Paper:

Development of Fluffy Screen System and Field Trial at a Shopping Mall

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Digital signage has been used for services such as advertisement and guidance in public spaces. The use of interactive digital signage has been increasing in recent years. To make full use of the interactivity of digital signage, it is necessary for people to start to interact. In this study, we made a hypothesis that fluffy objects have attraction affordance, and aimed to verify this hypothesis by developing a fluffy screen system. The proposed system is inflated with air. Then, multiple touch inputs from the outside of the screen are detected by cameras inside the screen, and clustering is performed. The information is presented by LCD projectors based on the results of clustering. A field trial in a shopping mall was conducted to verify the hypothesis. A very high interaction rate was realized during the trial of four hours. The results strongly support the hypothesis.

Keywords: interactive digital signage, touchscreen, attraction affordance

1. Introduction

In recent years, digital signage has been widely adopted for guidance and advertisement services in public spaces such as train stations, airports, and commercial facilities [1, 2], and the market has been rapidly expanding. Digital signage was defined as a "remotely managed digital display, typically tied in with sales, marketing, and advertising" in [3].

By using digital signage, unlike classical signage, it has become possible to present dynamic content such as moving pictures and context-based content based on time and other parameters. Dynamic content can attract more attention than static content [4]. Personalization and situational context are important for the content of digital signage [5–7]. According to Müller et al.'s study, people's expectations about the content of the digital signage influence their attention towards the signage [8]. Colley et al. reported that see-through augmented reality content attracts more attention than static content [9]. Much of the research on digital signage has focused on content.

Digital signage has evolved from a display for broadcasting to an information terminal for interaction with customers. As an input method, touchscreens are becoming mainstream (superseding conventional methods using mice, keyboards, and buttons) for digital devices such as computers and mobile phones [10]. Because touchscreens can be operated by directly touching the content, they have been applied to digital signage. The use of touchscreens and other sensing technologies (e.g., cameras) has changed digital signage from a unidirectional information providing device to a device for acquiring information through bidirectional interactions [11–14].

With interactive digital signage, not only push-type information presentation but also pull-type information presentation has become possible. On the other hand, most of the information presentation devices remain as hard surfaces.

Because interaction with a digital signage is considered to lead to purchasing behavior, it is very important to initiate interaction. According to Dalton et al.'s study, digital signage is rarely looked at [15]. Furthermore, although touchscreens enable people to interact with the signage, it is quite difficult for people to determine whether a screen in front of their eyes is interactive or not based on appearance only, without prior knowledge or instruction.

According to Gibson's definition of affordance [16], a hard planar screen has an affordance for pushing or touching to people. From the viewpoint of interface design, on the other hand, the screen does not have "perceived affordance," as proposed by Norman [17]. Usually, for a person to interact with a certain object, it is necessary for the person to be attracted to the object and to observe it. Saffer insisted that a screen that people want to touch is equipped with "attraction affordance" [18]. Interactive digital signage should be designed to have this attraction affordance.

To address this issue, we set the hypothesis that soft and fluffy objects have an affordance for touching to surrounding people. The objective of this study is to develop a soft and fluffy screen and verify the hypothesis through an experiment in a real public space.

This paper is organized as follows: Section 2 shows an overview of the proposed fluffy screen system. A detection method for multi-touch inputs is described in Sec-

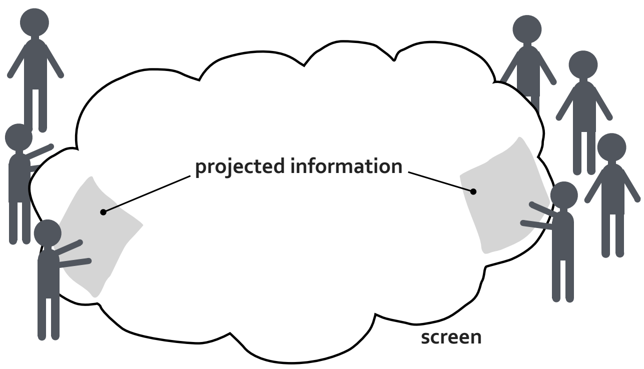

Fig. 1. Concept of the proposed system.

