Design and 3D Modeling of an Assistive Robot[1]

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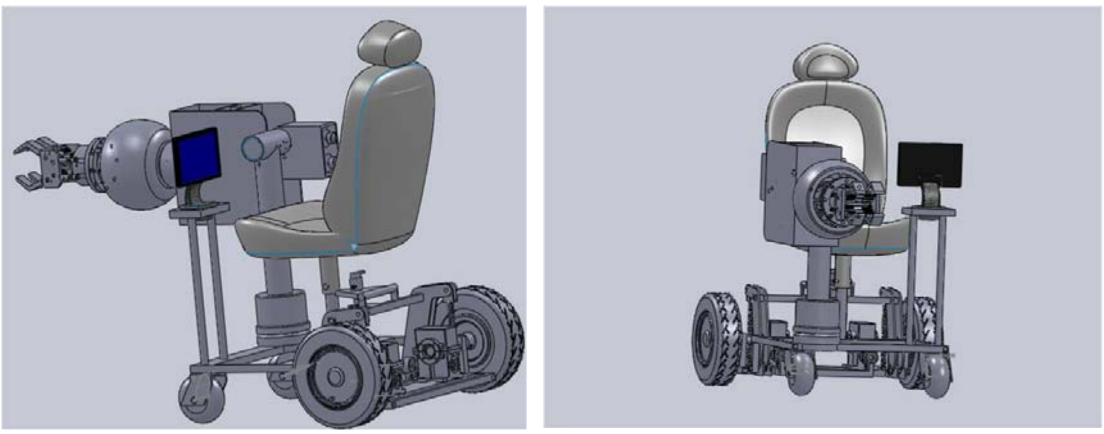
Abstract

Given the principal parameters of velocity, rated load and minimum turning circle, a wheelchair-based robot was designed for helping the old or the disabled. And two major modules, the driving system and a rotary-joint manipulator with 6 degrees of freedom (DOFs), were included in this robot. Finally, the robot with all of the parts was simulated via SolidWorks.

Keywords: Robot, Manipulator, Simulation, SolidWorks

1. Introduction

In this project, a wheelchair-based robot (shown in Fig. 1) with a 6-DOF manipulator was designed for assisting the aged or the disabled to travel at home or in public places, and to lift objects which are available for the manipulator (e.g. cups and apples).



(a) (b)

Fig. 1 3D Model of the Robot System under 2 Different Perspectives

First, the structure of the robot system as a whole and the corresponding major modules were designed, based on the requirements of the parameters of velocity, rated load and minimum turning circle. The robot system consisted of the driving module, the manipulator, and a wheelchair. All the modules could be easily assembled together and disassembled form the system. Finally, I simulated its 3D model via SolidWorks and the corresponding 2D CAD drawings were also generated and modified appropriately for manufacture in factory in the future.

2. Robot System General Structure

The robot system adopted 4-wheel structure, including 2 front initial wheels with

