Driving Methods of the Upper Limb Rehabilitation Exoskeleton Robot

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Abstract. In recent years, the number of patients with hemiplegia has increased year by year, and the use of upper limb exoskeleton robot assisted treatment is a novel and efficient treatment method. With the continuous development of science and technology and medical level, the demand for upper limb rehabilitation exoskeleton robot is increasing, and the requirements are getting higher and higher, among which, the choice of drive mode, control mode and material are the technical focus of upper limb exoskeleton robot research. Different driving modes are used for different therapeutic purposes, treatment sites and treatment plans. According to the driving mode, the upper limb rehabilitation exoskeleton robot can be divided into three categories, namely, motor drive, pneumatic artificial muscle, hybrid drive, and motor drive is divided into PRP model drive, underdrive, Bowden line drive, and twisted rope drive. In this paper, the structure and principle of these driving methods are introduced respectively, their advantages and disadvantages are expounded, and the future development trend of the upper limb rehabilitation exoskeleton robot is prospected. So that scholars can better understand the development status of upper limb rehabilitation exoskeleton robot drive.

Keywords: Upper limb exoskeleton robot; driving mode; motor drive; pneumatic artificial muscle drive; hybrid drive.

1. Introduction

Global Burden of Disease Study (GBD) data show that the incidence of stroke in China decreased from 222/100,000 in 2005 to 201/100,000 in 2019, but the prevalence is still on the rise. According to the data of the 2019 "Stroke High-risk Group Screening and Intervention Project", the population standardized prevalence of stroke in people aged 40 and above increased from 1.89% in 2012 to 2.58% in 2019, and the number of people aged 40 and above who are currently suffering from or have suffered from stroke in 2019 was about 17.04 million. Therefore, in order to curb the increasing burden of stroke disease, China's stroke prevention and control efforts need to be further strengthened [1]. Hemiplegia, also known as hemiplegia, refers to the movement disorders of the upper and lower extremities, facial muscles and tongue muscles on the same side, and is a common symptom of acute cerebrovascular disease. At present, the exercise rehabilitation of stroke patients is mainly assisted by rehabilitation physicians, but the rehabilitation medical resources in China are not enough to meet the urgent needs of stroke and hemiplegia rehabilitation. Robot-assisted rehabilitation therapy is a new technology to help stroke patients recover. Upper limb rehabilitation robot can assist upper limb hemiplegia patients to complete rehabilitation training, restore movement ability, and reduce doctors' work intensity, and has been applied in clinical treatment [2]. They provide assistive technologies to maintain and enhance patients' natural capacity for self-reliance and provide new therapeutic solutions for achieving universal health rehabilitation. Upper limb exoskeletons can significantly enhance human manipulation of the environment, which is critical to a patient's independence, self-esteem, and quality of life. At the same time, the upper limb exoskeleton robot makes up for the shortcomings of the end traction robot system, which is simple in structure and cannot train each joint of the human upper limb separately and effectively, and has better compatibility with the anatomical structure of the human upper limb. Therefore, the exoskeleton-type upper limb rehabilitation robot has been widely concerned.

In recent years, the incidence of stroke disease has further increased, and people urgently need more efficient treatment methods. Therefore, it is urgent and important to develop and improve a safe

and efficient new exoskeleton robot for upper limb rehabilitation. The driving mode is an important part of the upper limb exoskeleton robot. The driving mode of the exoskeleton upper limb rehabilitation robot will directly affect the mechanical structure and the design of the control scheme of the overall system. If the driving mode is immature, it will directly affect its rehabilitation efficiency and even cause safety problems. The current mainstream drive mode includes motor drive. As the most important power source at present, motor drive is widely used. It includes motor, underdrive, Bowden line drive and so on. For example, Shen Huimin et al from Shanghai University of Science and Technology developed a shoulder self-aligned rehabilitation exoskeleton [3], hydraulic drive: Chen Zheng et al from Zhejiang University designed a lower limb exoskeleton for load-bearing scenes [4], pneumatic artificial muscle drive. Qin Yandan et al from the School of Artificial Intelligence of Nankai University designed a pneumatic human muscle driven upper limb rehabilitation exoskeleton robot [5], twisted rope drive, and mixed combined drive: a hybrid drive upper limb rehabilitation exoskeleton robot designed by Yao Yulong et al., School of Mechanical Engineering, Anhui University of Science and Technology [6], etc. As the most important power source at present, motor drive is widely used. This includes a direct drive driven by a motor.

