Cooperative Walking Equipment for the Elderly

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Abstract. With the accelerated aging of our country and the increasing proportion of the elderly population, the health problems and quality of life of the elderly population in our country are receiving more and more attention from the society. Due to the aging of physiological function, the old people's exercise ability is getting weaker and weaker, and the deterioration of exercise function causes various kinds of exercise difficulties, thus making the old people have different degrees of assistance needs in standing, walking and balancing. Based on this, we plan to design a walking aid device to maintain the walking function of the elderly. The device meets the walking requirements of the elderly through the coordination and cooperation of a multi-rod mechanism, a damping mechanism and a slider mechanism. Mainly to reduce the weight of the knee joint of the elderly, while assisting in regular exercise, exercise stimulates physiological activity and reduces physical decline. The device assists the elderly to walk and has three main functions of reducing joint load, increasing balance ability and assisting walking.

1. Introduction
China is one of the countries with the fastest population aging growth in the world. According to the data of the United Nations, 2030 to 2050 will be the period with the fastest population aging in China. By 2050, China's aging population will reach one fifth of China's total population, accounting for a large proportion, which will make China enter the stage of ultra-high aging.

Based on the current situation of aging in our country, it is concluded that the aging population in our country has the characteristics of large population base, fast growth rate, obvious aging degree, high prevalence rate of the elderly, which brings great challenges to the fields of economy, medical care, and pension services that can improve the living standard of the elderly. At present, the health problems and living environment of the elderly population in our country have become the focus of attention of the whole society.
The aging of our society is getting more and more serious, the retirement age is prolonged, and the travel of the elderly becomes more and more necessary. In order to solve the problem of walking inconvenience caused by physical strength decline, organ function degeneration and joint bearing capacity of the elderly, we designed a wearable walking equipment for the elderly. The equipment can increase the balance of the elderly when walking, reduce joint load, assist the elderly to walk more labor-saving and safer, increase an auxiliary balance device, reduce the probability of the elderly falling down due to insufficient leg strength, and improve the problem of inconvenient walking of the elderly.

2. Research Background

2.1. Target population

Our equipment is for the elderly without congenital disability and acquired injury. According to the physiological and psychological state of the elderly and the current situation of the elderly in our country, we divide the elderly into 4 stages in Table 1.

| Old age            | Age group | Proportion | Characteristics                                |
|-------------------|-----------|------------|-----------------------------------------------|
| Healthy active period | 60—64     | 24%        | Suitable for healthy walking                  |
| Self-care period   | 65—74     | 60%        | Have auxiliary needs                          |
| Slow period of action | 75—84     | 60%        | Application of assisted walking               |
| Care period        | Over 85   | 16%        | Can't walk on his own                         |

This equipment is aimed at people who have some difficulties in long-term sports but can basically take care of themselves. It can be seen from the table that they are mainly the elderly who are in the period of self-care and slow movement. This stage of the elderly due to natural aging lead to a gradual decline in motor ability, forming mild dyskinesia, at this time not timely intervention, is likely to gradually aggravate the dyskinesia. Considering the muscle strength, motor function and other factors of the elderly, it is not appropriate to carry out intensive exercise. Walking is the best exercise method.

Although the elderly at this stage can walk a little without using walking aids, using walking aids will reduce the chance of falling during walking, avoid more injuries, and at the same time can bear part of the weight to protect the lower limb joints that have begun to age, especially when walking, and reduce the damage to the knee when going up and down stairs, so that they can go further.

Based on this, our designed walking equipment for the elderly aims to assist the elderly with mild dyskinesia caused by natural aging and delay the decline of their motor function.
2.2. Physiological characteristics of target population

The main reason why the elderly have difficulty walking is aging and deterioration of various organ functions. The aging of organs is mainly reflected in: 1. The endurance of joints is weakened; 2. Decline of skeletal muscle strength; 3. The balance is weakened; 4. The endurance is weakened; 5. The movement ability decreases and the speed slows down; 6. Attenuation of visual nerve.

