Time-Lapse Panoramas for the Egyptian Heritage

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While laser scanning and Photogrammetry has become commonly-used methods for recording historical sites and archaeological sites in 3D, they still lack photorealism. On the other hand, panoramic images can provide photorealistic record of a site but with no 3D information.
In most historical sites, the time dimension is very important because it dramatically affect how the architecture and sculptures look through daylight changes, a factor that site visitors are unable to experience and is very important for the complete documentation of a site image.
In this paper, we are going to present a pipeline for recording time-lapse panoramas as an affordable method for the complete documentation of site image. This includes: 1) shooting multi-row panoramic images using a motorized head, 2) aligning the images using features detection to create extended exposure images and time-lapse images, 3) rendering aligned images into spherical panoramas, and 4) Displaying the result using an Immersive Virtual Reality system.
The paper will also presents two case studies made in two mosques listed in UNESCO's World Heritage list. In addition, the paper will discuss the advantages and disadvantages of the presented technique with conclusion on how to further develop it to overcome its current limitations.

Keywords: Heritage recording, Spherical panorama, Time-lapse, Features detection.

Introduction

Digital documentation of historical sites is becoming an essential part of the heritage management cycle. Good documentation of a historical site is defiantly a basic step towards its (digital) preservation, (virtual) reconstruction, and virtual visit. Logically, the more complete the documentation is the better result we can get out of it. But what could be considered as complete documentation of a historical site?
Among endless possible attributes that could be documented in a site, if we consider the documentation of the visible attribute of a historical site, the site image, then we must think of two main aspects: the image field of view (FoV) and the image colors. For the FoV aspect, spherical panoramas are a perfect mean to cover the complete FoV of a site image from a fixed position. For the color aspect, it is more complicated. Colors of a historical site image are extremely dependent on the light. In its own turn, lights are affected by two main factors: the time of the shooting and the camera exposure values used in the shooting. The colors of a site are affected by the daylight changes. In (fig. 1), the effect of daylight changes on the appearance of a historical site is very obvious. To completely preserve the variations of the site colors, we should consider recording the site (panoramic) image in different time through the day. Even for a given time, digital cameras are still incapable of recording the full range of light intensity using single exposure settings. As we can see from (fig. 2), images taken using different shutter speeds can capture different parts of the complete range of

light intensity. For the complete documentation of a site image, we should consider fusing different exposures to generate a naturally looking image.

