

## A METHOD FOR FABRICATING REFLECTORS PRESENTING MULTIPLE COLORED IMAGES BY RAISED LINEAR STRIPES

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### ABSTRACT

Several methods that present multiple images by a reflector have been proposed. These types of reflector present different images depending on an observation condition such as lighting, viewing direction, or both directions. However, these methods are limited to presenting only two colored images. We propose a method for fabricating a reflector that can present three or more images. The reflector presents an image but hides other images under the observation condition. Our reflector utilizes anisotropic reflections whose colors change depending on the observation condition. The reflectors consist of a number of small-scale linear stripes by printing with an ultraviolet printer. We design the small-scale geometry of these reflectors, with which we produce the desired anisotropic reflection properties needed to display multiple images. We demonstrate the effectiveness of our method by showing fabricated examples that present three or more colored images.

### 1. INTRODUCTION

A number of techniques for presenting multiple images from reflectors under different observation conditions have been developed for increasing variations of industrial designs, for example aesthetic packages' appearances. In this paper, we focus on presenting multiple colored images, and propose a new approach to achieve this.

There are two methods that have the same goal as ours [1][2] but these are used to fabricate reflectors that present two images only. In our paper, we propose a method fabricating reflectors that present three or more images.

For one of the previous methods a high resolution grid pattern is printed on the surface of a reflector made of metal [1]. The grid pattern causes anisotropic reflections on a macroscopic scale and two different images are presented when viewed from two different directions. Although, when using this method, images with high contrast and high chroma can be presented, the number of images is limited to two. Our method extends this idea to presenting more images.

We have developed a technique that, instead of using a grid pattern, uses special small scale patterns, which increases the number of displayed images. The patterns are printed on the surface as a height map using an

ultraviolet (UV) printer. We make use of the masking/shadowing effects of the height map to display clear multiple images. Unlike the previous reflectors, we assume that the reflection properties of both the reflector and the printed pattern are diffuse, which makes them easier to be fabricated.

### 2. RELATED WORK

As mentioned above, two methods by which two different colored images are obtained from a reflector have been demonstrated.

Pjanic and Hersch succeeded in presenting different colors with a metallic reflector when viewed from two different directions [1]. This was achieved by printing a grid pattern, or a collection of horizontal and vertical line segments, on the reflector. The direction of the anisotropy caused by the horizontal line is almost perpendicular to that caused by the vertical line, making it possible to present two different colors. With this method colors within the range produced by combinations of the following four color inks can be displayed: cyan, magenta, yellow, and white. A lookup table is used for the relationship between the amount of each ink and the observed color.

The other method also uses a metallic reflector but in this case has two colored images printed on it [2]. This method takes into account both the specular and diffuse reflections, and makes one image invisible under certain viewing conditions. Although the purpose of this method is to hide one image in the other image, it can be used to present two images. However, both these methods [1][2] are limited to the presentation of two color images; it is impossible to present three or more images.

BRDFs can also be used for presenting multiple images. Lan et al. developed a method for producing the microgeometry for a colored reflector with an arbitrary BRDF [3]. This was done using a 3D printer and UV printer.

In the method developed by Levin et al., specular lobes are controlled by designing to appropriate microgeometry [4]. An etching process for creating the microgeometry was employed. However, the cost of etching is expensive.

Several methods aim at presenting grayscale images by controlling shadows [5], diffuse reflections [6], and

occlusions [7]. However, multiple colored images cannot be displayed using these methods.

Methods based on mechanisms other than reflection have also been proposed for presenting multiple images, for example, refraction by a lens [8], shadows [9], and specular holography [10]. One problem with these methods is that the fabrication processes for these are lengthy and time consuming. The fabrication process for our reflector is much faster.

