

Design of a Underactuated Robotic Hand with Three Articulated Fingers

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Abstract—An intelligent flexible hand with eight degrees of freedom is developed which reconfigures itself in real time to achieve a grasp with different shaped target objects. It has three articulated fingers, driven by four DC motors, which is a typical underactuated structure. Grasping action of each finger is independently controlled by a motor and the outer two symmetrical fingers centered on parallel joint axes around the entire palm can both be rotated synchronously 180 degrees by the fourth motor. The design of mechanical transmission, embedded development board, sensors and force sensor calibration are introduced in detail. All embedded development board, controller, sensors, motors and drivers are integrated inside the palm of the hand or on the surface of the fingers, which has the advantages of compact structure and easy operation. Use standard serial communication to send control commands, all valid commands are parsed in the controller, and the target objects can immediately be grasped. The research provides a design method for the underactuated robotic hand.

Keywords—flexible grasp; underactuated hand; grasping; multi-fingered hand; optimized design ; robot hand

I. INTRODUCTION

The multi-fingered hand is a robotic end tool that resembles the structure and function of a human hand. It can flexibly manipulate objects of various shapes and perform complex tasks such as grabbing assembly, maintenance operations, and equipment operations [1-2]. Grasping and manipulation skills are at the core of the development of modern robotic systems, so the underactuated hand is as an ideal solution based on the requirements. It means that the number of actuators included is less than the degree of freedom of the system, and more work tasks can be realized with fewer actuators [3-4].

Thus, researches on the topic of underactuated robotic hand have become a significant work. William [5] presented the design and operation of a BarrettHand, an intelligent, highly flexible eight-axis gripper. The i-HY hand, an underactuated hand driven by five actuators that is capable of performing a wide range of grasping and in-hand manipulation tasks was introduced in [6]. A two-fingered gripper topology was presented which enables an enhanced predefined in-hand manipulation primitive controlled without knowing the size, shape, or other particulars of the grasped object [7]. In order to overcome the shortcomings of traditional coupled fingers and self-adaptive fingers, Yang, et al [8] proposed a novel single-column hybrid underactuated finger mechanism with coupled and self-adaptive grasp mode. In the design of the underactuated mechanism, Ryuta, et al [9] proposed a design method of transmissions for underactuated hand which

consisted of active and passive gear trains that align a series of gears over several joints. Shin [10] presented a dual-mode robot finger that simultaneously achieves fast bending motion and a large grasping force with a single motor. Grasping adaptation of a one Dof anthropomorphic finger mechanism in LARM hand has been proposed by using flexible links and/or underactuated mechanisms with additional spring elements or flexural joints [11]. In addition, Rossi et al [12] proposed a finger mechanism by tendon-driven to verify the feasibility of using one motor to drive four fingers. These hands involved mechanism design, control system, sensors, and drive motor, providing some experiences and methods for developing new underactuated hand. Compared to full-actuated hands, the underactuated hand further reduces the complexity of the mechanism and control and has a high reliability.

Based on the design method of mechanical system, control system and sensing system of above-mentioned underactuated hand, this paper presents of a simple underactuated hand with three same articulated fingers. In Section II, we develop mechanical design of hand. In Section III, we design an embedded development board. In Section IV, we design and calibrate of force sensor. In Section V, we develop the actual prototype and some simple tests. Conclusions are drawn in Section VI.

II. MECHANICAL DESIGN OF UNDERACTUATED HAND

A. Overall Design of Underactuated Hand

The prototype of the underactuated hand with three articulated fingers and a palm is as shown in Fig. 1. The entire hand design has eight degrees of freedom driven by four DC motors and integrates force sensing, joint angle sensing and tactile sensing. Each finger can be grasped with two degrees of freedom by a single motor, one of which is fixed to the frame, and other two fingers can also rotate in the opposite direction with two degrees of freedom along the palm surface. Grasping action of each finger is independently controlled by a motor and symmetrically opposable fingers centered on parallel joint axes around the entire palm can be rotated from 0 to 180° by the fourth motor.

The lengths of the links from the base to the fingertip for sinner finger are $a_1=52$ mm, $a_2=70$ mm and $a_3=56$ mm, and adjustable grasp force cover ranges of 0~20 N (Fig 2). Harmonic reducers, synchronous belts and wire ropes mounted on the axes are used to transmit movement and force, and therefore it has a variety of characteristics of compact structure and no noise. Each finger has two force sensors, joint sensor,

touch switch and encoder, and the palm has a force sensor with a large area of coverage. The rotation angle of the proximal joint is about 0~140 degrees. The distal joint of the finger rotates ranges from 0° to 50 degrees. The body and some components are made of high-strength aluminum and Plastic 3D Printing, so the whole hand weighs only 1.2kg. It is designed to have two kinds of grasping methods, called precise fingertip grasping and envelope grasping.

