ISSN 2959-6157

Deep Learning and Human-machine Integration in Smart Prosthetic Control: Process and Perspectives

Yunjie Lan[1], Zimo Wu[2] and Xiaoming Yang[3],*

[1]Shanghai Starriver Bilingual School, Shanghai, China
[2]HuaiBeiShi First High School, HuaiBeiShi, China
[3]College of Intelligent Systems Science and Engineering, Harbin Engineering University, Harbin, China
*Corresponding author: 1242584234@hrbeu.edu.com

Abstract:

With the rapid development of science and technology and the maturity of deep learning technology, intelligent prosthetic limb control has made significant progress in human-machine integration. While traditional prosthetic technology has seen improvements in form and function, it still faces challenges in user experience and physiological adaptability. Deep learning, with its powerful pattern recognition and decision-making capabilities, offers new possibilities to address these issues. This paper reviews the current status and future development of the application of deep learning in intelligent prosthetic limb control, emphasizing its close relationship with the concept of human-machine integration. Intelligent prosthetic control involves not only mechanical engineering and bioengineering, but also interdisciplinary integration of the fields of neural engineering, electrical engineering, motion control and computer science. This paper reviews the limitations in traditional prosthetic technology, such as accuracy and user adaptability, introduces the successful cases and latest research results of deep learning in the medical field, and explores the potential of deep reinforcement learning in optimizing complex movements and adapting to different environments. Finally, the future direction of deep learning technology in smart prosthetic limb control is envisioned, and research challenges and recommendations are presented in the hope of providing theoretical support for the innovative development of smart prosthetic limb technology and improving the quality of life of people with disabilities.

Keywords: Deep learning; smart prosthetics; human-machine integration; motion control; bio signal processing.

1. Introduction

As a species more than 3 million years old, the human body remains vulnerable even today. Loss of hands and feet can significantly affect an individual's quality of life, making basic daily activities challenging. To address this challenge, scientists have developed modern prosthetics. This traditional prosthesis serves as a mechanical alternative to the body parts is designed to relieve pain and provide them with basic functions of the body parts. However, since these devices are entirely mechanical hardware, they also have many drawbacks. First, their structure lacks convenience and flexibility. As a result, traditional prostheses can only complete specific tasks. They struggle to adapt to changes in force, speed, and terrain in different environments. This limitation makes it difficult to meet multi-scenario applications, leading to abnormal gait, reduced safety, and increased energy consumption for users. At the same time, the fine and complicated mechanical structure of the traditional prosthesis makes it not only expensive, and cannot be mass produced. Therefore, the traditional prosthetic limb is contrary to its original design purpose and fails to effectively improve the condition of the disabled population. Disabled groups make up 10% of the world's population today. That means about 650 million people have inconvenient in life because of a lack of physical function [1]. Among them, about 57.7 million people are amputees or have limb disabilities [2]. It can be said that in today's society, special groups have a stronger demand than ever before for the support system that can improve their daily lives.

However, this need is not limited to the disabled group. The elderly group (over 65 years old) also has similar inconveniences in daily life due to physical aging. And as aging increases, so does their demand for ancillary support technologies. With 703 million people in the world today, aged 65 and over, the number is expected to reach

1.5 billion by 2050 [3]. Prosthetics and other assistive technologies not only improve the lives of specific groups but may also profoundly impact the future development of all humanity. Driven by medical, social, and technological needs, prosthetic technology research has advanced significantly. With the continuous progress of science and technology and people's continuous pursuit of a healthy quality of life, the intelligent prosthetic limb, as a revolutionary medical technology, is gradually changing the life of the disabled group. Different from the traditional prosthesis which is purely a hardware mechanical structure, intelligent prosthesis is a system that integrates mechanical electronics, information science, neurorehabilitation medicine, biomechanics, and artificial intelligence, and uses two-way feedback, accurate control, sensor, intelligent control and drive technologies. The combination of hardware and software in intelligent prostheses enables a wide range of applications. The technology has been slightly effective in both helping people with disabilities resume treatment, replacing motor control of their limbs, and improving the social conditions of vulnerable groups. In addition, it can be combined with the existing artificial intelligence technology in its use. A striking example is the intelligent prosthesis based on deep learning. With the development of artificial intelligence and the improvement of machine intelligence, human-machine collaboration has changed from a simple interactive work to a more complex cooperative relationship. Human-machine integration is mainly reflected in three aspects: bionic design, intelligent perception, and intelligent control. With the ability of intelligent robots in self-perception, reasoning and decision-making, and actively interacting with people, intelligent robots gradually develop to the equivalent of human beings, so as to complete tasks with human cooperation together and efficiently. In the concept of human-computer integration, it is important not only for the machine to perform instructions, but also to understand the intention and context of human commands in order to interact with humans more intelligently and effectively. All three can improve the performance of the intelligent prosthesis.

