Passive Actuator-Less Gripper for Pick-and-Place of a Piece of Fabric

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Abstract—In this paper, we propose a Passive Actuator-Less Gripper (PALGRIP) for picking a piece of fabric from a stack of fabric parts and placing the picked fabric part. The picking of a piece of fabric from a stack is a simple but difficult process to automate. The proposed gripper can pick a piece of fabric from the stack by simply pressing the fingertips of the gripper against the stack. The fingers are closed and opened by the relative motion between the fingers and the housing of the gripper. The grasping motion of the gripper is generated by two mechanisms: a passive pinching mechanism and a self-locking mechanism. These mechanisms allow the fingers to perform open and close movements and to maintain the fingers in either open or closed state. The kinematics of the mechanisms are analyzed to design the gripper. The relation between the movement of the fingers and the force required to operate the gripper is also investigated through static force analysis and the experiment. Finally, experiments using PALGRIP are conducted, and the experimental results illustrate how the pick-and-place operations are carried out using the prototype of PALGRIP. The proposed gripper allows the robot to automate fabric pick-and-place operations easily by attaching it to the robot's endpoint.

Index Terms—Mechanism design, Robot gripper, Passive mechanism.

I. INTRODUCTION

MUCH effort has been made in the garment manufacturing industry to overcome the shortage of skilled workers. There are many different processes involved in making a garment from fabric, such as cutting, picking, gripping, placing, folding, sewing, pressing, etc. Fabric pick-and-place is one of the most commonly used operations in these processes, such as destacking a piece of fabric from stacked pieces to place it for the automated process.

The pick-and-place of a piece of fabric is difficult to automate and is usually carried out by a human worker for operating automatic systems, such as pocket setters [1] and automatic fusing machines [2]. Today’s so-called automatic systems are designed to automate a part of a process so that workers can operate it without much training. Most of the workers operating the automatic machines are involved in the pick-and-place operation. How to robotize the pick-and-place of fabric parts is one of the key issues in automating garment production.

Several research studies have been carried out on grasping a piece of fabric, and various robot hands for grasping fabric parts have been developed using vacuum or electrostatic force to secure a fabric part on the hand [17]–[23]. Some hands hold a fabric part by sticking small needles to the piece of the fabric part [16]. However, using these robot hands requires power sources, such as air supply and electricity. If we could design a robot hand without any power supply, the robot hand would be much easier to implement on the robot.

In this paper, we propose a novel gripper, Passive Actuator-Less Gripper (PALGRIP), for picking and placing a piece of fabric. Fig. 1 shows a prototype of PALGRIP. This gripper has two fingers to pinch the fabric, and the fingers move relative to the housing of the gripper as defined by the groove cams. By pressing the fingertips of the gripper against the fabric on the stage, the fingers’ motion is constrained by the stage, and the housing moves relative to the fingers. The relative motion is used to make the fingers open and close. While the fingers are moving on the fabric, friction is generated between the fingertips and the fabric. This frictional force and the movement of the fingers slightly lift up the fabric and pinch the lifted fabric with its fingers. Due to this structure, the manipulator can grasp the fabric simply by pressing the gripper against the fabric.

The contribution of this paper is as follows:

- A novel passive actuator-less gripper (PALGRIP) is proposed to pick-and-place a piece of fabric. The proposed
A gripper that uses needles or electro-adsorption at its fingertips has been proposed. Yamazaki et al. proposed a gripper with a cylindrical brush roller on the fingers to hook up the fabric and roll it up [15]. Ku et al. proposed a soft robotic gripper that has micro-needles to increase the friction between the gripper and the fabric [16]. Digumarti et al. developed a gripper with electroadhesive skin on the fingertip and demonstrated that the gripper can grasp several types of fabrics [17].

A gripper that picks up and holds a piece of fabric by attracting force has also been studied instead of grippers with fingers. Adsorption methods include the use of the electrostatic force [18]–[20], and the use of suction force [21]–[23]. This type of gripper is easier to operate than the finger-type gripper, although additional power source is required to generate electrostatic or suction force.

B. Passive Gripper

Several studies on grippers that do not use any actuators to grasp objects have been reported. Arisumi et al. developed a passive gripper for catching an object by the casting manipulation [24]. Each finger of the gripper is naturally closed by the elastic force of the spring. The gripper’s fingers are maintained open to allow mechanical hooks before the gripper is thrown to the object. When the palm part of the gripper hits the object, the hooks to fix the fingers are released. Finally, the fingers are closed by the spring, and the gripper grasps the object.

