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Design of a Tactile Sensing Robotic Gripper and Its Grasping Method *

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***Abstract*—Although computer vision has the advantages of long detection distance and large amount of information, it also has certain limitations for complex scenes such as dimness, reflections, and smoke. In order to solve the problem of robot grasping in these scenes, we designed a novel gripper that can search, identify and grasp objects based on tactile information. The gripper can effectively grasp the objects in real life, and can sense the shape and posture of the objects through the touch. We proposed a lifting finger structure that allows the gripper to switch between sensing and grasping modes. We applied visual-tactile detection methods to obtain tactile information and propose a feature extraction algorithm based on U-net. We designed a method of grasping the center of mass of the object contour, and the success rate of the grasping can reach 85%. In addition, we also designed experiments to show the feasibility of object searching and grasping by tactile information when visual information is not available.**

I. Introduction

Tactile perception is the most important human sense besides vision and hearing, and it is an important part of human–machine Interaction. When a robot interacts with its environment, such as assembling a workpiece or inserting a pin into a hole, the operator cannot get a realistic feeling from the information provided by the visual images only, but tactile perception technology can provide the operator with more accurate contact information. Therefore, tactile information plays an important role in robot gripping and assembly operations.

People have designed various grippers for complicated operations. Most grippers use camera to obtain the object information for grasping. However, it is difficult to obtain the pose and shape of the object through camera in dark room, reflective space, underwater and other special environments, which leads to the failure of using the visual detection method to complete the grasping. In those situations, tactile sensing cab be used instead. In the past few years, a variety of tactile sensors have been proposed, such as pressure sensitive sensors [1] and piezo-resistive sensors [2]. But they have low resolution and small detection area, which makes it difficult to measure the object accurately in real environments.

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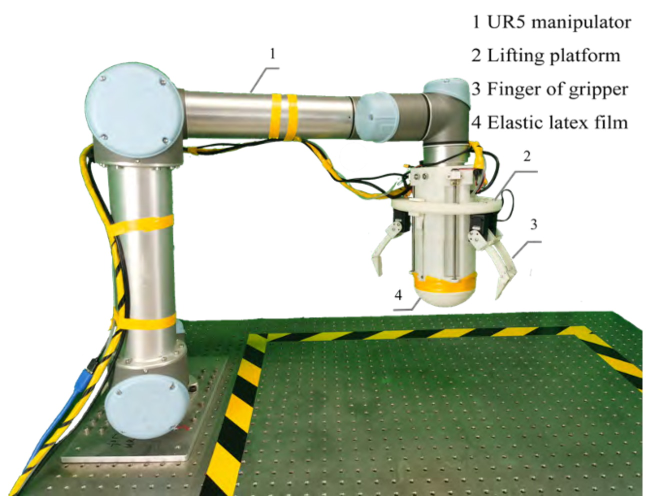


Fig. 1. Tactile sensing gripper attached to a UR5 arm.

In this paper, we design a gripper as shown in Fig. 1, which has strong tactile perception capability and large detection range. The gripper consists of three parts. The first is a vision-based tactile sensor, which uses an inflatable latex film as the outer surface. A built-in depth camera is used to detect the deformation of the elastic inflatable film through U-net [3] to obtain the tactile information. The second part is a three-finger structure with adaptive finger joint. When grasping objects, the three-finger structure and the inflatable elastic latex film can stably hold the object in the center of the gripper. The third part is a lifting platform to assemble the fingers. When searching for objects, the fingers will move away from the sensor; and when grasping, the fingers will be pushed out. The design of the gripper imitates the process of human searching and exploring objects in the dark environment, where the palm is used to search the objects first and then the fingers are used to grasp the objects. The inflatable elastic latex film can be treated as the palm of the gripper. Based on this gripper, we propose a method to grasp various objects in real life.

The contributions of this paper are threefold. First, inspired by the searching-grasping process of humans during blind grasping, a novel finger platform with lifting structure is designed, which can switch between sensing mode and grasping mode to achieve a more stable recognition and grasping. Second, a tactile sensor is designed using elastic inflatable film and a depth camera is used instead of RGB camera to obtain the deformation information, which allows the sensor to have a larger detection area and better resolution than traditional tactile sensors and can acquire the contour information of the objects more accurately. Third, a tactile information extraction method based on image segmentation is proposed, which can realize object recognition and grasping tasks based on tactile information.