### 3. BASIC IDEA

Our method consists of two printing steps. The first step prints a colored image on a substrate. The image is composed of all presenting images. We give the subpixels of the printing image the colors of the presenting images. In other words, each pixel of the printing image contains colors of presenting images as subpixels. The second step prints an element having an anisotropic reflection on the subpixel. The element contains a collection of small-scale linear stripes in the same direction. The linear stripes consist of raised lines. Let us call the element a *patch*. Figure 1 shows the linear stripes in the patch. The linear stripes are built by overprinting. When the viewing direction is parallel to the stripes, both the top and bottom surfaces are visible. However, when the viewing direction is perpendicular to this, only the top surface is visible (see Fig. 1). By assigning different colors to the top and bottom surfaces, two different colors can be displayed with a single linear stripe. By printing sets of linear stripes with different directions, we can display multiple colors. Each patch is composed of linear stripes of the corresponding angle to each image.

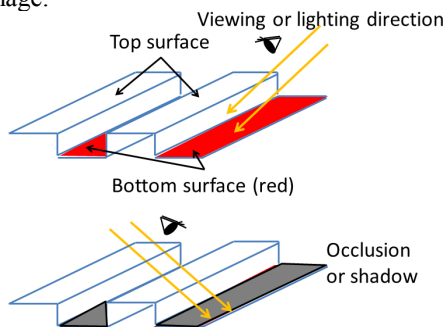


Figure 1: Changing appearance under different viewing or lighting condition by a linear stripe. In the top image, the linear stripe does not occlude the viewing and lighting rays. In the bottom, the linear stripe occludes the rays and the bottom surface disappears.

Although reflection from the surface is diffuse, the appearance of a patch is anisotropic on average; it presents two colors depending on the viewing and lighting directions. By arranging several patches of different azimuthal angles, the reflector shows multiple images under specific observation conditions.

In order to fabricate the reflector, we used an UV printer. The UV printer provides us with many benefits.

It can print special inks on a wide range of materials, such as plastic, wood, polyethylene terephthalate, acrylonitrile butadiene styrene, etc. The UV curable ink can be stacked by overprinting. The linear stripes can, therefore, be built by an UV printer. We believe, therefore, that the UV printer is currently the best device for our purpose.

As a general problem, it is almost impossible to predict the shapes of ink droplets because the shapes are easy to change depending on conditions, for example, a material and surface roughness of substrate. Therefore, we do not predict shape and height of a stack of inks. We build the linear stripes with the experimental approach as described in Section 4.

### 4. DESIGN OF OUR REFLECTOR

Our goal is to present three or more colored images with a single reflector. Our method consists of two steps as mentioned in Section 3. Here especially describes printing linear stripes of the second step. We first describe the conditions for printing the linear stripes. Then, we assign the patches to each pixel in the reflector. The outline of each patch is limited to a rectangle. Each subpixel of the printing image in the first step is the same shape of the corresponding patch.

The linear stripes are formed using an UV printer. They are produced by drawing line segments with the printer. The UV printer is an inkjet printer that propels droplets of UV curable inks from print head nozzles. The inks are cured after being deposited on the surface. Although the resolution of a printable dot is known, the shape or size of it is not. The appropriate resolution for the linear stripe is also unknown. Before exposure, the ink is a flowable liquid, and it is almost impossible to numerically accurately predict the shape and height of a stack of inks. Because the shape of the stacked layers of ink is unknown, the bi-scale material design approach [11] cannot be applied to simulate the appearance. We therefore measured the amount of an occlusion of printed linear stripes to confirm the amplitudes of the anisotropy.

To print the linear stripes, we investigated the conditions for printing parallel line segments. First, we predicted the line width from the printer specification. Next, we printed patches that contain line segments arranged at different intervals. We then examined the patches to find the appropriate conditions for printing the line segments.

#### 4.1. Experimental environment

We used Roland VersaUV LEF-12 UV printer, which has a resolution of 720 dpi. The interval between the dots is approximately 0.035 mm. Our line width was set to twice the size of the interval, 0.070 mm, because, based on our experiments, we confirmed that it is impossible to randomly place dots at the highest resolution.