Sakai et al. proposed a pick-and-place hand mechanism using link and gear mechanisms for agricultural robots [25]. The mechanism called c-FFSS which consists of a gravity gear, a state gear, an I/O bar, and a cylinder was designed to switch the picking state and the placing state of the gripper. The finger connects to the I/O bar of c-FFSS through links. The finger closes and picks the object when the fingertip contacts the ground, and the finger opens and releases the object when the fingertip contacts the ground again.

Ottonello et al. also proposed a passive gripper using a push-latch mechanism [26]. The finger of this gripper is composed of the link mechanism. The fingers close to pinch the object when the object to be grasped is pressed against the center link between the two fingers. The center link is connected to the cam mechanism, and the state of the gripping is changed by the cam.

Passive grippers have been developed for the aerial robot to grasp an object or to land on perches [27], [28]. Hsiao et al. presented a fully passive mechanism without using any actuators for a gripper [27]. The fingers of the gripper are connected to each other through a link mechanism. When the center link between two fingers is pressed by the object, the fingers close. A bistable mechanism, proposed by the authors, controls the opening and closing state of the gripper using the force applied to the fingers.

Firouzeh et al. presented a passive dynamic gripper inspired by the structure of bird legs, in which the claws are activated by the impact energy when the gripper contacts the object to be grasped [28]. The claws of the gripper are closed at high speed using elastic tendons when an impact is applied to the base of the gripper. In addition, a tendon-locking mechanism using an electrostatic adsorption clutch has been developed to keep the claws closed.
Fig. 2. PALGRIP grasps a piece of fabric while the fingers push the piece of fabric on the stage. The relative motion between the housing and the fingers is used to open and close the fingers. The fingers pinch the piece of fabric utilizing the friction between the fingertips and the piece of fabric and the movement of the fingers generated by the relative motion.

Fig. 3. Simplified mechanical diagram of PALGRIP. (a) The open state of the gripper. (b) The closed state of the gripper. The blue box represents the passive pinching mechanism, the orange box represents the self-locking mechanism, and the red box represents the spring.

Fig. 4. The open-to-close motion of the passive pinching mechanism. The fingers move along the shape of the finger groove cams when the pushing force applies to the fingertips. The horizontal and vertical linear sliders constrain each finger to move horizontally and vertically.

Fig. 5. The motion of the self-locking mechanism. The SL pin always moves clockwise along the groove of the heart cam in this figure. The state depends on the position of the SL pin. (a) The SL pin is located at the bottom of the heart cam, and the gripper is opened state. (b) The SL Pin moves from the bottom to the top of the heart cam. (c) The SL pin moves from the top to the middle point of the heart cam. (d) The SL pin moves from the middle point to the top of the heart cam. (e) The SL pin moves from the top to the bottom of the heart cam, and the gripper becomes an open state.

Passive grippers use contact between the gripper and the environment or an object to grasp and release the object. By controlling the motion of the passive gripper, the gripper can grasp or release an object. These grippers have been designed for grasping a rigid object [24]–[28]. In this paper, we propose a passive gripper for grasping a piece of fabric.

III. GRIPPER DESIGN

A. Structure of the Gripper

Consider picking up a piece of fabric from a single layer or from a stack of fabric pieces that are laid flat. There are various approaches proposed so far as described in Section II. PALGRIP, which we propose in this paper, picks up a piece of fabric by pinching it.

Fig. 2 shows how PALGRIP grips the fabric. When the fingertips of PALGRIP come into contact with the fabric on the flat stage, the movement of the fingers in the direction perpendicular to the stage is constrained by the stage, while their movement along the surface of the stage is generated by the relative movement between the housing and the fingers. The motion of the fingers along the surface of the stage and the friction between the fingertips and the fabric achieve successful pinching. Once closed, the fingers are kept closed by a mechanism that locks the relative movement between the housing and the fingers. The locked state is mechanically released when the closed PALGRIP comes back into contact with the stage. In this way, the manipulator can perform a pick-and-place operation simply by pressing the PALGRIP against the fabric on the stage and the gripped fabric on the stage.

