Gait Parameter Identification of Lower Limb Exoskeleton based on Neural Network

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Abstract. With the continuous development and improvement of related technologies, as well as the increasing aging of the population, the increasing demand for assisted walking equipment for the elderly and other issues, the lower limb exoskeleton will play a more important role in the field of rehabilitation medicine. The physical condition and rehabilitation needs of each patient are unique, and the lower limb exoskeleton based on neural network can automatically adjust the rehabilitation plan according to the specific situation of the patient to achieve personalized treatment. This personalized program can better meet the needs of patients and improve the rehabilitation effect. With the continuous development of artificial intelligence and robotics, lower limb exoskeleton based on neural network is expected to become an important direction of rehabilitation technology in the future, and its research results will bring revolutionary changes to the rehabilitation medical field. Therefore, based on the relevant theoretical knowledge of neural networks, this paper will explore and discuss several different neural network related algorithms, namely GNN, recurrent neural network, long short-term memory network (LSTM) combined with Conformer framework, and explore their specific effects on the parameter identification of lower limb exoskeleton and gait recognition.

Keywords: Long short-term memory network (LSTM), GNN, recurrent neural network, parameter identification, gait recognition.

1. Introduction

As an important branch of artificial intelligence, neural network has developed rapidly since the 1980s. Especially in recent years, with the rise of deep learning technology, neural networks have made remarkable achievements in image recognition, speech recognition, natural language processing and other fields. As an important application direction of robot technology, the design, manufacture and control technology of lower limb exoskeleton robot are also improving. The maturity of robot technology provides a solid technical foundation for the research of lower limb exoskeleton. However, nowadays, with the increase of aging and the progress of medical science and technology, exoskeletons are more and more widely used in daily life. At the same time, exoskeletons instead of flesh can not only bring great convenience to all aspects of the action of the disabled, but also increase the efficiency of manual labor and save time and effort, and are used in many industrial manufacturing.

At present, there has been a lot of progress in the research of neural network and lower limb exoskeleton parameter identification at home and abroad. As for exoskeleton design, in 2008, Sun Jian and Yu Yong team of University of Science and Technology of China designed the first generation of wearable exoskeleton, which is composed of support skeleton, power drive device, control unit and multiple sensors. Since 2010, Professor Cheng Hong and his team from the University of Electronic Science and Technology of China have made progress in the clinical application of rehabilitation-assisted exoskeleton, and found that in the process of cooperation between humans and exoskeletons, the human-computer interaction torque exerted by the wearer on the exoskeleton cannot be clearly described using only a simple physical model, which depends on the behavioral characteristics of the wearer. At the same time, the university has also had papers related to the identification of lower limb exoskeleton parameters for reference, such as "Research on the identification and control of lower limb Exoskeleton parameters based on DeLaN" [1]. Later, many scholars have conducted relevant studies, such as Guo Zhiyuan, Zhou Sicheng et al. 's team also published a paper on lower limb exoskeleton, "Ergonomics based Research on lower limb Exoskeleton Robot Design for the elderly population" [2]. For the recognition of lower limb gait, Pappas and his team embedded gait phase detection sensors (GPDS) into the insole. GPDS includes a miniature gyroscope and three varistors, which can measure foot speed information and plantar pressure data. Based on these gait sensing data, they proposed a gait detection algorithm based on prior knowledge. It can recognize non-walking disturbances, such as sitting and standing up, and prevent non-gait movements from interfering with the controller. In the field of gait recognition, the domestic start is relatively late, but a lot of progress has been made. The team of Gao Zenggui of Zhejiang University proposed to establish a knee joint motion recognition model by using gene expression, and use the collected gait data for training and verification, which can effectively recognize and predict joint motion, and verify the feasibility of this system as an exoskeleton human-machine interface. Recently, there are also artificial intelligence related scholars Sun Xiaoqiang; Yu Xudong et al. published an overview paper on gait recognition for lower extremity exoskeleton, A Review of “Gait Recognition Systems for Lower extremity Exoskeleton Robots” [3].

However, the parameter identification of lower limb exoskeleton is a complex process, which needs to consider many factors such as mechanical structure, sensor accuracy, control algorithm and so on. How to accurately and quickly identify the parameters of lower limb exoskeleton is one of the important topics in current research. Neural network has strong learning and adaptive ability, and can accurately identify various parameters of lower limb exoskeleton during movement, such as gait cycle, joint Angle, speed, etc., by training a large amount of data. This precise control is helpful to improve the pertinence and effectiveness of rehabilitation training. Therefore, this paper will discuss the identification and research of lower limb exoskeleton parameters and gait combined with existing neural networks.

