Efficient Light Field Measurement for Rendering with Mirror Spheres Array

Natsumi Yano* Takao Makino*Toru Ishii** Norimichi Tsumura* Toshiya Nakaguchi* Yoichi Miyake*
Chiba University, JAPAN*, DIC Corporation **

Abstract

Modified conventional method for capturing light field using mirror ball is proposed to extend the capturing light field. Two types of mirror sphere array pattern is introduced to capture the rays from various directions and positions passed the light fields and inter-reflected rays by neighbored sphere are also considered to capture the light field. Amount and direction of those captured rays are evaluated by the ratio of the acquired light fields and it is shown that the rays can be captured precisely and effectively compared with conventional method. It is also shown that the method is significant for the appearance of computer generated synthetic object.

Introduction

Recently, computer graphics is used to design the shape and appearance of products. The designers can control the appearance of the design very easily in computer graphics. On this situation, it is required to reproduce the appearance of the products in the real world scene (e.g. selling space). This is because the consumers will buy a product in the real world scene. To reproduce appearance of products in the real world scene, it is required to capture the spatially varying rays (referred as light field [1]) in the scene. The spatially varying rays have an important role in the visual appearance of products. Unfortunately, the spatially varying rays are not captured by a general environment mapping method. Unger et al. [2] solved this problem using an array of mirror spheres. However, this method cannot capture enough rays for realistic rendering.

In this paper, we propose three extensions to the conventional method for capturing more rays. In the first extension, the measurement system is moved every taking an image to capture the light field widely. In the second extension, two types of mirror spheres array patterns are used to capture the light field precisely. By using these extensions, the many rays those pass through a variety of positions and have various directions can be acquired. In the third extension, interreflected rays are considered to capture the light field effectively. By using this extension, we can acquire the rays those cannot acquire using the conventional method. We also newly define a percentage of acquired light field to evaluate the amount and the spatial distribution of acquired rays numerically. We perform experiment to acquire the light field practically, and confirm the effectiveness of our method. Moreover, a synthetic object is rendered by using captured illumination. From the rendered images, we confirm that the appearance of computer-generated synthetic object is improved compared to the conventional method.

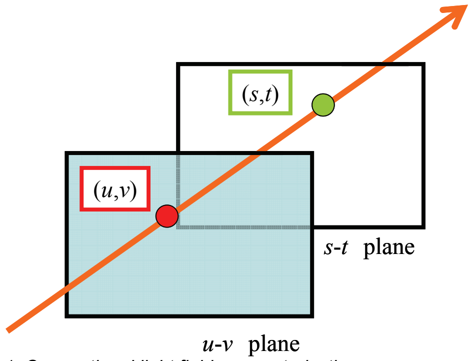


Figure1: Conventional light field parameterization

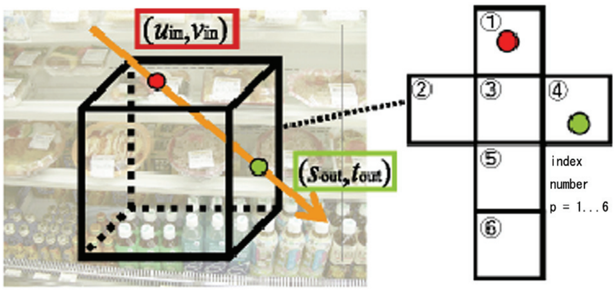


Figure 2: Our light field parameterization.
Our light field function defined by $P = P(p_{in}, u_{in}, v_{in}, p_{out}, s_{out}, t_{out})$.

Light Field Parameterization

In this section, we show the detail of the light field. A light field describes the lighting distribution in a static scene with fixed illumination. Levoy et al.[2] and Gorlter et al.[3] have presented light field parameterization by using the two-plane parameterization. The ray in the real world scene passes through the two plane (u-v plane and s-t plane) as shown in Figure 1. We extend this idea and define the space for placing the synthetic object as a cube as shown in Figure 2. From Figure 2, the each side of cube has an index number p (p=1, 2… 6). The ray in the real-world scene enter the cube from the point (p_{in},u_{in},v_{in}), and go out the cube from the point (p_{out},s_{out}, t_{out}). Therefore, our light field function is defined by P = P(p_{in} ,u_{in},v_{in}, p_{out} ,s_{out}, t_{out}).

