Locating Projectors Using Intensity of Reflected Beams Based on Phong Shading Model

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Abstract. In this work we focus on handheld projector-camera systems and discuss how to find out where and in which orientation those projectors are. We propose a way to find out them by measuring the intensities of the beams reflected on the screen. The point is that our system does not rely on fiducial markers which are usually stuck on the screen to help to locate the projector. Additionally, in our system, a laser-based projector is used, and the intensity of beams being projected and reflected on the screen is modeled based on Phong shading model. Through the evaluation, we show the potential of our system in HCI areas.

Keywords: beam intensity, Phong shading model, laser-based projector, real-time calibration, projector-camera system.

1 Introduction

Because of the downsizing and portability, projectors are easily installed anywhere and widely used in various ways as well as in common use such as presentations. Usually projectors are fixed on-centered to the screen. If projectors are put angled, the projected images will be distorted. Sukthankar et al. [1] built a projector-camera system where the projector is allowed to be off-centered to the screen. In the system the projector projects a calibration pattern and the camera captures it on the screen. From the correspondences between the calibration pattern and observed calibration pattern, the mapping between the camera and projector coordinates is obtained. And also the mapping between the camera and screen coordinates is obtained by observing the outline of the screen. These two mappings give the desired mapping between the projector and screen coordinates. By using the desired mapping, the projected image is corrected to appear not-distorted. In contrast to using one projector, other researches focus on multiple projectors to display a single tiled image on a large screen. Chen et al. [2] aligned 24 projectors to project a large seamless image. Likewise this system needs to be calibrated by obtaining the mappings mentioned above.

On the other hand there is another way of use of a projector, which is allowed to move while projecting images. In this case, real-time calibration, or quick calibration,

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is required whenever the projector moves. If the mapping between the projector and screen coordinates is obtained every time the projector moves, the calibration pattern will interrupt the projection. So, the calibration pattern cannot be used. Instead, the outline of the quadrilateral illuminated by the projector is used. Beardsley et al. [3] and Rehg et al. [4] built a projector-camera system capable of real-time calibration. Four fiducial markers are stuck on the screen, which show the four corners of a rectangle where the projected image is supposed to appear. The camera captures both the outline of the quadrilateral illuminated by the projector and the four fiducial markers. Before images are projected, they are pre-warped first, and then projected on the screen. This pre-warping is always performed. As a result, those images appear not-distorted within the four fiducial markers even while the projector is moving.

In addition, projector-camera systems capable of real-time calibration are useful for HCI because the current orientation and position of those projectors are available all the time when in use. The work of Beardsley et al. [3] is a good example of projector-camera systems used in HCI. In their system, a mouse cursor is placed at the center of the illuminated quadrilateral while projecting the desktop image of MS-Windows within the four fiducial markers. The cursor moves when the projector is panned. At the time, as mentioned above, the desktop image is kept within the four fiducial markers. So the projector can be used as a mouse. However fiducial markers make the interaction area be limited around the markers. In this work, we aim to extend the interaction area by no use of fiducial markers.

Previously we proposed a way to find out the orientation and position of a projector by measuring the intensities of the beams reflected on the screen [5]. As that technique needs no fiducial markers, the screen can be extended as far as the reflected beams are observed. In that work, a DLP projector was used and the intensities of the beams were modeled by their own defined equations.

Recently, handheld laser-based projectors were released by AAXA Technologies Inc. Those projectors benefit from use of laser, so the projected images are always in focus. This feature could solve a problem posed in the previous work, that the projected images become blurred badly when the DLP projector is paned in either direction. Therefore, in this work the DLP projector is replaced with the laser-based projector. This will also simplify how the intensities of the reflected beams are calculated because of no need to take into account blurring caused by the projector being out of focus. That is, the intensities depend only on the positions of the projector and camera. In computer graphics area, Phong shading model [6] plays an important role in providing a way to give the intensities of the beams reflected on objects with respect to the positions of light sources and an observer. Thus, in this work, we take an advantage of Phong shading model to create the intensity curves of the beams reflected on the screen. And then, the orientation and position of the projector is obtained based on the intensity curves.

