Geometric alignment of a multiprimary display built by stacking six DLP projectors

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ABSTRACT

In this paper, we describe the construction of a six-primary display using consumer DLP projectors and the virtual alignment of projector fields-of-view performed in software. Projecting a series of structured-light patterns viewed by a connected digital camera performs the process of projector alignment, while commercially available interference filters are placed in the optical path of light as it leaves the projection lens. Compared to existing multiprimary display systems which rely upon the physical, optical alignment of projector views, the described system represents a significant cost savings that could, if mass produced, reduce the cost of six-primary display to just twice that of traditional RGB projectors.

1. INTRODUCTION

Increasing the number of primaries beyond red, green and blue in display systems has been proposed by several authors. Most commonly, in single-chip DLP projectors, which employ sequential projection of the primaries by using a rotating filter wheel in the optical path, a white channel is typically added by introducing a transparent segment in the filter wheel to increase the projector's brightness.[1] Furthermore by adding secondary colours like yellow, magenta and cyan, a significant increase in the colour gamut of the display can be achieved.[2,3] Recently, it has also been proposed to increase the number of display channels in order to reduce observer metamerism and, thus, obtain a more consistent colour reproduction between different observers.[4]

Several approaches exist to implement a multiprimary display. One way is to introduce more than 3 or 4 segments in the filter wheel, but this approach decreases the output luminance and contrast ratio, as well as requires significant intervention in the projector's mechanical and electronic hardware. Another way to increase the number of primaries is to superpose two or more projectors with different primaries by replacing the filters in the filter wheel with custom designed ones. This still requires an intervention in the projectors mechanical hardware but would avoid modifying the electronics and firmware. External filters could also be used to make the primaries of different projectors different such as has been proposed to create a 6-channel multispectral camera using an RGB sensor with an absorption filter.[5]

For any approach involving stacking several projectors, a crucial problem is the physical registration (alignment) of the color channels, since the colour primaries are derived from multiple sources. Here, we propose an approach for aligning the images from multiple DLP projectors, associated with immersive display environments,[6,8] where a digital camera is used along with a series of structured-light images or test patterns to determine the projector to screen mappings such that images can be re-interpolated to the projector's screen position (Fig. 1).

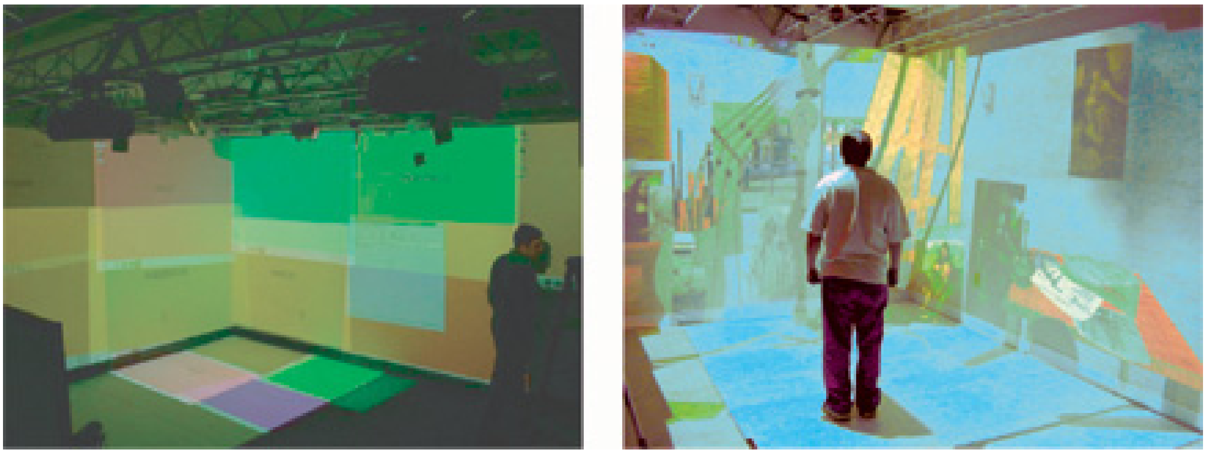

Figure 1: The immersive display environment at the University of Kentucky[6] before (left) and after (right) projector alignment.