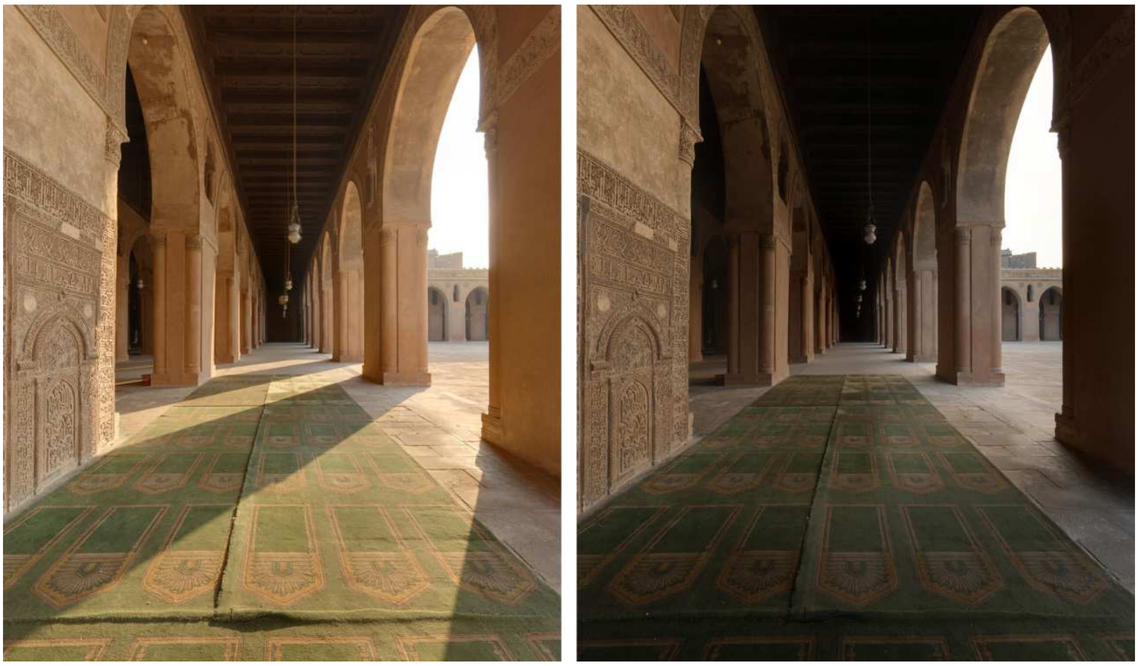

Fig. 1 – Left image was taken at 4:50 PM, right image was taken at 5:50 PM.

Fig. 2 – Left image was taken at 1/50 shutter speed, right image was taken at 1/6 shutter speed.

In the following sections, we will present a pipeline that has been developed at CULTNAT (The Center for Documentation of Cultural and Natural Heritage) in an attempt to achieve complete documentation of historical sites images. The pipeline uses spherical panorama to capture the complete FoV of a site, corrects the image colors for a single time period by fusing different images taken using different exposure, and preserves the color changes over time by recording multiple panoramas from the same position in site over during the whole day. We will start by presenting the pipeline in details, after that we will present results from two World Heritage sites, and finally we will discuss the advantages, disadvantages and future of applying the proposed pipeline for the documentation of historical site.
It is worth mentioning here that another approach that we could have taken is to generate 3D model of the site and simulate the light changes, but obviously this approach is expensive in two ways: the digitization of historical sites details requires very high sampling rate and the artificial light simulation of the digitized model will need high computation power to render a photorealistic image.

The pipeline

The pipeline of creating time-lapse spherical panoramas is divided into two main stages: images acquisition and images processing. Images processing contains 3 main processes: extending the images exposures, creating the time-lapse and finally stitching the images into spherical panoramas.

Shooting the panorama

To shoot spherical panoramas we attach a Nikon D200 DSLR camera to an automatic panoramic head from CLAUSS systems as seen in (fig. 3). The head has two motors, one is for the vertical movement and the second is for the horizontal movement of the camera. Together the two motors can accurately orient the camera in to any specific direction around its center of rotation. The head is remotely controlled by a laptop through a Bluetooth connection. Using the head own software, we were able to program the head to shoot multi-row panoramas in the exact shooting strategy that is needed.
Our shooting strategy was to let the camera scan the environment by rotating around its vertical axis, taking three photos each 36 horizontal degrees at 45, 0, -45 degrees. By adding extra two images for the up and down view, we ended up with 32 images for each single spherical panorama. Using an 18 mm lens, this strategy gave us enough overlap for the next stages of images alignment.
The head is programmed to take additional two images for each angle at over and under exposure values to be fused later into a single correctly exposed image preserving as much colors as we can at each angle in the multi-panorama.
This process of shooting multi-exposures images in a multi-row panoramic shooting order is repeated from the same fixed position in a site multiple times over the day. The number of repetition depends on the speed of light changes during the daylight. In summer we might need to longer time intervals between shooting sessions.
The result of the shooting process is a huge dataset of images taken from the same position in site. If we assumed 5 times intervals for a single day, this will give us 480 images for a single position. In the next

sections we will discuss how these images are accurately aligned together to generate a time-lapse, corrected exposure spherical panorama.

Fig. 3 – The camera attached to the shooting head.