The rest of the paper is organized as follows. In Section II, related work on grippers and tactile sensors are introduced. In Section III, the hardware structure of the gripper is introduced. In Section IV, an object recognition algorithm and a grasping method based on feature extraction are proposed. In Section V, two experiments are presented to verify the feasibility of the algorithm. Finally, conclusions are given in Section VI.

II. RELATED WORK

In recent years, a variety of grippers have been designed for different tasks, such as fragile object grasping [4], deformation object grasping [5], etc. When grasping, these grippers also need to use vision or the combination of vision and touch to obtain the pose information of the object. For example, the method of attitude estimation based on depth vision is introduced in [6], and the method of combining vision and touch is used in [7] to grasp objects.

Although vision-based grasping is widely used in daily life, it is sensitive to environmental changes. For example, in dark and smoky environments, visual detection does not work well. In view of this problem, relevant scholars have also studied ultrasound [8] and radar detection [9]. However, these technologies have low resolution and poor reliability, so most of them can only be applied to indoor environment.

In [10], a method of object classification and scene construction through multiple contact with objects is proposed. The fingers of the gripper with tactile sensor are used to touch objects, and the three-dimensional contour information of objects is constructed according to the collision relationship. The traditional tactile sensors, such as piezoelectric sensors, pressure sensitive sensors, and piezoresistive sensors usually have a small detection range, although the detection accuracy is high. In addition, because these sensors are full of electronic components, they have poor flexibility. It is difficult to detect the shape of objects with uneven surface.

Vision-based tactile sensors such as GelSight [11], GelSim [12], and FingerVision [13] have higher resolution. This kind of sensors can sense the texture and shape of the object by collecting the texture information of the surface. Using camera to collect the surface information of the sensor can obtain the geometric deformation of the sensor surface. However, most of these sensors are installed on the fingers, which are small in size, and can only obtain partial information of the object rather than the overall contour.

In [14], a sensor using elastic inflatable silicone film as the surface is proposed. The gripper proposed in this paper is motivated by its design principle. But we have adopted depth camera rather than RGB camera. Compared to RGB camera, the depth camera can directly obtain the deformation of the inflatable elastic silicone film without changing the shape. Therefore, the detection of elastic latex film deformation by using depth camera has higher detection accuracy.

As for the finger design, grippers on the market can be divided into two categories. One is the two fingers gripper, which is widely used in industry [15]. The operation of a two-finger gripper is easy, and the object can be grasped by two parallel fingers close to each other. In addition, because the structure of the two-finger gripper is simple, it has high reliability. The other is the three-finger gripper [16], which can wrap the object to the central axis of the palm during grasping, so it has a larger load. However, in order to make the grasping of objects more stable, the fingers of the three-finger gripper need more degrees of freedom, which leads to a more complex structure. In addition, grippers with more than three fingers are rarely used in industrial applications. Although the gripper with this structure can be highly dexterous, its control complexity is high and its load capacity is poor, so it is often used as a human prosthesis to complete some auxiliary tasks.

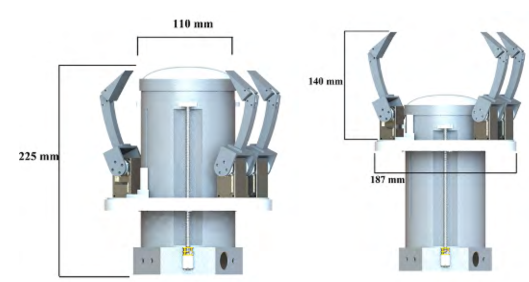
As an important component of the gripper, the tactile sensor is also the basis for the robot to complete dexterous operations. The position of the sensor installation also determines the performance of the gripper. Most of the grippers install the sensor on the fingertip, such as [17], [18]. This design allows the robot to adjust the grasping force more accurately when grasping, but the disadvantage is that it cannot obtain accurate contour information of the object.

III. HARDWARE DESIGN

The gripper imitates the blind grasping behavior of humans, as shown in Fig. 2. When people close their eyes or search for objects in a dark environment, they first use their palms and fingers as a sensor to search and recognize the objects. After finding the target object, they use fingers to complete the grasp.

(a) Search (b) Grab

Fig. 2. People search for objects by tactile information.