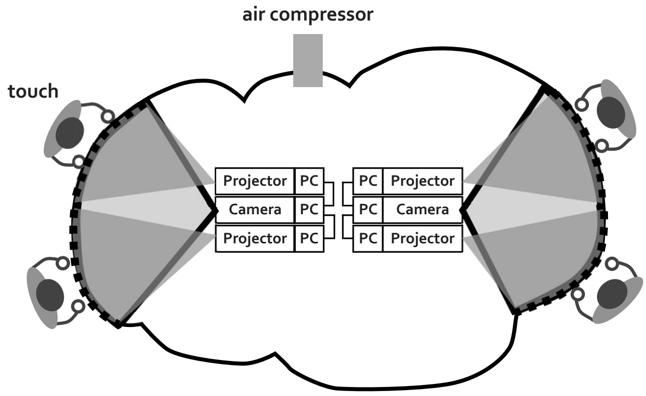

Fig. 2. Structure of the proposed system.

tion 3. Section 4 describes an experiment in a real shopping mall to verify the hypothesis proposed in this section. We discuss the results in Section 5 and conclude the paper and mention future work in Section 6.

2. Overview of Fluffy Screen

The concept of the proposed fluffy screen system is shown in **Fig. 1**. In our concept, multiple people simultaneously interact with the system by touching and seeing the displayed objects on the screen.

Figure 2 shows the structure of the proposed system.

The screen is made of thin white nylon that transmits light and is inflated by an air compressor. The system is a rear projection system. That is, information is projected onto the screen from the inside by the LCD projectors, thereby presenting information outside the screen. To detect touch input from people outside, cameras installed inside the screen are used. Details of the detection method will be described in the following section. By transmitting information such as input position from the image processing PC to the video output PCs, the input information is reflected in the output. As can be seen in **Fig. 2**, the system is equipped with multiple cameras and multiple projectors to enable simultaneous interaction by multiple

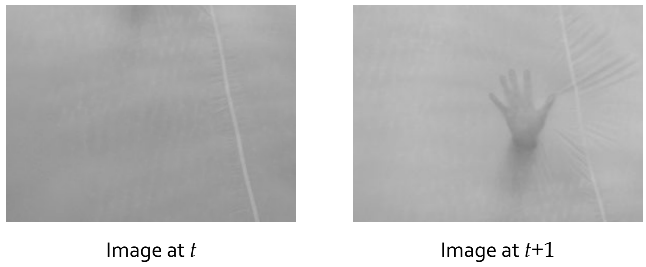

Fig. 3. Change of obtained image under touch input.

people. The coordinate transformation between cameras and projectors is performed by a simple perspective transformation in which the screen is regarded as a plane.

3. Detection of Multi-Touch Input

It is necessary for the proposed system to detect touch inputs by people. Wilson proposed an imaging touch screen system using stereo infrared cameras and infrared illuminant behind the screen [19]. However, because the detection method is based on the assumption that the position and orientation of the screen plane is known, the method cannot be applied to a deformable screen. Funk et al. proposed an interactive shower curtain [20]. The system detects user input using a thermal camera and a background subtraction algorithm. This method can be applied to a deformable screen; however, the afterimage due to heat remains for a long time.

On the other hand, our detection method utilizes not only the transparency but also the deformability of the screen. As shown in **Fig. 3**, when a person touches the screen, the person's hand can be seen through the screen from inside the screen. Furthermore, the screen deforms around the contact position because the screen is inflated with air. Therefore, the proposed system can observe both the hand and the deformation using a normal CMOS camera inside the screen.

To estimate the touch location, we first calculate the optical flow of the obtained image sequence at each pixel using the Lucas-Kanade method [21]. After calculating the optical flow, the image is divided into $m \times n$ non-overlapping square blocks $b(i,j)$. $s(i,j)$, the magnitude of the optical flow of $b(i,j)$, is calculated as follows:

$$s(i,j) = \|\boldsymbol{u}(i,j)\|, \quad \dots \dots \dots \dots \quad (1)$$

where $\boldsymbol{u}(i,j)$ is the averaged optical flow of the block $b(i,j)$.

Our algorithm for detecting and clustering multiple touch inputs is explained using the example in **Fig. 4**.

