Design of a multifunctional nursing wheelchair

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Abstract. This paper designs a wheelchair with multi-function nursing ability. With Raspberry Pi as the main control board, it has functions such as assisting in getting in and out of bed, terminal monitoring, intelligent risk avoidance. It also has the ability of rehabilitation training for the elderly with stroke or similar conditions, to prevent muscle atrophy and other problems caused by long-term inability to exercise independently. Finally, the lightweight aluminum profile material is used as the main body to complete the prototype production and function verification. The prototype test shows that this new type of intelligent nursing wheelchair has a reasonable design, and the integration of multiple functions has brought great convenience to the caregivers and users. It has the prospect of large-scale promotion and marketing.

1. Introduction

According to the 2015 Report on World Population Ageing published by the Population Division of the United Nations, in 2015, there were 900 million people aged 60 or above, accounting for one eighth of the world's total population. It is estimated that there will be 1.4 billion people in 2030, accounting for 1/6 of the total population, and nearly 2.1 billion people in 2050, accounting for 1/5 of the total population. Among such a large number of elderly people, nearly 60% of them have leg problems and cannot take care of themselves due to various diseases [1]. In addition, according to the World Health Survey, about 785 million (15.6%) people aged 15 and over live with a disability, of which 190 million (3.8%) have severe disabilities, such as quadriplegic, leg disability, etc. [2]. These elderly, disabled, patients need a lot of nursing staff to help them complete daily travel, assist in getting in and out of bed, artificial hand and foot rehabilitation training, it requires a lot of manpower and time. However, the WHO 2020 report states that there are now 27.9 million nurses worldwide, accounting for more than half (59%) of the world's health workers. It can be seen that the total number of nurses only accounts for 0.378% of the world's population. Compared with the number of people in need of care, there is a big shortage of nursing staff in the world. However, there is no nursing wheelchair on the market that has the function of automatic nursing and can carry on the function of rehabilitation and exercise to the user's body according to the demand.

Wheelchair design in this article can make use of automatic armrest, feet and head pad on the limbs, the neck, back rehabilitative training in any direction, at the same time users can adjust the angle and height to assist user in getting in and out of bed. The wheelchair also carries Intelligent terminal
monitoring and infrared obstacle avoidance and other functions, which can realize the user to go out for a walk, in the sun, in the case of no one care. Meanwhile, in order to be convenient for the user to take the escalator, corresponding to the wheelchair is equipped with a travel switch electromagnet and a series of auxiliary devices, making it easier for users to travel safely. The nursing wheelchair reduces the working intensity of the nursing staff, greatly facilitates the rehabilitation training of the users, and improves the autonomy and quality of life of the users.

2. Mechanical structure design and principle

2.1. Overall structural design
According to the existing medical literature: Take China as an example, the number of strokes in China is about 70 million, and the number of PVS is about 1.4 million and keeps an annual growth rate of 70,000-80,000. High blood pressure, irregular work and rest and mild depression may lead to cerebral vascular rupture resulting in stroke, most patients often accompanied by partial paralysis of the body, systemic paralysis (PVS) and other symptoms, For wind-stroke syndrome users and other similar patients, this article designs a type of nursing wheelchair like figure 1, with Scissor-Type lifting institutions to control the height, using the activity type nursing armrest, back of a chair, by devices such as legs, complete periodic rehabilitation training, using the mecanum wheel, and has auxiliary up and down the escalator electromagnet structure, so as to complete the corresponding auxiliary functions.

![3D model of wheelchair](image)

1- Nursing armrest  2-Nursing backrest  3- Nursing legrest  
4- Scissor-Type lifting institutions  5- linear actuator  6- Mecanum wheel

Figure 1 3D model of wheelchair

2.2. The principle of Scissor-Type lifting institutions
Through the linear actuator to push the shaft to do rotating movement so as to drive the Scissor-Type lifting institutions up and down movement. The hinge connecting the push rod and the shaft is welded to ensure that there is no relative rotation in the process of movement, which ensures the stability and safety of the wheelchair in the process of overall rise and fall. The user can adjust the height of the seat by remote control via Bluetooth. When close to the bed, use the sensor device near the seat (more on this later) to lift to the level of the bed. Cooperating with armrest and legrest putting flat, it completes the function of assistance in getting in and out of bed and taking the objects placed on high places, which facilitates the daily life of the user. The schematic diagram is as follows:
Figure 2 The schematic diagram of Scissor-Type lifting institutions

