

Virtual Restoration of Cultural Heritage Through Real-Time 3D Models Projection

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Abstract

The color techniques used in sculpting items of cultural heritage change over the years. The demand to restore a unique version of history to the detriment of the rest of time motivates us to research to attain full restoration of the polychromes (painting on stone).

This problem, along with currently prevailing non-invasive trends in restoration, lead us to use Augmented Reality to achieve virtual restoration of the portico of the Saint Mary's Cathedral in Vitoria (Spain). By projecting the rendered image of the 3D model of the polychromed sculpture in real time over the original sculpture, we can make the sculpture appear to the eyes of the observer as if it had the same polychromes/paint as it did in the past. In this fashion, we achieve the desired restoration effect without touching the stone while being able to show the polychromes of each and every one of the eras that the portico has stored up.

To carry out this project, we need to conduct a study prior to the use of projectors on the portico, and, in effect, the offered solution to use the Augmented Reality is valid to obtain the restoration objective. Due to the fact that the portico is not able to be worked on, we cannot do a complete, on site study. We solve this problem by conducting a 3D simulation of the entire portico. With the virtual portico, we can validate the display of the polychromes and the layout and lighting over the projectors. To validate the restoration using projectors, we test the projection on the central element of the portico: the chest of the White Virgin. We project the model that was scanned in 3D with polychromes discovered by restorers on the chest, thus validating the entire system when it comes to the quality of the polychromes, technically and economically speaking.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation-Digitizing and scanning I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Virtual Reality

1. Introduction

This project objective is to analyze the technical viability of a viewing system based on Virtual Reality and Augmented Reality that enables us to present polychromes applied on sculpting items to the public. Specifically, we studied the portico of Saint Mary's Cathedral in Vitoria.

In order to attain our objective, we projected images of a polychromed 3D model that "paints" the sculptures and items that make up the portico. This system was previously studied [RLW01], [MPWG05], but varies in our case as we applied these techniques to a real restoration project of items that have cultural heritage. We had to project onto a surface that was very irregular when it came to geometry and reflectance and we had to be as strict as possible when it came to the quality of the result.

To the eye of the observer, the system we are describing makes it look like the portico has been fully restored. It also lets you choose the polychromes that you want to see without harming the items that are to be restored.

Using projectors along with generating images in real time using a computer that will be projected, gives us the ability to interact and take the leading role of the event which is just the opposite effect as when static, analog methods were used leaving the observer passive in the process. This is what happened in the "Cathedrales en lumiere" project at the cathedral of Amiens (www.cathedralesenlumiere.com) where they also projected images to "paint" items on a portico. In addition to the fact that the paintings that are projected in Amiens are not historically accurate (which greatly reduces interest), they project glass slides using floodlights

(static projection). We used dynamic projectors that display the image of the already painted 3D model over the real item. The projection is done in real time, projecting non-static, moving images with lighting effects, reflections . . .

We display the 3D model over the original model that was scanned. We do not project 2D items as they did in [MPWG05] where they projected flat textures. Our polychromed 3D model was projected over the real, unpainted model which means that the textures always matched up perfectly on the real item. The calibration system is also different. Markers were used in project [MPWG05] and a calibration system using 20 reference points on the real and virtual model was used for [RLW01]. Matlab was used to get the resulting projector. We calibrated it measuring distances and entering the data collected into the application so it would generate a view of the same properties that the projector we were calibrating has. Our project was structured in 5 phases:

- Generating the 3D model
- Pre-study of projectors
- 3D study of the placement of projectors
- Polychromes viewing module
- Interactively adjusting the projection

2. Generating the 3D model

Given the fact that the portico has restoration scaffolding, we had to build a 3D model of it in order to carry out the projector simulations.

2.1. Getting 3D data of the portico

To validate the proposed system, we needed to get a 3D model with the detailed elements of the portico that we would project onto and create the 3D model of the entire portico in order to analyze the projection system. There are many different types of technology that exist for creating real, 3D objects. For this project, we chose to use photogrammetry and laser scanning techniques just like the ones used in project [AP04]. We also have studied other systems for getting 3D models such as in [GWM*04] and [1802]. But due to the fact that our situation didn't require us to obtain a complete model of the statues in order to do the simulation (only the front of them), we discarded the scanning system using structured light range as a possibility to carry out this project. We decided to validate the proposed projection system on just one of the items of the portico, the most difficult one technically and historically, the statue of the Virgin which is the central portion of the portico. Just as was done in other projects of cultural heritage such as [STH*03] and [LPC*00], we used laser scanning technology on the statue of the Virgin because it is quick and precise. We used a MINOLTA VIVID 910 optical laser scanner. We performed 127 scans with a medium sized lens at a distance of 0.75 to 1.25m.

