Title:
An Underactuated Robotic Hand with a Deployable Palm

Authors:
Ruiqin Wang, wruiqin@foxmail.com, Hebei University of Technology
Jiaqi Gu, gujiaqi5632@foxmail.com, Hebei University of Technology
Jian S. Dai, jian.dai@kcl.ac.uk, Southern University of Science and Technology
Shijie Dai, dsj@hebut.edu.cn, Hebei University of Technology

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Introduction:

As an important end effector, the robotic hand has always been a key research object for researchers. Based on the relationship between the number of active components and degrees of freedom in the system, robotic hands can be divided into two categories: fully actuated robotic hands and underactuated robotic hands. The fully driven robotic hand has high flexibility and powerful grasping function, but it has numerous sensors, a relatively large volume, and complex control. Due to their simple structure and control, as well as high reliability, underactuated robotic hands have become one of the main research directions for robotic hands.

In recent years, underactuated robotic hands have made significant progress. Meng H et al.[5] optimized the parameters of the linkage mechanism to linearize the fingertip trajectory, thereby gripping smaller objects. Jiaming Fu et al.[2] uses a variable stiffness structure, allowing rigid robotic hands to smoothly contact fragile objects. Mathew AT et al. **Error! Reference source not found.** uses a reconfiguration mechanism to change the direction of the robotic hand's fingers, allowing the robotic hand to better adapt to grasping objects of different shapes. Elangovan N et al.[1] proposed a robotic hand with a movable finger base to expand the workspace and improve gripping performance. For different types of grasping objects, there are their own types of robotic hands. But in fields such as home life services, there seems to be a greater need for a universal robotic hand that combines multiple functional modes to better grasp objects of different types and sizes.

Structure Design

Overall design of the robotic hand

For underactuated multi-finger robotic hands, the number of fingers has a significant impact on grasping stability. In the design process of a robotic hand, the complexity of its structure increases with the number of fingers, and the number of driving devices also increases accordingly, leading to difficulties in controlling the gripper. And the three fingers basically meet the grasping requirements of the robotic hand for objects, so the robotic hand proposed in this article has three fingers, and the overall structure is shown in Figure 1. The robotic hand is mainly composed of 3 fingers, a palm, a frame, and a motor, with a total of 12 degrees of freedom. The rotational degrees of freedom of finger 1 and finger 2 in the horizontal direction are directly controlled by the motor, making it easy for the fingers to reorient and adhere to objects. In addition, their bending degrees of freedom are controlled by one motor, and the bending degrees of freedom of finger three are controlled by another motor. The vertical motion freedom of the moving platform of the palm is controlled by a linear motor, combined with a deployable mechanism, which can change the finger spacing and adapt to objects of different sizes.

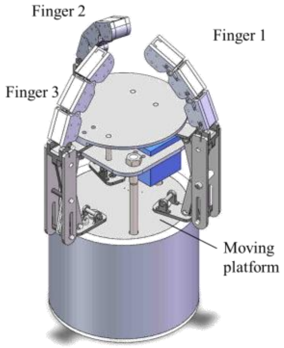

Fig. 1: Overall structure of the robotic hand.

Finger structure design

A new type of adaptive underactuated mechanical finger has been designed based on the principle of underactuation. The three-dimensional model of the mechanical finger is shown in Figure. 2. Fingers consist of three phalanges, three pulley systems, torsion springs, and tension springs, with one end of the torsion spring fixed to the corresponding pulley and the other end connected to the phalanges. When the tendon is pulled by the motor, the pulley at the MCP joint will rotate and apply torque to the connected torsion spring and the next stage pulley. During this process, the torsion spring will increase the torsion angle and apply torque to the phalange, causing them to rotate. Similarly, the three phalanges of the finger can be controlled to bend through a motor. In addition, as the torsion angle of the torsion spring can be changed, the fingers can achieve adaptive grip, and the joint torque of the fingers can be changed; that is, the fingers have the function of variable stiffness.

A reset torsion spring is placed on the side of the finger to restore its initial position. Due to its different torsional stiffness, it generates different torques that affect the trajectory of finger movement. Therefore, the stiffness of the reset torsion spring can be changed to allow the finger to choose different motion trajectories, such as rotating only around the MCP joint, or rotating all three joints of the finger simultaneously at a certain coupling ratio. In this article, we chose coupled motion for faster grasping and to prevent objects from escaping[3].

