Design on Wrist and Gripper of manipulator Based on Kinematics Analysis

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Abstract. Joint-manipulator installed on the intelligent wheelchair robot decides the whole system capability. The kinematics analysis and structure design about mechanical wrist and gripper for joint-manipulator are discussed in this paper. Based on the D-H coordinate method, the kinematic equation of joint-manipulator is determined firstly, and its correctness is verified by doing the MATLAB simulation experiment. Then, according to the experimental results, the BR wrist of the manipulator is chosen and the gripper which can clamp both cylindrical and box objects is designed. In addition, the corresponding analysis is made by ANSYS software.

Introduction

With the development of technology, more analysis has been made on the joint-manipulator[1-3] by the application of the quantitative analysis tools[4]. Nowadays, micro-manipulation technology, as one of branch of micro electrical and mechanical systems (MEMS), is an important key issue. Parallel micro-manipulators use flexible joints which avoid gap and friction between pairs that general joints possess. In 1960s, Ellis[5] was the first one who introduced parallel mechanisms into micro-manipulators. And they were used in the field of biology technique and microsurgery, etc. To improve the precision of micro-manipulators, Magnani[6] and Pernette[7] studied the R-joints, P-joints, U-joints and S-joints in style of flexible structure. Here, R, P, U and S indicate revolute, prismatic, universal and spherical, respectively. After that, many parallel micro-manipulators come forth continuously. Pernette[8] developed parallel robots in micro-robotics which could be used in locating on fiber negative. Hudgens and Tesar[9] presented a fully-parallel six degree-of-freedom (DOF) micro-manipulator with flexible joints which could be used in error compensation and force control. Lee[15] studied a micro-manipulator with 3-DOF parallel mechanism. In China, many researches[11-14] on parallel micro-manipulators had been performed.

Wheelchair robot is an important kind of Service Robots, widely used to assist old people and disabled people to do daily activity, such as opening the door and pouring water. Therefore enhancing static-dynamic performance of the joint-manipulator is essential to be apply to maintenance, repair transportation, cleaning, security, assistance, guardianship, and so on. Based on modeling and kinematics analysis, the mechanical structure of joint-manipulator[16]which installed on multifunctional disabled wheelchair is designed in this paper.

Kinematics Analysis of the Joint-manipulator

Kinematics Model Based on D-H Method. The common joint-manipulator consists of a series of joints connecting rod. The kinetic process of manipulator is researched by using the D-H method in this paper. In D-H method, a coordinate system is fixed at the end of each bar joints, and the position and orientation relationship among various coordinate systems and base calibration are determined by using homogeneous transformation matrix. At last, we use MATLAB software to complete the simulation test, so the model is verified.

The relationship between the connecting rods can be described by four parameters, i.e. connecting rod length a_n, twist angle α_n of connecting rod, link distance d_n and coupler angle θ_n.

For the position and posture of manipulator on multifunctional disabled wheelchair, the pose matrix is often used to analyze the changes of manipulator. And the pose matrix of two stroke depends on the structure parameters, movement form and motion parameters of the connecting rod and the geometric model established by different order of these parameters. According to the rules that establish the coordinate system based on D-H method, and on the basis of analyzing the 3D model, the D-H coordinate system for multifunctional disabled wheelchair robot is established, as shown in Fig. 1.

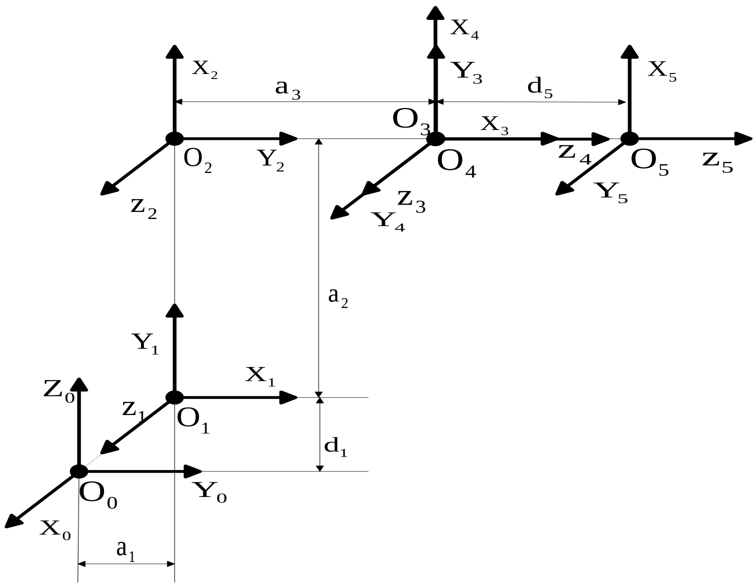

Fig. 1 D-H rod model of Joint-manipulator

According to the structure of the joint-manipulator, the D-H parameters are determined and listed in Table 1.

