Design of flexible mechanism for flexible manipulator

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Abstract

Based on the study of the kinematic limitations of the rigid manipulator structure and the characteristics of the existing flexible manipulator in different categories, this paper proposes a structure assumption of flexible manipulator based on the advantages of high load of rigid joint and high flexibility of flexible manipulator. This paper designed a flexible manipulator structure driven by wires. Using the forward kinematics analysis, the sport model of the structure. The motion range of the end of the manipulator arm and the length changes of the wires were simulated with the movement of the model.

Keywords: Flexible manipulator, Wires driven, Kinematic model

1. Introduction

With the development of science and technology, rigid robot devices have been widely used in social production activities. It is well known that the industrial robot is applied in the manufacturing industry. The rigid manipulator consists of a rigid connecting rod connected by a rigid motion pair, which can quickly and accurately complete the corresponding control tasks [1]. However, due to the rigid structure of the manipulator, its flexibility is poor, and it cannot work properly in the complex and changeable environment. Its structural characteristics limit its application in dangerous and complex environments, such as exploration and disaster relief, nuclear power hazard management, space missions and other environments. If the manipulator is to be applied to the above engineering fields, it needs to meet the requirements of safe interaction between the machine and the environment, safe human-computer interaction, high flexibility and intelligence. The flexible manipulator is made of soft materials. Compared with the rigid robot, the manipulator has the characteristics of multiple redundant degrees of freedom, flexibility and safe human-computer interaction. Its characteristics greatly make up for the shortcomings of rigid robots, so it has been widely concerned and studied by scholars and institutions [2].

2. Classification of prior research

The development status of flexible manipulator is introduced according to the driving mode classification. The flexible manipulator is divided into the following driving modes: SMA driven, pneumatic - hydraulic driven, and wire driven, etc.

2.1. *SMA driven*

SMA, full of Shape Memory Alloys, can be heated to eliminate the deformation of alloys at a lower temperature, making it revert to the initial state and achieving the effect of "memory". It can be driven by direct heating of current, and its deformation can be controlled by heating and cooling. It has been widely used in aerospace and industrial intelligent manufacturing. As shown in the Fig.1, the manipulator can realize large spatial bending and complete the grasping action of different positions.

Fig.1 SMA flexible mechanical arm [3]

2.2. *Pneumatic-hydraulic driven*

Pneumatic or hydraulic driven respectively use compressed air and hydraulic oil as the power source of the mechanical arm bending. Pneumatic - hydraulic driven manipulator is usually made of elastic material as the main body, surrounded by a driving cavity. The bending of the manipulator can be realized by changing the volume deformation of the driving cavity by changing the input of the power source as showed in Fig.2. When the inner rubber air bag is filled with compressed air, the internal pressure rises, the inner rubber air bag expands along the radial direction, and then the force transmission effect of the outer fiber is transformed into the axial contraction force to achieve the driving effect.

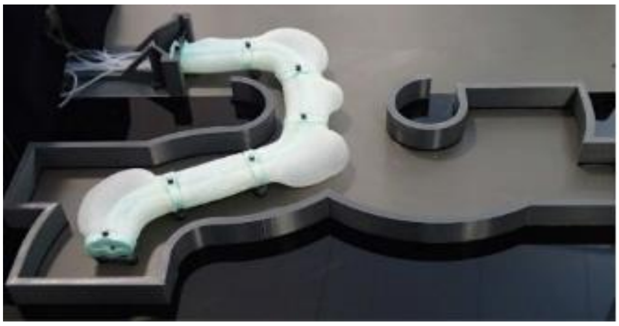


Fig.2 Pneumatic driven flexible manipulator [4]

2.3. *Wire driven*

Wire driven is a popular driving method for flexible manipulator. The bending motion of the flexible arm is generally realized by the stretching of the wire driven by the motor. The wire driven flexible manipulator is driven by the wires embedded in the interior of the flexible manipulator to realize the deformation movement of the flexible manipulator as showed in Fig.3. Usually, mechanical equipment such as motor is used to generate traction on the wire. The wire embedded in the flexible manipulator with eccentric eccentricity generates axial force on the manipulator while generating bending moment on the neutral surface, making the flexible bending motion of the manipulator.