2. Explore the Principle of Gait Parameter

2.1. Overview of Neural Network and Lower Limb Exoskeleton

Neural network is an algorithmic mathematical model that mimics the behavior characteristics of animal neural network and performs distributed and parallel information processing. The basic principle is: each neuron multiplies the initial input value by a certain weight, and adds the value of other inputs to this neuron (and combined with other information values), and finally calculates a sum, and then adjusts the deviation of the neuron, and finally normalizes the output value with an incentive function. Through the connection and calculation of a large number of nodes (neurons), the neural network realizes the combination and output of nonlinear models, and has the ability to automatically learn, analyze and predict from the data.

Lower limb exoskeleton is a mechanical device that can be worn on the outside of the human body and assist the human body to walk, mainly used to help patients, the elderly, the disabled and other people walk normally and improve their quality of life. The design of lower limb exoskeleton involves complex mechanical structure and control system, and its parameters need to be accurately identified and effectively controlled.

2.2. Application of Neural Network in Parameter Identification

Dynamic system identification: The neural network can identify the dynamic system of the lower limb exoskeleton through mechanisms such as backpropagation algorithm. Through the input of the system's motion data (such as joint Angle, velocity, acceleration, etc.), the neural network can learn and simulate the dynamic behavior of the system, so as to identify the key parameters of the system [4].

Pattern recognition: The neural network has a strong pattern recognition ability and can identify the characteristic patterns of the lower limb exoskeleton in different motion states. This helps to understand the motion characteristics of the system more accurately, and provides a basis for the design of control strategies.

Adaptive learning: Neural network has adaptive learning ability, which can automatically adjust parameters and model structure according to the actual operation of the system. This enables the neural network to cope with the complex and changeable motion environment in the identification of lower limb exoskeleton parameters, and improves the accuracy and robustness of the identification [5].

2.3. GNN and Exoskeleton Gait Identification and Prediction

To optimize Human Exoskeleton Interaction, a paper published in the journal Frontiers in Neurorobotics, "Gait Neural Network for Human-Exoskeleton Interaction," A Gait Neural Network (GNN) model for gait recognition and prediction based on temporal convolutional networks is proposed. It consists of intermediate network, target network and recognition prediction model. The algorithm has a novel structure and can make full use of the historical information of the sensor. GNN performance was evaluated based on publicly available HuGaDB datasets as well as data collected by inertia-based wearable motion capture devices. The results show that compared with the existing methods, the proposed method has higher efficiency and superior performance. In the course of daily use, the data collected by the exoskeleton is mostly inertial data, which is essentially a kind of time series data. At the same time, if the exoskeleton robot cannot identify the wearer's movements and predict the inertial data such as the acceleration of each joint in advance and make corresponding adaptations, the wearer will have a sense of bondage and affect the quality of interaction. In order to solve this problem, GNN has improved the structure of the model, so that the prediction and recognition effect for this task has been improved.

The overall model structure of GNN is shown in the Figure 1. Its feature extraction module is composed of two TCN, while the final recognition and prediction module is composed of two fully connected layers. Considering the time required for the exoskeleton robot to calculate the input data and the greater influence of the similar time step pairs in the time series, we do not directly use the past data to predict the future gait data, but. Each TCN is a part of feature extraction, and the first TCN can be regarded as a miniaturized supervised learning model. The input is the normalized gait data, and the output is the intermediate data between the input time step and the target predicted time step. Then, the output of the first TCN (the gait data of the intermediate time step) and the original input of the model are joined together, so that a complete time series before the target time step can be approximately obtained. In this way, the problem of calculating the time of the system can be effectively solved and the continuity of the entire time series can be approximately preserved.

2.4. RNN and Exoskeleton Gait Parameter Identification

Recurrent neural network (RNN) is a special kind of neural network structure that has memory function and can process sequential data,which is shown in the Figure 2. The application of RNN in exoskeleton parameter identification is mainly reflected in its ability to process time series data, such as gait data, so as to realize the gait recognition and prediction of lower limb exoskeleton. Through RNN, gait features can be extracted effectively and parameters can be identified. Specifically, applications of RNN in exoskeleton parameter identification include gait recognition and prediction. For example, through the combination of full connection and RNN, a fast gait recognition network and a gait prediction network can be designed to realize fast recognition and effective prediction of human gait. This method has important application value in the field of exoskeleton robot, which can improve the stability and reliability of exoskeleton robot when assisting patients walking [6].