In the process of human body falling when walking, the human body adjusts the appropriate activities of lower limb muscles according to the information reflected by the sensory-motor system (including the external information from vision and the internal information from proprioceptive receptors), and adjusts the balance through muscle and nerve feedback and adjustment of joint angle changes such as hip, knee, ankle, etc. For the elderly whose overall motor function is declining, the interference of external factors often leads to falls.

Table 2. Comparison of anti-interference ability of the elderly

|                         | Middle aged and elderly (45-64 years old) | Early aging (65-74 years old) | Late aging (75 years old) |
|-------------------------|------------------------------------------|-------------------------------|--------------------------|
| Balance ability         | Slight decline                           | Obvious decline               | Significant damage       |
| Mobility capability     | No obstacle                              | The movement ability decreases and the movement speed slows down | Limited movement, slow speed |
| Respiratory function and muscle strength | A slight decrease                        | Decreased function, weakened skeletal muscle strength | Obviously decreased, obviously loose and fragile bones, weak muscle strength |

The elderly have poor postural response to external disturbances, and often adopt multiple compensation strategies to deal with front, rear and medial disturbances. First, gait speed is obviously reduced, while stride length is greatly reduced. Ankle joint muscle strength plays an important role in anti-interference ability. The vertical reaction force and impact force of elderly patients with lumbago and backache are greater, and the horizontal pedal force is significantly reduced, so the gait pattern tends to be slow and smooth. Therefore, it is of great help to improve the stability of body posture to focus on developing the lower limb muscle strength of the elderly.

The experiment proves that there is not much difference in the movement speed between the young and the old, but the action time of the muscles of the old is different, that is to say, the central nervous system of the old is slower. Therefore, the elderly walk with a shorter step length and a wider step width as a stable support, and the center of gravity transition is slow, so the pace is slow.

2.3. Problems to be solved

When observing the walking condition of the elderly, it is found that in the walking process of the elderly, the feet follow the ground, the knee joint bends, the hip joint stretching action of the swinging leg is not sufficient, the degree of leg elevation decreases with age, the stride length decreases, the pace speed decreases, etc. It shows the phenomenon of seeking stability rather than speed when sitting and walking backward slightly. During the aging process of human body, the functions of human muscles and nervous system also change, muscle fibers decrease and atrophy, and fast muscle fibers atrophy faster than slow muscle fibers. Therefore, the fast motor ability of the elderly is the first obstacle, while the flexibility and balance of motor nerves are also restrained.

2.4. Principle of device design

(1) The design of this device should take the elderly as the design object and design scale. It is necessary to meet the physiological needs of the elderly as well as the psychological needs of the
elderly. At the same time, create products that can adapt to the physical and emotional care of the elderly, and let the elderly get more meticulous care in every detail of the products.

(2) The elderly are weak in physique, weak in muscle strength, poor in balance and slow in reaction. Therefore, the walking aid products used by the elderly should ensure the safety of the elderly and prevent falls and falls.

(3) During the design of the device, attention should be paid to reducing the operation requirements, making simple products multifunctional, simplifying the functions of complex products, reducing unnecessary functions and finding the best balance point. And consider the comfort and privacy of the elderly.

3. Technical Solutions

3.1. Seven-axis knee joint

3.1.1. Comparison of existing knee joints. At present, the knee joints available on the market can be roughly divided into load-bearing self-locking knee joints, fluid control knee joints and multi-axis knee joints.

The first is a load-bearing self-locking knee joint. This kind of knee joint is equipped with brake pads. When the leg is straight, brake is applied by its own weight to prevent the knee joint from bending.

The second is the fluid controlled knee joint. Fluid control knee joint includes two control modes of air pressure and oil pressure. These two control modes are very suitable for swing period. It can output non-linear damping very similar to human muscle. These two control modes can make the activities of patients' lower legs more normal.

The third is the multi-axial knee joint. The center of rotation of the knee joint of a normal person is not fixed, and the movement of the knee joint of a normal person is rotation plus movement. In order to fit the normal human knee joint movement better, a multi-axis knee joint with variable instantaneous rotation center has been developed, which not only has all the characteristics of multi-axis knee joint, but also ensures the stable fixation of the knee joint from the foot following ground to the middle support period from the geometric perspective, and can also well prevent the patient from falling down due to knee joint flexion during walking.