Through deep learning model training, intelligent prostheses evolve beyond mere mechanical substitutes into adaptive, personalized assistive devices. Through personalization and autonomy, humans can use the intelligence and computing power of machines to enhance their own capabilities, while machines can learn and understand human needs through neural networks to better serve and support them. It is also an advanced medical tool that can support personalized rehabilitation through biofeedback and data collection. In the concept of human-computer integration, the machine can not only execute instructions, but also understand the intention and context of its order in combination with the habits of the user, so as to interact with humans more intelligently and effectively. Although the rapid development, deep learning prosthesis is an emerging field after all. As an immature technology, there are still many research gaps, and there are many obstacles before achieving the goal of "man-machine integration". Even the most advanced prosthetic arms struggle to match the complexity, flexibility, and adaptability of the human hand. At present, most of the intelligent prosthetic limbs are controlled by internal mechanical sensors, human-computer interaction mismatch, motion lag and other problems. At the same time, the cost of most intelligent prosthesis is generally high, and there are still some obstacles from mass production. In the deep learning model, different training methods, training data and training objects have brought extremely complex, extremely different and frequently fluctuating practical results. Therefore, to overcome the current technical difficulties encountered, a unified summary of the different achievements and technologies in this field becomes crucial. In this paper, we will analyze the software and hardware technology of intelligent prosthesis, analyze the way of deep learning model construction and control of prosthesis, and uniformly compare and discuss the cutting-edge research in this aspect. List its application in different fields, and thus look into the future development trend of deep learning-assisted intelligent prosthesis, and move towards the goal of "man-machine integration".

2. Intelligent prosthetic system design

2.1 Intelligent prosthetic system design

When designing upper limb wearable robots, it's crucial to consider the characteristics and activities of shoulder, elbow, and wrist joints. This ensures the robot's motion matches the natural movement of the human upper limb. Similarly, when developing intelligent bionic legs in the lower limbs, in order to pursue the coordination of the wearer's comfort and action, we need to start from the three key joints of hip, knee, and ankle to perform detailed structural design and optimization.

2.2 Upper limbs

The upper limbs wearable robots have been widely used in medical rehabilitation and military operations. Although studies began in the 1960s, initial results were limited. From the end of the 1990s to the beginning of the 21st century, key technologies such as progress, human-machine coupling and other key technologies made breakthroughs, and exoskeleton development has achieved remarkable results, such as Caden-7 and three-free mobile exoskeleton robots.

The design structure of the upper limb intelligent limb system is divided into arms outer skeletal robots and upper limb bionic nerve prosthetic robots. Both arms exogenous robots are mainly to assist individuals with upper limb dysfunction for rehabilitation training. At present, the upper limb exoskeleton robot is mainly rigid structure. Its design incorporates multiple key joints including the shoulder, elbow, and wrist. It is usually driven by motor, pneumatic muscles or hydraulic pressure to enhance the power of the wearer and realize people through rigid soft coupling people. Interchange. A typical portable upper limb rehabilitation robot is Rupert, developed by Arizona State University. It uses pneumatic muscle actuators to drive 4 air muscles, enabling 5 degrees of freedom. These include shoulder joint rotation and flexion, elbow flexion and extension, forearm rotation, and wrist and finger movements. Rupert can assist with daily activities such as rehabilitation training and eating.

The University of California in the United States has developed a flexible superior upper extremity outer bone bone robot CRUX for upper limb rehabilitation, as shown in the Fig. 1 [4]. This is a lightweight, multi -freedom, flexible exoskeleton robot that can adapt to non -linear muscle skeletal structure. Because the classic external bones are difficult to conform to the natural human movement in a flexible manner, the outer bones of the upper limbs are transmitted by a pull -driven drive mechanism. CRUX has six independent motors and can run parallel, which means that if there is an appropriate controller, it can almost adapt to the arm movement of each user. Compared to its predecessors, this flexible upper limb exoskeleton meets the need for a new, flexible, and smooth design.

This design can not only meet the non -linearity of the human body, but also provide meaningful functions that enhance physical strength. However, the research on the effectiveness of active assistance at present is not yet comprehensive.

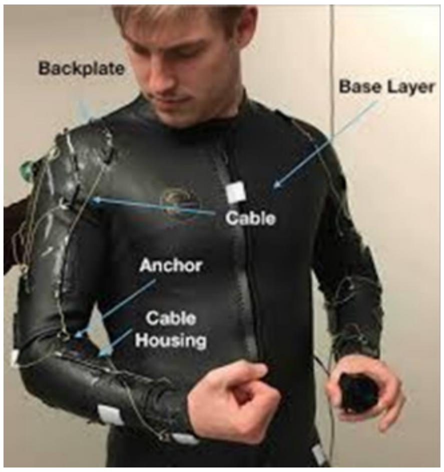

Fig. 1 Flexible superior upper extremity outer bone bone robot CRUX [4].

