P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

Structural design and analysis of exoskeleton handling robot based on virtual simulation technology in artificial intelligence environment

Dr.Satish Menon
Professor School of Business Alliance University Bangalore
Email : satish.menon@alliance.edu.in

Abstract: With the rapid development of our economy and the acceleration of the aging of the population, more and more manual jobs can not find suitable candidates, and the exoskeleton assisted transport robot(EATR) has become a research hotspot. Most of the existing exoskeleton assisted robots at home and abroad are expensive and complex in structure, which is not suitable for the actual needs of ordinary workers in India. Based on the virtual simulation technology(VST), the structure of exoskeleton assisted handling robot(EAHR) is designed and studied in this paper. Through the VST, the virtual prototype of the bone assisted handling robot is simulated, and the virtual prototype model of the exoskeleton robot(ER) is established. The driving function of each joint handling action is established for the human body(HB) handling action. The simulation results show that the movement trajectory of the lower limb joints of the ER is almost identical with the input angle of the lower limb joints of the HB's gait movement, and has high response and stability characteristics.

Keywords: Virtual Simulation Technology, Exoskeleton, Handling Robot, Structural Design

1. Introduction

EAHR can assist the HB to carry heavy objects, which is suitable for different working places. It is a robot mechanism with huge market potential and human-machine interaction. However, nowadays ERs are generally relatively complex and expensive in structure, which is not suitable for the needs of ordinary workers. Therefore, in view of the above problems, it is necessary to introduce VST to the designed ER structure on the basis of research at home and abroad to analyze the reliability of the designed structure.

At present, many researches have been carried out on exoskeleton upper limb assist robots at home and abroad. Cacciaiga g and others have designed a new exoskeleton drive mechanism for exoskeleton assist robots. Through the clutch device of the drive device, the robot can only start to assist the back of the HB when bending down to carry objects, making the force assistance more targeted [1]. Han j et al.

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

Designed an exoskeleton upper limb rehabilitation robot based on hydraulic system, and carried out experimental research on position servo control and force servo control of the designed robot prototype; The test results show that the robot has good power assist performance, but the system response is relatively slow and has a certain sense of lag [2]. Based on MATLAB and virtual prototype technology, hamaya m et al. Simulated and verified the control system of the exoskeleton upper limb rehabilitation robot they designed, and proposed a control algorithm that can ensure human safety in the process of movement according to the actual situation of HB [3].

Based on the analysis of the research on ERs at home and abroad, this paper proposes the VST, and uses the parametric gait planning method to plan the human gait. The obtained gait planning data is used as the driving data of the gait movement of ERs, and the gait simulation of ERs is carried out in the virtual prototype. The simulation results of gait motion are as follows: the angular acceleration of hip joint, knee joint and ankle joint is compared with the normal human motion data, which meets the requirements of normal human motion, and verifies the reliability and stability of the ER in handling and gait motion. Finally, the human-machine coupling model is established to compare the consistency between the HB and the ER during the movement of the human-machine coupling model. The results show that the similarity of the human-machine coupling model in the movement process is close to the maximum value 1, which meets the design requirements [4].

2. Research on Structure Design of EATR

2.1 Structural Analysis of EATR

2.1.1 human motion analysis

Firstly, the bone structure of each part of the HB related to the designed robot needs to be analyzed. On the premise of ensuring safety, it can meet the wearing requirements of most people with different body sizes. Since the main function of the designed EATR is to support the transport objects during the transport assistance and gait movement, it is necessary to analyze the HB's transport action and gait action to lay a foundation for the structural design of the EATR [5].

2.1.2 analysis of human bones and joints

When determining the DOF of the robot, it is necessary to analyze the bone joints related to the HB. According to the main motion joints of HB in the process of movement, the knee joint of HB is analyzed firstly. And the knee joint has only one DOF. During the movement, the articular cartilage rubs against the inner and outer meniscus, and is driven by the inner and outer ligaments to complete the movement.