2.3. The principle design of nursing armrest
The main function of the armrest is to complete the rehabilitation training of the user's hand by completing the periodic slow and periodic pulsating cyclic rotation. It can also be flatten when assisting the function of getting in and out of bed. It is convenient for the user to move his or her body slightly to get into bed. So we can use the parallelogram linkage steering. The schematic diagram is as follows:

Figure 3 Armrest mechanism principle design drawing

Armrest is movable using symmetrical double-hinge movable hinge. The handrail is also made of aluminum profiles with the same cross-section size. A beveled edge is provided in the upper support frame to mount the air spring, the parallelogram linkage steering mechanism is installed in the place where the support frame is recessed, and the travel of the air spring is also solved by the drawing method. The design drawing is shown below:

Figure 4 Armrest parameter design drawing

2.4. The principle design of nursing backrest and nursing legrest
The nursing legrest requires you to rotate around the part of your seat that's connected to it, considering that the wheelchair can be lifted or lowered, which may cause changes in the motor push rod stroke. Therefore, in this result, the other end of the push rod motor is fixed under the seat plate of the wheelchair, so that the travel of the push rod on the leg does not change during the lifting process. The main function
of backrest and armrest is to assist the user by the leg and back rehabilitative exercise, depend on both sides of the legs have their respective degrees of freedom are unconstrained which can work alone, in the subsequent process can be finished under the control of various types of rehabilitation training, can according to user's requirements in terms of motion curve fitting, the common movement law has the bicycle repeated movement, the simulation walks the movement and so on. The main principle is similar to the oscillating guide-bar mechanism, the schematic diagram is as follows:

![Figure5 Legrest mechanism principle design drawing](image)

The principle of the backrest is similar to that of the leg part and will not be repeated. the schematic diagram is as follows:

![Figure6 Backrest mechanism principle design drawing](image)

2.5. **Shock absorption design of Mecanum wheel**

The moving chassis of the wheelchair uses four Mecanum wheels with a diameter of 100mm. The speed direction of a single wheat-wheel is perpendicular to the rubber roller, and the omnidirectional movement is carried out by the combined speed of each wheel. But the Mecanum wheel has some problems, such as unstable driving and large vibration. In order to ensure the safety and comfort of the users, based on the existing damping methods, we add a spring washer and damping plate to the driving structure of the wheel-wheel, and distribute the resistance moment through a cushioning damping arm to achieve the effect of damping. [4]

![Figure7 Schematic diagram of Mecanum wheel shock absorption design](image)
3. the realization of control system

The overall control system flow chart is shown in figure 8. The temperature and humidity sensor and the infrared distance sensor are connected through an Arduino to get the temperature and humidity data and the distance from the chassis to the ground respectively. The remote-control handle which is connected to the Arduino as well controls the electric push rods for rising and falling wheelchair and controls the motors for moving wheelchair. The encoder feeds back the pulse signal which is processed into the motion information such as the speed of the motor to the Arduino and then upload the information to the Raspberry Pi through serial. The Raspberry Pi is connected to a Lidar, an inertial measurement unit (IMU), a camera, a Buzzer and a LED lamp. Lidar gets information about the environment, the IMU gets information about its own acceleration and the camera gets images from time to time. These data along with the motion information from Arduino, is uploaded from the Raspberry Pi to the terminal via the WIFI for algorithmic processing and monitoring.

The Mecanum wheel is driven by a planetary gear reduction motor, which can convert the low torque and high speed input into the high torque and low speed output through the gear set, providing high torque power for driving heavy load wheelchair. For the safety of the user, the motor used in this work provides 35.5KG.CM torque. The idling limit is about 90 RPM (3 rad/s) for each wheel, while the maximum linear speed of a single hub with a radius of 50 mm is about 0.5 m/s.

