Spreading and Isolation of Stacked Cards using Vacuum Hole Array

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Abstract

This report describes a new mechanism that performs the spreading and isolation of stacked cards using a array of vacuum holes. The separation and isolation of cards including tickets and bills are key operations in the backyard of stations and banks. Operations must be performed robustly against oil or water attached on cards in a small operational area. This report introduces a simple mechanical system that can perform the spreading and isolation of stacked cards robustly. In addition, we will show that the proposed mechanics can perform the orientation control of a misaligned card after the isolation process.

keywords *cards, papers, handling, separation, isolation, orientation control*

1 Introduction

This paper describes a new mechanism that performs the spreading and isolation of stacked cards using an array of vacuum holes. The spreading and isolation of cards are critical in mechanical systems that handle paper sheets including cash dispensers and copy machines. Since the card separation must be performed in a short time, specialized mechatronic systems have been developed in the past three decades. Basically, the separation is conventionally achieved by two driving belts with different velocities. The drawbacks of this method are that a large operational area is necessary and failure to separate the cards, due to water or oil on them, occurs too often. Thus, a new method is required to be able to reliably separate cards, even with water or oil on them, in a small operational area.

The handling of soft fabrics has been studied in robotics in the past decades [1, 2]. Some robotic systems have been developed to separate fabrics [3, 4]. Unfortunately, these robotic systems require several seconds to separate a fabric from a stack. Thus, these systems cannot be used for card separation, which must be performed within a few seconds. Some systems have been developed based on the recently proposed concept of *distributed manipulation* [5]. In distributed manipulation, a massive collection of simple actuators, such as vibration devices and pneumatic devices, performs specific operations. An array of micro actuators can convey a flat object on a plane by controlling individual devices [6, 7]. An array of air holes generates a pressure field on a planar surface to translate, rotate, and flip objects on the surface [8]. A vibration-based planar manipulator has been proposed to manipulate objects on a plane independently [9]. These systems can manipulate separated planar objects but cannot handle stacked objects. Fast operation is possible in distributed manipulation since the individual devices have a simple structure. In addition, deformation of manipulated objects is relatively small in distributed manipulation because only small, distributed forces are applied to the object. Note that the deformation of thin cards makes card separation more difficult. Thus, we will introduce the concept of distributed manipulation into the separation of thin cards, which can deform easily during the separation process.

In this paper, we will present a new mechanism to spread and isolate stacked cards using an array of vacuum holes. The proposed mechanism can control the normal forces applied to stacked cards in a distributed manner to perform the spreading and isolation of the cards by a simple ON/OFF control of vacuum holes. First, we will briefly explain the principle of the spreading and isolation of stacked cards. Second, we will describe a prototype of a card spreading and isolation system that uses an array of vacuum holes. Next, we will give out experimental results of the card spreading and isolation to evaluate the performance of the prototype. Finally, we will demonstrate that the proposed system can perform the orientation control of a misaligned card after the isolation process.

2 Card Spreading and Isolation using Vacuum Hole Array

2.1 Principle

Due to the uncertainty in friction between cards, it is difficult to control continuously the relative velocity between two neighboring cards. Thus, we control the relative velocity discretely. We divide the velocity into two states: a stationary state and a moving state. Two neighboring cards have no relative motion in the stationary state while move relatively in the moving state. Consequently, we will control the transition between the stationary state and the moving state. Let f_d be a driving force applied to a card on a table and N be a normal force applied to the card. The maximum static friction is then given by $\mu_s N$, where μ_s denotes the coefficient of static friction. The card remains in a stationary state when the driving force is smaller than the maximum static force, while the card moves when the driving force exceeds the maximum static force. That is,

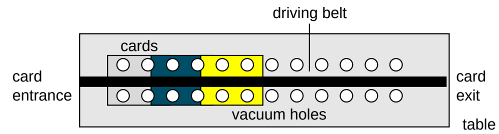
$$
\begin{aligned}
f_d &< \mu_s N \quad \text{stationary state,} \\
f_d &> \mu_s N \quad \text{moving state.}
\end{aligned}
$$

We have three options to realize the transition between the two state: 1) control of the driving force f_d, 2) control of the friction coefficient μ_s, and 3) control of the normal force N. Note that the driving force and the friction coefficient may vary according to temperature and humidity of the environment and strongly depend on materials of the belt, the table, and cards. This suggests that it is difficult to control the driving force and the friction coefficient. Contrary, we can control the normal force by regulating the vacuum force applied to a card by a vacuum hole. We apply an array of binary controlled vacuum holes instead of a single continuously controlled vacuum hole. Consequently, simple ON/OFF control of individual vacuum holes realizes the spreading and isolation of stacked cards.