(a) Sensing mode (b) Grasping mode

Fig. 3. The gripper structure diagram.
(a) The gripper is in the sensing mode, the lifting platform of the gripper is lowered, and the palm is used to detect the object. (b) The gripper is in the grasping mode, and the lifting platform of the gripper is raised, and the gripper is used to complete the grasping of the object.

Similarly, the gripper can switch between sensing and grasping modes. The structure of the gripper is shown in Fig. 3. In sensing mode, the fingers are moved back to avoid interference with the palm, and the palm is used to search and recognize the objects. While in grasping mode, the fingers are moved out so it can grasp the object.

According to the observation of human searching for objects in the dark environment, the gripper is divided into two parts: finger and palm. The palm includes an elastic latex film, a depth camera and a shell. The fingers are attached to a lifting platform. The overall structure of the gripper is made of light curing 3D printing, which has the characteristics of light weight and low cost. In addition, the surface of the mechanism obtained by this printing method is smoother, which can prevent the leakage of gas.

A. The palm of the gripper

The main function of the palm of gripper is tactile detection. The tactile information is obtained by collecting the deformation of the elastic latex film with the depth camera. The structure of the palm is shown in Fig. 4.

(1) Elastic latex

Compared with silica gel, the elastic inflatable latex film has better flexibility, which allows it to better fit with the shape of the detected object. What's more, inflatable latex film also has a larger detection range than silica gel.

By comparing the indexes of elasticity and tensile property, we have selected 0.4mm latex film as the material of elastic film. This material has elasticity and ductility, and has wear resistance to ensure that the sensor has a long service life.

(2) Shell

In order to reduce the assembly difficulty of the gripper, the shell is divided into an upper part and a lower part. The upper part is composed of the sealed gas chamber of the sensor, and is separated from the lower parts by transparent glass. The air pressure in the air chamber is kept stable by the air pump and the air pressure sensor. Stable air pressure can make the inflatable elastic film stay tight and ensure that the sensor has enough detection area. The lower part is used to install the depth camera, wirings, and inflation valve.

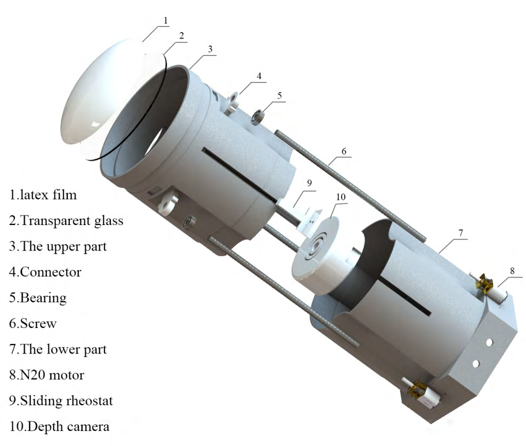


Fig. 4. Assembly exploded view for the palm of the gripper.

The assembly of the sealed air chamber is the most critical step in the production of the shell, and the accuracy of the installation will directly affect the detection performance of the sensor. The required materials in Fig. 5 are as follows: the upper part, transparent glass (In order to ensure that the transparent glass is dust-free, its surface needs to be protected with plastic wrapping paper before the installation), tie-wraps, line, sealant (In order to ensure the air tightness of the air chamber, tie wraps, line and seal are required), latex film, etc. The assembly process of the sealed gas chamber in Fig. 6 is as follows: before putting in the transparent glass, we need to coat the inner side of the shell with sealant to ensure the leakproofness of the gas chamber. After that, put on the elastic latex film and tie it tightly with a rolling strip, seal it with sealant, then replace the strip with string when the sealant is dry, and finally trim off the surplus latex film.

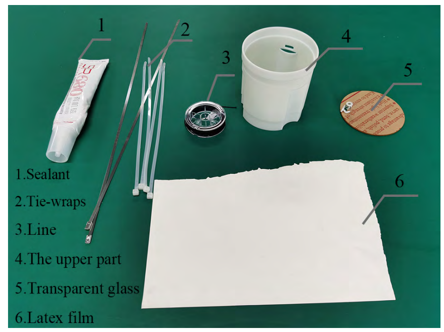


Fig. 5. Materials required for the sealed air chamber.

