Picking of One Sheet of Cotton Cloth by Rolling up Using Cylindrical Brushes*

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***Abstract*— In this paper, we describe a method for automating the process of lifting one sheet of cloth from a stack of cotton sheets. In factory manufacturing of cloth products, many of the procedures for installing fabric parts on machines are still performed manually. In this study, we propose a method that first detects the edge of a sheet of cotton cloth, and then lifts it up by means of a cylindrical brush. Advantages of this method are that it avoids cloth damage, as well as its future potential for enabling dexterous manipulation by means of fine brushes. In verification experiments, the proposed end-effector was attached to the tip of a serial link manipulator. Then a system combining a color camera, a tactile sensor, and a lighting source was constructed. Using the system, we confirmed that a certain level of picking performance was obtained. In addition, we organized possible failures on the picking task and devised a vision process that can distinguish failure patterns.**

I. INTRODUCTION

Clothing is among the many products that are mass-produced in factories. Improving the efficiency of these production processes will reduce the human workload. However, due to cloth's deformability, many steps of clothing production are hard to automate. For example, in the process of sewing two layers of cloth together, the work of placing the cloth parts properly into the sewing machine is in most cases still performed manually.

In this work, we aim to automate the process of picking up the top sheet from a stack of cotton sheets. Figure 1 shows an example of this operation, which occurs frequently and in many contexts, including the aforementioned placement of fabric parts in sewing machines. However, sheets of cotton are thin and deform easily. Also, the surfaces of such sheets tend to stick together, which can make this operation difficult even for humans. Moreover, when a number of sheets are cut together as a stack their edges will be well-aligned, but when sheets are re-stacked after some other operation, subtle misalignments of the sheets' edges occur. The picking process has to account for both of these issues. We automate the process by means of the following operation sequence: first we detect the edge of the top sheet, then rolling the edge of the sheet up using a cylindrical brush, and then selectively lifting up the top sheet. This approach has the advantage of minimizing fabric damage. On the other hand, it is necessary to investigate what kind of brush to use, and to construct the system while confirming the appropriateness of the method of rolling up with a brush.

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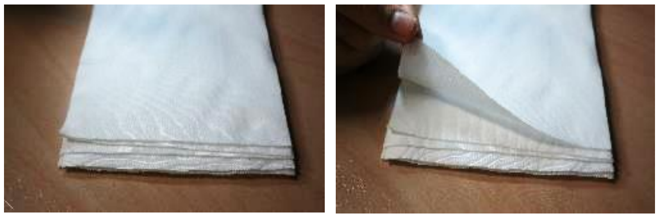

Fig. 1. Left: Stacked cotton sheets. Right: picking up the top sheet.

The contributions of this work are as follows:

- We demonstrate the effectiveness of cylindrical brushes for picking up thin sheets of fabric that easily adhere together.
- We report that the placement of the brush on the cloth affects the success rate of the picking process, and propose and implement procedures for finding the proper placement and recognizing failures.
- We evaluate the effectiveness of the proposed method by performing the picking procedure using a physical robotic system.

The paper is structured as follows. Section 2 discusses related work. Section 3 explains the problem setting and approach. Section 4 explains the individual elements of the picking procedure, including the developments that led us to this approach. Section 5 explains sensor data processing and failure recognition. Section 6 presents our experimental results, and section 7 concludes the paper.

II. RELATED WORK

A. Mechanical hardware for cotton sheet picking

One approach for picking cloth items from a stack is the use of robotic hands. Research and development from a similar perspective has been ongoing. Ono et al. [1] proposed a robot hand to pick up a piece of cloth. The number of stacked items was assessed using measurements from a sensor in the tip of the hand. The hand was then inserted into the stack so as to grasp a given number of items. There are other approaches as well. Related to the rolling motion adopted here, there is work on flipping pages using roller-type effector [2]. In [2], a roller equipped with a piezoelectric sensor was used to flip pages of a booklet and assess whether a page actually flipped. However, the cotton sheets targeted in the present work are more flexible than paper and tend to adhere together, hence one can easily foresee that it would be difficult to flip up individual sheets with this type of approach. For the same reason, it is difficult to use a conventional robot hand [3] [4] for the purpose of handling cloth. Therefore, a new method is required.