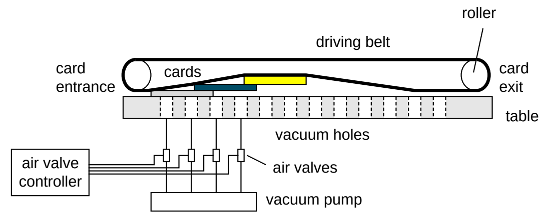
2.2 Prototype System

Fig. 1 describes the proposed mechanism to perform the spreading and isolation of stacked cards. A belt drives cards on a table. An array of vacuum holes controls the normal force of the cards. ON/OFF valves control their corresponding vacuum holes.

Spreading and isolation process is illustrated in Fig. 2. In the spreading process, all vacuum holes are activated as illustrated in Fig. 2-(a) before stacked cards enter the operational area. Since vacuum force is applied to the bottom card alone, the bottom card stops while the others are moving as shown in Fig. 2-(b). The two cards continue moving and reach to



(a) top view



(b) side view

Figure 1: Basic structure of separation system

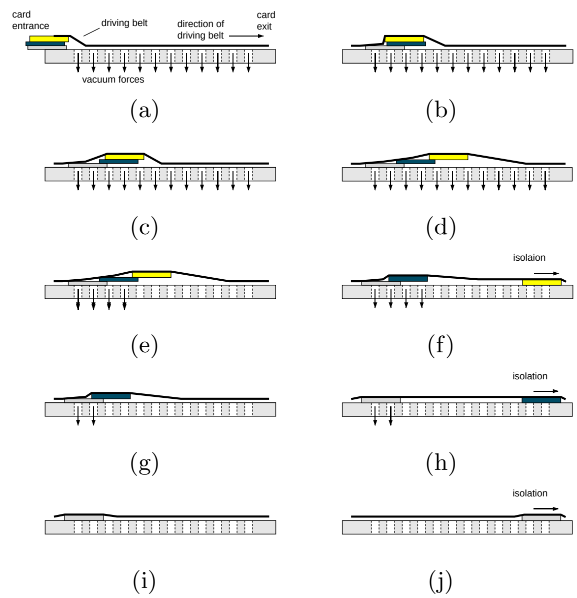


Figure 2: Process of card separation

the next vacuum holes, resulting that the middle card stops as shown in Fig. 2-(c). The top card continues moving before it stops in the next vacuum holes. As a result, all cards are spread out on a table as illustrated in Fig. 2-(d). In the isolation process, vacuum holes are inactivated in sequence from the exit side to the entrance side. The top card is isolated when vacuum forces applied to the card is lost, as illustrated in Fig. 2-(e) and (f). Then, the middle card is isolated as shown in Fig. 2-(g) and (h) before the bottom card is isolated as shown in Fig. 2-(i) and (j). Consequently, ON/OFF switching of an array of vacuum holes realizes the spreading and isolation of stacked cards.

Fig. 3 shows the prototype of card spreading and isolation system. It has a 2×50 array of 2.0mm holes

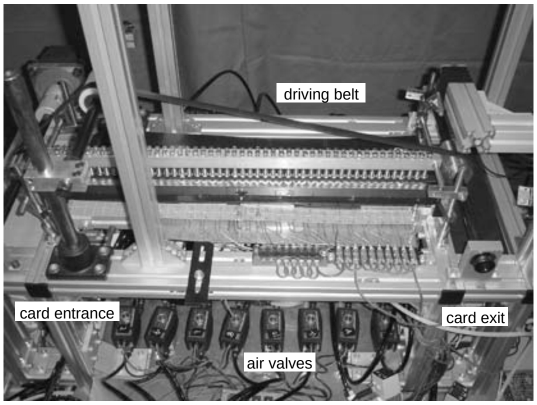
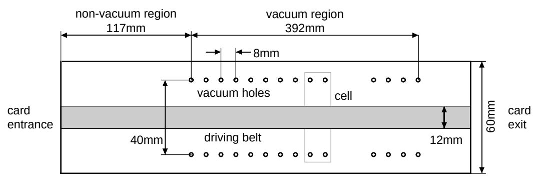
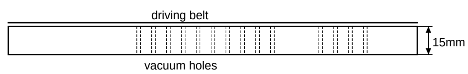