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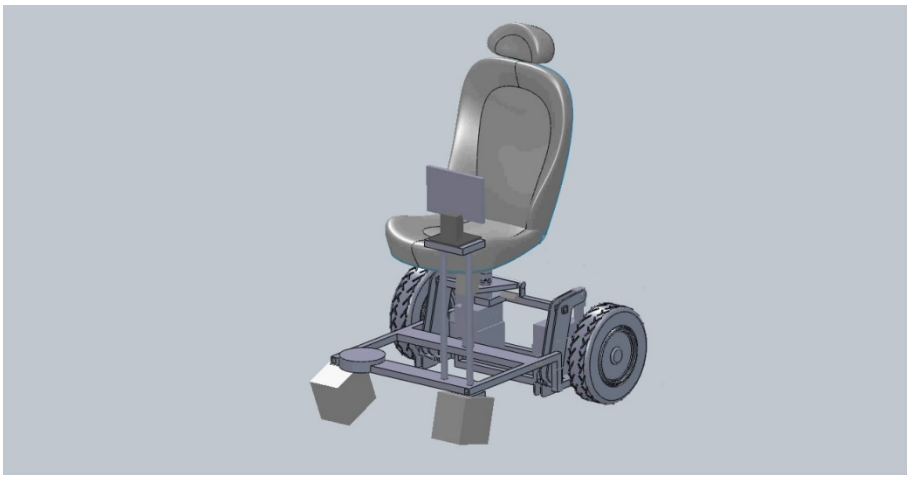
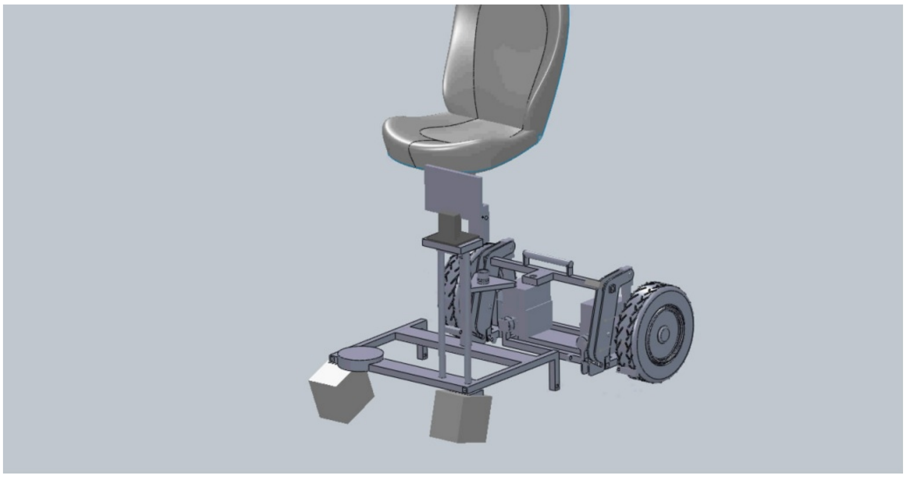
arbitrary direction turning, and 2 rear driving wheels actuated by 2 DC motors respectively. By controlling the angular velocities of the 2 driving wheels, the robot realized omnidirectional steering and thus could travel and turn in narrow space, like the bedroom and passageway.

In addition, the robot was convenient to carry, since all the modules (i.e., the wheelchair, the driving system, and the manipulator) could be easily assembled and disassembled (shown in Fig. 2). Moreover, the workspace of the manipulator is considerable due to its 6 revolute joints.



(a)



(b)

Fig. 2 (a) Assembly Drawing, and (b) Disassembly Drawing

3. Driving System Design

The robot was driven by the 2 rear driving wheels. In the driving system, the 2 rear wheels were actuated by 2 DC motors through 2 single-stage worm-gear reducers respectively. The schematic representation of the driving system and its 3D model are shown as follows.