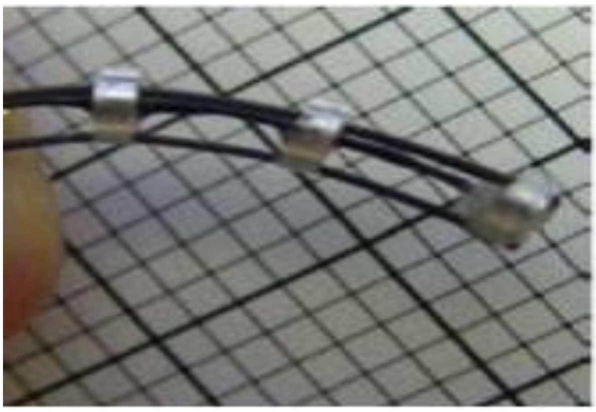
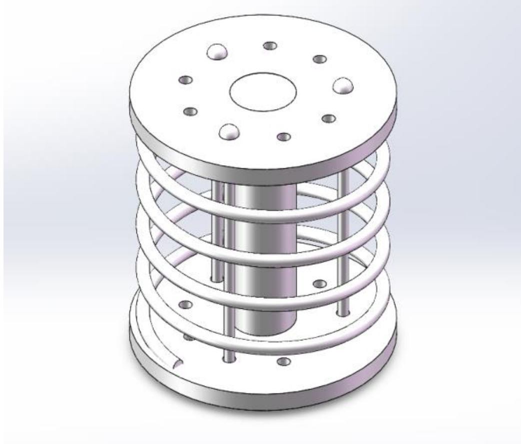


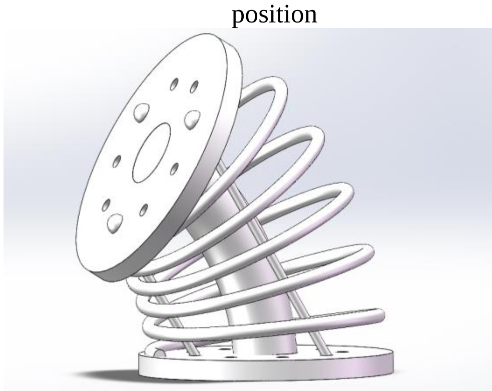
Fig.3 Wire driven flexible manipulator [5]

3. Model scheme

The flexible robot arm is composed of three layers of single-section robot arm, the height of the single-section robot arm is 200mm, and the height of the entire robot arm is 600mm. The central flexible column is a soft plastic material with good flexibility and bearing capacity. The hardness and elastic modulus of soft plastics can be controlled by additives to adapt to different application scenarios. The flexible column is used as the main body of the flexible manipulator. The flexible column is non-stretchable, incompressible and can be twisted arbitrarily. Bend the flexible column by tensing and relaxing the three driving wires to tilt the support plate. The outer part is covered with a spring to protect the flexible manipulator. The single-section mechanical arm is shown in Fig. 4. Integrated model scheme is showed in Fig.5.



a. A single segment robotic arm in an upright position



b. A single segment robotic arm in a bent position

Fig.4 Single segment robotic arm

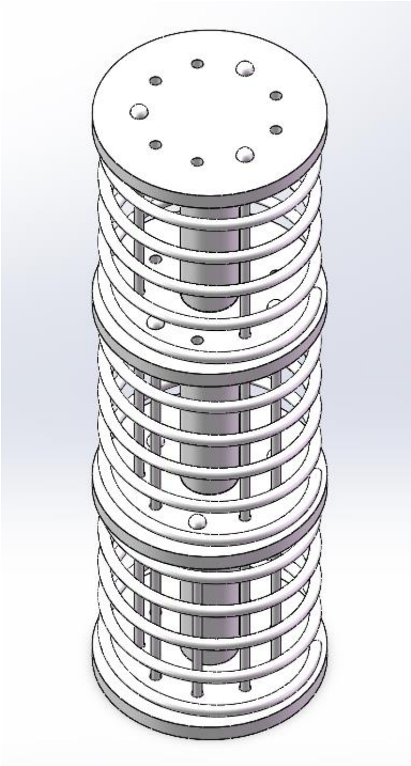


Fig. 5. Integrated model scheme

4. Kinematic analysis of model

The spatial mapping relationship of the robot arm is shown in Fig.6. This paper analyzes the kinematics model of the flexible manipulator through forward kinematics. The forward kinematics analysis of the manipulator arm is to calculate the end pose of the manipulator arm according to the information of the driving space.