2.1.3 analysis of human handling action

As the main force generating joint of the HB, the hip joint uses the strength of the waist to complete the transportation of heavy objects in the process of transportation. After lifting a heavy object, the HB mainly uses the strength of the legs and elbow joints to complete the support of the heavy object. According to the above analysis, in order to enable the exoskeleton assisted carrying robot to assist the HB in carrying goods, it is necessary to assist the hip joint of the HB in the process of completing the whole carrying action, so that the wearer can reduce fatigue and move the articles that

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

he may not be able to move before [6].

2.1.4 basic dimensions of HB

Since the EATR needs to be worn together with the HB, the structural size of each part of the robot needs to be designed with reference to the size of the HB. The reference body size data is from gb10000-88 indian adult body size, and the main size data required are shown in Table 1. The designed structure needs to be coordinated with the limbs of the HB. Therefore, the dimensions of the limb structure of the designed EATR mainly refer to the dimension data of height, upper arm length, forearm length, thigh length and calf length shown in Table 1.

Table 1.Indian adult male body size table

Percentile	10	50	90	95	99
Height (CM)	1611	1686	1764	1789	1830
Body weight (kg)	50	57	66	70	78
Upper arm (CM)	294	313	333	339	350
Forearm (CM)	221	237	254	259	269
Lower leg (CM)	346	372	399	407	421

2.2 Structural Design of EAHR

According to the motion characteristics of the joints of the HB and the design principles of the EATR summarized by the above analysis. The structure of the designed EATR is mainly divided into exoskeleton upper limb, back support and exoskeleton lower limb.

2.2.1 upper limb structure design

The elbow joint of exoskeleton has one DOF, which is the degree of flexion and extension in the sagittal plane. According to the previous analysis of the joints of the human upper limb, the human shoulder joint has three degrees of freedom, namely, the rotational movement in the horizontal plane, the coronal plane and the sagittal plane. In the process of the human transport, the movement in the median plane of the HB is not involved. Therefore, the designed exoskeleton shoulder joint has two degrees of freedom, namely, the rotational movement in the coronal plane and the sagittal plane [7]. The human elbow joint has only one DOF, so the designed exoskeleton elbow joint also has one DOF, which is an extension movement in the sagittal plane.

2.2.2 structural design of exoskeleton lower limbs

Exoskeleton lower limbs are mainly composed of exoskeleton thigh regulating mechanism, exoskeleton thigh, exoskeleton knee joint, exoskeleton lower limb ankle joint regulating structure. One end of the exoskeleton thigh adjusting mechanism is rotationally connected with the exoskeleton waist because the length of the

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

exoskeleton leg can be adjusted by inserting the exoskeleton thigh adjusting mechanism into the inner side of the exoskeleton thigh. The other side of the exoskeleton thigh is connected with the exoskeleton knee joint through bearing rotation [8-9]. Because the thickness of the human leg and the position of the ankle joint of different human bodies are slightly different, it can adjust the size of the ankle joint of the exoskeleton in the horizontal plane and the sagittal plane respectively to adapt to the difference in the wearing of different people and conform to the design principle of universality. The angular motion range of lower limb joints is shown in Table 2.

Table 2. The range of motion of lower limb joints

Lower limb joint	Movement form	Range of motion (°)
hip	Flexion / extension	-120 ~ 65
	Adduction / abduction	(-30 ~ -35) ~ 40
	Spin in / spin out	(-15 ~ -30) ~ 60
knee	Flexion / extension	(-120 ~ -160) ~ 0
ankle	Plantar flexion / dorsiflexion	-20 ~ (40 ~ 50)
	Varus / valgus	(-30 ~ -35) ~ (15 ~ 20)
	Spin in / spin out	-15 ~ (30 ~ 50)

The exoskeleton thigh and the exoskeleton waist are connected by a bracket support structure, and the outside of the bracket support mechanism is wrapped by a spring. The gravity of the exoskeleton waist can be converted into the spring force of the spring on the bracket support mechanism, and the elastic force can be transmitted to the exoskeleton thigh. The exoskeleton waist is connected together through a threaded pipe, and is connected together through a threaded pipe. During the connection process, the threaded pipe rotates into the exoskeleton waist mechanism. Through the rotation of the thread, the width of the human waist can be adapted according to the body size of different wearers [10].