In this paper, the design principles, advantages and disadvantages, development prospects and other aspects of different driving modes of upper limb rehabilitation exoskeleton robots are summarized, and targeted views and suggestions are put forward.

2. Classification of Upper Limb Exoskeleton Drive Modes

2.1. Motor-driven Exoskeleton Robot for Upper Limb Rehabilitation

2.1.1. PRP model driven

One of the schemes of motor drive is to transfer the disk motor to the rotating joint, and use the rotation of the motor rotor to drive the rotation of the joint. One of the three degrees of freedom exoskeleton robots uses the RPR model.

The RPR model exoskeleton robot designed by Yi Ziyuan et al., School of Mechanical Engineering, Zhejiang University of Science and Technology, mainly consists of four parts: lifting platform, upper arm joint, lower arm joint and base. The motor installed on the base drives the upper arm to rotate through a wheel set, so as to realize the shoulder joint abduction and adduction rehabilitation training. The RPR model exoskeleton robot was shown in Figure 1.

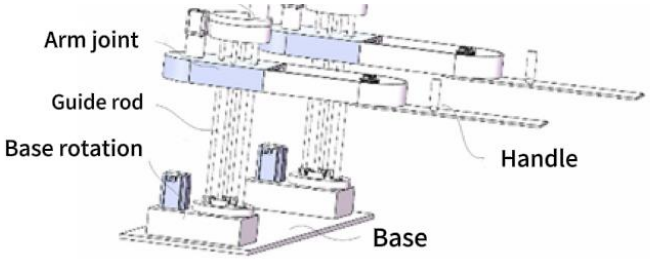


Fig 1. Holistic model of upper limb rehabilitation robot [7].

The Z-axis motor is connected with the ball screw, and the motor drives the ball screw to move, thus driving the lifting platform to adapt to the height needs of different patients, and at the same time driving the shoulder joint of patients to achieve forward flexion and extension rehabilitation movement; The motor installed on the lifting platform drives the movement of the wheel group, thereby driving the rotation of the forearm, and then realizing the rehabilitation training of the patient's elbow joint [7].

2.1.2. Under actuation

In robotics, the degree of freedom refers to the amount of freedom in which a robot can move independently. When a robot has more degrees of freedom than it actually needs, that is, it has excess degrees of freedom, this situation is called the underdrive of the robot.

The under actuated structure designed by Mihai Dragusanu et al. uses a single motor to drive the two front joints, enabling functions such as hand gripping. And its flat design makes the robot less driven and more portable [8]. The under actuated structure was shown in the Figure 2.

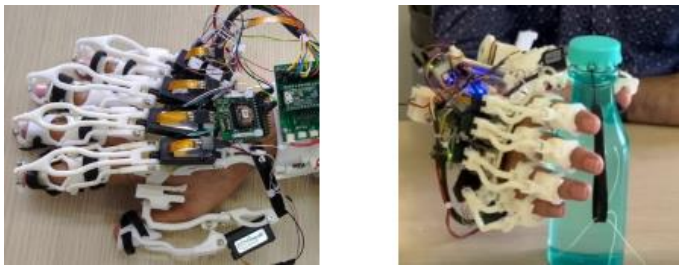


Fig 2. Underactuated hand exoskeleton [8].

2.1.3. Bowden line drive

Bowdoin wire drive means that the outside of the Bowdoin wire is a wire sheath wrapped inside the wire. The wire sleeve generates thrust. The convention calls the two ends of the wire sleeve and steel wire respectively: front end and back end. The front end of the fixed wire sleeve, the front end of the Larry face wire, and the motion of the back end of the wire sleeve is opposite to the back end of the wire. If the back end of the wire is fixed again, the back end of the wire sleeve is equivalent to pushing out. That is to say, pulling the wire is equivalent to pushing the wire sleeve. If only the push wire sleeve is used, the compression stiffness of the wire sleeve is not enough and it will bend (buckling). However, when fixing the front end of the wire sleeve and the back end of the wire, pulling the front end of the wire hard, if the wire sleeve is bent, it will bend with the wire inside. The bending of the wire drags its own front end to the back end, and the force of the front end pulling the wire will prevent the wire from dragging the back end, which will prevent the wire sleeve from bending. It is equivalent to when the wire sleeve is bent, the steel wire inside will pull the wire sleeve to the other direction of the bend, and the wire sleeve is not so easy to bend. So in this way, the wire sleeve can generate thrust [9].