Another aspect to take into account was the lack of space in order to set up the scanner (Figure 1).



Figure 1: Scanning process on the scaffolding of the portico.

2.2. Generating the 3D model of the entire portico

Since a 3D model of the portico doesn't exist and there is only a photogrammetric restoration of it, we had to use this data to make a model of the elements of the portico. Among the items that needed to be modeled apart from the basic structure were: figures (statues), tympanums, archivolts, and pilasters. The tympanums and statues required a special modeling process. The rest of the items were able to be modeled using the existing AutoCAD plans. The modeling process for the tympanums and statues of the Cathedral's portico required performing different tests to determine the most adequate way to obtain an approximate model of them.

- Displacement Maps: involves using real, touched up images to generate a 3D volume. We concluded that this system is the most adequate for modeling tympanums. Also used in [GWM*04]
- CAD polylines from the photogrammetry: Using the polylines obtained from the photogrammetry process, we came up with different models once we applied different modifiers in 3DMax. We concluded that this system is the most adequate for modeling the statues.

Unlike [DRT*04] and [RD03], we used these techniques because we considered that they made our model as real as possible while generating an adequate number of polygons to handle the 3D model in real time.

2.3. Applying textures

The objective of applying different textures on the three-dimensional scan of the Virgin was to obtain a "painted" model using the results from the polychrome correspondence study performed by the Saint Mary's Cathedral Foundation. To do so, we used the model of Virgin texturized in smooth stone and the 3D model was painted on directly.

3. Pre-study of projectors

The analysis of the technical viability of the viewing system involved conducting a study on the amount and characteristics of the projectors, weighing the quality of the finish that the different placements of the projectors produce. There were three clearly different items studied in this analysis:

- The projection surface.
- The projectors
- The observers.

3.1. Problems with the projection surface

Before studying the problem of projectors, we focused on the projection surface which is the only unchanging item of this system. Since it is not a real screen, the projection surface created a series of problems that we tried to solve or avoid:

- Differences in color/material on the wall. This makes it so it responds differently to the light shined on it. We had to modify the projected image in order to fix this problem. It was also necessary to take into account the superimposing of beams of light from different projectors [MHTW00] [RLW01]. The portico will be restored which means that the color of the stone will change.
- The different projection planes for one projector can create blurry spots due to the fact that we can only focus on one spot, and since the projector doesn't have very much depth of field, there can be areas where it is out of focus.
- Existence of hollow points on the illuminated items [RLW01]. Possibility of illuminating the same item with various projectors. It is important to consider the position of the observer.
- Many items of the portico don't receive projected light perpendicularly which means that each part of the portico's surface receives a different amount of light. This must also be taken into account when the image is projected.

3.2. Problems with the projectors

The projectors had many different features and not all of them had the perfect ones for our study. In this case, the most important ones were: resolution in pixels (higher resolution means higher quality), pixel size on the projected surface, projector cell size (the projector projects the pixels in cells and they are seen if they are a certain size), type of projector (CRT, LCD, DLP), light strength, focal length, depth of field (we are projecting onto a surface that is not flat), size (taking into account that we have limited amount of space to put it in), contrast and price.

3.3. Problems with the observers

Observers position and height are very important factors in deciding where to place the projectors. Assuming that the

projectors are placed on the ground as far as possible from the projection surface, they will illuminate from a low position so that they don't produce shadows for the observers, but not too low so that the observers don't produce a shadow.

4. 3D study of the placement of projectors.

Projectors study was conducted in order to optimize the number of projectors to be used, and most of all, to reduce the price. Before analyzing the 3D study of the distribution of the projectors, we conducted a 2D pre-study of the distribution where we only had to take into account the projection area possible for each projector which depends directly on the focal length. In order to conduct this study, we defined an interactive 3D application in real time with the following functions:

- Creating virtual projectors and being able to interactively modify their features as if they were real in order to conduct a study on the projectors that would be used on the portico.
- Studying the lighting using geometry that simulates the projection cone (locating the non-lighted areas) or simulating true light (finding areas of light that are overexposed or underexposed).
- Creating polychrome projection simulators using virtual projectors.



