Augmented Reality Applications and User Interfaces Using Head-Coupled Near-Axis Personal Projectors with Novel Retroreflective Props and Surfaces

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ABSTRACT

One motivation for the development of augmented reality technology has been the support of more realistic and flexible training simulations. Computer-generated characters and environments – combined with real world elements such as furniture and props to 'set the stage' – create the emotional, cognitive, and physical challenges necessary for well-rounded team-based training. This paper presents REFLCT, a mixed reality staging and display system that couples an unusual near-axis personal projector design with novel retroreflective props and surfaces. The system enables viewer-specific imagery to be composited directly into and onto a surrounding environment, without optics positioned in front of the user's eyes or face. Characterized as a stealth projector, it unobtrusively offers bright images with low power consumption. In addition to training applications, the approach appears to be well-matched with emerging user interface and application domains, such as asymmetric collaborative workspaces and mobile personalized guides.

1. INTRODUCTION

Military, police, and fire training often benefits from augmented reality approaches that enable users to practice physically tangible aspects of "in the dirt" training, while also learning from programmable computer-generated imagery. These systems, referred to as "mixed reality" [7], enable a user's emotions, mind, and body to become engaged in a themed, staged environment where there are props and synthesized images projected onto screens.

Mixed reality systems are ideal for single users; however, they begin to reveal unfortunate artifacts when used for team-based training because they are unable to present, for each user, the correct perspective view of the projected scene. Just as a portrait painting can appear to stare simultaneously at all viewers, these systems create misleading imagery: For example a projected image of an enemy pointing a rifle at a single soldier in a room would appear as if the rifle were aimed at all soldiers in the room.

There have been three main approaches to creating individualized and perspective correct imagery for multiple users: projector arrays, head-mounted displays (HMDs), and head-mounted projective displays (HMPDs).

Projector arrays coupled with asymmetrically diffusing screens [2][6] can create individualized perspective-correct views, but are expensive in terms of hardware and calibration effort. They require more projectors than users, with projectors positioned everywhere that a user might be. In most cases, they are configured to offer only horizontal image isolation. Eye-tracked autostereoscopic systems may be used to reduce the number of projectors required, but commercial systems are limited in size and viewing angle [10].

HMDs correct for individual perspective using two techniques: video overlays and optical overlays. Video overlays mix camera imagery of the world with synthetic imagery using standard opaque head-mounted displays. Unfortunately, downsampling the world to video resolution, video frame lag (typically 1/30 of a second), and other artifacts limit the immersive qualities of this technique. With the optical overlay technique, virtual imagery is overlaid upon the real world using displays that are semi-transparent. This can be accomplished in a number of ways, among which are systems that magnify a small display reflected through a partially reflective surface. Neither overlay technique supports all training applications because each places bulky optics in front of a user's face, making eye to eye contact difficult and rapid physical motions awkward.

HMPDs have also been used for individualized augmented reality imagery. These systems use micro-projectors that project onto a semi-transparent mirror surface in front of a user's eyes to create a projection path aligned with a user's optical path [3][4][5]. The partially reflective surface in front of the eyes also can interfere with eye contact and head movements such as sighting down a rifle.

2. A NEAR-AXIS RETROREFLECTIVE PROJECTOR SYSTEM

We have developed a near axis retroreflective projector system called REFLCT (Retroreflective Environments For Learner-Centered Training) that we believe to be conducive to mixed reality training. REFLECT builds on useful characteristics of currently available systems with an end goal of unobtrusively delivering mixed reality training experiences. REFLCT:

- Places no glass or optics in front of a user's face
- Needs only a single projector per user.
- Provides each user with a unique and perspective correct image.
- Situates imagery within a physical themed and prop-based environment.
- Can be low power, lightweight, and wireless.
- Works in normal room brightness.

