Analysis of the Structure and Working Principle of Intelligent Bionic Hand

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Abstract. Intelligent bionic prosthetic hand controlled by intelligent neural networks with perceptual feedback function is a hot topic of research for scientists around the world. This article analyzes the development status of electromyographic prosthetic hands both domestically and internationally over the years, and provides a detailed introduction to the structure of intelligent bionic hands. The intelligent bionic hand consists of three important components: 3D printed bionic hand bone structure, sensors, and intelligent neural network algorithm control system. Among them, the intelligent neural network algorithm control system is its core. The focus is on the working principle of an intelligent bionic hand, where sensors collect electromyography and neural electrical signals generated by human muscle movements. Through the intelligent neural network algorithm control system, the data information obtained is continuously optimized and adjusted to achieve motion control of the prosthetic hand. This article analyzes some problems of intelligent bionic hands and provides development ideas and suggestions. It is pointed out that the reconstruction of the sensing function of the intelligent bionic hand should focus on multimodal feedback, using diverse stimuli and more sensitive sensors for human-machine interaction, so that the intelligent bionic hand can move flexibly and freely, benefiting most disabled patients.

Keywords: Intelligent bionic hands, Neural network algorithms, 3D printing, Sensors.

1. Introduction

Due to factors such as traffic accidents, diseases, work-related injuries, and war, the number of physically disabled individuals is increasing year by year. The loss of limbs has brought great inconvenience to the lives of people with disabilities, making it difficult for patients to take care of themselves in their daily lives. They not only suffer physical pain, but also bear enormous economic and psychological pressure, seriously reducing the quality of life. Intelligent prosthetics are high-tech devices that integrate 3D printing, sensors, and artificial intelligence control systems. Disabled people can flexibly control the movement of prosthetics. Upper limb prosthetics can restore the upper limb function of amputees to a certain extent and improve their quality-of-life Upper limb prostheses can restore the upper limb function of amputees to a certain extent and improve the quality of life of amputees [1].

This article starts with the development history and current situation of intelligent bionic hands, introduces the structural characteristics and working principles of intelligent bionic hands, points out some problems and challenges faced by intelligent bionic hands, proposes some innovative ideas, and puts forward prospects for the future development of intelligent bionic hands. The research in this article helps to promote the research and development of highly intelligent, flexible, convenient, and affordable bionic hands, and provides development ideas for the industrial application of intelligent bionic handicrafts.

2. Development status of intelligent bionic hands

The development of prosthetics has gone through a long process from low-level to high-level, simple to multiple functions. In 1948, German scientist Reihold Reiter successfully developed the world's first prototype system for electromyographic controlled prosthetics. It used the muscle electrical signal EMG from the amputee's stump to control the opening and closing of the prosthetic limb, Established information interconnection and collection between residual limb nerves and prosthetics, achieving control of prosthetics by the human brain [2]. With the rapid development of artificial intelligence and biotechnology, intelligent prosthetics have become the core feature of the new generation of prosthetics. In 2003, Italian scientists developed the CyberHand electric intelligent hand, which is controlled by the nervous system to improve the efficiency and comfort of patients using prosthetics [3]. In 2007, Touch Bionics, a British company, successfully developed the world's first multi degree of freedom flexible prosthetic product i-Limb, where each finger can move independently. Since 2005, DARPA in the United States has launched the "Revolutionary Prosthetics" program, becoming the largest research program in the field of prosthetics in history. More than 30 research institutions, including Johns Hopkins University, have participated, and successively launched the "Luke's Hand" and MPL intelligent prosthetics. The "Luke's Hand" was certified by FDA in 2014 and entered clinical application in 2016.Through a simple and intuitive control system, the LUKE bionic prosthetic arm can perform very agile arm and hand movements, as well as grip feedback. The prosthetic limb is powered by modular batteries and has a size and weight similar to that of a human arm [4]. In 2015, Japan's Exii company opened 3D printing for the HACKberry intelligent bionic hand. Most of the hardware of the bionic electromyographic prosthetic limb was printed using 3D printing technology, and the various components were quite consistent. Users can use smartphones to control the HACKberry to complete various rich movements [5]. BrainRobotics intelligent bionic hand, born in the innovation laboratory of Harvard University, is a product highly integrated with Brain–computer interface technology and artificial intelligence algorithm. It passed the FDA certification in 2022 [6]. This intelligent bionic hand can recognize the wearer's movement intention through the arm's neuromuscular signals, and convert the movement intention into the movements of the intelligent bionic hand, thus achieving dexterity, intelligence, and hand tracking [7].