B. Cloth manipulation system

Within the field of Intelligent Robotics, too, progress is being made in robotic cloth manipulation [5-7]. As picking cloth up is the first step in manipulation it, this subtask is addressed in many lines of cloth manipulation research. Willimon et al. [8] address the task of selecting a single grasp point for lifting up a cloth item from arbitrary messy shape configurations. Doumanoglou et al. [9] proposed a method for spreading out unknown cloth items presented in arbitrary shape configurations. They used Hough forests for grasp point detection. Ramisa et al. [10] proposed a method for detecting characteristic parts like collars and cuffs in images of shirts etc. in arbitrary shape configurations. Yamazaki [11] proposed a method for simultaneous detection of multiple grasp points on cloth items in arbitrary shape configurations. As these examples illustrate, many studies have demonstrated success in picking up cloth items. However, these methods assume problem settings where the cloth can be properly grasped by just extending the hands to approximately detected grasp points, whereas we target dexterous picking of densely stacked items.

Focusing on high-precision picking, Le [12] et al. developed an end-effector equipped with proximity sensing abilities. Nagata et al. [13] proposed a towel-picking method using touch sensors. Both approaches contribute towards increased dexterity. However, these end-effectors cannot easily be applied to the problem setting of densely stacked thin cotton sheets assumed here.

III. PROBLEM SETTINGS AND OUR APPROACH

A. Problem settings

We assume that cotton sheets used to produce underwear etc. are cut to a specified shape and stacked. The number of sheets in the stack is assumes to vary from one to tens of sheets. The sheets' edges may be well-aligned as when the stack has just been cut to shape, or may have various degrees of misalignment as when the sheets are manually re-stacked after another processing step. The fabric is thin, and when attempting to lift up the top sheet, the underlying sheets easily adhere to and move along with the top sheet. The sheets' shape varies, but we assume that it contains at least one 90° corner connecting two straight edges, which we will use as the grasping point in this study.

Our goal is to separate and lift up the top sheet from the stack. Afterwards, the sheet would be fed into e.g. a sewing machine. This requires that we can release the grasped sheet at a given position. At that time, it is desirable that the sheet can be placed at a specified location in a specified orientation.

B. Approach

In order to automate cloth picking in the setting laid out in the previous section, we need the following:

- A mechanism and method for grasping and releasing a single sheet of cloth.

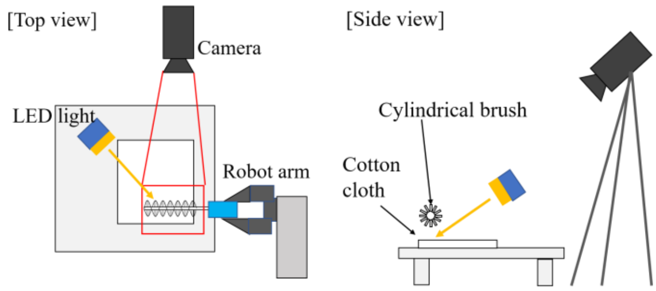

Fig. 2. Schematic of the experimental setup

- Robotic hardware with a sufficient range of motion for realizing the above.
- Methods for determining the grasp position and current grasp state.

For the first item, we take an approach to using a cylindrical brush to selectively lift the topmost sheet up. The brush is firstly pressed against a cotton sheet and then is rotated to roll it up. With the sheet grasped in this way, we can release the sheet by simply rotating the brush in the opposite direction.

The success rate of this method depends strongly on the position at which the brush is pressed against the sheet. Therefore, we include an automated process to select this position. Also, since there are times where we fail to pick up the sheet, as well as times where we unintentionally pick up 2 or more sheets, we also implement procedures for estimating the grasp state during or after the pick-up attempt.

Figure 2 shows an overview of a system built to include the above issues. We mount a cylindrical brush at the end of a robot arm. At the connection between the brush and the arm, we place a tactile sensor for measuring contact pressure with cotton sheets. We further install a camera for observing the state of the stack and the state of the grasping process. Finally, we set up the lighting conditions so as to facilitate cloth edge detection.

In the next section, we describe in order the explorations that led to the proposed picking method, the determination of the motion's timing and contact position, and the failure detection procedure.

IV. EXPLORATION OF THE PICKING METHOD

A. Selection of picking mechanism and rolling surface material

Here we discuss the exploration process that led to the selection of cylindrical brushes, as well as results of our experimentation with various brush types.