Through long-term evolution and development, upper limb wearable robots have demonstrated their indispensable importance in various fields, including industry and rehabilitation. However, its further development still faces many challenges and improvements. For example, the current material and component technology leads to the large weight and volume of the robot's overall weight, which brings a lot of inconvenience to the wearables and carrying users. In response to the current development bottleneck, we believe that the main development direction of system mechanical design should focus on the lightweight and localization of the upper limb exoskeleton robot. While ensuring effectiveness, durability, and user safety, consider replacing traditional rigid structures with flexible materials. This could achieve a lighter, more comfortable wearable experience. In terms of driving method, this paper can explore a light -quality driver such as pneumatic driver, or place the driver on the part where the user will not directly bear the pressure. Loss of energy. In addition, the design of the upper limb exoskeleton should further develop in the direction of localization and miniaturization to achieve a more lightweight design and improve work efficiency. For example, the design of the exoskeleton on the hand, the agency can closely fit the human hand to achieve synchronization with human movements, and provide users with more natural and efficient auxiliary. However, the design of finger institutions is relatively complicated and is still studying the development stage.

2.3 Lower limb verses

In view of the multiple factors such as accidents, diseases, and war, hundreds of thousands of people have to undergo amputation surgery of lower limbs each year, which leads to partial or completely lost their lower limb function and then lose their walking ability. Currently, medical technology is unable to regenerate lost limbs. Therefore, we mainly rely on the effective means of installing prosthetic limbs as a walking ability to restore lower limb amputations.

In intelligent lower limbs, the knee joint is the most important and most complicated component. A bionic design that mimics the human joint’s compensation mechanism is crucial for seamlessly integrating the amputee, prosthesis, and environment. At present, the design of the traditional knee joints is divided into initiative and passiveness, and there are also a small number of scholars proposed to be active and passive hybrid driving types. Passive prosthetic and knee joints use air pressure, hydraulic pressure and other damping devices and intelligent control technology to achieve adaptive adjustments to make the gait more natural.

Mature products such as Genium hydraulic prosthesis and knee joints [5]. In China, the Shanghai Institute of Technology Yufliu Group tried the first domestic intelligent hydraulic pseudo-limb knee I-KNee, and proposed 6 types of electronic control hydraulic damping cylinder structures for smart knee joints [6]. Independent adjustment of joint flexion and stretching damping. The main advantages of passive prosthetic knee joints are low energy consumption and stable performance. However, they cannot provide the high-force output required for high-torque movements, such as climbing stairs.

Active prosthetic knee joints use motors or pneumatic muscles to generate torque, enabling active flexion and extension of prosthetic limbs. Pneumatic muscles drive value by controlling the injection of high -pressure air. Compared with pneumatic muscles, motors have higher energy efficiency and easier to control accurate control. It is currently the most driving method in the knee joint application. Martinez, etc., designed a power knee ankle joint prosthetic limb [7]. The prosthesis is driven by two series elastic drives composed of DC motors and spring mechanisms parallel to the joint axis. In the subsequent research, the team proposed a deserted series elastic dealer and a torque coupled series elastic force. The two prosthetic limbs can effectively reduce the energy consumption of puppies. However, most active prosthetic energy consumption, high noise, etc. are still in the laboratory stage.

A common disadvantage of existing passive and active prostheses is their high energy consumption. They cannot accurately simulate the energy metabolism of human muscle groups during normal gait, which involves a mix of active and passive effects. Therefore, in recent years, some researchers have begun to study active and passive hybrid hybrids. At present, most of the hybrid damping and motor -driven mixed mechanisms are adopted. Such as Lenz, etc., a hybrid -driven pseudo -limb knee joint is proposed, combined with the driver and damping device, using a passive mode when walking in a flat ground, and using an active mode when climbing the building [8].

As an important part of the lower limbs, the knee joint of the intelligent prosthetic limb has always been aimed at the normal movement trajectory of the knee joint. Despite rapid advancements in knee joint research in recent years, many scientific issues and key technologies still require in-depth exploration.

In the future, when conducting the research of smart knee joint prosthetic systems, in terms of bionic structure and driving design, we need to focus on the following possible technical breakthrough points: main passive mixed compensation drivers. Because most of the torque provided by most prosthetic limbs and knee joints cannot be effectively coordinated with the motivation of amputated people themselves, amputated people also need to change their gait to adapt to prosthetic exercise. The hymnic limb needs to replenish the driving force required for real -time motion. Nowadays, a single initiative or passive can no longer meet the driving force. It is a future research and development direction for the use of prosthetic limb knee joints.

