

Liquid Light Projection and Interaction

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Abstract

We present an *automated projection and interaction software that creates a multi-projector display on objects of any size and shape in minutes by precision manipulation of light via computer-vision-based algorithms. We call it “liquid light” due to the fluid-like capability it imparts to the illumination, adapting quickly to different surfaces.*

Author Keywords

Multi-Projector Displays; Liquid light displays; 3D reconstruction; structured light reconstruction; interactive projections.

1. Introduction

Projectors, unlike panels, can create displays of any shape and size, since the projection is physically separated from the device. This imparts illumination from projectors with a “fluid-like” capability to flow and reshape or resize itself to cover any object and create on them a display together with other projectors (Figure 1).

However, to create a legible display on an arbitrarily complex shaped surface, the projection needs to be “manipulated at a pixel level” to land with the right content at the right place. This is not possible with projection mapping software in today’s marketplace that use a limited number of cameras (most often only one) and offer semi-automatic projection mapping methods that do not recover the display surface shape or the positions and orientations of the devices (projectors and cameras alike) to provide the level of precise pixel-level manipulation required to create such *liquid light projection*. With such precise information on which pixel of which projector illuminated which point on the 3D surface, refined interaction with the display is possible (e.g. painting on the display using a laser pointer).

Contributions: We present the first scalable software solution that uses multiple cameras to allow precise manipulation of light from multiple projectors at pixel level to map content seamlessly on objects of any shape and size (e.g. tabletop objects to life size statues to room size environments) and interact with it. More importantly, these displays are built completely automatically in minutes by our liquid light projection software using computer-vision-based algorithms that use multiple cameras to recover the 3D shape of the projection surface, and parameters of the cameras and projectors (e.g. focal length, distortion, pose orientation, color variation) accurately and create a *pixel level mapping* between the projectors, cameras and the display surface. This precision mapping identifies all the projector pixels (from one or more projectors) illuminating a particular projection surface point to provide the same content at the point with appropriately modified color to provide a seamless display. This pixel level mapping also allows interaction with the liquid light display created by multiple projectors. Any action (e.g. via a laser pointer or a tablet) can be mapped to the display and projector pixels via the pixel level mapping to provide accurate reaction. Finally, our software can operate in the presence of ambient light without requiring

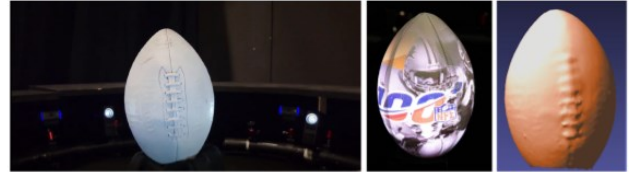


Figure 1: (Left) Our 360-degree multi-projector setup for tabletop objects using 6 mini projectors and 8 Logitech cameras. This shows two projectors and three cameras behind the football (one camera is occluded by the football). (Middle) A completely automated projection mapped football. (Right) The digital twin of the white football is created via structured light technique used for the automated projection mapping.

disrupting other operations around.

To the best of our knowledge, no other software exists in the market place today that can provide such liquid light projections and interaction on objects of any size and shape via precision control of illumination, going beyond by leaps from traditional projection mapping. This allows creation of unique interactive experiences hitherto not possible.

2. Software Overview

Our liquid light projection and interaction software has three different components.

Calibration: The one-time calibration step finds the system parameters, namely the 3D surface shape and the device parameters (like focal length, lens distortion, pose, orientation, spatial color variation) which in turn are used to find the pixel level mapping between the projectors, cameras and the 3D display surface. From this a warp, an attenuation and an offset map is generated for each projector that are used to create a seamless liquid light display. Our calibration is ambient light tolerant, not requiring lights to be switched off.

Rendering: The rendering pipeline renders a 2D or 3D content onto the arbitrarily shaped display surface using the warp, attenuation and offset maps to create a seamless display.

Interaction: Our software allows interaction with the display using a laser pointer or a tablet. For laser pointers, the cameras are used for real time tracking of the interaction that triggers appropriate reaction. For tablet based interaction, the detected action through the touch interface is translated to the display space to trigger an appropriate reaction.

