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Particle Display System
- A Large Scale Display for Public Space -

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Abstract

In this paper, the authors propose a large-scale display for public spaces. The display is based on the particle display system (PDS), which consists of hundreds of randomly distributed pixels. PDSs can be realized with random distributions, unlike traditional displays that require ordered matrices. Effective visual presentation techniques for a display system with randomly distributed pixels are employed to overcome the drawbacks and even realize advantages. The proposed display system can be used in applications in large spaces and public art and architecture facade displays, owing to its features described in this paper. In addition, the authors report the design principle and an implementation of a life-size prototype of a large ceiling display.

Categories and Subject Descriptors (according to ACM CCS): B.4.2 [Hardware]: Input/Output Devices—Image display

1. Introduction

Innovation in display technology in recent years has brought us many new ways to present information effectively in the real world. As a result of this innovation, information presentation in the real world has changed and is changing dramatically in various aspects. By combining computer generated information with that available in the real world, users are intuitively able to understand the information that relates to their physical environments. Numerous research projects have been carried out in these areas, e.g., Augmented Reality (AR) or Pervasive Display [RWC*98] [IKS*99].

Other notable examples of emerging applications of visual displays are "Public Art" and Architecture interior and exterior display". Out of the white cube, public art is site-specific and cannot be removed from its site. Many artists use cutting-edge display technology for their artistic expressions, e.g., high-definition video projectors, which involve the use of countless bright and colorful light emitting diodes (LEDs), and laser beams [3wa] [niUni08]. The status of architecture and displays are similar. Currently, architecture also involves the application of information and display technologies. Buildings with displays on their facade have now become common [bix] [Cen], and many visual displays are installed both inside and outside buildings [SBE08].

Although these technologies gave artists and architects new forms of expression, they have limitations. A great obstacle is that most of them require large structures and involve long installation processes. The authors have proposed a particle display system (PDS), which is a visual display system in which pixels are physically separated and located in irregular order, as a solution for the them [Sat08] [SHTH08b] [SHTH08a].

In this paper, the authors propose the design principles and development process of large-scale displays for public spaces, as an extension of the proposed PDS.

2. Large-scale display for public space

To define the concept of a large-scale display for public spaces, it is necessary to consider the requirements and the limitations of existing display systems. In the following subsection, the authors define the requirements and limitations.

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2.1. Requirements for large-scale display for public spaces

The major applications of large-scale displays include architecture and public arts. In recent years, many displays in public spaces have involved the use of media technologies [bix] [niUni06] [SBE08] [3wa] [Cen].

There are several demands for these types of applications as large-scale displays for public spaces.

Dynamic extensity Allow users/audiences to experience the spaciousness of their surroundings while enjoying the artwork. It can be achieved by constructing displays that utilize real space [STA07].

Location Specific Information Presentation Make users/audiences feel that the displayed information is strongly connected to the current location. This stimulates users/audiences to believe that the presentation is familiar [STA07].

2.2. Limitations of existing display systems

2.2.1. Inflexible hardware

Common visual displays have physical limitations. Computer displays like cathode ray tube (CRT) displays, liquid crystal displays (LCD), and plasma display panels (PDP), are examples of these displays. While they have relatively high resolution, their physical presences are very solid and inflexible. Among them, three features were defined as inflexible characteristics:

- resolution,
- size, and
- shape.

2.2.1.1. Resolution The visual displays mentioned above can provide high-resolution images , e.g., 1000×1000 pixels, or million-order pixels. The pixels are physically structured in a matrix and fixed to the position. The *resolution distribution* is uniform, and while it is convenient for creating, transferring, and displaying image data , it is sometimes inefficient (Figure 1).

The spatial distributions of the information or image to be displayed are not always uniform, resulting in inefficient use of resources. If the resolution is set so as to produce high-definition display for a given area, the potential resolution cannot be exploited to the fullest in other areas. In real world displays, this problem is compounded. The total area for displaying information grows, and the information density varies. While some information, like text or graphics, requires high resolution, other information, for instance, directions in the real world, requires only low resolution.