Extending the exposure

As previously mentioned, our aim is to fully document a historical site's image. But unlike the human eyes, digital cameras still have limitations in recording high and low levels of brightness using the same exposure values (shutter speed, aperture, and ISO settings). A typical solution is to blend over an under exposed images of the same viewing angle into a single "extended exposure" image that is more "naturally looking". To accomplish this, we use free software enfuse that is available through the interface of the Hugin free software for panoramic images processing. But exposures fusing is not a straightforward process.
Over and under exposed images taken during the shooting sessions, even taken at the same time and from the same angle, are not always perfectly aligned. This is because of the vibration resulting from the shutter movement or winds during the shooting. To overcome this problem and perfectly align images to sub pixel accuracy, we use features detection and matching techniques. Specifically, we use a special feature detector called (align image stack) that is available through the Hugin software. This features detector works on multiple images taken from the same angle to find out tens of features matching (similar regions in two or more images). These features are then used to accurately reposition the individual images with different exposures to reach sub-pixel alignment.

The result from this process is a 32 extended exposure images covering the complete spherical view that are ready to be stitched into a naturally looking panorama.

Aligning the Time-lapse

Just like multi-exposures images, time-lapse images are not necessarily perfectly aligned because of mechanical inaccuracy in the head motors or the winds. To overcome this problem, extended exposures images will go through an alignment process similar to the one described earlier.

The result from this process is a set of aligned extended exposures images for different time periods along a single day that are ready for stitching.

This process is very important to increase the visual quality of the time-lapse visualization as will be explained later.

Rendering the panoramas

The final step is to render each 32 images into a spherical panorama. This is done by first creating a "master panorama" for any of the time periods, and then uses the master panorama parameters (individual images positions) to automatically render the remaining panoramas, thus making sure all the time-lapse panoramas are perfectly aligned.

.To render the master panorama, the 32 extended exposure images must first be aligned “back” in their correct spatial locations in a virtual sphere that surrounds the camera lens center in a reverse operation to shooting. This could have been simply done by using the same angles that were used in the shooting, but due to panoramic head motors inaccuracy and other external factors like the wind, using angles will not result in a precise alignment of the images to. Alternatively, we use features matching again, but this time for overlapping areas between adjacent images.

After creating a list of features points using the Hugin software, the software will attempt to change images parameters to ensure most of the features in one image are as close as possible to their matches in the corresponding image in a process called optimization. For each image slightly different position will be calculated, while lens parameters are calculated once for all the images since they were shot using the same lens. For a complete spherical panorama, Hugin CP detector automatically extracts and matches more than 2k features. As a final step, the 32 images are blended using the free software enblend, available through the Hugin software.

Results

The pipeline was tested in two sites listed in the UNESCO World Heritage List in Egypt. Ibn-tulun mosque (fig. 4) built in the 9th century and considered to be the largest in Egypt. And Al-azhar mosque built in the 10th century and considered to be the first in Cairo.

Images in (fig. 4) use Equirectangular projection that can display spherical images on flat surfaces, but with a lot of distortion in the image. For the best viewing experience, we used CULTURAMA, an Immersive Virtual Reality system developed by CULTNAT, to view distortion-free panoramic images (fig. 5). Based on real-time graphics, CULTURAM system also enabled the smooth transition between different panoramas taken in different time periods increasing the illusion of traveling through time, an option that is not possible for even the visitors of the real site.