Based on the calculated magnitude of the optical flow, $r(i,j)$, which is defined by the following equation, is calculated for each block (**Fig. 4(a)**).

$$r(i,j) = \min\{\log(s(i,j) - \varepsilon_d + 1.0), a\}, \quad \dots \quad (2)$$

where ε_d and a are constant parameters. $r(i,j)$ is used for

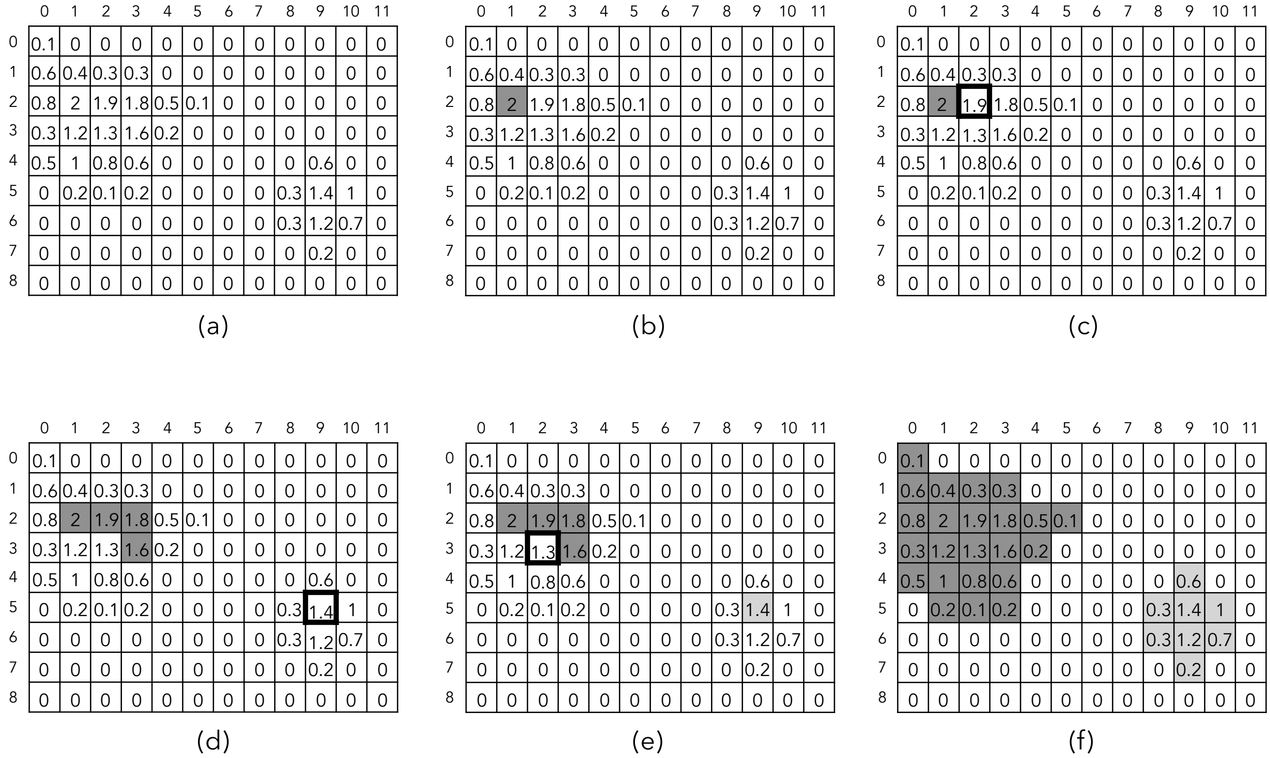

Fig. 4. Example sequence of clustering multiple inputs.

determining whether block $b(i,j)$ should be added to the existing clusters or not.

The following process is performed in descending order of $r(i,j)$ values. As can be seen in **Fig. 4(b)**, $r(2,1)$ is the largest.

Therefore, the block $b(2,1)$ is added to a new cluster c^0. Then, the second largest block $b(2,2)$ is processed (**Fig. 4(c)**). $d(c^0, b(2,2))$, the Euclidean distance between $b(2,2)$ and the representative point of the cluster c^0, is calculated. Based on the distance, $p(c^0, b(2,2))$ is calculated using the following equation:

$$p(c^k, b(i,j)) = \frac{1}{\sqrt{2\pi}\left(\frac{1}{r(i,j)}\right)} \exp\left(-\frac{\left(\frac{d(c^k, b(i,j))}{\varepsilon_r}\right)^2}{2\left(\frac{1}{r(i,j)}\right)^2}\right), \quad (3)$$

where k is the index of the cluster and ε_r is a constant parameter. Blocks with smaller $r(i,j)$ values are more likely to be added to existing clusters; blocks with larger $r(i,j)$ values are more likely to be judged as a part of a new cluster.