3.1.2. Walking gait research. Normal gait is usually taken as the basic control of abnormal gait, so normal gait should be analyzed before studying the seven-axis knee joint. Human gait cycle. As shown in the figure, it starts from the heel of the reference side to the heel of the same side. A complete gait cycle comprises a supporting phase and a swinging phase, wherein the supporting phase refers to the period from one foot following the ground to the same toe leaving the ground, and the swinging phase refers to the period from the toe leaving the ground to the same foot following the ground, and the supporting phase and the swinging phase respectively account for 60% and 40% of the whole gait cycle.
According to the contact between human body and ground, the support phase and swing phase can be further divided, as shown in the table.

**Table 3. Periodic table of contact between walking process and ground**

| Phase              | Subphase                        | Definition                                                                 | Proportion |
|--------------------|---------------------------------|---------------------------------------------------------------------------|------------|
| Supporting phase   | First landing period            | The moment the heel touches the ground                                    | 2%         |
|                    | Bearing reaction period         | The process of the foot following the ground to the full contact between the sole of the foot and the ground | 10%        |
|                    | Medium support phase            | The supporting foot touches the ground completely, and the contralateral foot leaves the ground until the trunk is located directly above the supporting lower limb | 19%        |
|                    | End of supporting phase         | Support the lateral heel off the ground to the opposite lower limb heel off the ground | 19%        |
| Oscillating phase  | Early swing phase               | The foot of the opposite lower limb follows the ground to the toe of the supporting lower limb and leaves the ground | 12%        |
|                    | Early swing phase               | The foot tip of the lower limb on the supporting side leaves the ground to reach the maximum flexion angle of the knee joint on that side | 13%        |
|                    | Middle swing phase              | The knee joint reaches the maximum flexion angle until the foot is perpendicular to the ground | 12%        |
|                    | End of wobble phase             | The foot touches the ground again with the heel perpendicular to the ground to this side | 13%        |

3.1.3. *Structural analysis of seven-axis knee joint*

(1) Data setting

The knee joint of the seven-axis prosthesis is a six-bar mechanism, and the structural diagram is shown in the figure.

AB rod connected to thigh HI, AB rod length: 25mm.
The process of obtaining instantaneous center position of knee joint of seven-axis prosthesis; Structural analysis → 3D modeling → motion simulation → instantaneous center solution.

(2) Three-dimensional modeling

In order to obtain the motion trajectory of the knee joint of the seven-axis prosthesis in the motion process, this paper uses inventor to carry out three-dimensional modeling of the knee joint. The model is shown in the figure.

(3) Motion simulation

After the model is built, it is imported into Adams for motion simulation, and AB rod is set as the fixed pair, ABCDEFG seven shafts are set as the rotating pair, A shaft is the driving shaft, and the rotating speed is 5.0d/s (rotating 5 degrees per second). In order to obtain the instantaneous center of the knee joint at different corner positions, the motion simulation is set to save the motion state once every 2 seconds (10 degrees) of rotation, and a total of 12 states are saved. As shown in the table.

(4) Instantaneous center solution

The instantaneous center of the six-bar mechanism is solved by the method of advanced mechanism. The kinematic chain diagram is transformed into its transformation diagram, i.e. the components are represented by points and the rotating pair between the two components is represented by a two-point connecting line.

It can be seen from Figure 4 that the instantaneous center track of the seven-axis knee joint is very close to that of the normal knee joint, which shows that the seven-axis knee joint can well simulate the instantaneous center track of the normal knee joint.
(5) Calculation of motion data of torque control shaft

The knee joint kinematics data collected in the experiment are angles, which are the angles around the knee joint between the lower leg and thigh. Putting this motion relationship on the seven-axis prosthetic joint becomes thigh fixation and the prosthetic leg swings. The collected change angle is regarded as the swing angle of the prosthetic leg (output rod) as shown in figure β, but we need to know the angle change α of the torque control shaft. Assuming that the control axis is the origin of coordinates, the coordinates of other points are shown in fig. 5.

