3D High Dynamic Range Display System

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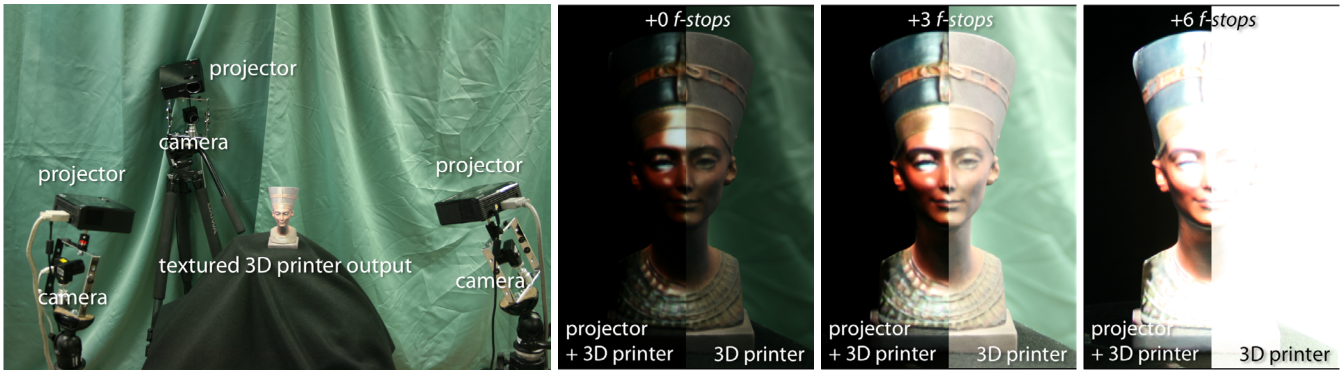

Figure 1: Superimposition of multiple projected images onto a textured 3D printer output leads to multiplicative luminance and chrominance modulation. This consequently leads to contrast enhancement. The leftmost image shows the experimental setup, and the remaining three images show the appearance of the object by the proposed method (left) and 3D printer output (when viewed under environment light) alone (right) captured under different exposures.

Abstract

This paper introduces a new high dynamic range (HDR) display system that generates a physical 3D HDR image without using stereoscopic methods. To boost contrast beyond that obtained using either a hardcopy or a projector, we employ a multiprojection system to superimpose images onto a textured solid hardcopy that is output by a 3D printer or a rapid prototyping machine. We introduce two basic techniques for our 3D HDR display. The first technique computes an optimal placement of projectors so that projected images cover the hardcopy's entire surface while maximizing image quality. The second technique allows a user to place the projectors near the computed optimal position by projecting from each projector images that act as visual guides. Through proof-of-concept experiments, we were able to modulate luminance and chrominance with a registration error of less than 3 mm. The physical contrast ratio obtained using our method was approximately 5,000:1, while it was 5:1 in the case of viewing the 3D printout under environmental light and 1,000:1 in the case of using the projectors to project the image on regular screens.

Index Terms: I.3.3 [COMPUTER GRAPHICS]: Picture/Image Generation—Display algorithms; I.4.0 [IMAGE PROCESSING AND COMPUTER VISION]: General—Image displays

1 Introduction

High dynamic range (HDR) display technologies allow the display of images on 2D surfaces with luminance ranging several orders of magnitude. Most of these displays are based on the principle of double light modulation using transmissive spatial light modulators, such as LCD panels [4]. On the other hand, a new approach based on reflective image modulation has been recently introduced for viewing static HDR content [1]. Images are projected onto hardcopies, such as photographs, to boost contrast beyond that obtained using hardcopies (when viewed under environment light) or projectors (when projecting onto regular screens) alone.

This paper presents a novel HDR display system that allows the generation of a physical 3D HDR image without the use of any stereoscopic methods (Fig. 1). Transmissive methods cannot be used for this purpose. Because transmissive modulators are limited to planar surfaces, they display virtual 3D HDR content using a stereoscopic approach. In contrast, reflective approaches generate images by using 3D textured physical objects as hardcopies. A physical 3D HDR display is indispensable in specific applications, such as in industrial design for the assessment of a product prototype or in archeology for the realistic physical reproduction of digitally archived historic objects. In these fields, an enhanced material perception (e.g., specularity) of the displayed 3D information is required. We employ a multiprojection system to superimpose images onto a textured solid hardcopy that is output by a 3D printer or a rapid prototyping machine.

2 3D HDR Display Technique

The process flow of the proposed technique is shown in Fig. 2. There are two important issues to be considered by the proposed system. First, the placement of the projectors should be carefully considered, because it affects the reflected image quality (i.e., the spatial resolution and radiance of projected images on a hardcopy surface). In addition, projected images must cover a hardcopy's entire surface while maximizing the image quality. Second, as pointed out in [1], the precise geometric registration of the projected images to a hardcopy is very important in reflective HDR methods.