2. MULTIPRIMARY DISPLAY ALIGNMENT

Our prototype, multiprimary display system is shown in Fig. 2, where for this particular system, we mounted six Optosigma interference filters to the projection lens of six different ViewSonic PJ250 DLP projectors. In the future, we will have custom filters made that match in size and shape the existing RGB filters, which they will replace. But this is a very expensive process (approximately \$6k/filter) given the low volume of filters, and hence our existing system is simply a proof-of-concept system allowing us to demonstrate the accuracy to which multiple projectors can be virtually aligned.

In order to align the multiple projectors, we use algorithms commonly associated with immersive display environments where multiple, commodity projectors are tiled side-by-side to create large, full-room displays working on the principal of warping images inside the processing unit prior to being projected, based upon projector to camera coordinate mappings, such that the cameras see a true proportioned image. And in order to determine the projector to camera mappings used for image registration, we use a successive pattern projection and capture technique, developed by Ganesh *et al,*[7] to reach a set of parametric transform equations between a camera coordinate $\{x_c, y_c\}$ and a projector coordinate $\{x_p, y_p\}$. We assume that the camera and projector field of view/projection intersect to include a center region at least half as large as the full view.

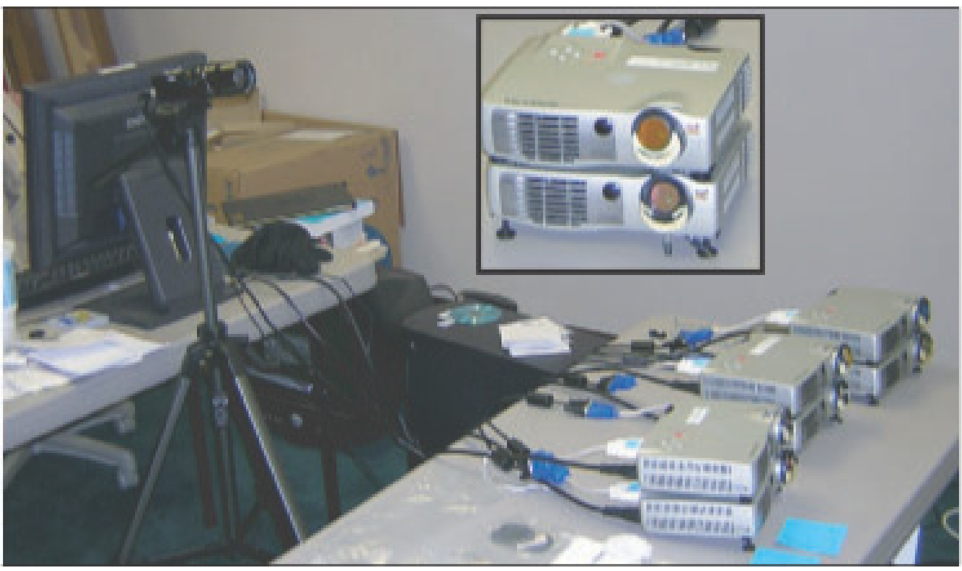

Figure 2: The experimental six-projector, multiprimary display system.

The first step is to obtain a zero order model by projecting a single point in the center of the projection field such that the projector pixels are mapped to camera coordinates according to a fixed horizontal and vertical offset, Fig. 3. From this first model, a second spot is added in the center of the top-right quadrant of the projected image such that a second order mapping is derived where projector pixel coordinates are offset and then scaled by fixed amounts.

From the 2-dot pattern, we introduce a 3-by-3, then a 5-by-5, and then a 9-by-9 spot pattern where the model is updated to account for errors in the current projection by increasing the order of the polynomials until we reach a 9-parameter model with the derived mapping being the one that minimizes the mean-squared error between the predicted and the actual observed camera coordinates of the projected spots. Without introducing additional parameters, this final mapping is updated two additional times using a 15-by-15 and 31-by-31 spot pattern.