![Figure 4. Seven-axis knee joint and instantaneous center track of human knee joint](image)

![Figure 5. Design parameters of seven-axis knee joint](image)

The relation equation of each point is as follows:

\[(x1+25.5)^2+y1^2=2152.96,\]
\[(44.8\cos(\alpha)-x1)^2+(44.8\sin(\alpha)-y1)^2=870.25;\]
\[(44.8\cos(\alpha)-x2)^2+(44.8\sin(\alpha)-y2)^2=432.64,\]
\[(x2-x1)^2+(y1-y2)^2=299.29;\]
\[(x3-x1)^2+(y1-y3)^2=870.25,\]
\[(x3+25.5)^2+y3^2=5776;\]
\[(x2-x4)^2+(y2-y4)^2=36.6879^2,\]
\[(x3-x4)^2+(y3-y4)^2=16.5^2;\]
β=arctan((y2-y4)/(x2-x4)), β is the experimental data collected as the output angle. α in the equations is the required angle. Use MATLAB software to solve α as shown in Figure 6.

**Figure 6.** Figure showing the change of angle of torque control shaft with time

3.2. Spring assist mechanism

3.2.1. Spring assist principle. During walking, human beings consume energy generated by metabolism. Some of this energy is used to recover dissipated energy, such as passive movement of soft tissues. However, the largest part of the waste is on muscles, which consume energy to do positive work. As required by the law of conservation of energy, they also use metabolic energy to generate force and perform negative work, which increases the metabolic cost of maintaining tendons during weight support and tendon stretching and recoil.

According to the principle of positive and negative power conversion of calf muscle and spring energy storage element, an elastic power-assisted walking device consisting of clutch and spring can be established. During the movement, the human body movement can be simulated by connecting and disconnecting the device. The device is mainly composed of a clutch and a spring. It takes on some functions of calf muscle and tendon when walking. The device is parallel to the calf muscle of the user and shares muscle strength, thus reducing the metabolic capacity when contracting. The schematic diagram of the device is shown in fig. 7.

**Figure 7.** Schematic diagram of elastic clutch device
When the foot is on the ground, the ankle joint movement keeps the device relaxed, thus contributing to muscle contraction. When the user lifts the foot, the foot is allowed to move freely in the air.

3.2.2. Selection of ratchet mechanism. Regarding the structure of the clutch, the wheel tooth type ratchet mechanism has a simple structure, and the size of the ratchet rotation angle can be adjusted step by step. However, as the pawl slides on the ratchet tooth back during the return trip, it is easy to wear and generate noise. In addition, in order for the pawls to smoothly engage between the teeth of the ratchet wheel, the displacement of the pawls must be greater than the corresponding displacement of the movement angle of the ratchet wheel, which leads to backlash and impact.

Friction ratchet mechanism does not have the above disadvantages, and the rotation angle of the driven wheel can be adjusted steplessly. However, due to sliding between contact surfaces, the accuracy and reliability of its movement are worse than those of wheel tooth ratchet mechanism.

| Type               | Advantages                                                                 | Disadvantages                                                                 |
|--------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Tooth ratchet      | The mechanism is simple in structure and reliable in operation, and the size of the rotation angle can be adjusted step by step. | It is easy to wear and has high noise. The pawl displacement must be larger than the relative displacement of the ratchet wheel movement angle. There is a gap that is easy to produce impact. It can only be adjusted step by step and the transmission stability is poor. |
| Friction ratchet   | The friction force between the pawl and the ratchet wheel transfers the movement, thus realizing stepless intermittent movement of the ratchet wheel. Smooth and noiseless transmission | Not suitable for high-speed or high-precision occasions, suitable for low-speed light-load occasions |
| Transcendental ratchet | Besides intermittent movement, it can also realize transcendental movement, with simple structure and reliable work. | Larger size and noise                                                          |

After comparing the above ratchet wheels, the friction ratchet wheel is finally selected. The stepless movement of the friction ratchet is more in line with the movement of the human body. At the same time, selecting materials or coatings with excellent properties can reduce the relative sliding between the ratchet and the pawl and improve the accuracy. The clutch structure is shown in Figure 8.