2.3 Overall Configuration Scheme Design of Lower Limb Exoskeleton Assist Robot

The overall configuration of the lower limb exoskeleton assist robot is based on meeting the function objective of assisting walking. The lower limb joints of the exoskeleton are placed outside the lower limb of the HB, so as to simplify the joint freedom of the robot as much as possible, and avoid the problems such as control difficulty and redundant mechanism due to excessive joint freedom [11]. Considering that the internal / external rotation degrees of freedom of the ankle joint have little influence on the normal walking of the HB during walking, only the remaining 6 degrees of freedom are considered for the single leg in the structural design of this scheme; The lower limb joints of the exoskeleton assist robot are added with multi-level cushioning and vibration reduction devices to reduce the negative impact of the vibration and impact force from the ground on the lower limb joints of the HB and the signal detection system of the ER when the user goes up and down steps or performs

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

strenuous exercise [12]. The motion range of the lower limb joints of the exoskeleton assisted robot is shown in Table 3; The main structural dimensions of the finally determined exoskeleton assist robot are shown in Table 4:

Table 3. The ranges of joint angles of lower-limb exoskeleton-assisted robot

Lower limb joint	Movement form	Range of motion (°)
hip	Flexion / extension (active)	-45~45
	Adduction / abduction (passive)	-15~15
	Spin in / spin out (passive)	-20~20
knee	Flexion / extension (active)	-90~0
ankle	Plantar flexion / dorsiflexion (passive)	-20~25
	Varus / valgus (passive)	-10~10
	Spin in / spin out (none)	None

Table 4. The structure size of lower-limb exoskeleton-assisted robot

Body parts	Bone scale	Parameter index (mm)	Design value (mm)
Hip knee	0.206H	330-370	370
Knee ankle	0.220H	352-396	387
Ankle ground	0.045H	72-80	80
Two crotch	0.190H	304-342	340
Shoe length / width	0.147H/0.057H	250/98	250/98

2.4 Design of Key Components of EAHR

The driving system of EATR is mainly used to provide power to the HB when the HB carries heavy objects, and assist the wearer to complete the transport of objects. The stress diagram of HB when carrying heavy objects is shown in Fig. 1. The main stress joints of HB when lifting heavy objects are shoulder joint and hip joint. The torque of hip joint and shoulder joint are represented by K1 and K2 respectively.

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

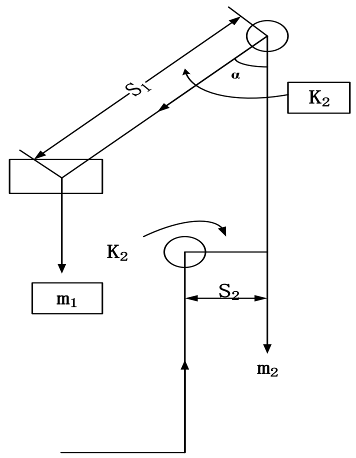

Figure 1. The figure of heavying objects

It can be found that the moment of K1 is expressed by the following formula:

$$K1 = S_2 \times m_2 \times G \quad (1)$$

Where: K1 represents the moment of hip joint; S2 represents the width of the back bracket; M2 represents the weight of the back support; G represents the gravitational acceleration coefficient. The moment of K2 is expressed as:

$$K_2 = S_1 \times \sin(\alpha) \times m_1 \times G \quad (2)$$

Where: K2 represents the moment of shoulder joint; S1 represents the arm length; M1 represents the weight mass; α Represents the included angle of the shoulder joint, where the maximum mass of M2 is 20kg and the length of S2 is 200mm, so K1 = 40nm. According to Table 2.1 indian adult male body size table, the maximum value of 1l within the design range is 619mm, the maximum mass of 1m is 20kg, and the initial angle of upper limb shoulder joint α= 30, so K2 = 62nm after calculation.