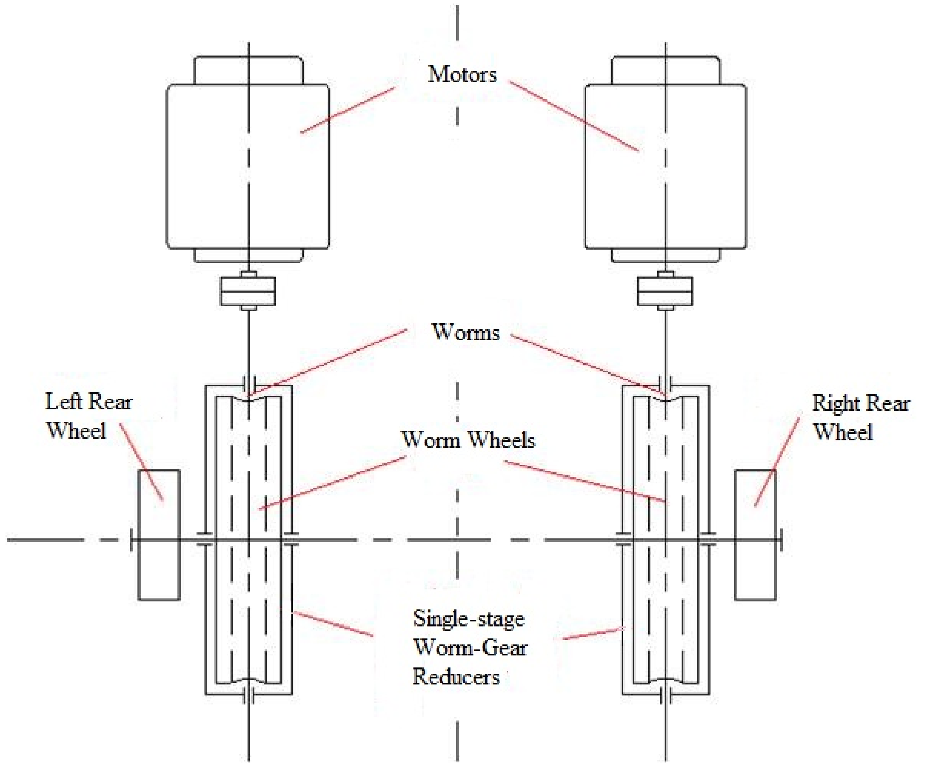


Fig. 3 Schematic Representation of the Driving System

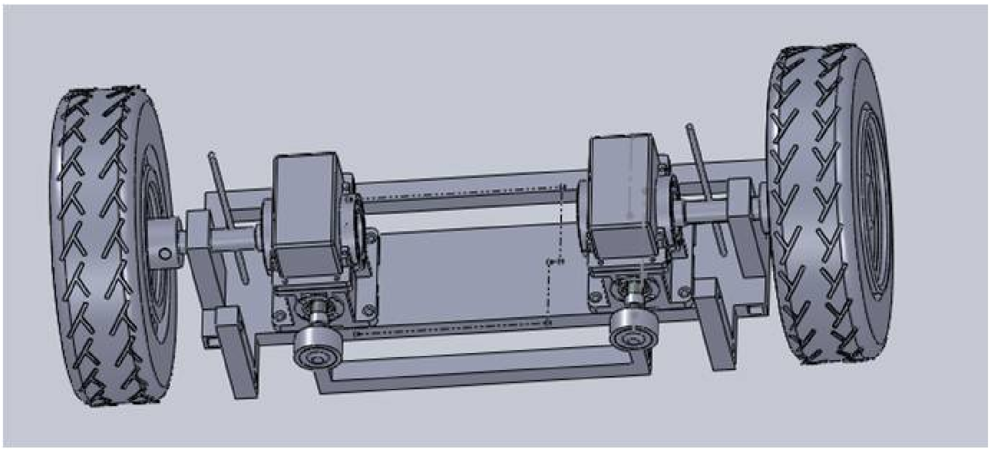


Fig. 4 3D Model of the Driving System

3.1 Motor Selection

Based on the design requirements, the minimum power of the motor could be calculated by Formula 1.

$$\begin{aligned} P_e &= \frac{1}{2} \times \frac{1}{\eta_T} \left(\frac{G f u_{a\max}}{3600} + \frac{C_D A u_{a\max}^3}{76140} \right) \\ &= \frac{1}{0.8} \times \left(\frac{2450 \times 0.02 \times 6}{3600} + \frac{0.8 \times 0.9 \times 6^3}{76140} \right) \\ &= 52W \end{aligned} \quad (1)$$

Wherein:

P_e: Minimum power for each of the two motors.

G: Gravity of the robot.

f: Rolling resistance coefficient of the floor, often $f = 0.02$.

$u_{a\max}$: Maximum velocity of the robot.

C_D: Coefficient of air resistance.

A: Windward area.

η_T: Mechanical efficiency of the gearing

Based on the calculation, the motor of ZXQD-0.25 was adopted, with the rated power of 250 W.