The mechanical structure of PALGRIP is shown in Fig. 3. PALGRIP consists of two mechanisms: a passive pinching mechanism and a self-locking mechanism. The passive pinching mechanism is used to convert the relative movement between the housing and the fingers into the open-and-close movement of the fingers. The self-locking mechanism is used to keep the fingers closed once they are pinched.
to switch between open and closed finger states. Combining these mechanisms allows the fingers to perform open and close movements and maintain the fingers in an open (Fig. 3a) or closed state (Fig. 3b).

Fig. 4 shows the mechanical structure of the passive pinching mechanism. The passive pinching mechanism consists of two fingers, one vertical slider, and two horizontal sliders. Each finger has a finger groove cam connected to a horizontal linear slider. The finger groove cam consists of an inclined part and a vertical part. The pin for the finger groove cam, the vertical slider, and the upper end of the spring are fixed to the housing.

When the pushing force is applied to the fingertip, the relative motion between the fingers and the housing is generated, and the finger moves along the inclined groove relative to the housing. The movement of each finger is constrained by the horizontal linear slider that is attached to the vertical linear slider attached to the housing. As a result, both fingers move symmetrically, close when the force is applied to the fingertips, and open again when released by a spring installed between the horizontal slider and the housing.

Our proposed self-locking mechanism consists of a self-locking groove cam (SL groove cam) and a heart cam as shown in Fig. 5. A heart cam is widely used in push-latch mechanisms to change the open/closed state of the door [29]. The vertical linear slider of the passive pinching mechanism is connected to the SL groove cam, and the SL groove cam moves vertically together with the vertical linear slider.

When the fingers are in the open state as shown in Fig. 3a, the SL groove cam is located at the bottom of the heart cam as shown in Fig. 5a. When the fingers are pushed, the SL groove cam, which moves together with the vertical linear slider, goes upward along the vertical linear slider. The self-locking pin (SL pin) also moves along the SL groove cam and the groove of the heart cam until it reaches the top of the groove of the heart cam as shown in Fig. 5b, and the fingers are closed.

When the fingers are pushed again and the SL groove cam goes up, the SL pin moves along the groove of the heart cam as shown in Fig. 5c. When the pushing force is removed, the SL groove cam goes downward, returning to the initial position as shown in Fig. 5d, and the fingers are open. This heart cam groove structure is designed so that the SL pin moves unidirectionally along the heart cam groove.

Based on these mechanisms, the prototype of PALGRIP is designed as shown in Fig. 6. PALGRIP consists of two fingers, a slider base, a spring and a housing. The slider base has the SL groove cam and a horizontal linear slider rail. The two fingers are connected to the slider base via horizontal linear sliders, which slide along the rail. The housing has four fixed pins, the straight grooves for the slider base, and two heart cams. The slider base moves along the vertical grooves of the housing. The two fingers have two finger groove cams and a horizontal slider, which is attached to the rail of the slider base.

To increase the friction between the fingertips and the fabric, a flexible rubber is attached to the fingertips. When the fingers of the gripper are fully closed, the rubbers deform. The deformation allows the gripper to grip different thicknesses of fabric and helps it maintain its grip on the fabric.
B. Kinematics

We analyze the relation between the vertical and horizontal finger displacements of the passive pinching mechanism relative to the housing. Let us consider a one-finger model as shown in Fig. 7a, where the pin for the finger groove cam and the base of the vertical linear slider are fixed to the housing. The finger groove cam consists of the inclined part and the vertical part. Let the angle of the finger groove cam be $\theta_{\text{cam}}$, the length of the inclined part of the finger groove cam be $l_{\text{cam}}$ and the length of the vertical part of the finger groove cam be $h_v$. Then, the vertical and horizontal displacements of the finger relative to the housing, $h_{\text{pp}}$ and $w_{\text{pp}}$, are calculated as follows for given $l_{\text{cam}}$ and $\theta_{\text{cam}}$:

$$w_{\text{pp}} = l_{\text{cam}} \sin(\theta_{\text{cam}}), \quad (1)$$

$$h_{\text{pp}} = l_{\text{cam}} \cos(\theta_{\text{cam}}). \quad (2)$$

On the other hand, for given $h_{\text{pp}}$ and $w_{\text{pp}}$, the $\theta_{\text{cam}}$ is calculated as

$$\theta_{\text{cam}} = \tan^{-1} \left( \frac{w_{\text{pp}}}{h_{\text{pp}}} \right). \quad (3)$$

Considering the horizontal displacement of two fingers, the opening width of the fingers, $w_i$, is expressed as follows:

$$w_i = 2w_{\text{pp}}. \quad (4)$$

These relations are used for the design of the passive pinching mechanism later.

