artificial limbs. This paper summarizes several applications of AI in the intelligent artificial limb and analyzes the flaws of current devices or algorithms. Also, this paper discusses many approaches to improve the product and many advantages of this product in the future. It indicates that the problems that the product is facing can be solved by changing the algorithms of AI and the types of trained models. This paper reveals the innovation of provided services and advanced algorithms of AI. AI can involve structure design, signal recognition, and motion control. Different trained models can adjust their motion models according to different situations to help disabled people with motion rehabilitation.

2 Design Requirements for Intelligent Artificial Limbs

2.1 Concept of Intelligent Artificial Limbs

An intelligent artificial limb is a dominant type of prosthetic limb for disabled people to recover their ability to move. It contains the AI part, the embedded active control part, the dynamic part, and so on [1]. Intelligent artificial limbs have adaptive human-machine interface systems and powerful dynamical systems to complete basic, even complex, movements for disabled people.

2.2 Design Requirements for Intelligent Artificial Limbs

The design requirements of intelligent artificial limbs can be divided into two sections. One is the hardware section. The other one is the software section. For the hardware section, an intelligent artificial limb should guarantee its stability and durability. The density and texture of material as well as the structure need to adapt to any movement of disabled people. For the software section, intelligent artificial limbs should adjust to the movement preference of a specific disabled person automatically. Furthermore, the software system needs to recognize the movement of people and provide dynamic support to disabled people appropriately to recover their ability to move.

Structural Design Requirements for Intelligent Artificial Limb. The structure of intelligent artificial limbs satisfies stability comfort and portability. Intelligent artificial limbs need to keep the balance between probability and durability to guarantee safety for heavy-weight people. The material and structure of intelligent artificial limbs can be carbon fiber [2]. Addictive manufacturing has a promising application in intelligent artificial limb manufacturing. the comfort of the prosthesis user is not influenced by the hydraulic units whose weight and overall dimensions. The embedded actuator can control the limb actively to achieve some essential flexion and extension [1]. Soft structures with wire-actuated exoskeletons are preferred in rehabilitation processes because they are more friendly for daily life due to their lightness and performance [3]. Thompson et al. [4] represented a cable-driven soft actuation system for shoulder and elbow joints to increase the muscle strength of the operators. Hybrid actuation mechanisms are on the rise these days, giving great satisfaction in certain cases. Thompson et al proposed a hybrid exosuit that integrates NMES to facilitate whole upper limb muscle strength with motor recovery [4]. The various types of materials of the intelligent artificial limb as well as its proportion of types are shown in Fig. 1. The degrees of freedom are another main factor that influences the product's portability and comfort. Different types of products fit different people. The choice of degrees of freedom and types of motion control is shown in Fig. 2.

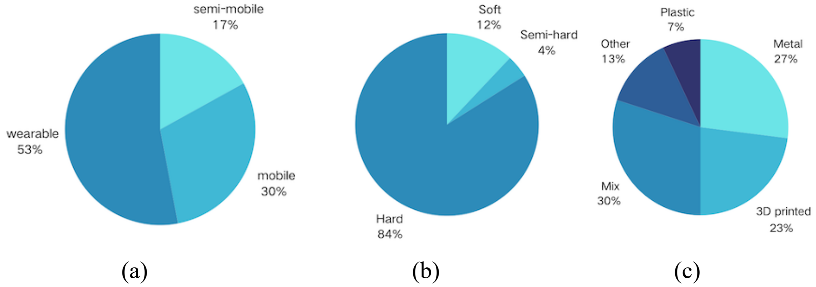
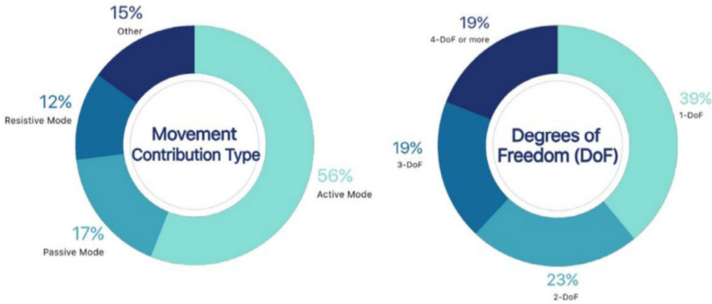


Fig. 1. The overall distribution of physical attributes of robotic exoskeletons. (a) Portability; (b) Exoskeleton type; (c) Any applicable structural material.