3.2 Major Parameters

3.2.1 Maximum Gradeability

After a lengthy calculation the maximum gradeability of the robot can be gained i.e., 10.3°, which can be briefly shown in Formula 2.

$$\begin{aligned}
&F_{t\max} = F_{\psi} \\
&\Rightarrow 480N = 2450 \times (0.02\cos\alpha + \sin\alpha) \\
&\Rightarrow \alpha = \arcsin\frac{9.8}{\sqrt{50^2+1}} - \arcsin\frac{1}{\sqrt{50^2+1}} \\
&\Rightarrow \alpha = 11.3° - 1.1° = 10.3°
\end{aligned} \tag{2}$$

Wherein:

$F_{t\max}$: Joint Driving forces applied to 2 rear wheels actuated by 2 motors

F_{ψ}: Joint resistance applied to 2 rear wheels caused by roads or floors

α: Degrees of slope

Other Parameters are the same as those in Formula 1.

3.2.2 Acceleration Time

Acceleration time describing the process of the velocity increasing from 0 to 6 km/h, can be briefly calculated here.

$$\frac{du_a}{dt} = a = \frac{F_X}{m} = \frac{T_t/r - Gf}{m} = \frac{3318.33\pi\frac{P_e\eta_T}{u_a} - Gf}{m} \tag{3}$$
$$\Rightarrow t = 2.91s$$

Wherein,

t : Acceleration time with the velocity increasing from 0 to 6 km/h.

u_a : Velocity of the robot.

a : Acceleration of the robot.

F_X : Joint forces applied to the robot.

T_t : Joint torque applied to two rear wheels.

r : Radius for each of two rear wheels

m : Mass of the robot

Other Parameters are the same as those in Formula 1 and Formula 2.

3.2.3 Minimum Turning Radius

The minimum turning radius (shown in Fig. 5) of the robot can be roughly obtained as below.

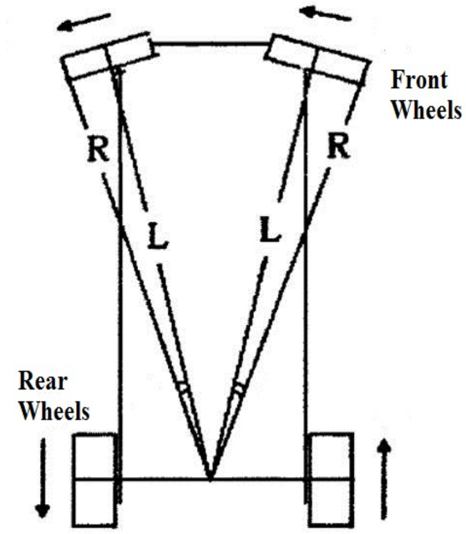


Fig. 5 Schematic Drawing of the Robot Turning Radius

$$R_{\min} = \sqrt{r_f^2 + L^2} = 737.5mm \tag{4}$$

Wherein,

$R_{\min}$: Minimum turning radius.

r_f : Radius for each of two front wheels

3.3 Single-stage Worm-Gear Reducers

The detailed design and calculation of the parameters involved in worm and worm wheel gearing is not shown here. Here I only present its 3D model, shown in Fig. 6 and Fig.7.