The rest of this manuscript is organized as follows. In Section 2, how projectors are located is explained. And the intensities of the beams reflected on the screen are modeled in Section 3. In Section 4, our system is evaluated, and the concluding remarks are given in Section 5.

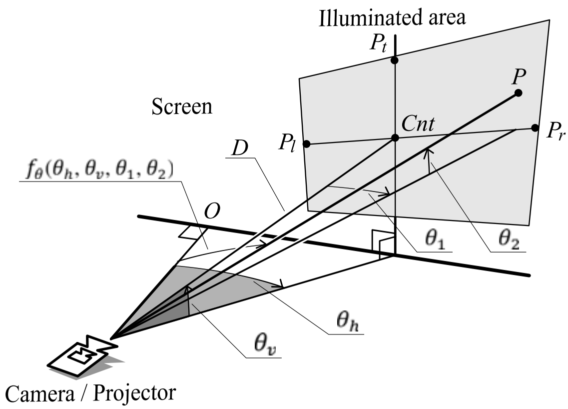

Fig. 1. Our projector-camera system. A camera is attached on a projector, and captures the images projected by the projector.

2 How to Locate Projectors

First of all it is assumed that projectors project beams of the same intensity in every direction when a one-colored image, such as a white-filled image, is projected. Fig. 1 illustrates our projector-camera system, where a camera is attached on a projector. θ_h and θ_v are the angles at which the projector is angled horizontally and vertically toward the screen, respectively. Cnt is the center of the projector's perspective on the screen, and D is the distance between the projector and Cnt. P is a position on the screen. θ_1 and θ_2 are the horizontal and vertical angles to P from Cnt. O is the nearest position on the screen from the projector. The angle at the projector between O and P is obtained as follows.

$$f_\theta(\theta_h, \theta_v, \theta_1, \theta_2) = \mathrm{acos}(\cos\theta_h \cos\theta_v \cos\theta_1 \cos\theta_2 - \cos\theta_h \sin\theta_v \sin\theta_2 - \sin\theta_h \sin\theta_1 \cos\theta_2) \quad (1)$$

When intensities are observed at P_t, P_l and P_r as I_t, I_l and I_r, respectively, then the projector can be located, or θ_h, θ_v and D can be derived from the following simultaneous equations.

$$I_t = f_I\left(f_\theta(\theta_h, \theta_v, 0, \tfrac{\theta_{pv}}{2}),\ D\, f_\theta(\theta_h, \theta_v, 0, 0)/f_\theta(\theta_h, \theta_v, 0, \tfrac{\theta_{pv}}{2})\right), \quad (2)$$

$$I_l = f_I\left(f_\theta(\theta_h, \theta_v, -\tfrac{\theta_{ph}}{2}, 0),\ D\, f_\theta(\theta_h, \theta_v, 0, 0)/f_\theta(\theta_h, \theta_v, -\tfrac{\theta_{ph}}{2}, 0)\right), \quad (3)$$

$$I_r = f_I\left(f_\theta(\theta_h, \theta_v, \tfrac{\theta_{ph}}{2}, 0),\ D\, f_\theta(\theta_h, \theta_v, 0, 0)/f_\theta(\theta_h, \theta_v, \tfrac{\theta_{ph}}{2}, 0)\right), \quad (4)$$

where $f_I(\theta, D)$ gives the intensity of the beam reflected at Cnt when the projector is angled by θ in either direction and is placed D away from Cnt. θ_{ph} and θ_{pv} are the horizontal and vertical angles of the projector's perspective.