2.1 Calibration

Our calibration starts by projecting a set of patterns from the projectors which are then observed by the cameras. These patterns are processed to provide multiple capabilities, namely removing spillover light to surrounding objects to avoid blinding the audience; ambient light estimation; surface reconstruction;

recovering device parameters (e.g. focal length, lens distortion, lens shift, pose and orientation) of both projectors and cameras; recovering the spatial color variation across the display and morphing them appropriately to create imperceptible color variations that maximize the display dynamic range and color gamut [1,2]; recovering the black offset and deciphering the black offset correction to yield a seamless black across the display.

This calibration process generates the per pixel mapping from the camera to projector coordinates, projector to display coordinates and the camera to display coordinates. This helps us to create a per projector warp that can be used to wall paper any 2D content onto the projection surface. Further, it also helps us to create a per projector per channel attenuation and offset map to provide seamless color and black offset.

2.2 Rendering

The 2D rendering uses (a) the warp maps to split and distort the images correctly to conform to the display shape; and (b) the attenuation and offset maps are used to modify the inter and intra projector color variation and also the higher brightness in the

overlap region of the projectors to result in a seamless stitched display. The 3D rendering uses 2-pass rendering method [3] to provide real-time navigation of a 3D scene using the same warp, attenuation and offset maps.

2.3 Interaction

Using these mappings, we can enable interactions. The detected actions are mapped to appropriate mouse actions to provide reactions.

Laser Pointer Based Interaction: Post calibration the cameras are used to detect the bright point light from the laser pointer to track it as it moves.

Tablet Based Interaction: In the tablet based interaction, the display surface can be mapped to the 2D digital canvas or the reconstructed 3D model. Touch based actions on this canvas or 3D model can trigger an appropriate reaction.