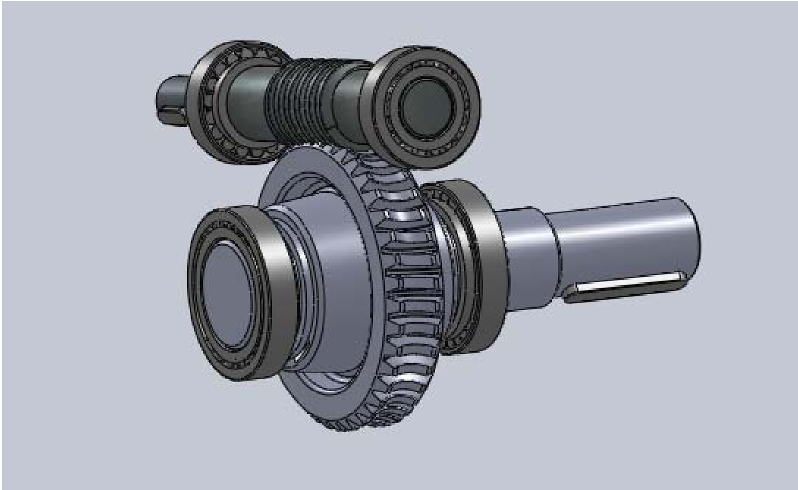


Fig. 6 Worm and Worm Wheel in Mesh

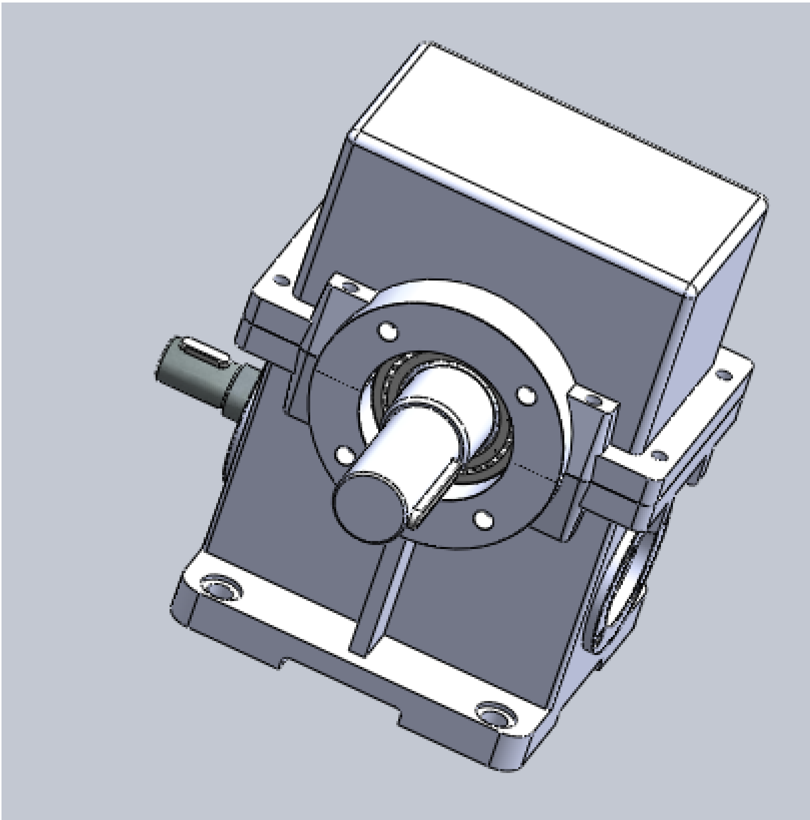


Fig. 7 Single-stage Worm-Gear Reducer

4. Six-DOF Manipulator

Referring to the mechanical structure and kinematic configuration of the famous PUMA 560 robot, I designed a 6-DOF manipulator, and simulated it via SolidWorks.

4.1 Whole Structure of the Manipulator

There were six joints in the waist, shoulder, arm, elbow, and wrist respectively. The end-effector of the robot arm can reach a point within its workspace from any direction. In particular, three joint axes intersected at some point in the wrist.

The whole structure of the manipulator is shown in Fig. 8.

