Continuous Photometric Compensation for Deformable Objects

Naoki Hashimoto
The University of Electro-Communications
W9-603, 1-5-1 Chofugaoka, Chofu
Tokyo, Japan 182-8585
naoki@cs.uec.ac.jp

Koki Kosaka
The University of Electro-Communications
W9-603, 1-5-1 Chofugaoka, Chofu
Tokyo, Japan 182-8585
kosaka@ims.cs.uec.ac.jp

ABSTRACT

In this research, we propose a photometric compensation technique for deformable objects, such as a curtain that is continuously swinging. In photometric compensation, it is necessary to exactly obtain an inter-pixel correspondence and a response function between a projector and a camera. Therefore, compensation for deformable objects is a major challenge. In our proposal, we reconstruct the inter-pixel correspondence by using the uniformity of a re-estimated reflectance property of the response function. By using a fast implementation with a GPU, it is possible to provide continuous photometric compensation, even for deformable objects, without using a coaxial projector-camera system.

CCS CONCEPTS

•Human-centered computing → Mixed / augmented reality; Virtual reality;

KEYWORDS

photometric compensation, inter-pixel correspondence, response function, deformable target

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1 INTRODUCTION

Recently, due to advanced reductions in their size, high-performance projectors are used for various scenes of general households. Along with this, a photometric compensation technique that enables projection of any image onto colored and textured surfaces has attracted attention. However, it is impossible to accurately compensate the projection onto an object that changes its position and shape, because feedback control must obtain accurate and dense pixel-level correspondence between a projector and a camera. Further, the response function used for feedback control also changes by the deformation. In a room space, it is effective to project images onto a large curtain or an instant screen made with an ordinary cloth. Nevertheless, due to the inaccuracy of both the correspondence and the response function, keeping accurate photometric compensation on a flexible curtain is quite difficult.

Fujii et al. used a special projector-camera system in which the coaxial arrangement of the camera and projector prevented false inter-pixel correspondence [Fujii et al. 2005]. However, the compensation capability was lowered significantly because the projector light was halved by the half mirror used to achieve the coaxial arrangement. Additionally, the adjustment operation for system construction was time-consuming. Hashimoto et al. proposed a system to reconstruct the correspondence between pixels in real time by using a depth camera to measure the shape of the projection surface [Hashimoto and Watanabe 2010]. Although they achieved continuous compensation, the low resolution and severe noise of the depth camera did not allow precise photometric compensation.

2 OUR PROPOSAL

In this research, we propose a photometric compensation technique for objects in continuous deformation by using only a simple projector-camera system. When the target object is deformed and the inter-pixel correspondence is false, the reflectance property toward an observation point also changes according to the shape change. Therefore, using the uniformity of the estimated reflectance property of the target object, we perform sequential estimation of the inter-pixel correspondence.

2.1 Estimation of the reflectance property

First, it is assumed that the pixel correspondence is obtained correctly. In this case, the characteristics of the projector output are expressed by an exponential function. The response function at each point on the object surface illuminated by the same light source is based on the fact that the projector output has the same characteristics as the light source itself and is proportional to the ratio of the reflectance of the point as a reference. As a result, in this research, we use the following response function:

$$C(i) = KV\{(W - B) \cdot (\frac{i}{255})^{\gamma} + B\}, \tag{1}$$

where i is a projector input value, W and B are maximum and minimum luminances at the reference point, V is a color mixing matrix, and K is a reflectance property compared with the reference point.

In Eq. 1, assuming that the inter-pixel correspondence is known, we can estimate the reflectance K as a variable parameter. To perform the compensation continuously, we use a recursive least-squares algorithm. The compensation operates as an adaptive filter