For the first issue, we propose a method to determine the optimal placement of projectors. For each combination of projector positions, we evaluate the images projected on a hardcopy surface in terms of both the reflected image quality and the degree of coverage on the basis of the geometric and photometric models of the projectors. In particular, for each part of the hardcopy surface, our

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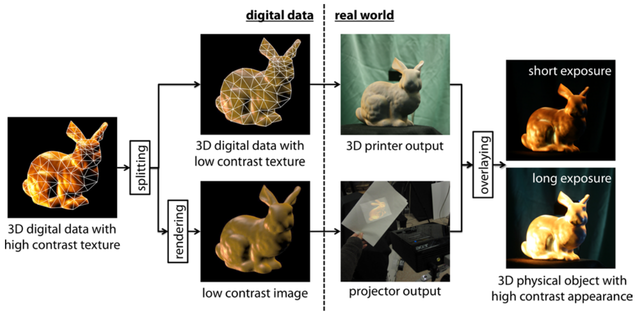

Figure 2: Process flow of the proposed 3D HDR display technique.

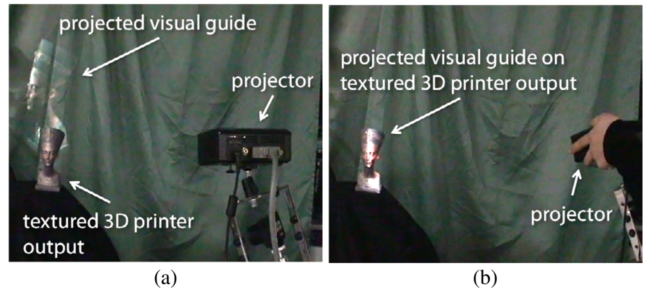

Figure 3: Manual placement of each projector with the proposed visual guide: (a) each projector projects a visual guide and (b) a user places and adjusts the projector manually.

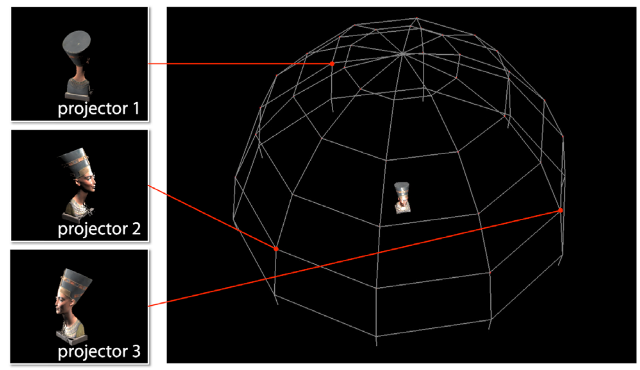

Figure 4: Computed projector placement (right) and projection image for each projector (others): grid points represent candidate positions of projectors and red lines indicate the selected projector positions.

method selects the optimal projector that preserves the largest number of high-spatial-frequency components of the original image for enhancement of the spatial resolution as well as the peak luminance of the projected image. We model the projected pixel as an ellipse rather than a simple pillbox to obtain a more accurate spatial frequency property of the projected pixel [3]. We search for the optimal combination that maximizes the evaluated value.

For the second issue, we propose a two-pass geometric registration method. Initially, each projector projects an image, which is generated by assuming that the projector is placed at the optimal position (Fig. 3(a)). The user adjusts the projector such that the projected image is registered on the hardcopy (Fig. 3(b)). That is, the projected image is a visual guide that enables the user to place the projector near the optimal position. Then, we measure the shape of the hardcopy by projecting structured light pattern, in particular gray code, from each projector. The iterative closest point (ICP) algorithm is applied to find out the actual relative position and orientation of each projector to the hardcopy. We manually retrieve more than six correspondences between the measured shape data and the original 3D data for initial estimation of the ICP. The calculated geometric information is used to generate a new projected image, which is registered on the hardcopy.

3 Display Results

We used three LED projectors (100 ANSI lumen) and a hardcopy (160 mm height) printed from a ZPrinter 450. The 16-bit color information was split into two 8-bit RGB values for the projectors and the hardcopy as proposed in previous research [1]. The optimal placement of the projectors was automatically calculated from 50 candidate positions on a hemisphere whose center and radius corresponded to the hardcopy and the focal length of the projectors (0.9 m), respectively (Fig. 4). We positioned the projectors using the proposed visual guides and registered the projected images by the ICP algorithm. We were able to modulate luminance and chrominance with a registration error of less than 3 mm. A physical contrast ratio of around 5,000:1 was achieved using our method, while it was 5:1 in the case of viewing the 3D printout under environmental light and 1,000:1 in the case of using the projectors to project the image on regular screens.

4 Discussion

We split the original 16-bit image into two 8-bit images and projected them without any modifications. However, the appearance of the projected result could be different from the desired result because of various factors such as inter-reflections of projected light, noise in printed colors, and misregistrations of projected images. The image quality of the projected results can be improved by applying a radiometric compensation technique after geometric registration.

The contrast of the hardcopy was very low using the current system. However, color 3D printers have recently appeared in the market. As some color 3D printers operate on the same principle as ordinary inkjet printers, we believe that the contrast of color 3D printers will be improved to be nearly the same as that of the ordinary inkjet printers (100:1).

5 Conclusion

We propose a novel HDR display system that allows users to generate a physical 3D HDR image without the use of stereoscopic methods. We employed a multiprojection system to superimpose images onto a textured solid hardcopy output by a 3D printer. Our method boosts contrast beyond the individual capability of hardcopies or projectors. Our proposed technique extends the range of spatial augmented reality (SAR) or projection-based mixed reality [2] in which a low dynamic range projector is applied. Because SAR applications generally require dynamic visual content on physical surfaces, in a future study, we will extend the system to allow a dynamic 3D HDR representation.

References

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