2.2.1.2. Size and Shape The size and shape in existing technologies and research projects are also fixed. This is not a problem in desktop computers because the scene at

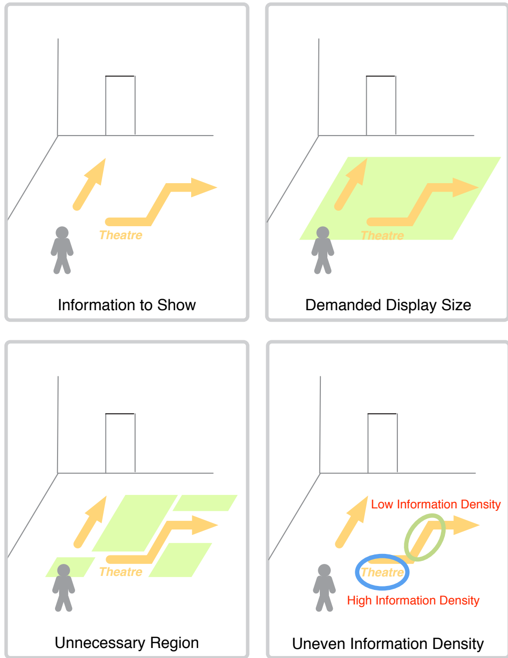

Figure 1: *Inefficiency in existing display systems*

the user's location does not change and there is no need to change the size or shape of the display. Users can select the appropriate model with the best size and shape according to their conditions. On the contrary, for large-scale displays, it is virtually impossible to know the precise size and shape before the implementing the display.

Moreover, the required shape of the display is not always square. In the *real world*, the environment is not flat but full of obstacles, and at the same time, users want to fit the display to the space. To present information on the real world, these applications are popular, and display technology that is suitable for these applications are required.

3. PDS

Against the background of the above discussion, the authors propose a novel real world display system, named the "Particle Display System," as a solution to overcome the limitations of existing display technologies. The key features of the PDS are its flexible shape, easy installation, easy modification , non-directional pixel distribution, and distance/direction oriented presentation. These features provide users with a flexible, on-demand display for use in the real world. Furthermore, by exploiting its characteristics to the fullest, the PDS helps overcome existing drawbacks in display systems and even gain advantages. It can virtually help

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achieve higher resolution with a high refresh rate and enables scrolling of images, as described later.

3.1. Concept of PDS

The basic concept and prototypes of the PDS were proposed in [Sat08] [SHTH08b] [SHTH08a]. In this subsection, a brief description is presented.

Figure 2 shows a schematic of the *PDS*. Every pixel in this display can be distributed over a larger area. Each pixel can be installed on every surface in a room, the wall, floor, or every step on stairs, and the ceiling. We can design the shape of the display so that it fits the environment and the displayed information. The resolution of the PDS on the illuminated graphics can be modified by changing the number and the density distribution of the distributed pixels.

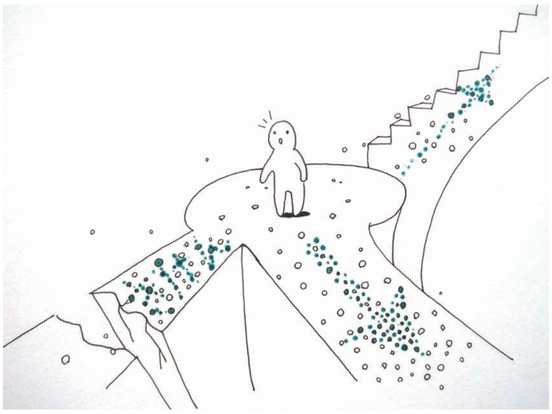

Figure 2: *Schematic of the PDS. The randomly distributed pixels light in a synchronized manner and form one image.*

3.2. Potential drawbacks

The nature of the PDS may introduce some limitations, e.g., *small number of pixels* and *nonuniform pixel distribution*. In the following discussion, the author defines "perceivable resolution" as *the fineness of the display that humans can perceive*.

The cost per pixel would increase since a microcontroller and other additional electronic components are required for control and communication purposes. As a result, the total number of pixels (LED nodes) is reduced. The details of the image to be displayed may not be represented appropriately because of the nonexistent pixels where "important information" on the image exists.

3.2.1. Nonuniform pixel distribution

As the display is installed by just distributing pixels manually, pixels are not aligned according to a matrix; in fact, in this case, it is impossible to do so. The casual process of distributing pixels results in nonuniform pixel distribution. The distribution of the pixels may result in noise in the represented image because the medium is not *innocuous*.

The *perceivable resolution* on the figure displayed by the PDS may be inferior compared to that of the ordinary LED display with matrix order. It is possible to convey the information required by the recipient, a human, by using some optimizations. The challenge here is to enhance the display capability by adopting optimization methods exploiting the characteristics of the image as well as the nature of human vision to modify the geometry and spatial frequency of the display.