TABLE I lists various methods for picking up a cotton sheet. We experimented with a vacuum pad, but the permeability of the fabric leads to a large pressure loss. Various pressure strengths were explored, but we found it impossible to selectively lift a single sheet. Using a needle, it is possible to selectively pick up one or two sheets by controlling the depth to which the needle is inserted into the fabric, but this approach has the disadvantage of damaging the fabric. As for adhesion-based methods we found that we can selectively lift the top

TABLE I. Various cloth-picking methods

Method	Device type
Adsorption	Vacuum adsorption
Pinch	Mechanical hand、Needlestick
Adhere	Gel,Catch hook,Magic tape
Rolling	Cylindrical brush,Sand paper,Magic tape

sheet using Velcro or sandpaper wrapped around a cylinder, but this caused fraying of the cloth, and the sheet could not easily be released by reverse rotation, limited the applicability of these materials. The use of cylindrical nylon spiral brushes, which are often used to polish tubes, allowed for selective picking of the top sheet as well as easy release by reverse rotation, making this the best match for our purpose. Furthermore, we found that the sheet adheres to the brush strongly enough to withstand pulling on the sheet with some force. This suggests that this picking method would be viable even for moderately large sheets of fabric.

We also experimented with brushes of pig hair, brushes with stainless steel hairs, and brushes treated with abrasives. However, with each of these we encountered problems such as the fabric failing to adhere to the brush during the rolling motion or the sheet failing to detach when rolling back the brush. It seems that for the sheet to properly catch onto the brush, the hairs of the brush have to stick into the fabric. Consequently, brushes with long hairs do not perform well due to bending of the hairs. There are likely other factors involved in the compatibility of brush and fabric. Furthermore, we find that if a brush's hairs point in mixed directions, or if the ends of the hairs are rough and uneven, then the cloth tends to fail to detach from the brush upon reverse rotation.

B. *Picking procedure*

The proposed rolling motion makes it relatively easy to pick up a single sheet from a stack of adhering cloth sheets. Also, the picked-up cloth can easily be released by rotating the brush by the same amount in the opposite direction. However, the position where the brush is placed on the cloth, as well as the amount of pressure exerted on it, both strongly affect success rates. In consideration of these factors, we adopt the following procedure.

1. Detect the sheet's edge using image processing.
2. Bring the brush to the intended contact position, and start pressing the brush against the cloth.
3. When the tactile sensor detects a pressure force exceeding a set threshold, stop pressing.
4. Separate the top sheet from the underlying sheets by rotating the brush. In tandem with this rotation, move the brush in horizontal direction in order to avoid displacing the sheets remaining in the stack.
5. Lift up the brush (sheet).

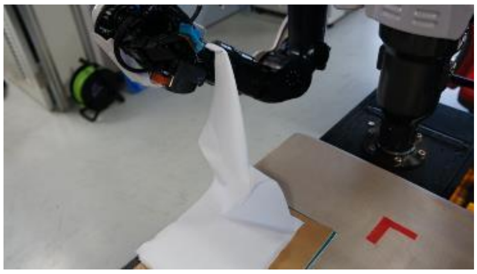

Fig. 3. Example of adherence between sheets of cloth

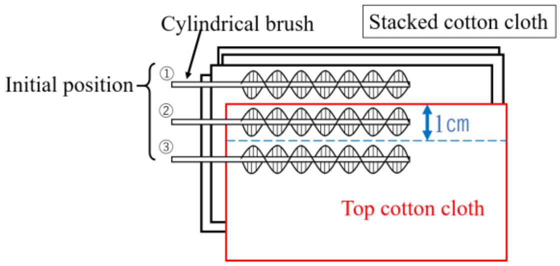

Fig. 4. Brush placement in relation to the cloth

6. Release the sheet by rotating the brush in the opposite direction.

While rolling up the sheet, moving the brush horizontally enables to controls the tension within the cloth. With the proper tension, we can obtain a strong grip of the hairs of the brush into the cloth, which facilitates an easy pick-up. Meanwhile, overly high tension causes the hairs of the brush to slip over the surface of the cloth. This was found to produce failures in releasing the cloth when the brush is rotated back in the opposite direction. Conversely, insufficient tension leads to a loose roll-up and consequently insufficient grip on the cloth. This was observed to result in the cloth falling off the brush prematurely.

As another abovementioned issue, sheets have a tendency to stick together. If we lift the top sheet while the sheet below is stuck to it, situations as shown in Fig. 3 occur. To avoid them, instead of directly lifting up the top sheet after the pressing blush to the sheet, we insert a motion that slightly (in our experiments, 0.8mm) lifts the sheet, and then start rolling. This additional motion has the effect of making it easier to separate the sheet from the brush on releasing phase.

