Study on Ergonomic Design of Artificial Intelligence Lower Limb Assist Brace for the Elderly

Yu Zhen
Science and Art Integration Research Center, China Academy of Art.
m-yad@qq.com

ABSTRACT

The ergonomic design study of artificial intelligence lower limb-assisted brace for the elderly is a new design standard of lower limb-assisted brace for the elderly with mobility problems. Based on Human Factors Engineering, this study tested and analyzed the advantages and disadvantages of human lower limb motion mechanics, human gait motion law and existing lower limb assisted brace design cases at home and abroad, and concluded that the common external assisted method is less man-machine efficient than the internal assisted method. Therefore, a new brace joint rotation curvature, component parameters and other key information was designed based on the structure of the medial assistance method. Subsequently, Rhino software was used for digital modeling, physical prototyping, experimental testing and analysis of the design solution and continuous optimization of the design. At the same time, the perceptual engineering design method was utilized to meet the humanized aesthetic design requirements. The prototype of the design study was finally completed, which is more in line with the evaluation criteria of "human-machine-environment system" than the existing market design in terms of functional rationality, human-machine performance and human experience. This demonstrates the validity of the design method and is an important reference for the design standard of the lower limb support for the elderly.

Keywords: Lower limb-assisted brace, Human Factors Engineering, styling design, structural design, elderly-assisted, humanized design

1. INTRODUCTION

Since 2014, China's population aged 60 years and above has been growing, and the aging process in China has accelerated, and the Chinese population has now entered the elderly type. At the end of 2021, China's population aged 60 and above will be 267.36 million, accounting for 18.9%, an increase of 3.29 million compared to 2020. Among the 267.36 million people aged 60 and above in China in 2021, the population aged 65 and above will be 20.56 million, an increase of 9.92 million or 14.2% from 2020. The proportion of population aged 60 and above and 65 and above in China will be 18.7% and 13.5%, respectively, in 2020; the proportion of population aged 60 and above and 65 and above in China will increase by 0.2 and 0.7 percentage points, respectively, in 2021 compared with 2020, and the degree of aging will further deepen [1]. As the aging of the elderly population deepens and the cost of rehabilitation treatment for the elderly increases, the operational load of social nature care institutions such as homes for the elderly, hospitals and rehabilitation institutions and the cost of care for their families will be greatly increased, and the pressure and resistance to social development will be further expanded.

In order to cope with this global social phenomenon and problem, many countries in the world have already developed lower limb assistance braces for the elderly. Along with the continuous research and development of related products, the technology of lower limb assistance brace has been continuously improved. However, the current product technology on the market tends to be homogeneous and expensive, and its design ideas are relatively solidified, and the suitability design standard has not been effectively established and not effectively combined with today's new industrial technology capabilities, module integration capabilities and humanized use demand scenarios. This has led to low patient coverage and the inability to effectively exploit the functional advantages of this type of product. Ultimately, the research field cannot be developed sustainably, resulting in a delay in the development of the research field. Under the same level of assistance, the lower limb assistance brace with more ergonomic structure and design aesthetics can improve the experience of the elderly; through a more reasonable structural design to reduce product falsification, can make the elderly have a more suitable assistance products. The design research direction can effectively supplement and enrich the research field of lower limb assistance brace at home and abroad, fill the relevant industry gaps, promote the
development of artificial intelligence lower limb assistance brace industry, and become a new development trend and design standard of lower limb assistance brace in the future.

1.1 Status of foreign research on artificial intelligence lower limb brace

Lokomat is a lower limb gait training brace system used to enhance the mobility of the elderly. It consists of a human gravity support, a gait corrector and a running table, and the parameters of Lokomat are adjusted to simulate the different physiological gait trajectories of different elderly people with mobility problems, and to drive the elderly’s lower limbs for walking training.

Table 1. Lokomat lower limb gait training brace[2]

The ALEXI lower limb assistance brace from the United States uses a nonlinear filter to assist the elderly to walk according to a preset trajectory[3].

The HAL Lower Extremity Assist Brace from Cyberdyne, Japan, provides gait training and lower extremity walking assistance for the elderly. The structure of HAL is a lateral traction brace that is strapped to the leg of the elderly and uses biosensors to monitor the bioelectrical signals on the leg muscles to enhance the strength and stability of walking.