4. Overcoming potential drawbacks

4.1. Visual interpolation

In the PDS, the phenomenon of "*visual completion*" is exploited [PN99] (Figure 3). This phenomenon is also well known as the "closure" of *Gestalt Principles*. The human brain compensates for the lack of information in the presented image and tends to complete the construction of incomplete elements. If the image has a cyclic pattern, the observer can imagine the elements even if it is totally missing. The observer also can complete straight lines or smooth curves, even if there is a gap in them (Figure 3). In this study, this phenomenon is exploited to enhance the presentation of a visual display. As the distribution of pixels is not uniform, important information on the image can be conveyed by choosing the best location in the whole display.

4.2. Virtual pixels

Another optimization method is to multiply the number of perceivable pixels by scrolling images over the randomly distributed pixels. Figure 4 illustrates the principle of an ordinary one-dimensional LED-array display. In a multi-slit display, viewers can observe finer details in the image than those allowed by the spatial Nyquist frequency of the slit interval. This is because of spatial and temporal integration in the human vision system [Nis04]. This phenomenon is also observed in randomly distributed LEDs (Figure 5). Some examples of computer simulated images are shown in Figure 6 and Figure 7. By scrolling an image over the randomly distributed pixels, the resolution along the axis of scrolling can be enhanced. In this paper, these multiplied pixels and the technique with this principle is termed "virtual pixels."

4.3. Advantages

While ordinary scrolling LED array displays involve the use of one-dimensional LED arrays, the PDS involves the use of randomly distributed pixels that yield performance that not only matches but exceeds that of the one-dimensional LED arrays by virtue of certain advantages. The two major advantages of the "proposed random pixel display" over "an ordinary LED scrolling display" are as follows:

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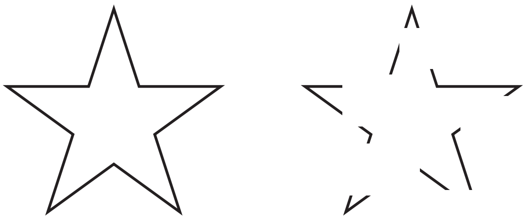

Figure 3: *“Visual completion" (“closure" of Gestalt principles).*

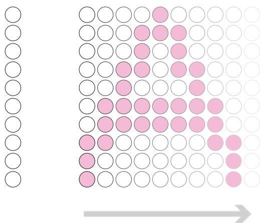

Figure 4: *Principle of a scrolling LED array display*

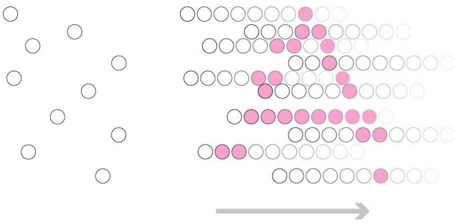

Figure 5: *Principle of a scrolling randomly distributed LED display*

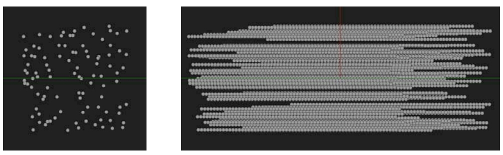

Figure 6: *An example of positions of real pixels (LED) and virtual pixels (64 pixels separated by 0.03 × side length of the display area).*

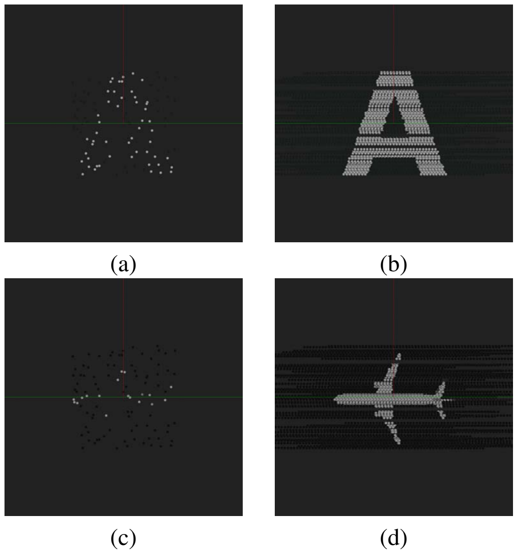

Figure 7: *Example of displayed images. (a): “A" without virtual pixels, (b): “A" with virtual pixels, (c): an airplane without virtual pixels, (d): an airplane with virtual pixels.*

- Better signal-to-noise ratio in spatial frequency
- Capability of omni-directional scrolling

4.3.1. Broader frequency spectrum

While pixels (Figure 8 (a)) ordered by a matrix have a cyclic and directional spatial frequency distribution (Figure 8 (b)), pixels in a random distribution (Figure 8 (c)) have a flat spatial frequency distribution (Figure 8 (d)). While the arrangement of pixels in an ordinary matrix display does not change the nature of noise (cyclic pattern), the display with randomly distributed pixels changes the nature of noise. As a result of these characteristics, the special frequency of the image to display will be delivered to the viewers effectively with randomly distributed pixels.

