Image Correction Techniques for 3D Interactive Surface using a Transparent Elastic Gels

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ABSTRACT

There are many kinds of three dimensional displays that have been developed to date. Most of them provide 3D visual sensation to the users, but they do not provide 3D haptic feedback. On the other hand, an interactive surface system using transparent gels enables users to touch a 3D surface. The main issue of the system, however, is that the image is distorted due to "lens effect" of the gels. This paper describes a method to solve the image distortion through the use of a light field display (LFD) which is discussed in detail in section 2. By combining the LFD and transparent gel interface, it becomes possible to show correct 3D images on gels from any viewing position.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces

General Terms

Input devices and strategies

Keywords

Interactive Surface, Light Field Display

1. INTRODUCTION

Many kinds of three dimensional displays have been developed to date. Such displays are roughly divided into two categories, those that require glasses and those that do not. Most of them provide 3D visual sensation to the users, but they lack haptic feedback. In virtual reality researches, there have been systems that combine 3D displays and haptic feedback [1, 2, 3, 5]. It is, however, often the case that the mechanical setup for enabling haptic feedback is substantially complex.

On the other hand, Sato et.al.[6] developed a 3D interactive surface system named PhotoelasticTouch using a liquid crystal display (LCD) and transparent gels. PhotoelasticTouch enables the development of a multi-touch capable 3D display at very low cost. Users can make their own 3D surface by using inexpensive tranparent gels.

The main issue of PhotoelasticTouch, however, is that the image projected on the LCD is distorted due to "lens effect" of the transparent gels. The light from the LCD changes its direction depending on the gel's shape. It is suggested that this issue can be solved by preparing pre-distorted images. If the gel's shape is known in advance, it is possible to calculate the pre-distorted image which produces a correct image when covered by the gel. This issue is hard to solve because the image distortion depends on the user's viewing position. Figure 1 shows such an example. A transparent half ball is placed on the LCD which displays grids. The left figure is an image observed from an angle almost perpendicular to the LCD. The right figure is an image observed from an oblique position. As is shown in the figure, the observed images differ depending on the user's viewing position.

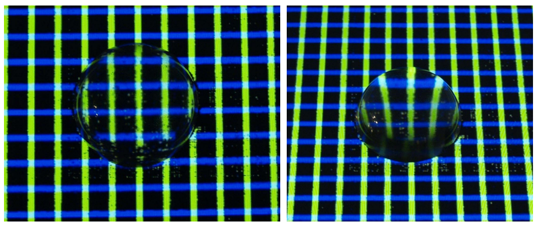

Figure 1: Distortion due to changes in viewpoint

This paper describes a method to solve the image distortion issue by using a light field display (LFD) which is discussed in detail in section 2. By combining the LFD and a transparent gel interface, it becomes possible to show correct 3D images on gels for any viewing position. In section 2, we describe the essence of the LFD. In section 3, a method of distortion correction is described. Section 4 discusses the limitations of our method. Section 5 concludes the paper.

2. LIGHT FIELD DISPLAY

A LFD is a 3D display that does not require glasses. Unlike normal displays, the LFD shows its image by reproducing point light source which orients in the space. Our LFD