Consider the relation between the vertical displacement of the SL groove cam and the self-locking mechanism. Since the SL groove cam is connected to the finger, its displacement relative to the housing is caused by the finger groove cam. Let us define the parameters of the self-locking mechanism, $h_{\text{hc}}$ and $h_{\text{lock}}$, as shown in Fig. 7b. $h_{\text{hc}}$ is the moving distance of the SL groove cam from the bottom to the top of the heart cam. $h_{\text{lock}}$ ($< h_{\text{hc}}$) is the moving distance of the SL groove cam from the top to the middle point of the heart cam, in which the gripper’s motion is locked.

Since $h_v$ is the length of the vertical part of the finger groove cam as defined before, the following relations hold:

$$h_{\text{hc}} = h_{\text{pp}} + h_v, \quad (5)$$

where

$$h_v \geq h_{\text{lock}}. \quad (6)$$

C. Force Analysis

Let us consider the static relation between the displacement of the fingers and the pushing force applied to the fingers. As shown in Fig. 3, the horizontal slider of the passive pinching mechanism is connected to the spring. Note that in the prototype, the horizontal slider of the passive pinch mechanism is a part of the slider base connected to the spring. Note also that the friction between the SL pin and the SL groove cam is assumed to be negligibly small since the motion of the SL groove cam is not related to the pinching motion of the fingers.

Let us consider the relation between the pushing force applied to the fingertips and the displacement of the fingertips. Let a spring coefficient be $k$ and the displacement of the spring be $x_s$. Let the offset displacement of the spring in the housing be $x_{\text{offset}}$, then the elastic force of the spring $F_s$ is calculated as

$$F_s = k(x_s + x_{\text{offset}}). \quad (7)$$

The offset displacement, $x_{\text{offset}}$, is used to keep the fingers open when the pushing force is not applied to the fingers. Let $F_{\text{ext}}$ be the external forces applied to the fingertip $i$ ($i = 1, 2$) and $\Delta h$ be the vertical displacement of both of the fingertips.
from its initial position as shown in Fig. 8. Let $F_{\text{ext}}$ be the total external forces applied to both of the fingertips, then

$$F_{\text{ext}} = F_{\text{ext},1} + F_{\text{ext},2} \quad (8)$$

The external force applied to each fingertip, $F_{\text{ext},i}$, is decomposed by the pin and the finger groove cam into a force along the finger groove cam $F_{\text{f}}$ and a force perpendicular to the finger groove cam $F_{\text{p}}$, as follows:

$$F_{\text{f}} = F_{\text{ext},i} \cos \theta_{\text{cam}}, \quad (9)$$

$$F_{\text{p}} = F_{\text{ext},i} \sin \theta_{\text{cam}}. \quad (10)$$

$F_{\text{f}}$ is the force to move the finger $i$ along the finger groove cams of each finger.

In this analysis, we assume that friction is generated in the sliding parts of the actual mechanism. The frictional force in the vertical motion of the finger is defined as $F_{\text{v},i}$, and the frictional force in the horizontal motion of the finger is defined as $F_{\text{h},i}$. Since the finger moves along the finger groove cam, the frictional force in the direction of the finger groove cam is defined as $F_{\text{f},i}$, and $F_{\text{h}}$ is calculated as

$$F_{\text{h}} = \sqrt{F_{\text{h},i}^2 + F_{\text{f},i}^2}. \quad (11)$$

$(F_{\text{h},i} - F_{\text{f},i})$ is decomposed into vertical and horizontal forces $F_{\text{v},i}$ and $F_{\text{h},i}$. $F_{\text{v},i}$ and $F_{\text{h},i}$ are calculated as

$$F_{\text{v},i} = (F_{\text{h},i} - F_{\text{f},i}) \cos \theta_{\text{cam}}, \quad (12)$$

$$F_{\text{h},i} = (F_{\text{h},i} - F_{\text{f},i}) \sin \theta_{\text{cam}}. \quad (13)$$

