Pre-emptive Shadows: Eliminating the Blinding Light from Projectors

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ABSTRACT
Users interacting with front-projected displays often work between the projector and the display surface. This causes undesirable projection on the user as well as temporary blindness from looking into the bright light of the projector. In this paper, we present *pre-emptive shadows*, a technique that uses a camera-projector system to detect and turn off pixels that would otherwise be needlessly cast upon users' bodies, especially their faces. We present measurements that show that system reduces the brightness of the blinding light by about a factor of 5.

Keywords
Display, projection, camera, infrared tracking, shadow.

INTRODUCTION
Spatially immersive displays that physically surround the viewer with a panorama of imagery are becoming common [2]. These displays are typically room sized, accommodate several viewers, and are usually implemented with several fixed projection display units. Since rear projection requires a large amount of space, many systems utilize front-projected displays. Users interacting with these displays often occlude the light from reaching the display surface. This has the dual effect of (1) casting shadows on the display surface, and (2) projecting undesirable, and often blinding, light on the user (see Figure 1).

Researchers have done work to eliminate shadows by projecting pre-warped images from extreme angles, or by using multiple redundant projectors to 'fill in the blanks' [4]. However, in many applications, the shadows go largely unnoticed, while the projection on the user causes unwanted distraction. For example, while presenting to an audience, a speaker might move in front of the projector, both causing undesirable projection on the body, as well as temporary blindness from the bright light.

In our system, we attach a camera to the projector and locate the shape of the user relative to the display surface. We use this information to turn off the pixels that would have been needlessly cast upon users, blinding them and creating shadows on the display surface (see Figure 2). We demonstrate the effectiveness of this technique by measuring the amount of light that reaches the user's eyes with and without our system.

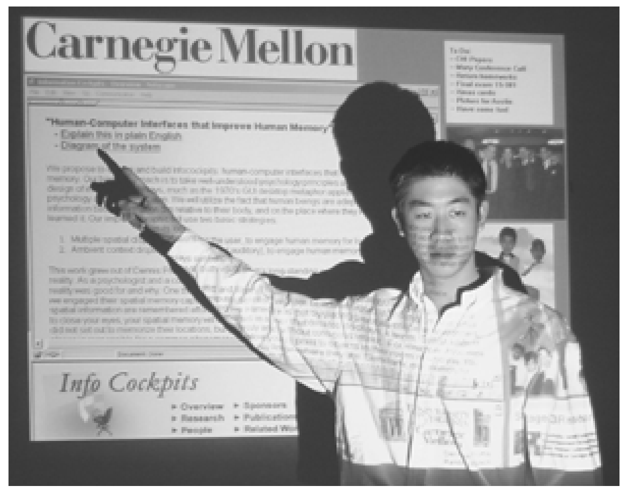

Figure 1: Before pre-emptive shadows – user with unsightly projection and blinding light.

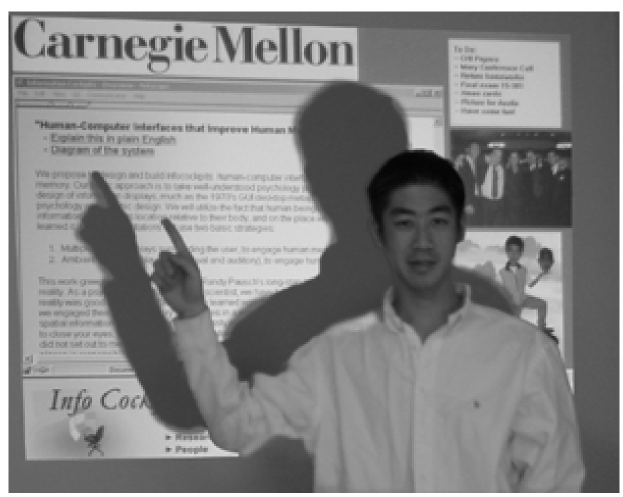

Figure 2: After pre-emptive shadows – user comfortably standing in region of blocked out pixels.

