Library Assisting Robot

Xuehui Shen, Yang Gao, Xinsheng Gu, Shibo Zhao
School of Engineering and Applied Science
Columbia University in the City of New York
New York, USA
Emails: xs2419@columbia.edu, yg2764@columbia.edu, xg2381@columbia.edu, sz2946@columbia.edu

***Abstract*—This paper proposes to design a wheelchair attachable robotic arm to assist disabled people with grasping books away from their reachable area in the library. The robot has an RPPP structure, which could be controlled by using the embedded computer in the wheelchair. This lightweight manipulator is designed to extend the reachability for people on wheelchairs, and is also detachable, portable and user friendly, which increases the independence of disabled people.**

***Index Terms*—library assisting, RPPP, robotic arm, grasping, wheelchair attachable**

I. Introduction

As humanization has been increasingly propagated in society, supporting services are provided in many public places to assist disabled people. However, asking for help on trivial matters, such as picking up a book from the bookshelf could also bother the disabled. Moreover, disabled people are deprived of solitude hours in public places such as grocery shopping and strolling in the library, which are the most common routine to normal people. To solve this problem, a detachable RPPP robotic arm is designed to be equipped on the wheelchair to help them get the objects in unreachable areas without asking for any help. In this report, an analysis on the mechanical system and dynamic simulation are performed.

A. Prior Works

These kinds of robotic systems supporting disabled people to work with books have been evolving with time. The first one named RAID can pick up books from shelves and carry documents [1]. Its manipulator movement is totally controlled by the user. A more advanced one, CAMP, can locate a specified book with a bar code reader and a library map [2]. A similar system is able to identify books with the OCR system. Another robot called FRIEND [3], supports the user to catalog collections of books with an integrated system.

B. Motivation and Novelty

The main motivation for this design is to let disabled people enjoy the freedom of independence and self-caring as normal people. Users can easily manipulate the robot from the computer embedded in their wheelchair to get the book they need.

II. Robot Mechanical System Design

A. 3D Structure of the Robot

The robot is attached on the left side of the wheelchair, and a computer will be implemented on the other side. Fig.1. shows the overall design of the robot attached to a wheelchair. A camera equipped on the top of z-axis can map the books to the screen, and the robot will plan the path and move automatically to the location of the selected book. The end-effector is made of silicon to prevent the damage of the book.

Based on the research, the average height of the library bookshelves is about 2m, and the average height of the wheelchair from floor to the arm is about 80 cm. Thus, the linear rail in z-direction is designed to be 100 cm to meet the height of the book on the top level of the bookshelf. The robot rests on the arm and is mounted at the bottom of the seat to ensure stability. The material is selected to be stainless steel alloy, and the inner geometry of the rail satisfies the lightweight demand.

Fig. 1: 3D Structure of the Robot on Wheelchair.

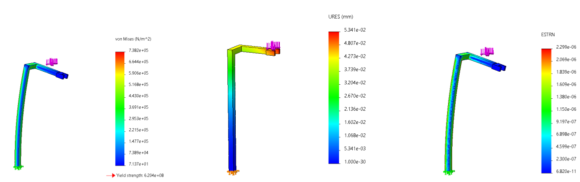
B. RPPP Mechanism

The robot is designed with an RPPP structure, which consists of a rotary base, a linear rails in z direction and y direction, a linear actuator extending in x direction, and an end-effector with parallel clamps. The robot can rotate 90 degrees to the direction facing the bookshelf and travel 100 cm in z direction to reach the height of the book. A 12 cm travel distance in y-direction allows the robot to slightly adjust the end-effector position to meet the book location, and 25cm travel in x axis is designed to grasp the book on the bookshelf. Figure 2 shows the structure of the RPPP manipulator.

Fig. 2: RPPP Mechanism.

C. Force Analysis

A force analysis is performed on the robot by applying the general weight of the book – 1.5kg to the end-effector. Fig.3 shows the stress, displacement and the strain distribution respectively. It's indicated from the figure that the maximum displacement of the robot while holding a book in its extreme position is about 5.341e-2mm.