Akita introduced an image sensor with pseudorandom pixel distribution to solve the problem of directional singularity in the clarity of image representation [Aki08]. The image sensor has four types of pixels that are shifted to the four corners of the array (like an Anoto pen marker). While Akita's approach is similar to ours, it involves a combination of exactly four types of pixels whose corresponding photo diodes are placed at each corner; therefore, the resolution, size, and shape of the image sensor is fixed. Akita's approach also involves the use of an ordinary method for sensing and displaying pixels in the matrix order.

4.3.2. Capability of omni-directional scrolling

Another advantage of this flat spatial frequency distribution is omnidirectional scrolling. When observing Figure 8, we

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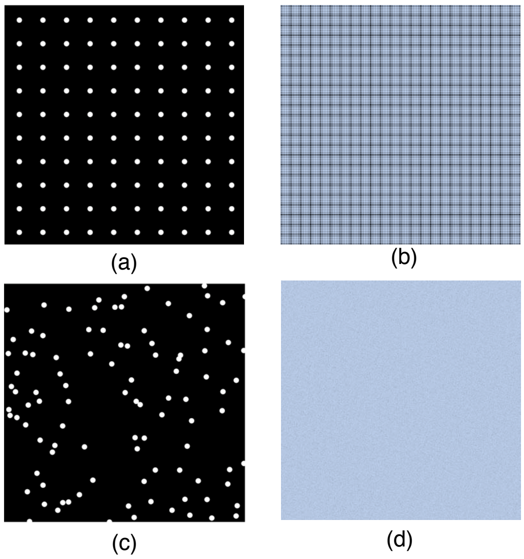

Figure 8: *Original and discrete Fourier transform (DFT) images of the pixel distribution of displays. Arrangement of pixels: (a) 100 pixels arranged in matrix order, (c) 100 pixels arranged in random order (Note: the sizes of the white dots in (a) and (c) are larger than the actual sizes (1 pixel dot) so that they are visible.). (b) and (d) are the DFT images of (a) and (c), respectively.*

can see that Figure 8 (d) does not indicate directionality, while Figure 8 (b) indicates strong directionality.

This flat spatial frequency is also suitable for multi-directional scrolling applications because scrolling toward any of the directions results in almost the same characteristics and representation performance.

5. Implementation to a large scale display

The reconstruction of a scrolling image discussed in the last section is dependent on the pixel density of the display. The key point here is that the parameter is not the density on the surface of the display but the density on a viewer's retina. Therefore, $pixels/rad^2$ is the selected parameter. To implement a large-scale display, the necessary density of pixels is examined by using this parameter.

5.1. Characteristic test of PDS and virtual pixels

When the spatial or temporal frequency of visual stimuli changes, the visibility of the displayed pattern also varies with the display. To determine the relationship between the spatial/temporal frequency and the visibility of PDS optimized by creating virtual pixels, a display experiment in which the alphabet "A" is scrolled was conducted to determine the display characteristics (Figure 9).

A randomly distributed LED display is suspended at eye level; a subject stands in front of it, and the alphabet "A" is scrolled from right to left on the LED display. 100 pixels (white LEDs of diameter 5 mm) are randomly distributed over a 400 × 400 (mm) square. Each pixel (LED) has a luminous intensity of 3000 (mcd). The subjects are eight ordinary women and men in their 20s and 30s. Figure 10 shows the result of the display experiment. The average of the closest distance to the display is plotted. The error bars correspond to the standard distribution. If a subject cannot see a clear image, the trial is not taken into account for calculating the average and distribution. Here, "temporal frequency" on the X-axis represents the cycles of the main stimuli of the image presented. Figure 10 indicates that one must stand at least 2 m away from the display to see the image clearly.