Nicola Vitiello designed a hand exoskeleton based on the Bowden line. Using the Bowden line transmission, the drive mode is placed at the far end to realize the remote transmission, simplify the design of the mechanism, reduce the weight of the mechanism, and improve the portability [10]. The Bowden lin hand exoskeleton was shown in the Figure 3.

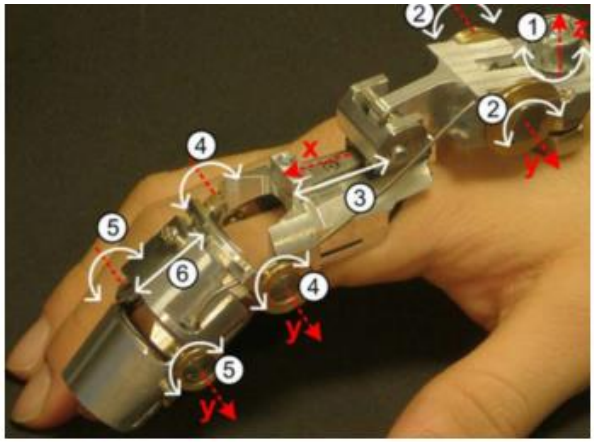


Fig 3. Bowden line drive [10].

2.1.4. Writhing rope-driven upper limb exoskeleton robot

Twisted rope drive is a new type of drive mode, the principle of the drive mode is relatively simple, mainly two or more cables wound and twisted together, a section is fixed on the power source, the other end is fixed on the load, through the rotation of the power source and the length of the cable wound and reduced, thus providing the load along the direction of the power source linear displacement and tension.

Jiang Lei designed a new driving device that uses the twisting cable of DC motor to generate tension along the axis of the motor, and established a mathematical model of the twisting rope driving mode [11]. The Writhing rope-driven upper limb exoskeleton robot was shown in the Figure 4.

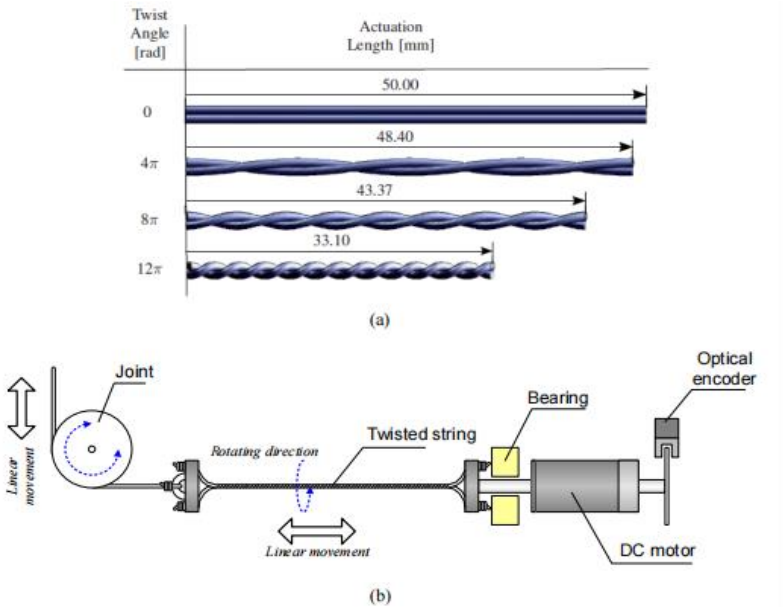


Fig 4. (a) Basic concept of twisted string actuator; (b) Configuration of actuation for the proposed assistive robotic system and the schematics of the twisted string [11].

