An Underactuated and Compliant Gripper with Multi-sensor Feedback

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Abstract

We report on the development of an underactuated and compliant gripper equipped with tactile sensors. The gripper has three fingers and each finger has a torsion spring to gain its compliance for grasping objects. The gripper can also change the finger configuration to provide better adaptability to objects with different shapes. Various sensors are implemented in the gripper, including pressure sensing array, force-sensitive resistors, potentiometers, and accelerometers. In addition, we also develop a control strategy programmed in the gripper, so it can autonomously search the object in the workspace, identify its shape, and grasp it stably. By mounting the gripper on the custom-made SCARA robot arm, the performance of the gripper is experimentally evaluated.

Keywords: Gripper, underactuation, SCARA, shape identification

1. Introduction

The sense of touch is essential for human in daily life. Without tactile sensing, we don't know whether we holds a cup of coffee stably or not, or how much force should we apply to open the door. Tactile sensing provides subtle cues about the environment that can't be provided by any other perceptual sensors [1]. Similarly, tactile sensing is vital in robotics. Despite computer vision can recognize the position and orientation of the object, tactile feedback provides indispensable information of the objects they are manipulating. Tactile sensor can help the gripper maintain stable grasp if the friction between objects and finger is measured. Tactile sensing is not only used in objects manipulation but also in object shape construction. Researchers develop the state of contact and model the contact situations for different shapes of sensors [2]. By using three thin force-sensitive resistors, the gripper can detect the gradient of the object surface and find the object's shape [3].

Almost all robot tasks require the end effector of the robot to be contacted with the environment. Because in the past the robots are mainly used in structured environment such as factories, the contact can be achieved by precise position control. Recently the robot development gradually moves toward the "daily life" applications whose environment is usually unconstructed. Consequently, the robot needs to be adaptable to the tasks. More specifically, the gripper should be capable of adapting itself to grip objects with various shapes and stiffness, to prevent unexpected contact or slippage [4]. The adaptability can be achieved from both design and control aspects: compliance and tactile-sensory feedback.

The compliance of the gripper can be achieved by using underactuated mechanism. Underactuation means that the number of actuators is less than the degrees of freedom (DOFs). Graspers with underactuation are relatively cheap, lightweight, and easy to control in comparison with ordinary fully-actuated grippers. The underactuated gripper can also grasp various objects because the fingers of the gripper can adapt themselves to the shape of the objects by their passive mechanical behaviors [5]. In recent years, many flexible and universal gripper designed by the industrial manufactures. Unlike the traditional gripper, the universal gripper can adapt itself to various kinds of tool shape. The direct advantage is the decrease of the manufacturing cycle time and of space for gripper inventory. The famous adaptive grippers includes a 2-Finger Adaptive Robot Gripper which produced by Robotiq [6], Barrett Hand manufactured by Barrett Technology Inc. [7], and SDH Gripping Hand made by SCHUNK [8]. The 2-Finger Adaptive Robot Gripper have different grasping modes and can create an astonishing grasping force due to its passive compliance. The Barrett Hand are underactuated and can adapt to multiple objects. Moreover, it has an ability to spread two of its three fingers to the opposite position of the third finger, creating difference grasping postures. The SDH Gripping Hand has tactile sensing, making it intelligent for various robot tasks.

On the control side, tactile sensory feedback is crucial in grasping tasks since the successfulness of the grasping strongly depending on the force interaction between the gripper and the object. Tactile information can be obtained by either force/moment transducer or pressure sensors. Owing to limitation engineering technique, the size of the force transducer is usually large so it is mostly installed on the wrist for monitoring large scale contact and manipulation. On the other hand, the pressure sensor can be fabricated very small, so it is also possible to be made in the array to provide more subtle contact information. The tactile array is one of the key component to endow the gripper to be capable of object shape detection.

Here, we would like to report our progress on developing an underactuated gripper with tactile-sensory feedback, to solve the grasping problem from both design and control aspects. The configuration of the fingers can also be changeable between two-finger grasping and three finger grasping, mimicking the two frequently used human hand configurations in grasping. The main tactile sensing source, the pressure sensory array, is made by ITRI [https://www.itri.org.tw/chi/msl/].

Section 2 describes the mechanical design, followed by the tactile system in Section 3. Section 4 introduces control strategy for gripper to execute the task in the workspace. Section 5 reports the experimental results, and Section 6 concludes the work.

2. Mechanical Design

In this chapter, we introduce the design of the gripper and the SCARA. The specification of our gripper is shown in Table 1.

Table 1 The specification of the gripper.

