Design of multifunctional combined walking aid

Jie Gu\textsuperscript{1,a}, Jingyuan Wang\textsuperscript{2,b}, Ming Sun\textsuperscript{3,c}, Qing Wu\textsuperscript{4,d,*}

\textsuperscript{1,2,3,4}East China University of Science and Technology, Shanghai, China
\textsuperscript{a}email: jieguchuroc@163.com
\textsuperscript{b}email: wjysmhs@gmail.com
\textsuperscript{c}email: 992377121@qq.com
\textsuperscript{*}corresponding author: *email: qwu@ecust.edu.cn

Abstract: In view of the lack of a portable walking aid with multiple functions in the current market, a multifunctional combined walking aid is designed. The device is based on raspberry pie, and controls the whole device through human-computer interaction of touch screen; the dynamic and non dynamic switching is realized through disassembly structure, which can have the advantages of walking aid and crutch structure; a stacked connection structure is designed, which can realize the functions of folding and drug storage in a cylindrical structure at the same time; a vertical driving wheel is adopted, which can realize the function of folding and drug storage. The independent driving of two wheels enables the user to enter the control position from the rear side of the walking aid. The experimental results of the prototype show that the device has the advantages of strong functionality, convenient operation and broad application prospects.

1. Introduction
With gradual increase of the elderly population in China, the mobility of the elderly decreases, so it is inconvenient for the elderly to go out. Therefore, the research and design of better walking aids has high social value \cite{1}. Because of the particularity of the elderly group, the physical condition of each elderly is not the same, which leads to the diversification of the design requirements of walking aids \cite{2}. At present, there are many kinds of walking aids in the market, but most of them have monotonous function and slow action, which are characterized by the absence of wheels, restricting long-distance movement of the elderly. In the process of moving, the elderly need to make their own efforts, which greatly increases the consumption of strength of the elderly and increases the difficulty of action. Two-wheel or four-wheel walking aids or wheelchairs are large in size, and many of them can't be folded and are inconvenient to carry. Sometimes they need others' help to carry, which goes against the original intention of helping the elderly to act independently. In this paper, a multi-functional combined walking aid is designed, which can realize the switching between dynamic and non dynamic, has a number of convenient functions, can adapt to more diverse travel scenarios, and has great practical value and broad market prospects.

2. Structural design

2.1. Overall design
The overall design of the walking aid conforms to the ergonomic design concept, and the parameters \cite{3}
are shown in Table 1. The whole walking aid is shown in Figure 1, including independent front bar, U-shaped support frame, vertical driving wheel and some important connecting parts. The front bar is connected with the whole body by the plug structure through the electric push bar encapsulated in the U-shaped support frame. The two ends of the U-shaped support frame are connected with the rear bar by virtue of a cylindrical stacking structure. The structure is compact and safe, and can realize many convenient functions.

**Table 1. Ergonomic parameters**

| Elbow height while sitting (mm) | Body width (mm) | Hand height while standing (mm) | The length of forearm (mm) | Hand height while bowing (mm) |
|--------------------------------|-----------------|-------------------------------|--------------------------|-----------------------------|
| 600                            | 460             | 1050                          | 450                      | 850                         |

![Fig.1 Overall design](image)

2.2. **Design of independent front bar**

The dimension parameters of the front bar refer to the data in Table 1. The overall shape design ensures that the center of gravity is below the grip under the premise of beauty appearance. The tilt angle of the front bar is 24.6 degree when it is installed, which is the angle that can reach the maximum value when the force is applied on the premise of ensuring the user's comfort. Refer to 3.3. The connection between the front bar and the U-shaped support frame is realized by the bolt structure, and the bolt adopts the electric push rod, which is convenient to realize the movement of the bolt.

After the front bar is striped down, it can be transformed into two independent crutches. The specific disassembly process is as follows: the connection between the front bar and the U-shaped support frame can be released by controlling the contraction of the push rod through the raspberry pie, and then the front bar can be removed from both sides, and the landing point of the front bar can be changed by changing the grip angle, so as to realize the switch between the wheel mode and the bar mode.

