Research on Assistive Devices for the Elderly to Urinate and Defecate

Zhen Yan, Tianyi Cheng, Jie Zhou, Cong Cao, Ye Tao, Yufeng Xu, Zihan Wang, Xinze Shao

Wuhan University of Technology, Wuhan City, Hubei Province, China

*Corresponding author: yz0121804940130@whut.edu.cn

Abstract. At present, the aging problem is becoming more and more serious, the number of empty nesters living alone is increasing, and the toilet falls of the elderly often occur. The existing protective device has single function, insufficient protective effect and low humanization. To this end, we designed a humanized device to assist the elderly living alone in toilet and daily activities.

1. Research background and significance

1.1. Research background

At present, China's aging problem is getting worse. According to estimates, in 2020, China’s disabled elderly will reach 42 million, the elderly over 80 will reach 29 million, and the empty-nest and alone elderly will continue to increase to 118 million. People pay more and more attention to the daily independent life of the elderly.

As the elderly grow older, their physiological functions decrease year by year. In particular, the muscle strength of the legs deteriorates. A considerable number of elderly people have problems such as difficulty in sitting up. The standing up movement is a necessary movement for normal life. People need to do a lot of sit-ups every day, an average of 60±22 times a day. For the elderly who live independently, assistive standing equipment is particularly important.

In addition, the bathroom is the most frequently used space for the elderly, and it is also the space where the elderly get up frequently and are most prone to unsafe events. It is not uncommon for the elderly to fall down in the bathroom and cause serious injuries. Data show that every year, about 40 million elderly people in China fall down due to slippery ground or difficulty in getting up and down. 50% of them occurred in toilets. Living alone increases the risk that old people can't be found in time after injury, which leads to aggravation of injury. Therefore, the design of auxiliary standing equipment for the elderly living alone should pay attention to the standing of the elderly in the toilet process.

At the same time, according to the survey results and network data, the following problems were found:

(1) It is common for the elderly to live independently, and the empty nest and the elderly living alone account for a large proportion.

(2) Nearly half of the surveyed elderly people have difficulty getting up independently. Old people sit for a long time, resulting in numbness of legs and feet and difficulty in getting up. The problem of
sitting up is widespread among the elderly, such as weakness of legs and feet and inability to support their bodies during sitting down.

(3) People don't know enough about the toilet protective equipment in the process of the elderly going to the toilet, and the elderly can't get proper protection in the process of getting up and sitting in the toilet.

(4) The existing toilet protection products for the elderly mainly include simple handrails or toilet chairs, which have single function and insufficient protection effect. At the same time, the existing auxiliary standing products can't fit the movement curve of the elderly when they stand up, and the humanized design is inefficient.

2. Functional design

2.1. Material selection and size design of the whole device

According to the national standard GB10000-88 of the People's Republic of China, it can be seen that the height of male standing is about 1706mm, that of female standing is about 1558mm, that of male weighing about 66.2kg, that of female weighing about 57.3kg, that of male sitting leg plus foot is 370-460mm, and that of female sitting leg plus foot is 380-470mm.

According to the above conditions, 6061 aluminum alloy is selected as the main material of the device, and the main parameters of the material are:

| Ultimate tensile strength | Tensile yield strength | Elongation rate | Elastic coefficient | Modulus of rupture |
|---------------------------|-----------------------|----------------|--------------------|--------------------|
| 124MPa                    | 55.2MPa               | 25.0%          | 68.9GPa            | 228MPa             |

Common domestic wheelchair parameters in the market are: seat width is about 440mm; vehicle width is about 650mm; backrest height is about 390mm; seat height from the ground is about 495mm; vehicle height from the ground is about 900mm; vehicle length is about 1030mm.

The size of the family bathroom is: the door width is about 1000mm; the distance from the center of the toilet to the wall is about 400-450mm; the width of the toilet is about 360mm; the distance of the water tank is about 773mm; the squatting part is about 390mm from the ground.

According to the above conditions, the shape size of the designed device is:

| Total length | Total width | Sitting height | Extended length |
|--------------|-------------|----------------|-----------------|
| 1060mm       | 560mm       | 500mm          | 1800mm          |

2.2. Auxiliary standing function design

2.2.1. Existing product analysis. Analysis of existing devices has the following shortcomings:

(1) The device is simple. The elderly mainly rely on the strength of upper limbs to assist the sitting-up movement in the toilet. There is a great potential danger for the elderly with weak upper limbs, and the applicable range is too narrow.

(2) The movement of the device is single, which is not ergonomic, and cannot be fitted to the hip curve when the human body stands. Most of the auxiliary lifting motions of existing products are unidirectional motion or fixed axis rotation. There is no better solution to the comfort level of assisting the elderly to sit up, and there is a lack of humanized design.