Table 1 Manipulator link parameters

rod	θ_n	$d_n(mm)$	$a_n(mm)$	$\alpha_n(^\circ)$
1	θ_1	$d_1 = 20$	$a_1 = 20$	90
2	θ_2	0	$a_2 = 133$	0
3	θ_3	0	$a_3 = 116$	0
4	θ_4	0	0	90
5	θ_5	$d_5 = 82$	0	0

Establish the Kinematic Equation. For the manipulator installed on multifunctional disabled wheelchair, the connecting rod parameters can be used to calculate the transformation matrix A_n ($n = 1, 2, \ldots, 5$) of each connecting rod and the total pose matrix T_5 which is the coordinate of the end connecting rod relative to the base coordinate system, as follows:

$$A_1 = \begin{bmatrix} \cos\theta_1 & 0 & \sin\theta_1 & a_1\cos\theta_1 \\ \sin\theta_1 & 0 & -\cos\theta_1 & a_1\sin\theta_1 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix},\ A_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i & 0 & a_i\sin\theta_i \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} (i = 2, 3, 4),$$

$$A_5 = \begin{bmatrix} \cos\theta_5 & 0 & \sin\theta_5 & 0 \\ \sin\theta_5 & 0 & -\cos\theta_5 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix},\ T_5 = \prod_{j=1}^{5} A_j = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{1}$$

Where the pose matrix T_5 is the function of joint variable θ_n ($n = 1, 2, \cdots, 5$). In T_5, the vector *n*, *o*, *a* are the direction vectors in the base coordinate system corresponding to the end connecting rod coordinate (*x*, *y*, *z*) and the vector *p* is the position vector in the base coordinate system corresponding to the end connecting rod coordinate origin, respectively.

Let $c_i = \cos\theta_i$, $s_i = \sin\theta_i$ ($i = 1, 2, \cdots, 5$), the detailed calculation is as follows:

$$
\begin{aligned}
n_x &= s_1 s_5 + c_5(c_4(c_1c_2c_3 - c_1s_2s_3) - s_4(c_1c_2s_3 + c_1c_3s_2)),\\
n_y &= c_5(c_4(c_2c_3s_1 - s_1s_2s_3) - s_4(c_2s_1s_3 + c_3s_1s_2)) - c_1s_5,\\
n_z &= c_5(c_4(c_2s_3 + c_3s_2) + s_4(c_2c_3 - s_2s_3)),\\
o_x &= c_5s_1 - s_5(c_4(c_1c_2c_3 - c_1s_2s_3) - s_4(c_1c_2s_3 + c_1c_3s_2)),\\
o_y &= -c_1c_5 - s_5(c_4(c_2c_3s_1 - s_1s_2s_3) - s_4(c_2s_1s_3 + c_3s_1s_2)),\\
o_z &= -s_5(c_4(c_2s_3 + c_3s_2) + s_4(c_2c_3 - s_2s_3)),\\
a_x &= -c_4(c_1c_2s_3 + c_1c_3s_2) - s_4(c_1c_2c_3 - c_1s_2s_3),\\
a_y &= -c_4(c_2s_1s_3 + c_3s_1s_2) - s_4(c_2c_3s_1 - s_1s_2s_3),\\
a_z &= c_4(c_2c_3 - s_2s_3) - s_4(c_2s_3 + c_3s_2),\\
p_x &= a_1c_1 - d_5(c_4(c_1c_2s_3 + c_1c_3s_2) + s_4(c_1c_2c_3 - c_1s_2s_3)) + a_2c_1c_2 - a_3c_1s_2s_3 + a_3c_1c_2c_3,\\
p_y &= a_1s_1 - d_5(c_4(c_2s_1s_3 + c_3s_1s_2) + s_4(c_2c_3s_1 - s_1s_2s_3)) + a_2c_2s_1 - a_3s_1s_2s_3 + a_3c_2c_3s_1,\\
p_z &= d_1 + a_2s_2 + d_5(c_4(c_2c_3 - s_2s_3) - s_4(c_2s_3 + c_3s_2)) + a_3c_2s_3 + a_3c_3s_2.
\end{aligned} \tag{2}
$$

Analyzing the kinematics of the joint-manipulator in this paper, it is observed that only θ_n is variable, so the position and posture of manipulator can be determined while the angles θ_n are given.

MATLAB Simulation

In order to examine the accuracy of the kinematic equation established in this paper, we select five special angles to calculate the position. From Table 1 and Eq. 2, the positional parameters can be obtained. The calculation result is shown as Table 2.

