Conformal optics for 3D visualization

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Abstract A novel type of 3D visualization display is presented: a head-mounted projective display (HMPD) with a retro-reflective projection screen conforming to the environment. Application to 3D medical visualization is specifically considered. The imaging concept of the HMPD is modeled and compared to that of a conventional head-mounted display (HMD) for stereo-pair images generation. The HMPD presents several advantages compared to HMDs and other 3D visualization techniques.

1. INTRODUCTION

One of the current challenges in medical visualization is that of correlation of medical models or data with a patient's or model patient's (i.e. in the case of medical education) anatomy. For example, modern surgeons, have at their disposal a vast array of advanced technological data dissemination devices. The ring of high resolution monitors circling the typical operating area to display pre-operative and real-time patient data is esteemly supportive. Surgeons take advantage of medical data during surgical procedures by shifting their gaze point off the operative area onto the remote display monitors. The drawback of such head and eye movements is that it requires the surgeons to frequently shift their gaze and head away from the principle field of interest. In addition, surgeons can be extremely challenged with having to correlate these remote data with exposed anatomical structures. One of the next milestones of computer-guided surgical procedures remains the ability to quickly access medical data during the procedure so that it can be used to effectively enhance the surgeon's knowledge.

Furthermore, in the application of the technology for guided surgery, we hypothesized that a fundamental reason for the lack of main stream acceptance of head-mounted displays in surgery is the fact that those displays intrude in the critical areas of interest and action of the surgeon. Therefore it appears that a device that would offer similar capabilities as a head-mounted display by providing hands-free ancillary medical data near the field of interest, without intruding into the critical area of operation, may constitute a paradigm shift for use of digital information in computer-guided procedures.

In medical education, the availability of medical data in books or even in computers, but remote from the patients, makes it difficult for students to form accurate mental models of internal anatomy.[1] In medical visualization in general, the ability to superimpose medical data overlaid or close to a field of interest may enhance the ability to form mental models of various anatomical components within their anatomical context. We are currently testing this hypothesis in the context of a virtual reality tool (i.e. VRDA tool) for visualization of dynamic anatomy such as joint motion.[2] While conventional see-through HMDs may be used in such applications, the technology we shall describe may provide advantages as we shall discuss to that of both conventional HMDs or other 3D visualization techniques such as projection combined with stereo glasses.

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We offer in this paper an alternative to remote displays, head-mounted displays, and stereo projection systems: a head-mounted projective display (HMPD) coupled with a supple, non-distorting, durable projection surface which may be both worn by a user. For a surgeon, for example, the projection surface can be positioned as an outer covering of either his gloves, a surgical tool, or an easel in his critical field of view.[3] Such an approach would allow surgeons to dynamically and deterministically position the location of ancillary data to their convenience during procedures. If located on the gloves, for example, the data can never obstruct the surgeons' view of the operative area, yet the data are in its extreme proximity.

Some configurations may include the projection surface in the environment, remote from the user. For example in the design of the virtual reality dynamic anatomy tool (VRDA), the projection surface may be placed around the anatomical joint being visualized. The fact that bending the sheet around the joint does not induce distortions of the perceived images is critical to the working of this technology. Fergason et al. also applied the technology in designing an inspection visualization platform for mechanical parts and envision potential applications to medical visualization as well.[4]

We shall first present the overall display approach and provide details on the components of the poof of concept prototype display system developed in our laboratory. The impact of the technology on the requirements for stereo pair images is also addressed. Finally, we discuss the advantages and limitations of HMPDs.