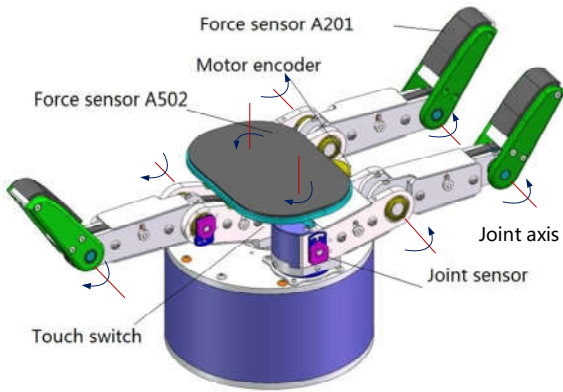


Fig. 1. Solidworks 3D model of underactuated hand

B. Transmission Mechanism Design of Single Finger

Since the finger design play vital role in determining the performance of a hand, we develop a modular finger that is easy to install and configure to the palm. The finger has 2 degrees of freedom to open and bend which is driven by a motor. The Maxon EC 20 flat with integrated electronics is a brushless DC motor. The Harmonic gearhead of CSF-Mini Series is employed to be coupled directly to a motor. The motor shaft is attached directly to the gearhead input element. Hence this makes the entire hand simple and controllable due to the reduction of several drivers.

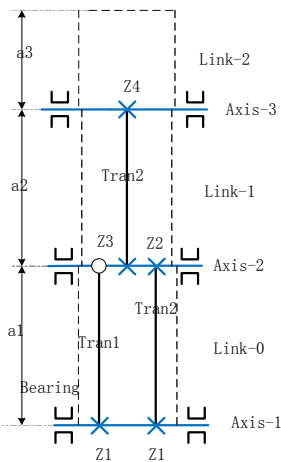


Fig. 2. Transmission routing configuration of single finger

The transmission routing configuration of the single finger is shown in Fig.2, and the joint axis-1 is driven by a single DC brushless motor with harmonic reducer. The selected DC brushless motor has a power of 5 watts and the harmonic

gearbox has a transmission ratio of 30:1. The link-0 indicated by dashed lines is fixed on the frame and cannot be rotated. The link-1 can rotate around joint axis-2, and also the link-2 can rotate around joint axis-3. The symbol ‘X’ indicates that the gear is attached to the joint axis and the symbol ‘O’ indicates that the gear can be rotated around the joint axis. The first transmission routing named Tran1 is synchronous belt drive form axis-1 to 2, and its role is to drive link-1 rotation around the axis-2. At the same time, the second transmission routing named Tran2 is fine-wire rope drive form axis-1 to axis-2, form axis-2 to axis-3 and its role is to drive axis-3 rotation. In this way, the link-2 fixed on the joint axis-3 are driven to rotate together. Therefore, the driving torque from the joint axis-1 is divided into 2 ways to control the movement of the link-1 and the link-2 respectively.

C. Three-finger Installation Layout

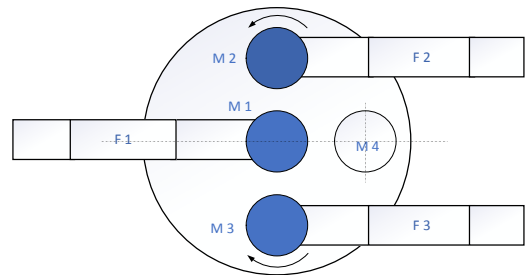


Fig. 3. Installation layout of three fingers

The installation layout of the three fingers on the underactuated hand is shown in Fig. 3. Due to the difference in the installation position of the fingers, a variety of grasping plans for the underactuated hand can be constituted. Here, the installation position of three fingers must be on the same center line and have equal spacing. The axes of all motors are perpendicular to the front panel of hand frame, and each motor (M1, M2 and M3) drive the finger directly through the bevel gear drive. The three fingers (F1, F2 and F3) fixed on the front panel can be opened and bent, while the outer two fingers (F2 and F3) can also be rotated in the opposite direction synchronously along the axis of the motor M2 and M3. As shown in Fig. 3, the motor M4 is directly connected to the axes of the finger 2 and the finger 3 through two timing belts, so both fingers can be simultaneously rotated from 0 to 180 degrees. Therefore, it will support grasping more kinds of objects than the fixed two-finger and three-finger grippers.

