Shadow Dance: An Interactive Installation Using Shadows as Imaging Device

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Abstract

Cast shadows and projectional imaging systems are commonly used in computational photography and artworks. My project, "Shadow Dance", creates an art installation that highlights the dual nature of projectors as a source of illumination and an imaging system. Building on Rafael Lozano-Hemmer's "People on People", the installation reveals images inside the cast shadows of the viewers as they interact with the projected imagery. The physical installation involves three projectors oriented at different angles. The videos fed to the projectors are preprocessed with planar homography and image decomposition, so the projections align with each other and must be linearly combined to reveal the legible frames. The viewers are encouraged to spontaneously interact with the installation. This project demonstrates the potential of applying computational photography in art and generating artistic effects that challenge visual conventions and reveal scientific facts beyond general optics.

1. Introduction

Rafael Lozano-Hemmer's "People on People" is an interactive video installation that exploits the nature of light and projectional imaging [3]. The piece captures images of the public with cameras that track faces and movements. One set of floor-mounted projectors cast shadows of the public onto a wall, and another set of hanging projectors project images inside the shadows. As people walk around the room, they see inside their shadows the live and recorded images of themselves and each other. This installation reverses the common belief that light is equal to information and imagery while shadows block and interrupt its transmission. In addition, it sheds light on the duality embedded in the projector as simultaneously a source of illumination and an imaging device. It does so by engaging the viewers in an interactive experience and involving them in the imaging system. This artwork lends itself well to the foundation of an experimental computational photography project, where algorithmic and hardware tools are developed to enhance imaging and eventually shape the viewers' visual and intellectual experience of interacting with them.

In my project, I intend to recreate the key effect of imaging through shadows in Lozano-Hemmer's installation while emphasizing the computational photography components. In Lozano-Hemmer's project, the two sets of projects are used solely for imaging or illumination that casts shadows. Through computational photography, each projector can simultaneously serve both purposes. Specifically, images or video frames are decomposed into components that are illegible when displayed alone or all together; legal images are only revealed as, in a certain pattern, certain projections get blocked and the rest are combined. It is hoped that this installation demonstrates the exciting possibilities of applying computational photography in art and interactively reveals its capacity to show what lies beyond general optics.

2. Related Work

Both projectors and shadows are commonly used as imaging devices in computational photography. For example, in dual photography [2] and reconstruction using structured light [1]. While this project is an art installation, the questions and challenges it responds to are closely relevant to computational photography. Some of the challenges include:

- How to align imagery projected from different orientations?
- How to create a range of legibility by decomposing the images, such that only the aggregation of two projections shows meaningful imagery?
- How to engage the viewers in an interactive and inspirational experience that reveals the nature of projectional imaging systems and optics, through the use of cast shadows in real-time?

The rest of this report describes how this installation responds to these questions with computational photography and art.

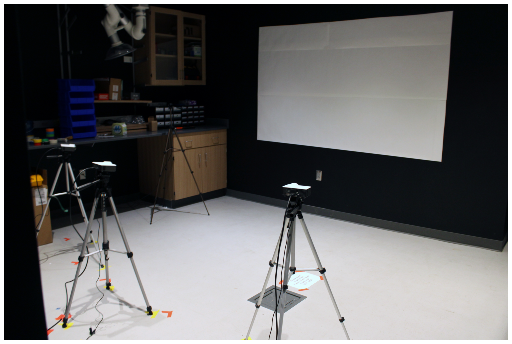

Figure 1. Physical Installation

3. Physical Installation

The project is installed in a dark room with a flat, diffuse white wall. The three projectors are installed on tripods across from the wall and spaced apart from each other so that the projected images overlap reasonably. All three projectors are connected via HDMI cable to a laptop as external displays. The space between the projectors and the wall is wide enough such that viewers can comfortably walk before and block each individual projector while being able to see the projected images and cast shadows easily. See Figure 1 for a reference of the spatial setup.