Figure 3: Overview of prototype



(a) top view



(b) front view

Figure 4: Arrangement of vacuum holes

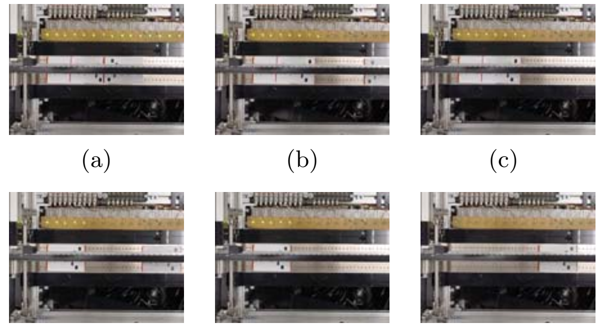
and 25 independent air valves, arranged as illustrated in Fig.4. Each valve controls a *cell* of 2×2 holes. The driving belt is composed of polyester fabric and millable polyurethane. Touch rollers above the belt enable the belt to push the cards beneath it with a constant force.

3 Experimental Assessment

3.1 Spreading and Isolation

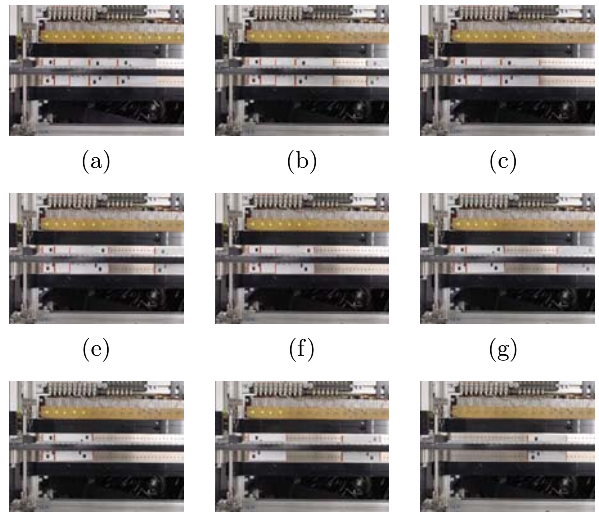
we will describe an experimental evaluation of the prototype of the card separation system. The cards are 57mm in width, 85mm in length, 0.2mm in thickness, and 1.5g in weight. The belt is driven at the speed of 0.42m/s. All the cells are activated before the spreading process and are inactivated one by one at 400ms intervals during the isolation process.

Fig. 5 demonstrates the spreading and isolation of three stacked cards. Vacuum pressure is equal to 4.0kPa. The stacked cards enter from the left side of the figure and the isolated cards exit from the right side. First, vacuum pressure is applied to all 25 cells and the stack is sent to the card entrance. The three stacked cards are then spread out over the vacuum hole array as shown in Fig.5-(a). After 17 of the 25 active cells are switched off, the top card is removed as shown in Fig.5-(b) but the other two cards remain over the array of holes as shown in Fig.5-(c). After 3 of the remaining 8 active cells are switched off, the middle card is removed as shown in Fig.5-(d) and the bottom card stays over the array of holes as shown in Fig.5-(e). Finally, all of the active cells are switched off and the bottom card is transported to the exit as shown in Fig.5-(f).



(a) (b) (c) (d) (e) (f)

Figure 5: Separation of three stacked cards



(a) (b) (c) (e) (f) (g) (h) (i) (j)

Figure 6: Separation of five stacked cards

Fig. 6 shows the spreading and isolation of five stacked cards. As shown in the figures, we find that the prototype can spread and isolate five stacked cards. Vacuum pressure is equal to 4.0kPa. The stack of five cards is spread out over the array of holes as shown in Fig.6-(a). The cards are isolated one by one as shown in Fig.6-(b) through (j).

Let us measure the distance between two neighboring cards after the spreading process. Let l be the

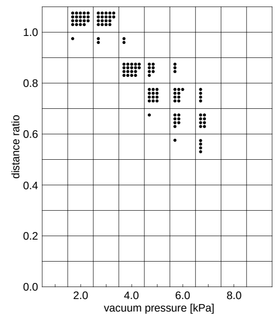
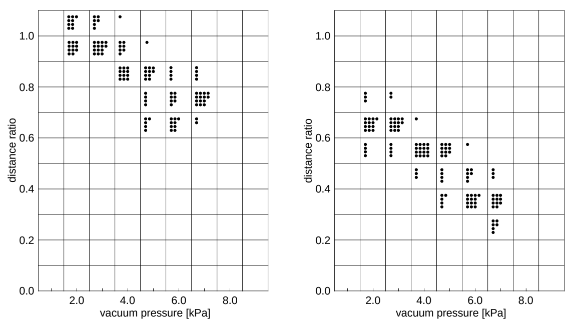