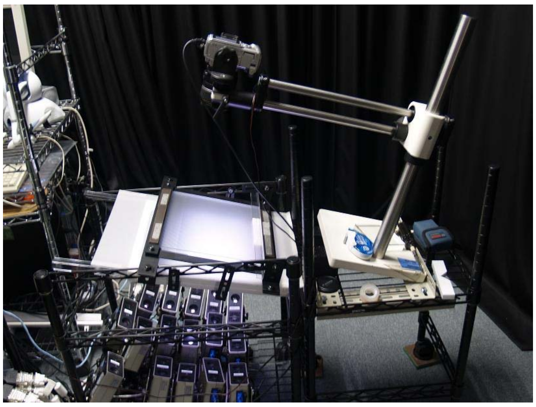

Figure 2: Light Field Display prototype

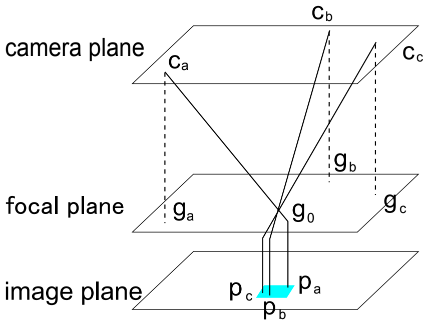

Figure 3: ray path

is composed of the following components: projectors, two lenticular lenses (10 lpi), a digital camera for initial configuration, and a PC (Figure 2) [4]. Two lenticular lenses have the same role as a lens array in integral photography system. Reproduction of point sources is done by using the optical properties of the lens. Pixel position of projector images for lenses is compatible with ray direction after passing through the lenses. It is possible to control the direction of the ray from each lens. The point where the rays converge after passing through the lens is referred to as the "deflection optics fulcrum:g_0".

Let the pixel of the projector which is observed by the digital camera be p_i(i=a,b,c), the reaching position of the ray from p_i be C_i, and the position projected C_i to the focal plane be g_i (Figure 3). The direction of the ray after passing through the lens is written as $g_i - g_0$.

Let the relation between the pixel of the projector and the direction of the ray be M_{g_0} , and the pixel position corresponding to the ray which is perpendicular to the lens after passing through the lens be $p_\perp$. The relationship is written as follows.

$$g_i - g_0 = M_{g_0}(p_i - p_\perp)$$

The LFD outputs images by estimating these parameters (M_{g_0}, $p_\perp$).

3. DISTORTION CORRECTION

The image distortion caused by transparent gels is dependent on the user's viewing position. In normal displays, each pixel emits the same ray to any direction. Therefore, even if image correction for a particular viewpoint is made, it will not work for other viewpoints.

In order to do the distortion correction for multiple viewpoints simultaneously, it is necessary to do the distortion correction for each viewpoint and to produce different rays from each pixel. To do this, we use the LFD, which can control the direction of the ray from each pixel.

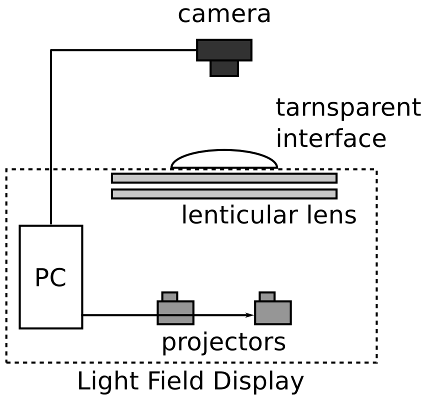

Figure 4: system configuration

3.1 System Configuration

Our system is composed of the LFD and transparent gels on the display. The transparent gel is placed on the LFD (see Figure 4). It is important to use the transparent material that does not affect polarization. We used highly transparent and smooth material to eliminate undesired effects other than the shape distortion of the object. Such transparent gel can not be remoulded after they are created.

The software system is composed of the calibration module, analyzing module, and image correction module.

3.2 Distortion Correction Process

When the transparent gel is placed on the LFD, g_0 appears to be rising from its original position. To show the image correctly, this g_0 position must be estimated. Then M_{g_0} and $p_\perp$ are estimated using g_0. Our method estimates the deflection optics fulcrum with the transparent gel using the following three steps: (1) capturing from five viewpoints by the digital camera for ray measurement; (2) calculating the ray direction by analyzing the captured images; (3) estimating the new deflection optics fulcrum from the ray information. Following section describes the detail of the method to estimate these parameters.

3.2.1 Measuring the Rays

Firstly the projector projects the gray code pattern in each direction x and y. By using the gray code pattern, it is possible to allocate unique ID to each pixel of the projector. The gray code is 10 bit for each direction due to the VGA resolution of the projector. There are five point positions of the camera to measure the ray information, center of the display, 10cm from center to left, right, top and bottom. Camera parameters are ISO800, F22 and exposure time 1/20. Measurements are all to be taken in a darkroom.