3. Technical Description

REFLCT is a head-mounted projector system that takes advantage of the imperfect performance characteristics of retroreflective fabrics and beads. Light is not reflected purely on-axis, thus offering substantial energy at slightly off-axis angles. By mounting a micro-projector *near* a user's eyes, this energy will be seen by the user. This approach was not feasible with older generation, lower brightness micro-projectors where, due to the intentional misalignment, little light reaches the user's eyes. Newer micro-projectors offer enough brightness such that this is not an issue. This off-axis technique eliminates the bulky optics required to align the projector's optical axis with the user's eyes.

Figure 1: An example near-axis retroreflective projector system in a military style helmet. Note the opening where the center axis of projection is located.

3.1 Physical Form and Device

A Texas Instruments micro-projector and a rechargeable battery pack are mounted on the interior of a military replica helmet and four active LED markers are mounted on the exterior (see Figure 1). The markers are part of a PhaseSpace Impulse tracking system that provides head and prop coordinates to a personal computer running Panda3D for graphics and VRPN for tracking data communication. Imagery is rendered and projected so as to approximately correspond with the location and shape of tracked and stationary retroreflective screens and props. Images in this paper were photographed with the standard test pattern.

3.2 Retroreflective Props and Screens

Standard retroreflective surfaces quickly proved to work well with REFLCT, and explorations began to integrate them with themed sets designed for mixed reality training. Toward this end, a number of innovative retroreflective approaches were developed, including partially transparent and spatially curved surfaces.

In order to present virtual images in the middle of a room, clear sealants lightly mixed with glass beads were bonded to glass surfaces and a series of different density laser-cut patterns in retroreflective cloth were created (see Figure 2). When no image is projected, such surfaces essentially fade away to invisibility since users can see props and live actors through them.

Complex shaped retroreflective props were created by coating a figure with retroflective cloth (see Figure 3), or by depositing glass beads onto the surface of the prop. When coupled with accurate tracking of the prop, this enables a very realistic spatial presentation of imagery as in Shader Lamps [8].

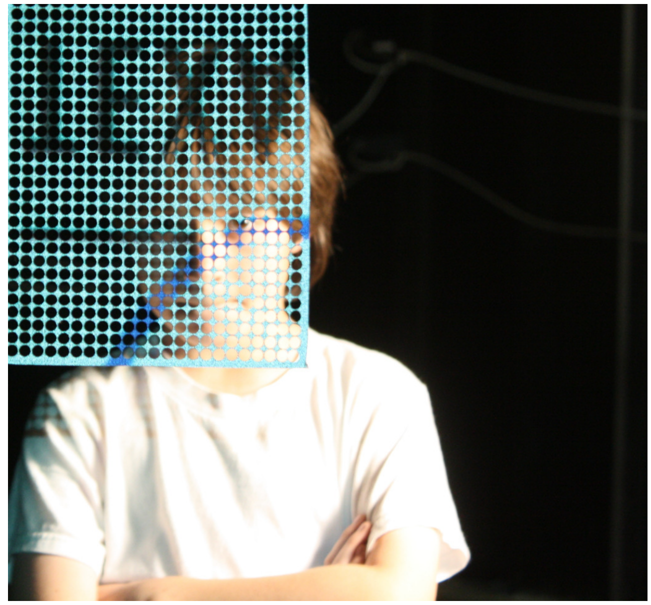

Figure 2: Example of a perforated retroreflective test surfaces allowing "compositing" of props and live actors.

4. PERFORMANCE AND DISCUSSION

Using the REFLCT system is liberating as it allows the user to look out into an environment without glass or other elements in front of the face. REFLCT's virtual imagery offers realistic depth cues as images are projected directly onto props and the user's eyes can focus at the appropriate distance, instead of a fixed distance determined by the HMD optics. Additionally, real objects can come between the user and the virtual image. This allows natural occlusion of the virtual image, instead of computed occlusion, where all potential occluders must be tracked and masked out during virtual image generation. REFLCT's technique is beneficial for proper handling of occluding objects such as a user's hands and weapon, which are rapidly moving and will often occlude images of hostile virtual opponents.

Figure 3: Retroreflective material applied to a mannequin head prop and illuminated.