2.3. **Design of medicine storage tank**

The drug storage structure is composed of a steering gear, a pair of gears and a set of screw nuts. The structure is shown in Fig. 2. In the cylindrical stacking structure of U-shaped support frame and rear bar,
the thread transmission mode in which bolt rotates and nut moves is adopted to realize the lifting of the drug tank, while the bolt rotation is driven by the steering gear, and the transmission device adopts the gear transmission with the transmission ratio of 3:2. The mechanism makes full use of the cylindrical space at the joint and adds the function of medicine storage, which is convenient for the elderly to carry medicine bottles when they go out. In terms of lifting mechanism, the elderly can pick up medicine bottles without reaching into the narrow slot to grab medicine.

![Drug storage structure diagram](image)

**Fig. 2 Installation diagram of drug storage structure**

### 2.4. Design of folding structure
The stacking structure extends a thin wall to cover the rear bar, and the inner part is connected with the rear rod by a spring, so that the rear bar has an axial degree of freedom and constrains the radial degree of freedom. After the rear bar is pulled out of the thin wall, the radial constraint is liberated and the folding can be realized. If there is no external force to overcome the elastic force, the rear bar can not be released from the shackles, and the walking aid is in the unfolding state. The above description can switch the folding and unfolding states of the walking aid.

### 2.5. Design of vertical wheel
The vertical driving wheel is composed of a stepping motor, a steering gear, a pair of bevel gears, two pairs of spur gears and a plurality of bearings. The vertical driving wheel adopts the vertical design. This kind of structure design comes from CN2905529. This model is simplified to realize the effect of vertical drive. The internal structure is: a motor is packaged in the tubular structure connected with the rear pole. The wheel speed is directly controlled by a set of gear train, and the steering gear on the side controls the steering of the wheel. The design can realize two independent rear wheel drive, so that the user can...
enter the control position from the rear of the walking aid; in addition, with the help of the transmission system, the steering gear can directly control the steering of the wheel, which is more accurate than the differential rotation, easier to control and more convenient for the elderly. Each wheel has a set of independent drive system, and the circuit can be directly encapsulated in the system, which solves the problem that the circuit is complex and difficult to distinguish and arrange.

3. Strength check and simulation analysis

3.1. Strength check of push bar joint

It is assumed that the pressure on the walker is 479.5 N\(^4\), and the model of the walking aid is simplified for stress analysis. The simplified stress analysis diagram is shown in Fig. 3, and four equilibrium equations can be listed.

\[
\begin{align*}
F_1 + F_3 &= F \\
F_2 \times (l_1 + l_2) - F \times l_2 &= 0 \\
F_3 \times l_3 &= F_1 \times l_1 \\
F_4 \times l_4 + F_5 \times l_5 &= F_3 \times l_3
\end{align*}
\]

(1)

In the joint equation, \(L_1 = 320\) mm, \(L_2 = 350\) mm, \(L_3 = 60\) mm, \(L_4 = 520\) mm, \(L_5 = 200\) mm, the force acting on the joint is about 620 N. 6063-T5 aluminum profile is selected as model material for analysis, the shear strength limit of which is 145 MPa \(^6\). The diameter of push bar is 10 mm, and the shear stress is:

\[
\sigma_s = \frac{F}{S} = \frac{4F}{\pi d^2} = \frac{4 \times 620}{\pi \times 0.01^2} = 7.89\text{N}
\]

(2)

\(\sigma_s\) is far less than the ultimate strength, so the connection is safe and stable.