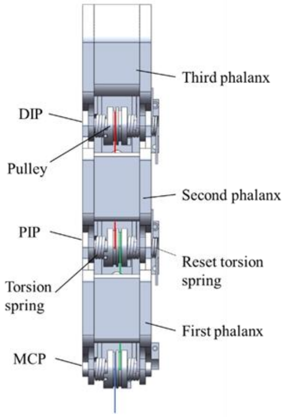

Fig. 2: Finger structure.

Palm structure design

The palm structure proposed in this article is shown in Figure 3, which mainly includes a moving platform, a reconfiguration mechanism, a deployable mechanism, a frame, a servo motor, and a linear motor. A motor can directly drive the fingers connected to the reconfiguration mechanism to change the orientation of the finger contact surface, thereby better fitting the object. The moving platform is driven by a linear motor, which changes the degree of expansion and contraction of the deployable mechanism through the distance moved by the moving platform, thereby changing the position of the finger base. The reason for choosing this deployable mechanism is that it allows the robotic hand to have a smaller initial volume.

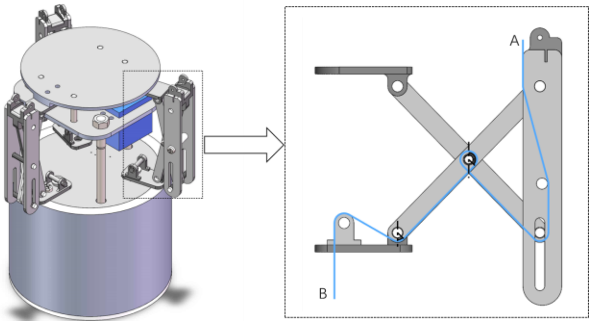

Fig. 3: Palm structure.

In order to ensure that the rotation of the reconfiguration mechanism, the movement of the deployable mechanism, and the bending of the fingers do not interfere with each other, it is necessary to arrange the tendon reasonably. The arrangement of tendon is shown in Figure 3. Firstly, the tendon needs to pass through the rotation center axis of the reconfiguration mechanism. Secondly, during the movement of the deployable mechanism, the length of the tendon rope needs to remain constant, that is, the distance from point A to point B remains unchanged. Finally, in order to reduce the number of drivers, a motor was used to control the bending motion of finger 1 and finger 2 through a differential mechanism.

<u>Determination of torsion spring parameters</u>

Considering that the torsion spring has a maximum rotation angle, if the rotation angle of the torsion spring exceeds the maximum rotation angle, it will cause the spring to fail and the material to undergo plastic deformation, making it impossible to restore its original state. Therefore, when determining the parameters of the torsion spring, this situation needs to be considered.

Neglecting the initial torque of the tension spring to restore the finger to its original position, after determining the stiffness of the reset torsion spring and the torsion spring, the rotation angle of the torsion spring should be proportional to the reset torsion spring. According to the torque balance, it can be concluded that

$$k_{33} = k_3 ra_3 \tag{1}$$

$$k_{22} = \frac{k_2 n_{23} + k_3 r_2}{n_{23} ra_2} \tag{2}$$

$$k_{11} = \frac{k_1 n_{12} n_{23} + k_2 n_{23} r_1 + k_3 r_1 r_2}{n_{12} n_{23} ra_1} \tag{3}$$

where, k_1, k_2, and k_3 represent the stiffness of the torsion spring; k_{11}, k_{22}, k_{33} represent the stiffness of the reset torsion spring; ra_1, ra_2, ra_3 represent the ratio of rotation angle to torsion angle; r_1 represents the ratio of the pulley radius at the MCP and PIP joints; r_2 represents the ratio of the pulley radius at the PIP and DIP joints; n_{12} represents the ratio of the torsion spring rotation angles corresponding to the MCP and PIP joints, and n_{23} represents the ratio of the torsion spring rotation angles corresponding to the PIP and DIP joints.

In this article, the finger parameters we selected are ($k_1, k_2, k_3, r_1, r_2, ra_3$)=($0.56, 0.56, 1.3, 2.5, 2.5, 2$), Using DIP:PIP:MCP=1:1.2:1.44 as the objective, solve for $ra_1 = ra_2 = 2$, $n_{12} = n_{23} = 1.2$,The stiffness of the reset torsion spring is $k_{11} = 3.68, k_{22} = 1.63, k_{33} = 0.65$.