3. Structure Design of EAHR based on VST

3.1 Virtual Prototype Simulation of Bone Assisted Handling Robot

The virtual prototype simulation technology is based on the designed structural model, and then simulates the actual working conditions in the computer. In the virtual prototype, the possible problems of the designed structure can be found in advance, the modifications can be made in advance, and the reliability of the designed structure can be verified. Therefore, the virtual prototype technology is of great significance to verify the stability and reliability of the exoskeleton assisted robot structure. In the actual work, the EATR mainly performs two actions, namely, the transport action and the gait action. Therefore, it is necessary to simulate and analyze these two actions in the virtual prototype. In the process of gait movement, the movement is more complex. Therefore, we need to use the parametric gait planning method to plan the gait of the ER, and then carry out the simulation analysis of its gait movement in the virtual prototype.

3.2 VST

3.2.1 introduction to VST

The biggest advantage of the virtual prototype system is that it can save the time and cost of making the physical prototype system, and through the post-processing in

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

the virtual prototype system, you can visually view the results required in the virtual prototype system, and quickly modify the initial design according to the problems that may exist in the post-processing system until the required results are reached.

3.2.2 Virtual Prototype Simulation of ER

The virtual prototype simulation of the EAHR mainly focuses on the simulation of the main motion states required by the ER, that is, the handling state and the gait motion state. The simulation flow is shown in Fig. 2. After the model is built in the three-dimensional design software Pro / E, in ADAMS, according to the actual material and motion state of the prototype to be built in the future, after the pre-processing, the model after the pre-processing is checked. If there is no problem after the model is checked, then add the required drive function for the imported model according to the actual motion state of the model. The drive function of the model added in different motion states is different. After the simulation, you can view the required data in ADAMS / post processor module and compare it with the actual situation to determine the correctness of the established model.

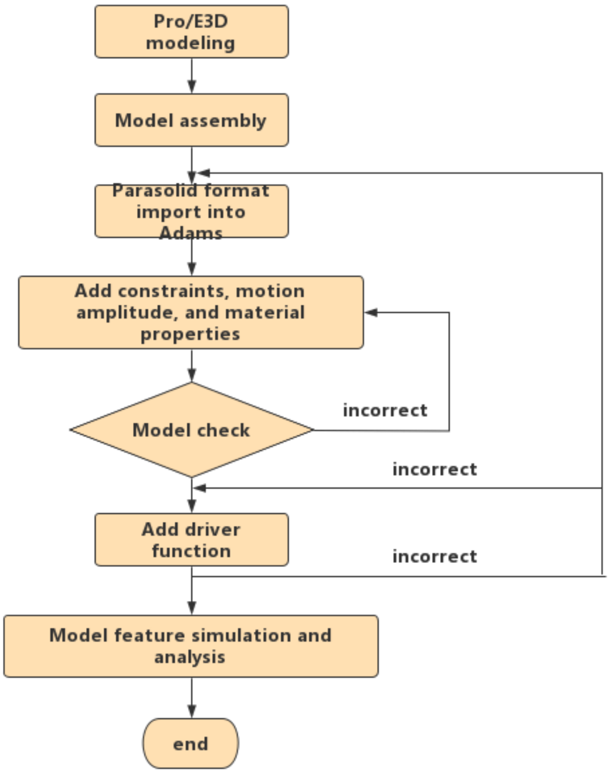

Figure 2. Virtual prototype simulation process

3.2.3 establishment of virtual prototype model

After the model is imported, the Boolean operation is used to calculate the combination, difference and union of the imported model structure, and the unit of the imported model is modified. The unit in ADAMS is set to "mmks", which is consistent with the accuracy in the 3D model. Secondly, the material and motion amplitude are applied to the imported model, and the main components of the

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

exoskeleton limbs and back are set as aluminum alloy materials in ADAMS. The exoskeleton feet collide with the ground during gait movement, and the impact between the exoskeleton feet and the ground is large. Therefore, the exoskeleton feet need to be made of soft material, so the material of the exoskeleton shoes is made of rubber to reduce the impact between the exoskeleton shoes and the ground.