Figure 7: Distance ratio between two separated cards

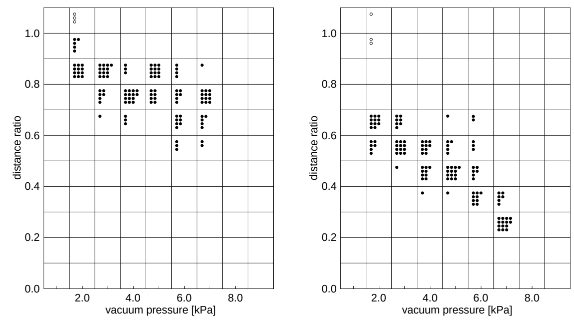


(a) top and second (b) second and bottom

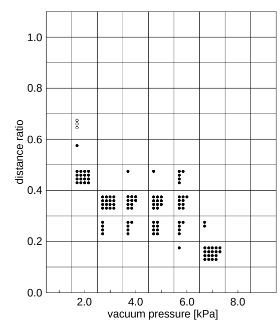
Figure 8: Distance ratio between three separated cards

length of a card. Let d be the ratio of the distance between two neighboring cards to card length l. This ratio is referred to as the *distance ratio*. Let P be vacuum pressure applied to the vacuum hole array. Fig.7 shows the distance ratio between two spread cards. The abscissa denotes P, the vacuum pressure, and ordinate represents d, the distance ratio of two separated cards. We performed 20 trials with vacuum pressure values of 2.0, 3.0, 4.0, 5.0, 6.0, and 7.0kPa. Two cards were separated successfully in all trials with individual vacuum pressure values. As shown in the figure, two cards were separated completely in 19 trials while two separated cards have a small overlapped region in 1 trial at $P = 2.0$kPa. Also, it turns out that the distance between two separated cards decreases as the vacuum pressure applied to the vacuum holes increases.

Fig.8 shows the distance ratios after three stacked cards are spread. Fig.8-(a) shows the distance ratio between the top card and the second card while Fig.8-(b) represents the distance ratio between the second card and the bottom card. Three cards were separated successfully in all trials with individual vacuum pressure values. From the figure, we find that the distance between two neighboring cards decreases as the vac-

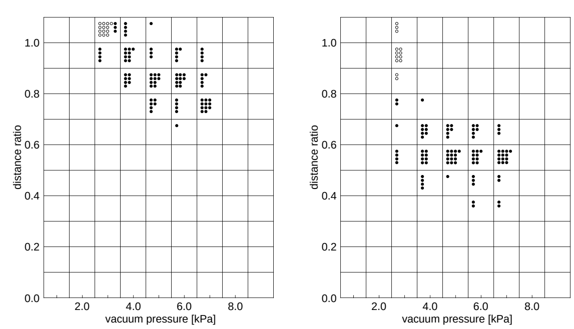


(a) top and second (b) second and third

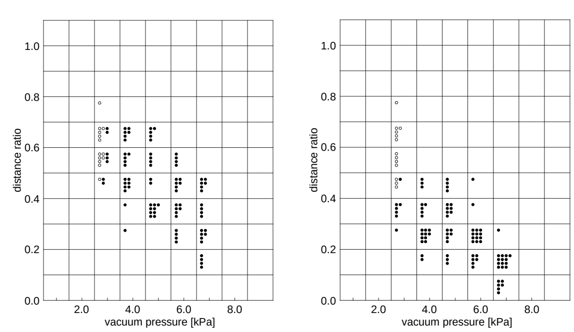


(c) third and bottom

Figure 9: Distance ratio between four separated cards



(a) top and second (b) second and third



(c) third and fourth (d) fourth and bottom

Figure 10: Distance ratio between five separated cards

uum pressure applied to the vacuum holes increases. Also, it turns out that the distance between the top card and the second card is larger than the distance between the second card and the bottom card.

Fig.9 shows the distance ratios after the spreading of four stacked cards. The white circle in the figure represents a trial in which the top card did not stop on the vacuum hole array. The figure shows that the top card did not stop in 3 trials out of 20 trials at $P = 2.0$kPa. The other three cards stopped on the vacuum hole array and were isolated. The figure shows that the distance ratio between the third and bottom cards was less than 0.2 in 1 trial out of 20 trials with $P = 6.0$kPa and in 18 trials out of 20 trials with $P = 7.0$kPa. In these trials, the second and third cards started moving at the same instance during the isolation process. Namely, the isolation between the second and third cards was not successful. Moreover, it turns out that all cards are isolated successfully when all of the distance ratios exceed 0.2. Note that the length of a card is equal to 85mm, which covers 5 cells. Thus, switching off one air valve inactivates vacuum pressure in a 20% region under a card. This causes the failure of card isolation when any distance ratio is less than 0.2. Thus, all four cards are separated successfully in all trials at vacuum pressure less than 6.0kPa, since all distance ratios exceed 0.2.