Figure 10 also indicates that 5–12 (cycles/s) is the appropriate scrolling speed. As the width of the character stroke for "A" is 65 (mm), one cycle of the stimuli can be simplified to 130 (mm). The appropriate scrolling speed is

$$Scroll\ Speed \simeq \arctan(\frac{f}{D})(rad/sec) = \frac{f}{D}(rad/sec) \quad (1)$$

where f is the temporal frequency (cycles/s) and D is the distance (m) between the display and viewer. With the variables above, the appropriate *ScrollSpeed* is calculated as 0.325–0.78 (rad/s).

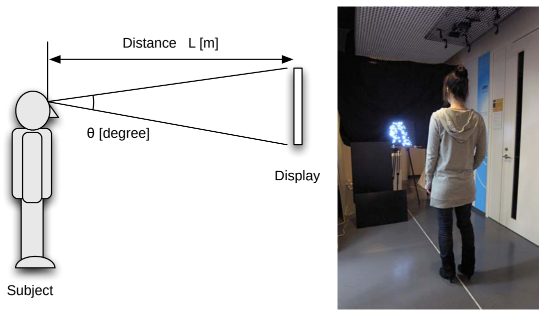

Figure 9: *Spatial experimental setup*

5.2. Design principle and calculation of required pixel density

In the case of our earlier evaluation of the PDS with 100 LEDs in a 400 × 400 (mm) square, the characteristics of the display were determined (Figure 9, 10).

The view angle of a display is expressed by the following equation:

$$View\,Angle = \arctan(\frac{D}{L})(rad) \quad (2)$$

where L (m) is the distance between the display and a viewer,

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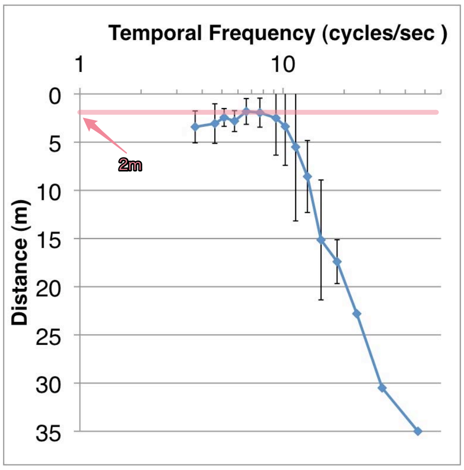

Figure 10: *PDS with virtual pixels - Visible distance chart. Error bars correspond to the SD.*

and D (m) is the length of a side of the square. Therefore, the pixel density $(pixels/rad^2)$ of this display is expressed by the following equation:

$$Pixel\ Density = \frac{m}{(\arctan(\frac{D}{L}))^2} \quad (3)$$

$$\simeq \frac{m}{(\frac{D}{L})^2} \quad (4)$$

$$= \frac{m \cdot L^2}{D^2}(pixels/rad^2) \quad (5)$$

where m is the sum of pixels. It is assumed that D/L is sufficiently small.

With the above equation, the pixel density is

$$Pixel\ Density \simeq \frac{100 \cdot L^2}{0.4^2} \quad (6)$$

$$= 625 \cdot L^2(pixels/rad^2) \quad (7)$$

Here, Figure 10 shows that a distance of approximately 2 (m) from the display is needed to view images clearly. With this assigned distance, the required *pixel density* is approximately

$$2500(pixels/rad^2). \quad (8)$$

6. Discussion

Currently, the authors are planning the development of a large-scale display for the ceiling of a public transportation building. Figure 11 and Figure 12 show the planned installation of the large-scale display. The height of the ceiling (from the human eye level) is 16 (m), and the display area is approximately 323 (m^2). With the equation above and these parameters, the pixel density is

$$Pixel\ Density = \frac{m \cdot 16^2}{323}(pixels/rad^2) \quad (9)$$

Therefore, the required number of pixels is approximately 3000 (pixels), which corresponds to approximately 9 ($pixels/m^2$). This is very low “resolution" compared to ordinary displays, and consequently, installation is easy and inexpensive and fewer physical components are required.

A model of this installation with 300 embedded LEDs is developed with a scale of 1/50 (Figure 13).

A prototype having the actual size is also built. The dimensions of prototype one are $5m \times 6m$, and it contains 27 LEDs; the resolution and the selected parameter 16 (m) away from the display are $0.9(pixels/m^2)$ and 230 $(pixels/rad^2)$, respectively, (Figure 14, 15). The dimensions of prototype two are $1m \times 6m$, and it contains 61 LEDs; the resolution and the selected parameter 16 (m) away from the display are $10.2(pixels/m^2)$ and 2600 $(pixels/rad^2)$, respectively, (Figure 16).