(a) Stress. (b) Displacement. (c) Strain.

Fig. 3: Force Analysis.

D. Forward Kinematics

As it is shown in Fig.4, this robotic arm is an RPPP manipulator, which consists of four links and four joints with an end effector. The Denavit-Hartenberg parameters are shown in Table.1.

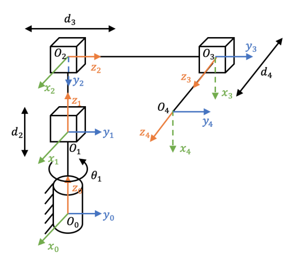


Fig. 4: RPPP Manipulator Frame Assignment.

TABLE I: DH Parameters for the RPPP Manipulator

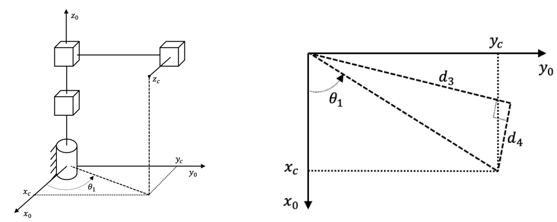
Link	a_i	α_i	d_i	θ_i
1	0	0	d_1	θ_1^*
2	0	$-\frac{\pi}{2}$	d_2^*	0
3	0	$\frac{\pi}{2}$	d_3^*	$\frac{\pi}{2}$
4	0	0	d_4^*	0

In this convention, each homogeneous transformation matrices can be computed. Then, the final transformation matrix can be obtained by multiplying the homogeneous transformation matrices:

$$T = \begin{bmatrix} 0 & \text{-s}_1 & \text{c}_1 & \text{d}_4 c_1 - d_3 s_1 \\ 0 & \text{c}_1 & \text{s}_1 & \text{d}_3 c_1 + d_4 s_1 \\ \text{-1} & 0 & 0 & \text{d}_1 + d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

E. Inverse Kinematics

For the inverse kinematics problem, we tried a geometric approach to find the solution. Fig.5.A below shows the RPPP manipulator with the components of wrist center o_c denoted by x_c, y_c, z_c . Then, we project o_c onto $x_0 - y_0$ plane as shown in Fig.5.B.



(a) General Config. (b) Projection on $x_0 - y_0$ Plane.

Fig. 5: Inverse Kinematics of RPPP Robot.

By means of geometry, we can solve the variables as below,

$$\begin{cases} \text{d}_1 + d_2 = z_c \\ \text{d}_3^2 + d_4^2 = x_c^2 + y_c^2 \\ \theta_1 = \arccos\left(\frac{d_3}{\sqrt{x_c^2 + y_c^2}}\right) + Atan(x_c, y_c) \end{cases}$$

In this structure of RPPP, the degree of freedom is redundant. For the set of equations shown above, there are three equations while we have four variables. Therefore, we can obtain infinite numbers of solutions.

III. Dynamic Simulation

This section will verify the accuracy of the solutions from the library assisting robot below. The Robotic Vision and Control MATLAB package is used for analysing forward kinematics, inverse kinematics, singularity and workspace.

A. Simulation Using Toolbox

Initial parameters of the robot at rest are as follows: θ_1=0; θ_2= -90°; θ_3=0; θ_4=0; L2=100; L3=12; L4=25. In Fig.6, it represents the position of the robot at rest and the working condition while the user interacts with it.

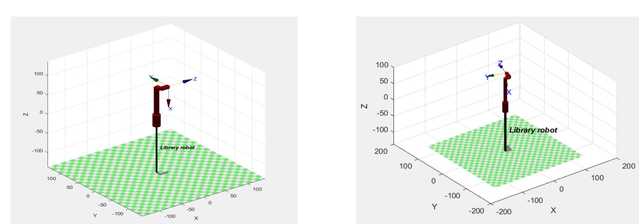


Fig. 6: Position of the Robot.