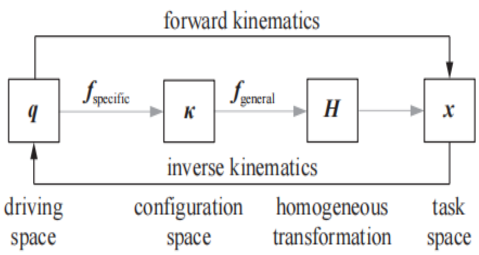


Fig.6 Spatial mapping of kinematic [6]

4.1. *The mapping relationship from driving space to configuration space*

According to the length variation of three wires, the bending angle θ and the rotating angle α and radius of curvature R of the mechanical arm are solved by geometric method. The solution method is to establish a set of equations by using bending angle θ, rotating angle α and curvature radius R to represent the corresponding arc length and chord length of the projection of the line from the anchor point of the lower support disk to the curvature radius of the single-section mechanical arm, so as to obtain the array of bending angle θ and rotation angle α and curvature radius R represented by the length of the driving wires .The mapping relationship from driving space to configure space is Eq.(1).

$$\begin{cases} \alpha = arctan\dfrac{\sqrt{3}(H_1 - H_2)}{H_1 + H_2 - H_3} \\ \theta = arcsin\dfrac{\sqrt[2]{H_1^2 + H_2^2 + H_3^2 - H_1H_2 - H_2H_3 - H_3H_1}}{6r} \\ R = \dfrac{(H_1 + H_2 - H_3)r}{2\sqrt{H_1^2 + H_2^2 + H_3^2 - H_1H_2 - H_2H_3 - H_3H_1}} \end{cases} \quad (1)$$

4.2. *The mapping relationship from configuration space to task space*

Solving the mapping relationship between configuration space and task space that is the homogeneous transformation matrix from local reference frame to global reference frame is solved. Matrix elements are composed of configuration variables α、θ and R. The solution is to use the D-H method, and the transformation relationship between the coordinate system from the lower support disk to the upper support disk is regarded as a series of sequential rotation and translation results.

D-H method (Denavit-Hartenberg method) is a matrix general method for establishing the relative position and attitude relationship of serial robots. It uses four parameters of connecting link length, joint angle, link offset and link twist to describe the structure and kinematic relationship of the series mechanism. These four parameters are collectively referred to as D-H parameters. The spatial geometric relation of each link relative to the fixed reference coordinate system is described by homogeneous transformation, and the spatial geometric relation between two adjacent links is expressed by homogeneous transformation matrix. The equivalent homogeneous coordinate transformation matrix of the end actuator coordinate system relative to the base coordinate system can be derived by the homogeneous transformation, and the kinematics equation of the robot can be established [7]. Generation steps of homogeneous transformation matrix is showed in Fig.7.

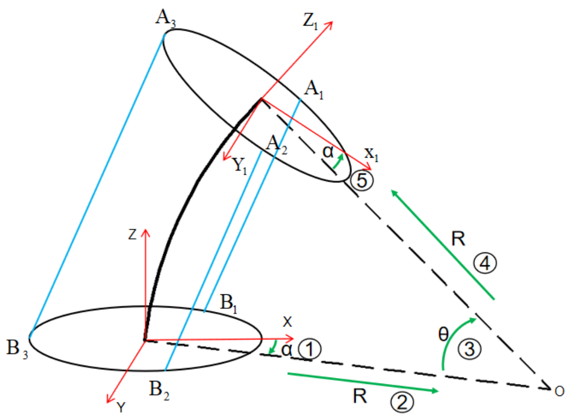


Fig. 7 Generation steps of homogeneous transformation matrix

The final homogeneous transformation matrix from configuration space to task space is Eq. (2), Eq. (3) is the rotation matrix. Eq. (4) is the translation matrix.