Table 2. HAL Lower Extremity Assist Brace[4]

The ReWalk Lower Extremity Assist Brace is also a lateral traction assist brace to assist the elderly in walking.
Ekso Bionics is a lower limb assistance brace developed for military, medical and other fields. Ekso has built-in high-precision sensors, anthropomorphic skeletal joints, micro drive motors, a powerful central processor and drive software system.

The inflatable lower limb support brace developed by Panasonic uses soft mechanical principles to support a variety of lower limb muscle movements, and compared to the traditional lower limb support brace, it can do including turning and other conventional complex lower limb support brace can not achieve the movement, the quality is also lighter, more easy to wear, there is still a certain distance from the mass production of products.

1.2 Status of domestic research on artificial intelligence lower limb power-assisted brace

Shanghai Jiaotong University fuses surface EMG signals and interactive forces into a lower limb-assisted brace. Beijing DAI's Ailegs Lower Extremity Assist Brace is made of titanium alloy and adopts the form of assisted structure with external traction, strapped to the leg of the elderly, which can be adjusted in size to fit different body types of the elderly and can bear up to 100 kg of weight. Shanghai Fourier FourierX1 lower limb assistance brace integrates mechanics, human biosensor, electromechanical drive integration, gait analysis and other multi-disciplinary science and technology to help the elderly achieve basic assistance functions such as sitting, standing, walking and going up and down stairs. The Auto-LEE Lower Limb Assist Brace from the Shenzhen Institute of Advanced Technology of the Chinese Academy of Sciences can drive each component independently and work together to assist the elderly to walk without the assistance of other devices compared to the traditional assist brace.
2. OVERVIEW OF HUMAN FACTORS ENGINEERING

Human Factors Engineering, also known as "human Factors Engineering", is an interdisciplinary discipline involving Human Factors Engineering, perceptual engineering, engineering, psychology, physiology, anthropometry, anatomy, environmental science, system science, management, safety science, labor science and other disciplines. It has been widely applied in many fields.

Human Factors Engineering takes human as the core factor and emphasizes the factors that prioritize human needs in engineering and work management. By systematically studying basic human data such as information on human abilities, behaviors, limitations and characteristics, and parameters of various behaviors. By systematically applying these data elements to the design and manufacture of products, operating procedures, and the environment in which they are used, we study the interaction between humans and machines and solve the problem of the efficiency of collaboration between humans and machines. The interaction between the "human-machine-environment system" is optimized so that its operation is compatible with the physiological composition and psychological needs of human beings. Therefore, Human Factors Engineering research is often accompanied by the application of perceptual engineering. By quantifying the various perceptual factors of human beings in an engineering way, the relationship between each perceptual quantity and the product design is matched and finally transformed into the physical design elements of the product.

Human Factors Engineering enables human beings to act efficiently, safely, conveniently, healthily and comfortably under different conditions in activities such as living, working and leisure by analyzing and changing the interrelationships between human beings and human behavior and the products, equipment, facilities, procedures, systems and their associated environments used.

3. DESIGN METHOD OF LOWER LIMB ASSISTANCE BRACE FOR THE ELDERLY

3.1 Gait detection and data analysis of the lower limbs of the elderly

Gait detection and analysis are crucial in the ergonomic study of the lower extremity of the elderly. The lower limb gait of the elderly includes walking, running, going up and down stairs and other periodic movements in which the legs alternate and move forward to drive the body forward, among which the most frequently used movement is walking, in which the legs and limbs need to be highly coordinated with each other. In order to design a comprehensive and applicable lower limb assistance brace for the elderly. It is necessary to master the design of various parameters at different levels of gait movements of different elderly people through in-depth research on the gait movement rules of the elderly. The synchronized study of basic human data of the elderly, together with various parameters such as information related to the ability, limitation and characteristics of gait movement of the elderly, can provide the
engineering data support for the design of the lower limb assistance brace for the elderly in a reasonable and suitable range.