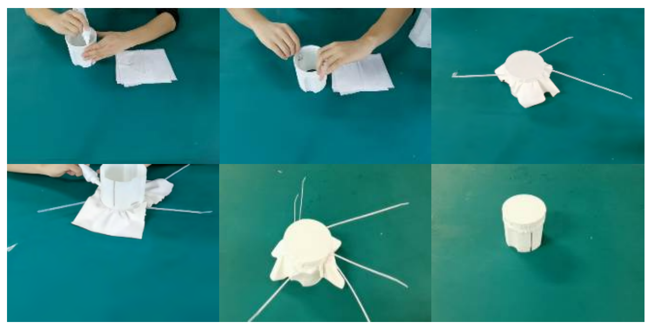


Fig. 6. Manufacturing process of the seal chamber.

(3) Depth camera

In order to obtain the tactile information of the gripper, the deformation information of the latex film is obtained by using RealSense L515 camera. The detection range of the camera is 0.25-9 m, but the minimum detection range can be set to 0.15 m by adjusting the internal parameters. The depth field of view is 70°×55°, the depth output resolution is up to 1024×768, the depth frame rate is 30 fps. The depth accuracy of camera detection is less than 5mm in the range of 1m.

B. The fingers of the gripper

In order to grasp the object, we designed three fingers with passive adaptive joints and a lifting platform, as shown in Fig. 7.

(1) Passive adaptation finger joint

In order to improve the success rate of grasping objects, an elastic finger joint with passive adaptability is designed. The grasping process is shown in Fig. 8. The structure can keep the end link of the finger parallel to the desk, which is conducive to more stable grasping of the object. In addition, the gripper can bend passively after contacting with the object so it can avoid broken due to excessive pressure.

We use LX-15D servo as the actuator for the finger joint. The precision of the servo is 0.24°, the torque is 17 KG.cm (7.4v), and serial bus communication mode is used.

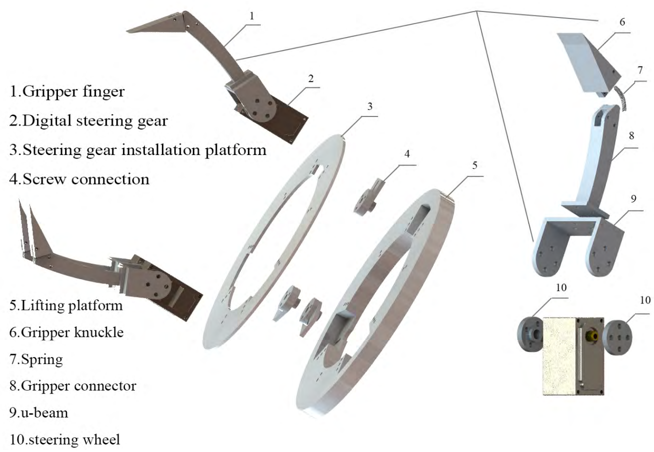
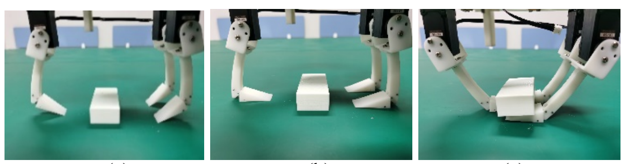


Fig. 7. Assembly exploded view for the fingers of the gripper.



(a) (b) (c)

Fig. 8. Finger variations during the grasping process.(a) The gripper approaches the target object. (b) The fingers touch the table and bend passively to keep the end link parallel to the table. (c) The fingers are closed to complete the grasping of the target object.

(2) Lifting platform

In order not to affect the detection of the sensor, the finger platform of the gripper is designed as a lifting structure. The finger platform is driven by three 12V reduction ratio (1:150) N20 metal gear motors, which have small volume and large torque. At the same time, a sliding resistor with a length of 128 mm and resistance of 10kΩ is used to give feedback on the position of the lifting platform, where the position is obtained through the resistance value. This structure is simple and have high stability.

C. Circuit system

The circuit system mainly includes a central control circuit, a pneumatic control circuit and an actuator driving circuit. The central control circuit consists of a main control board and a voltage stabilizing module. The air pressure control circuit includes an air pressure sensor and an air pump. The driving circuit of the actuator includes N20 metal motor, servos, and their driving modules.