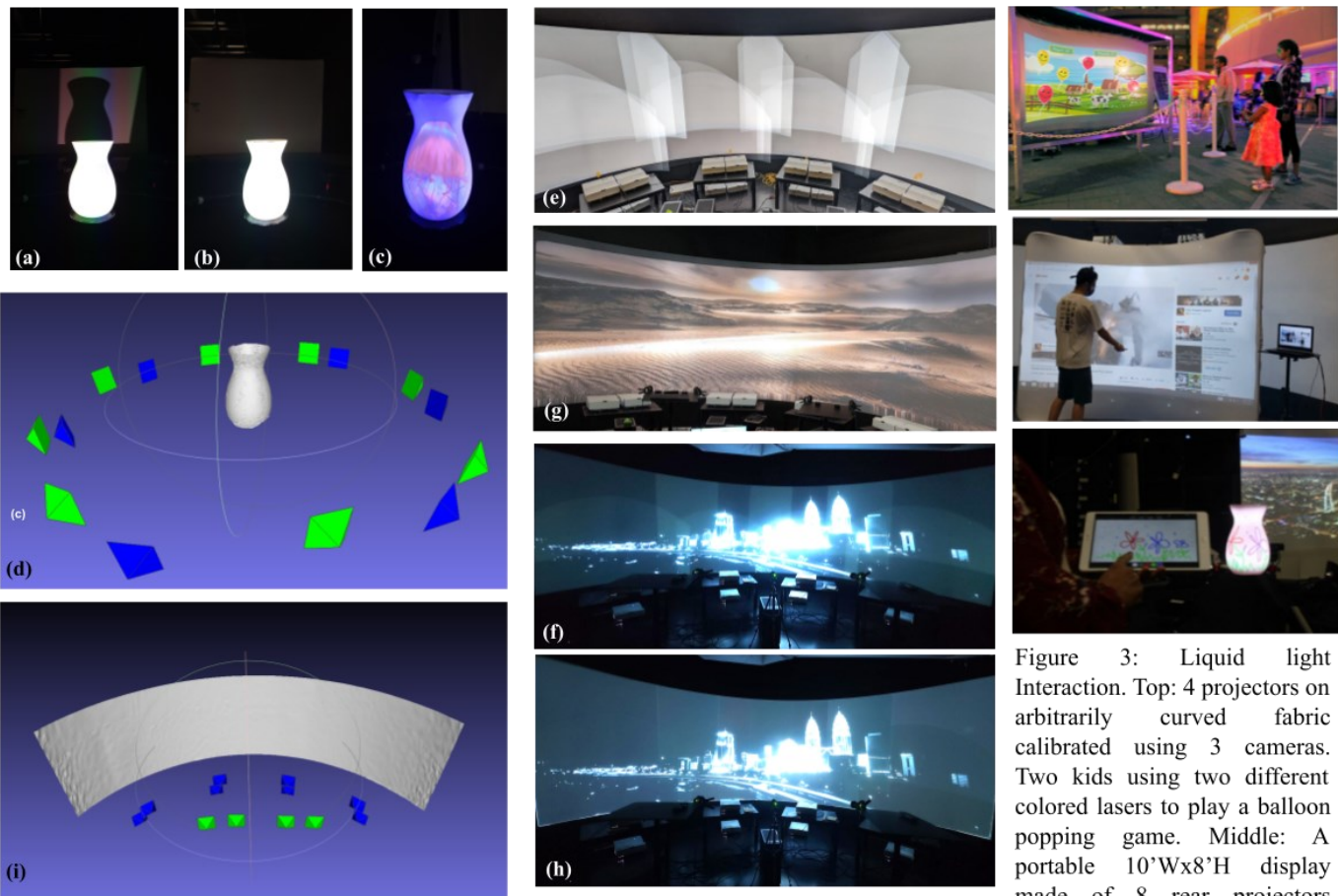


Figure 3: Liquid light Interaction. Top: 4 projectors on arbitrarily curved fabric calibrated using 3 cameras. Two kids using two different colored lasers to play a balloon popping game. Middle: A portable 10'Wx8'H display made of 8 rear projectors creating a seamless display on a backdrop. Interaction with applications are done using the laser pointer as a mouse. Bottom: A tablet based painting interaction on a vase (6 projectors calibrated with 8 cameras)

Figure 2: (a-d) This shows our calibration and rendering on a table top object, a vase illuminated by 6 mini projectors and calibrated by 8 Logitech webcams – (a) all projectors ON showing white with visible spillover; (b) removing spillover light to avoid blinding; (c) Seamless display on vase; (d) 3D reconstruction of the vase with projectors in blue and cameras in green. (e-i) Calibration and rendering on a 8-16 projector display using 4 Blackfly FLIR cameras on a 24'Xx8'H cylinder - (e) all projectors ON showing white with visible spillover; (g) seamless display with spillover removal; (f) dark content *before* offset correction; (h) dark content *after* offset correction; (i) 3D reconstruction of the display surface.