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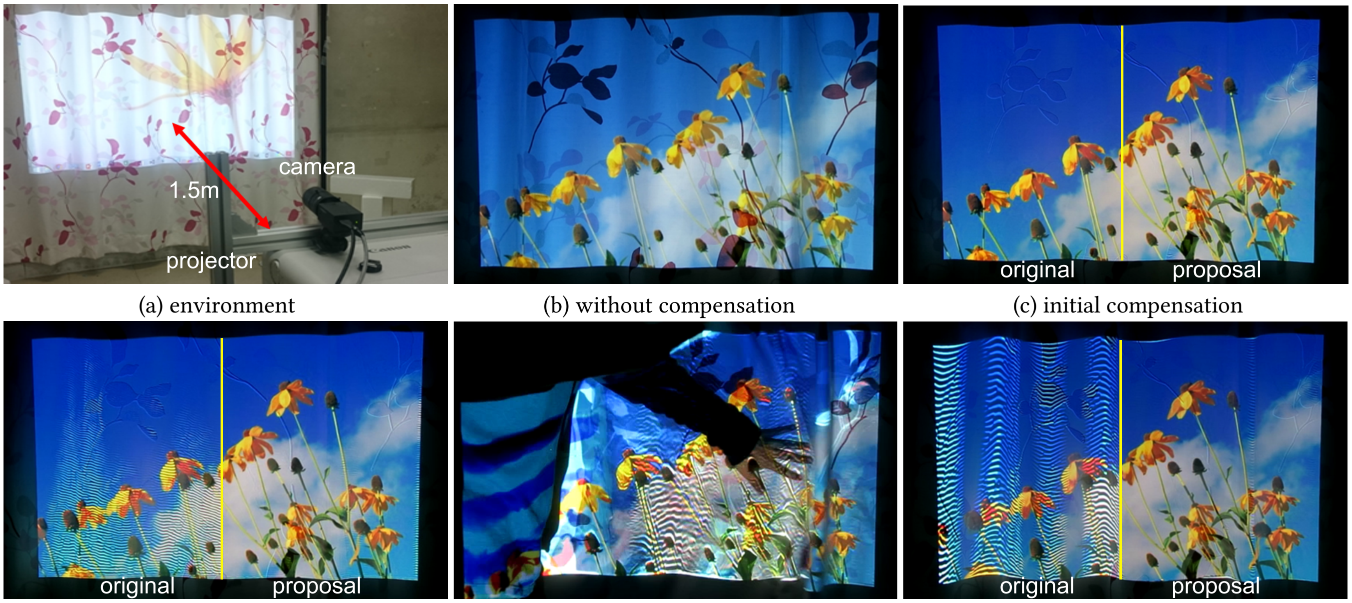

(a) environment (b) without compensation (c) initial compensation

(d) slightly deformed (e) heavily deformed (f) after heavy deformation

Figure 1: Results of photometric compensation on a swinging curtain.

based on the least-squares method and enables fast convergence to the target value.

2.2 Estimation of inter-pixel correspondence

For dynamic reconstructing of the inter-pixel correspondence, it is necessary to estimate the inter-pixel shift amount between the projector and the camera before and after the deformation of the target object. This estimation is performed by using the reflectance property of the response function, described in 2.1.

The inter-pixel shift can be limited by using an epipolar constraint between the projector and the camera. In the epipolar constraint, the corresponding points between the camera and the projector are positioned on the epipolar line. Therefore, when the depth of an observation target viewed from the projector is changed, the corresponding point in the camera image can be found on the epipolar line.

When the shift amount of the corresponding point is $\pm d$ [pixel], the search for the corresponding points on the epipolar line is performed on the basis of the reflectance property estimated by using the shift amount. If the shift amount is appropriate, the reflectance property should be correctly estimated according to the actual projection plane. In typical curtains, it is assumed that the neighboring pixels have a locally uniform reflectance property. Therefore, the uniformity of the reflectance can be evaluated by the variance of the reflectance in the neighboring region. The shift amount that minimizes the variance is supposed to be correct, and so that amount is used for estimation of the reflectance property.

On the other hand, at edges in the texture of the target object, at which the reflectance property largely changes, the uniformity of the reflectance is not guaranteed. Therefore, the region including the edge is treated as an outlier, because the variance is very large. The shift amount of such region is interpolated from the neighboring region.

By repeating this process at high speed, we can provide appropriate photometric compensation toward a target object that is in continuous deformation.

3 RESULTS

We implemented our proposal on an actual curtain swinging by wind blowing from an air conditioner. We used a Canon WUX450 projector (1280 × 800) and a FLIR GS3-U3-23S6C camera (1920 x 1200). The processing speed of the compensation was 1.3 ms/frame by using a GPU (NVIDIA GeForce GTX 1080). The total processing time, including the delay of the camera and the projector, was 78.5 ms/frame.

In Fig. 1, we can see that both the original compensation and our proposal cancel the texture of the curtain (Fig. 1(c)). Therefore, when the curtain is swinging naturally, our proposal can continue its compensation (Fig. 1(d)-left). In the original compensation, artifacts, such as banding due to the false inter-pixel correspondence, become noticeable (Fig. 1(d)-right). In addition, even when the curtain is greatly changed (Fig. 1(e)), the proposed method can be confirmed to converge again to the correct compensation (Fig. 1(f)).

As a next step in the near future, we intend to achieve a more high-speed implementation for faster deformation. We will also apply our technique to flexible objects other than a curtain.

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