4. Algorithmic Implementation

4.1. Projection Alignment

A major challenge presented by the physical setup is aligning the projections from three orientations that are non-orthogonal to the wall. For the linear combination of the frames to work, all three projections need to be warped according to their spatial orientation such that their positions match each other. Performing camera calibration or computing the planar homography between the camera and image coordinates can warp the images, and the latter is selected for its relative simplicity. To detect and match features between different projections, an image of a chessboard is projected by each of the three projectors. A camera is set up behind the projectors to capture the projected pattern. The corresponding feature points were detected by `findChessboardCorners` provided by OpenCV. RANSAC was used to improve the accuracy of the computed homography.

The relationship between the chessboard position in the original image, $\mathbf{x}_0$, and the projected chessboard captured by the camera, $\mathbf{x}_i$, is

$$\mathbf{x}_i = \mathbf{H}_i \mathbf{x}_0 \tag{1}$$

Let the desired position of the projected image in camera coordinates be $\mathbf{x}$, the computed homography matrices be

Figure 2. The original image $\mathbf{x}_0$ and a photo of its projection $\mathbf{x}_3$ from $\mathbf{P}_3$

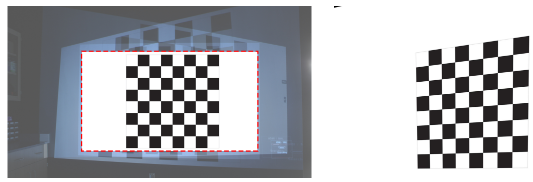

Figure 3. The desired position $\mathbf{x}$ and the warped image $\mathbf{x}_3^{'}$ using the computed $\mathbf{H}_3$

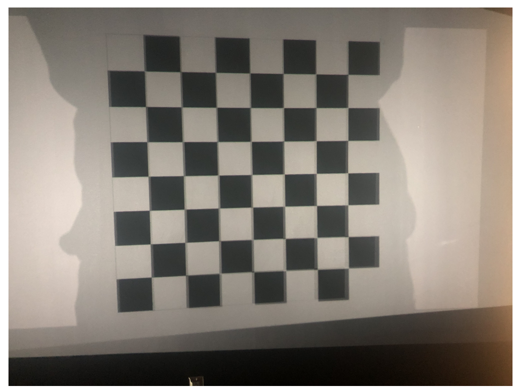

Figure 4. The alignment result

$\mathbf{H}_1$, $\mathbf{H}_2$, and $\mathbf{H}_3$, then the images fed to the projectors,$\mathbf{x}_i^{'}$ in image coordinates, can be computed by

$$\mathbf{x}_i^{'} = \mathbf{H}_i^{-1} \mathbf{x} \tag{2}$$

Note that $\mathbf{x}$ needs to lie in the overlapping region of the three projections.

See Figure 2 for the original chessboard image and one of the three projections in camera coordinates. In Figure 3, the inverse of the computed homography matrix of this pair is used to warp the image fed to the same projector to get the undistorted image at the desired location (inside the overlapping region of the three projections). After performing homography, all three projections overlap as can be seen in Figure 4.

4.2. Frame Decomposition

The premise of only revealing legible images through shadows requires exaggerated visual distinctions between legible and illegible image pairs. Specifically, among the

Figure 5. Frames $\mathbf{V}_1$ and $\mathbf{V}_2$ to be decomposed

Figure 6. Frames $\mathbf{P}_1$, $\mathbf{P}_2$ and $\mathbf{P}_3$ after decomposition

three projections, the linear combination of any two projected images should be a legible image, while the combination of three or only one should be illegible. Since the combination of projected images are additive and negative light is unavailable in this setup, methods for decomposing the images are limited.

This installation ends up using two original videos of the same dimensions, frame rate, and length. Let $\mathbf{V}_1$ and $\mathbf{V}_2$ be the per pixel intensity of the legible frames to be displayed (see Figure5), and $\mathbf{P}_1, \mathbf{P}_2$, and $\mathbf{P}_3$ be the per pixel intensity of the three projections (see Figure6). It was defined that

$$\mathbf{P}_1 = a * min(\mathbf{V}_1, \mathbf{V}_2) \tag{3}$$

$$\mathbf{P}_2 = \mathbf{V}_1 - \mathbf{P}_1 \tag{4}$$

$$\mathbf{P}_3 = \mathbf{V}_2 - \mathbf{P}_1 \tag{5}$$

where a is a value between 0 and 1. In practice, a local minimum filter of `size=10` was applied to $\mathbf{P}_1$ to make the decomposed images smoother before deriving $\mathbf{P}_2$ and $\mathbf{P}_3$. After performing decomposition, blocking $\mathbf{P}_2$ reveals $\mathbf{V}_2$ while blocking $\mathbf{P}_3$ reveals $\mathbf{V}_1$.