3. Intelligent prosthetic limb control method

3.1 Electromyography

Electromyography (EMG) is divided into surface electromyography (sEMG) and intramuscular electromyogram (iEMG).Surface EMG (sEMG) is one of the easiest bioelectric signals to obtain. When an electrode sheet is attached to the human skin, it can record the weak potential difference caused by muscle contraction. These weak potential differences are amplified and converted by EMG acquisition circuits to produce processable surface EMG signals. Since surface EMG signals are ahead of their time compared to their specific muscle actions, and since it is very easy to acquire surface EMG signals, sEMG signals can be processed to determine the patient’s intention to move. This method is popular in medicine and related research fields because of its fast response, accurate judgment, and simple operation. Nevertheless, sEMG still has limitations, such as its signal source is easily affected by the dryness of the skin surface and sweat, and it is extremely difficult to manipulate a multi-degree-of-freedom prosthesis with only two electrodes, also due to the insufficient number of signal sources [9]. In order to increase the informativeness and feasibility of the signals, some researchers have changed the location of the signal sources. For example, manipulating an upper limb prosthesis with the lower leg is a feasible and easy-to-learn method since the hand and leg share a similar form of cortical innervation. Subjects were able to perform thumb flexion and extension, flexion and extension of the remaining four fingers, wrist flexion and extension, and internal and external rotation of the forearm using the ankle and toes of one leg. Despite some confusion between internal and external ankle rotations during testing, the response speeds were comparable to those of regular sEMG and target muscle reinnervation (TMR) prostheses after restricting certain degrees of freedom [10]. This method is undoubtedly a very suitable solution for disabled patients with an able-bodied lower limb, and due to its unique technical characteristics, the training can be completed in close to 1h, which can be a blessing for some patients who have just suffered an accident, and likewise for patients with perennial disabilities, who, from a psychological point of view, are much more receptive to it. In contrast to the surface EMG signal, the intramuscular EMG signal acquisition method is to implant the electrodes directly into the muscle, so that the signal can be acquired directly in the muscle. This method provides more accurate signals than sEMG and is more resistant to interference. Similarly, the iEMG is also better at controlling multi-degree-of-freedom prostheses.

3.2 Neural network-based control method for prosthetic limbs

As derivatives of robotic arms in medicine, intelligent prosthetic limbs face similar challenges. Therefore, the smart prosthetic limb is also susceptible to more uncertainties in practical applications, such as friction, noise, electromagnetic interference and so on. Therefore, it is impossible to establish an accurate model, so it is difficult to get satisfactory results in control and deviation control. To address these issues, researchers have proposed various solutions including adaptive control, sliding mode control, and PID control. These methods can more or less reduce the motion deviation and improve the robustness. In order to improve the convergence speed of the control system, so some researchers proposed the control method of non-singular terminal sliding mode. This method typically requires accurate kinetic model parameters of the mechanical prosthesis. However, neural networks can approximate nonlinear functions. Thus, they can be used to estimate kinetic model parameters, reducing dependence on the actual model [11]. Autoregressive wavelet neural networks are feedback dynamic networks which can help the system to adapt to time-varying characteristics. Due to the tight branching nature of their wavelets, they have an advantage in the approximation of functions with sharp variations and discontinuities. The structure of SRWNN is shown in Fig. 2, with Ni inputs Ni*Nv mother wavelets.

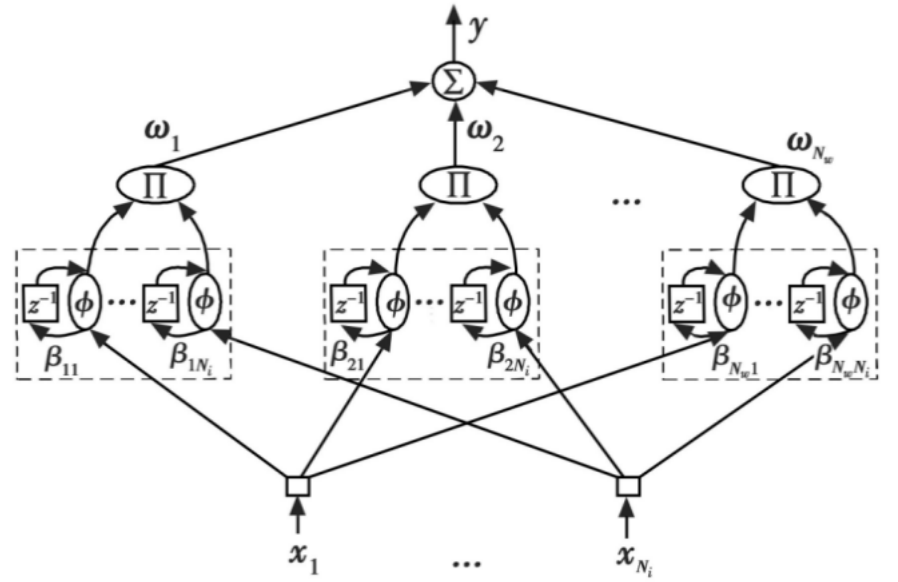

Fig. 2 Structure of autoregressive wavelet neural network [12].