Fig.10 shows the distance ratios after the spreading of five stacked cards. All the trials fail at $P = 2.0$kPa, which are not plotted in the figure. The figure shows that the top card did not stop in 13 trials out of 20 trails with $P = 3.0$kPa. The other four cards stopped on the vacuum hole array and were isolated in these trials. Moreover, we find that the distance ratio between the fourth card and the bottom card is less than 0.2 in some trials at vacuum pressure greater than 4.0kPa. Card separation has failed in these trials. Thus, it turns out that all five cards are separated successfully in all trials at vacuum pressure of 3.0kPa alone.

From the above experiments, we have found that the developed prototype can separate five stacked cards successfully by choosing appropriate vacuum pressure. It turns out that the distance after the spreading of upper cards is larger than the distance between the lower cards.

3.2 Orientation Control of Misaligned Card

The proposed approach can be applied to the orientation control of each isolated card. A driving force exerted by a belt and a friction force caused by a set of vacuum holes are applied to a card, as illustrated in

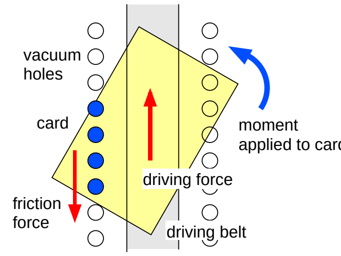


Figure 11: Orientation control by vacuum holes

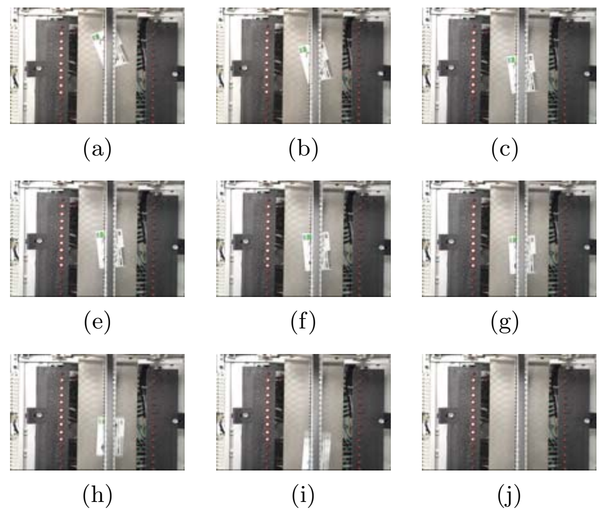


Figure 12: Orientation control of misaligned card

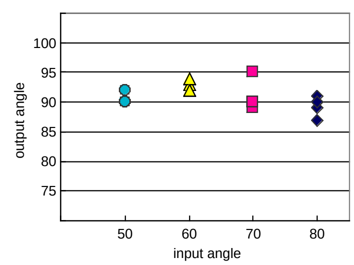


Figure 13: Experimental result of orientation control

Fig. 11. The moment of these forces rotates the card in clockwise or in counterclockwise. A CCD camera mounted on the top of the table captures a successive images of a card to measure the orientation of the card. According to the measured angle, a controller determines whether individual vacuum holes are activated or not.

Fig. 12 demonstrates the orientation control of a misaligned card. Applying Sobel filter and morphology filters to an image of a moving card detects the orientation of the card. As shown in the figure, a misaligned card can be aligned through ON/OFF control of a vacuum hole array. Fig. 13 summarizes the relationship between the input and output angles of a misaligned card. The angle is equal to 90° when the card is aligned. As shown in the graph, any misaligned card can be aligned using an array of vacuum holes.

4 Concluding Remarks

This paper has described the spreading and isolation of stacked cards using an array of vacuum holes. We have succeeded the spreading and isolation of five stacked cards by the first prototype. We have developed the second prototype, which can separate more than 10 cards in the same operational area.

The density of the vacuum holes in the current system is not sufficient since a card covers four cells at most. We are going to miniaturize the air distribution system using MEMS technology to improve the density of vacuum holes. We are going to apply this approach to the handling of tickets and bills in the backyard of stations and banks. In addition, our approach using a vacuum hole array will be applied to the assembly of flexible printed circuits in mobile phones.

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