The main control board adopts Arduino Mega 2560, the input voltage is 12.8v and is stabilized to 12V through the voltage regulator module, the N20 motor driver is L298N, and the air pump is Kamoer kvp300-kd brushless DC motor, which can produce 0.1MPa positive pressure and -0.05mpa negative pressure.

IV. METHODOLOGY

Compared to silica gel, elastic inflatable film has better elasticity and deformation capability. After inflation, it will become a hemispherical shape, and its shape is related to the area and the air pressure inside the sealed air chamber. When it contacts with an object, the shape of the elastic film and the air pressure of the air chamber will change at the same time, it is difficult to extract the tactile information through mathematical modeling. So we design a recognition and classification algorithm based on feature extraction. In order to improve the generalization of the algorithm, we use the method of feature extraction before classification, which can achieve good detection results for both known and unknown objects. The tactile information processing and grasping procedure is shown in Fig. 9. The related algorithms are introduced below.

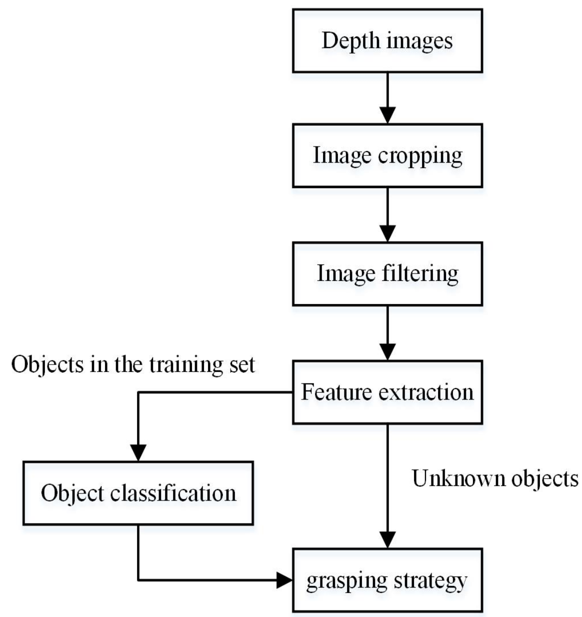


Fig. 9. Data processing flow chart.

A. Image processing

The original image detected by the depth camera is shown in Fig. 10. Due to the influence of camera perspective and environmental changes, there are many noises in the center and edge of the image, so it is necessary to preprocess the image.

Image clipping: Because the angle of view of the depth camera will be larger than that of the elastic inflatable film, there will be uncertain noise when the edge of the film is detected. In order to reduce the influence of noise, the edge of the image is clipped. The depth image obtained by clipping is shown in Fig. 11.

Image filtering: The depth camera collects the depth information first through the IR transmitter and receiver. However, because there is a layer of transparent glass between the elastic film and the camera, according to the principle of reflection, there will be a bright spot in the center of the depth camera. Therefore, we filter the image and get the result as shown in Fig. 12. However, it should be noted that image filtering can only reduce the impact of reflections, but cannot completely eliminate it.

Two examples of the depth images after preprocessing are given in Fig.13, including a triangular prism and a cube.

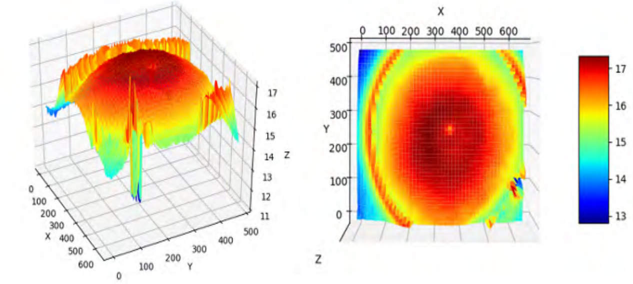


Fig. 10. Original image.

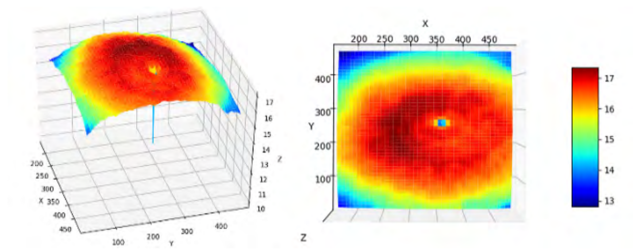


Fig. 11. Clipped image.