2. METHOD

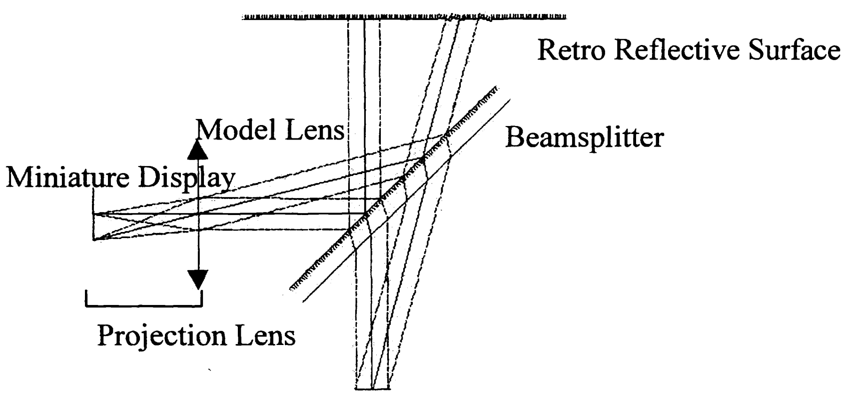
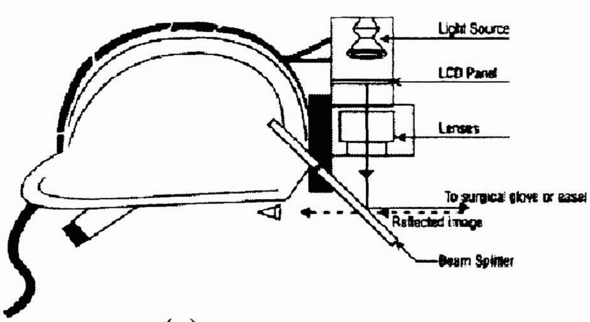


Fig. 1. Imaging concept of the head-mounted projection display modeled in CodeV.

2.1. Imaging concept The principle components of the device consist of the head-mounted projection system which includes the image source and projection optics, an optical-grade beam splitter positioned directly before the user's gaze, and the projection surface which is made up of micro corner-cubes retro-reflectors. An image is projected through the imaging optics and is reflected off the beamsplitter towards the projection surface. When the image reaches the projection surface, it is reflected back on itself, in the same direction. The image is then transmitted through the beam splitter before reaching the eye of the viewer. An image is then formed on the retina of the eye. The imaging concept, modeled in CodeV is illustrated in Fig. 1. Both the semi-transparent mirror and the retroreflective surface were modeled as non-sequential surfaces. The local slope of the surface was adjusted to reflect rays on themselves. More advanced modeling in progress in our laboratory includes defining the slope of the surface statistically to account for small errors in the direction of the reflected rays. This will be reported elsewhere.

2.2 Projection components: a proof of concept prototype Our technique streams real-time images such as patient data to a light-weight HMPD system. A mono or a stereo configuration can be provided. In its current implementation, the prototype is configured as a stereo head mounted projector. Two miniature (1.3" diagonal active area) color 640 X 480 non-interlaced LCD panels are mounted above the brim of the HMPD. Light sources fixed above the LCD panels provide backlighting. Once illuminated, the panel displays are imaged through the imaging optics, and then reflected off a high-grade beam splitter towards the projection surface. In this proof of concept prototype, off-the-shelf components were selected. The imaging optics were Yashica camera lens with a 50 mm focal length. The displays were proprietary miniature LCD displays. The beam splitter is suspended off the brim of the HMPD before the user's eyes, and is mounted at a 45 degree angle relative to the surface of the optical system as shown in Figure 2a. The first proof-of-concept prototype is shown in Fig. 2b. A second prototype in progress uses reflective LCDs and a custom optics projection lens.



(a)

(b)

Fig. 2. (a) Components of the head-mounted projector ; (b) Jim Parsons, one of the authors of this paper, tests the first prototype: the retroreflective sheets in this demonstration were layout on a table and 3D stereo graphics projected through the HMPD. In one of the tests, we verified that the images remain undistorted upon bending of the sheets.

2.3 Retro-Reflective Surface The retro-reflective sheeting surface is a durable and bendable optical surface that allows undistorted 2D or 3D optical viewing of virtual objects regardless of the shape of the underlying projection surface. The sheeting surface is covered with thousands of micro corner cubes--precisely 47,000 per square inch. Such sheeting material is commonly available from 3M or Reflexite, Inc. and is routinely used in photoelectric process control. An individual corner cube has the unique optical property to reflect light back along its incident direction regardless of the ray angle of incidence on the retroreflective surface.