Acquisition of the light fields

In this section, a measurement system is shown used in the research and conventional and proposed methods are introduced based on this measurement system.

The measurement system consists of an array of 3×3 2”diameter mirror spheres and a standard digital camera as shown in Figure 3. The light field is acquired by taking a picture of mirror spheres array and using the ray tracing method. If our measurement system itself is reflected in a mirror spheres array, we don’t use this area in the image. To capture the full range of luminance values in a real-world scene, we use a high dynamic range photography technique [7].

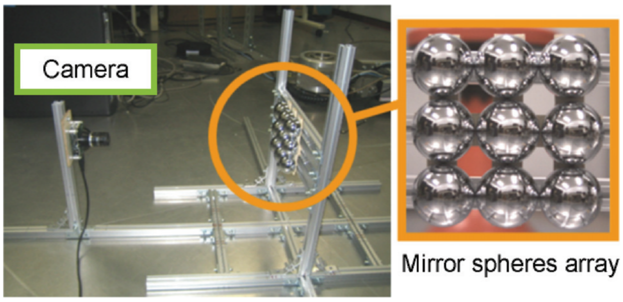


Figure 3: The measurement system for capturing light fields

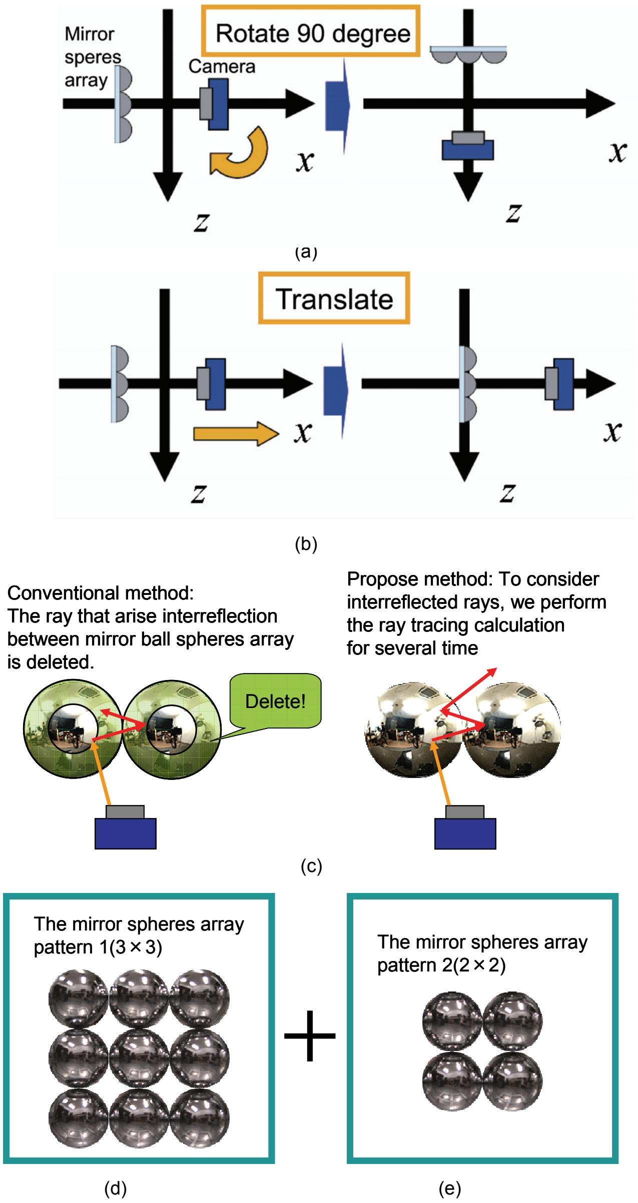


Figure 4: Proposed measurement conditions.
(a) Rotate the measurement system
(b) Translate the measurement system
(c) Changing mirror spheres array pattern
(d) Interleflected rays: Conventional method
(e) The ray tracing calculation several times
We use a combination of the photograph of pattern1 and the photograph of the pattern2.