IMPLEMENTATION

Our initial implementation of a camera-projector system used background differencing to detect the shape of the user. Since we know the image that is projected at each instant, such a system merely has to check for pixels that deviate from the anticipated values. This approach had several problems. First, the physical offset of the camera and projector made the task of matching pixels seen by the camera to the corresponding projected pixels a non-trivial task. This problem is aggravated by the drastic lighting changes caused by dynamic content (e.g. movies and animations). Second, choosing the appropriate thresholds to separate pixels that were hitting the intended surface from those that were not was difficult when parts of users and their clothing mimic the reflective properties of the display surface.

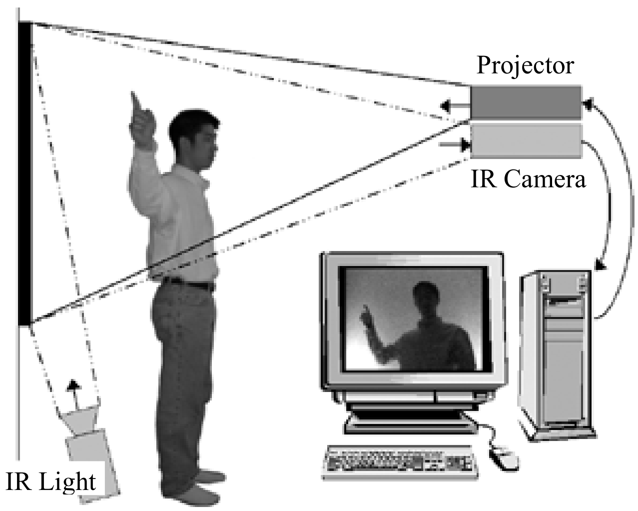

Figure 3: User casts IR shadow on camera lens (image seen on the monitor). This matches the projected shadow and is used to turn off appropriate pixels.

Thus, rather than illuminating users from the front and trying to identify them by reflective properties, we uniformly light the display surface with non-visible IR light from the rear and identify users using occlusion (see Figure 3). In the current system, we attach an infrared (IR) camera to the projector. We place IR lights as close to the display surface as possible (~1 foot), lighting the surface while reducing the possibility of illuminating the user. Users, backlit by the non-intrusive IR light, cast a robust shadow onto the lens of the camera (see monitor inset in Figure 3). We assume that our camera and projector share a common focal point. Since we are not doing any per-pixel differencing, it is sufficient that the IR shadow cast on the camera closely matches the shadow that would be cast by the projector on the wall. We process this image using standard machine vision techniques provided by the Intel Image Processing library [1] and use this information to mask out the appropriate projected pixels. Running on a PIII 700 MHz computer, the system tracks multiple objects at 30 frames per second.

RESULTS

To quantify the effectiveness of pre-emptive shadows in reducing blinding light, we compare the difference in brightness with and without the system. The measurable quantity that most closely corresponds to brightness is luminance, or the intensity of light per unit area of its source [3].

We used a Sekonic L-508 Zoom Master photometer to make our luminance measurements. We measured the luminance values for a user standing 8 feet away and looking directly into an Epson Powerlite 703c projector, rated at 1000 lumens. We found that the luminance with pre-emptive shadows was about an order of magnitude less than without (see Table 1). This roughly corresponds to a 5-fold perceived difference in brightness. More importantly, the light level is reduced from being close to the threshold of tolerance to more comfortable levels.

Luminance (cd/m^2)	**Condition**
1	Dark room
130	White Paper in good reading light
4,000 – 6,500	*With pre-emptive shadows*
8,200	Florescent Lamp
65,000 – 120,000	*Without pre-emptive shadows*
150,000	Threshold of visual tolerance

Table 1: Luminance values for various conditions.

CONCLUSION AND FUTURE WORK

We have presented pre-emptive shadows, a method that eliminates unnecessary projection that is cast upon the user rather than the display surface. We have shown that the perceived light hitting the user in front of the projector is reduced from excessive, and painful, levels to tolerable levels. We are currently applying pre-emptive shadows to the domain of creative stage lighting. Inverting our current approach, we are working with lighting designers to develop a system that tracks and illuminates only the actors without throwing the spotlight on background elements.

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