2.4 Generation of the stereo pair of images From an optical point of view, the projecting lens provides a real image of the miniature displays that can be projected either in front or behind the sheet. If projected behind, the reflective sheet transforms the real image into a virtual image and this condition is equivalent to that obtained with conventional HMDs. If projected in front, the reflective sheet transforms the real image into a real image. In either case, the algorithms employed for HMDs to generate stereo pairs of images apply.[5-6] The impact of eyepoint location and eye movements also undergo the same treatment as in HMDs.[7] Consequently, 3D objects can be simulated to appear either in front or behind the reflective sheet.

3. ADVANTAGES AND LIMITATIONS OF THE HMPD

One of the main advantages of the HMPD is the ability to provide occlusion of virtual objects by real objects interposed between the reflective sheet and the user's eye. This means that if a user reaches out to grasp a virtual object, any other object behind his hand disappears as it occurs in the real world. This cannot be achieved with conventional HMDs. Another advantage of HMPDs is the ability to provide brighter images with no conflict with external lighting. In conventional HMDs, the virtual images are superimposed on some external environment and virtual and real illuminations often compete with each other. In HMPDs, the sheet occludes the background scene, and simulated images are thus rendered at higher contrast.

Some properties of HMPDs are equivalent to those of HMDs. For example, the difficulty to design wide field of view devices remains because the projection is performed along the user's line of sight. This also applies to aiming at ergonomic designs. Moreover, the eyepiece (i.e. in the case of HMDs) or projection lens (i.e. in the case of HMPDs) only use at any time an effective pupil diameter of about 3mm. Thus, the optics in both HMDs and HMPDs can tolerate higher F-numbers with less aberrations than in non head-mounted systems.

HMPDs have several advantages compared to conventional projection systems as well. Various groups have developed in the recent years a virtual workbench made of a diffusing table top with a back projector in order to generate a multi-user virtual space.[8-9] Similarly a system called *the cave* uses back projection screens around a room.[10] Such systems are in fact intrinsically limited in capability because to generate multi-user viewpoints simultaneously, the image generation must be time multiplexed which is intrinsically limited by the achievable frame rate. The upper bound is typically two users in the best cases. With the HMPD, no time multiplexing is required as the images always appear from the correct viewpoint. Certainly, various image generators may be required and cost may be a limitation as well. HMDs provide the same advantage as HMPDs in this respect while HMPDs are more suited to the workbench concept because they include a projection surface. It is important also to note that contrary to projection systems, both HMDs and HMPDs provide images to each user with no crosstalk to other users. The HMPD may provide the long awaited technology to provide an effective virtual workbench or cave.

Another important advantage of HMPDs compared to conventional projection systems is the absence of keystoning frequently observed in head-projectors. Keystoning is a consequence of off-axis projection with respect to a user's eyepoints. Moreover, distortion of the reflective sheet by concave or convex bending in no way effects the image quality of the projected images. Therefore, the optics conforms to the work environment with no induced distortions. Finally, because this conformal optics sheeting is commonly available off-the-shelf, it does not add significantly to the overall cost of the visualization system.

One apparent limitation of HMPDs that we discovered in testing the first prototype is that the images become blurred as the user gets about two feet away from the reflective sheet. We attribute this finding to the user accommodating on the sheet as he approaches it. The working range for an application can be established based on the various types of sheet and is under investigation. Any pattern on the sheet would aggravate this effect.

4. CONCLUSION

We described the imaging principle of a head-mounted projection display that presents various advantages over both conventional head-mounted displays and projection systems. Most importantly, HMPDs have the ability to provide (1) occlusion of real objects in the virtual environment, (2) a new type of virtual workbench or cave for multi-user team work, and (3) distortion-free images when projected on curved surfaces. The latter defines the technology as a type of conformal optics specifically suited for medical visualization but likely various other 3D visualization applications as well.

5. ACKNOWLEDGMENTS

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