Unger et al. took a picture of mirror spheres array as a digital image. In our proposed method, more than one images are taken to capture the light field effectively. The proposed three extensions are shown as follows:

- The measurement system is rotated and translated as shown in Figure 4(a), (b). The measurement system is rotated 90 degrees and takes a picture from that angle. This procedure is repeated four times and obtained four images. On the other hand, the measurement system is translated forward 3cm and takes an image from that position. This procedure is repeated five times and obtained five images. By moving the measurement system, we can acquire the many rays those pass through a variety of positions and have various directions.
- We change mirror spheres array pattern and also take a picture. We use a combination of the image of pattern 1 and pattern 2 as shown in Figure 4(c). By changing mirror spheres array, we can acquire the rays those cannot be acquired when we use mirror spheres array pattern 1 only.
- Unger et al. discounted the rays in a region that is subject to interreflection as shown in Figure 4(d). To acquire more rays, we perform the ray tracing calculation for several times to add interreflected rays to the data sets as shown in Figure 4(e).

Evaluation by the percentage of the acquired light fields

In this section, we define a percentage of the acquired light field to evaluate the amount and spatial distribution of acquired rays numerically. The percentage of the acquired light fields is defined as the ratio of the number of captured rays to the total number of rays in the acquisition space. The total number of rays in the space is represented as the combination of all input and output rays. As we indicated before, we define the light field acquisition space as a cube. The each side of the cube is divided into a certain resolution as shown in Figure 5(a). The high spatial distribution indicates that rays have various input and output on the cube.
The examples of the acquired rays when the resolution of the each side of the cube is 4×4 are shown in Figure 6(a) and (b) to explain the defined percentage easily. For the purpose of illustration, we show a cube in section as shown in Figure 5 (b). In the case of Figure 6(a), the spatial distribution is low. On the other hand, the spatial distribution is high in the Figure 6(b). From Figure 6 (a) and (b), both examples acquired 4 rays regardless of spatial distribution. Next, the resolution of the each side of the cube set to 2×2 as shown in Figure 6 (c) and (d). From Figure 6(c), some rays are regarded same rays in order to have same input and output. However in Figure 6 (d), the number of rays doesn't change because the rays has high spatially distribution. Therefore, if the spatial distribution is high, the percentage is high in the low resolution.

We perform experiments under our proposed measurement conditions and calculate each percentage. The percentages are plotted against resolution of the space on a graph as shown in Figure 7. From Figure 7, both the part of low resolution and high resolution has high percentage compared to conventional method.

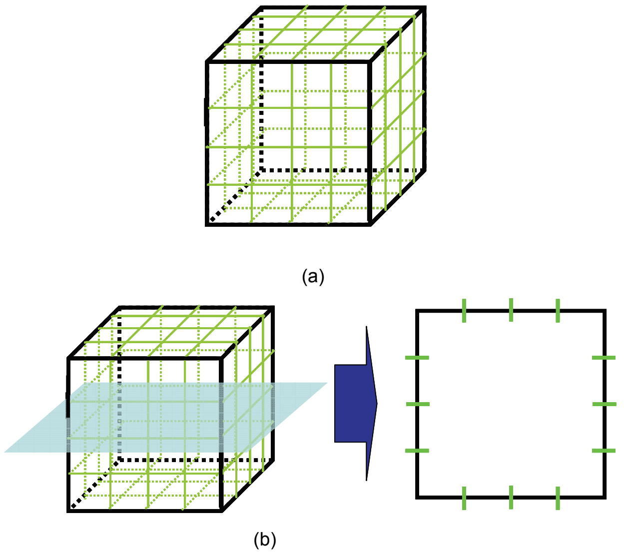


Figure 5: The each side of the cube is divided into a certain resolution for discretizing the space.
(a) the resolution of the each side of the cube is 4×4.
(b) The cross-section drawing of the cube