Figure 11: *Planned installation of a large-scale display*

Figure 12: *Schematic of the planned installation*

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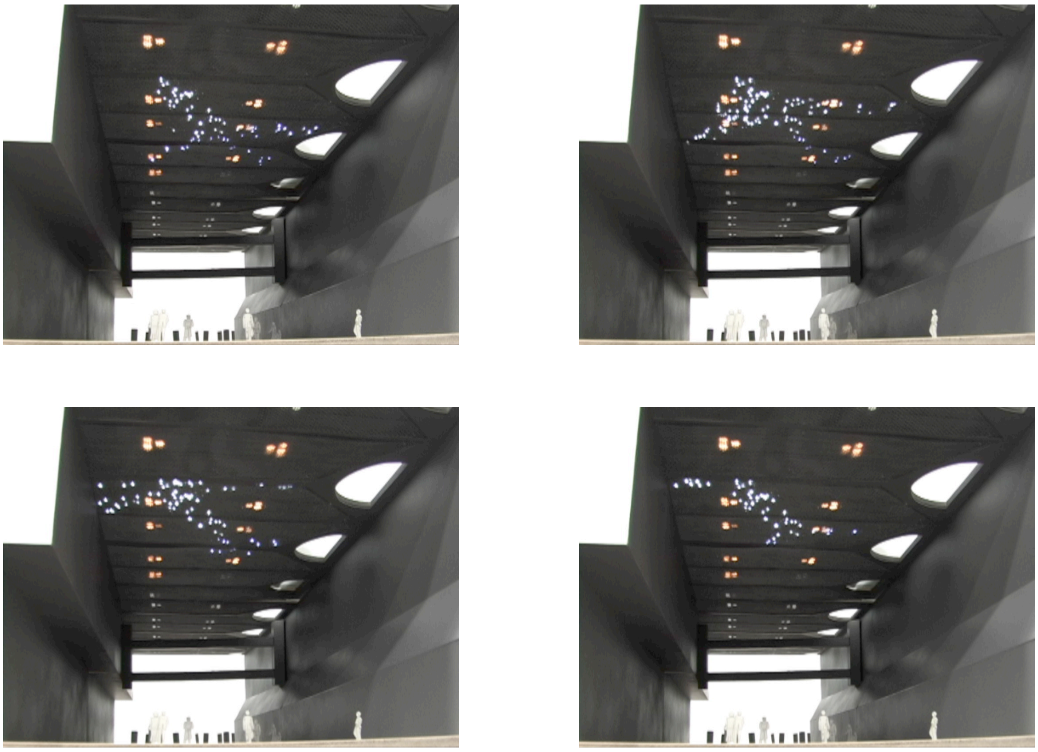

Figure 13: *Model of a large-scale display (300 LEDs; scale: 1/50) that shows a flying airplane.*

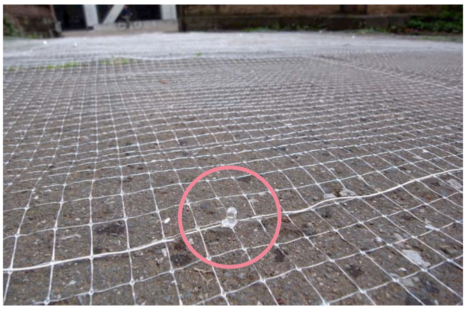

Figure 14: *Close-up view of the large-scale display prototype. An embedded LED is marked with a pink circle.*

Figure 15: *Large-scale display prototype one in operation; the dimensions of the prototype are* $5m \times 6m$ *and it concludes 27 LEDs. The picture is taken around 10 (m) away from the display.*

7. Conclusion

In this paper, the authors proposed a large-scale display for public spaces; the display is based on the particle display system (PDS). The characteristics of the small-size PDS are described. The advantages of randomly distributed pixels, virtual pixels, omni-directional scrolling, and better signal-to-noise ratio are retained in the large-scale display.

A method to exploit these advantages is based on the design principle of the necessary number of pixels, as proposed by the authors. On the basis of these results, the design principle for extending the PDS to a large-scale display for public spaces is discussed.

A future task is to conduct a more general examination of display capabilities for a life-size implementation involving a wide range of subjects and viewers. Content that can effectively be used to fully exploit the potential of the installation environment and context is required. Another future task is

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Figure 16: *Large-scale display prototype two in operation; the dimensions of the prototype are* $1m \times 6m$ *and it includes 61 LEDs. The picture is taken around 15 (m) away from the display.*

to carry out research on much easier and more cost-effective methods of implementing this display.

8. Acknowledgement

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