A Method for Realistic 3D Projection Mapping using Multiple Projectors

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(a) (b) (c) (d)

Figure 1: *Realistic 3D projection mapping: (a) System overview, (b) System output, (c) Original object, (d) Samples for blending*

Abstract

Recently researchers have shown much interest in 3D projection mapping systems but relatively less work has been done to make the contents look realistic. Much work has been done for multi-projector blending, 3D projection mapping and multi-projector based large displays but existing color compensation based systems still suffer from contrast compression, color inconsistencies and inappropriate luminance over the three dimensional projection surface giving rise to an un-appealing appearance. Until now having a realistic result with projection mapping on 3D objects when compared with a similar original object still remains a challenge.

In this paper, we present a framework that optimizes projected images using multiple projectors in order to achieve an appearance that looks close to a real object whose appearance is being regenerated by projection mapping.

Keywords: gamuts, light transport, multi-projector blending

Concepts: P**rojection mapping; Multi-Projector Systems;**

1 The Proposed Method

We generate our results by first measuring the projector response (figure 2) by projecting flat images with different intensities on the projection surface. Then we optimize the projector outputs per pixel guided by the measured projector response. Finally to blend the projector outputs onto the projection surface, we sample the projection output sparsely and compute the light transport as viewed from the observer's view-point.

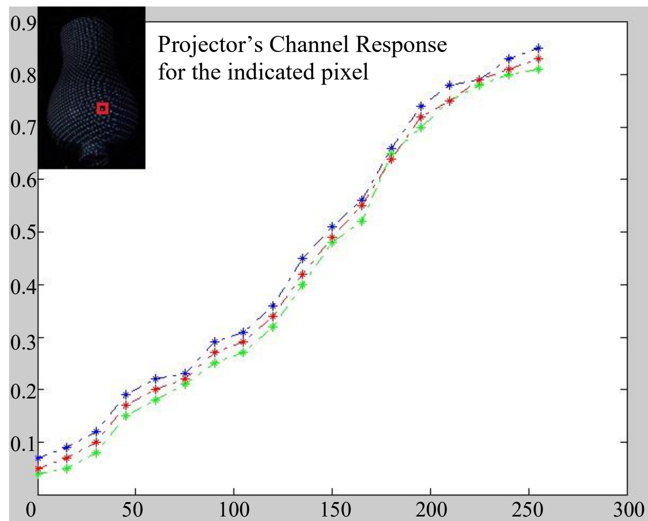

Figure 2: *Projector's channel response for a sample taken to perform blending*

1.1 Acquisition & Calibration

Our system consists of two projector-camera pairs, a 3D projection surface and a third camera placed at the user's view point for blending purposes as in figure 1(a). As a pre-requisite, we photometrically calibrate the cameras using Gretag-Macbeth color charts under D50 lighting and calibrate the projector camera pairs geometrically establishing the projector-camera correspondences to generate projector views as proposed by Lee et.al. We did not choose a coaxial setup to ensure better brightness levels and contrast. Next, we measure the projector response in CIELUV space by projecting white light onto the three dimensional object using HDR imaging [Debevec et.al]. Since our projection screen is a 3D object, we do not assume the projector brightness to be constant all over the surface rather each pixel corresponds to a projector response curve with each sample being 15 intensity levels apart giving us the luminance ranges for our projectors. One such response curve for a small area of the 3D

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SIGGRAPH '16 Posters, July 24-28, 2016, Anaheim, CA,
ACM 978-1-4503-4371-8/16/07.
http://dx.doi.org/10.1145/2945078.2945154

object is shown in figure 2 for our LG PF1500 projectors. Now, we fit the measured target appearance (figure 1(c)) to the measured projector response for each pixel. For the intensity levels not sampled, we chose to interpolate within the projector response curve.

1.2 Framework

To this end we have consistent colors with the original object but we need to blend the projector outputs together. For a seamless appearance, we sparsely sample (see figure 1(d)) the projection surface using the third camera and solve for the light transport to achieve blending of the output from the two projectors. By constructing a light transport matrix that defines light transport from multiple projectors to a single camera, we were able to design a constrained mathematical system that optimizes projector images whose pixel values are well within the projector's measured output range. The light transport matrix consists of camera pixels along rows and projector pixels along the columns. By using the projector-camera correspondences, the intensity values are inserted into appropriate row and columns. The system is subject to luminance constraints that come from the measured per pixel projector response. These constraints ensure that none of the final output to the projectors contains values that are outside its measured response. Furthermore it ensures that we do not run into clipping problems and that the projector outputs result in an artifact free appearance over the 3D object.

The light transport matrix contains the contributions from both projectors and hence the solution to the constrained system provides seamless blending. Solving the large light transport matrix remains a challenge so we subdivide the system into smaller counterparts with similar corresponding constraints as suggested by Aliaga et.al. Since this kind of solution approach can cause artifacts, we use the intensity profiles of the projection surface samples and calculate a weight for each sub-solution patch and optimize each projector pixel by a weighted sum of the corresponding surface intensity profiles. Finally we re-construct projector views for each projector using the solutions to the smaller sub-systems and then convert back to sRGB color space while using white point values for D50 lighting in the perceptually uniform CIELUV space.

This provides seamless blending of the projected images over the three dimensional projection surface. Traditional methods rely on defining a luminance range starting from the brightest black and ending at the dimmest white from a set of projectors and then blending the projector images over the area of overlap using image based methods. This causes unnecessary contrast compression and worse black levels. Since our method does not rely upon blending using intensity masks, we were able to achieve better black levels and less contrast compression. The constrained optimization based approach ensures that each projector is fed with an input that remains within its output capabilities by using its measured response. The results show that the reproduced colors are consistent with the original object which we intend to mimic.

The photometric and geometric calibration process takes around 5 minutes of computation time. Luminance fitting for a single projector took 21 seconds while solving the light transport matrix consumes about 75 minutes using matlab. Light transport needs to be solved once and then can be used for different textures as long as the projector-camera correspondences are valid. If relative positions of projector-camera pairs and 3D object are changed, the pixel correspondences along with the solution to the light transport matrix needs to be recalculated.

2 Conclusion & Future Work

In this paper we presented a framework that optimizes a multi projector-camera system to reproduce appearance of a real object by projection on a same shaped object realistically. Our framework does not suffer from worse black levels and contrast compression as seen in existing multi projector systems. The results show promising outcomes and the only bottleneck to color reproduction is the limited gamut of the projector itself. However in the future we are looking forward to optimize the algorithm for real-time performance and extension to adapt to dynamic projection mapping as well as view dependent effects such as specular highlights for a more immersive user experience.

Acknowledgement

This work has been made possible to completion by the support and financial grant by Ministry of Culture, Sports and Tourism (MCST) and Korea Creative Content Agency (KOCCA) in the Culture Technology (CT) Research Development Program. Grant number R2014100088.

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