Mobile in-situ visualization

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1. Narrative

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 when any of the projectors move.

In this work we present a new distributed technique to geometrically calibrate multiple 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. The method uses a completely distributed approach in a loosely coupled, casually aligned general system, relying on cross-correlation and cross-validation of the device parameters and the surface geometry yielding an accurate estimation of all the device parameters and the display shape. Auto-calibration of the projectors allows us to quickly recalibrate the system in the face of projector movements, by recalibrating only the moved projector and not the entire system. To the best of our knowledge, this is the first work that can achieve accurate geometric calibration of multiple projectors on an arbitrary surface without the constraint of every point of the surface being observed by at least two or more cameras. 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.

Results

We implemented and tested our method in different real systems with different display sizes, shapes and different number of projectors and cameras in order to show the accuracy, robustness and scalability of our method.

The first system is a sand pit of size 4'x3' using 4 or 6 projectors and 4 cameras. Figure 1 shows the result of our method. The projected grid shows the accuracy of registration in the overlap area of projectors. And the projected elevation map on the sand pit shows the accuracy of the surface geometry reconstruction using our method.

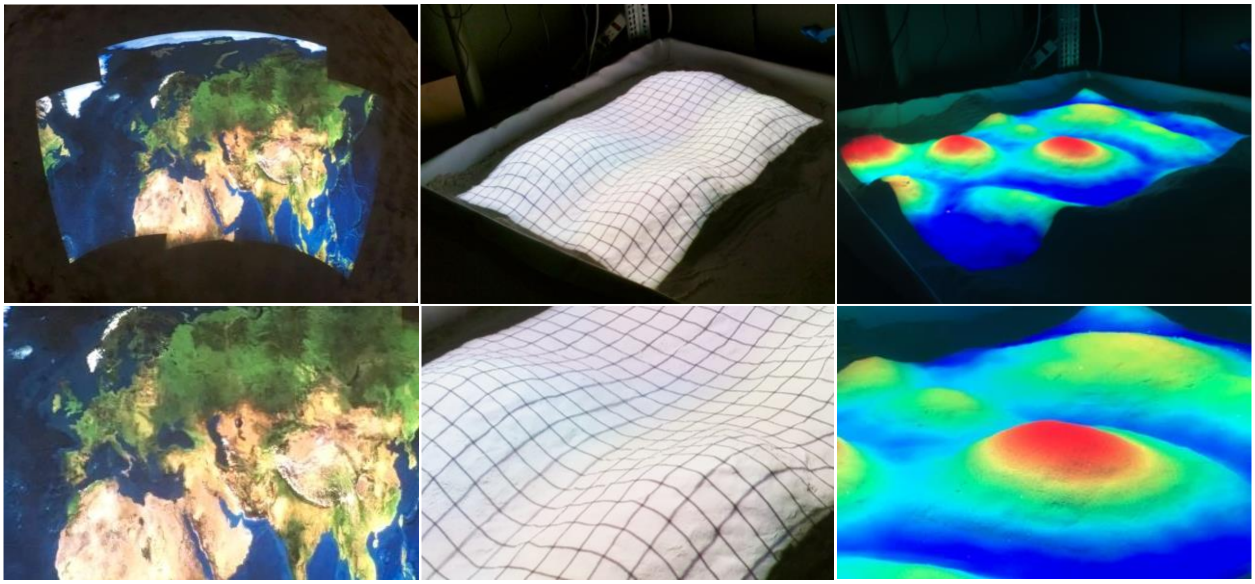


Figure 1 Left: Result of our system using 3 projectors and 3 cameras on a hemisphere. Middle: Showing our result projecting on a sand pit with 4 projectors and 4 cameras. The projected gird shows the accuracy of registration in the overlap area of the projectors. Right: A seamless elevation map projected on an arbitrary shape of sand pit. Note that warmer colors light higher regions and cooler colors for lower parts demonstrating the accuracy of surface geometry reconstruction.

The second system is a 90 degree partial cylinder lit by an array of 2x5 projectors seen by four cameras. Figure 2 shows the result for this system demonstrating the scalability of our method to a large number of projectors and cameras.