If the value of $p(c^0, b(2,2))$ is larger than a predefined threshold value p_{th}, the block $b(2,2)$ is added to cluster c^0 and the representative point is updated by weighted average, with $p(c^0, b(i,j))$ as a weight. In this way, certain blocks are added to cluster c^0. In the case of **Fig. 4(d)**, the value of $p(c^0, b(5,9))$ is smaller than that of p_{th}. The threshold value p_{th} was empirically determined. If $r(5,9)$ is smaller than the threshold value r_{th}, the block will not belong to any cluster. In this case, however, $r(5,9)$ is larger than r_{th}; therefore, a new cluster c^1 with $b(5,9)$ as a representative point is added. In the case of **Fig. 4(e)**, $b(3,2)$ is considered. Initially, $d(c^0, b(3,2))$ and $d(c^1, b(3,2))$, the distances between the block and the representative point of two clusters, are calculated and compared with each other. The nearest cluster is determined as a candidate cluster of the block. That is, the candidate cluster is determined according to the following equation:

$$\hat{c}(i,j) = \underset{d(c^k, b(i,j))}{\operatorname{argmin}}\ c^k, \quad \ldots\ldots\ldots\ldots \quad (4)$$

in the case of **Fig. 4(e)**, the candidate cluster of $b(3,2)$ is c^0 because $d(c^0, b(3,2))$ is shorter than $d(c^1, b(3,2))$. The value of $p(c^0, b(3,2))$ is larger than the threshold p_{th}; therefore, the block $b(3,2)$ is added to cluster c^0. Finally, all blocks are processed and two clusters are formed, as shown in **Fig. 4(f)**. The system determines that there are two inputs, and regards the representative points of each cluster as their respective input positions. The process is performed at each frame. The clusters are maintained between consecutive two frames, and the initial position of the representative point of each cluster is the position at the previous frame.

The algorithm for detecting multiple touch inputs is summarized in **Algorithm 1**. The proposed algorithm is a type of agglomerative hierarchical clustering, in which Eq. (3) is regarded as a distance function.

Algorithm 1 Detecting and clustering multiple touch inputs at time t

Input: Image I
Output: Set of clusters $C = \{c^k\}$

Calculate the optical flow at each pixel in I
Divide the image I into square blocks $(b(i,j))$
for all $b(i,j)$ **do**
  Calculate $s(i,j)$
  Calculate $r(i,j)$
end for
Sort the blocks in descending order of $r(i,j)$.
for all $b(i,j)$ **do**
  for $k \leftarrow 1, K$ **do** $\triangleright$ K is the number of clusters.
    Calculate $d(c^k, b(i,j))$
    Calculate $p(c^k, b(i,j))$
    The candidate cluster $\hat{c}(i,j)$ is determined
  end for
  if $p(\hat{c}(i,j), b(i,j)) < p_{\mathrm{th}}$ **then**
    if $r(i,j) < r_{\mathrm{th}}$ **then**
      Judge that $b(i,j)$ does not belong to any cluster.
    else
      Add a new cluster with $b(i,j)$ as a representative point.
      $K \leftarrow K + 1$
    end if
  else
    Add $b(i,j)$ to the cluster $\hat{c}(i,j)$
    Update the cumulative weight and the representative point of the cluster by weighted average with $p(c^k, b(i,j))$ as a weight.
  end if
end for
for $k \leftarrow 1, K$ **do**
  if The cumulative weight or number of elements of the cluster is sufficiently small **then**
    Empty and delete the cluster c^k
  end if
end for

According to the algorithm, if block $b(i,j)$ is close to a representative point of a cluster that already exists, it will belong to the cluster; otherwise, it will belong to a new cluster with the point as a representative point. In addition, the larger the optical flow, the easier the block is to be regarded as belonging to a new cluster; when the flow is smaller, the block is more likely to be regarded as belonging to an existing cluster. As a result, small noise is merged into the existing clusters, and its influence is negligible.

4. Evaluation of the Proposed System

To verify that the proposed system affords touching to surrounding people, we implemented the fluffy screen system and conducted a field trial in a real shopping mall.