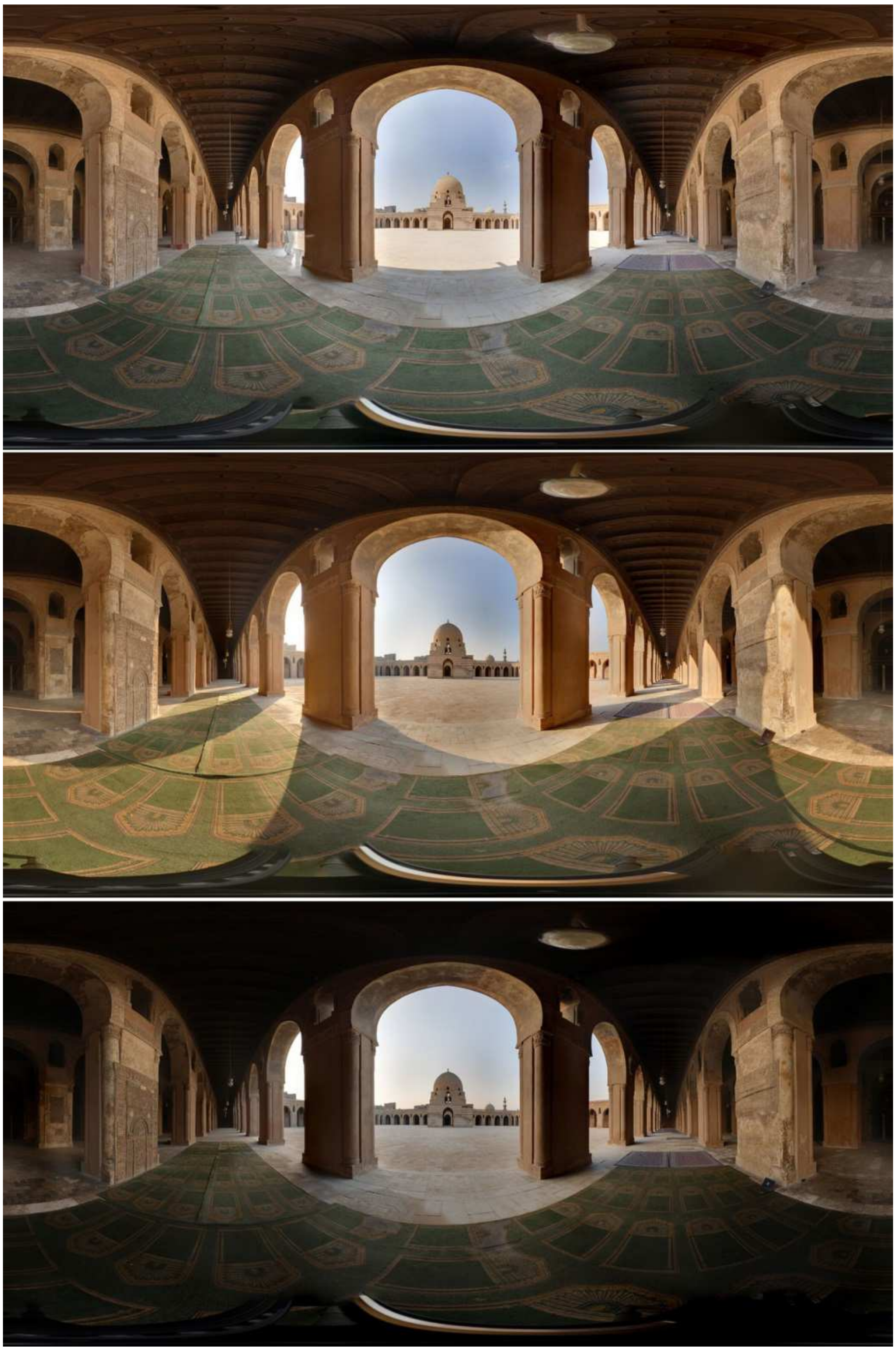

Fig. 4 – Time-lapse panorama in Ibn-tulun mosque taken at: 1:20 PM, 4:50 PM, and 5:50 PM.