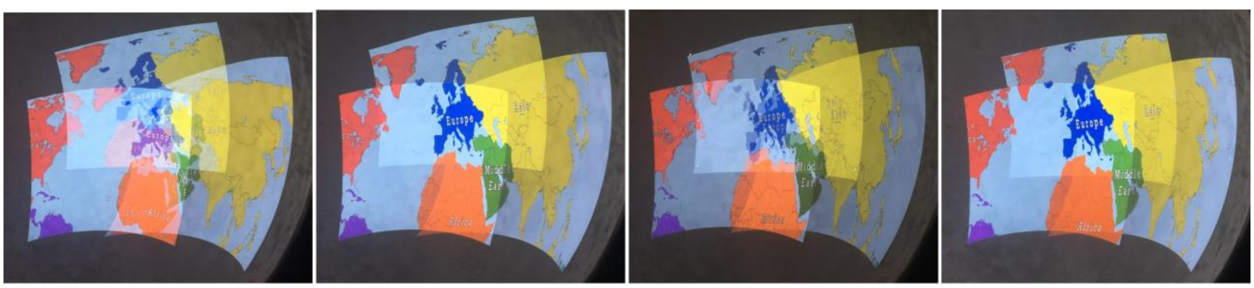
Figure 2 Our result of projecting on a half cylinder using 10 projectors and 4 cameras.

The third system is a table top vase lit by 6 projectors in a tiled configuration and seen by 8 cameras driven by 3 computers. Figure 3 shows the final result of geometric registration on the vase. This setup shows our calibration and registration accuracy by projecting on small objects.

a *b* *c* *d*

Figure 3 This figure shows our result on small objects. (a) Shows our setup with 6 projectors and 8 cameras around the vase (b, c and d) show the result of projector different textures on the vase to change the appearance of the object.

The last system is a hemisphere of 5' diameter lit by 3 projectors in tiled configuration. Finally, since we fully calibrate all the projectors we can recalibrate the system in case of projector movement or changing the geometry of the surface. Figure 4 shows our result for this system and the result of the projector recalibration in case of projector movement.



a *b* *c* *d*

Figure 4 (a) Projected image with 3 projector before correction. (b): Geometrically registered image with theses 3 projectors. (c): Distorted image after moving a projector. (d): Corrected image after projector recalibration.

Significance and impact

The main impacts of this work are as follows:

1. Unlike any prior system our system does not need every surface point to be observed by at least two cameras. Thus significantly simplifying the deployment of the system.
2. Unlike any prior multi-projector displays we fully calibrate the projectors. This enables us to recalibrate the system in case of projector movement. This allows to create dynamic systems were users can interact with the system and move the projectors and register the image in real time.
3. Since we do not assume pre-calibrated devices, our system is very easy to use with non-expert users and they do not need to learn calibration procedures of devices.

4. Using cross validation between devices we can improve the quality of geometric registration and 3D reconstruction of the surface.

Where might this lead?

This in-situ visualization system enables extremely useful applications especially in modeling, simulation and training. For example, we can use a system of multiple projectors to have a dynamic visualization on a relief map in order to demonstrate natural phenomenons such as simulating the course of a river. Since we reconstruct the shape of the model accurately we can simulate complex phenomena like flooding and impact of building a dam via changing the shape of the relief map. Such an in-situ visualization system can be used to create impromptu large displays on a flexible rollable canvas on war-fields, interactive educational visualization systems in museums or schools (e.g. effects of weathering) and hand-held light single projector-camera ensembles which can be used by multiple users to visualize and interact with 3D models (e.g. visualizing human circulatory system on a mannequin).

2. How did the fellowship make a difference?

This fellowship provides enough funding to buy the required equipment for this project. Besides since the link foundation fellowship provides the salary, I was able to focus on the project and spend all of my time working on my research. This helped me a lot to have more progress on my research and PhD.

3. Future Plans

In this work we addressed and solved the projector geometric calibration and registration in multi-projector display systems. But, still the color correction of multi-projector systems has been not addressed in such systems. Different projectors may have different color gamuts which cause a visible color changes across the projected image. My future plan is to work on color correction of such display systems to have a seamless image without such color variation across the display surface.

4. Publications, Presentations, and Other Outputs.

This work have been submitted to the following journal and will be acknowledge Link Foundation support.

- Mahdi Abbaspour Tehrani, M. Gopi, Aditi Majumder, "Automated Projector Calibration and Registration for Arbitrary-Shaped Multi-Projector Systems", Transaction on Visualization and Computer Graphics (TVCG) 2017.