B. Inverse Kinematics Algorithm

In section II.D above, there are infinite numbers of solutions for inverse kinematics. Due to the fact that MATLAB can only offer one solution at one given goal point, which is shown in Fig.7, we run out one solution as an example by using (0,0,0) as the initial point and (18.237,19.942,88.732) as the goal point.

```
val(:,:,50) =

    0.2840   -0.9588         0   18.2370
    0.9588    0.2840         0   19.9420
         0         0    1.0000   88.7320
         0         0         0    1.0000
```

Fig. 7: One Possible Solution for Inverse Kinematics.

C. Workspace

Since this is a 4 DOF robot, the robot can technically reach most points in 3D space and its workspace is technically bounded by the limitations of thetas and the arm length. It is not bounded by workspace constraints and is limited by physical constraints. The workspace in 3D space and XY plane is also shown in Fig.8.

The following limits were set. θ_1(0,180°), L2(0,100), L3(0,12), L4(0,25).

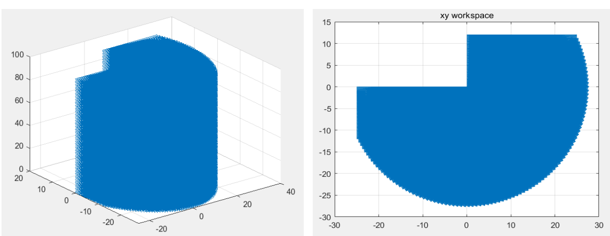


Fig. 8: Workspace in 3D Space and XY Plane.

D. Position, Velocity and Acceleration

The total time step is 50. For a given goal position, (18.237, 19.942, 88.732), the position, velocity and acceleration plots of the robot end-effector are shown in Fig.9.

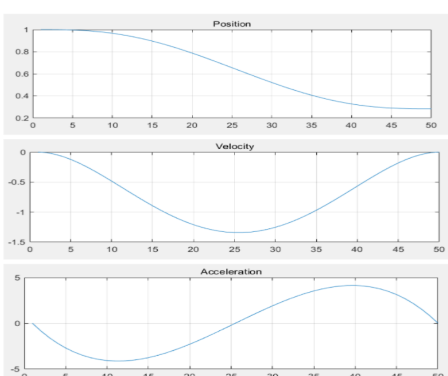


Fig. 9: Position,Velocity and Acceleration.

IV. Discussion

During real-word implementation, the user could select the book he/she likes through the screen linking to the camera attached on the z-axis. After getting the position of the book, the end-effector could track the trajectory calculated by the system to obtain the book and give it to the user automatically. There are two main aspects to discuss for this application, safety and functionality.

From the results of force analysis, the maximum displacement of the robot while holding a book is trivial. Therefore, this mechanism design is able to hold the book safely during task implementation. Besides, unlike the usual sophisticated and bulky arm design shown in prior research, this mechanical arm is lightweight and easy for users to manipulate through a screen.

Furthermore, from the results of simulation analysis, the workspace of the arm is sufficient to cover the bookshelves besides the wheelchair and able to obtain the book selected by the user automatically through trajectory planning.

But there are still some limitations that this RPPP mechanism design may face. For example, it is hard to obtain a tilted book and can only obtain the book on one side of the wheelchair, which will limit its usage to some extent.

V. Conclusion

Overall, through the 3D modeling, simulation and analysis, this RPPP mechanism is feasible to attach and take off from the wheelchair, and capable of extending the reachability of the disabled person to help them move and catch the object they click on the screen.

In the future, an extra rotation degree of freedom would be added at the end-effector to enable the robot to catch objects from different angles, and the location of the arm should also be adjusted to enable the robot to obtain objects on both sides of the wheelchair. And with different end-effectors design, this robot arm could be able to obtain objects with different shapes and be used in other scenarios such as grocery stores.

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