Due to tracker noise, we are continuing to experiment with both the PhaseSpace Impulse active optical marker tracking and camera based fiducial tracking. We have also found that projector focus, or more specifically, projector depth of field is a design constraint that becomes less of an issue with brighter projectors or laser based projectors.

The initial “proof of concept” systems were not optimized for fast rendering. As such, rendering delays were noticeable, and would make the virtual image appear to bob slightly out of sequence with head motion. Experience indicates this can largely be eliminated by moving to a different code base; however, care should be given to the nature of retroreflective targets. For example, a simple cylinder might work better than the precise mannequin head due to the lack of specific misaligned features. Additionally the use of black boarders or physical frames would help with misaligned edge effects.

4.1 Effective Brightness and Extinction

Intraocular distance (the measurement between a single user’s eyes) is too small to allow effective isolation of left and right 3D stereoscopic views given the imperfect off-axis performance of retroreflective beads and cloth; however, the typical distance between users provides more than enough illumination falloff to enable individual views. A 16 inch translation between axes of projection is enough to ensure that two users, each with a personal REFLCT display and standing shoulder to shoulder, will experience unique images (see Figure 4). Outdoor tests indicated that a system built with off-the-shelf micro-projectors could be used on an overcast day.

Figure 4: Retroreflected illumination level near the optical axis of the micro-projector (above) and the retroreflected illumination at 16 inches from the optical axis (below) with screen placed behind concrete wall prop.

4.2 Alternative Projector Configurations

Alternative configurations were tried with the goals of stereoscopic imagery and wide field of view imagery (see Figure 5). While not an issue for wide field of view, preliminary experiments indicated that an additional form of extinction, such as polarization or time sequential optics would be required to limit bleed for stereoscopy as the projectors are mounted but 2.5 inches apart. When projectors become small enough to consider head-mounted projector arrays, it may be possible to create a system that works by bonding higher performance retroreflective materials with anisotropic diffusers. Initial experiments indicated that this more closely focuses the returning energy between the eyes and allows for head roll.

Figure 5: A projector configuration for a wider field of view (left) or for 3D stereoscopic imagery (right).

4.3 Alternative Screen Forms

While the perforated screens allow partial transparency of the virtual imagery, they cannot occlude objects that may pass behind the virtual image. This could be corrected by computed occlusion, i.e., tracking the objects and masking the virtual images. Creating a partially transparent screen that could quickly be deployed or retracted is also of interest. In addition to physically moving screens, experiments using water and other materials in a laminar flow [9], as well as a controlled cascade of released glass beads, are being tried to create a retroreflective cloud that could be made to appear anywhere within a physical environment.

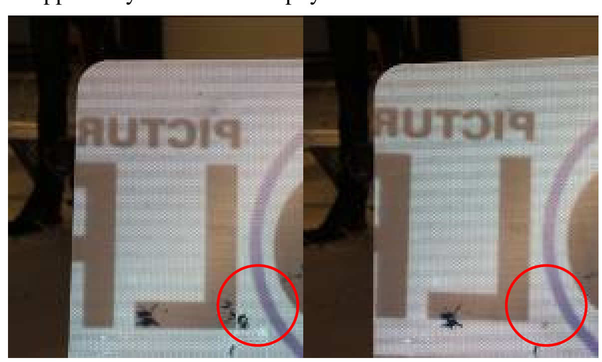

Figure 6: Hardened retroreflective screens withstand paint pellet simulated munitions (left) and can be cleaned (right). Note encircled corner of the "L".

Some mixed reality military applications involve trainees firing paint pellets. Commercially available road sign material was tested under repeated firings at close range from such (see Figure 6) at the Infantry Immersion Trainer (IIT) [11] and the materials appeared to clean and perform again after a simple wipe down, although the materials did present a chromatic rainbow effect off-axis.

4.4 Alternative User Interfaces

Retroreflective surfaces open up new user interface capabilities and possible applications. First, retroreflective screens can be thought of as extremely high-gain projection screens that drastically increase the efficiency of micro-projectors for individual users. This enables the projectors to be used in products with smaller form factors, with less battery usage and longer life, and over longer distances, because the high gain of the retroreflective material concentrates energy back to the user.