Kinematics	Number of fingers: 3 Number of movable fingers: 2 Number of motors: 4 Per finger: 1 Grasping mode change: 1
Motor Type	RC Servo motor Futaba BLS172SV (Torque:31 kg-cm)
Working Range	Three-finger mode : 15-70 mm Two-finger mode : 0-70 mm
Payload	40 N
Weight	800 g

2.1 Underactuated finger mechanism

There are plenty reasons why grippers fail to grasp objects, uncertainties in object position is probably the most common. As a result, we develop an underactuated gripper by putting a torsion spring to create compliance. When the fingers touch the object, the configuration of the fingers will deform to fit the exterior surface of the objects. As Fig. 1 shows, the torsion spring is added in point A, it provides a torque to resist angle A from rotating outward. Each finger is composed of five bar linkage and there is a mechanical limit at angle A that it cannot rotate inward. This design cause an effect that when the upper side of the distal phalanx first touches the object or the fingertip touches the ground, angle A tends to rotate inward but will be restricted. Consequently, the five bar linkage degenerates into four bar parallel linkage. The gripper will grasp the object with its fingertip, which we cal as ‘’Parallel Grasp’’. On the other hand, when the lower side of the distal phalanx touches the objects or the fingertip touches the ground, angle A will rotate outwards and envelope the objects, which we call as ‘’ Envelop Grasp’’. Envelop Grasp provides higher payload than Parallel Grasp due to the additional torque produced by torsion spring.

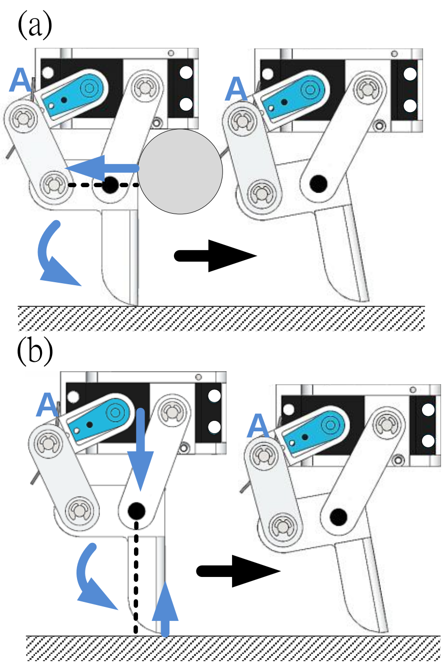

Fig. 1 Change of finger configuration during contact: (a) The distal phalanx first touches the object, and (b) the fingertip touches the ground.

2.2 Configurations of the gripper

As a human, if we want to grasp multiple objects with different size and shape, we’ll need to use different hand posture. Similarly, gripper needs to create more grasping mode in order to grip objects in various directions. Hence, we use the worm and worm gear to develop palm spread motion, which means the two of three fingers can rotate simultaneously and eventually combine together, the two modes are shown in Fig. 2.The advantages of three fingers mode is providing higher payload and holding bigger objects. However, when the gripper needs to grasp small objects in the crowded environment, two fingers mode is more appropriate because its enveloped range is smaller and can reach into small gap or a basket full of various objects.

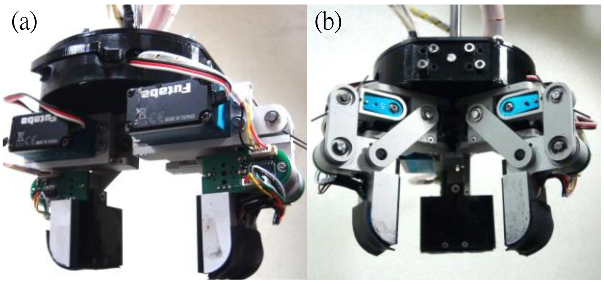

Fig. 2 Two grasping modes of the gripper: (a) Three-finger mode and (b) two-finger mode.

2.3 The SCARA robot

For testing the function of the gripper, we build the SCARA to implement the gripper, it brings the gripper throughout the workspace and execute several tasks. Table 2 shows the specification of the SCARA.

Table 2 The specification of the SCARA

Total DOFs	4
Arm length	J1+J2=355 mm (180+175 mm) J3(Z):200 mm J4:360 degree
Motor type	DC brushed motor
Motor power	J1: 150 W J2: 150 W J3: 60 W J4: 60 W
Weight	13 kg
Payload	3 kg
Workspace	about 200 mm x 200 mm

Fig. 3 Photo of the SCARA robot with gripper.

3. Sensors of the gripper

Tactile sensors are essential for a gripper to handle objects, it can sense the multiple information such as weight, object configuration, texture, etc., which even vision system cannot obtain. In this paper, we use the tactile sensor for detecting the object, local shape recognition, and slip detection. All these procedures are done automatically and only based on tactile sensing. In this chapter, we will introduce all the sensors on the fingers. Fig. 4(a) shows the placement of all the sensors in the finger.