Table 2 Manipulator joint variables and positional parameters

No.	θ_1(°)	θ_2(°)	θ_3(°)	θ_4(°)	θ_5(°)	p_x	p_y	p_z
1	0	90	-90	-90	0	218	0	153
2	90	90	-90	-90	0	0	218	153
3	0	90	-90	0	0	136	0	235
4	90	90	0	-90	0	20	0	351
5	0	90	-90	-90	90	218	0	153

Further more, with the software MATLAB, the result obtained by the equation can be verified by the simulation. When the five angles are $\theta_1 = 90^\circ$, $\theta_2 = 90^\circ$, $\theta_3 = -90^\circ$, $\theta_4 = -90^\circ$, $\theta_5 = 0^\circ$, the MATLAB simulation result of the 3D map for manipulator is shown in Fig. 2, where x, y and z is the coordinate of the hand position, respectively, and ax, ay and az express the hand posture.

In Fig. 2, we can get the 3D coordinate, that is $p_x = 0$, $p_y = 218$, $p_z = 153$, which is the same as the value obtained by the kinematic equation.

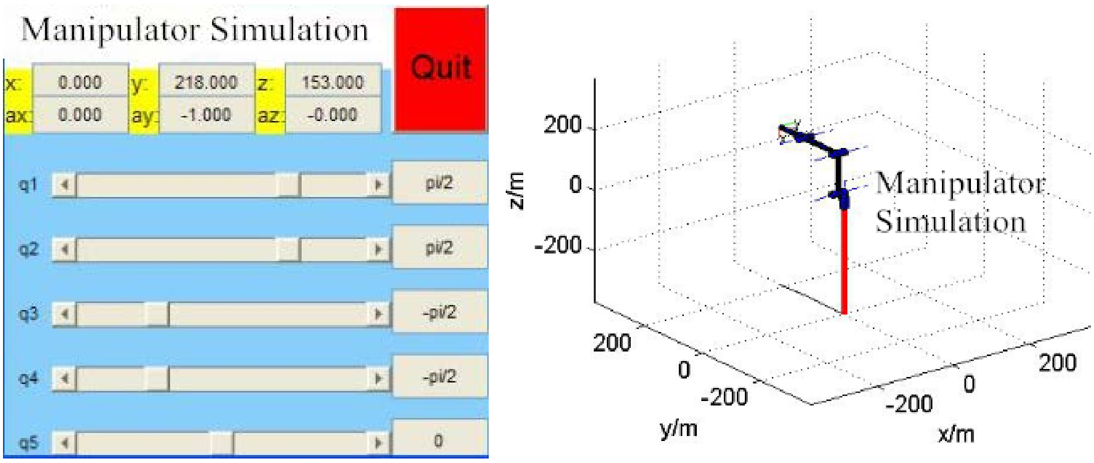

Fig. 2 The three-dimensional simulation map of manipulator

Mechanical Structure Design of Joint-manipulator

Mechanical Design and ANSYS Analysis of Wrist. The wrist of manipulator connect gripper and arm, support the hand and change its posture. To complete the arbitrary posture movement, at least three degrees-of-freedom is necessary. In this paper, considering the manipulator is installed on the multifunctional disabled wheelchair which assist to do some life demand, the posture is simple, so two degree-of-freedom is designed for wrist.

The common three kinds of wrist with two degree-of-freedom are BB, RR, BR, where B is a kind of bending joint and R is a rotary joint. The joint-manipulator in this paper uses the BR wrist, its structure is easy to realize, and its rod is short, the stiffness of the manipulator has increased. Fig. 3 shows the BR wrist with two degree-of-freedom.

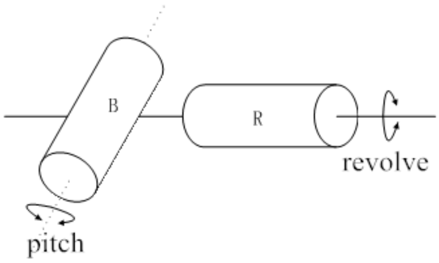

Fig. 3 BR wrist

Establish the three-dimensional model, and analyze the structure by ANSYS software, the result is shown in Fig.4.