So in summary, we only need to capture a total of seven images to get a coordinate transformation that will compensate for radial, rotation, scale, perspective, and offset distortions, which we then repeat for subsequent projectors. Shown in the left part of Fig. 4 is the resulting image produced in our camera after aligning the red and green channels from two different projectors placed side-by-side. The difference in intensity that is visible in Fig. 4 is easy to correct and will be done so in future iterations of our system. In the right part of Fig. 4 we show a projected image which illustrates the color gamut we achieved using our six-projector setup.

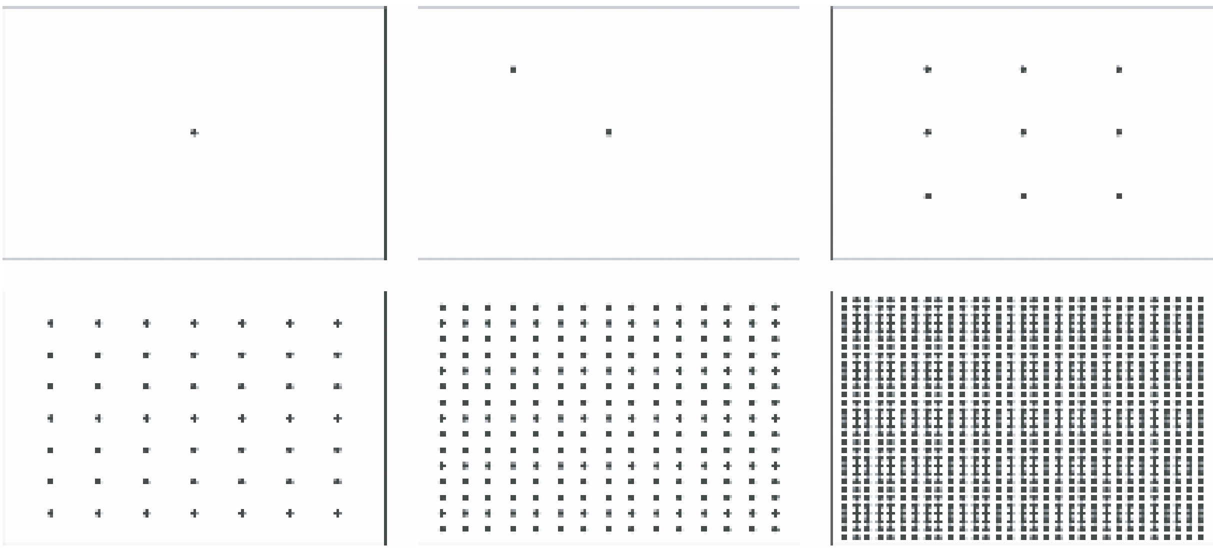

Figure 3: The six patterns, shown negated, used by our algorithm to align two projectors.

3. CONCLUSIONS AND FURTHER WORK

We have proposed an algorithm for the virtual alignment of projectors in a multiprimary display system using consumer DLP projectors and a set of commercially available interference filters. The algorithm is based on the projection of a series of structured-light patterns viewed by a connected digital camera. We have demonstrated that we achieve good alignment using our methodology.

Compared to existing multiprimary display systems which rely upon the physical, optical alignment of projector views, the described system represents a significant cost savings that could, if mass produced, significantly reduce the cost of multiprimary projection display systems.

In future iterations, we will attempt to install the filters inside each projector by replacing the existing RGB filters of the projectors' wheels, but our existing system clearly demonstrates the feasibility of employing multiple projectors for multiprimary displays with image registration performed in software instead of physical optical alignment techniques. Furthermore with the general processing functionality of today's consumer graphics cards, all of the image re-interpolation could be performed by the video-card without burdening the CPU of the host computer.

Figure 4: Left: the aligned patterns deriving from the red and green colors from two different projectors. Right: The color gamut obtained using our six interference filters. The shown images are photographs of actual projected patterns.

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