III. CONTROL SYSTEM DESIGN OF UNDERACTUATED HAND

A. Control System

The control framework is as shown in Fig. 4. It is mainly composed of a Stm32F103 development board, DC motors and drivers, FSR force sensors, joint sensors, and touch switches, etc. The control system is divided into two layers, the upper layer adopts laptop computer to achieve the grasping plan, and the lower layer adopts the embedded controller to achieve grasp action. Laptop is used as upper control computer in test platform whose CPU is Intel Core i7-6500U 2.50 GHz and

Memory is 8 GB. A friendly man-machine interface is developed by using LabVIEW in the upper computer, some complicated planning algorithms can be run and the operational results can be sent to the embedded controller.

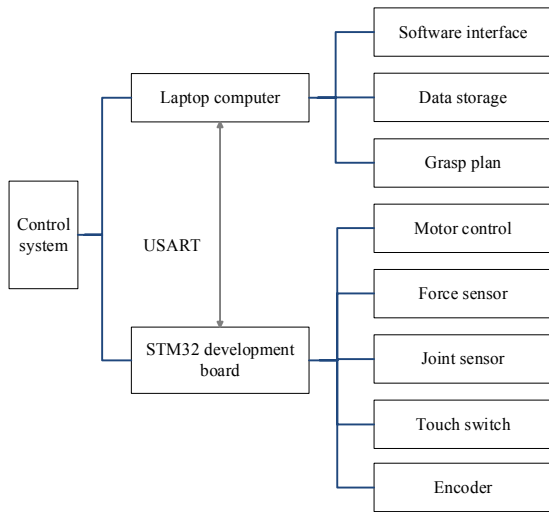


Fig. 4. Control system structure frame

B. Design of Embedded Development Board

The designed embedded development board based on the an MCU-STM32F103 integrate the ARM Cortex-M3 core-based processor, USB full-speed interface, CAN, USART, signal amplifiers, etc (Fig. 5). Data acquisition of force sensors, joint angle sensors and touch switches are all deployed to the STM32F103 controller. The position calculation of fingers is mainly collected by the motor encoder. The joint axis of each finger is equipped with a joint sensor to measure joint angle in real time. As rotary position sensor, it is used with the output terminals directly connected to the A/D port of a microprocessor. Tactile switches installed on the bottom connection of the fingers can achieve finger reset, and the joint angle sensor can also assist the finger reset by detecting the desired threshold. Since most robots are equipped with serial ports, control commands consisted of a series of corresponding ASCII values can be sent via the serial port, such as position and force control commands. Communicating by the USART of controller, it can communicate and accept commands from other controller via standard ASCII RS232 serial communication protocols.

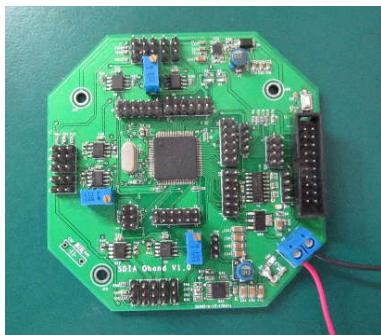


Fig. 5. SDIA development board

IV. DESIGN AND CALIBRATION OF FORCE SENSING DEVICE

A. Force Sensing Design of FSR Device

To provide fingertips and palm force sensing, each fingertip is affixed with two FSR201 force sensors, and a FSR502 force sensor is attached to the surface. FSR is a polymer thick film device which exhibits a decrease in resistance with an increase in the force applied to the active area, allowing creating a sensor that is able to detect force. The device is tied to a measuring resistor in a voltage divider configuration. The signal amplification circuit of FSR device is as shown in Fig. 6. The OPA2330 amplifier is used to amplify the signal of FSR device. For a simple force-to-voltage conversion, it is described as follows

$$V_o = -V_T * (R_f / R_s) \quad (1)$$

Where V_T and V_o denote the excitation power supply and the measured output voltage. R_s is resistance change of the sensor under the force and $R_f = 50 \text{ k}\Omega$ is a resistance in voltage divider configuration. Therefore, all fingertips and palm have force sensing capabilities, providing the potential for flexible grasp and manipulation.