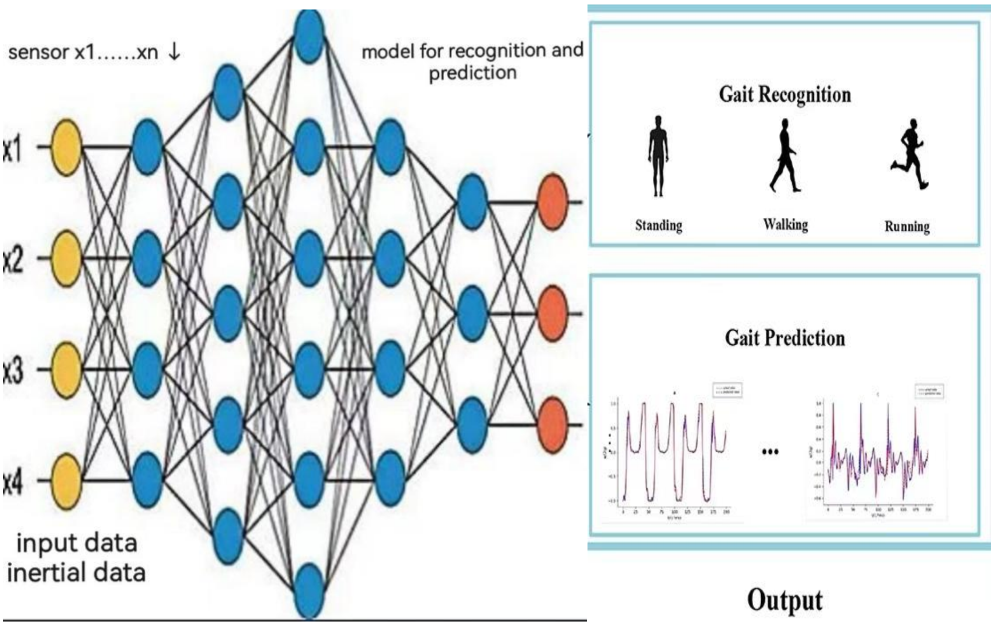

Fig. 1 CNN and gait (Photo credited: Original)

The advantage of RNN in exoskeleton parameter identification is that it can process time series data, extract gait features, and realize rapid recognition and prediction of gait. However, the training process of RNN is complicated and requires a lot of data and computing resources. In addition, how to optimize the structure and parameters of RNN and improve its performance is still a challenge.

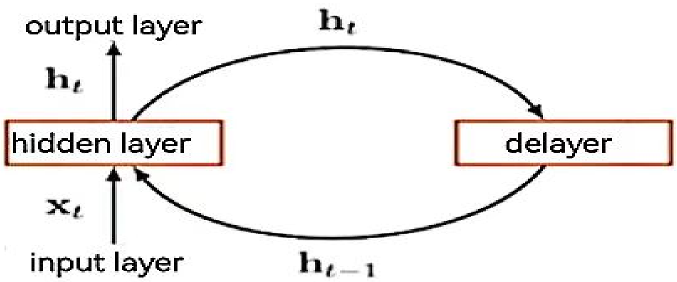

Fig. 2 RNN (Photo credited: Original)

2.5. Exoskeleton Gait Parameter Analysis based on LSTM-conformer

As can be seen from the structure diagram, the LSMT network structure consists of Input layer, memory module and Output layer,which is shown in the Figure 3. The memory module consists of Input Gate, Forget Gate and Output Gate. The LSTM model controls the read and write operations of all neurons in the neural network through these three control gates. The basic principle of LSTM model is to suppress the defect of gradient disappearance of RNN neural network through multiple control gates. The LSTM model can save the gradient information in a long time and extend the processing time of the signal, so the LSTM model is suitable for processing signals of various frequencies and mixed signals of high and low frequencies [7].

The lower limb gait prediction model should have sufficient ability to capture time and space features to predict gait trajectory. At present, there are many models with the above characteristics, such as Long Short-term Memory neural network (LSTM), which has a strong learning ability in the aspect of long-term information dependence and is widely used in the training of long sequence data [8]. Conformer model, which has achieved good results in the field of natural language processing (NLP), is a Seq2Seq(sequentially to sequence) model combining convolutional neural network (CNN) and Transformer model. The ability of CNN to effectively extract local features makes up for the poor ability of Transformer model to extract local features, while retaining the Transformer model's ability to capture content-based global interaction. Inspired by the Conformer model, this paper will explore the processed lower limb gait data sequence as the input of the gait prediction problem, and take the category label matrix of the next state as the output. After the above processing, the gait prediction problem can be regarded as a Seq2Seq problem, and the Conformer model can be introduced to improve the prediction accuracy [9].