Then, for the imported EATR structure, the motion amplitude is added at the joints where it moves. Since the EATR simulates the motion state of the HB, the motion amplitude of the ER is mainly the rotation amplitude. The rotation amplitude is added to the HB median plane at the elbow joint and shoulder joint of the upper limb of the exoskeleton, and the rotation amplitude is also added to the HB median plane at the knee joint and hip joint of the lower limb of the ER.

Before the formal simulation of the virtual prototype model, the set model needs to be tested to prevent a series of problems that may occur in the actual model simulation process. The inspection of virtual prototype model mainly checks the number of degrees of freedom of the established virtual prototype model, the composition of the system and the components without defined quality. According to the virtual prototype model, there are 10 rotating pairs in the model, which is consistent with the actual situation. There are no components with undistributed mass and no redundant constraints. The reliability of the virtual prototype model in the static state is preliminarily verified.

4. Simulation Analysis of EAHR

4.1 Transport Simulation Drive Function

The main driving joints of the HB are hip joint, knee joint, shoulder joint, elbow joint and ankle joint moving in the median plane of the HB. For the simulation of the handling action, the third-order polynomial approximation step function, i.e. step function, is established in Adams according to the angular displacement of each driving joint as the target curve to drive the hip, knee, shoulder, elbow and ankle joints in the virtual prototype model.

4.2 Gait Simulation Analysis

Based on ADAMS virtual prototype technology, the collision force generated by contact is mainly generated by the following two situations: the elastic force generated by cutting between the two components in contact and collision and the relative velocity between the components in contact and collision. The expression of impact function is:

$$M\_impact = \begin{cases} 0, g > g_0 \\ k(g_0 - g)^t - c_{\max}(\frac{dg}{de})step(g, g_0 - d, 1, g0, 0), g \le g_0 \end{cases} \tag{3}$$

Where G0 is the initial distance of the mutual contact members; G the actual distance of the members in contact with each other; Dg / de represents speed; k. Cmax, t, D are stiffness coefficient, maximum damping coefficient, collision index and maximum penetration depth. The step function is expressed as follows:

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

$$step = \begin{cases} s_0, x \le x_0 \\ s_0 + z \cdot \Delta^2 (3 - 2\Delta), x_0 < x < x_1 \\ s_1, x \ge x_1 \end{cases} \quad (4)$$

4.3 Control System Design and Simulation of EAHR

The EATR needs to maintain certain stability and reliability in the movement process. A reasonable control system is of great significance to the stability and reliability of the robot in the movement process. Therefore, the selection and design of the control system scheme of the ER is a very important content in the realization process of the ER. Therefore, this chapter first introduces different control strategies and methods in robot control, and comprehensively compares the actual control effects of different control schemes. Finally, combined with Adams and MATLB joint simulation technology, the gait control of the ER joint simulation is realized by combining the virtual prototype model of the ER, the gait information of the ER and the fuzzy adaptive PID control scheme, and the established control system of the ER is comprehensively analyzed and verified.

4.3.1 control strategy of EATR

The motion control of the ER is mainly based on the designed control algorithm, comparing the output signal of the control system with the target signal. The control strategy of the ER is shown in Fig. 3.