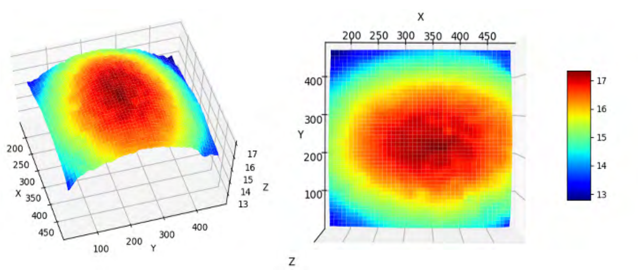
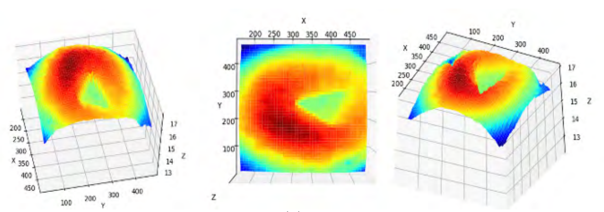
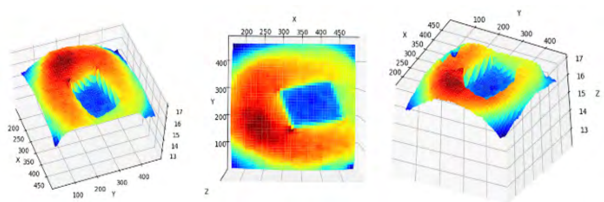


Fig. 12. Filtered image.



(a)



(b)

Fig. 13. Examples of image after preprocessing.
(a) Image for a triangular prism. (b) Image for a cube.

B. Feature extraction

In sensor tactile information extraction, we use U-net image segmentation algorithm to extract sensor deformation information. The problem of sensor feature extraction is regarded as a image segmentation problem based on depth image. U-net network can classify the image at pixel level, so that the tactile information can be separated from the elastic film. The input information of the U-net is the preprocessed depth image collected by the depth camera, and the output is the segmented depth image.

In order to collect the dataset of image segmentation, we choose five common objects in daily life as the tested objects. As shown in Fig. 14, they include a screw, a hex key, a USB drive, and a test tube. We collect the depth image as a dataset when the sensor contacts with different objects.

After the completion of data acquisition, we screened out a total of 500 training images and 200 test images, and then used the annotation software to annotate these images at the pixel level. The image is divided into two areas. One is the deformation area due to the contact between the sensor and the object, and the other is the area where the elastic film of the sensor does not contact with the object.

Fig. 14. Test objects.

Different from using RGB image for training, depth images have only one-dimensional data, so model training is faster. It has 93% segmentation accuracy when training to the 50th epochs. The result of the image segmentation is shown in Fig. 15, where the blue curve indicates the outline of the segmented area. This result proves the feasibility of feature extraction using U-net for the vision-based tactile sensor with inflatable structure.

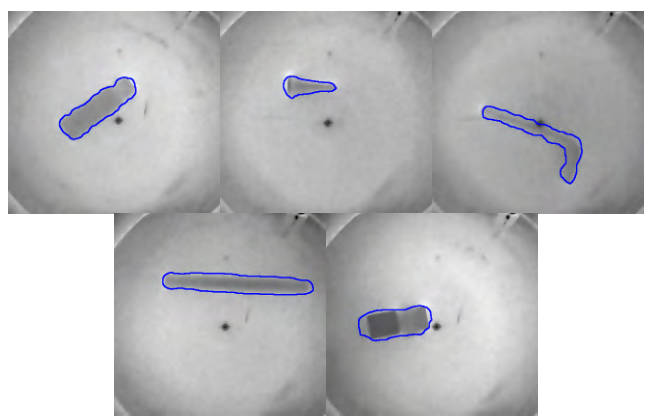


Fig. 15. image segmentation of the image.

C. Image classification

In order to complete the search task based on tactile information, we need to do object classification after feature extraction. The contour information of the object obtained in the previous step is used for classification.

We design classification model based on convolutional neural network. Compared with MLP (Muti-Layer Perception) network, CNN (convolutional neural network) has fewer parameters, and can deal with the relationship between pixels in the image, so it has better detection accuracy. As shown in

Fig. 16, we design a network model with three layers of convolution network, and use the contour information of the object after feature extraction for training. The classification accuracy reach 98.5%, which proves the effectiveness of the network in model classification.