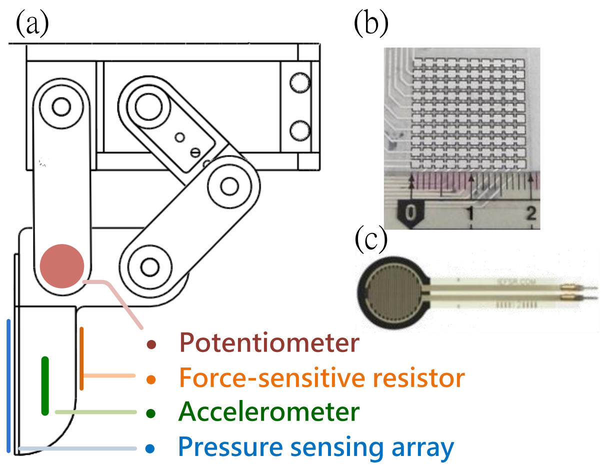

Fig. 4 Sensors of the gripper: (a) All of the tactile sensors on the finger, (b) pressure sensing array made by ITRI, and (c) force-sensitive resistor

3.1 Potentiometer

Potentiometer is used for angle feedback, we can find out the position of the distal phalanx by forward kinematics [9].

3.2 Pressure Sensing Array

Figure 4(b) shows the pressure sensing array made by ITRI is a resistive sensor array consisting of 10 x 10 elements. Each element has a size of 1.9 x 1.9 mm 2 , and can measure from 0 to 144 psi with resolution 0.61psi. We mount the array sensor on the inner side of every distal phalanx and cover them with rubber plate.

3.3 Accelerometer

Accelerometer can detect small vibrations when gripper touches the object, and it can provide useful grasping signal as well [10].A 3-axis accelerometer ADXL327 made by Analog Device is chosen and is embedded inside the distal phalanx. This analog accelerometer can measure tri-axial acceleration in the range of ±2 g m/s. The analog signal first pass through a low pass filter with cut-off frequency 500 Hz and then be sensed by a 12-bit ADC module.

3.4 Force-sensitive resistors

In order to let the gripper detect contact from all the directions, we need other force sensors be installed on the outside of the distal phalanx.

The sensing device we chose is “Force sensor”, which are force-sensitive resistor produced by

INTERLINK ELECTRONICS, Inc. [11]. The sensing area is 14.7 mm in diameter and it can sense from 0.2 to 20 N. The sensor resistance decrease linearly while adding the force on the sensor.

The sensing resistance is measured by using non-inverting configuration of OP amplifier, the circuit is shown at Fig. 5. According to the circuit, the variable resistance (Rs) can be obtained as

$$Rs = (Vs \times R_1)/(V_{sense} - Vs) \tag{1}$$

After obtaining the sensing resistance, we want to know the relation between the exact force and the sensing resistance. To do so, we use the load cell produced by Transducer Techniques[12] to measure the actual force.

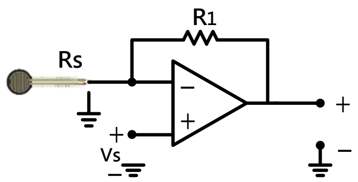

Fig. 5 The force-sensitive resistor measuring circuit.

4. Control Strategy

In this chapter, we present our control strategy which gripper can autonomously find the objects, identify it, and grasp it stably. For testing the gripper, there is some object randomly placed in the workspace, containing sphere, cubic, rectangular solid, and cylinder. The system can differ several shape primitives and choose a suitable configuration to grasp it. Finally, the gripper and the held object will be delivered to where we decided and release the gripper to lay down the object.

The control strategy contains five main parts, including "Search", "Contact relative", "identification", "Grasp" and "Move". In the "Search" mode, gripper follows the fixed trajectory which is priorly decided. The trajectory will search all over the workspace, it stops searching until the force sensor value exceed the threshold or the vibration detected by the accelerometer. Then the gripper will move toward the object and enclose the object. It will close the fingers individually. One of the fingers detects the contact force between the finger and the object then move the other finger. The process of closing fingers individually reduce the impact to the object. It can prevent the object rolled away. After the gripper closes the fingers, it will shift to the next procedure. In the "Identification" mode, we can differ different size and shape of the object. By the potentiometer, we will know the configuration of the fingers. Then we can determine the distance between the fingers which is the length or the diameter of the objects. After knowing the size of the object, we use the pressure array identifying the exterior surface of the object. There is three kind of surface - spherical, cylindrical, and plane surface. It is discriminated by some properties of the value from the pressure sensing array including mean, standard deviation, and the aspect ratio of the touch area. Fig. 6 shows the sequence of discrimination. We also need to grasp two times to differ from cubic to rectangular sold or cubic to cylinder. After it grasp the first time, it will rotate 90 degrees and carry out the second grasp. Because both of cubic and rectangular solid has planar surface, distinction depends on the distinct length. On the other side, the cylinder has one of planar surface. Two times grasp can ensure touch with the cylindrical surface.