3 Intensity Curves

It is already explained in the previous section that the projector can be located if $f_I(\theta, D)$ is known. In this section, $f_I(\theta, D)$ is modeled by observing the intensities of beams by the camera. A white-filled image was projected and the reflected beams from Cnt were observed by the camera at 5×6 = 30 positions: D = 50, 75, 100, 125, 150 cm and $\theta = 0^o, 10^o, 20^o, 30^o, 40^o, 50^o$. Fig. 2 shows the intensities of the observed beams. The intensities range from 0 to 255. Eqn. (5) of Phong shading model was best fit to those intensities as shown in Fig. 2.

$$f_I(\theta, D) = I_c = \frac{1}{a+b(2D)+(2D)^2}\left\{K_d\, I_p \cos\theta + K_s\, I_p \cos^{\alpha}(2\theta)\right\} + K_a, \qquad (5)$$

where I_c and I_p are the intensity of the beams observed by the camera and the one projected by the projector, respectively. a, b, K_d, K_s, α and K_a define the intensity curves. I_p was set to 255 because a white-filled image was projected. The set of optimal values was obtained by the steepest descent method as follows. a =9582.668, b =18.613, K_d =14781.993, $K_s = -2148.044$, α =1.026, $K_a = 10.388$.

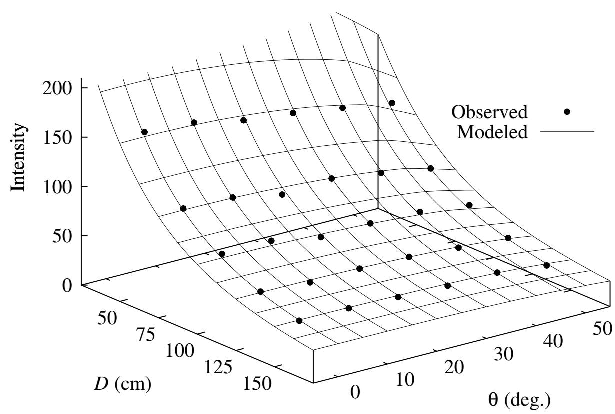

Fig. 2. Intensity curves

4 Evaluation

Finally we evaluated our system. The projector and camera were put at each of the same 30 positions but θ_v was kept to 0 in order to check the accuracy of θ_h. The orientation of the projector and the distance from the screen, or θ_h and D were estimated by Eqn. (3) and (4). Fig. 3 shows the result. There are about 6^o error on θ_h and 5 to 10 cm error on D. The estimation errors could be caused by fluctuation in the intensities of the observed beams.

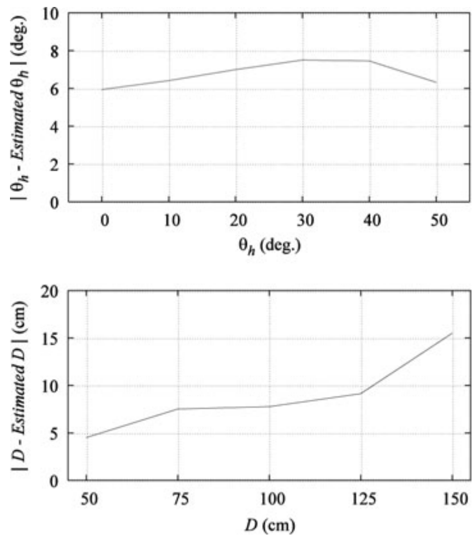

Fig. 3. Accuracy of estimated values of θ_h and D

5 Conclusions

In this work, we proposed a way to find out the orientation and position of a projector by measuring the intensities of the beams reflected on the screen. Specifically, there were two main changes from our previous projector-camera system. That is, a laser-based projector was used and intensity curves were modeled based on Phong shading model. From the evaluation, it showed the successful first step towards use of handheld projector-camera system without fiducial markers, especially for HCI purposes. In the future, we will discuss the effect of the estimation errors on usability in application use, and also improve the estimation process for higher accuracy.

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