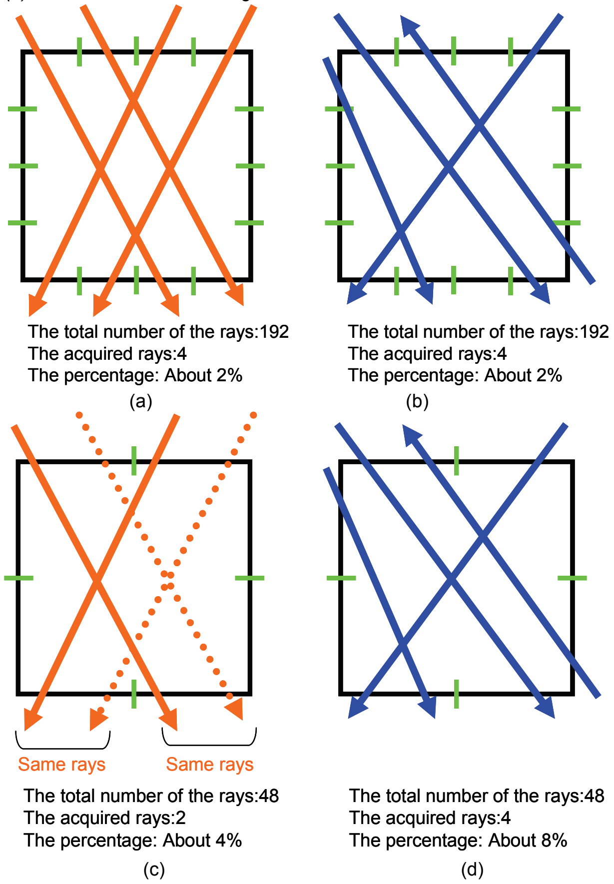


Figure 6: The example of the acquired rays
(a) Example 1:When the resolution of the each side of the cube is 4×4
(b) Example 2:When the resolution of the each side of the cube is 4×4
(a) Example 1:When the resolution of the each side of the cube is 2×2
(b) Example 2:When the resolution of the each side of the cube is 2×2

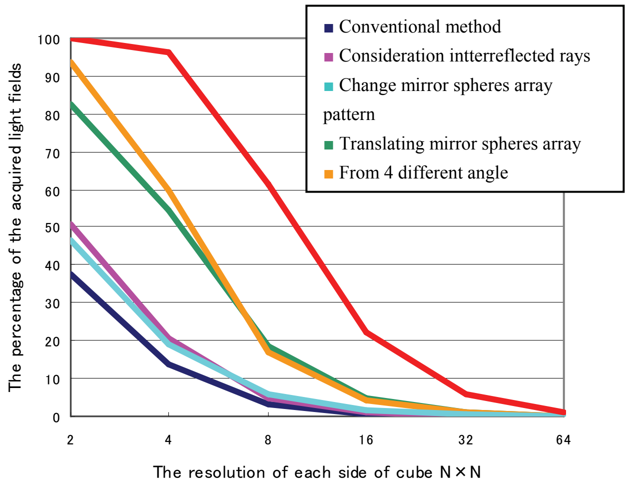


Figure7 : The percentage of the acquired light field

Therefore, we confirm that both amount and spatial distribution of acquired rays is raised remarkably by using all extensions compared to conventional method. When the measurement system is moved, the percentage is high remarkably. On the other hand, when the interreflected rays are considered or changed mirror spheres array pattern, the percentage is not very high. Therefore, the moving our measurement system is most efficient in our proposed extensions.

Rendering with the acquired Light Field

In this section we show our method for rendering synthetic objects illuminated by real world lighting using captured light fields. All our rendered images were generated using the PBRT system[8] with our custom shader. Our custom shader is asked to return radiance information of the ray that is selected by PBRT system. PBRT represent a ray with a point $\boldsymbol{o}$ (x_p,y_p,z_p) for the origin and a vector $\boldsymbol{d}$ (x_v,y_v,z_v) for the direction. A ray denoted by $\boldsymbol{r}$; it has origin $\boldsymbol{o}$ and direction $\boldsymbol{d}$ as shown in Figure 8. Here, the origin $\boldsymbol{o}$ is a point on the synthetic object. Figure 9 shows rendering procedure. First, PBRT require radiance information of a ray $\boldsymbol{R}$ whose origin is $\boldsymbol{R}_o$ and direction is $\boldsymbol{R}_d$. Second, the rays those are similar to $\boldsymbol{R}_d$ are found in the acquired light field. Third, these rays and $\boldsymbol{R}$ are projected on a surface whose normal vector is $\boldsymbol{R}_d$ and origin is $\boldsymbol{R}_o$. Finally, we find the closest point to the origin of the surface and a ray of closest point is selected. We then return the radiance information of the selected ray to PBRT system.

Experiment and results

In this section, we show the improvement of proposed method by rendering synthetic objects. For this purpose we performed experiment in two environmental spaces. One is a simple space and the other is a high-frequency space as shown in Figure 10.