Substituting (9) into (12) yields

$$F_{\text{v},i} = F_{\text{ext},i} \cos^2 \theta_{\text{cam}} - F_{\text{f}} \cos \theta_{\text{cam}}. \quad (14)$$

Let the total vertical force, $F_{\text{v}}$, and the total friction force, $F_{\text{f}}$, be defined as follows:

$$F_{\text{v}} = F_{\text{v},1} + F_{\text{v},2}, \quad (15)$$

$$F_{\text{f}} = F_{\text{f},1} + F_{\text{f},2}. \quad (16)$$

Then,

$$F_{\text{v}} = k (\Delta h + x_{\text{offset}}) = F_{\text{v}}. \quad (17)$$

The relation between $\Delta h$ and $F_{\text{ext}}$ is expressed as follows:

$$F_{\text{ext}} = \frac{k(\Delta h + x_{\text{offset}})}{\cos^2 \theta_{\text{cam}}} = F_{\text{f}} \cos \theta_{\text{cam}}. \quad (18)$$

Since the direction of the total frictional force $F_{\text{f}}$ depends on the direction of the fingers’ movement as follows:

$$\begin{cases} F_{\text{f}} & (\Delta h \geq 0) \\ -F_{\text{f}} & (\Delta h < 0) \end{cases} \quad (19)$$

As mentioned in Section III, the finger groove cam of the passive pinching mechanism has two parts: the inclined part and the vertical part, and the inclined angle of the finger groove cam $\theta_{\text{cam}}$ is expressed as follows:

$$\theta_{\text{cam}} = \begin{cases} \Delta h \leq h_{pp} \\ 0 & (\Delta h > h_{pp}) \end{cases} \quad (20)$$

IV. SPECIFICATION OF DESIGN PARAMETERS

Let us consider how the design parameters of the PALGRIP are specified for a given open width of the finger, $w_{pp}$. $w_{pp}$ is calculated by (4). Based on the relations from (1) to (3), we need to specify two parameters, the vertical displacement $h_{pp}$, and $\theta_{\text{cam}}$. The specification of these parameters is not so simple.

For a given $w_{l}$, the dimension of the gripper is desired to be small, which is related to $h_{pp}$. To specify a small $h_{pp}$, we need to select a large inclined angle of the finger groove cam $\theta_{\text{cam}}$, from (3). Unfortunately, the large inclined angle $\theta_{\text{cam}}$ increase the force to close the fingers as shown in (8). $h_{pp}$ is related to the design and fabrication of the heart cam. We could not fabricate a small heart cam and $h_{pp}$ could not be small.

In the design of the prototype of PALGRIP, we experimentally determined $\theta_{\text{cam}} = 10^\circ$ for given $w_{l} = 4.0$ mm. Using these parameters, $h_{pp}$ was calculated by (2) as follows:

$$h_{pp} = \frac{2.0}{\tan(10^\circ)} \approx 11.34 \text{ mm}. \quad (21)$$

$h_{v}$ is determined to satisfy (6). Considering the fabrication of the heart cam and the diameter of the SL pin, we determined $h_{v} = h_{\text{lock}} = 10.0$ mm. Hence, $h_{hc}$ is calculated as 21.35 mm by (5).

A spring with a spring constant $k$ of 1.16 N/mm and a natural length of 35 mm was used for the prototype. Pre-load is applied to the spring to keep the fingers open when the pushing force is not applied to the fingers and the spring is mounted in the housing so that the $x_{\text{offset}}$ is 5 mm relative to the natural length. The maximum external force $F_{\text{max}}$ required to close the fingers is estimated by (8) as

$$F_{\text{max}} = 1.16 \times (21.34 + 5.0) \approx 30.55 \text{ N}. \quad (22)$$

In the actual prototype, the required maximum external force is greater than $F_{\text{max}}$ because of the effects of friction inside the mechanism. The design parameters of the prototype of PALGRIP are shown in Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
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<td>$x_{\text{offset}}$</td>
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<td>mm</td>
</tr>
<tr>
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</tr>
<tr>
<td>$h_{\text{lock}}$</td>
<td>10.0</td>
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V. EXPERIMENT

We carried out three experiments to demonstrate the performance of the prototype of PALGRIP. In the first experiment, the pushing force of the gripper is measured to investigate the result of the force analysis in Section III-C. For the second experiment, a simple motion planning of the manipulator to use the gripper is implemented, and the picking up of a piece
of fabric on a stage using a single manipulator is conducted. In the third experiment, a dual-arm manipulator system is used to pick-and-place one piece of the fabric from a stack of fabric pieces to evaluate the success rate of grasping a fabric from the fabric stack.

