Auto-Calibration of Multi-Projector Systems on Arbitrary Shapes

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***Abstract*—In this paper we present a new distributed technique to geometrically calibrate multiple casually aligned projectors on a fiducial free arbitrary surface using multiple casually aligned cameras where every point of the surface is seen by at least one camera. Using a multi-step method that uses binary blob patterns, we estimate robustly the display's 3D surface geometry, the cameras' extrinsic parameters, and the intrinsic and extrinsic parameters of the multiple projectors. Thus, our work can enable easy deployment of large scale augmented reality environments playing a fundamental role in increasing their popularity in several applications like geospatial analysis, architectural lighting, cultural heritage restoration, theatrical lighting, training, simulation and visualization.**

I. Introduction

As projectors become portable and inexpensive, they are used to light arbitrarily shaped surfaces in a large number of applications such as gaming, 3D visualization, appearance modification, augmented reality, and so on. Since a single projector often cannot light every part of an arbitrary shape at the desired resolution, it is popular to tile multiple projectors to create a high resolution display on these surfaces. The challenge lies in automatic registration of the images from the multiple projectors on the display surface to create a seamless image. A bigger challenge lies in making this system completely automated so that even lay users can deploy it easily and recalibrate it quickly.

II. Related Work

A large body of work exist on centralized calibration techniques for multiple projector units using a single camera. When considering outside-looking-in systems using smaller objects, some of the early techniques used a single camera [1], [2] without reconstructing the geometry. However, such techniques can only correct the imagery for the viewpoint of the calibration camera and perspective distortions become apparent as the user moves from that viewpoint. Raskar et al. [3] used carefully calibrated projectors and cameras to reconstruct the geometry and light the model assuming the underlying surface is white. Zollmann et al. [4] address small scale surfaces lighted by single-projector camera systems. This work tries to achieve correct imagery with small movements of a moving observer (on whose head the camera rests) without recovering the surface geometry. Aliaga and Xu [5] present a geometric calibration technique for objects with arbitrary shape using projected light from fully superimposed projectors. This method uses a combination of photometric and geometric stereo to avoid the use of calibrated stereo cameras.

Inside-looking-out reliefs or architectures are more suitable candidates in geospatial analysis, architectural relighting, or augmented office environments. Such setups are harder to calibrate since the projectors are usually tiled (not superimposed) providing fewer constraints for geometric calibration. In a recent effort on relighting outside-looking-in environments using centralized techniques, Tateosian et al. [6] proposed a system that uses a laser scanner to recover the geometry of a white relief map and then relight it with a single projector for geospatial modeling. The use of a laser scanner limits the size of the artifact that is being relighted and also increases the cost of the system. On the other hand, we use the projectors and cameras themselves to register the geometry; consequently, we can register surfaces of varying size without using expensive laser scanners. Further, the use of multiple projectors allows us to tremendously increase the resolution and amount of available light. Inside-looking-out systems have also been explored extensively using centralized techniques in the large display domain. While [7], [8], [9], [10], [11], [12], [13], [14], [15] address only planar displays, Sajadi et al. developed a set of auto-calibration techniques using a single uncalibrated camera for special classes of constrained non-planar surfaces like vertically extruded surfaces [16], [17], [18], [19], swept surfaces [20], and domes [21] that rely on certain features of the boundaries of these surfaces. Even though these techniques do not require calibrated devices and are primarily designed for inside-looking-out environments they are still centralized and need the surface to be completely visible from a single camera used for the calibration.

Sajadi et al. [22] presents a method to light arbitrary shape relief maps with multiple projectors. But, since they only use cameras for estimating the 3D geometry of the display surface, every part of the display surface have to be seen by at least two cameras.