2.2. Pneumatic Artificial Muscles

Pneumatic artificial muscle (PAM) is driven by externally supplied compressed air and acts as a push and pull, just like the muscle movement of the human body. It is a new type of driving mode, which has the characteristics of clean and safe, high power density and good flexibility [5]. Compared with the rigid robot driven by the traditional motor, hydraulic cylinder, cylinder, etc., the flexible exoskeleton based on PAM has attracted more and more attention from scholars at home and abroad.

Qin Yanding et al. based on PAM driven exoskeleton robot, using the combination of rope drive and direct drive, can complete shoulder joint adduction/abduction, shoulder joint forward flexion/backward extension, elbow joint forward flexion/backward extension three degrees of freedom. In order to adapt to the size of the upper limbs of different users, a size adjustment mechanism was designed at the shoulder joint and elbow joint. The exoskeleton is designed to be compact, meet the requirements of wearability and achieve a large working space [5]. The Pneumatic artificial muscles was shown in the Figure 5.

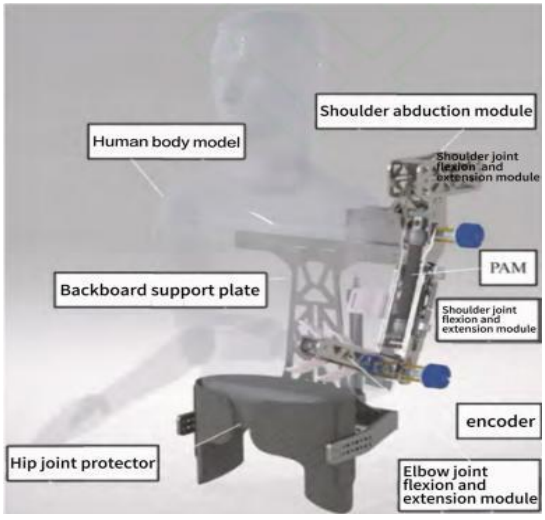


Fig 5. Pneumatic artificial muscles [5].

2.3. A Hybrid Drive Upper Limb Rehabilitation Exoskeleton Robot

There are many combinations of hybrid drive modes, and multiple joints of the upper arm can be separated to arrange different drive modes, such as direct drive and remote drive. To jointly process the analysis of the intention sent by the sensor in a collaborative manner, and make up for the shortcomings between different driving modes to cooperate with the wearer to make corresponding actions.

Yao Yulong et al. from Anhui University of Science and Technology designed a hybrid upper limb rehabilitation exoskeleton robot through the study of human upper limb anatomy. The design features are that the shoulder joint is directly driven by the motor connected to the joint, while the elbow joint and the wrist joint are driven by the motor and the rope. That is to say, the shoulder joint adopts the direct drive method, high performance, high precision, and fast effect speed, while the elbow joint and the wrist joint adopts the rope drive transmission device of Bowden line transmission. Compared with the traditional robot whose motor is directly installed on the joint, the weight of the robot itself is reduced, the movement is more flexible, the inertia is small, the control is more convenient and has better portability, and the remote transmission can be realized [6]. The A hybrid drive upper limb rehabilitation exoskeleton robot was shown in the Figure 6.

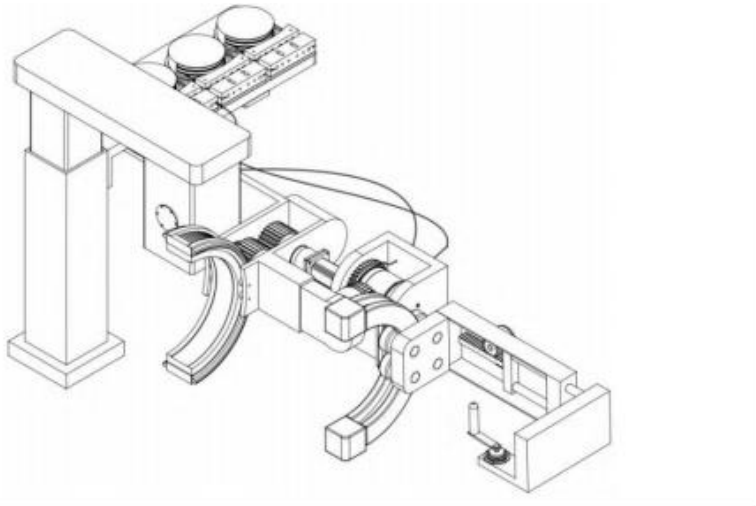


Fig 6. A hybrid drive upper limb rehabilitation exoskeleton robot [6].