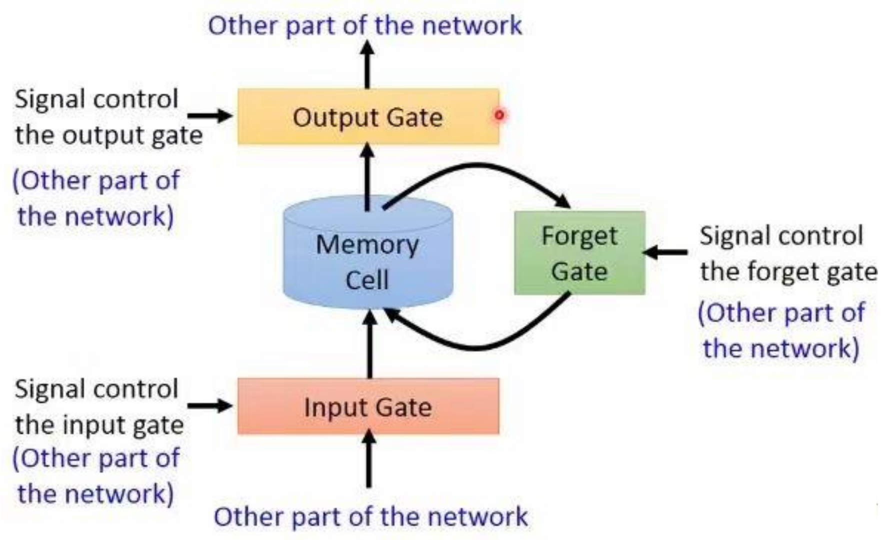

Fig. 3 Basic process of LSTM (Photo credited: Original)

In this model, the pre-processed gait data are input into the LSTM unit according to the time axis in each characteristic dimension, and the LSTM network initially captures the time characteristics in each dimension. However, gait data contains not only time information, but also rich spatial information. If only LSTM unit is used for feature extraction, the spatiotemporal information cannot be fully utilized and the ideal prediction accuracy cannot be achieved. For this reason, this paper input the feature data initially extracted by LSTM into the Conformer block after dimensional transformation. Conformer layer does spatial convolution of all dimensions along the time axis to extract spatial information while digging deeper time information. Finally, the output of the Conformer layer is decoded by the ReLU activation layer and a fully connected layer to predict the category label of the output step state. The proposed model can fully combine the advantages of the two models, improve the ability of capturing implicit temporal and spatial features, and then improve the accuracy of pre-measurement, and provide a reliable basis for solving man-machine collaboration problems [10].

The network built by combining LSTM and Conformer model is as follows:

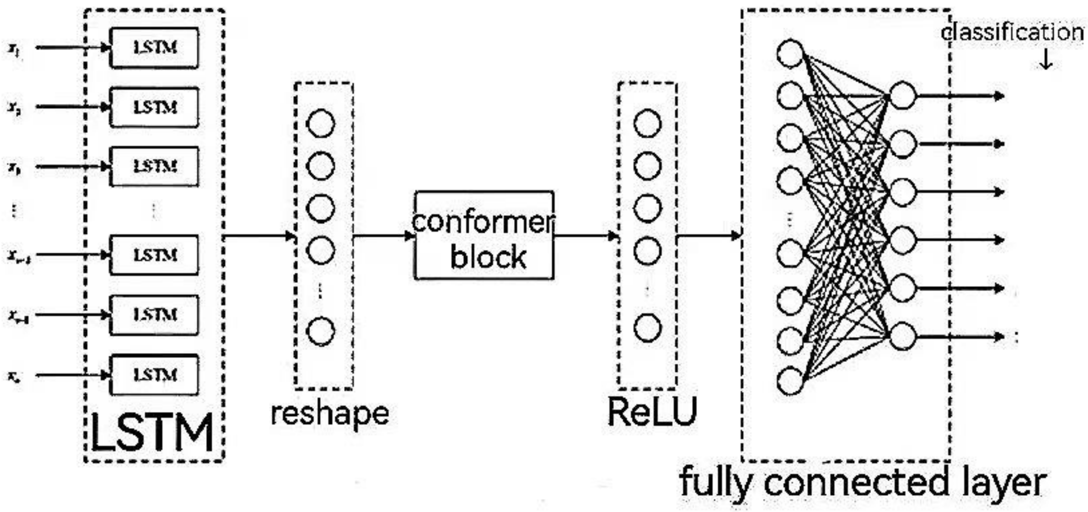

Fig. 4 LSTM-Conformer [7]