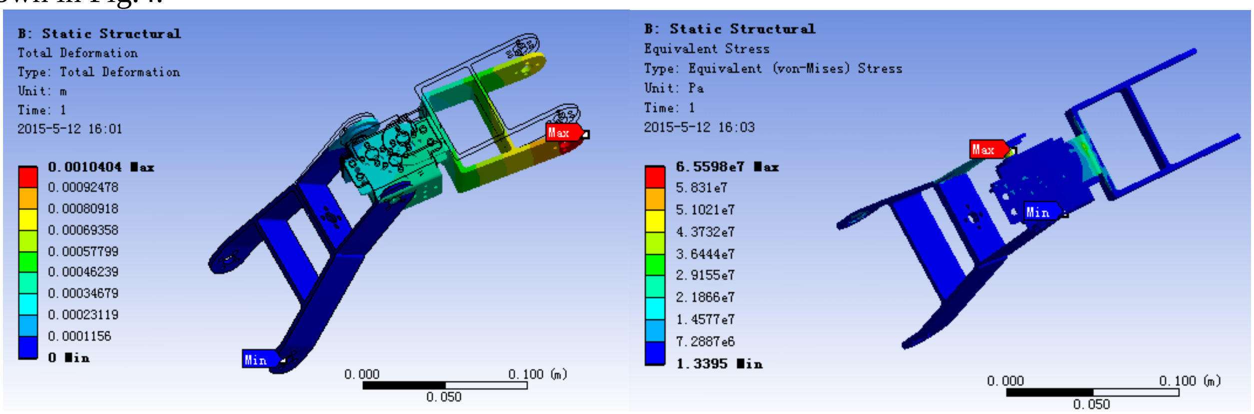

Fig. 4 ANSYS analysis of wrist

From Fig. 4, it can be found that the displacement deformation and the structural stress are reasonable.

Design and Static Analysis of Gripper. The gripper is installed on manipulator to catch objects directly. There are various types, such as clamp gripper, adsorption gripper, bionics fingers, and so on.

In this paper, the clamp gripper is designed. Taking into account that the gripper should not be too long and transferring the force should be uniform and its execution speed should be faster, four-bar linkage is used skillfully to realize the motor rotating 90 degrees, and the finger from fully open to fully close is achieved. Besides, the reaction of gripper is more quickly.

Because of its paralleled clamp, manipulator can not only clamp cylindrical objects, but also catch square objects, which expand the clamping range. The gripper model is shown as Fig. 5.

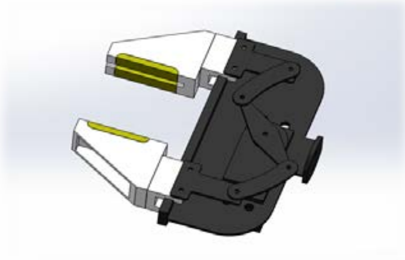

Fig. 5 Gripper physical model

The static analysis of the gripper is completed by the ANASYS software. Analysis result of the displacement deformation and stress map is shown in Fig. 6.

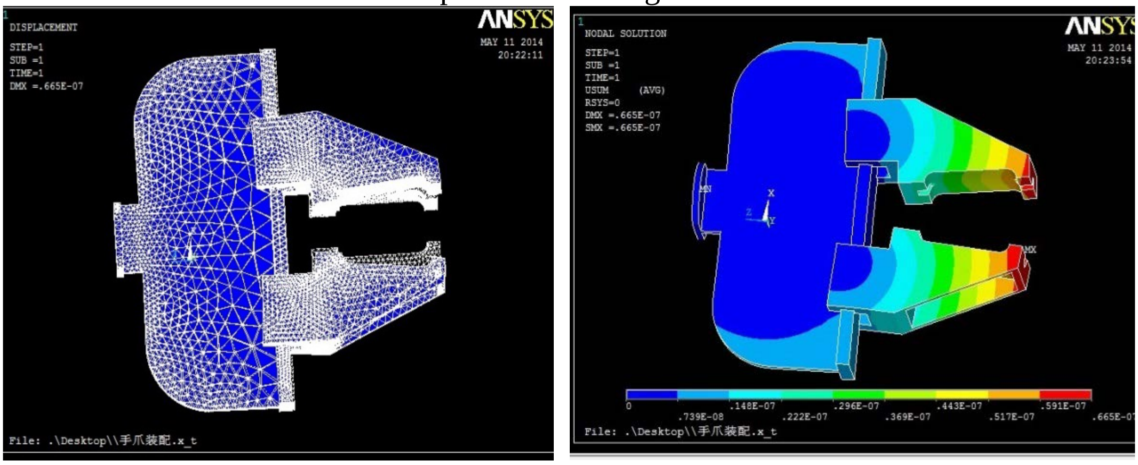

Fig. 6 The gripper simulation map

From Fig. 6, it can be found that the displacement distribution and the stress distribution are reasonable.

Conclusion

With the aid of MATLAB software simulation and ANAYS software analysis, the kinematic equation derived in this paper is proved to be right, and it gives an unified result which provides data and reference for the choice of wrist and the design of gripper. The BR type wrist is easy to install, and its reliability is good. The new-designed gripper can clamp cylindrical objects, in addition, it can also grab square objects, which expands the clamping range tremendously.

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