The whole body muscles need to be involved in the process of gait movement of the elderly, coordinating with the hip, knee and ankle joint rotation and flexion, tilt and rotation of the trunk and the lateral, longitudinal, forward and backward movement of the human body, which is a complex movement of the elderly body. The three main joints of hip, knee and ankle are the basic joints in the gait movement of the lower limbs of the elderly, while other lower limb joints play more or less the role of regulation.

In the detection of gait motion of the elderly, the macroscopic view is that the torso is the main body of the whole movement, and the two lower limbs are in the subordinate position; microscopic view is that the thighs belong to the main body, and the lower legs are in the subordinate position, in decreasing order, and they are connected by the joints that play the role of mutual connection and support, so the range of activities of each independent joint is calibrated according to the need of human factors engineering, and the body movement pattern of the elderly is obtained after a sampling test. In the walking process of the elderly, a gait motion cycle starts from the landing of one foot to the end of the landing of the foot again. The process includes a number of movement phases such as foot landing, single foot support, single foot off the ground, and single foot swing. There is basically no difference in the proportion of each phase among older adults of different genders, ages and heights.

The gait study of the elderly utilizes foot sensors, and the subject team collects the movement trajectory and time of the elderly walking to quantitatively analyze and assess the kinematic and kinetic parameters of gait cycle and mechanics, mainly including the parameters of stride length, stride width, stride frequency, and joint operation angle. For example, the normal value of stride length is 1500~1600mm. The normal value of step width is 50~100mm. The rotation angle of the foot joint is 0~7°, etc. And this is used to construct the gait motion model.

The regularity, parameters, and periodicity of normal human gait motion are relatively stable, although there are very slight individual differences. However, as the joints of the lower extremities of the elderly age or develop disease, the gait motion characteristics will change significantly. According to the principle of Human Factors Engineering, this requires the design process to customize different lower limb brace assistance structures and modes according to the aging degree of different elderly people's lower limbs, and therefore requires the lower limb assistance brace to have the function of independent adjustment of joints.

![Gait cycle diagram for the elderly](image)

**Figure 6. Gait cycle diagram for the elderly[^11]**

### 3.2 Human Factors Engineering research method intervention

The design and development of the artificial intelligence lower limb brace follows the ergonomic design principle. Thanks to the new industrial technology capability and module integration capability, the lower limb brace can be more humanized, i.e., the integration and humanization of the artificial intelligence lower limb brace body when it is used with people is improved.

The use of ergonomic principles of systematic study of the same height, size, weight of people in various scenarios of movement conditions with the change in posture, the location of the support point and to meet the comfort of the pressure of the contact area size and morphological changes, build the human dynamic support force parameters model. Through the experimental test data and results to derive the most universal to meet the comfort and integration of the human body and the body of the support structure components, and its anthropomorphic joints, hydraulic devices, power motors and transmission systems and other power components between the most reasonable relative position relationship and angle, in order to reduce power transmission loss, improve the ability to assist the movement, to achieve the most consistent with the comfort of the use of assistance.
As most of the existing artificial intelligence skeleton is based on the lateral skeleton leg support, which leads to too many restrictions on the range of activities and activities, and poor human-computer interaction experience, therefore, the development project of artificial intelligence-assisted lower limb for the lower limb assistance bracket robot ergonomic design of wearing comfort, use experience, human-computer interaction temperature and mechanical structure, control model, power module, new materials and other aspects of innovative research and design research, the main technology is as follows:

3.3 Modeling and structural design

The modeling design of the elderly artificial intelligence lower limb assistance brace needs to meet the functional needs, suitability needs and potential humanized sensibility needs of consumers. The research direction is to adopt the medial assistance method. Compared with the traditional external traction assistance method, it can be changed into the form of support assistance. This type of assistance is similar to the assistance unicycle, the person in the realization of all walking, standing, squatting, stairs and other movements, equivalent to sitting on the seat of the assistance support, such a way can effectively share the weight of the elderly themselves, so that users have a more relaxed and comfortable experience. It can prevent the traditional structure of long-term use will lead to the body of the brace and the human body in contact with the skin compression, blood is not smooth and even a certain degree of abrasion and bleeding problems.