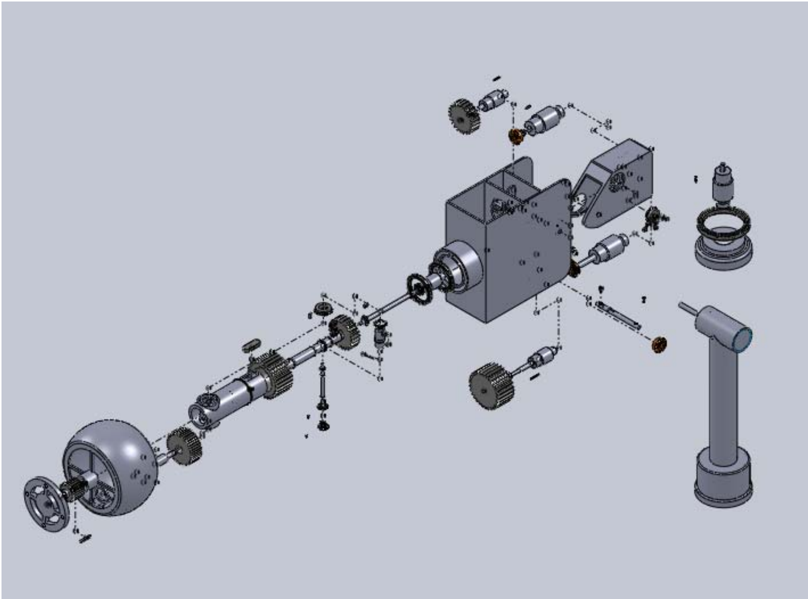


Fig. 8 An Exploded View of the Manipulator

4.2 Transmission Routs for the 6 Joints

Those joints were actuated by 6 DC motors, via 6 harmonic gear reducers, some spur gears and bevel gears. And the schematic diagram of the transmission routs for 6 joints is shown in Fig. 9 and Table 1.

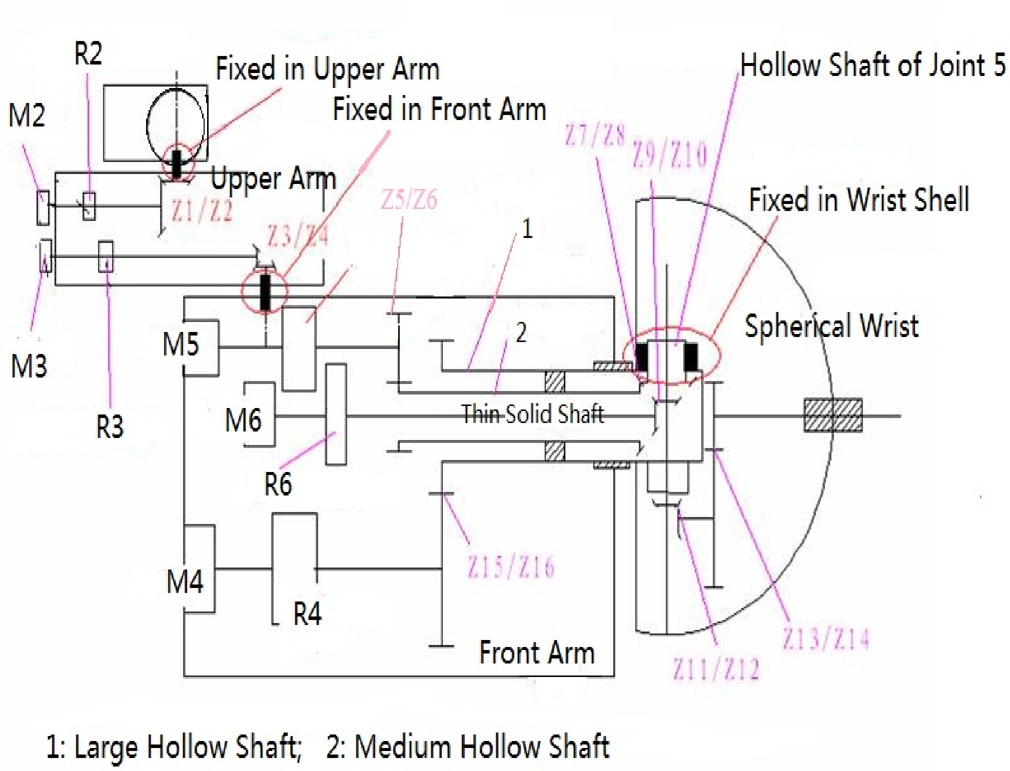


Fig. 9 Schematic Drawing of 6 Joints

Joint Number	Transmission Routs ("→" shows the direction of torque transmission.)
1 (Waist)	Motor 1 → Reducer 1 → Joint 1
2(Shoulder)	Motor 2 → Reducer 2 → Bevel Gears Z1/Z2 → Joint 2
3(Upper Arm)	Motor 3 → Reducer 3 → Bevel Gears Z3/Z4 → Joint 3
4 (Wrist)	Motor 4 → Reducer 4 → Spur Gears Z15/Z16 → Large Hollow Shaft → Joint 4
5 (Wrist)	Motor 5 → Reducer 5 → Spur Gears Z5/Z6 →Medium Hollow Shaft → Bevel Gears Z7/Z8 → Joint 5
6 (Wrist)	Motor 6 → Reducer 6 → Thin Solid Shaft → Bevel Gears Z9/Z10 → Bevel Gears Z11/Z12 →Spur Gears Z13/Z14 →Joint 6