Intelligent prosthetics are a new generation of high-performance prosthetics. Compared with ordinary prosthetics, their main functional feature is the ability to automatically adjust the parameters of the prosthetic system according to changes in external conditions and work requirements, making it reliable, moving freely, and having better bionics. The detail development history is shown in table 1.

Table 1. Detail development history

Lead time	Name of intelligent bionic hand	Control source	Major function
In 1948	Electromyography controlled prosthetic hand	Myoelectric control	Realized the control of artificial limbs by the human nervous system
In 2003	CyberHand	Myoelectric control	Neural system controlled prosthetic hand
In 2007	i-Limb	EEG control Myoelectric control	Directly sense the signals emitted by the brain and make corresponding movements
In 2014	Luke's Hand and MPL Intelligent Prosthetics	EEG control Myoelectric control Intelligence Algorithms	The arm can perform very agile arm and hand movements, and was certified by the FDA in 2014
In 2015	HACKberry intelligent bionic hand	3D printing hardware EEG and EMG control Intelligent algorithms	Users can use smartphones to control HACKberry to complete various rich actions
In 2022	BrainRobotics intelligent bionic hand	High integration of Brain–computer interface technology and artificial intelligence algorithm	Dexterous and intelligent, with hands following the heart. In 2022, it passed the FDA certification in the United States.

3. Structure of intelligent bionic hand

The intelligent bionic hand realizes the transmission of human-computer interaction signals by connecting the neural synapse with the artificial limb. Among them, nerve synapse refers to the connection point between two nerves or nerves and muscles. Through the transmission of electrical signals, the cells where the nerve synapses are located will transfer work to the corresponding muscles to achieve human movement. The intelligent bionic hand connects the neural synapse with the artificial limb, and implants sensors and actuators on the artificial limb. By transmitting electrical signals and processing data, intelligent control of the prosthetic limb can be achieved, providing accurate feedback on the amputee's movement intention. Portable AI bionic hand System is shown in figure 1.

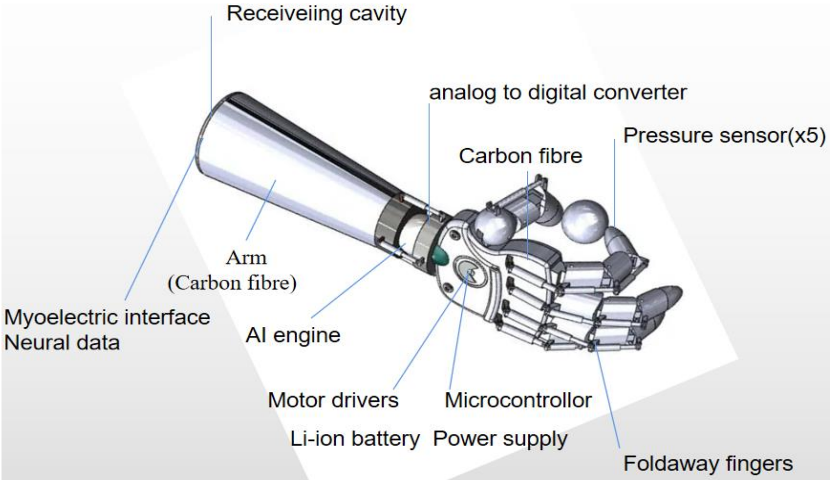

Figure 1. Portable AI bionic hand System (Photo/Picture credit: Original)