In order to decide the position of the lens which is on the display, white light is captured. Following, a mask image, gray code patterns, and a verification mask image are then captured. For measuring ray information, it is necessary to do the calibration with pixel level precision. If there is any difference between the mask image and the verification mask image due to the vibration of the camera or the changes in lighting conditions, the measurement process is to be repeated from the first step.

3.2.2 Image Analysis

The next step is to create a data table from camera images. This data table associates projector image pixel position with ray information after passing through the lens. By looking up the pixel's ID in the data table, we obtain the position of the pixel in the camera image. The ray information is composed of position of deflection optics fulcrum of each lens: g_i and position of camera image reached the ray : c_i.

3.2.3 Estimation of Parameters

This step estimates the deflection optics fulcrum from the analyzed ray information after setting the transparent interface. Thus, LFD will show a corrected image using these estimated parameters.

- Obtaining ray information from same deflection optics fulcrum

  Firstly, we obtain the ray information from the same deflection optics fulcrum after setting a transparent interface (a solid line in Figure 4). Then, we obtain the ray information, reaching from deflection optics fulcrum, prior to setting the transparent interface from pixel position on camera (a dotted line in Figure 4). Therefore, the ray after passing through the interface has a same vector with dotted line.

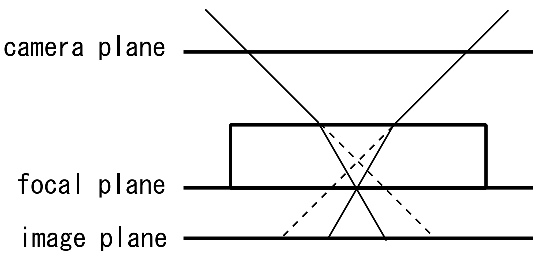

Figure 5: Route of rays

- Estimation of Z

  Let the intersection of two rays $(c_i - g_i)$ and $(c_j - g_j)$ be Z. The vector directed to Z from g_i and g_j are $(Z - g_i)$ and $(Z - g_j)$ (Figure 5). $(Z - g_i)$ and $(Z - g_j)$ are on the same line. In other words, the cross product is 0. Z position is calculated using least-square method as E which is the sum of the cross product of a five measurement points approximated to 0.

$$E = \sum_i \left| \frac{(\mathbf{Z} - \mathbf{g_i}) \times (\mathbf{c_i} - \mathbf{g_i})}{(\mathbf{c_i} - \mathbf{g_i})} \right|^2$$

We differentiate both sides with Z. Then we get the following relation by unit vector $\overline{(\mathbf{c_i} - \mathbf{g_i})}$ of $(\mathbf{c_i} - \mathbf{g_i})$.

$$\sum_i (\mathbf{Z} - \mathbf{g_i}) = \sum_i [\overline{(\mathbf{c_i} - \mathbf{g_i})}(\mathbf{Z} - \mathbf{g_i}) \cdot (\mathbf{c_i} - \mathbf{g_i})]$$

Therefore, the value of Z is obtained by observed value c_i and g_i obtained by each measurement position.

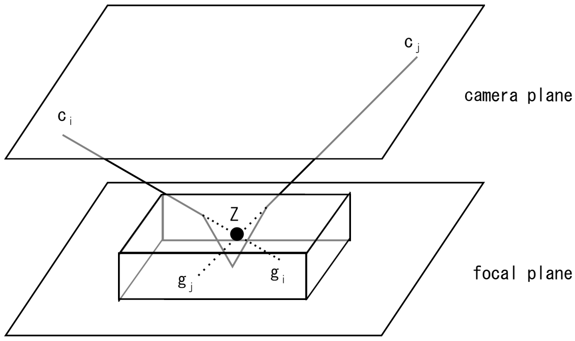

Figure 6: Estimation of Z vector

- Estimation of M_{g_0} and $p_\perp$

  We estimate M_{g_0} and $p_\perp$ using estimated Z and ray information obtained at each camera potision. These parameters interpolate data for viewpoints where measurements were not taken. Here we made the assumption that the distance between two points on the gel where the ray from the different view points passes through is small enough and therefore we could approximate the object surface as planar. From these 5 points, the correct image for any direction can be obtained using the data.