First, we show the effectiveness of our method over the environment mapping method. The effectiveness of our method is that the appearance of rendered image is changed in accordance with the position in the scene.

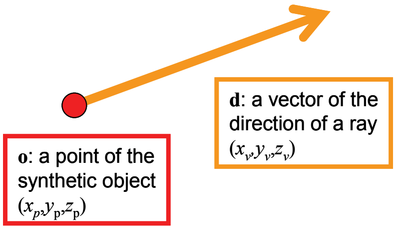


Figure 8: Description of a ray in PBRT

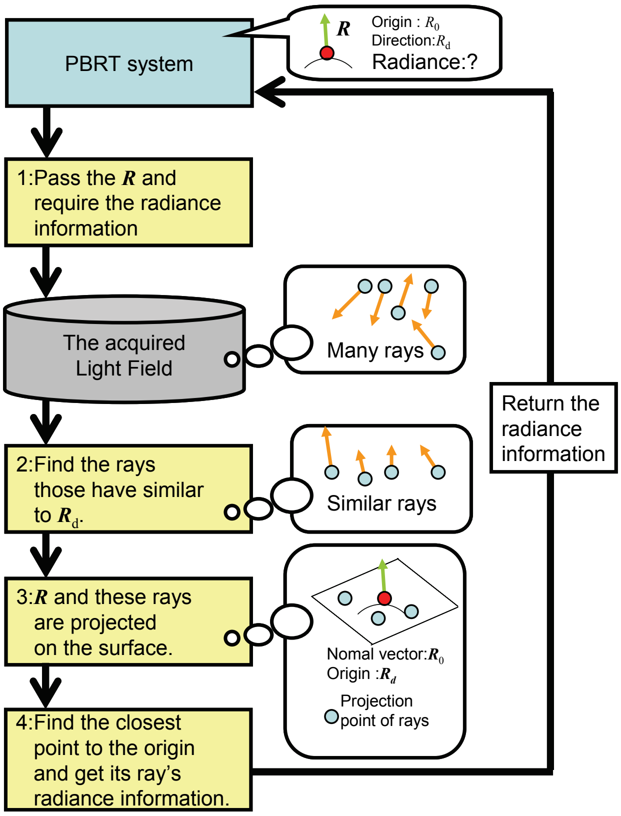
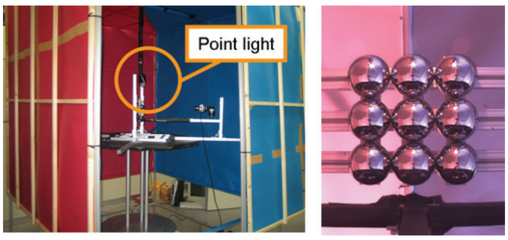
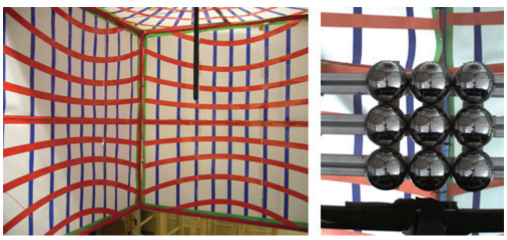


Figure 9: The rendering procedure



(a)



(b)

Figure 10: The measurement environments.

(a) The simple space and the photograph.

This space is separated by the color red and blue and has a point light.

(b) The High frequency space and the photograph.

This space has stripe pattern.

For this purpose, an image of a mirrored beverage can is rendered with acquired light field as shown in Figure 11(a).This light field is acquired in the simple environmental space. The mirrored beverage can is putted in the center of the space. Figure 11(b) shows a rendered image of mirrored beverage can that is translated behind 3cm from the center of the space. Figure 11(c) and (d) shows extended figure of top of the mirrored beverage can. From Figure11, we can see that the appearance of the rendered image is changed appropriately. On the other hand, the same scene is rendered using the general environment mapping method as shown in Figure 12 (a) and (b). Figure 12(c) and (d) shows extended figure of Figure 12(a) and (b). From Figure 12, the appearance of the rendered image does not change even if a mirror can is translated. Therefore, our method clearly shows a remarkable improvement compared to the environment mapping method. We obtain the similar result when we use the light field or environment map of the high-frequency space.

