Portable Projection-Based AR System

Jihyun Oh, Byung-Kuk Seo, Moon-Hyun Lee, Hanhoon Park, and Jong-Il Park

Department of Electrical and Computer Engineering, Hanyang University,
17 Haengdang-dong, Seongdong-gu, Seoul, Korea
{ohjh,nwseoweb,fly4moon,hanuni}@mr.hanyang.ac.kr,
jipark@hanyang.ac.kr

Abstract. Display systems with high quality and wide display screen can be used at fixed place due to big size and heavy weight. On the other hands, mobile systems have small display screen and thus decrease user-immersion because it is compact. In this paper, we resolve these drawbacks of established display systems by proposing a novel portable projection-based augmented reality (AR) system. The system uses a camera mounted on PDA and a small projector to measure characteristics of screen surface. We use geometric correction and radiometric compensation technique to project undistorted image in user viewpoint onto an arbitrary screen surface. Rather than float point operations, we use integer point operations to enhance system performance. Our proposed system not only supports mobility but also wide display screen. Usability of our system is verified through experimental results and user evaluation.

Keywords: portable, projection, display system, augmented reality.

1 Introduction

Display systems with high quality and wide display screen such as High Definition Television (HDTV) have been rapidly widespread. But there has been a limitation that they can be used at fixed place because of their big size and heavy weight. On the other hands, mobile display systems, e.g. mobile phone, Personal Digital Assistant (PDA), Portable Multimedia Player (PMP), and so on, have recently come into spotlight as a new trend of display system because they are quite handy to use anywhere. However, they have other limitations such as small display screen and lack of user-immersion. In this paper, we propose a novel display system based on AR technology for resolving these drawbacks of existing display systems. The system is a portable projection-based AR system which uses a PDA and a small projector not only to support high-resolution and wide display screen, but also to enhance mobility of the system.

A number of mobile AR systems have been already developed and applied to various applications. Wagner *et al.* [1] proposed an AR system for education and entertainment on PDA platform. The AR system shows 3-D virtual information instead of AR markers on the PDA screen and enables multi-user to simultaneously enjoy by offering infrared radial communication service. Bruns *et al.* [2] applied AR technology to a mobile phone that shows additional information for exhibitions in the museum.

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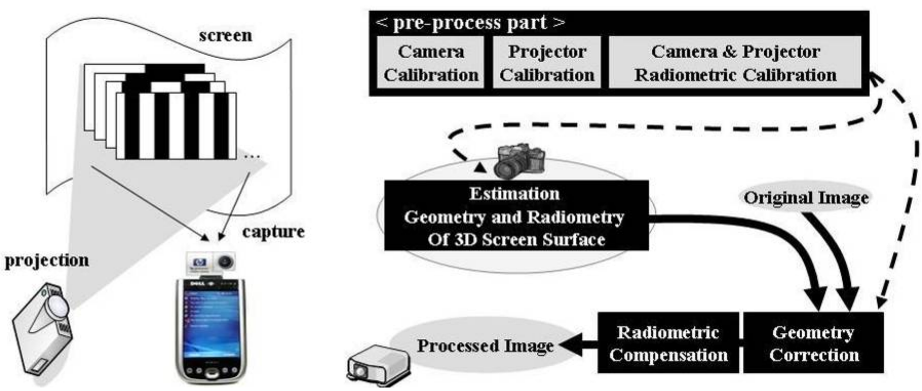
As another branch of AR systems, a number of projection-based AR systems have been also developed. Raskar *et al.* [3] proposed a projection-based AR system, called iLamp, this accurately provides visual information without geometric distortions onto an arbitrary screen. Mitsunaga *et al.* [4], Nayar *et al.* [5], and Grossberg *et al.* [6] resolved problems that projection images are distorted onto colorful textured screens by proposing radiometric compensation techniques. Park *et al.* [7] also proposed an integrated AR system that handles not only geometric and radiometric distortions, but also viewpoint-ignorant projection and uneven projection.

In this paper, we try to combine the benefits of mobile-based AR system with those of projection-based AR system. That is, our system enables visual information to display without geometric and radiometric distortions anywhere and anytime by using a PDA and a small projector.