$$H(k) = \begin{bmatrix} \Theta(k) & \Psi(k) \\ 0 & 1 \end{bmatrix} \quad (2)$$

$$\Theta(k) = \begin{bmatrix} cos^2\alpha cos\theta + sin^2\alpha & cos\alpha sin\alpha(cos\theta - 1) & cos\alpha sin\theta \\ cos\alpha sin\alpha(cos\theta - 1) & sin^2\alpha cos\theta + cos^2\alpha & sin\alpha sin\theta \\ -cos\theta sin\alpha & -sin\alpha sin\theta & cos\Theta \end{bmatrix} \quad (3)$$

$$\Psi(k) = [Rcos\alpha(1 - cos\theta) \quad Rsin\alpha(1 - cos\theta) \quad Rsin\theta] \quad (4)$$

5. Flexible manipulator motion space simulation analysis:

The motion space diagram of the single-section flexible manipulator is shown in Fig.8.

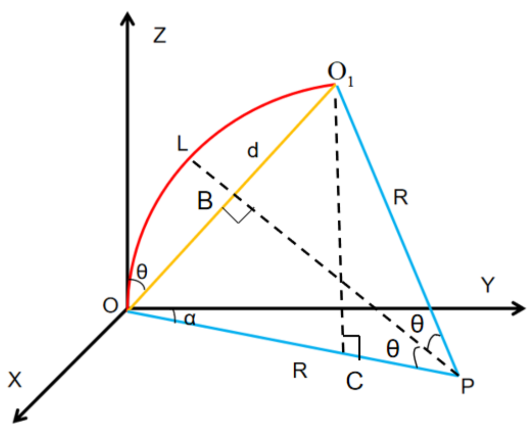


Fig. 8 Space analysis diagram of flexible manipulator motion

The red part OO_1 of the circular arc represents the continuous flexible body. The head end point O is the fixed point, and the end point O_1 is the free moving end. Let the length of the continuous flexible body (spring) be L. The arc OO_1 corresponds to the chord length d. When the continuous flexible body is not subjected to external forces, its initial state is reconnected with the Z-axis. The angle between the projection of arc OO_1 on the X-O-Y plane and the positive direction of the Y-axis is set as α, and the angle between string d and the positive direction of the Z-axis is set as θ.

The free end point O_1 of the center line of the flexible arm is obtained. The expression in the coordinate system is Eq.5. The bending Angle is 0 to 90° and the rotation Angle is 0 to 360°.

$$\begin{cases} x = \dfrac{L}{2\theta}(1 - cos2\theta)sin\alpha \\ y = \dfrac{L}{2\theta}(1 - cos2\theta)cos\alpha \\ z = \dfrac{L}{2\theta}sin\theta \end{cases} \quad (5)$$

The length L of the prototype single section flexible arm in the natural state is set to 200mm, and the end point motion relation is obtained by using MATLAB to get the end point motion range diagram (Fig.9).

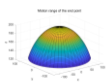


Fig. 9 Flexible manipulator motion space simulation

6. The simulation of length changes of the wires:

The vectors representation of the driving wires is obtained by superposition of the vectors, and then the maximum wire length variation of the single flexible arm is obtained by solving the modulus of the vector. The activity limit of the initial single-section mechanical arm is the rotation angle 0°-360° and the bending angle 0°-90°. Through simulation analysis in Fig.10, when the bending angle is 90° and the rotation angle is from 0° to 360°, the length of the drawstring changes the most. The simulation results are shown in the figure below. The maximum variation value of wires length of single section manipulator is about 95mm-265mm.

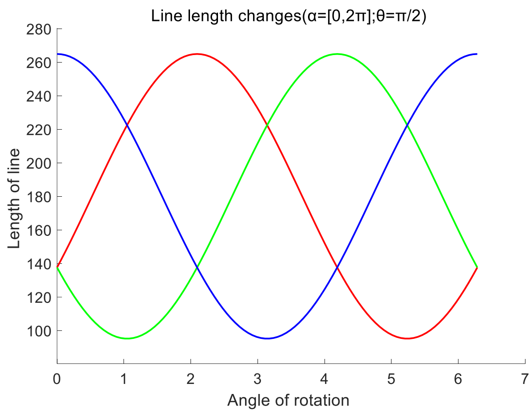


Fig. 10 The simulation of length changes of the wires

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