3. Discussion

(1) Drive mode key technical analysis (advantages and disadvantages)

The advantages of motor drive are a wide range of applications, easy control and maintenance, simple system, high safety, and can provide a high torque-mass ratio.

Among them, the upper limb exoskeleton robot of the RPR model has a variety of combinations, which can adapt to the needs of patients with different heights and different angles of joint activity. Moreover, the movement process of the rehabilitation robot is smooth, which can meet the requirements of rehabilitation training and will not cause secondary damage to the affected limb. Cons: The advantages of twisted rope drive and Bowden line drive are that the joint mass is greatly reduced, and the friction between the drive joint and the robot is reduced, which effectively avoids the red-west nonlinear problem when the robot joint is directly driven by clicking. However, it is also difficult to model, difficult to determine parameters, and after a long time of use, the rope cable is easy to produce elastic deformation and even fracture problems, which will increase the control complexity of the robot and reduce the control accuracy of the robot.

Although the underactuated mode has the advantages of small number of drives and good portability, it also has the technical problems that the motor and the two finger joints are kinematically coupled, the kinematic relationship is complex, the motion range is limited, and the optimization design is difficult

A hybrid drive upper limb exoskeleton rehabilitation robot mentioned above not only reduces the weight of the exoskeleton robot compared with the traditional robot whose motor is directly installed on the joint, but also makes the movement more flexible, with less inertia and more convenient control. And because the shoulder joint is directly driven by the motor, while the elbow and wrist joints are driven by Bowden line transmission, the control accuracy of the entire exoskeleton robot will be improved to a certain extent. However, at present, the most important difficulty of the hybrid drive method is the selection of the motor, the determination of parameters, etc., and what kind of drive method is more suitable for different joints. It is necessary to ensure that different drive modes can be better coordinated and adapted, cooperate with each other, and be used for services and users, so as to obtain efficient control accuracy.

(2) Prospects for the upper limb exoskeleton rehabilitation robot

The above mentioned several drive methods have some shortcomings, and now researchers around the world are working to amplify their advantages and narrow their shortcomings, such as the motor Bowden line drive may be improved by the reliability optimization design of the Bowden line and the high-reliability drive system design of the Bowden line. At the same time, researchers are constantly developing new driving methods. For example, Octobot of Harvard University is a flexible robot, which adopts a microfluidic control mode [12]. And the mature exoskeleton rehabilitation robots on the market today have a variety of more than driving ways to work together, and the robot will be more sophisticated and complex, which may also be a development trend.

The iterative updating of the control strategy is a very important part, and the control strategy plays an important role in the stability of the device, the control accuracy, the reaction lag and so on. Yang Shu of Changsha Civil Affairs Vocational and Technical College used iterative learning control algorithm to control the upper limb exoskeleton robot for feasibility analysis. On this basis, he proposed to use PD iterative learning control algorithm to control the robot [13].

Robotic exoskeletons tend to be large and inconvenient to wear. Optimization of the mechanical structure can reduce the wearing quality, easy to wear and unload, highlight its lightweight characteristics, so as to better fit for users to wear.

4. Conclusion

In this paper, several driving methods of upper limb exoskeleton rehabilitation robot are introduced, their advantages and disadvantages are analyzed, and the prospect of upper limb exoskeleton robot in the future is discussed. At present, the technology of motor drive is more mature, and the application scenarios are more abundant, including PRP model drive, underdrive, and Bowden line drive and so on. Other driving methods, such as pneumatic artificial muscle drive, twisted rope drive and hybrid drive, also have different advantages and disadvantages. Under different therapeutic purposes and treatment plans, different driving modes can be selected. Researchers are also working on narrowing the disadvantages of various drive methods and amplifying their advantages. It is believed that under the continuous summary and optimization of predecessors, more excellent equipment will appear, not only the driving mode is safe and reliable, but also the control strategy is more accurate and stable, giving users a better wearing experience and a more efficient rehabilitation effect.

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