The control of the chassis is to operate the joystick on the armrest of the wheelchair, and the user can freely control the direction of the wheelchair. With Simultaneous Localization and Mapping (SLAM) technology, the wheelchair can stop at the designated target position and avoid the movable or immovable obstacles on the way.[5] However, considering the size and mass of the wheelchair, the mobility of the wheelchair and the safety of the elderly, this design is realized without using the automatic navigation mode, only using the SLAM algorithm as the assistant of the manual remote control, to achieve terminal monitoring, recording the movement path and alarming for short-range obstacles. Compared with GPS positioning, SLAM positioning can reveal the exact position of the wheelchair relative to the surrounding environment in indoor and small scenes. The wheelchair is convenient for the elderly to do activities alone in the nursing home or nearby outdoor. When they need help, the caregivers can quickly lock their position, which can reduce the pressure of some of the caregivers, and also facilitate the elderly who have the ability to control the wheelchair and need to go out for enjoying the sun or other activities.

3.1. The terminal monitoring

The System adopts the Robot Operating System (ROS) framework, and the SLAM algorithm completes its own positioning and recognition of the surrounding environment, which is transmitted to the terminal.
through the LAN. Visualization tools are called at the terminal to constantly monitor the position of the wheelchair and observe the specific situation of the elderly through the camera.

3.2. Alarm for close range
After processing the point cloud information returned by the lidar, if the distance from the object around the wheelchair is less than a certain threshold and the actual speed is greater than a certain threshold, the LED light flashes to prompt the operator to pay attention to deceleration.

3.3. Anti-rollover
In the bottom of the wheelchair is equipped with infrared ranging sensors, if a sudden change in the distance is detected, it means that the wheelchair encounters pits, stairs and other similar situations, the motor will brake and buzzer will alarm. If the IMU detects that the wheelchair has a large turnover, it will give feedback and alarm to the terminal.

3.4. Assistance in getting in and out of bed
The specific process is as follows: firstly, the user controls the wheelchair to the bedside and makes it connecting to the bed. And then the lifting mechanical structure will automatically lift until that the pressure sensor mounted on the side of the wheelchair reaches to the edge of the bed which returns pressure signal and control signal. When the cushion is equal to the height of the bed, the armrest, backrest and legrest are placed flat in turn. When the overall structure is parallel to the bed, the user only needs to slightly move his or her hips to get into bed. Even the problem of getting into bed for the users with inconvenient legs and feet is solved.

3.5. Other auxiliary functions
The electromagnet device is used to start the electric signal by remote control when the user goes up and down the escalator, so that the electromagnet has the magnetic force adsorbing the magnetic escalator, improving the running stability and ensuring the safety of the user.

4. Function verification of the prototype wheelchair

4.1. Wheelchair size design and manufacture of prototype

| Major component | Seat plate | Backrest | Headrest | Legrest | Armrest (single) |
|-----------------|------------|----------|----------|---------|-----------------|
| width           | 500mm      | 420mm    | 200mm    | 360mm   | 40mm            |
| length          | 480mm      | 480mm    | 120mm    | 440-500mm| 320mm           |
| Thickness (height) | 30mm      | 30mm     | 40mm     | 30mm    | 360mm           |

Considering the operability of the experiment, the prototype was made at a ratio of 3:4. The model of the prototype is shown below:
4.2. Wheelchair load-bearing capacity checking
When using 1640 aluminum profile material, let's say the user weighs 100kg, therefore, the force of the component bars of each Scissor-Type rod is 250N. Through the simulated force analysis, it can be seen that the stress and strain of the maximum stress bar are both within the adaptive range, so it can withstand most users.

4.3. Verification of the function of assistance in getting in and out of bed
Considering that the average height of the existing beds for Asian people in the market is about 45-55cm, we conduct 3 groups of experiments to compare the experiments of automatically rising to the same height as the bed with the automatic lifting structure and the pressure sensor beside the cushion at different heights. It can be seen from the experimental data that the accuracy of the automatic lifting structure is basically maintained at more than 85%, which is basically in line with the use of all kinds of height beds on the market.

Table 2: Lifting precision test data of lifting structure

| Bed height | Number of test | Times of the wheelchair successfully lift to the bed height | Experimental success probability |
|------------|----------------|----------------------------------------------------------|---------------------------------|
| 40cm       | 50             | 47                                                       | 94%                             |
| 50cm       | 50             | 46                                                       | 92%                             |
| 60cm       | 50             | 44                                                       | 88%                             |
4.4. Verification of periodic rehabilitation movement function of armrest, backrest and legrest

4.4.1. Movement of armrests
Armrests are driven repeatedly by 12V small steering gear, the switch module controls the starting of the whole armrest rotation. Two switches are used on both sides of the armrest. The angular velocity of repeated motion can be controlled through the bluetooth of the mobile phone (if there is no input angular velocity, the default is $\pi/60$ rad/s), maximum range of motion is 105°, repeated pulsating cycles can prevent muscle atrophy in users who have been unable to exercise for a long time, and can also help middle-aged and elderly people who have suffered a wind-stroke syndrome move their bodies.