V. Sensor Data Processing

A. *Detection of brush placement position*

Fig. 4 shows the placement of the brush on the surface of a fabric sheet. When the brush is placed at the position marked (1), the second sheet in the stack will be rolled up along with the top sheet, resulting in the picking of two sheets. When the brush is placed near the edge of the top sheet, such as the position marked (2), the sheet alone can be picked. However, when the first brush position is too far removed from the edge of the sheet, such as the position marked (3), then the picking might fail because the edge of the sheet cannot be lifted when

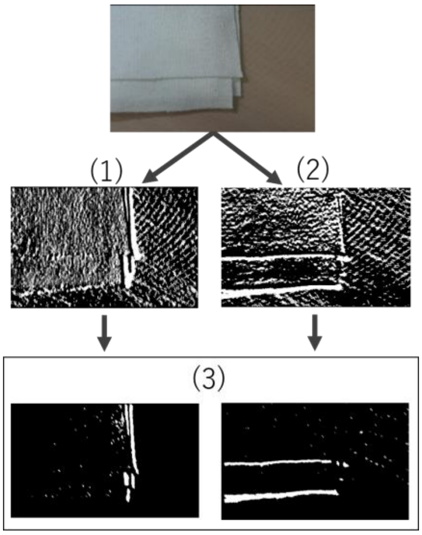

Fig. 5. Example result of vertical and horizontal edge detections

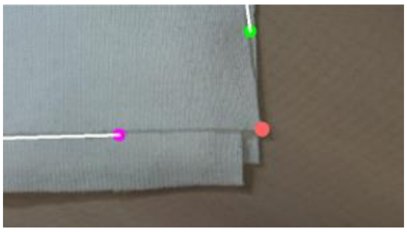

Fig. 6. Example corner detection result

rotating the brush. For this reason, a pre-process to specify the hem of the top sheet is necessary.

Image processing for that is as follows. First, we perform a perspective projection transformation on the image, to virtually obtain a top-down view of the stack. Next, we perform edge-detection by means of the Sobel operator, obtaining the image's derivatives in in vertical and horizontal direction (Fig. 5 (1), (2)). Then we threshold the image to leave just the pixels that represent strong edges. We identify pixels with a directional component between -20°and 20°as horizontal edges and pixels with a directional component between 70° and 110°as vertical edges. Next, we discard edges with a surface area (i.e. pixel count) below a given threshold, as illustrated in Fig. 5 (3).

From among the remaining edges, we select the edge closest to the image's origin (its top-left corner) in the horizontal direction as our vertical edge and the edge closest in the vertical direction as our horizontal edge, and fit a straight line to each. Then we find the intersection of these lines to identify the corner of the cloth. An example is given in Fig. 6. On the basis of this result, we select a brush placement position near the corner, as a distance of about 10mm from the edge.

B. Measurement of pressing force

To reliably pick up the cloth, the brush must be pressed against it with the proper amount of force. If this force is too small, the brush's hairs will not latch onto the fabric. Conversely, applying too much force increases the risk of lifting multiple sheets. Moreover, the difficulty of lifting one sheet varies with the number of sheets in the stack.

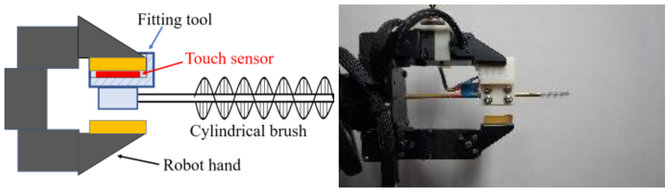

Fig. 7. Placement of the touch sensor in the robot's hand

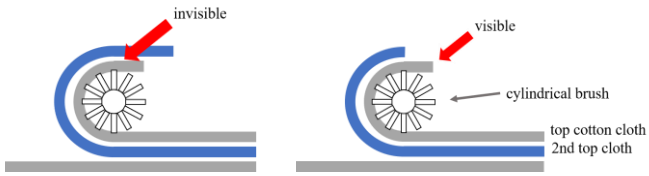

Fig. 8. Scenarios where the rolling motion catches two sheets

To control the amount of force applied to the sheet, we construct the mechanism shown in Fig. 7. We use a small tactile sensor of high sensitivity. The sensor was chosen in consideration of the need to keep the device compact, and for its ability to measure force on three axes. We install the sensor in between the robot's fingertip and the fixture holding the brush. This allows us to measure the amount of force being exerted on the handle of the brush. In the present work we let the robot move the brush straight down onto the top sheet, press down until the measured force exceeds a set threshold, and then transition into the rolling motion.