(3) The device has weak pertinence, which does not solve the potential danger of the elderly going to the toilet at night. Through analysis, it can be seen that the existing products are not comfortable enough and do not conform to ergonomics. Designing a mechanism that can move better can solve the above problems.
2.2.2. *Hip curve of simulated human body.* In order to design an ergonomic mechanism, we build a simplified human body model to calculate the motion curve of human body. The force state of human lower limbs is simplified to a simplified model as shown in the figure, including one heavy object, three rigid bars and four muscles. The upper body of human body is simplified as a weight fixed to buttocks, thighs, calves and feet are simplified as three rigid rods, ankles, knees and hips are simplified as hinge points, and muscle forces are simplified as four pairs of unknown relative forces acting on rigid rods, which are located on both sides of thighs and calves.

According to the mathematical relationship and the conditions set by the ankle joint, the coordinates \((x_q, y_q)\) of the knee joint can be obtained:

\[
x_q = l_1 \cos \theta_1 \tag{1}
\]

\[
y_q = l_1 \sin \theta_1 \tag{2}
\]

Similarly, the coordinates \((x_k, y_k)\) of the hip joint are:

\[
x_k = y_q + l_2 \cos(180 - \theta_2) \tag{3}
\]

\[
y_k = z_q + l_2 \sin(180 - \theta_2) \tag{4}
\]

To sum up, the coordinates of hip joint can be obtained by simplification:

\[
x_k = l_1 \cos \theta_1 + l_2 \cos \theta_2 \tag{5}
\]

\[
y_k = l_1 \sin \theta_1 + l_2 \sin \theta_2 \tag{6}
\]

From the transformation matrices of \(l_1\) and \(l_2\), as well as the coordinates of knee joint and hip joint, the homogeneous transformation matrix of hip can be obtained, and its position and angle can be further obtained:

\[
x_t = l_3 \sin(\theta_1 + \theta_2) + l_1 \sin \theta_1 \tag{7}
\]

\[
y_t = l_3 \cos(\theta_1 + \theta_2) + l_1 \cos \theta_1 \tag{8}
\]

\[
\theta_1 = \arctan \left( \frac{y_t}{x_t} \right) - \arctan \left( \frac{l_2 \cos \theta_2}{l_1 + l_3 \cos \theta_2} \right) \tag{9}
\]

\[
\theta_2 = 180^\circ - \arctan \left( \frac{l_1^2 + l_3^2 - (x_t^2 + y_t^2)}{2l_1 l_3} \right) \tag{10}
\]

Derived from the above formula, the acceleration of buttocks can be obtained as follows:

\[
\ddot{x}_t = -l_3 \sin(\theta_1 + \theta_2) \left( \dot{\theta}_1 + \dot{\theta}_2 \right)^2 - l_3 \cos(\theta_1 + \theta_2) (\theta_1 + \theta_2) - l_1 (\sin \theta_1) \dot{\theta}_1^2 - l_1 (\cos \theta_1) \dot{\theta}_1 \tag{11}
\]

\[
\ddot{y}_t = -l_3 \cos(\theta_1 + \theta_2) \left( \dot{\theta}_1 + \dot{\theta}_2 \right)^2 - l_3 \sin(\theta_1 + \theta_2) (\theta_1 + \theta_2) - l_1 (\cos \theta_1) \dot{\theta}_1^2 - l_1 (\sin \theta_1) \dot{\theta}_1 \tag{12}
\]

Combined with the model, it can be seen that the hip movement displacement \(x\) changes in the horizontal direction and the movement displacement \(y\) changes in the vertical direction during the human standing process.
2.2.3. Variable proportion scissor mechanism. Common scissor mechanisms are assembled in the way of hinged middle points of straight bars, as shown in the following figure. The movement of this kind of mechanism is a linear movement perpendicular to the ground, which does not meet the requirements of this project. In this project, the mechanism moves according to the established curve by redesigning each shear bar in the two-stage scissor mechanism.

This project adopts the idea of reverse design. Firstly, the second stage of the two-stage scissor mechanism is designed. The shear bar 1 is designed to be a folding bar with a short end length of 81mm and a long end length of 108mm, with an included angle of 170. Shear bars 2 are folding bars, all of which have a length of 108mm and an included angle of 170.

It is impossible to realize the process from the initial horizontal position to the end inclined position by changing the shear bar of the second-stage scissor mechanism alone. Based on this, the first-stage scissor mechanism is designed to compensate the displacement of the second-stage scissor mechanism. The shear bar of the first stage is designed as a straight bar with a long end of 126.5mm and a short end of 123.5 mm. The movement of the mechanism is shown in the following figure.

Figure 1. The hip movement curve during a human sitting up.

Figure 2. Variable ratio scissor mechanism.
From the simulation results, it can be seen that the trajectory of the designed variable scale scissor mechanism has a high fitting degree with the hip movement curve when the human body sits up, which meets the project requirements.