3.1. 3D printing of bionic hand bone structure

Due to the lightweight and high strength characteristics of carbon fiber, a carbon fiber shell is selected as the skeletal structure of the hand, which is bonded to the 3D printed palm component with epoxy resin, and then assembled with other parts of the hand. The design of biomimetic fingers has biologically inspired anatomical features, including proximal phalanges, middle phalanges, and distal phalanges. Using carbon fiber to make 3D printing molds, SLA 3D printing can print complex mold shapes and fine details [8]. The 3D printing manufacturing method requires a detailed CAD model, and biomimetic features can be complex modeled as assemblies in CAD software, assigned unique materials, and made into individual parts. This CAD model completely mimics the biological mechanical structure of human hands [9].

3.2. Sensors

Including pressure sensors, torque sensors, angle sensors, etc. These sensors can sense parameters such as the position, direction, and force of the robotic hand, enabling it to perform precise actions. There are pressure sensors on each finger, which can replicate tactile sensation for users, connect sensors on residual limb muscles, or control through Bluetooth applications. The intelligent bionic hand can independently move each finger.

The function of the sensor is to convert changes in external conditions into extractable analog electrical signals. The electromyographic signal sensor is used to train neural networks to obtain and adapt to the processing and storage of these signals. The infrared imaging sensor inputs the identified target object into a computer to form an image signal sequence, which is then recognized by the neural network. Pressure sensors can obtain force information from objects and the environment, allowing the robotic arm to feel the force required to grasp the object. The torque sensor accurately measures the rotational torque of an object by measuring its deformation or changes in electrical properties after being subjected to force, thereby achieving measurement and control of the rotational torque of the object. Angle sensors have advantages such as high sensitivity, high resolution, and high accuracy. When the sensor is connected to an object, as the object rotates, the sensor generates a changing signal. These signals can be read by sensors, then converted into digital signals, processed, and analyzed by processors, ultimately obtaining the accuracy and direction of object rotation.

3.3. Artificial Intelligence Algorithm Control System

AI collects signals from sensors, analyzes and identifies them, adjusts motion parameters, force parameters, structural parameters, etc., makes decisions and sends control commands to corresponding parts of the prosthesis, so that the bionic hand can work as required. The control system adopts intelligent neural network algorithms to control the motion of the bionic hand through computer programs. The intelligent neural network algorithm is an effective combination of genetic algorithm and BP neural network algorithm, which can make the robot hand imitate human hand movements, such as clenching, stretching, rotating, etc. These algorithms can also make the machine feel the external environment, such as obstacles, to avoid collisions and cause harm [10].

Each joint of the intelligent bionic hand is powered by a micro hydraulic propulsion system, which controls the movement and control of each finger by implanting sensors in the amputee's residual muscles. The independent propulsion system makes the fingers appear more natural and flexible than regular prosthetics. By using sensors located in the fingers and palms, the nerves and muscles at the amputated stump can sense objects and control grip strength based on actual situations.

4. Working principle of intelligent bionic hands

Intelligent bionic hand is hand is a robotic hand that can mimic human hand movements, based on advanced sensors and control systems. Sensory sensors sense the external environment and the position of the robotic hand, collect electromyography and neural electrical signals generated by human muscle movements, and continuously optimize and adjust the obtained data information through intelligent neural network algorithm control system to achieve motion control of the artificial hand, enabling the intelligent bionic hand to achieve flexible movement.

4.1. Signal recognition and processing

Information acquisition refers to the conversion of sound and light information through sensors to electrical signals, and the use of computers to classify and extract important features of images, effectively eliminating unnecessary features, thereby enabling image recognition.

