14.3: Illumination Design of a Multi-Touch Sensing Projection Screen for Augmented Virtual Environments

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Abstract

The paper presents the illumination engineering for a low-cost multi-touch projection screen. Eight near infrared emitting diode (IRED) strips with optimized line densities serve as the illumination sources for the finger tracking. The design achieves highly uniformed illumination, with an illumination efficiency of 55% and contrast of 0.098. Implementation and experimental results are presented.

1. Introduction

Augmented reality (AR) differs from virtual reality in the sense that virtual objects are superimposed on a real world scene. It not only enables a user to perceive a cohesively synthesized information space, but also allows the user to naturally interact with the synthesized information using techniques adapted from real-world experiences, promoting a seamless merging of the worlds of atoms and bits [1]. Among the many technical challenges persisting in AR, human computer interface (HCI) design is one of the essential component that can affect the wide application of AR systems. Many 3D interface techniques have been explored and examples include motion trackers, joysticks, and datagoves. The interaction techniques using these devices, however, differ quite a bit from the way people naturally interact with the real world and are mostly limited to a single user regime. It is highly desirable to allow a user to directly manipulate a synthesized scene with his or her hands.

Recently, Hua proposed to develop a multi-user workbench system integrated with multi-modality 2D and 3D interfaces [2]. At the center of the workbench, a rotating table covered with retro-reflective materials can provide stereoscopic multi-views when the user wears a see-through head mounted projection display (HMPD) [3-5]. Surrounding the 3D viewing area, eight projectors are tiled together to form a large 2D display area, covering the four sides of the square shaped workbench. Multi-users can share information through both the 2D and 3D displays and may fluently move information between the 2D and 3D displays.

One of the essential components of the workbench system is to develop an effective method allowing concurrent user interactions with the 2D and 3D displays without requiring a user to switch between different interface devices. Among the many candidate technologies we evaluated, we conclude that multi-touch sensing, finger tracking, and gesture recognition would provide an excellent interaction support. In this paper, we present the illumination engineering we developed to support multi-touch sensing for the 2D projection display. We firstly set up the design criteria, such as the merit function, and parameters for the illumination optimization. We then discuss choices of near infrared emitting diodes (IREDs) to maximize the merit function as well as to achieve the goal of compactness and low cost. In section 4, we present the illumination optimization based on three parameters: line density distribution of IRED, distance from the IRED strip to the projection screen and the pointing angle of the IRED strip. The optimization results are presented with 55% illumination efficiency and 0.098 contrast. Finally, the experimental implementation and results are presented in section 5.

2. Methods

Figure 1 illustrates the proposed workbench illumination setup. The IRED sources are assembled into eight strips, four for the outside edges of the workbench and four for the inside edges. In Figure 1 (a), which is the top view of the workbench, the red lines indicate the locations of eight IRED stripes, where \( d \) (1/mm) stands for the line density distribution of the IREDs on the peripheral strip and \( d' \) (1/mm) for the center IREDs strip, where line density stands for the number of IREDs per mm. The shadowed area indicates the effective 2D projection screens, which serve as the 2D multi-touch interface, while the center white area accounts for the 3D display. Point \( O \) indicates the center of the workbench. Figure 1(b) shows the side view of the workbench. The IRED strips are located \( H \) (mm) below the projection screen. For simplicity of implementation, both peripheral and center strips point up at the same angle \( \alpha \) to the projection screen. Between the LED strip and the projection screen are reflecting mirrors indicated by bold lines, forming a light guide to trap and redistribute the illumination near infrared (NIR) rays.

![Figure 1. Schematics of the workbench illumination](https://via.placeholder.com/150)

When fingers are not touching the screen surface, the IRED sources uniformly illuminate the projection screen and most of the light transmits through the screen. When being imaged by a NIR camera placed underneath the workbench, the projection screen is seen as a uniform dark background. On the contrary, when fingers touch the screen surface, some of the light is back scattered and transmitted back through the projection screen, forming locally modulated bright spots in the NIR image. These enhanced spots can be analyzed for finger tracking and touch gesture recognition. A similar method based on frustrated total internal reflection (FTIR) was presented by Han for multi-touch sensing [6].

The goal of illumination engineering in this paper is to achieve a uniform NIR illumination pattern on the projection screen with...
the highest possible illumination efficiency. A merit function [7] to evaluate the optimization can be defined as follows:

$$ M = \text{efficiency} \times (1 - \text{contrast}) $$

(1)

In order to maximize $M$, many parameters, such as $d$, $d'$, $H$ and $\alpha$ are set as variables. In following sections of the paper, we will discuss on how to choose those parameters to maximize $M$ value.

3. **IRED Modeling**

We have selected the SFH product line of IRED sources from OSRAM. The IREDs in this product line have a radiant power of 25mW and center wavelength of 880nm. In order to determine how the emission profile affects the design, we modeled several IREDs with different emission profiles: SFH485P with a 40-degree half angle, SFH487 of 20-degrees and SFH486 of 11-degrees. To model and optimize the illumination design, we have used a non-sequential ray tracing software, LightTools®, by Optical Research Associates [8]. Figure 2 (a) below shows the modeling of SFH487. Figure 2 (b) shows the spectral intensity with 880nm center wavelength. Figure 2 (c) shows the intensity pattern with 20-degree half angle.