Next, we show a change in an appearance of computer-generated synthetic objects in accordance with the percentage of the acquired light fields. For this purpose, the same scenes are rendered with the light field which have different percentage of the acquired light field. The result of the rendered images and the used measurement conditions are showed in Table 1. The appearance of the mirrored beverage can and the back ground has the error if the percentage is low in the 4×4 resolution. However, if the percentage is sufficient, the appearance of the mirrored can and the background is improved. In addition, if the percentage exceeds the certain value, the appearance of the rendered image is not changed any more. We obtain the similar result, when the light field of the high-frequency space is used.

The rendered image using the light field that has highest percentage still have error in the background. We consider that this error is caused by the insufficient rays.

Conclusion

In this paper, we proposed three extensions to the conventional method for capturing light field using mirror spheres array. We also defined the percentage of acquired light field to evaluate the amount and the spatial distribution of acquired rays numerically. We performed experiment practically and confirmed the effectiveness of the proposed extensions. Moreover, a synthetic object was rendered by using captured illumination. From the rendered images, we confirmed that the appearance of computer-generated synthetic object is improved compared to conventional method.

In future works, we compress many similar rays for reducing rendering times because many similar rays are captured.

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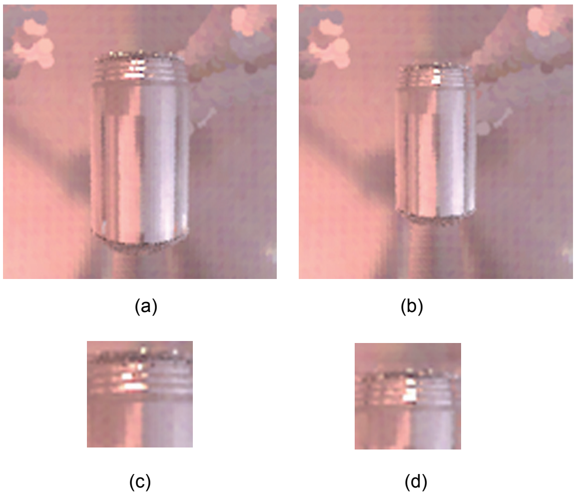


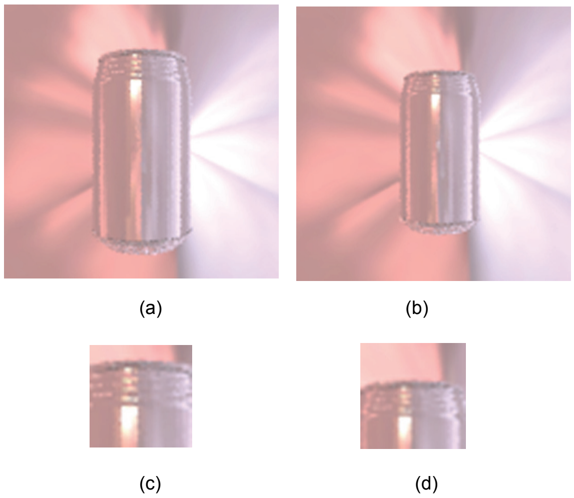
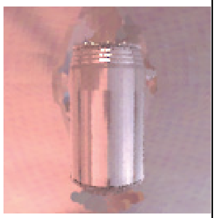
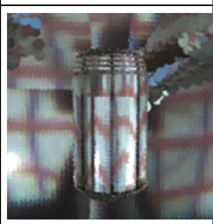


Figure 11: Proposed method
(a) A rendered image using our method
(b) Translated behind from the position of the (a)
(c) Extended figure of (a)
(d) Extended figure of (b)

Figure 12: The environment mapping method
(a) A rendered image using environment mapping method
(b) Translated behind from the position of the (a)
(c) Extended figure of (a)
(d) Extended figure of (b)

Table 1: The result of the rendered images and the using measurement conditions

Translation	Nothing	5 times	Nothing	5 times	5 times
Rotation	Nothing	Nothing	4 angles	4 angles	4 angles
Array Pattern	Pattern1	Pattern1	Pattern1	Pattern1	Pattern1 & 2
The percentage (4×4)	20.4%	54.4%	59.5%	95.3%	95.5%
In the simple space					
In the high-frequency space					

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Author Biography

Natsumi Yano was born in Japan, 1985. She is a graduate student in the Dept. of Advanced Integration Sciences, Chiba University. Her research interest is computer graphics.