3. Discussion

3.1. The Inherent Limitations of Neural Networks

Data dependency: Deep neural networks typically require large amounts of labeled data for training, and obtaining large-scale labeled data in reality is often an expensive and time-consuming task. In areas where data is scarce, the performance of deep neural networks may be limited.

Overfitting problem: The number of parameters in deep neural networks is usually very large, and the model is prone to overfitting. Overfitting will result in good performance on training data, but weak generalization ability on unseen data, so it is necessary to take some regularization means to alleviate the overfitting problem.

Difficulty of interpretation: Deep neural networks are often black-box models whose internal structures and decision-making processes are not easy to explain. This may be limited in some application scenarios that require a high degree of model interpretation, such as medical diagnosis, financial risk assessment, etc.

3.2. The Advantage of Neural Network for Parameter Identification

Representation learning ability: Deep neural networks can extract high-level and useful features from raw data through multi-level feature extraction and combination. This enables the model to automatically learn more effective representations, improve the performance and generalization ability of the model, and facilitate the screening and identification of key information of exoskeleton and gait.

Massively parallel processing: The training process of deep neural networks can be massively parallel processed by hardware such as GPU, which accelerates the training speed of the model. This parallel computing capability is essential for processing large data sets and complex models, which greatly improves the efficiency of parameter identification.

Interpretability improvements: In recent years, researchers have made significant progress in the interpretability of neural networks. Through visualization technology, attention mechanism and other methods, we can better understand the decision process of neural network, increase the interpretability of the model, and greatly improve the accuracy in the process of parameter recognition.

3.3. Solutions to the above Limitations

Interpretability of the model: Strengthening the ability to explain the internal structure and decision-making process of deep neural networks is an important research direction. By designing a more interpretable structure and introducing explanatory constraints, the interpretability of the lower limb exoskeleton model is improved, and users' trust in the model is increased.

Weak supervision and transfer learning: Exploring how to make the best use of small amounts of labeled data and domain knowledge to improve the data efficiency of deep neural networks remains a challenge. Methods such as weakly supervised learning and transfer learning are expected to provide solutions to this problem.

Joint Learning and multi-modal fusion: The capabilities of deep neural networks can be further enhanced through joint learning and multi-modal fusion. This method can combine the information of multiple tasks and modes organically to form a more comprehensive and accurate model.

Several classical neural network algorithm optimization techniques can also be used, such as gradient descent algorithm, regularization algorithm, activation function algorithm, improvement of convolutional neural network, transfer learning, adaptive learning rate algorithm, etc., which not only improves the training speed and accuracy of neural network, but also strengthens the model generalization ability and robustness [11].

4. Conclusion

This paper describes the use of neural network and other machine learning technology to automatically extract and analyze the external shape of human lower limbs and gait features. These parameters are of great significance in the fields of motion analysis, rehabilitation training, disease diagnosis and human-computer interaction. The neural network model, Convolutional Neural Network (CNN) - excels in the field of image processing and is able to automatically extract spatial features in video frames. RNN - Good at processing sequence data and able to capture changes in gait features over time. Multi-modal fusion, using multi-modal neural network, improve the accuracy of recognition. Feature extraction: Automatic extraction of external morphological features and gait features of lower limbs by neural network. Gait recognition faces many challenges such as data diversity. Real-time requirements In some application scenarios, such as security monitoring, need to achieve fast and accurate gait recognition. Privacy protection, gait recognition involves personal privacy. With the development of deep learning technology, the recognition of lower limb external and gait parameters based on neural networks will make further breakthroughs in following aspects: model optimization: by improving the network structure, optimizing the training algorithm. Multimodal fusion: combining a wider variety of data sources and sensors. Real-time processing: development of efficient algorithms. Privacy protection,:strengthen the research of privacy protection technology. In summary, the recognition of lower limb external and gait parameters based on neural networks is a field full of challenges and opportunities. With the continuous progress of technology, its prospects will be broader.

Authors Contribution

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

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