Fig. 3 illustrates that the autoregressive wavelet neural network comprises four layers. The researchers developed an adaptive NTSM controller for robotic arm based on SRWNN. They suggested the use of non-singular terminal sliding modes to help design the controller. They used multiple SRWNNs with adaptive update rates to approximate the robotic arm dynamics parameters. They also designed an integral control term to compensate for the proximity error. The SRWNNs were utilized to estimate the system dynamics parameters and a control system was designed as shown in Fig. 3.

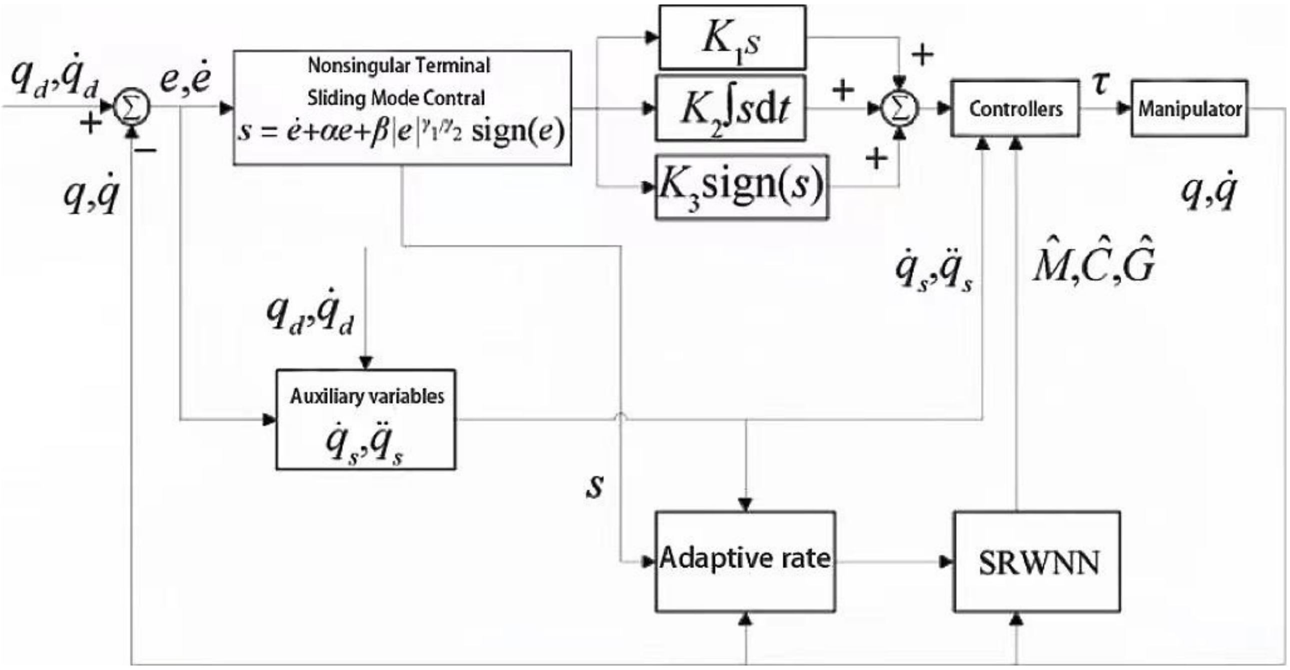

Fig. 3 Schematic diagram of the control system [11].

After a series of simulation tests, the researcher concludes that a more stable control effect can be realized based on this method. In the case of model uncertainty and unknown perturbation, this method not only circumvents the problem of singularities in the traditional sliding film control, but also accelerates the convergence speed of the control system. And multiple SRWNNs are utilized to approximate the unknown dynamic parameters in real time, and the weights are adjusted in real time using the adaptive law. In addition to this, an integral control term is also set up to correct the estimation error of the SRWNN in order to facilitate the counteracting of the effects of the unknown perturbations. This method can better realize the stability control of smart prosthesis.

4. Application of intelligent prosthesis based on deep learning

When operating contemporary prosthetics devices, limb disabilities need to convert their EMG signals into commands as an alternative to restore their motor capacity. However, the activity of the stump muscles is very limited and it becomes gradually inefficient in signaling. Therefore, ordinary prosthetic devices can only meet the basic needs of disabled groups, and it is difficult to provide personalized help, let alone improve the stump condition of users.

The advancement of AI technology has offered potential solutions to these challenges in prosthetic control. Based on deep learning of intelligent prosthesis all one characteristic is according to the user feedback learning the sample data inherent law and expression level, and through the analysis of the characteristics of the user's daily habits to construct personalized model to adapt to his muscle signal, so as to better interpret the user's behavior intention.

As a result, the intelligent prosthesis can learn iteratively to complete specialized tasks beyond daily activities. The more significant example is the application of deep learning prosthesis in the field of amputation therapy and disability sports. This chapter will analyze the training methods of deep learning models in these two fields, and discuss the impact of intelligent prosthesis based on deep learning on the field and the development potential of human-machine collaboration and integration under multi-scenario application around the product characteristics of personalized, precise and autonomous products.