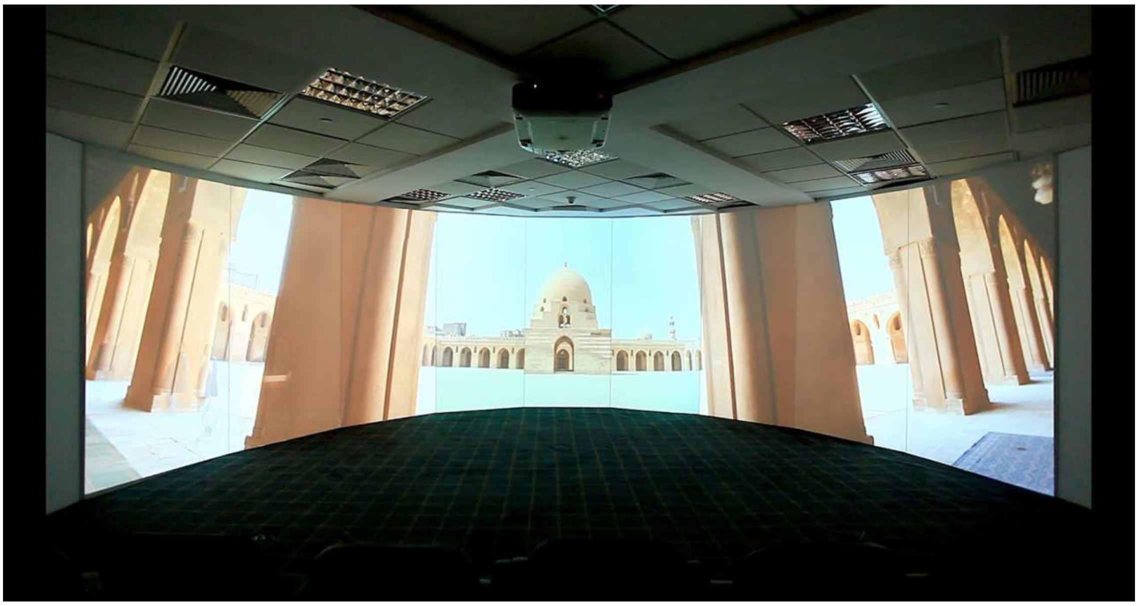

Fig. 5 – Time-lapse panorama in Ibn-tulun mosque displayed on the CULTURAMA Immersive Virtual Reality system at CULTNAT.

Discussion

Time-lapse panorama as a mean for the documentation of historical sites has its advantages (opportunities and strengths) and disadvantages (weaknesses and threats) as listed below:

Strengths:

1. Photorealistic image of the site.
2. Complete documentation of the site image.
3. The pipeline could be entirely automated, making it faster and cheaper.
4. The overall cost is low compared to 3D documentation.

Opportunities:

1. The rich details found in almost all historical sites and buildings facilitate the process of images alignment, since all the images alignment processes are based on features detection and matching.
2. The recent advancement in digital cameras and computer vision algorithms increase the quality and speed of the alignment process.

Weaknesses:

1. Lack of 3D navigation, the site can only be explored from fixed points of view where the panoramas were taken.

Threats:

1. Moving people and objects.

From the above SWOT analysis we can conclude that while the time-lapse panorama has many advantages over 3D documentation, the lack of 3D information hold it from being the first choice for complete documentation of sites leading us to the following questions: Can we merge advantages of 3D and panorama in single system?

It is seems like this combination is possible by either apply time-lapse panoramas to points clouds generated by laser scanners or use time-lapse panoramas in the reconstruction from images technique.

In (BILA 2013), the authors use a points cloud that is generated from a Time of Flight (ToF) laser scanner and a panoramic image to generate a "fused texture" that replaces the points colors in the points cloud. A time-lapse panorama could easily replace the one-time panorama to generate time-lapse texture. The result would be a 3D model of the site with photorealistic colors that can be changed to any time during the day.
In (D'ANNIBALE 2011), the authors are already using panoramas for 3D reconstruction as an alternative to typical reconstruction from normal images. This technique is ready to use the time-lapse panoramas to generate time-lapse 3D reconstruction.
Obviously the two previous examples introduce a new limitation in shooting time. Since each panorama will take a full day to completely record the daytime changes in colors. A solution could be similar to what the authors in (SHAN 2013) introduced. Their system automatically gathers images from different resources: flicker-based, ground-level imagery, aerial views, and street view to generate what they called "re-lightable" 3D model. This is obviously taking advantages of the huge images database available on the Internet which contain almost all possible light variations for famous heritage sites, not only for a single day but possibly for the whole year. The result is acceptable and needs further research to become photorealistic.

Conclusion

In this paper we presented the time-lapse spherical panorama as an affordable method to fill the current lack in complete documentation of a historical site image. The main advantage of this technique is its ability to provide a complete photorealistic image of the site at affordable cost, while the main disadvantage is the lack of 3D. We suggest the integration between both, by adding the time-lapse information to point clouds or by directly reconstruct 3D models from time-lapse panoramas. A complete and affordable solution to fuse 3D and time dimension to provide the ultimate documentation of historical sites is still required.

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