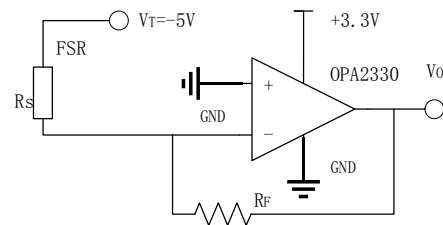


Fig. 6. Force signal amplification circuit

B. Force Calibration of FSR Device

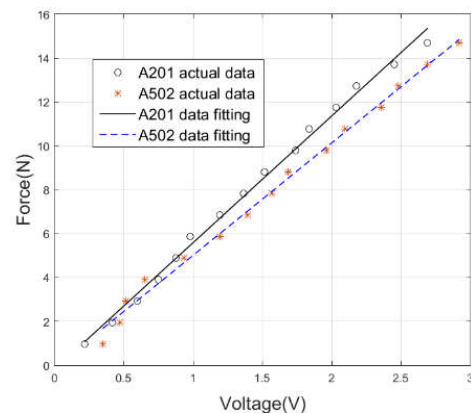


Fig. 7. Force calibration of FSR device

FSR device is simple calibrated by using a set of standard weights. A custom filter is designed to deal with data acquisition to improve the accuracy of calibration. Add up all the numbers after removing the maximum and minimum value and then divide by how many numbers there are. It is observed that the force and the measured voltage approximately agree

with the linear relationship, in Fig. 7. Two simple formulas of straight line fitting through data processing are described

$$F_1 = 5.7744V_1 - 0.1286 \quad (2)$$

$$F_2 = 5.1216V_2 - 0.1064 \quad (3)$$

Where $V_i \rightarrow F_i (i=1,2)$ denotes actual voltage-to-force conversion of two force FSR devices. The first equation shows the linear function relation between the actual measured voltage V_1 of the FSR 201 device and the corresponding fingertip force F_1 . The second equation shows the linear function relation between the actual measured voltage V_2 of the FSR 502 device and the corresponding palm force F_2 . Due to the force sensing capability, assuming an increased force control algorithm, the robot can achieve flexible grasping and manipulation of fragile objects.

V. GRASPING EXPERIMENTS OF UNDERACTUATED HAND

Test prototype of the underactuated hand is designed as shown in Fig. 8. The blue part of the palm and fingertips are covered with some thin film force sensors, which can achieve force detection. A power cable and a serial cable are left on the side of the hand and are respectively connected to a power supply and a standard serial device. The hand can be installed using screws and plug in the connector of an industrial robot. The significant advantage of module finger is that each finger has an independent position controller to be easy to implement, and force controller will guarantee the quality of grasp force.

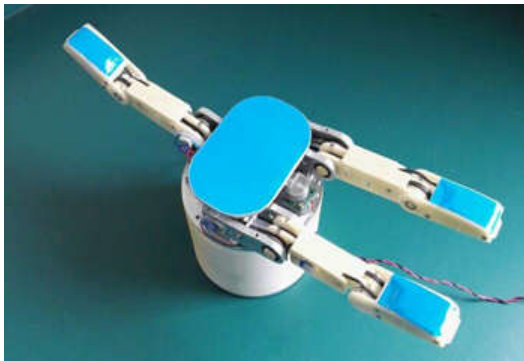


Fig. 8. Test prototype of underactuated hand

The control system adopts two layers of control structures, the lower embedded controller mainly realizes finger position back to zero, finger control, sensor data acquisition, etc. The man-machine interface programming uses LABVIEW, and it sends a series of ASCII to control the MCU by the serial device. Once the fingers are completely reset, and then waits for control commands of the upper computer. All the effective control commands sent from serial device are parsed in the embedded controller and all the grasping action are implemented immediately. The fingers arrive at the desired position and subsequently contacts an object. It can use fingertip grasping and envelope grasping for light objects. Next, we will carry out an experimental study of grasp force optimization and control algorithms for the underactuated hand.

VI. CONCLUSION

An eight-degree-of-freedom underactuated hand with force and joint angle sensing is presented in the paper. The main hardware design of mechanical body, control system and sensor system are illustrated sequentially in detail. The underactuated hand neatly houses an MCU, software, communications electronics, drivers and all brushless motors. In each of its three multi-joint fingers, each finger can be individually opened and bent. In addition, two outer fingers can be rotated synchronously from 0 to 180 degrees in the opposite direction along the palm to support the grasp more kinds of objects. With standard serial port communication, grasping and manipulation can be performed immediately. The grasping experiment shows that it is capable to ensure both the encompassing grasp to different shaped and sized objects. The underactuated hand will replace a variety of fixed-shape grippers and has lower costs, so it has obvious application prospects in robotics and automation. Future work will focus on grasping force optimization algorithm and grasping force control algorithm of the underactuated hand.

ACKNOWLEDGMENT

This work is supported by the National Key Research and Development Program of Shandong Province (2017CXGC09716, 2017GGX30120,2018GGX103040), and the Shandong Provincial Natural Science Foundation of China (ZR2013FM026). * Corresponding author is Yunhai Zhu on the paper.

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