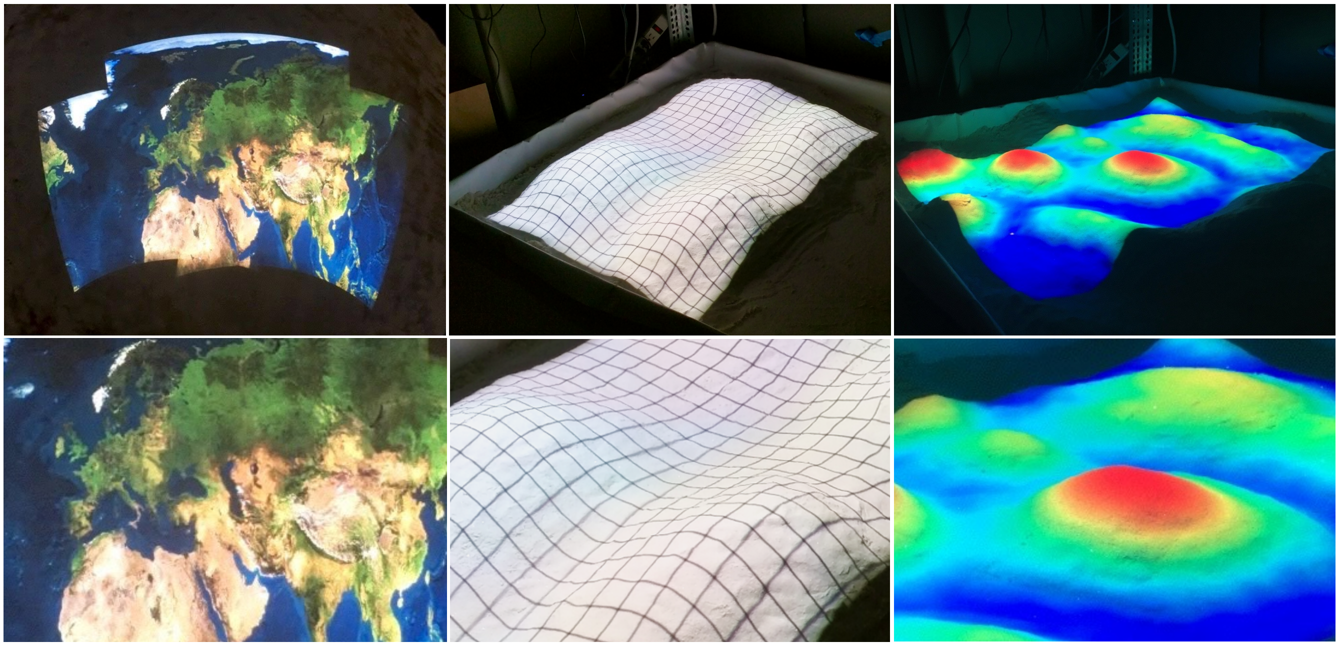

Fig. 1: *The top row of this figure shows our result on the dome with 3 projectors and 3 cameras (Left) and our results on the sandpit with different geometries of the surface (Middle and Right) with 4 projectors and 4 cameras. Also bottom row shows the zoomed in image of overlapping areas of projectors .*

III. Algorithm

We consider a very general system architecture where m projectors, run by p computers, are tiled on an arbitrary surface S. Our method can find the complete calibration of the cameras and the projectors including both the intrinsic and extrinsic parameters.

First we use the overlap of projectors to calibrate each camera with respect to its adjacent cameras and to recover the local geometry in its FOV. Next, they communicate with each other to discover the common coordinate system and recover the surface geometry of the entire relief. Following this geometric calibration and surface reconstruction, we can then register images on the model in a seamless manner.

Our method has 4 steps. In the following we explain the goal of each step.

1) Step 1: First step is identifying the connectivity between projectors and cameras. We achieve this by projecting white color by each projector and capturing the display surface by all the cameras.
2) Step 2: The second step is partially recovering the geometry of the display surface. For this purpose we find the geometry of the display surface in the overlap of FOV of cameras using structure-from-motion (SfM) techniques.
3) Step 3: In this step we calibrate all the projectors in order to find their intrinsic parameters. Using the reconstructed geometry of the overlap regions, we can find the geometric parameters of all the projectors
4) Step 4: The final step of our method is recovering the whole geometry of the display surface. At this step we can use all projectors and cameras to find the 3D geometry of the display surface.