C. Failure detection during rotating the blush

It might not succeed to pick up only one piece of cotton sheets in the case that a small amount of misalignment occurs during brush positioning. On the other hand, even if the positioning is appropriate, there are cases where two or more sheets are taken up due to the nature of the cotton fabric being easily stuck. These are difficult to completely avoid. Therefore, it is necessary to add a function to detect failure in order to stably pick up one cotton sheet.

In this study, we propose the following method. First, five images are taken at regular intervals from when the brush is placed on a cotton sheet until the end of rolling. The images are input to a convolutional neural network (CNN), and state discrimination is performed. There are three types of states: the number of the rolled sheet is 0, 1 or 2 sheets. The reason why the image of during rolling the brush is also used is that there are situations where it is not possible to distinguish only with the image taken after rolling. For example, in the case of a lower panel in Fig. 8, it is difficult to determine whether two sheets have been rolled or not.

In the learning of CNN, 100 sets of data were collected manually for each of the three states mentioned the above. Then the CNN, which consists of two convolutional layers, a pooling layer, a convolutional layer, a pooling layer, and a fully-connected layer, from the side closer to the input, was learned. The activation function used was ReLU, and the Softmax function was used for the fully-connected layer. The network input was a 64x64x5 tensor that consists of 5 grayscale images scaled from original1920x1200 sized images.

VI. EXPERIMENTS

A. Experimental settings

For the experiment, HIRO manufactured Kawada Industry Inc. was used. HIRO is a dual-armed robot, but for the purpose of this study, only one arm which is a serial-link manipulator with 6 DoFs was used. The cylindrical brush used was DA-46 manufactured by SUNPOWER Inc. In addition, Shokac Chip [8] manufactured by Touchence Inc. was used to measure the force applied to the cylindrical brush. A camera was FDR-AXP35 made by Sony Inc.

The size of the cotton sheet was 130mm long, 150mm wide, and 0.5mm thickness. In order to carry out the experiment under realistic conditions, multiple cotton sheets were stacked with a maximum deviation of 2mm in the horizontal direction. As already mentioned, cotton sheets have the property that its surfaces tend to stick together. In addition, there are directions that easy to stretch or not, due to the difference in cloth sewing. For the picking up operation, the brush and cotton sheet are more strongly bonded and the success rate is higher when the direction is easy to stretch. This is a useful finding when incorporating the proposed method into an automated line. Therefore, in all the following experiments, the brush was applied in the direction in which a cotton sheet was easy to stretch.

When pick-up of the cloth is successful, the brush and cloth adhere strongly enough that even a slight pull on the cloth will not cause it to separate from the brush. This grip remains until the brush is rotated back to release the cloth. Consequently, a successful pick-up implies sufficient grip on the cloth for a successful cloth fetching operation. When the top sheet is lifted up after the pick-up, underlying sheets may adhere to it and inadvertently be lifted up along with the top sheet. We found that proper separation of the top sheet and underlying sheets can be ensured by lifting the top sheet by 10mm after pick-up, so we conclude each experiment when a lifting height of 10mm is reached.

B. Picking up under conditions where the hem position is known

The effectiveness of taking up was investigated under the condition that the position of fabric hem was properly known. The experimental procedure is as follows.

1. Put a cotton sheet on the place so that the brush matches the edge of the sheet.
2. Lower the brush toward the cotton sheet and stop when the value of the tactile sensor exceeds the predefined threshold.
3. Rotate the brush to roll the cloth.
4. Lift the brush 10mm.

TABLE II Success rates for stacks of various heights

Number of cloths	Success rate[%]
1	60
2	0
3	60
4	60
5	90
6	80
7	100
8	100
9	100
10	100

The rotation angle in step 3 was set to 30 degrees. The threshold value of the tactile sensor was set to 0.1N based on prior examinations. Only when one cotton cloth was lifted after step 4 was completed, it was judged successful.

The pick-up operation according to the above procedure was performed by changing the number of cotton cloths to be stacked between 1 and 10. **TABLE II** summarizes the results. The number of experiments for each number is 10 times. When 5 to 10 sheets were stacked, it was almost successful. On the other hand, the success rate decreased when 1 to 4 sheets were stacked.