Fig. 3 Stress analysis diagram

3.2. Stress analysis of curved bar structure

The material of the crutch is 1100 aluminum alloy, the yield strength of which is 123MPa. The mass of the crutch is 1.14 kg. Assuming that the device is under normal temperature and pressure. When the crutch is landing on the foot set, the force acting on the crutch grip is about 480 N. Therefore, the fixture is selected on the foot sleeve, and a vertical downward force of 480 N is applied to the horizontal rod of the crutch. After meshing, the stress analysis diagram is obtained, as shown in Figure 4. It can be seen from the analysis in the figure that the maximum yield strength of the whole device is 41MPa, which does not exceed the yield strength limit.
3.3. Front bar tilt analysis
In order to ensure the comfort of the elderly, the tilt angle of the front bar and the maximum bearing force under this angle are analyzed by software. The experiment assumes that the force on the arm of the elderly is in the same plane as the arm, and the angle between the force and the arm is $\alpha$. $\alpha$ is evenly distributed from 0 degree to 90 degree to obtain the angle range in which the maximum force can be obtained, and then the most appropriate angle is obtained by gradually narrowing the range through the two-point method. The experimental data are shown in Table 2. The results show that the arm can bear the maximum force at 24.6 degree.

| Angle (deg.) | Force (N) | Angle (deg.) | Force (N) |
|--------------|-----------|--------------|-----------|
| 0            | 125       | 26           | 147.75    |
| 20           | 142.75    | 27           | 145.5     |
| 24.4         | 150       | 28           | 143.5     |
| 24.5         | 150.25    | 29           | 141.5     |
| 24.6         | 150.25    | 30           | 139.75    |
| 24.7         | 150       | 45           | 121       |
| 24           | 149.25    | 60           | 113.25    |
| 25           | 149.75    | 90           | 12.5      |

4. Control system
The control device mainly uses raspberry pie, sensors and L298N modules, cameras and other auxiliary components.
4.1. **Speed control system**

In order to adapt to the speed conditions of different scenarios and different groups of people, the device has four speed gear options: high, medium, low and adaptive. The user can adjust the values of the three speed gears. For the adaptive speed gear, the device uses the acceleration sensor to record the user's travel speed within a period of time as the training sample, which is transferred into the raspberry pie. By training these samples with the neural network in raspberry pie, we can get the most suitable speed of users after a period of time and record the speed value, so as to realize the automatic speed adaptation.

4.2. **Call system**

4.2.1. **Face recognition**

After the video information is captured by the camera, it is imported into the neural network preset in OpenCV library by frame. The detectMultiScal function is used to analyze whether it is a face, and a rectangle that can completely frame the face is generated at the face. The position and size of the rectangle can be returned at the same time, so as to judge whether there is a face and calculate the size of the face.

4.2.2. **Realization of call function**

Judging the distance between human and computer by the size of the rectangle obtained from face recognition can realize the function of accurately summoning to the elderly. Firstly, according to the Euclidean norm distance between the rectangle frame and the image center, the steering angle and direction are adjusted continuously to make the distance less than a small threshold and stop the direction rotation. By analyzing the size of the rectangle, we can get the approximate distance from the user according to equation 3, and drive to this position.

\[ D = K \sqrt{S \cos \alpha} \]  

In the equation 3, D is the driving distance, S is the rectangle obtained by the camera, K is the sight distance coefficient, and \( \alpha \) is the angle between the camera and the ground.

5. **Conclusion**

The structure of the multi-functional combined walking aid designed in this paper has the characteristics of both dynamic and non dynamic walking aids. It can achieve a number of convenient functions. The design is in line with ergonomics. After a lot of simulation tests and strength verification, the use of the walking aid can greatly increase the convenience and safety of the elderly when they go out.

**Reference:**

[1] Li, M.C., Research on the design of barrier free walking aids for the elderly in Guangdong [J]. Packaging engineering. 2016 (6): 75-78, 91

[2] Qin, S.W., Wu, B., Research on design elements of walking aid for the elderly [M]. Modern salt chemical industry. 2020 (6): 165-166

[3] Lu, R.F, Jiang, Q., Zhang, Y., song min. ergonomics [M]. Chongqing University Press: basic teaching material for art design major in Colleges and universities, 201409.199

[4] Jiang, S.D., Research on elderly walking aid based on ergonomics [D]. Hubei University of technology, 2018

[5] An, Q., Gu, D.Q. Mechanical design [M]. Beijing: Science Press, January 2016

[6] Huang, S.Z., Yu, Y.H., Yang, H.Y., Design of multifunctional toilet chair [J]. Mechanical design and manufacturing engineering, 2020, 49 (10): 53-58