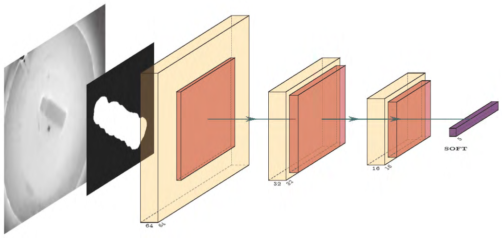
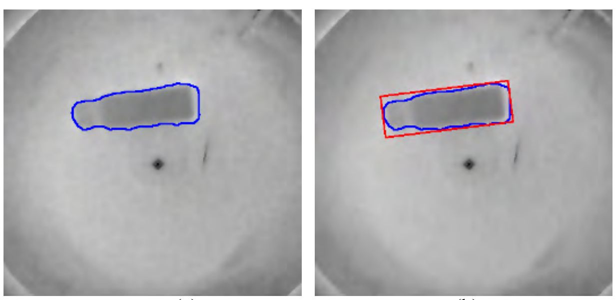


Fig. 16. CNN classification network structure.

D. Grasping strategy

Due to the three-finger structure of gripper, the fingers can wrap the object when grasping an object. Therefore, for the object with uniform mass distribution, the grasping can be completed according to the contour information of the object, as shown in Fig. 17.



(a) (b)

Fig. 17. The gripper gripping method. (a) shows the image after feature extraction. The red line in (b) indicates the smallest outer rectangle of the contour.

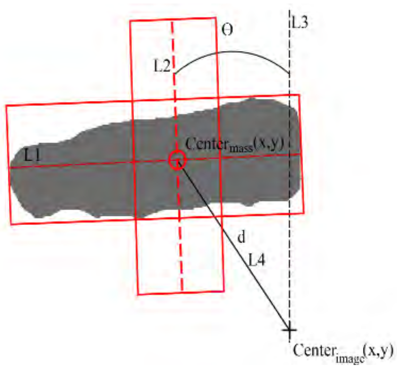


Fig.18. Grasping parameters.

Taking the contour information detected in Fig. 17 as an example, the calculation method is shown in Fig. 18. Using the center-of-mass detection function built into the Opencv image processing library to obtain the position of the object as $Center_{mass}(x,y)$, the coordinate of the image center is $Center_{image}(x,y)$, the Euclidean distance between the image center and the centroid of the object is d, and the center line of the minimum circumscribed rectangle is L1. Make the vertical line of L1 in $Center_{mass}(x,y)$ to get L2. The angle between L2 and the image center line L3 is Θ. Thus we get the position of the object with reference to the center of the sensor as $Center_{mass}(x,y)$, the relative distance as d, and the attitude angle with reference to the gripper as Θ.

After obtaining the relevant parameters, a simple strategy is used to ensure a stable grasp. We first adjust the position and orientation of the gripper by controlling the gripper to move the distance of d along the direction from the image center to the object centroid, and rotate the angle of Θ. Then grasping is proceeded by closing the fingers.

V. Experiments

In order to verify the feasibility of gripper searching and grasping objects by tactile sensing, we installed the gripper on a UR5 arm and designed two experiments: the unknown object grasping and the known object searching and grasping.

A. Grasping of unknown objects

We chose five unknown objects out of the training set to take experiment, including batteries, tapes, wrenches, remote controls, and metal profiles. These objects are common in real life, and have different shapes and masses. Each object is grasped for twenty times. The movement of the arm is controlled to make the gripper close to the object.

The air pressure sensor is used to detect whether the sensor is in contact with the object. When the gripper contacts the object, the air pressure in the sensor increases rapidly due to the collision so that the mechanical arm stops moving down. Then the image segmentation network is used to extract features and the object is grasped according to the profile information of the object. The process is shown in Fig. 19. As shown in Fig. 20, the overall success rate of grasping is more than 85%, which proves the feasibility of the designed gripper to grasp objects through touch. The main reason for grasping failure is that the object's pose changes during the grasping process and slips off.

