Ubiquitous Display for Dynamically Changing Environments

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ABSTRACT
This paper proposes a novel method for ubiquitous displays using projectors in indoor environments. In particular, our method consists of two distinct features: automatic scene modeling of a dynamically changing indoor environment, and automatic selection of surfaces onto which various contents are displayed by taking into account both geometric and photometric properties. As a result, our method can be applied to dynamically changing scenes such as a meeting room where furniture and other objects are moved frequently.

Keywords
Computer vision, augmented reality, camera-projector systems, ubiquitous information display, scene modeling

INTRODUCTION
The concept of projecting various contents on all surfaces in a real environment including walls, desks, and floors has been proposed recently. Such functionality, called *ubiquitous display*, is particularly useful for accessing and browsing digital information at arbitrary places in our everyday lives since we do not have to wear any display devices.

Pinhanez recently introduced an interesting method for ubiquitous display called *Everywhere Display* which uses a projector with a pan-tilt mirror for covering a large area with a single or a few projectors. Other researchers have studied another approach that uses many projectors distributed in an environment [4][5].

These previous methods share some difficulties. With one exception described in [4], they cannot handle changes of surface shapes, and do not take into account photometric properties of projection surfaces. Raskar et al. suggested photometric and geometric compensation [4]. However, it is not straightforward how to extend their compensation technique to dynamically changing environments, and an actual implementation has not been reported.

To overcome the common limitation of the previous methods for dynamically changing scenes, we introduce a new method for ubiquitous information display in indoor environments. In particular, our method demonstrates two distinct advantages: automatic scene modeling of a dynamically changing indoor environment, and automatic selection of surfaces onto which various contents are displayed by taking into account both geometric and photometric properties. Our method is particularly advantageous for applications in indoor environments such as in a meeting room where furniture and other objects are frequently moved and rearranged. In the rest of this paper, we describe each of these two aspects of our method in detail.

MODELING OF DYNAMICALLY CHANGING SCENES
It is required in our method to detect changes in the scene efficiently. At the same time, we need to be able to obtain a detailed model of a scene such as surface shapes and reflectance properties for projection with correct calibration. To satisfy these requirements for efficiency and accuracy, our method takes a coarse-to-fine approach: coarse scanning of a scene using a range scanner and a fine scanning for projection areas by using a combination of a projector and a color camera.

Coarse Scanning using Range Finder
In order to detect changes in a scene quickly, we measure the coarse shape of the scene by using a uniaxial laser range finder attached to a rotary table mounted on the ceiling (Figure 1). By using this range scanner, the whole shape of a scene (Figure 2) is measured approximately twice per minute. Thus the system can accommodate changes of surface shapes relatively rapidly.

As mentioned before, shape data measured by the range sensor do not have enough resolution. In addition, they do not provide reflectance properties of the scene which is used later for evaluating appropriateness of each surface for projection. Accordingly, we need more detailed shape scanning by a camera and a projector.

Figure 1: *Range sensor, SICK LMS200*

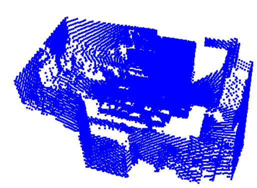

Figure 2: *Scanned shape of a whole room*

CHI 2003, April 5-10, 2003, Ft. Lauderdale, Florida, USA.
ACM 1-58113-637-4/03/0004

Fine Scanning using Camera and Projector

Our method uses a scanning technique based on triangulation with gray code pattern projection by using a color camera and a projector for measuring the shape of a scene at a finer resolution. This is done only for a part of the scene where some changes are detected by the coarse scanning stage. For example, Figure 3 and Figure 4 show a part of the scene and its 3D shape obtained from the fine scanning stage.

Figure 3: *Background scene*

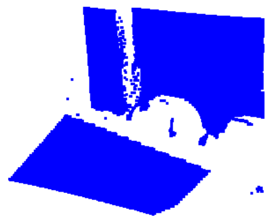

Figure 4: *Scanned shape of the scene*

EVALUATION OF APPROPRIATENESS AS PROJECTION SURFACE

After shape scanning, we need to evaluate the appropriateness of each surface in the scene for projection. In our method, this is also done automatically. First, our method extracts planer regions by using the range image segmentation technique developed by Hoover et al. [2]. Here, we assume that planar regions are the most appropriate ubiquitous display in terms of geometrical aspect because projection on regions with complex shapes is susceptible to changes of a viewpoint.

After planer regions are extracted, reflectance properties of each of the planar regions are examined to determine if the region is appropriate for ubiquitous display. Roughly speaking, a region is considered to be more suitable for projection if it is a uniformly-colored diffuse surface with low saturation and high brightness. By using a color image segmentation technique [1], regions with a uniform reflectance property are extracted from the scene (Figure 5), and diffuse reflectance parameters are estimated for each region based on the Lambertian model and the illumination direction with respect to the region's surface normal.

One problem that we need to consider is how to treat specularity on a surface. Theoretically, we can estimate specular reflectance properties of a surface by illuminating and observing the surface from different directions. However, if positions of cameras and projectors are fixed as in our method, it is difficult to estimate the specular reflectance properties reliably. For this reason, we assume the Lambertian model without explicitly taking specularity into account. Then we avoid specularity by choosing a surface so that the viewing direction is not close to the reflection of projection direction about the surface normal of the surface. To do this, we need to know the position of a user in the scene. Our current implementation of the system does not include tracking of a user, and therefore this is left for our further study.

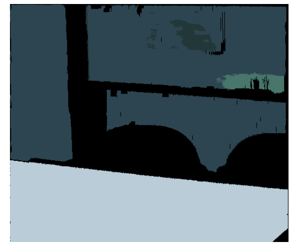

Figure 5: *Segmentation by diffuse parameters*

(a) On a desk *(b) On a wall*

Figure 6: *Actual projections*

CONCLUSIONS

We introduced a new method for ubiquitous display for dynamically changing indoor scenes. In particular, In particular, our method has two distinct features: automatic scene modeling of a dynamically changing indoor environment, and automatic selection of surfaces onto which various contents are displayed by taking into account both geometric and photometric properties.

Our future studies include extension of our current system by incorporating tracking of multiple users in an indoor environment in order to avoid specularity, and multiple projectors with pan-tilt capability.

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