3.3 Correction Results

We applied our method to various shapes. Figure 7 shows one such example.

In the figure, the left image and right image show the before distortion correction and after distortion correction.

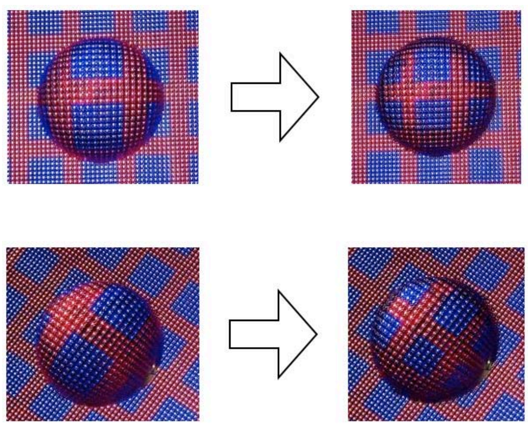

Figure 7: Result of distortion correction

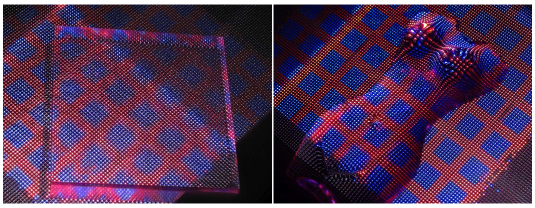

Figure 8: Other result of distortion correction. (left) flat plane, (right) shape of human

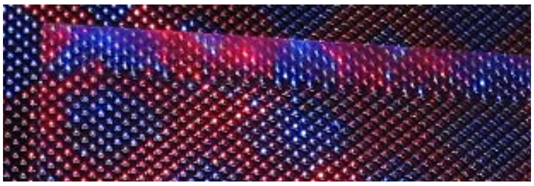

Figure 9: A failure example due to the total reflection

From the two left images, it is notable that the distortion is different when the viewing position differs. However, from the right images it is also notable that the distortion is corrected at both viewing positions.

This method was applied to other transparent gels. As seen in Figure 8, the method corrects distortion well.

4. DISCUSSION

Even if our method was applied, some distortion examples were still seen. This is due to the reflection of the transparent material and the complexity of the material's shape (see Figure 9). When the transparent material is put on the display at a high angle, it shows total reflection. Since such distortion cannot be corrected by principle, it is necessary to use a shape where total reflection rarely occurs.

Next, there was the disorder of the image due to the lens effect (see Figure 10). The transparent material that has a high curve ratio shows a strong lens effect and results in pixel magnification of the image. Our algorithm cannot correct the distortion that is smaller than a pixel in size.

Finally, it is not possible to interpolate the camera calibration when the material's shape is too complex. We have made an assumption that the ray information obtained from five images during calibration changes linearly. However, if the material's shape is too complex, this assumption does not hold true. In order to minimize this issue, we will be required to increase the points of calibration.

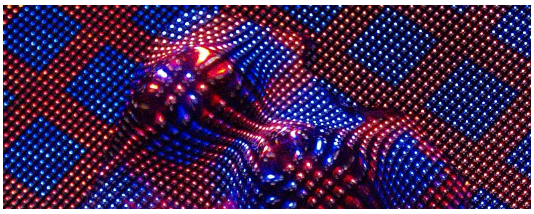

Figure 10: Lens effect

Figure 11: An failure example due to the pixel magnification

5. CONCLUSIONS

This paper shows a method for correcting distortion when 3D transparent gels are placed on an LCD display. By combining the LFD and transparent gels, it is possible to provide tactile 3D images through the placement of these gels that can then be viewed from any direction without requiring glasses. Our next step will be to extend our algorithm to real-time processing. As a result, users will be able to put any 3D transparent gels shape on the surface, and the system will provide the respective 3D views in real-time.

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