The remainder of the paper is organized as follows. Section 2 introduces our system briefly. Section 3 explains detailed techniques for implementing the system. Experiment results and user evaluation are given in Section 4. Finally, the conclusion is drawn in Section 5.

2 Overview of the Proposed System

Portable projection-based AR system is considered as an intelligent display system that project undistorted images onto a 3-D surface that is an arbitrary screen in mobile environment. In our system, entire operations are performed by a PDA based on Window CE 5.0 platform. A camera that mounted on the PDA and a portable projector are used to analyze geometric and radiometric characteristics of 3-D surface.



(a) (b)

Fig. 1. System structure, (a) illustrated a portable projection-based AR system (b) a flow of processing

Proposed system structure is illustrated shown in Fig 1. The structure is divided into three processing parts. First of all, a camera and a projector are geometrically and radiometrically calibrated, and that is one time preprocessing. And then the geometry and radiometry of 3-D surface are estimated by projecting and capturing a set of patterns as shown in Fig. 1(a). Finally, a compensation image is mathematically computed by using obtained information, and it is projected as undistorted image onto 3-D surface. In the following sections, we will explain these techniques in detail.

3 Component Techniques

3.1 Geometric Correction

Projection images are geometrically distorted unless a projection surface is planar and the projecting direction is perpendicular to the surface. In our approach, the geometric distortion is corrected by using a compensation image which is pre-warped by homography. First of all, both a camera and a projector are calibrated in advance. The camera is calibrated by using Zhang's calibration method [8]. For calibrating the projector, we used a modified version of Zhang's calibration method [7] since the projector can be considered as an inverse model of the pinhole camera. With knowing the geometric information, the geometry of a 3-D surface is recovered by applying a binary coded structured light technique [9] and a linear triangulation method [10] (see Fig. 2). The binary coded structured light technique is used for finding correspondences between image points and points of the projected patterns. A set of patterns is successively projected and imaged by the camera. Both image points and points of the projected patterns have their own codeword, so correspondences are precisely computed by the codeword. Finally, the 3-D surface geometry is estimated by triangulation and is presented as the form of a triangular mesh.

Each triangle of the 3-D surface mesh is piece-wise and planar, so geometric relationships among the camera, the projector, and the 3-D surface can be defined by homographies [7, 11]. With these relationships, an arbitrary viewpoint image can be synthesized by projecting a projection image onto a viewer image plane as

$$\boldsymbol{x}_{veiewpo\,\mathrm{int}} = \boldsymbol{K}_c [\boldsymbol{R} \quad \boldsymbol{t}] \boldsymbol{X} \tag{1}$$

where $\boldsymbol{x}_{veiewpo\,\mathrm{int}}$ is a point of the viewpoint image, X is a point of the projection image, and K_c is the intrinsic matrix of the camera. Rotation parameter R and translation parameter t are specified by the position of the viewpoint. It is usually assumed that the viewpoint is perpendicular to the projection surface. Let the homography is H_{p-v} between a desired image which is and a viewpoint image which is distorted from 3-D surface, a compensation image for a desired image $x_{desired}$ without distortion in user's viewpoint is presented as

$$\boldsymbol{x}_{prewarped} = \boldsymbol{H}_{p-v}^{-1} \boldsymbol{x}_{desired} \tag{2}$$

where $x_{prewarped}$ is a point of the compensation image. Note that we assume that user's viewpoint is on normal direction of screen surface.

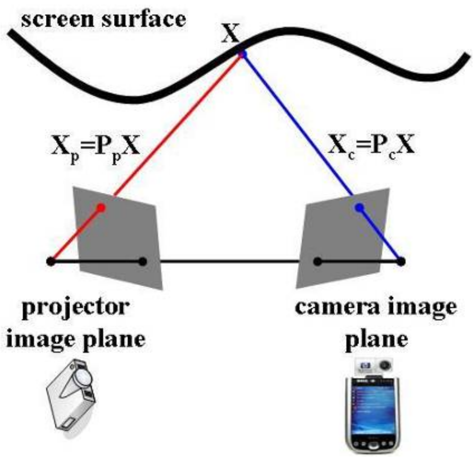


Fig. 2. The geometry of a 3-D surface is estimated by triangulation method

3.2 Radiometric Compensation

The fundamental problem with using an arbitrary surface is that the color of a projection image depends on that of a projection surface and ambient light. Radiometric compensation is a technique that makes the color of the projection image preserved by adjusting a color of the projector input image when the projection surface has colorful texture [3, 4, 5]. In this paper, we focus on distortion by the color of the projection surface with the assumption that ambient light is unchanged during the system operation.