A. Displacement of Fingers and Pushing Force

Fig. 9 shows the experimental system. The experimental system consists of an industrial manipulator (Denso: VS068), a force and torque (F/T) sensor (ATI Industrial Automation: Axia80-M8) attached to its endpoint, and the prototype PALGRIP attached to the F/T sensor. A desktop PC (CPU: Intel Core i9-11900K, Memory: 64 GB, OS: Windows and INtime) is used to control the manipulator in real-time.

In the experiment, the position where both of the gripper’s fingertips are in contact with the stage with the vertical displacement of the fingers $\Delta h = 0$. Then, the endpoint of the manipulator is moved from the reference position, $\Delta h = 0$, in the direction of pushing the gripper toward the stage. Since the maximum displacement of the fingers of the gripper is 21.35 mm from Table I, $\Delta h$ is varied between 0 and 21 mm in 1 mm increments. After the fingers have reached their maximum displacement ($\Delta h = 21$), the endpoint of the manipulator is moved upward from the stage 1 mm at a time until the gripper reaches a locked state ($\Delta h = 11$).

Once the finger is locked, the finger is pushed into the stage again, 1 mm at a time. When the finger is pushed in again to the maximum displacement ($\Delta h = 21$), the endpoint of the manipulator is moved upward from the stage 1 mm at a time to the initial position ($\Delta h = 0$). At each position, the F/T sensor measures the force to push the fingers in, i.e., the external force applied to the finger $F_{ext}$. The force measurement is performed five times by repeating the same experiment.

Fig. 10 represents the relation between the displacement of the fingers and the measured force in each state transition of PALGRIP. Each graph in Fig. 10 plots theoretical force calculated by (18) and measured force. Fig. 11 shows all of the plots from Fig. 10 together. In calculating the theoretical pushing force, the frictional force shown in Table II were assumed because it is very difficult to measure the friction inside the mechanism. The friction force was estimated based on the experimental results.

As shown in (18) and (19), the theoretical force varies

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**TABLE II**

**ASSUMED FRICTION OF THE MECHANISM**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</tr>
<tr>
<td>$F_{fv}$</td>
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with the direction of finger movement because of the friction of the mechanism. In the measurement results, the measured force differs depending on the direction of finger movement, confirming the hysteresis characteristics caused by the friction. The mechanism used in this gripper has several sliding parts, so the cause of this hysteresis is friction among the sliding contacts of the mechanism. The width of the hysteresis can be reduced by improving the design of the mechanism so that sliding friction is reduced.

B. Pick-and-place of a Single Fabric Part

To pick up a fabric part using PALGRIP, the position control is used for the robot control. The force information from the F/T sensor is used for the robot control. The force information from the B. Pick-and-place of a Single Fabric Part

To pick up a fabric part using PALGRIP, the position control is used for the robot control. The force information from the F/T sensor is used to switch the moving direction of the endpoint of the manipulator. The base coordinate system of the robot is attached to the base of the manipulator, and the sensor coordinate system is attached to the center of the F/T sensor as shown in Fig. 12a.

Fig. 12 illustrates the procedure of the picking motion. The manipulator moves the gripper downward along $z_{\text{base}}$ direction at a constant velocity $v_{\text{const}}$ (Fig. 12a) until the measured force $F_m$ reaches a preset threshold $F_{\text{th}}$ (Fig. 12c). When the measured force $F_m$ reaches the force threshold $F_{\text{th}}$, the moving direction of the endpoint of the manipulator is inverted (Fig. 12d). For releasing the fabric, the same control as the picking motion is carried out. In the experiment, the force threshold $F_{\text{th}}$ was set to 40.0 N based on the Fig 11.

An experiment was conducted to grasp a piece of fabric on the stage using the above procedure. The test piece of fabric is a cuff of a shirt, as shown in Fig. 14. The fabric part has a thickness of 0.24 mm and a mass of 0.34 g. The material of the fabric is woven cotton.

Fig. 13 shows the trajectory of the endpoint of the manipulator and the measured force along $z_{\text{sensor}}$ direction. The blue dot line represents the desired $z$ position of the endpoint of the manipulator. The red line represents the actual $z$ position of the endpoint of the manipulator. The black line represents the measured force along $z_{\text{sensor}}$. The green colored area is the picking motion. The yellow colored area is the placing motion.