![Figure 2](image)

**Figure 2. Modeling of the IRED in LightTools**

(a) The LED model (b) The spectral irradiance with center wavelength of 880nm and (c) The intensity pattern with 20-degrees half angle.

A trial simulation was done based on the illumination pattern produced by a single IRED. The IREDs with different half angles were put under the edge of the reflecting mirrors, at different heights and pointing angles. The illumination efficiency was recorded as a function of either the distance to the projection screen, shown in Figure 3 (a), or the pointing angle, shown in Figure 3 (b). In both cases, SFH485P with a 40-degree half angle always yields the lowest illumination efficiency. Although SFH486 with an 11-degree half angle always yields the highest efficiency, it is worth noting, with such a narrow emission profile, it is able to illuminate only a small area on the projection screen. As a result, using SFH486 may cause non-uniform illumination patterns without significantly increasing the density of the sources and modifying the IRED strip arrangements shown in Fig. 1. Due to the unique space limitations in our workbench system, modifying the strip arrangements is out of question. Taking into account the factors of both illumination efficiency and uniformity, we selected the model SFH487 with a 20-degree half angle for the multi-touch screen design.

![Figure 3a](image)

**Figure 3 (a) Illumination Efficiency vs. Distance to the Screen at pointing angle of 70-degrees. (b) Illumination Efficiency vs. Pointing Angle at 100mm to the screen.**

4. **Results**

After choosing the LED type, the remaining is to determine the parameters $d$, $d'$, $H$ and $\alpha$ to optimize the merit function indicated in Eq. 1. As suggested by the Figure 3 (a), the distance, $H$, from the IRED strip to the projection screen appears to have little effect on the efficiency. Further observation of Figure 3 (b) suggested that increasing the pointing angle, $\alpha$, reduces the efficiency. The efficiency can be below 50% when the pointing angle is above 80 degrees. Although decreasing $\alpha$ may help to improve the efficiency, it degrades the back scattering in the mean time. Based on all these concerns, the pointing angle $\alpha$ was set to vary within the range of 70 to 80-degrees, and the distance $H$ was set to vary between 50 and 200mm.

The IRED line densities $d$ and $d'$ are the key factors affecting the illumination uniformity. The simulation started with a uniform line density of about 25/mm on all sides. The illumination pattern along the center and edge of the workbench were recorded accordingly. Because of the non-rotational symmetric arrangement of the mirror reflectors, the resultant illumination pattern from a uniform source arrangement was obviously non-uniform. We compensated the non-uniformity by redistributing the IREDs in such a way that the line density distribution of the IREDs is inverse to the non-uniform irradiance pattern under the uniform line density distribution. After iterating the procedure through several trials, we ended up with the line density distribution shown in Figure 4. The line density in the figure refers to $d$ of the peripheral IRED strip. The line density $d'$ of the center strip was determined from $d$ by taking the average location of two adjacent peripheral IREDs.
In the optimization procedure, \( H \) was varied at an increment of 50mm, and \( \alpha \) was varied at an increment of 2.5 degrees. After a few trials, an almost uniform illumination pattern was achieved on the projection screen, as shown in Figure 5 (a). The contrast ratio in the 2D projection screen area is calculated from Figure 5 (b), as low as 0.098. The irradiance profiles at the center (Figure 5 (c)) and the edge (Figure 5 (d)) of the workbench shows good uniformity across.

Figure 5. Illumination simulation of the optimized parameters. (a) The irradiance pattern on the touch screen (b) Irradiance levels (c) Irradiance profiles along the center of the workbench (d) Irradiance profiles along the edge of the workbench.

Based on the line density distribution in Figure 4 and the geometrical dimension of the workbench, a total of 356 LEDs were used with a total radiant power of 8.9W. A total of 4.9W was collected by the projection screen, indicating an illumination efficiency of 55%. The distance from the LED strip to the touch screen is \( H = 140 \)mm. The pointing angle is \( \alpha = 76.5 \)degree. The contrast ratio at the finger touch area is as low as 0.098, resulting in a merit function value of 0.493, which is more than 4 times improvement before the illumination optimization.

Figure 6 shows the experimental implementation of the multi-touch sensing projection screen. Figure 6 (a) shows the workbench viewed from the top. Figure 6 (b) demonstrates the multi-touch screen. As shown on the 2D interface, 10 touch points of all fingers from two hands of the user are displayed for demonstration. Figure 6 (c) shows the captured multi-touch images by an NIR camera mounted underneath the workbench. Figure 6 (d) shows the bottom view of the workbench taken by a regular digital camera. LED strips mounted at the center and edge of the table can be seen.

5. Conclusions

In this paper, we have presented the illumination engineering of a multi-touch screen for augmented reality environments based on back scattering modulations. By correctly choosing the IRED type, as well as optimization parameters, \( d, d', H \) and \( \alpha \), an optimized irradiance pattern is achieved on a non-rotational symmetrical geometry. Experimental implementation of the illumination engineering shows high contrast between the finger touch points and the rest of the touch screen. The technology may be applied to rear projection displays for optical multi-touch sensing.

6. Acknowledgement

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7. References

[1] Hong Hua, “Merging the worlds of atoms and bits: augmented virtual environments,” Optics and Photonics News, 17(10), 26-33, October 2006 (cover story)
Figure 6. The workbench implementation based on the illumination engineering (a) The workbench viewed from the top (b) Multi-touch demonstration (c) NIR images of the finger’s touching spots (d) The workbench viewed from the bottom shows the IRED strips.