(a) (b)

Fig. 2. The distribution of the operating modes of robotic exoskeletons. (a) Movement contribution types; (b) Total degrees-of-freedom [5].

Signal Recognition and Processing Requirements for Intelligent Artificial Limb. The main problem of Signal recognition in intelligent artificial limbs is the way of denoising and normalization which can prevent signals from being distorted [6]. Signals can be disturbed by external factors and internal factors. Jitter caused by physical movement, periodic influence from the environment, position deviation, and self-measurement mistakes can all disturb the consequence of signal cognition. The processing requirement of intelligent artificial limbs should not be based on high-performance machines and systems.

Motion Control Requirements for Intelligent Artificial Limb. Motion control can be divided into 4 types of motion models: the active model, passive model, assisted model, and resisted model. The intelligent artificial limb is a combination of bionic structure design and AI control algorithm. Intelligent artificial limbs need to provide the motion of disabled people and change the motion models to adapt to their motion preferences and react with people through a human-machine interface system.

3 Applications of AI Technology in the Design of Intelligent Artificial Limb

AI technology makes the intelligent artificial limb able to adapt to any specific disabled person's motion preference through deep learning. Firstly, AI can test the best structure design of the product through geometry and bionics. Secondly, AI can recognize the signal through the trained model. Also, AI can judge the environment and body's conditions as well as predict the consequences of a series of motions of the patient.

3.1 Applications of AI Technology in Structural Design of Intelligent Artificial Limb

Intelligent artificial limbs need to adapt to specific people's preferences by scanning the stump and testing the best structural design of the limb. The intelligent artificial limb can give the best motion angle of the geometric structures. Three main aspects of structural design are portability and structural material.

The Portability of Intelligent Artificial Limb. portability determines the application of the limb. The 3D printing technique can make intelligent artificial limbs light enough and have a high performance in sport ability rehabilitation.

Structural Material. Generally, the artificial limb is composed of two or more types of material. The most common materials are plastics and metal. The maximum strength and pressure of the mechanical structure can be tested by ANSYS static analysis to select the best material. The structure is compact and portable as well as durable enough. Addictive fully 3D printing is the most promising technique that can be used for intelligent artificial limb making.

3.2 Applications of AI Technology in Signal Recognition and Processing of Intelligent Artificial Limb

In the signal recognition part, the signal denoising and normalization can make the consequence of the recognition more accurate. The noninvasive nature of surface electromyogram (EMG) recordings from residual limb muscles has led to their proposal and use as an input signal for motorized myoelectric prostheses and other rehabilitation robots [7-9]. The signal should record the flexion and extension angles at the ankle and knee. The force or pressure applied to the prosthesis is detected when it contacts the ground, and, using the sensory input, forecast the leg motion during the ascent of stairs. Such signal collection can provide sufficient information to guarantee accuracy and rapid response speed. The flow of signal recognition in the intelligent artificial limb is shown in Fig. 3.

Processing of signals in intelligent artificial limbs should build various specific models to match disabled people who have some similar characteristics. AI can make decisions and predictions through trained models. Neural networks with recurrent and convolutional architectures are two possible model algorithms. For the recurrent neural network, the recurrent neural network has been used in many mature products in the market. Recurrent neural network solves the motor control system successfully. Furthermore, recurrent neural networks can dispose of any random data efficiently.

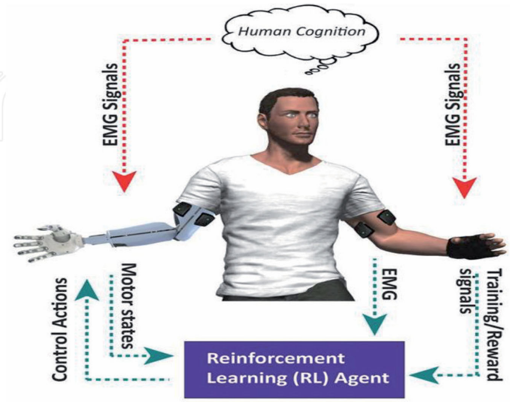


Fig. 3. Schematic diagram of the flow of information with artificial limbs [10].