4.1 Field of amputation treatment

Global statistics indicate that there are over 57.7 million people with physical disabilities worldwide. As the number of amputee's increases, rehabilitation treatments that prevent deterioration and enhance the independence of the disabled have become more important. But due to the lack of medical resources and low popularity, this emerging industry has now achieved little success. The emergence of deep learning intelligent prosthesis has brought a new option to the field.

Following training, intelligent prosthetics have been implemented in various settings including community hospitals, commercial products, and private clinics. Some public hospitals are now using LLPR data analysis to create personalized patient records for disabled individuals. This approach suggests potentially effective care plans, encouraging patients to actively participate in their rehabilitation programs [13].

In addition, in terms of products, the inexpensive and efficient 3D printing deep learning intelligent prosthesis has also been proven feasible [14]. For smaller groups, there are also institutions that use gestures to test the intelligent prosthesis trained by deep learning and exercise the subjects' hand control ability. In the experiment, 15 subjects were divided into 5 groups and the sample consisted of 75% of the training data and 25% of the validation data that were not trained in advance. As illustrated in Fig. 4, after 300 training cycles, the training accuracy reached approximately 99.4-99.8%, suggesting the potential effectiveness of deep learning in this context [15].

In practice, the deep learning-based intelligent prosthesis has multiple advantages in the field of amputation treatment. First, most obviously, in contrast to controlling multiple degrees of freedom limbs directly in individual joints, machine learning control can manipulate multiple degrees of freedom joints simultaneously through several independent EMG. This allows users to make more complex and natural movements, such as grasping items, greatly improving the daily life of disabilities. Second, deep learning models outperform shallow networks in decoding action intentions. Offline algorithms trained on pre-recorded data may not effectively translate to real-time prosthetic control [16]. In contrast, deep learning intelligent prostheses provide users with real-time visual feedback on current predictions. This allowed them to adjust muscle contractions to influence the next prediction, thereby progressively improving their ability to resolve motor intentions [17]. The patient's involvement in their own medical plan has also proven to be beneficial in the quality of care, its outcomes, patient satisfaction and healthcare costs [18].

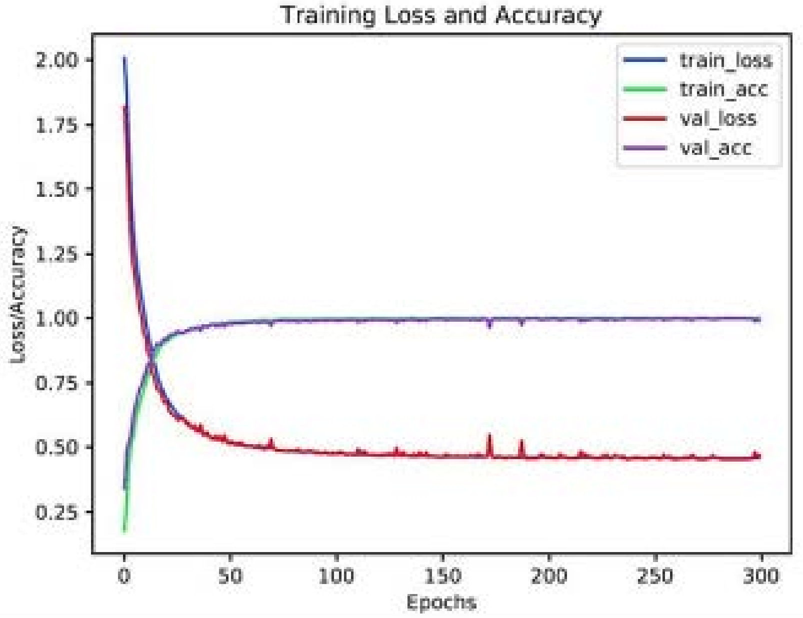

Fig. 4 Change curve of training data and validation data accuracy regarding training time [18].

Multiple studies have shown that deep learning-based intelligent prostheses effectively improve amputation treatment accessibility, enhance personalization, and reduce care costs by minimizing human intervention [19]. The development of this technology in this field fully reflects its advantages of individuation, precision and autonomy, and shows its development potential in user analysis and human-machine collaboration in medical and other service industries.

4.2 Disability sports field

In objective competitive industries such as sports outside the service industry which focuses on subjective experience, the development direction of intelligent prosthesis based on deep learning has shifted from man-machine collaboration to man-machine integration. In the field of disability sports, the use of this technology is particularly prominent.

Continuing to participate in sports has always been an important concern after amputation. A survey of lower limb amputees revealed that nearly 60% of respondents actively participated in sports or recreational activities [20]. In recent years, there are more and more opportunities for people with disabilities to participate in competitive sports. In the 2024 Paris Paralympics, there will be 4,400 competitors in a month [21]. As people pay more and more attention to the disabled athletes, the demand for the technological innovation of sports prosthetic limbs has also increased greatly. A motor prosthesis based on deep learning has emerged.