#### 4.2. Measuring quality of linear stripes

We investigated the most appropriate interval for printing the line segments. For this, we prepared six 10.0mm×10.0mm square patches with different line intervals: 0.05, 0.10, 0.15, 0.20, 0.25, and 0.30 mm. Figure 2 shows a photograph of the six patches. The black regions are the line segments and the white regions are the surface color.

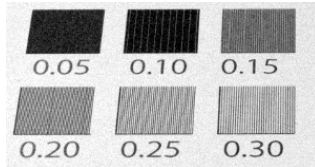


Figure 2: Line segments with six different intervals.

As shown in Fig. 2, we see no gaps between the lines when their intervals are less than 0.15 mm. That is, we need to choose the interval to be from 0.2 - 0.3 mm to leave some gaps between the lines. When the interval is 0.2 mm, however, the fluctuation in the linewidth is significant. This would cause undesirable color variations.

A narrower line interval would cause strong occlusion effects than a wider one, which is preferable for our method. We therefore decided that 0.25 mm would be the most appropriate interval.

Next, in order to verify the occlusion effects of the linear stripes, we estimated the amount of light that reaches the bottom surface by taking photographs. For this estimation, we took photographs under fluorescent light. If a photograph taken from a certain direction includes the color of the bottom surface, it means that the light rays from that direction have reached the surface. We took nine photographs per patch from different directions. The shooting directions were combinations of azimuthal angles of 0, 45, and 90 degrees and elevation of 15, 30, and 45 degrees. An azimuthal angle in this case is defined as the angle between the direction of the line segment and the direction from which it is viewed. The elevation angle is defined as the angle between viewing direction and the plane of the patch.

For estimating the linear stripes, the colors of each photograph were normalized so that the minimum and maximum colors corresponded to 0 and 1, respectively. For normalization, the maximum and minimum colors were defined by the values in the photograph taken from the vertical direction.

Figure 3 shows photographs of line segments with 0.25 mm intervals. The photographs were taken with azimuthal angles of 0, 45, and 90 degrees, and elevations of 15, 30, and 45 degrees. Table 1 shows the ratios of the areas of the bottom surfaces (white regions) of Fig. 3.

According to Table 1, the bottom surfaces appear in photographs with large elevations. The occlusion becomes effective when the azimuthal angle is greater

than 45 degrees and the elevation is less than 30 degrees. This observation indicates that the linear stripes occlude the lighting rays and that the appearance of the surface is anisotropic.

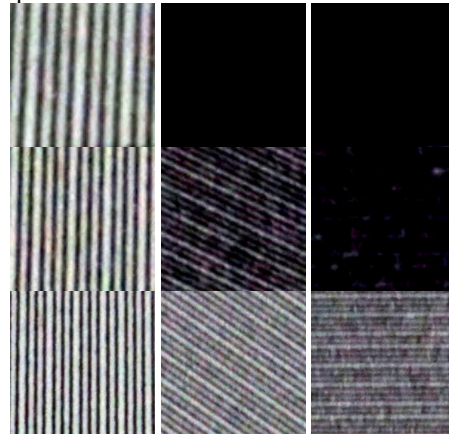


Figure 3: Photographs of a patch with 0.25 mm interval stripes taken from different directions. The top row is 15 degrees in elevation, the middle row is 30 degrees, and the bottom row is 45 degrees. The left column is 0 degree in azimuth, the center column is 45 degrees, and the right column is 90 degrees.

Table 1: Fraction of the bottom surface in Fig. 3.

Elev \ Azi	0 deg.	45 deg.	90 deg.
15 deg.	0.595	0.000	0.000
30 deg.	0.585	0.014	0.000
45 deg.	0.601	0.520	0.146

#### 4.3. Assignment of patches

We subdivide the surface of the reflector into a uniform grid with each cell corresponding to a pixel of the images to be displayed. Let us call the cell a reflector pixel. Each reflector pixel is further subdivided vertically and patches are assigned. We assign patches containing linear stripes with different angles to each subdivision of the reflector pixel. Figure 4 shows examples of assigning two and three patches.