This structure should not only have advantages in the external product function design, but also have excellent sensory visual effect in the product appearance. Compared with the traditional booster structure, the main components are hidden in the inner measurement of the legs, which can use the legs to cover the main bracket structure and have a better performance in terms of aesthetics.
In terms of suitability requirements, the structure is designed to be lightweight, and its weight is reduced to reduce the cost of materials, while fully considering the rationality of its structure and meeting the requirements of the lower limb brace's power-assist function and strength, so that the burden of the elderly to purchase and use the product is reduced.

Moreover, in terms of humanized sensual needs, according to the principle of sensual engineering design, compared with the traditional traction assistance method, which uses a machine to control people and tug them forward, this design method is more like a tool that can ride, which can transform the tool controlling people into the psychological implication of people controlling the tool.

The research of artificial intelligence lower limb assistance brace for the elderly needs to make comprehensive reference to the advantages and disadvantages of the existing international and domestic cases, as well as the real use experience and feedback of the elderly, to exclude the unreasonable and even hazardous parts of the existing design for the health of the elderly, and to make preliminary screening. In addition, we should fully consider the living habits of the elderly and the habits of using the lower limb brace, and design the structural and functional solutions according to the gait motion parameters of the elderly in order to meet the basic lower limb assistance function of the elderly and also meet other physiological and psychological needs of the elderly.

The main structure and joints are realized by 3d printing technology, and the main mechanical structure consists of hip seat support, hip joint, knee joint, ankle joint, exoskeleton module, foot module and other parts.

Adopting the design of a new structure, compared with the traditional traction type wearable lower limb power-assisted brace and suspension type wearable lower limb power-assisted brace, using a new technology, highly integrated, humanized design method, designed a new brace joint rotation curvature, component parameters and other key information, using Rhino software for three-dimensional modeling, physical prototyping, experimental testing analysis and continuous optimization of the design plan. The design of the brace is designed to solve the problems of the user's
movement being restricted due to the complex and large design of the body, the uncomfortable wearing due to the lack of ergonomic design, and the need for the user to overcome the psychological acceptance of wearing the brace.

The lower extremity brace for the elderly needs to be reasonably configured based on the degree of freedom and joint drive range of the brace, taking into account the degree of matching with the human lower extremity, joint drive and system complexity. The driving power of hip joint and driving distance of knee joint are in great demand, while the ankle joint is the motion end of the lower limb brace, and the position changes frequently and randomly. Therefore, the hip and knee joint degrees of freedom in the sagittal plane are assigned to the booster drive, i.e., the active drive is used for the hip and knee surface/extension; the ankle joint is configured as passive degrees of freedom, i.e., the ankle joint is a flexible passive joint, which maximizes the advantage of "man in the ring" and brings into play the ability of man in maintaining balance and reduces the difficulty of mechanism design and control. Reduces the difficulty of mechanism design and control. The joint range of motion of the human lower limb horizontal walking and the joint range of the booster are shown in the following table:

| Joint            | Degree of freedom | Human walking joint range of motion | Range of joint design of the brace |
|------------------|-------------------|-------------------------------------|-------------------------------------|
| Flexion/Extension | -125°~15°         |                                     |                                     |
| Knee             | Flexion/Extension | -130°~0°/0°                          | -120°~0°                            |
| Size of each file| max. 5 mb         | -20°~0°/0°~45°                       | -20°~20°                            |

### 4. SUITABILITY DESIGN

From the perspective of suitability design, the modular design of the artificial intelligence lower extremity brace for the elderly can reduce the upgrade cost by replacing only the modules for functional upgrade. The products on the market are limited by the limitations of earlier technical standards and design ideas, and the integrated structure is used to ensure the functional integrity and reliability of the whole. The modular design can effectively avoid a series of problems brought about by the integrated design, such as larger volume and weight, a single way to assist action, maintenance difficulties, re-purchase of new equipment, environmental protection, poor economy, etc. The use of modular design can make the lower extremity assistance bracket with the potential for subsequent functional upgrades, in order to achieve richer and more efficient functions without having to buy a new product can be replaced on the original equipment or pretend to new functional modules. At the same time, the modular design, if the equipment is damaged, only the corresponding damaged modules or parts need to be replaced, without the overall disassembly of the body for maintenance, low maintenance difficulty, low zero to whole ratio, high success rate of maintenance, short maintenance time, and even the elderly can replace the repair themselves according to the manufacturer's instructions.