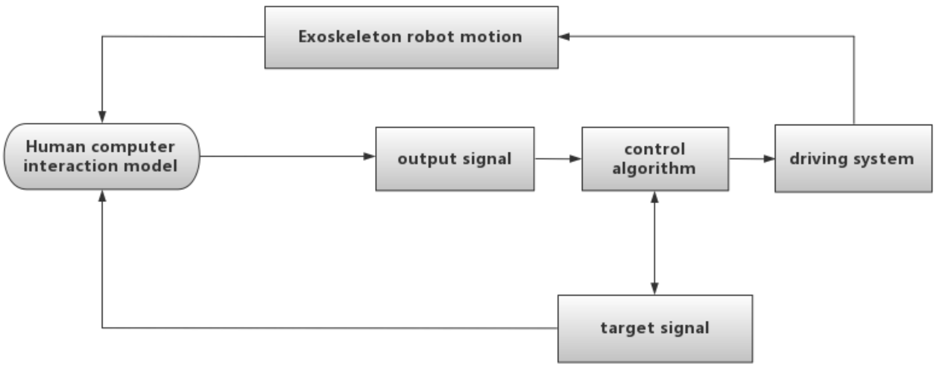

Figure 3. Sketch of robot control strategy

4.3.2 position control

The position control of the exoskeleton assist robot is mainly based on the data of the HB moving in the corresponding joints as the target data of the corresponding joints. Based on the kinematics of the exoskeleton assist robot, the corresponding control is carried out for the human joints. Take the hip joint and knee joint of the EATR during gait movement as an example. After the HB wears the exoskeleton assisted robot, the joints are separated and not bound together. The joints of the HB and the ER do not interfere with each other during movement. However, the ER and the human leg, thigh and foot are bound together by flexible straps, and the force between the wearer and the ER is transmitted through the binding belt. Therefore, the connection between the exoskeleton leg and the human leg can be regarded as a

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

spring resistance connection.

4.4 Handling Simulation Results

The hip joint torque and the hip joint angular velocity are shown in Fig. 4. It can be seen from the hip joint torque diagram of the carrying operation that the maximum value of the hip joint torque is 45nm when carrying heavy objects, which is basically consistent with the actual movement of the HB. It can be seen from Fig. 4 that the robot maintains an angular velocity of 30DEG / sec after startup, which conforms to the actual situation of human motion. The maximum torque of the shoulder joint during handling is about 18NM, and the angular velocity of the shoulder joint is 6deg / s in the first 5S and 13deg / s in the 5S to 10s, which is consistent with the actual movement of the HB.

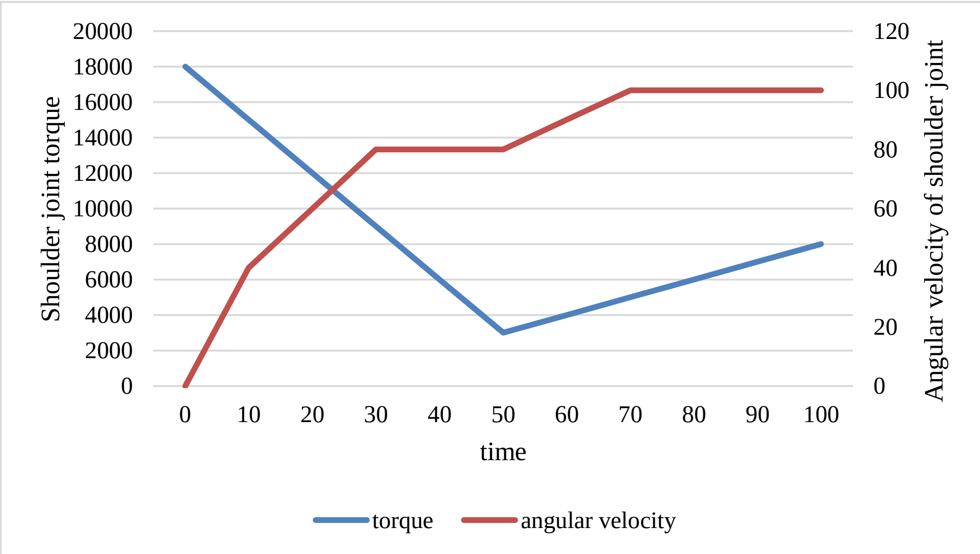

Figure 4. Torque and angular velocity of shoulder joint during lifting

The analysis of the handling action of the EAHR mainly analyzes the torque and angular acceleration of the torsion exoskeleton of the knee joint, hip joint and shoulder joint. Since the elbow joint is a mechanical self-locking structure of the ER, the elbow joint is not analyzed. From the analysis results, it can be seen that the torque and angular velocity of knee joint, hip joint and shoulder joint, which are the main force bearing joints of the carrying action, are compared with the corresponding actual human motion, which conforms to the actual human motion, and verifies the reliability of the exoskeleton assisted carrying robot in carrying heavy objects.