![Figure11 Armrest physical drawing](image1.png)

4.4.2. Legrest and backrest movements
Legrest and backrest movement mechanism is similar to the armrest, without further elaboration, difference on the leg and the back of a chair of the driver uses to compile the 220 v industrial push rod, the activities of the highest can complete 135°. Two legs drive by two push rods, which can be manually inputted motion curve required to complete the rehabilitation exercise, the wheelchair with simulated rehabilitation function has two legs and walking and running, cycling motion simulation, make the user can also do leg training in a wheelchair.

4.5. Verification of path logging and monitoring
Due to the difference between each motor and the wheel itself, the four wheels each set a set of PID parameters, adjust the size of the parameters so that the wheelchair can walk straight forward on the flat and start and stop smoothly. In the actual environment for testing, the PC terminal open ROS visualization tool rviz to view the laser point cloud information and movement status. Remote control wheelchair for moving and mapping and other operations. You can see the wheelchair's current location and the solid red line between the green starting point and the red ending point in figure 15 which is the wheelchair movement track.

![Figure12 the actual scene](image2.png) ![Figure13 grid map](image3.png)
4.6. Design and validation of other auxiliary functions
In the overall design of the wheelchair, we have added some features that are convenient for the user and caregiver.

1) In view of the common inclined escalator in the market, the wheelchair is easy to roll over or slide rapidly under the action of gravity during the operation of the escalator, so we add electromagnet to the chassis and push hands to the back of the wheelchair. When the user enters the inclined escalator, the electromagnet device can start the chassis through the switch, and the magnetic suction force of the escalator is used to stabilize the overall wheelchair, which greatly guarantees the overall safety performance and autonomy of the wheelchair. With this safety measure, the user can take the escalator autonomously.

2) Because the elderly use less intelligent tools, and most of them rarely use electronic products in their daily life, the intelligent wheelchair is added in the design of the temperature sensing module, which can measure the real-time temperature, convenient to the old dress selection and collocation. Besides, we use Bluetooth module to design the one-button call function and automatic positioning function. When the elderly has an accident or needs help, press the one-button call button, and the signal will be fed back by the Bluetooth module connected to Arduino. Through the transmission of the communication module, the carer's phone will be automatically dialed to prevent accidents.

3) In daily life, users always need to carry a lot of small parts and items, which are often easily dropped to the side and can not be picked up for themselves. However, in the traditional wheelchair, the inconvenience of storage and picking up of items is rarely taken into consideration. To solve these problems, we use embedded armrest device, and the armrest is provided with a storage structure, convenient for users to adjust the position of the armrest and can put medicine, remote control, reading glasses and other daily necessities.

5. Conclusion
This wheelchair meets the needs of users in terms of structure and control, after the prototype test, it completes the function of the expected, it is suitable for the occasions where more nurses are needed and the number of users with the difficulty in walking is huge. It alleviates the strain on the caregiver workforce. In addition, it can serve users independently, greatly meet the needs of users, and has the prospect of large-scale listing and promotion of use.

References
[1] Wan H, Daniel GK, and Paul K. (2016). An Aging World:2015. International Population Reports Publishing, New York.
[2] W.H.O, the World Bank. (2011). World Disability Report 1(Summary). Chinese Journal of Rehabilitation Theory and Practice, 2011(017)006.
[3] DU G. Research Status of Lifting Mechanism of Lifting Platform. Mechanical Engineering & Automation,2013,(2).205-207.
[4] Lian M, Yang HB, Yang B, Lan F. The invention discloses a shock absorber for a Mecanum wheel[P], Chinese patent:207388777 2017.11.13.
[5] Wang LR, Huang T. (2020) Design of laser SLAM intelligent robot for indoor map building, positioning and navigation based on ROS. Wireless Internet Technology, 17:64-66,75.