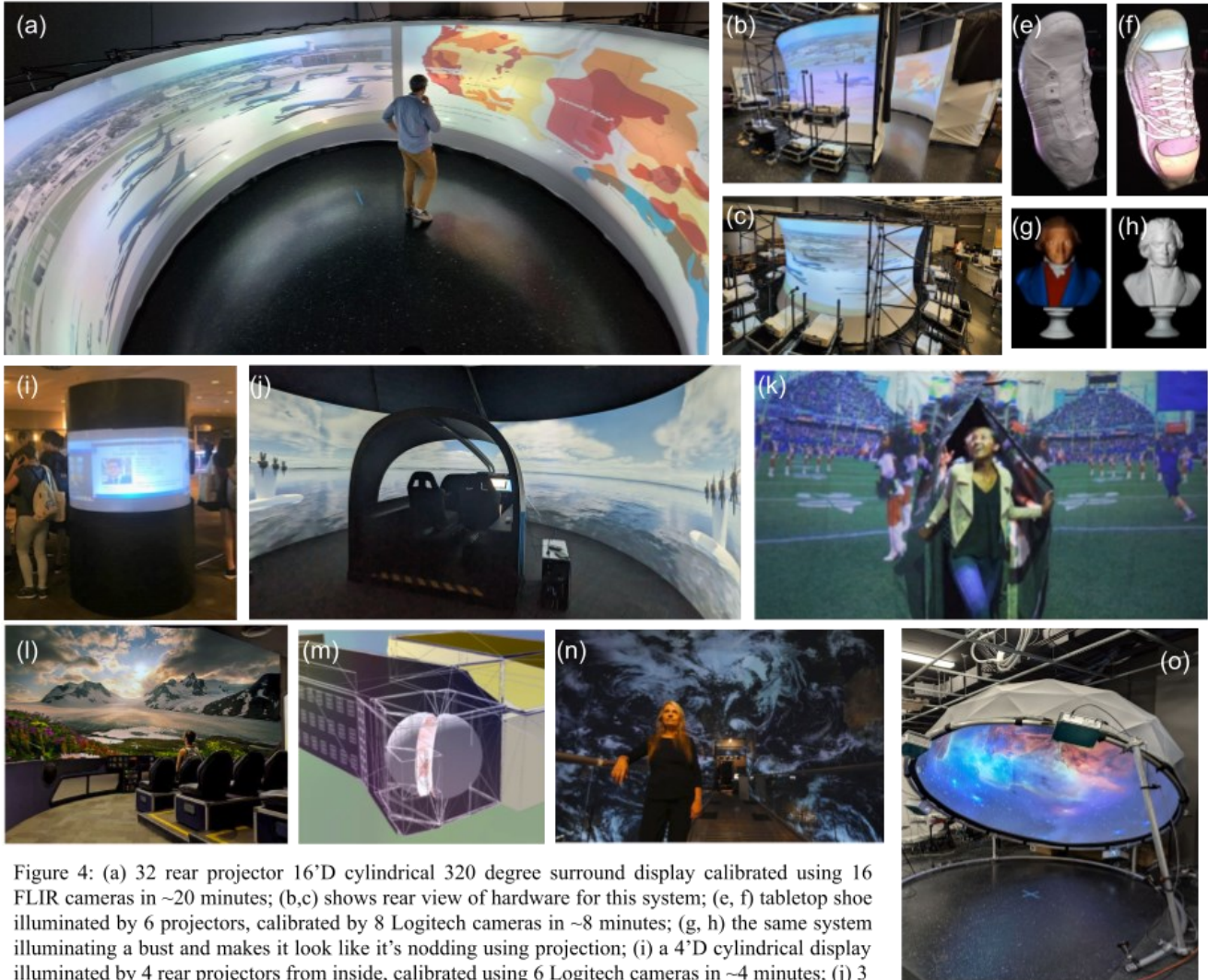


Figure 4: (a) 32 rear projector 16'D cylindrical 320 degree surround display calibrated using 16 FLIR cameras in ~20 minutes; (b,c) shows rear view of hardware for this system; (e, f) tabletop shoe illuminated by 6 projectors, calibrated by 8 Logitech cameras in ~8 minutes; (g, h) the same system illuminating a bust and makes it look like it's nodding using projection; (i) a 4'D cylindrical display illuminated by 4 rear projectors from inside, calibrated using 6 Logitech cameras in ~4 minutes; (j) 3 front projectors 230 degree surround cylindrical simulator calibrated in ~4 minutes using 3 cameras; (k) 13'R inflatable dome shaped surface illuminated by 5 front projectors and calibrated using 4 FLIR cameras in ~7 minutes; (l) a 24'Wx24'H cylindrical 3-front projector system calibrated by 6 Logitech cameras in ~5 minutes; (m,n) a 3-storied double hemispherical structure illuminated by 52 rear projectors and calibrated using 24 cameras; (o) a 4-front projected 10'D dome calibrated in ~10 minutes by 4 FLIR IP cameras.

3. Results

Figure 2 shows the results of our calibration and rendering process. We show the recovered 3D shapes, the camera and projector parameters, the seamless displays created using our calibration and rendering.

Figure 3 shows the results of our interaction paradigm. Laser based interactions are used to create entertaining games or are mapped to mouse input for controlling varied applications. Tablet based interactions create unique interactive experiences.

Figure 4 shows different multi-projector systems, all created using our singular software. Video results can be found at the following link (<https://youtu.be/tAJmz-6KZjc>).

Our completely automated calibration allows installation and recalibration of multi-projector systems in minutes. The time taken scales easily with the number of projectors leading to setup or recalibration in minutes.

4. Impact

Our liquid light software is fully automated (operated via a push of a button), projector agnostic, and provides flexible deployments in minutes (instead of hours or days) creating high quality displays (high resolution and color seamless).

Projector Agnostic: We have used our software for high end professional projectors (e.g. Panasonic, Epson, Digital Projection at price range of \$60,000 - \$150,000) and consumer level projectors (e.g. Optoma regular and mini, BenQ) alike. In terms of cameras, we can use any cameras as long as they provide an SDK for access. We have used consumer level cameras (e.g. Logitech) or better quality professional cameras (e.g. Blackfly FLIRs). The number of cameras to be used depends on their field of view and resolution. Our software needs every point on the display surface to be seen by at least two cameras. Therefore, when narrow field of view cameras are used, more cameras are needed. The number of cameras also depends on how close to the object they are. Therefore, when using

Logitech webcams of narrow field of view close to the table top objects we need 8 cameras for a 6 projector-system, but when using fish-eye FLIR cameras, 3 cameras suffice for 24'Wx8'H cylindrical display.