Second, the spatially-targeted nature of the information presentation is well-matched to other applications that require user specific data. For example, cell phones with embedded projectors could be used as “cheek-based displays”; at an airport, a user would hold a cell phone projector to his/her cheek and look at a blank retroreflective surface to see real-time directions, guidance arrows, and flight information, in the user’s preferred language.

Figure 7: Near-axis view cast in daylight test of retroreflective sign material as seen by user holding projector/mobile phone.

Devices such as the Stanford Duo [1] enabled a number of unique multi-user interactions, but were inherently limited by the need to multiplex imagery – typically in time, color, or polarization. Retroreflective materials, coupled with head-mounted projection, naturally segment imagery between each user and thus can be implemented to provide multi-person collaborative work surfaces. Note that because only one projector is needed per user, such interfaces are not limited to a single workbench-like surface. Retroreflective cloth could be inexpensively applied to multiple desktop surfaces as well as walls.

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REFERENCES

[1] Agrawala, M., Beers, A.C., McDowall, I., Fröhlich, B., Bolas, M., and Hanrahan, P. 1997. The two-user responsive workbench: support for collaboration through individual views of a shared space. In Proceedings of ACM SIGGRAPH ’97. (Los Angeles, California August 3-8, 1997) ACM Press, 327-332.

[2] Baker, H. and Li, Z. 2009. Camera and projector arrays for immersive 3D video. In IMMERSCOM '09: Proceedings of the 2nd International Conference on Immersive Telecommunications, (Berkeley, California, May 27-29, 2009), ICST, 1-6.

[3] Fergason, J.L., Optical system for a head mounted display using a retro-reflector and method of displaying an image, US Patent 5621572.

[4] Hua, H., Gao, C., Brown, L., Biocca, F., and Rolland, J.P. 2002. Design of an ultra-light head-mounted projective display (HMPD) and its applications in augmented collaborative environments. In Proceedings of SPIE, vol. 4660, (San Jose, California, January 21, 2002), 492-497.

[5] Hua, H., and Gao, C. 2005. A polarized head-mounted projective display. In Proceedings of the Fourth IEEE International Symposium on Mixed and Augmented Reality (ISMAR), (Vienna, Austria, October 5-8, 2005) IEEE Computer Society, 32-35.

[6] Matusik, W., and Pfister, H. 2004. 3D TV: a scalable system for real-time acquisition, transmission, and autostereoscopic display of dynamic scenes, In Proceedings of ACM SIGGRAPH ’04, (Los Angeles, California, August 8-12, 2004), ACM Press, 814-824.

[7] Milgram, P., and Kishino, F. "A Taxonomy of Mixed Reality Visual Displays." IEICE (Institute of Electronics, Information and Communication Engineers) Transactions on Information and Systems (Special Issue on Networked Reality), vol. E77-D, no. 12, pp.1321-1329, 1994.

[8] Raskar, R., Welch, G., Low, K., and Bandyopadhyay, D. 2001. Shader lamps : animating real objects with image-based illumination. In Eurographics Rendering Workshop, (London 2001).

[9] Olwal, A.; DiVerdi, S.; Candussi, N.; Rakkolainen, I.; Hollerer, T., 2006. An immaterial, dual-sided display system with 3D interaction," In Proceedings of IEEE Virtual Reality, (Alexandria, Virginia, 25-29 March 2006), IEEE Press, 279-280.

[10] Stolle, H., Olaya, J-C., Buschbeck, S., Sahm, H., and Schwerdtner, A. 2008. Technical solutions for a full-resolution auto-stereoscopic 2D/3D display technology, In Proceedings of SPIE, vol. 6803, (San Jose, California, February 29, 2008).

[11] Muller, P., Schmorrow, D. and Buscemi, T. The Infantry Immersion Trainer: Today’s Holodeck, Marine Corps Gazette, September 2008, p. 14-18.