Examples of failures are as follows. When the brush was pressed excessively on the cotton cloth, the cotton cloth was greatly deformed in step 3, and the edge could not be lifted. Another failure occurred in also step 3. The second and subsequent cotton sheets sometimes slipped on the table due to the rotation of the brush. This problem was likely to occur when the number of sheets was small. As a measure against it, one solution is to place non-slip material such as a sponge on the table.

C. Picking up including edge positioning

The edge positioning process was automated and the picking up work was examined. The procedure is the same as in the previous subsection, but only the visual part of 1. was replaced with the method described in section V-A. It was successful 24 times on 30 trials. Fig. 9 shows examples. A panel (1) shows a success case, and (2) is a failure that two sheets are rolled up simultaneously. (3) and (4) are cases where rolling up was not possible. (5) is the case where the brush was not placed on the edge of the cotton cloth stacked on top, and (6) shows a failure of the sheet to catch onto the brush due to improper pressure application.

One way to improve brush positioning error is to re-examine the lighting position. However, we assume that the picked-up cotton sheet is provided to the sewing machine etc. Therefore, it is necessary to arrange lighting so as not to obstruct the work. For this reason, careful consideration must be given to the overall system design.

D. Verification of failure detection

The method described in V-C was verified. First, for the learning of classifier, the number of iterations was 300, the batch size was 30, the optimization method was Adam, and

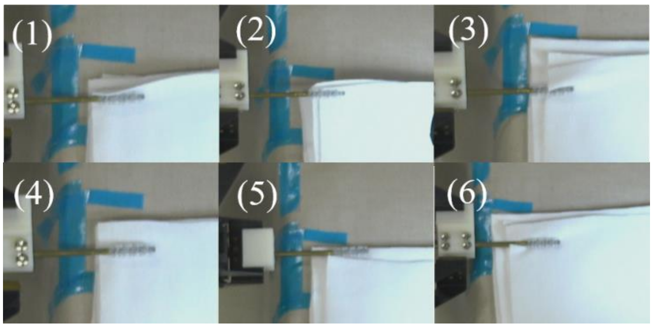

Fig. 9. Experimental results

the loss function was categorical cross-entropy. As shown in Fig.10, the accuracy rate of training data was almost 1.0 and the loss almost converged to 0.0. On the other hand, the accuracy rate of the test data converged to 0.9 and the loss to 0.29. A verification experiment was conducted using this result. TABLE Ⅲ shows the results of verifying 5 sets of 10 times for each of the three states. The overall accuracy rate was 88%. Even if only one sheet was visible after rolling, it was also possible to detect when two or more sheets were rolled. Almost miss-classification occurred when the position gap between cotton sheets was small. Therefore, in order to improve the accuracy, it is effective to increase the training data that such gap is small.

VII. Conclusion

In this paper, we introduced about automating the process of lifting one sheet of cloth from a stack of the sheets. We proposed a method that first detects the edge of a sheet of cotton cloth, and then lifts it up by means of a cylindrical brush. Advantages of this method are that it avoids cloth damage, as well as its future potential for enabling dexterous manipulation by means of fine brushes.

In verification experiments, the proposed end-effector was attached to the tip of a serial link manipulator. Then a system combining a color camera, a tactile sensor, and a lighting source was constructed. Using the system, we confirmed that the success rate of the picking work was 80%. In addition, we organized possible failures on the picking task and devised a vision process that can distinguish failure patterns. Its accuracy rate was more than 88%.

Future work, we improve the overall system, and introduce it into actual production line.

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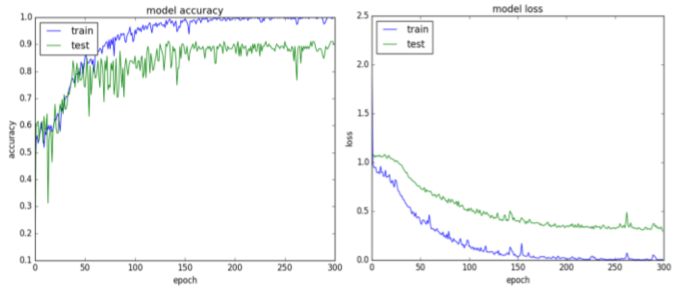

Fig. 10. Classification accuracy and training loss

TABLE III Evaluation results for failure detection. Second row shows the number of sheet(s) that is rolled up at once.

	Number of cloths			
	0	1	2 or more	total
1st set	100	90	100	96.7
2nd set	100	100	40	80
3ed set	100	100	100	100
4th set	90	90	40	73.3
5th set	90	90	90	90
total	96	96	76	88

Success rate[%]

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