Figure 4: Assignment of patches to reflector pixels. Two and three patches are assigned in the left and right hand figures, respectively.

We assign the azimuthal angles of the liner stripes to be equally spaced between 0 and 180 degrees. For example, when the number of the patches is three, the angles assigned to them are 0, 60, and 120 degrees. This simple method works well in our experiments but we avoid using the vertical direction by adding an offset

angle specified by the user. The reason for this is because, when using the vertical direction, a very long linear stripe would appear since the reflector pixel is subdivided only vertically. This would cause some artifacts.

## 5. RESULTS

We show our reflectors and the images observed from them. We used a 100 mm × 100 mm square acrylic sheet as a printing substrate. The color of linear stripes is set to black to effectively occlude light. We took photographs using a Canon EOS Kiss X7 camera and illuminated reflectors with an ASUS S1 mobile projector. The photographs were taken from the normal direction to the reflector with a fixed camera position. Instead of changing the camera position, we changed the lighting direction.

Figure 5 shows a reflector that presents three images. The pixel size is set to 2.0 mm × 2.0 mm. This figure shows images of a disk with three different colors, red, green, and blue, under specified conditions.

Figure 6 shows a reflector that presents four images. The pixel size is set to 3.0 mm × 3.0 mm.

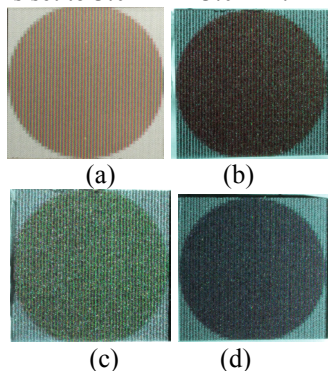


Figure 5: Reflector presenting three different colored disks. (a) is a photograph under fluorescent lighting. (b) - (d) are photographs under lighting from azimuthal angles of 0, 60, and 120 degrees, respectively.

## 6. CONCLUSIONS

We proposed a method for printing reflectors that can present three or more images. This method uses an UV printer to fabricate reflectors with small-scale stripes that reflect light anisotropically. We demonstrated that four colored images can be presented using our reflector.

Although the preliminary results shown in this paper indicate that our approach is promising, our small-scale linear stripe geometry reduces the range of colors that can be displayed. In order to address this problem, we plan to combine different inks to maintain the range. By optimizing the combinations, we expect that images can be presented with a higher contrast than the current results.

## ACKNOWLEDGEMENT

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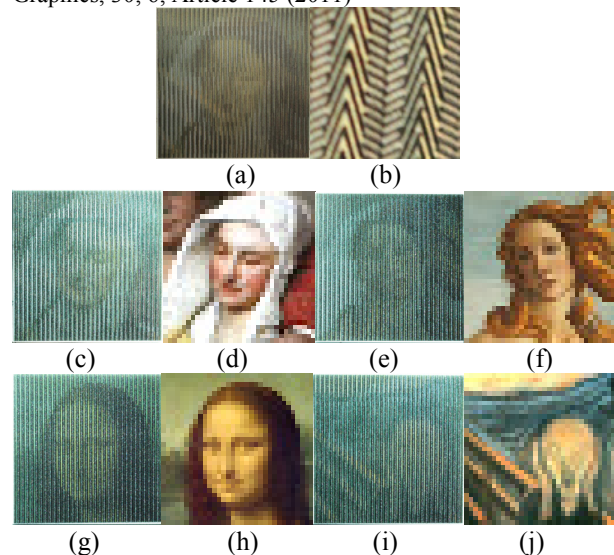


Figure 6: Reflector presenting four different images. (a) is a photograph under fluorescent lighting. (b) is a photograph of 2 × 2 reflector pixels in (a). (c), (e), (g) and (i) are photographs under lighting from azimuthal angles of 22.5, 67.5, 112.5, and 157.5 degrees, respectively. (d), (f), (h), and (j) are the original images.