Table 1 Transmission Routs of 6 Joints

4.2 Spherical Wrist Configuration

The spherical wrist configuration is shown in Fig. 10, in which the joint axes z3, z4, z5 intersect at some point o. As a key mechanism of the manipulator, it adopted a three-shaft nesting structure (shown in Fig. 11), i.e., the three shafts - a thin solid shaft, a medium-sized hollow shaft, and a large hollow one in the inside-to-outside order - were aligned in the same axial direction.

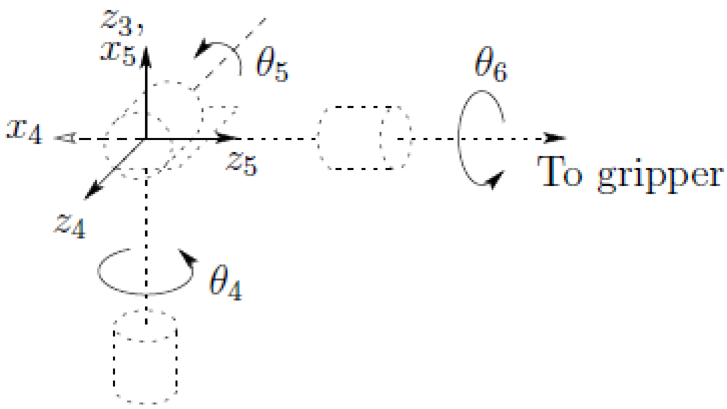
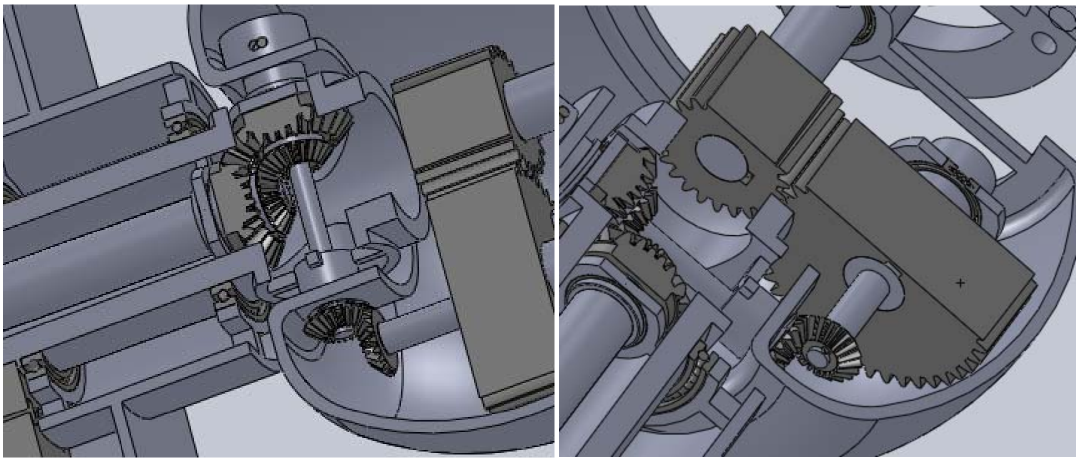


Fig. 10 The Configuration of the Spherical Wrist



(a) (b)

Fig. 11 The Configuration of the Three-shaft Nesting Structure

5. Future Improvements

Some dimensions of the manipulator need improvements to achieve optimal structure not only in shape but also in strength. Moreover, the research of robot control would be followed after the design of the robot, including path planning and navigation.

6. Conclusion

A wheelchair-based robot with a 6-DOF manipulator was designed for the aged or the disabled. And its major modules are discussed in detail. The principal parameters were calculated.

Through this project, I mastered the general design methods and research methods for industrial machinery and engineering machinery, and gained the ability to analyze and solve practical engineering problems.

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