5. Conclusions

In this paper, the VST is proposed for the structure of the designed EAHR. The multi-dimensional analysis and Simulation of the ER are carried out, and the reliability and stability of the designed EAHR are preliminarily verified. However, due to the limitation of time and conditions, it needs to be further strengthened: in the virtual prototype, the movement and gait of the ER are mainly simulated. However, considering that the working environment of the designed exoskeleton assisted robot will be complex, the next step is to simulate the exoskeleton assisted robot in complex working conditions; Function detection of exoskeleton assisted robot in practical

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2022.28.04.159

application. In this paper, the research on the lower limb exoskeleton assist robot is still in the stage of theoretical design and simulation, and some systems still need to be improved and perfected. The subsequent research on the structure design and control system as well as the performance test improvement need to be further verified by making a test prototype.

References

[1] Caccianiga G , Mariani A , Paratesi C , et al. Multi-Sensory Guidance and Feedback for Simulation-Based Training in Robot Assisted Surgery: A Preliminary Comparison of Visual, Haptic, and Visuo-Haptic[J]. IEEE Robotics and Automation Letters, 2021, PP(99):1-1.

[2] Han J , Yang S , Xia L , et al. Deterministic Adaptive Robust Control with a Novel Optimal Gain Design Approach for a Fuzzy 2DOF Lower Limb ER System[J]. IEEE Transactions on Fuzzy Systems, 2020, PP(99):1-1.

[3] Hamaya M , Matsubara T , Teramae T , et al. design of physical user-robot interactions for model identification of soft actuators on ERs[J]. The International Journal of Robotics Research, 2021, 40(1):397-410.

[4] Bhat K , Moschovas M , Onol F , et al. Evidence-based evolution of our robot-assisted laparoscopic prostatectomy (RALP) technique through 13,000 cases.[J]. Journal of robotic surgery, 2021, 15(4):651-660.

[5] Li S , Pan J , Ji J , et al. Numerical Simulation of Thrombolysis in Robot-Assisted Retinal Vein Cannulation[J]. Complexity, 2020, 2020(4):1-12.

[6] Bauer M O , Vizi M B , Galambos P , et al. Direct Drive Hand Exoskeleton for Robot-assisted Post Stroke Rehabilitation[J]. Acta Polytechnica Hungarica, 2021, 18(5):37-54.

[7] Hussain F , Goecke R , Mohammadian M . ERs for lower limb assistance: A review of materials, actuation, and manufacturing methods:[J]. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 2021, 235(12):1375-1385.

[8] Mitchell D , Choi H S , Haney J M . Safety Perception and Behaviors during Human-Robot Interaction in Virtual Environments[J]. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2020, 64(1):2087-2091.

[9] Borelli F . The Value Of Virtual Simulation Training: For Active Shooter Response[J]. Law Enforcement Technology, 2019, 46(3):30-32.

[10] Little J . Using Virtual Simulation To Increase Deep Learning in Radiography Students[J]. Radiologic Technology, 2021, 92(4):324-330.

[11] Liu W . The Effects of Virtual Simulation on Undergraduate Nursing Students' Beliefs about Prognosis and Outcomes for People with Mental Disorders[J]. Clinical Simulation in Nursing, 2021, 50(2):1-9.

[12] Jaberzadehansari R , Karayiannidis Y . Task-based role adaptation for human-robot cooperative object handling[J]. IEEE Robotics and Automation Letters, 2021, PP(99):1-1.