5. Video Editing and Syncing

To encourage the viewers to spontaneously participate and interact with the imagery, I edited the two videos to be compilations of dancing scenes from different films. A complete list of featured films can be found at the end of this report. After rendering the two video compilations, they are decomposed and warped to generate the videos fed to all three projectors. A script maps the videos to the three external displays, scales them, and plays them in sync. As the viewers cast shadows on the screen, they could visualize themselves as actively becoming part of the projected imagery of dancing figures. I also played lively dance music in the space to accompany the imagery and encourage spontaneous interaction with the installation.

6. Results and Analysis

Viewers were invited to experience the installation in the lab and are documented in a video. Some photos can be seen in Figure 7. Without explicit instructions, they spontaneously explored different ways of interacting with the imagery, by casting shadows from different depths in front of the projectors, in different postures, and overlapping their shadows with each other's in different forms.

One feedback from the participants was that certain clip pairs work better than others. The pairs that worked better tend to have similar radiometric properties, such as exposure, brightness, and contrast, since they allow the intensity-based decomposition algorithm to produce the best result. In future iterations, this can be improved with radiometric calibration and/or content-aware decomposition.

Another feedback was related to the fact that only two images got decomposed in the process. It was confusing to some viewers when $\mathbf{P}_1$ got blocked and did "nothing": since $\mathbf{P}_1$ is the common minimum of the $\mathbf{V}_1$ and $\mathbf{V}_2$, blocking it still gives two unrelated overlapping images. This can be resolved in future iterations with an optimized decomposition algorithm, or by rearranging the spatial setup so the projector $\mathbf{P}_1$ gets somehow hidden from the viewers.

7. Conclusion

In this project, I created an interactive installation that uses shadow as an imaging device and allows viewers to spontaneously participate in real-time imaging. It is a recreation of "People on People" where the projector's dual function as a source of illumination and an imaging device gets emphasized and explicitly presented. The project demonstrates the potential of applying computational photography in interactive and projectional art projects. Through interacting with the installation, the viewers are invited to contemplate on the conventional mechanism of projectional imaging and optical phenomena involving shadows. In the

Figure 7. Result photos from the installation

future, I aim to optimize the homography and decomposition algorithms to make them content-aware in order to further calibrate and enhance the visual effects. I also look forward to incorporating real-time video feed, not to emulate the precedent, but to facilitate more direct identification with the projected image and encourage more spontaneous engagement and interaction.

Acknowledgements

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List of films used in the videos

Bande A Part. Directed by Jean-Luc Godard, Columbia Pictures, 1964.

Happy Together. Directed by Wong Kar-wai, Golden Harvest Company, 1997.

In the Mood for Love. Directed by Wong Kar-wai, Block 2 Pictures, 2000.

La La Land. Directed by Damien Chazelle, Lionsgate, 2016.

Mulholland Drive. Directed by David Lynch, Universal Pictures, 2001.

Paprika. Directed by Satoshi Kon, Sony Pictures, 2006.

Pulp Fiction. Directed by Quentin Tarantino, Miramax Films, 1994.

The Three Caballeros. Directed by Norman Ferguson, Walt Disney Productions, 1944.

References

[1] J.-Y. Bouguet and P. Perona. 3d photography using shadows in dual-space geometry. *International Journal of Computer Vision*, 35(2):129–149, 1999. 1

[2] Pradeep Sen *et al*. Dual photography. SIGGRAPH 2005. 1

[3] Rafael Lozano-Hemmer. People on people, 2010. Manchester Art Gallery, Manchester, United Kindom. 1