In different sports events, athletes have different needs for physical function. Correspondingly, the training focus of deep learning models will vary, but it is certain that AI has been shown to be very effective in using sports biomechanics to analyze athletes' behavior. It can combine scores, athletes 'movements and other aspects to predict and provide timely feedback through athletes' behaviors, and effectively improve the accuracy of sports. In addition, the intelligent prosthetic limb combined with sensors also has the ability to analyze the sports that athletes engage in. The model shown in Fig. 5 uses a Bayesian statistical network (BSN) to collect EMG signals and IMU data to judge specific sports movements [22].

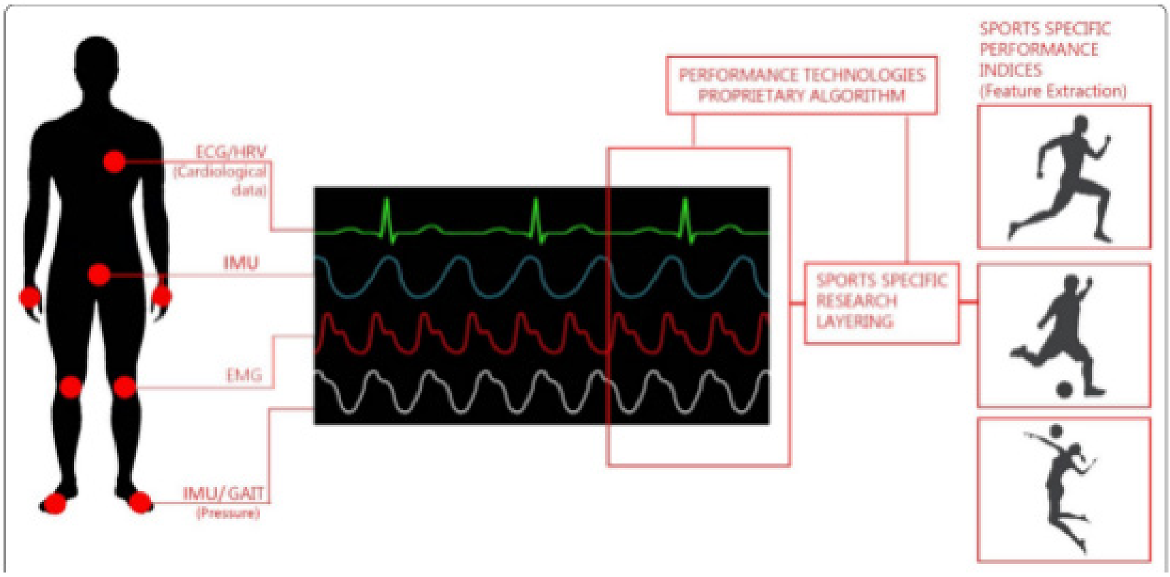

Fig. 5 Schematic diagram of the deep learning model to determine sports [22].

After assessment, deep learning prostheses can be tailored for specific sports. They are customized based on athletes' needs and conditions. Over time, these prostheses adapt to users' habits, helping maximize potential. This process aims to achieve seamless human-machine integration. The test of the intelligent prosthetic Michelangelo Hand sold on the market shows that the deep learning model trained with data from six tactile sensors of their hand joints can make them skillfully grasp basketball and pass movements and their risks, providing new possibilities for teamwork disability sports [23]. In terms of lower limbs, the study mainly focuses on the function of running and kicking. Recent studies have trained deep learning models in intelligent prostheses to analyze leg movement strength. These models have achieved 99% accuracy in vertical force prediction and 97% in transverse force prediction [24]. This is sufficient to show that the intelligent prosthesis based on deep learning models outperforms conventional machine learning algorithms and common prosthesis in both evaluation speed and prediction accuracy.

Deep learning-based intelligent prostheses offer numerous enhancements to para-sports, revolutionizing the field of adaptive athletics. First of all, it can find rules according to each athlete's project, better complete the control and strength of the movement and improve the athlete's athletic ability, so that he can participate in some sports and other activities that he may not be exposed to. At the same time, deep learning models can analyze risks and provide support to prevent secondary disability such as muscle strain during exercise. When athletes sustain injuries, deep learning prosthetic limbs enable them to maintain training and sports participation during recovery. This continuous engagement potentially accelerates and improves the rehabilitation process. Most importantly, deep learning-based intelligent prosthetic limbs can gradually fit into the user's habits through constant training, shifting people's attention from what athletes can't do to what they can do. By giving them the freedom to run, jump and be physically active, the technique enables athletes with disabilities to demonstrate their abilities rather than highlight their disability. It can be said that the intelligent prosthesis interprets the real spirit of sports-the spirit of perseverance and never give up, so that human beings to the goal of "man-machine integration".