Flexibility: Our software does not require exact positioning of the projectors or cameras since the software recovers the device parameters and surface shape. The projectors should be placed in a TLAR (that looks about right) manner to have around 10-15% overlap. The cameras should be placed as mentioned above so that every surface point is covered by at least two cameras. Since we recover all system parameters, we don't need any fiducials on the

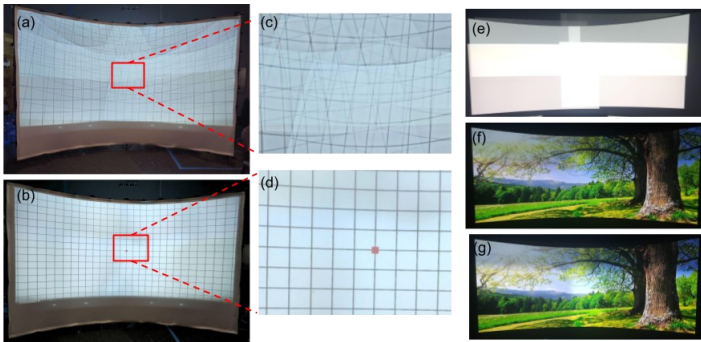


Figure 5: (a -b) This shows a 8 rear projector display on a pringle shaped 10'Wx8'H surface arranged in two stacks of 2x2 projectors - tiled to increase resolution and stacked to increase brightness - before (a) and after (b) calibration using 4 FLIR cameras. The zoomed in view of a overlap of right projectors are shown in (c,d) to demonstrate sub-pixel accuracy of our calibration. (e) shows a display on a 24'Wx8'H cylindrical surface using 2x2 array of 4 professional Epson projectors. (f) shows traditional blending while (g) shows our color seamlessness solution guided by perceptual parameter. The blotches visible in (g) is not perceptible in person since the parameter to tuned to the size of the display and rough distance of the user from it.

projection surface providing extreme flexibility in deployment – even remotely.

Speed: Our software reduces installation speed from hours or days to minutes. Even with existing software that uses camera assistance, multi-projector deployments take hours or even days when installing more complex systems. For example, the inflatable dome of Figure 4(k) used to take around 8-16 hours which was reduced to ~7 minutes using our software. The 32 projector cylindrical display in Figure 4(a) takes around ~20 minutes to calibrate which usually takes multiple man days. Further, this system is made of ultra short throw projectors with high distortions containing up to 8 projector overlaps at places which are avoided by existing software since calibrating them may take multiple man-weeks.

Scalability: Our software is scalable in multiple ways. First, it scales well with respect to the number of projectors which indicates setup within an hour even for a very large number of projectors. Since our software uses multiple cameras and recovers the surface shape, we can use any kind of projection surface including spherical or surround displays. providing scalability in surface shape. Further, our software can support multi-server architecture. The multi-projector systems are driven by clusters of dual-GPU PCs. Each PC can support up to 8 projectors. Our calibration is parallelized for such PC clusters. Finally, we have integrated our system with multiple rendering engines including Unreal, Unity and Cesium making it scalable to many different applications.

Complete Automation: Most existing software requires the geometry of the projection surface to be provided as input. This

needs manual alignment of the surface geometry to achieve calibration. Further, once this manual alignment is achieved, to avoid this time consuming process during recalibration, the devices need to be at the exact location as during setup. These requirements are completely removed since our software recovers the device position and orientation and the surface shape in each run. This complete automation brings in a sea-change in the deployment ease of such systems. Further, a varied number of shapes, not necessarily standard spheres and cylinders, can be accommodated.

Quality: Using multiple cameras provide high resolution input which combined with our sophisticated software allows for sub pixel accuracy in geometric calibration. Our novel color seamlessness method allows higher dynamic range than regular overlap blending as shown in Figure 5.

5. Conclusion and Future Work

In summary, our liquid light projection and interaction software provides hitherto unseen efficiency, flexibility, scalability and quality via complete automation. It can reduce maintenance and sustainment efforts to almost zero. In the future, we plan to explore ways to extend this method for real-time calibration on moving and stretchable objects like elastic fabric or waterfalls.

6. Acknowledgements

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