Simulation

In this section, the influence of torsion springs on finger movement trajectories will be verified in Adams. After importing the finger model into Adams and setting constraints, contacts, and other aspects, set the torsion spring force based on the above data. Apply a torque under the finger and simulate. The simulation results of the rotation angles of the reset torsion spring and torsion spring are shown in Figure. 4 and Figure. 5. In the grasping stage, MCP, PIP, and DIP joints all rotated, and the ratio of their rotation angles was close to the expected value.

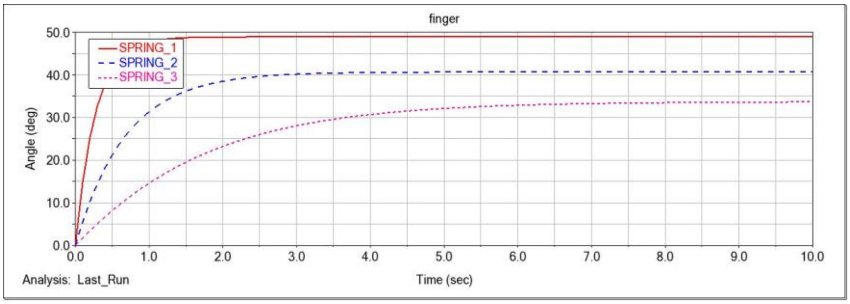

Fig. 4: Rotation angle of finger.

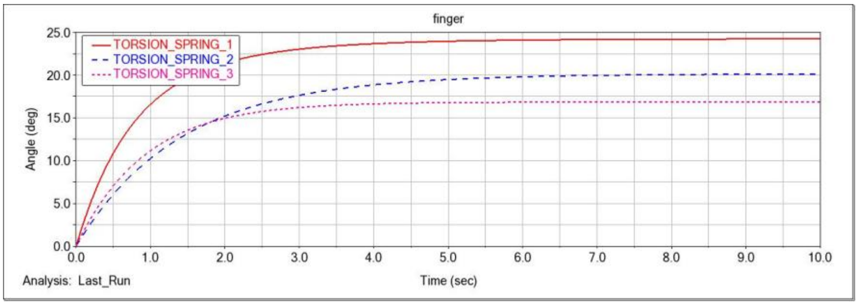

Fig. 5: Rotation angle of torsion spring.

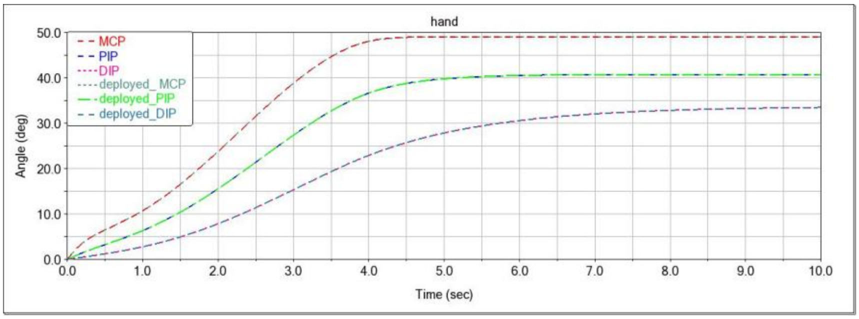

Fig. 6: Rotation angle of finger with and without deployment mechanism.

Next, the influence of the deployable mechanism on finger bending motion will be verified in Adams. After importing the robot hand model into Adams, create a driver for the moving platform and apply a torque expression of step (time, 0, 10, 4, 72) to the cable for simulation. Afterwards, fix the moving platform and simulate again. The bending results of the fingers in the two simulations are shown in Figure 6. The results indicate that the deployment motion of the robotic hand is independent of the bending motion of the fingers.

Conclusions:

This paper proposed a novel underactuated robotic hand with rigid-flexible variable fingers and a deployable palm. The special structure of torsion springs and cable composed in the fingers can achieve flexible contact and adaptive gripping. By configuring reset torsion springs with different stiffness, fingers can achieve different motion trajectories. The deployable palm can simultaneously achieve the rotation and distance adjustment of finger bases, thereby improving the range and stability of gripping objects. Therefore, robotic hands can achieve different grasping modes, such as enveloping grasping and parallel grasping, to better grasp objects of different sizes and shapes.

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