Finally, we use this information to geometrically register images on the surface. This registration can be achieved for the arbitrary viewpoint of a moving user, which is common in single-user application. Further, we can achieve a view-independent registration suitable for multiuser applications.

IV. Results

Our method can be used for registering multiple projectors in virtual reality system with non-planar display surfaces like domes or cylinders. We tested our method with different configuration of projectors and cameras. First we used our method with 3 projectors and 3 cameras on a dome (Figure 1). We also used a sandpit in order to be able to create any shape of the surface geometry. Figure 1 shows our result using 4 projectors on a sandpit with different geometries of the surface.

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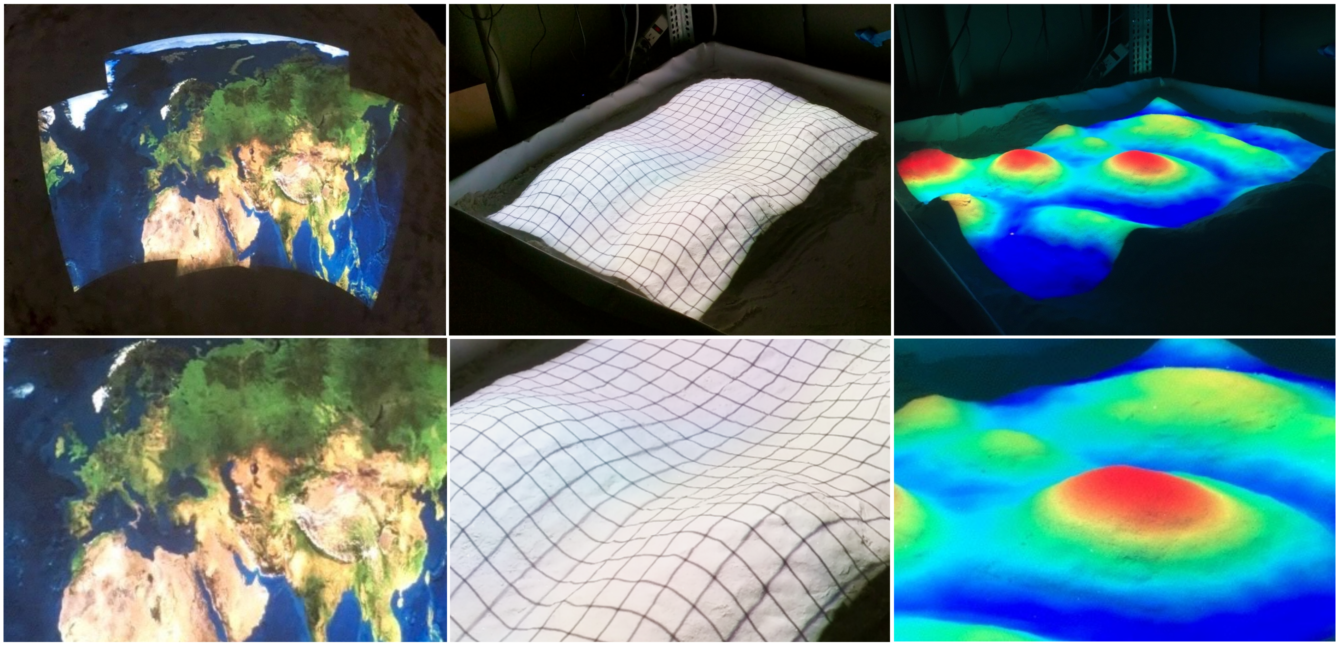

Fig. 2: *The top row of this figure shows our result on the dome with 3 projectors and 3 cameras (Left) and our results on the sandpit with different geometries of the surface (Middle and Right) with 4 projectors and 4 cameras. Also bottom row shows the zoomed in image of overlapping areas of projectors .*

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