5. Conclusion

The significant impact and potential of deep learning technology in intelligent limbs is gradually emerging, and it has a profound impact on future medicine and health. As a device that simulates and replaces or has lost physical function through advanced technology and engineering means. Traditional prosthetic design primarily relies on knowledge from mechanical and biomedical engineering. Generally, basic functional support is achieved through mechanical structure and simple control systems. However, with the advancement of deep learning and artificial intelligence technology, intelligent prosthetic limbs have been fundamentally developed. Deep learning has greatly helped the accuracy and adaptability of exercise control. The movement control of traditional prosthetic limbs depends on the preset mode and the simple control action of users, which limits its ability to understand and respond to the user's intention. In contrast, deep learning technology can use a large amount of sensor data, such as muscle electrical signals, inertia sensors, and visual data to achieve real-time analysis and prediction of user motion intention. Through deep learning models, the prosthetic limbs can learn and adapt to the individual movement mode of users, thereby providing more natural and accurate sports support. Deep learning also lays the foundation for the development of sensor technology. Its advancement enables the prosthetic limb to obtain richer and more accurate environmental information, such as tactile feedback and object recognition. Combining deep learning mode recognition and perceived processing ability, the prosthetic limbs can achieve more intelligent environmental adaptability, such as obstacle avoidance and automatic regulatory functions. These technologies not only improve the quality of life of prosthetic users but also enhance the independence and safety of their daily activities. The personalization and adaptation of intelligent legacy is also promoted under the develop.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Disabled-World, 2024, Disability Statistics: Information, Charts, Graphs and Tables, https://www.disabled-world.com/disability/statistics/

[2] Marcia Weaver, Juanita Haagsma, 2020, Global prevalence of traumatic non-fatal limb amputation, https://pubmed.ncbi.nlm.nih.gov/33274665/

[3] Grunzweig, 2019, Our world is growing older: UN DESA releases new report on ageing, https://www.un.org/development/desa/en/news/population/our-world-is-growing-older.html

[4] Hengxin Hu, Xudong Yu 2023 Artificial Intelligence 6 43-58

[5] Lan Xuteng 2023 Research on Design and Interaction Control Method of Wearable Upper Limb Rehabilitation Robot Changchun University of Technology

[6] Li Guoxin 2022 Research on the Design and Cooperative Control Technology of Upper Limb Wearable Robot System for Human-Machine Hybrid Intelligence China Academy of Science and Technology

[7] Zhu Chunyu, Li Sujiao, Yu Hongliu 2021 Biomedical Workbeds 25 375-380

[8] Wang Xiaoming, Li Linrong, Chen Changlong, et al 2023 Chinese Journal of Biomedical Engineering 42 486-501

[9] Yu Ping, Yu Lei, Chen Chuxin 2024 Journal of Yellow River Institute of Science and Technology 26 73-79

[10] Wei Qi, Yang Yong, Chen Shanlin 2020 Chinese Journal of Bone and Joint 9 853-857

[11] Yang Jia, Wu Peilin, Yang Li, et al 2024 Space Control Technology and Application 50 68-76

[12] Li Jiatian, Gao Qiang, Hou Runmin, et al 2021 Electro-Optics and Control 28 98-102+111

[13] Hargrove LJ, Englehart K, Hudgins B 2007 IEEE Trans Biomed Eng 54 847-853

[14] Li G, Li Y, Yu L, Geng Y 2011 Annals of Biomedical Engineering 39 1779-1787

[15] S. Nayak and R. Kumar Das 2020 Application of Artificial Intelligence (AI) in Prosthetic and Orthotic Rehabilitation Service Robotics In: IntechOpen

[16] Limb Loss and Preservation Registry 2014 How the LLPR Works [EB/OL]. (2014-02-13) [2024-07-15]

[17] Sachin Kansal, Dhruv Garg, Aditya Upadhyay, Snehil Mittal, Guneet Singh Talwar 2023 DL-AMPUT-EEG 126 Part C 106990

[18] G. Robert, J. Cornwell, L. Locock, A. Purushotham, G. Sturmey, and M. Gager 2015 BMJ 350 feb10 14 7714-7715

[19] J. Sumner, H. W. Lim, L. S. Chong, A. Bundele, A. Mukhopadhyay, and G. Kayambu 2023 Artificial Intelligence in Medicine 146 102693

[20] M. Pepper and S. Willick 2009 Current Sports Medicine Reports 8 339-344

[21] Paralympics 2024 Paralympic Games [EB/OL]. https://www.paralympic.org/paris-2024 [2024-07-16]

[22] A. A. Phatak, F.-G. Wieland, K. Vempala, F. Volkmar, and D. Memmert 2021 Sports Medicine - Open 7 1

[23] M. Columbaro 2024 Ensuring Safety in Upper-Limb Prostheses: Tactile Sensor and Machine Learning for Risk Prediction POLITECNICO DI TORINO

[24] S. Tarabotti, "Deep learning applied to 2D video data for the estimation of clamp reaction forces acting on running prosthetic feet and experimental validation after bench and track tests," thesis.unipd.it. https://thesis.unipd.it/handle/20.500.12608/40473.