Fig. 14. The test piece for the experiment.
contact with the fabric (Fig. 15b), the manipulator presses down on the gripper, and both fingers close while maintaining contact between the fingertips and the fabric (Fig. 15b - Fig. 15d). At that time, the fabric in contact with the fingers is pulled to the center between the two fingers by the friction, causing the fabric between the fingers to bulge (Fig. 15c) as mentioned in Section III. The self-locking mechanism transits to the locked state when the fingers are fully pushed in (Fig. 15d), and the measured force reaches the pre-set threshold $F_{th}$. The manipulator moved upward along the $z_{\text{base}}$ axis and the gripper picked up the fabric (Fig. 15e).

To release the fabric part, the fingers are fully pushed in again after picking up the fabric, and the self-locking mechanism transits from the locked state to the released state (Fig. 15f). Both fingers are opened while the endpoint moves upward (Fig. 15g and Fig. 15h). Finally, the gripper releases the fabric on the stage (Fig. 15h).

C. Pick-and-Place from a Stack of Fabric Parts

We conducted an experiment to demonstrate the performance of PALGRIP using a dual-arm system. Fig. 16a shows the experimental setup using the dual-arm system. The setting of each manipulator for grasping the fabric is the same as described in Section V-A. Both manipulators are controlled by a desktop PC (CPU: Intel Core i9-11900K, Memory: 64 GB, OS: Windows and InTime), and both manipulators’ motions are synchronized. The grasping position on the fabric is determined in advance. The piled fabrics with 10 layers were put on the stage in the middle of both of the manipulators. The fabric piece is the same as in the previous experiment.

Both manipulators press grippers against the stack of fabric parts on the stage, and both ends of the top layer of the fabric stack are grasped by the grippers. After the gripper picks up the top fabric part, both manipulators’ endpoints move 200 mm along the $y_{\text{world}}$ axis from the initial position as shown in Fig. 16b. The manipulators press the grippers against the stage again to place the fabric. After that, the manipulators move to the initial position and pick up the next fabric. The manipulators repeat this operation 10 times continuously. Pick-and-place of 10 layers was performed 10 times and the grasping success rate of the prototype gripper was calculated.

Fig. 17 shows the pick-and-place motion by the dual-arm system. The grippers attached to both manipulators performed grasping by separating only the top layer of fabric from the stack of the fabric parts. After repeating several pick-and-place motions, the dual-arm system was able to grasp the only single top fabric, even though the height of the piled fabric pieces changed. In an experiment in which 10 pick-and-place attempts were made on 10 layers of fabric, the pick-and-place motion was successful in all cases (Success rate 100%).
with simple control. The current prototype of PALGRIP has mechanical loss inside of the mechanism as shown in Fig. 11. Optimization of the design is a future challenge. In addition, although PALGRIP was designed to grip a single piece of fabric, the design concept of the gripper can easily be extended to grip other types of parts.

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REFERENCES


VI. CONCLUSIONS

We proposed the Passive Actuator-Less Gripper (PALGRIP) to pick and place a piece of fabric without using any actuators inside of the gripper. The passive pinching mechanism is used to mechanically open and close the fingers by utilizing the relative motion of the fingers and the housing of the gripper. The self-locking mechanism mechanically locks and unlocks finger movement when closed. With these mechanisms, the pick-and-place movement can be performed by pressing the gripper against the piece of fabric placed on the stage.

To design PALGRIP, the kinematics and statics of the gripper were analyzed and how PALGRIP is designed is also shown based on these analyses. Experimental evaluation of the relation between the displacement of the fingers and the pushing force using a robot system showed the hysteresis caused by friction in the mechanisms. To demonstrate the performance of PALGRIP, a pick-and-place test was carried out to pick a single piece of fabric from a stack of fabric pieces and a 100% success rate was achieved in 100 pick-and-place trials.

PALGRIP can be manufactured at a low cost because it does not use actuators. It allows the robot to grasp a piece of fabric by the dual-arm system. (a) - (d) show the picking-up motion by the dual-arm system. (e) and (f) shows the transport of a grasped fabric by the dual-arm system. (g) and (h) show the placing motion by the dual-arm system.