4.2. Signal transmission and prosthesis movement

The intelligent bionic hand relates to the prosthesis through the neural synapse, and implanted with sensors and actuators on the prosthesis. Through the transmission of electrical signals, data processing and intelligent control, it can accurately feedback the movement intention of the amputee, achieve the transmission of human-computer interaction signals, and then achieve human movement [11]. After the patient's brain emits a consciousness signal, an electromyographic signal is formed from the skin at the end of the residual arm. Through the contact between the skin of the residual arm and the prosthetic arm end in the receiving cavity of the intelligent bionic hand, the electromyographic signal is amplified through electrodes inside the prosthetic arm. The amplified electromyographic signal is then controlled by a reducer and force amplifier structure to control the micro motors in the arm and fingers, driving the functional movement of the fingers. Intelligent bionic hands have the ability to interact and control information in both directions. The nervous system can control the movement of prosthetic limbs according to their wishes, and the working status of prosthetic limbs can be fed back to the nervous system, achieving interconnection between prosthetic limbs and the human nervous system [12].

4.3. Neural network-based image recognition technology

Based on traditional image recognition, the intelligent neural network model is established by effectively integrating BP neural network algorithm and genetic algorithm. This is a calculation model simulating human brain neural network, which has the characteristics of self adaptation, learning, generalization, etc., and is widely used in signal processing. For example, in speech recognition, artificial neural networks can be used for feature extraction and classification recognition of speech signals [13].

5. Issues and Prospects

Due to the weak electromyographic signal and inaccurate sensor acquisition and extraction of electromyographic signals, intelligent bionic hands lack accuracy and sensitivity in control. It is necessary to use multiple information sources such as sound, EEG, and magnetoencephalography to design more agile sensors to transmit accurate signals to the control system. Invasive technologies such as implanting sensors in limb segments and direct nerve stimulation can achieve the accuracy of signal acquisition, but the non-invasive Mode of action of the human body, with the characteristics of low risk and natural feeling, will still be the preferred method in clinical practice.

The Skeleton of intelligent bionic hand is widely used due to the characteristics of light weight and good hardness of materials such as memory titanium alloy and carbon fiber, but it lacks in softness and skin perception function, so it is necessary to strengthen the research and application of human skin and artificial muscle.

The activities of the hand are delicate and very complex, making it difficult to obtain accurate mathematical models. There are difficulties in extracting and processing control signals. In terms of control systems, intelligent neural network algorithms need to be further improved and improved. More advanced intelligent algorithms are used to improve the dynamic and static performance of the prosthetic hand, so that it has good control performance.

The complex structure of intelligent bionic hands and the high cost of materials and control systems have become the main obstacles to their widespread promotion. It is imperative to use multimodal sensors combined with intelligent neural network algorithms to design lightweight, low-cost, and sturdy intelligent bionic hands that benefit the majority of disabled people. The flexible movement of intelligent bionic hands requires long-term and arduous training. In training, many phenomena or problems need to be inputted to learn from known cases. By utilizing training information, existing empirical models, and current learning information, ANN will continuously optimize and adjust all information obtained from this dataset, enabling the intelligent bionic hand to achieve flexible motion.

6. Conclusion

The intelligent bionic hand controlled by intelligent neural networks with perceptual feedback function is a hot topic of research for scientists around the world. This article analyzes the development status of electromyographic prosthetic hands both domestically and internationally over the years, and provides a detailed introduction to the three important components of intelligent bionic hands: 3D printed bionic hand bone structure, sensors, and intelligent neural network algorithm control system. The focus is on the working principle of intelligent bionic hands, where sensors perceive the external environment and the position of the robotic hand, and collect electromyographic and neural electrical signals generated by human muscle movements, By continuously optimizing and adjusting the intelligent neural network algorithm control system to obtain all data information, the motion control of the artificial hand is achieved, enabling the intelligent bionic hand to achieve flexible movement. The existing problems were raised, such as poor stability of sensor signal acquisition, insufficient material perception, and high cost, which are difficult to widely apply. Development ideas and suggestions were provided. It is pointed out that the reconstruction of the sensing function of intelligent bionic hands should focus on multimodal feedback, diverse stimuli, and the application of more sensitive sensors for human-machine interaction through diverse stimuli, so that the intelligent bionic hand can move flexibly and freely, benefiting the majority of disabled patients.

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