#### 4.1 Lightweight, integrated

The current market of the elderly lower limb assistance bracket due to the design mode for the traditional design approach, using a large number of mechanical structures, power systems, power transmission systems to drive the bracket to help the body. One of the two drawbacks is that the brace itself has a large number of structural components and uses metal or alloy materials to ensure the structural strength, and the overall mass is huge. Its power system needs to share a lot of energy to support its own weight, in order to use the remaining power reserves to help the body, resulting in low efficiency and poor range. Second, the structural components are complex and nested in layers, which not only leads to the bracket's own activity angle, amplitude and distance is limited, and because the body is too large, so that the range of motion and angle of human limbs is also limited.

There is a large amount of material redundancy in the middle part of the traditional brace structure, which can be hollowed out to reduce weight and optimize the structure design of the lower limb brace components. At the same time, on this basis, a large number of aluminum alloy, titanium alloy, carbon fiber, graphene and other lightweight composite materials are used in the key parts to further reduce the overall mass.

Combined with ergonomic principles, the combination of new materials is improved to simplify the structural components and achieve a highly integrated structural design. Compared with the existing research direction, while
ensuring the structural reliability of the exoskeleton, it can greatly reduce the self-weight of the lower limb power support, enhance the payload capacity, reduce the burden of wearing, and enhance the flexibility and comfort of wearing.

4.2 Modular 3D fabric printing design

At present, the domestic and foreign elderly lower limb assistance bracket mainly to meet the basic function of the realization, ignore the humanized use experience, the lack of ergonomic design, wear the shoes and other support the body's functional area of the form, size can not be more adjusted, replaced, resulting in different use of the crowd to wear the human body and the exoskeleton body force area and location of the possibility of unreasonable, poor wearing comfort, so that long-term use The exoskeleton body will lead to wear and tear of the skin in contact with the human body.

The body and foot moving parts are designed with modular customization, and 3D printing technology is applied to realize the customization of muscle body, which can achieve a higher conformity to the body auxiliary parts from Human Factors Engineering, and customize the product according to the user's bone size data, so that the man-machine model can cope with the different needs of the elderly with different gender, age, body size, and degree of mobility.

In addition, the 3D smart knitting machine can realize the digital molding of various colors, patterns, thicknesses and other design factors to achieve the goal of personalized customization of the bracket component units. It maximizes the physiological and psychological needs of elderly users. From the perspective of humanized sensual engineering design, the elderly will not just be satisfied with the ordinary assistance mode of traditional products. Replaceable foot intelligent assistance accessories, such as mountaineering, morning market, fishing and other higher levels of personalized use of a variety of assistance scenarios and hardware upgrade modification needs. Help different needs of the elderly to enhance limb mobility, expand the range of action and action time, which can expand the intelligent scenario and has the same important significance for the development of artificial intelligence lower limb assistance brace and human society.

5. COMPUTER SIMULATION TEST

The artificial intelligence lower limb assisted brace for the elderly uses an adaptive control method similar to the human-machine learning observer to allow the machine to learn the kinetic model feedforward that the system should have. This control method allows the lower limb assisted brace to overcome the damping of the motion process to guide the patient to complete the required motor movements, and gradually reduce the force according to the patient's completion, until the lower limb assisted brace is completely free of force, completely through the patient's own muscle force to complete the desired motor movements, to achieve the "suitable walking state" function. At the same time, this algorithm can also identify the robot's motion model and perform feedforward compensation during the motion.

The control software is the core of the whole set of lower limb assistance brace system for the elderly, which provides three modes for users to choose, walking mode, up and down stairs mode and ProStep (automatically sensing the user's body movement to trigger each step), the elderly can choose according to their own situation and assistance progress. At the same time, the product can walk through the intelligent bracket to achieve real-time data monitoring, and statistics and upload relevant data for caregivers to analyze and use.
With the help of computer 3D software and related simulation software to adjust the product between shape and structure. Simulate the changes of movement posture of people with different body sizes under different conditions in each scene movement conditions. The position, area size and morphological changes of the support contact surface to meet the comfort pressure are tested and recorded, and the human dynamic support force parameters are modeled according to these data parameters. A variety of exoskeleton structural components of various sizes and forms were prototyped with reference to the force parameter models and tested. Based on the experimental test data and results, the most versatile structural parts that meet the comfort and integration of the human body and the exoskeleton body can be derived from the experimental test data and results, so as to arrive at the optimal design direction and design scheme. The method of computer simulation can improve the efficiency and quality of design demonstration, shorten the research period and reduce the cost of research and development. The human-machine simulation experiments using computer software are shown in the figure:

![Figure 12. Human-machine simulation experiment diagram.](image)

### 6. CONCLUSION

Based on Human Factors Engineering, this study analyzed and researched the existing artificial intelligence brace lower limb brace at home and abroad, and proposed a new design method for the structure of the brace and the ergonomic design standard of the lower limb brace. It makes it possible to meet the humanized design principles of the elderly on the basis of meeting the lower limb gait movement assistance of the elderly.

The comprehensive design methods of ergonomic design research, user analysis, engineering analysis, behavior study, scenario analysis, functional design, structural design, and modeling design of the lower limb assisted brace for the elderly artificial intelligence brace are demonstrated. The rationality was verified by computer simulation and experimental prototype testing, which provided an important theoretical basis and prototype modeling reference for a new design standard in the field of lower limb assistance brace for the elderly.

The importance of human factors engineering in the field of lower limb assisted brace research for the elderly is reflected. The future research direction of the artificial intelligence-assisted brace for the elderly lies in the cross-collaboration of multiple disciplines under the continuous accumulation and transformation of design thinking and high technology, and it can be said with certainty that the humanization, comfort, applicability and convenience design of the lower limb-assisted brace is an inevitable trend. The elderly will thus be more willing to walk with the help of braces, which can greatly improve the quality of life, work efficiency and happiness of the elderly group.

### ACKNOWLEDGMENT

Humanities and social sciences research project of the Ministry of Education (19YJC760145)
REFERENCES

[1] R987544. Report on China Senior Services Industry Development Status Survey and Prospective Strategic Analysis Report 2022-2028 [R]. Wisdom Research Consulting, 2022.

[2] R. Rien, L. Lünenburger, I. C. Maier, G. Colombo, V. Dietz. Locomotor Training in Subjects with Sensori-Motor Deficits: An Overview of the Robotic Gait Orthosis Lokomat.

[3] BANALA S K, KIM S H, AGRAWAL S K, et al. Robot assisted gait training with active leg exoskeleton (ALEX)[J]. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2009, 17(1): 2-8.

[4] SANKAI Y. Leading edge of cybernics: robot suit HAL[C]/2006 SICE-ICASE International Joint Conference. New York: IEEE Press, 2006: 1-2.

[5] ESQUENAZI A, TALATY M, PACKEL A, et al. The ReWalk powered exoskeleton to restore ambulatory function to individuals with thoracic-level motor-complete spinal cord injury[J]. American Journal of Physical Medicine & Rehabilitation, 2012, 91(11): 911-921.

[6] Stephen W. John, Kenta Murakami, Mayumi Komatsu, Shinobu Adachi. Cross-wire assist suit concept, for mobile and lightweight multiple degree of freedom hip assistance, 2017 International Conference on Rehabilitation Robotics (ICORR), 17-20 July 2017.

[7] FAN Y J. Study on lower limb exoskeleton for rehabilitation based on multi-source information fusion including sEMG & interactive force and its clinical trail[D]. Shanghai: Shanghai Jiaotong University, 2014 (in Chinese).

[8] SHUAI M. Biped lower extremity exoskeleton rehabilitation training robot: CN304822498S[P]. 2018-09-18 (in Chinese).

[9] Fu Li intelligent technology co., LTD. Shanghai FourierX2 product introduction [EB/OL]. [2019-07-21]. http://www.fftai.com/product/X2.php (in Chinese).

[10] HE Y, LI N, WANG C, et al. Development of a novel autonomous lower extremity exoskeleton robot for walking assistance[J]. Frontiers of Information Technology & Electronic Engineering, 2019, 20(3): 318-329.

[11] Raúl Martín-Félez, Ramón A. Molineda, Javier Salvador Sánchez. Human Recognition Based on Gait Poses, Lecture Notes in Computer Science (LNCS, volume 6669)