3.3 Applications of AI Technology in Motion Control of Intelligent Artificial Limb

Artificial neural network. Artificial neural network is the dominant technique used in intelligent artificial limbs.

It performs effectively in motion planning and pathing learning. Furthermore, the prediction of motion and judgment of the environment during disabled people's usage is based on the artificial neural network. Artificial neural networks can recognize the situation of motion and change the motion model to adapt to disabled people timely through electromyography and force-myography signals.

Adaptive Algorithms. Adaptive algorithms can evolve spontaneously to learn the motion preferences of disabled people. Thus, it can record the motion track or EMG signals' characteristics rather than using a single or several trained models. For the intelligent artificial limb, such property is significantly important in the future.

Motion control of intelligent artificial limbs can have four main types -active model, passive model, assisted model, and resisted model. Active and assisted model is mainly used to provide motion support for disabled people through embedded dynamical parts. The passive and resisted model is mainly used for the rehabilitation of motor and neuromotor through stimulating the muscle or providing resistance.

For the active and assisted model, the inertia and intrinsic impedance of the actuator can be reduced by Series Elastic Actuators (SEA). Furthermore, SEA can make the force control more precise and stable. The active model can provide better sports performance for disabled people [6].

For the passive and resisted models, these kinds of devices relieve the load on the limb to be treated when placed in a real environment. It provides necessary support to help disabled people to rehabilitate their sports performances.

Furthermore, an XR gesture recognition system, body tracking, and anthropometric measurement systems can be used to improve the connection between patients and AI [11].

With the aid of a feedback system, adaptive controlling would allow a system to operate more in line with the intended output [12]. Recently, the latest advancement in AI-aided control systems is the mind-controlled limb. A modular prosthetic limb has been developed because of a collaborative effort between the Pentagon and Johns Hopkins Applied Physics Laboratory (APL) [13]. It can be controlled by the sensors that are implanted in the brain. It can even recover the sense of touch through electric impulses.

4 Research Prospects of Intelligent Artificial Limbs

Intelligent artificial limb has promising applications in both the medical field and technology field. The various algorithms and types of intelligent artificial limbs have many unknown techniques that can be explored. In the future, it will even be achievable to provide extreme sports performance to improve basic human ability. The applications of intelligent artificial limbs can involve not only the medical and technical field but also the sports field.

In the manufacturing of intelligent artificial limbs, AI can improve the quality of the product vastly. Because the characteristics of a patient's stump are different from person to person. AI can increase the degree of match of a specific person rather than the same limb model adapted to all disabled people. AI can judge which type of design can provide the best sports performance through the amount of data from testing and simulating the motion. The geometry and bionics also influence the artificial limb's structural design.

5 Conclusion

This review adopts a literature research method to summarize intelligent artificial limb studies in recent years. Interdisciplinary research is used to analyze the current problem and make advice on the development of intelligent artificial limb techniques in the future. In this research, AI has promising room for improvement in structure design and motion control. For structure design, AI can create different models to match specific disabled persons. AI can even make unique structures to match each patient through deep learning and 3D scanning. For motion control, AI can create different models to adapt to different sports conditions. The trained models can change the damping of the knee or other adjustable parts of the limb to help the patient move better. This paper indicates that the intelligent artificial limb has many flaws that can be solved. Although the product has some problems and bugs in the system that it cannot be produced and used widely in the market, it is still the most promising product in prosthetic limbs in the future.

Nevertheless, there is still huge room and flaws that can be improved. For structure design, AI can combine with 3D scanning to make more accurate designs to adapt to each person. With the development of the 3D scanning technique, the complete process can be rapid and easy. Every disabled person can enjoy his prosthetic limbs better using feeling. For the motion control section, AI can learn the specific motion demands of a specific person in the future. Deep learning can learn a patient's motion preference actively. Recurrent neural networks can avoid many signal errors or patient mistakes through their recognition of the order of time. Furthermore, AI may provide all-time motion adjustment instead of several specific motion models. Most studies do not involve the section above. Those changes can improve the quality of intelligent artificial limbs vastly. There are still some techniques that unmature. They cannot apply widely. In the future, scholars should focus on the improvement and development of such techniques to make the product more mature.

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