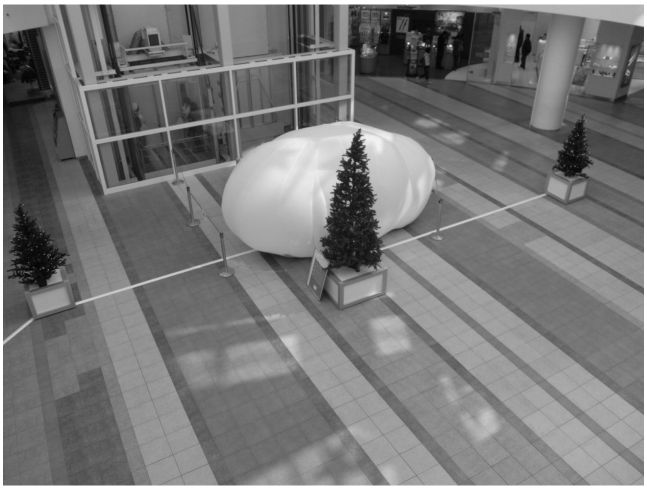

Fig. 5. Image of the developed fluffy screen system and the field trial site.

4.1. Experimental Setup

Figure 5 shows the image of the developed fluffy screen system and the field trial site. As a fluffy screen, an inflated portable room (Cloud, Offecct AB) was adopted. The screen is 5.3 meters in width, 4.0 meters in depth, and 2.3 meters in height.

Two USB cameras (VF0310, Creative Technology, Ltd.) and four LCD projectors (NP60, NEC Corporation) were installed inside the screen, as shown in **Fig. 2**. For image processing, we used Windows PCs (Intel Core 2 Duo 2.2 GHz with 4 GB RAM).

In this experiment, to avoid the influence of the presented content on the result of the hypothesis verification, the system presented only a circle at the touched position as the output.

The fluffy screen was set up in an open area of a shopping mall (**Fig. 6**).

As shown in the gray area in the figure, the region of interest (ROI) was set around the screen. We defined "interaction rate" as the proportion of people who interacted with the screen among people who entered the ROI, and used the rate as an evaluation index. The numbers of entering and interacting people were counted by observing the recorded video from the upper floor.

The field trial was conducted for four hours (from 17:00 to 21:00) on a national holiday in Japan.

4.2. Experimental Results

Throughout the experiment, the processing speed was about 10 to 15 fps. The frame rate dropped as the number of clusters increased. Processing was possible at such a frame rate when the number of input points was not greater than 4.

Figure 7 shows the interactions of visitors with the proposed fluffy screen system. As can be seen in the figure, multiple people simultaneously interact with the proposed system. In an extreme case, roughly ten people interact

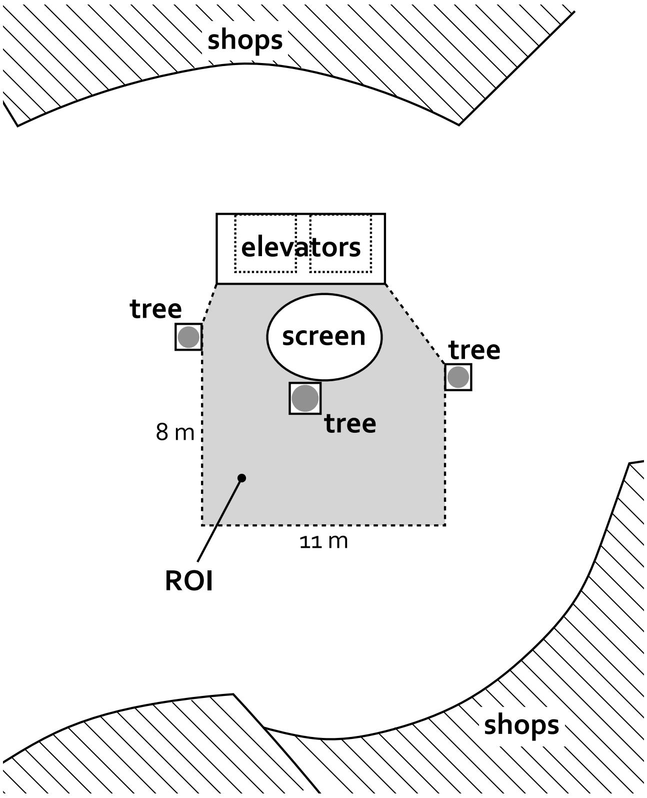

Fig. 6. Map of the field trial site.

Fig. 7. Interaction experiment in the shopping mall.

Fig. 8. Example of extremely crowded case.

Table 1. Numbers of the visitors who entered the region of interest (ROI) and interacted with the fluffy screen system.