With the geometric mapping between a camera image and a projector input image, the radiometric model of the pipeline from input projector color to the measured camera color is defined as

$$C = VP + F \tag{3}$$

where C is a point of camera image, V is color mixing matrix, P is points of projected image, and F is ambient light. Generally relationship between image radiance and image brightness is non-linear and the spectral response of the color channels of both devices can overlap with each other, so these factors are handled off-line in advance. Both devices' non-linear radiometric response functions are calculated as 4^{th} –order polynomial function [2] and also the couplings between the projector and camera channels and their interactions with the spectral reflectance of the projection surface points are all captured by the matrix V [3, 4, 5]. Once these unknown parameters are estimated, compensation image for a desired image without color distortion is obtained by

$$P_{compensation} = V^{-1}(I_{desired} - F) \tag{4}$$

3.3 Improve Computational Time on the Mobile Platform

Computational time is critical factor when system designed based on mobile environment. Especially, mobile environment does not have a floating point unit (FPU), which is a part of computer system specially designed to carry out operations on float point numbers such as multiplication, division, and so on, so computational time is more increased for processing floating points operations and thus it may affect system performance. In our method, we used integer operations from the step of image pre-warping to correct geometric distortion and made up a lookup table for pre-warping since it was assumed that 3-D surface was modeled one time after mobile device was fixed at specific position. Our method remarkably enhanced system performance on mobile platform and the result was shown in Table 1.

Table 1. Comparison computational time on mobile platform

486 × 536 color image			
		3-D surface reconstruction	image pre-warping
computational time (sec)	float point	8	0.265
	integer point	-	0.046

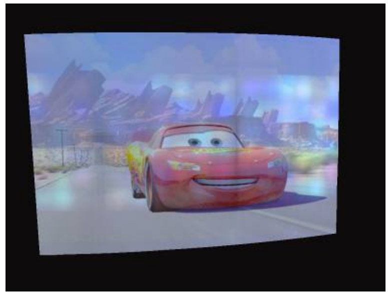
4 Experimental Results and Discussions

Our experimental environment was composed of a DLP projector (SAMSUNG Pocket Imager), a camera (HP mobile camera, SDIO type), and a PDA (DELL AXIM X51V) (see Fig. 4). The system was developed in Window Mobile 5.0 platform and used a modified version of OpenCV library.

Fig. 5 shows the example of applying our system to multimedia display. Projection images were geometrically and radiometically distorted on dynamic and colorful textured screen (see Fig. 5(a)). The compensation image was computed by analyzing the geometric and radiometric characteristics of the screen (see Fig. 5(b)) and then multimedia could be displayed without distortion in user's viewpoint (see Fig. 5(c)).

(a) (b)

Fig. 4. Experiment environment, (a) our portable projection-based AR system, (b) projection surface which is non-planar

(a) (b)

(c)

Fig. 5. Experiment results, (a) without any processing (b) compensation image (c) with geometric correction and radiometric compensation