During the identification, we know the size and the shape of the object. The system will choose the suitable configuration to grasp it. For example, the sphere is appropriate with three finger mode and envelop grasp. The laying cylinder is better with two finger mode and envelop grasp. Table 3 shows the combination of the grasping mode. Finally, the gripper moves and avoids the slippage of the manipulated object. When the object slips, the gripper increases gripping force to hold it firmly. The object will be delivered to the desired place.

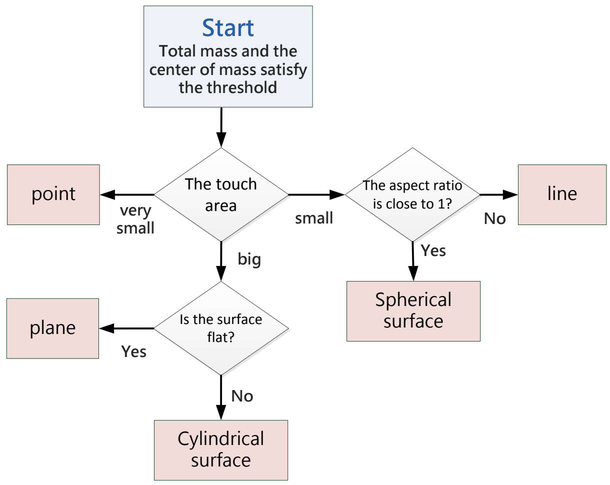

Fig. 6 The procedure of object shape identification.

Table 3 The grasping strategy

Shape	The Suitable Grasping Mode
Cubic	Two finger mode and Parallel grasp
Rectangular Solid	Two finger mode and Parallel grasp
Standing Cylinder	Three finger mode and Parallel grasp
Laying Cylinder	Two finger mode and Envelop grasp
sphere	Three finger mode and Envelop grasp

5. Experiment and Result

The testing objects, including 30 mm, 40 mm, 50 mm in diameter, are put randomly in the 200 x 200 mm 2 workspace. The gripper will find the object and grasp it by itself. Table 4 shows the result of the experiment. Each of the experiment grasps ten times.

Table 4 The successful rate of different objects.

Shape	The Successful Rate in Different Diameter		
	30 mm	40 mm	50mm
Cubic	80 %	70 %	50 %
Rectangular Solid	70 %	80 %	40 %
Cylinder	70 %	60 %	40 %
sphere	80 %	90 %	80 %

6. Conclusion

We have design an underactuated, sensor-rich, and finger configuration changeable gripper. The underactuation mechanism of the gripper provides better configuration adaptability to the objects with various shapes. The gripper can also change its configuration between two-finger mode and three-finger mode, providing yet another level of object shape adaption for better grasping. The fully autonomous algorithm for object search, identification, and pick is developed. The gripped programmed with tactile-feedback control strategy is capable of detecting the object shapes and grasping slipping condition. We have experimentally evaluated that the gripper can grasp and identify objects with various shapes, including sphere, cylinder, cube and rectangular solid.

We are currently developing a more subtle algorithm of the gripper so it can identify and grasp the objects with other shapes, sizes, and compliant properties.

7. Acknowledgements

The authors would like to thank Dr, Jui-Yiao Su and Mr. Yan-Chen Liu from ITRI for their help on developing and testing on the pressure sensor array. This work is supported by Industrial Technology Research Institute (ITRI), Taiwan.

8. References

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具被動自由度與順應性之多重感測回授夾爪

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摘要

提出具有被動順應性以及觸覺感測器之夾爪。夾爪含有三指，每一指皆有安裝扭簧，使其在夾取物體時產生順應性，另外夾爪能轉換三指與兩指的雙重使用模式，以配合不同形狀物體的夾取。整體配置多重觸覺感測器，包含壓力感測陣列、力感測器、電位計和加速規。此外，也提出控制策略，使其能自動地在工作空間中完成搜尋，判別物件形狀，和穩定夾取的任務。整體系統藉由將夾爪安裝在自製的SCARA機械手臂上進行實驗，並驗證其結果。

關鍵字：夾爪、被動順應性、SCARA、形狀辨識