2.3. Design of attitude conversion function

2.3.1. Design of six bar mechanism. The design of the six-bar mechanism enables the elderly to change from lying position to sitting position with the help of the device only by simple actions. Schematic diagram is as follows.

![Six-bar structure diagram.](image)

Connecting rod 1, connecting rod 2, connecting rod 5 and frame constitute the first parallelogram mechanism. The purpose is to complete the leg retraction process in the process of posture transformation for the elderly. Connecting rod 1, connecting rod 2, connecting rod 3, connecting rod 4 and connecting rod 5 constitute the second parallelogram mechanism, which aims to complete the back lifting and leg retracting at the same time, and realize the free conversion of the posture of the elderly on the device.

3. Calculation check

3.1. Strength check of variable proportion shear fork mechanism

In the process of assisting people to sit up, the variable proportion scissor mechanism mainly bears most of the weight of human body. Assume that someone weighs 65kg and the actual area of the variable proportion scissor mechanism is 400 mm * 440 mm. Due to assembly error and friction, the correction coefficient $\eta=1.5$. It can be calculated that the pressure that the device needs to bear is:

$$p = \eta \times F \times S = 1.5 \times 65 \times 10 \times 400 \times 440 \times 10^{-6} = 171.6 M Pa$$  \hspace{1cm} (13)

Because the variable proportion scissor mechanism is symmetrically distributed on the device, the pressure on the unilateral mechanism is as follows:

$$p_1 = \frac{p}{2} = 85.8 M Pa$$  \hspace{1cm} (14)

The stress analysis in inventor software is used to analyze the stress of unilateral variable proportion mechanism. In the physical processing, the slide rail 1 and slide block 2 are all purchased parts, and the connecting rod is made of alloy steel by laser cutting. The hinge of connecting rod adopts quenched and tempered steel shaft with diameter of 10, and both ends of the shaft are limited by shaft sleeves.
The stress analysis results are as follows:

Mises equivalent stress results:
As shown in the following figure, the maximum value and minimum value of Mises equivalent stress of the variable scale scissor mechanism are 12.14MPa and 0MPa.

![Figure 4. Mises equivalent stress of variable-scale scissor mechanism.](image)

Displacement result: The maximum displacement of the variable proportion scissor mechanism is 17.26mm, and the minimum displacement is 0.

Safety factor results: The safety factor of the variable proportion scissor mechanism is 15ul, which has a high safety factor.

3.2. Strength check of frame
When people use the device, the rack mechanism mainly bears most of the weight of the human body. Suppose someone weighs 65kg, and the actual surface area of the rack is 650 mm * 440 mm. Due to assembly error and friction, the correction coefficient $\eta=1.5$. It can be calculated that the pressure that the device needs to bear is:

$$p = \eta \cdot F \cdot S = 1.5 \times 65 \times 10 \times 650 \times 440 \times 10^{-6} = 278.8MPa$$ (15)

The stress analysis in inventor software is used to analyze the stress of the frame. In the physical processing, all the aluminum profiles are purchased parts, which are made of aluminum 6061 alloy by laser cutting. The hinge of connecting rod adopts quenched and tempered steel shaft with diameter of 10, and both ends of the shaft are limited by shaft sleeves.

The stress analysis results are as follows:
Reaction force and moment results on constraints:
Mises equivalent stress results:
As shown in the following Figure, the maximum value of equivalent stress of Mises of the frame is 0.7087MPa, and the minimum value is 0MPa.

![Mises equivalent stress of the rack](image)

**Figure 5.** Mises equivalent stress of the rack

Displacement result:
As shown in the following figure, the maximum displacement of the frame is 0.00291mm, and the minimum displacement is 0.

Safety factor results:
The frame has a high safety factor of 15ul.

4. Application prospect
1) The overall design of the device is humanized, the design concept follows ergonomics, and the motion curve of the device conforms to the human motion curve.
2) The device has a wide application range, can be applied to multi-scene sitting and auxiliary use, and has a wide application prospect.
3) The device has simple structure and convenient operation, and is suitable for the elderly.

References
[1] Niu Songyun. Design of multifunctional toilet assistive devices for the elderly based on user behavior analysis [D]. Shandong University, 2020.
[2] Mu Jiamin. Research on the development and safety control strategy of lower limb exoskeleton for the disabled [D]. Harbin Institute of Technology, 2019.
[3] Cao Zhenxin. From the perspective of human factors engineering, the design of toilets that make the elderly defecate smoothly [J]. Art Technology, 2017, 30(09): 250.
[4] Zheng Jun, Yu Na. Research on the function seat for the elderly [J]. Design, 2017(07): 114-115.
[5] Xu Lan. The design of helping the elderly to get up the chair[J]. Furniture and Interior Decoration, 2008(05): 32-33.