Time	Total	Interaction	Rate [%]
17:00 – 17:10	112	35	31.3
17:10 – 17:20	86	37	43.0
17:20 – 17:30	80	24	30.0
17:30 – 17:40	83	21	25.3
17:40 – 17:50	77	39	50.7
17:50 – 18:00	97	38	39.2
18:00 – 18:10	53	20	37.7
18:10 – 18:20	68	31	45.6
18:20 – 18:30	59	36	61.0
18:30 – 18:40	69	35	50.7
18:40 – 18:50	49	16	32.7
18:50 – 19:00	70	27	38.6
19:00 – 19:10	37	19	51.4
19:10 – 19:20	43	21	48.8
19:20 – 19:30	75	32	42.7
19:30 – 19:40	65	37	56.9
19:40 – 19:50	44	19	43.2
19:50 – 20:00	50	15	30.0
20:00 – 20:10	45	19	42.2
20:10 – 20:20	48	22	45.8
20:20 – 20:30	29	15	51.7
20:30 – 20:40	39	24	61.5
20:40 – 20:50	53	23	43.4
20:50 – 21:00	16	9	56.3
Total	1447	614	42.4

with the proposed system at the same time, as shown in **Fig. 8**.

Table 1 shows the change in the numbers of visitors who entered the ROI and interacted with the fluffy screen system every ten minutes. This table and **Fig. 9** also show the change in the interaction rate.

Although the interaction rate varied by time of day, it was over 25% at all times during the experiment. During the experiment, a total of 1447 visitors entered the ROI. Among them, 614 people interacted with the proposed system. That is, the average interaction rate was 42.4%.

5. Discussion

The obtained interaction rate was quite high. That is, the proposed fluffy screen system strongly induced interaction.

According to Burke's field trial results for approximately two million shoppers for interactive digital signage [22], 17.1% paused to look at the displays, 5.3% spent more than 5 seconds examining the displays, and

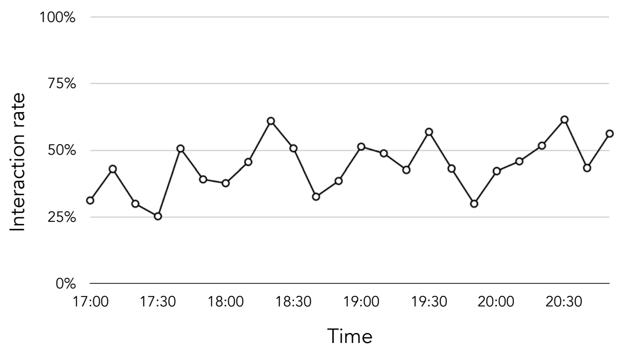

Fig. 9. Interaction rate.

only 0.42% stopped for 1 minute or more to interact with the displays. In his trial, large displays with small interactive touch screens were used. Because the experimental setup (such as the size of the display and the location) is different, we cannot make a simple comparison between their displays and our proposed system. Nonetheless, our proposed system outperformed the flat surface screens in terms of the interaction rate.

When we observed the types of interaction in detail, various interactions that were different from our initial assumption were performed. The proposed screen system was developed assuming an interaction such as touching or tapping lightly. In the real interaction during the field trial, however, pushing and slapping were sometimes observed. Furthermore, although rare, interactions such as leaning on the screen or rushing into the screen were also observed. Children tended to perform these strong interactions. Even for these input styles, the proposed detection method worked normally. However, it is necessary to investigate suitable information presentation methods for such an input style in the future. In general, the proposed fluffy screen affords vertical interactions to people.

Another important finding is the attraction effect of others' interaction with the proposed system. Because the proposed system can accept multiple people's inputs, one person's interaction encourages others to interact with the system. A similar effect was also reported by studies on the drawing power of crowds by Milgram et al. [23].

6. Conclusion

For digital signage systems that provide services such as advertisements, it is very important to have shoppers begin interacting with the systems. In this study, we made the hypothesis that fluffy objects have attraction affordance, and developed a fluffy screen system and verified the hypothesis.

The proposed system is inflated with air, and detects touch inputs using cameras inside the screen. Based on the detected inputs, the system presents information using LCD projectors. A detection and clustering algorithm are proposed in this paper. Using the algorithm, the system can accept multiple inputs simultaneously.

To confirm the effectiveness of the proposed system, a field trial was conducted at a shopping mall. During the trial of four hours, we achieved a very high interaction rate. From this result, it can be concluded that a fluffy screen has high attraction affordance.

The system proposed in this study is not suitable for applications that require detailed information to be presented or high position accuracy. In future work, it will be necessary to consider how to present information that is best suited to screens with fluffiness.

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