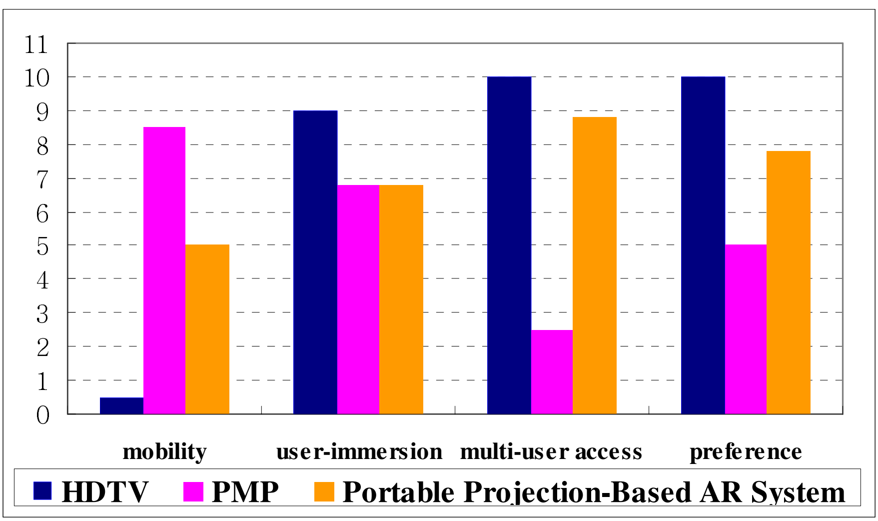


Fig. 6. Subjective evaluation and comparison

(a) (b)

(c)

Fig. 7. Various display systems, (a) HDTV (b) PMP (c) the Proposed System

To confirm the usability of our proposed system by comparing among established display systems as shown in Fig.7, we asked fifteen volunteers to complete a questionnaire that rates the established display systems on four areas: mobility, user-immersion about a display quality, multi-user access, and preference. The degree of evaluation was divided into ten scores and results are shown in Fig. 6.

In the user evaluation, HDTV got highest scores on the evaluated areas except for the mobility. HDTV scored very low on mobility due to the big size and heavy weight of HDTV. Volunteers gave PMP the highest score on mobility, because of the compact size, weight, and display. However, some complained that the display screen size of PMP is too small and thus prone to the easy eyestrain. And PMP received the lowest score on multi-user access and the lowest preference.

Portable projection-based AR system did not received a high score on mobility as expected, because our current prototype is not as compact as existing portable devices namely PMP. To the best of our knowledge, the mobile device that features our prototype is not produced yet. However, a compact portable projection-based display device will soon be offered as shown in Fig. 8, and then the mobility of the proposed portable projection-based AR system will increase. The proposed system got high scores on both user-immersion and multi-user access, because volunteers could watch not only the accurate visual information without a restricted projection screen but also high resolution images by a projector. And thus on preference, the proposed system got higher scores than PMP.

This indicates that the portable projection based AR system have more advantages and usability than exiting mobile devices. If the compact portable projection-based display device is produced and commercialized, intelligent display systems such as the proposed system will have more increased demands than now.

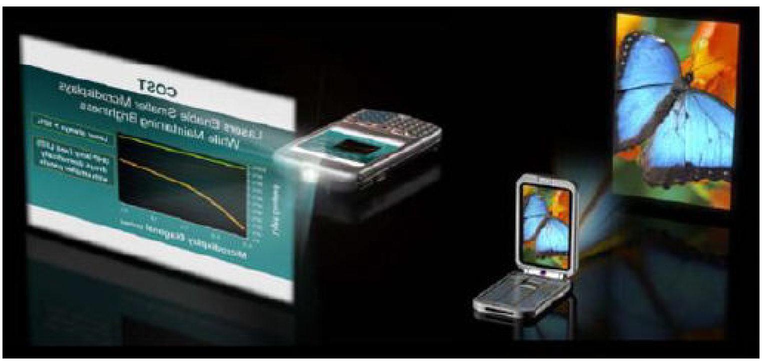


Fig. 8. Example of compact Portable Projection-Based Display Device (Illustrated by Partsnic Components Co., Ltd. in Daewoo, Korea)

5 Conclusions

The proposed portable projection-based AR system not only improved mobility by overcoming limitation of display screen and by offering wide display screen, but also enable to accurately project on an arbitrary screen without distortion on dynamic and colorful textured projection screens by performing geometric correction and radiometric compensation technique. Also, proposed system verified possibility performing on the mobile platform. That was possible because mobile processors have been becoming powerfully and system was optimized on mobile platform suitably.

In this paper, we confirmed usability of the portable projection-based AR system by user evaluation. If a compact mobile device is produced, user's satisfaction should increase more and more toward to the proposed portable projection-based AR system. Additionally, we are trying to applying imperceptible structured light technique [12, 13, 14] for compensating in real-time without interrupting normal operations. Finally intelligent display systems such as our system would be applied to variety application.

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