![Clutch structure diagram](image-url)

Figure 8. Clutch structure diagram
3.2.3. Spring-assisted workflow. A rope is wound on the ratchet wheel to provide clockwise pulling force when the messenger is sent. A spring under the ratchet wheel always provides counterclockwise torque to ensure the normal operation of the clutch. When the spring pulls the rope to rotate the ratchet clockwise, the ratchet can only rotate clockwise before reaching the maximum value, which makes the user's foot move freely in the air. When the ratchet wheel rotates clockwise to the maximum value, the spring wedge will spring the pawl, breaking the meshing state and allowing the ratchet wheel to rotate freely. Therefore, the counterclockwise torque provided by the spring will cause the ratchet to rotate counterclockwise to retract the rope. When the ratchet wheel rotates counterclockwise to the maximum value, the boss of the ratchet wheel will spring back to the pawl, causing the pawl to mesh with the ratchet wheel and circulate.

3.3. Auxiliary balance

3.3.1. Balance principle. In the process of the elderly walking forward, stride with forward leaning is the walking support period of one foot, accounting for about 40% of the gait walking period. When in the front swing posture during the walking support period, the muscles at the rear of the lower leg pull the sole of the foot to form a reverse torque to maintain body balance. It is not easy for the old people with reduced physical strength to walk for a long time, but they will be tired due to the increase of walking exercise and their ability to maintain physical balance will be weakened.

![Figure 9. Schematic diagram and physical diagram of damping rod-slider position slider; 2- calf; 3- damping rod; 4- sole plate](image)

The bottom end of the damping rod above the instep is fixed at an acute angle with the sole plate, and the rotating pair formed by the upper end and the sliding block meets the ankle rotation freedom degree during walking. Finally, the damping rod forms a triangular support with the lower leg and the sole plate, and the resultant force generated by the pressure exerted on the damping rod and the contraction of the inner muscle behind the lower leg of the elderly counteracts the horizontal component force of the forward movement of the center of gravity. The sliding damping rod supports the lower leg of the human body to offset part of the horizontal component of gravity when the human body leans forward, and reduces the energy consumption of maintaining balance when the elderly leans forward during walking.

3.3.2. Selection of auxiliary mechanism

(1) Damping rod mechanism

In order to provide reverse force auxiliary balance at the front end of the human body, a damping rod is used to support the design. According to the resistance between the sole of the foot and the lower
leg due to the characteristics of the gas spring, negative work is done to the lower leg when the body leans forward, and positive work is done when the body leans forward and returns to vertical. According to this, the expansion and contraction of the balance damper improves the stability of the elderly in the walking process, and part of the physical strength of the elderly is saved by the conversion of positive and negative work.

(2) Slider mechanism
The angle at which the elderly leans forward during walking gait is limited to 90, and damping is required when the included angle between the lower leg and the sole plate is at an acute angle. When the included angle between the lower leg and the sole plate forms an obtuse angle, no damping effect is required. According to the upper and lower stroke limit rating of the slide rail, when the slide block moves to the upper limit position, the body continuously leans forward, the slide block cannot stop moving upward, and the damping rod starts to play a role; On the contrary, when the critical angle of 90 degrees is not reached, the sliding block movement is used to cancel the telescopic motion trend of the damping rod.

4. Summary
In order to solve the problem of walking inconvenience caused by the decline of physical function of the elderly, we designed a wearable walking equipment for the elderly. The equipment can start with the weight bearing, assistance and balance of the elderly, and effectively solve the problems encountered by the elderly in walking. Wearing the cooperative walking equipment can enable the elderly to exercise healthily and prevent the deterioration of dyskinesia.

References
[1] Xing Siwei. Design of walker for the elderly based on ergonomics [D]. Harbin University of Science and Technology, 2018.
[2] Zheng Xinliang. Motion simulation and evaluation of the elderly based on moderate evaluation [D]. South China University of Technology, 2018.
[3] Mi Siyao. Research on the design of exoskeleton-type walking aids for the elderly [J]. Industrial Design, 2016(06):109+111.
[4] Zhang Hongliang. Research on the design of exoskeleton-type walking aids for the elderly [D]. Nanjing University of Technology, 2011.
[5] Fu Fenglan and Hu Yefa, Editor-in-Chief, Tolerance and Testing Technology, Science Press, 2006