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A Linkage-Driven Underactuated Robotic Hand for Adaptive Grasping and In-Hand Manipulation

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***Abstract*—The development of robotic hand that can imitate human movements has always been an important research topic. In this paper, a linkage-driven underactuated three-finger hand is proposed to imitate the flexion/extension (f/e) and abduction/adduction (a/a) motions of human hand. The robotic hand has three identical underactuated fingers, each of which contains an underactuated planar linkage, a spherical four-bar mechanism, and a set of bevel gears. The spherical four-bar mechanism is designed to provide 2-degree-of-freedom actuation, driving the f/e and a/a motions of the proximal joint simultaneously. Based on screw theory, the kinematic model of the spherical mechanism is established, and the maximum available workspace index (MAW) of the spherical mechanism is proposed to evaluate the workspace with the same adduction and abduction angle ranges. The effects of the parameters of the spherical mechanism on the MAW and the transmission efficiency are obtained, and the parameters of the spherical mechanism are optimized. The optimization results show that the MAW of the spherical mechanism can be increased by up to 3.5 times. Finally, experiments are carried out to show the proposed robotic hand can perform simultaneous adaptive grasping and in-hand manipulation.**

***Index Terms*—Dexterous hand, Underactuated planar linkage, Spherical mechanism, Grasp manipulation.**

I. Introduction

ROBOTIC hands have been widely used to replace workers in heavy, repetitive, and unsafe working environments [1, 2]. Since the first generation of dexterous humanoid gripper Okada was developed [3], the humanoid hand has attracted the attention of researchers all over the world due to its excellent dexterity. There are many representative humanoid hands [4], and some research results have been applied in practice. However, they can only be used to manipulate known objects in a structured operating environment. Uncertain environments in non-manufacturing fields, such as marine development, medical service, and entertainment, require that robotic hands can operate tasks like human hands. Thus, the demand for robotic hands with greater flexibility and adaptability increases sharply. Nevertheless, few robotic hands can fully imitate the function of human hand so far. To make the robotic hand imitate the function of human hand as much as possible, researchers have been working to make it more flexible, reliable, and widely applicable.

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Inspired by the work in [5] and our previous works [6, 7], this paper proposes a new linkage-driven three-finger robotic hand, which includes a planar linkage for finger grasping motion, a spherical four-bar mechanism for power transmission, and a set of bevel gears for realizing the a/a motion. The main contributions of this study can be summarized in three aspects:

1) To increase grasping dexterity, a three-finger robotic hand with a spherical four-bar mechanism is proposed to realize f/e and a/a motions of the finger.
2) The maximum available joint workspace (MAW) is proposed as a new index for the spherical mechanism to evaluate the workspace with the same adduction and abduction angle ranges.
3) Effects of the design parameters of the spherical mechanism on the transmission efficiency are obtained. Based on MAW and the transmission efficiency, the desired parameters of the spherical mechanism can be optimized.

II. Design of the Three-finger Underactuated Robotic Hand

As shown in Fig. 1, a novel dexterous three-finger robotic hand is proposed, which is composed of three identical underactuated fingers. To improve grasping dexterity, the metacarpophalangeal (MCP) joint of each finger can perform the f/e motion and the a/a motion of the proximal joint. The three-finger robotic hand is composed of four parts: the underactuated planar linkage, spherical four-bar mechanism, bevel gear set, and actuator.

It is necessary to use two rotary actuators to enable the underactuated finger to perform the f/e motion and the a/a motion, which are placed in parallel on the underactuated finger, as shown in (h) and (i) in Fig. 1. The actuator (i) is used to drive the spherical mechanism so that the underactuated finger can perform the f/e motion; the actuator (h) is used to drive the cross shaft so that the underactuated finger mechanism can perform the a/a motion.

III. Experimental Validation

A. Experimental Equipments

An experimental platform of the three-finger robotic hand was established, which was composed of a computer, a three-finger hand prototype, dSPACE rapid prototyping system, six MC5010 motor drivers, and six Faulhaber motors.

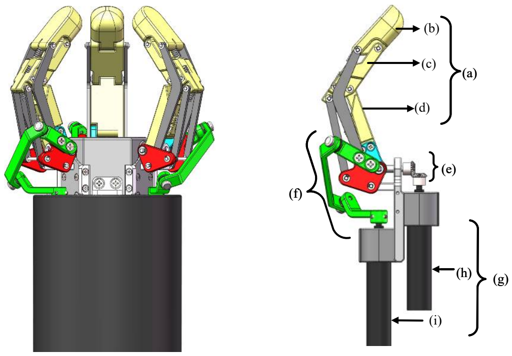

Fig. 1. An overview of the three-finger robotic hand. (a) Underactuated planar linkage used to generate grasping motion, (b) Distal phalange, (c) Middle phalange, (d) Proximal phalange, (e) Bevel gear, (f) Spherical four-bar mechanism, (g) Rotary actuator composed of motors (h) and (i).

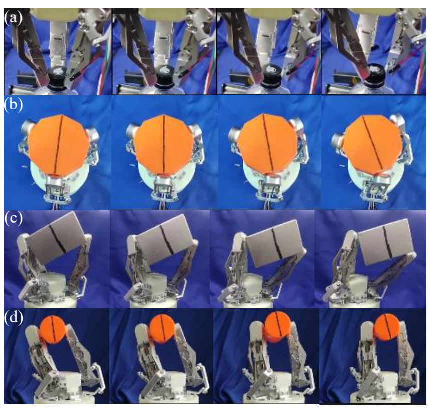

Fig. 2. In-hand manipulation experiment of the robotic hand.

B. Experiments of the In-hand Manipulation

As shown in Fig. 2, we used the a/a movement of the robotic hand to realize the rotation manipulation of various objects with different shapes and sizes. The experiments show that the robotic hand was capable of rotating objects with different shapes and sizes. In addition, we used the robotic hand to realize equilibrium point manipulation of different objects through the f/e and a/a movements of the robotic finger. The experiments show that the robotic hand was capable of twisting objects with different shapes and sizes. In summary, these in-hand manipulation experiments of objects with different shapes and sizes can show that the proposed robotic hand has good capability for in-hand manipulation.

C. Experiments of the Fingertip and Enveloping Grasp

As shown in Fig. 3, to test the grasping performance of the robotic hand, and objects were placed at random configurations. To verify the enveloping grasping performance of the robotic hand, several enveloping grasping experiments of objects with different shapes and sizes were first performed. The experiments show that the proposed robotic hand has good grasping performance. The reason is that the robotic hand can adjust the finger position through its f/e and a/a movements to guarantee a high grasp stability performance based on the grasp stability theory [7].

Fig. 3. Fingertip and enveloping grasping experiment of various objects using the robotic hand.

IV. Conclusion and Future Work

In this paper, a linkage-driven underactuated three-finger robotic hand was presented, which can imitate the f/e and a/a motions of the proximal joint of the finger. The robotic hand was composed of three identical underactuated fingers, consisting of an underactuated planar linkage, a spherical four-bar mechanism, and a set of bevel gears. The spherical four-bar mechanism was designed to provide 2-degree-of-freedom actuation, which was used to drive the f/e and a/a motions of the finger simultaneously. The effects of the design parameters of the spherical mechanism on the MAW and the transmission efficiency have been obtained, and the parameters of the spherical mechanism are optimized. The optimization result shows that the MAW of the spherical mechanism can be improved by up to 3.5 times while keeping high torque transmission efficiency. Finally, comprehensive experiments were performed to show the adaptability, fingertip grasping and in-hand manipulation performance, and enveloping grasping performance of the proposed robotic hand.

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