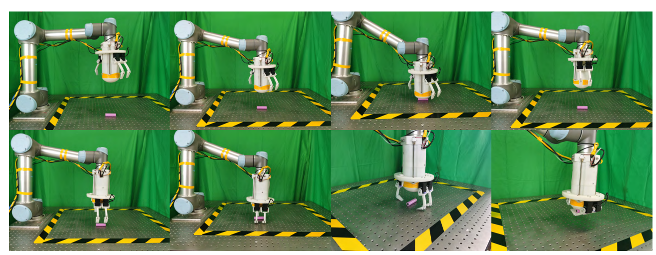


Fig. 19. The gripper gripping process.

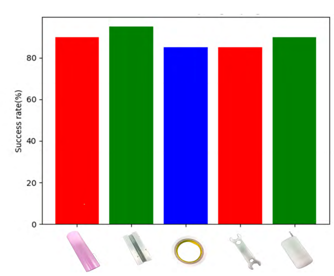


Fig. 20. Success rate of grasping objects.

B. Searching for known objects

In order to verify the capability of searching, recognizing, and grasping in dim, smoke, reflective environment, a search experiment based on tactile information is designed. The object is randomly placed in the detected area of the manipulator operating desk, and the object searching and grasping task is completed by the gripper. The selected object is the object in the previous training data set (screw, hex key, USB drive, and test tube).

We divide the detection region into 6×6 regions. The size of each region is designed according to the area of latex film on the surface of the gripper. Firstly, the gripper moves to the initial position of the detection region. Then, we transform the gripper into the searching mode and search the detection region grid by grid.

The gripper maintains the searching mode and moves downward. When it contacts with the object, the pressure sensor detects the sudden change of air pressure and stops moving downward. The depth camera is used to collect images, extract features and recognize the detected objects. If it is the target object, the gripper is transformed into grasping mode, and the grasping angle is adjusted according to the pose of the object to complete the grasping. If not, raise the gripper to the initial height and move to the next searching grid. Repeat the above process until the target object is detected. The operation process is shown in Fig. 21.

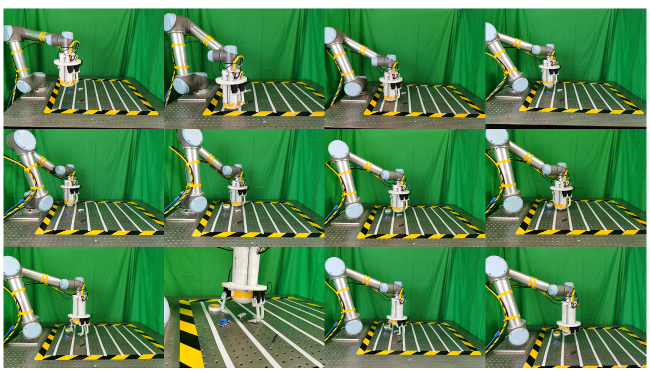


Fig. 21. Searching and grasping process.

The success rate of this experiment mainly depends on the grasping stage, and the sliding of objects during the detection process can have a significant impact on the grasping results. Twenty times of searching and grasping experiments are carried out. The probability of successfully searching and recognizing the object contour when grasping a known object is more than 90% and the overall success rate of searching and grasping is 80%, which proves the feasibility of the designed gripper to complete object searching task through tactile information.

VI. CONCLUSION & FUTURE WORK

In this paper, we propose an effective solution to the problem of grasping objects in dim, reflective, smoke, and other environments that cannot be detected by vision. In order to solve this problem, we design a gripper of tactile sensor with large detection range and strong flexibility. The sensor adopts a vision-based tactile detection scheme, and uses elastic inflatable film instead of elastic silicone film as the surface of the sensor, which greatly improves the detection range as well as the detection accuracy. And a depth camera is used instead of RGB camera to obtain the deformation information of the elastic inflatable film directly, which simplify the information reconstruction and reduce the modeling error significantly. We also designed a retractable finger platform to allow the gripper to switch between searching and grasping modes, which imitates the process of human blind grasping. Experimental results show that the success rate of grasping is more than 85%, and the success rate of searching and grasping is 80%, which verifies the effectiveness of the solution.

In the future, we plan to use depth camera with a smaller minimum detection distance so that the size of the gripper can be reduced and the flexibility of the gripper can be improved. Besides, by adding a tactile sensor to the fingers, the success rate of grasping might be improved. Finally, by improving the material and sealing performance of the gripper, it also has potential to grasp turbid underwater objects.

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