Figure 2: Interactive 3D application for studying projectors viewing the 3D model of the portico with three parallel projectors and their light beams.

With the interactive 3D application created with Virtools 3.0, we conducted a study of the different possible projector setups, observing the areas covered, the resolution of each projector, ... and we concluded that there are three general configurations that best fit the required characteristics and features of the current projectors.

5. Polychromes viewing module

We have developed an interactive application so that the restorers could validate the colors of the polychromes and the chest of the Virgin could be viewed in real time and be observed with the different applied polychromes. This way the restoration team had a visual tool to check what the polychromes looked like. Before creating a polychromes viewing module, the restorers had to define the different polychromes of the items on the portico. The next phase consisted in applying them to the 3D model. Focusing the study on the chest of the Virgin, we used a program that paints directly on the 3D model so that the restorers could view the polychromes on the statue and could give their approval. This polychromed model was approved by the restorers and was the one that we based the polychromes viewing module on.

On the other hand, this module will be used in the future as a visual aid for the guided visits that the Saint Mary's Cathedral Foundation gives and will be used as a virtual exhibit of cultural heritage as has been done with other projects [YD02] presented at UNESCO's Virtual Congress.

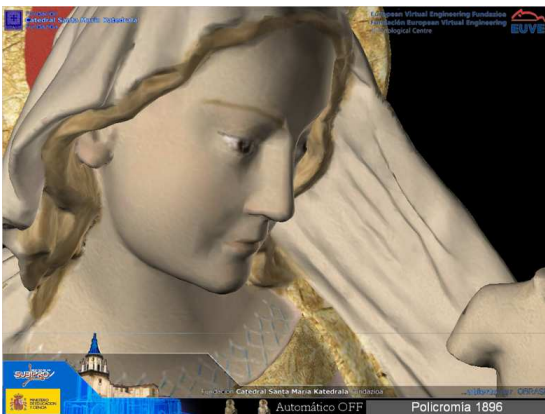


Figure 3: Polychromes viewing module showing the detail of the polychromes from 1896.

6. Interactively adjusting the projection

Our objective was to get a polychromed image in order to project it onto the actual portico [RCWS98] [MPWG05]. We studied three different options:

- Taking a static photo of what we were going to project and modifying it, applying the colors for each polychrome.
- Creating the image from the 3D model using pre-calculated static rendering.
- Directly projecting the 3D model with the modified polychromes in real time.

We choose the 3D model with the modified polychromes in real time. The benefits are significant:

- Rapid adjustment of the image that is to be projected. The projector can be static and we only have to change the properties of the virtual projector in order to adjust it to the real projector. The adjustment process with static images is tedious and inefficient.
- If we take photos, we would have to change them all every time we have to change the polychromes. If we paint the 3D model directly, there would be no need for these changes since the 3D model is what we would project.
- We have the ability to interactively change the colors and textures. This enables us to perfectly adjust the color to the true polychromes painted directly on the 3D model while we directly see the result on the stone. This way, the restorers can approve a polychrome by seeing the result on the spot. They can create a hypothesis of the color of the different items of the portico and see the result of the ensemble. We can also create lighting effects, texture and color animations, . . . Rendered images or modified photos are static and hinder you from performing these actions. This technology opens up a wide variety of huge, educational and entertainment possibilities. At any time, the user could choose which item he wants to see, how he wants to see it, and what lighting effects he wants to use. You can alternately illuminate the items referred to in the exhibit during the presentation of the guided visit of the portico.
- You can increase the abilities of the system, being able to use a unique, motorized system or one driven by the user to project which will illuminate different parts of the portico that the user wants with polychromes.

The best solution is to use the interactive model in real time to create the images you want to project. To do so, we created an application similar to the one we used to view the polychrome model of the Virgin (entering the data of the position, orientation, and optics, in addition to a corrective ratio of the width of the lens to calibrate it) and projected this image using the aforementioned projector.

If the measurements of the reference parameters of the original model are accurate, the projected image fits perfectly on the real model of the Virgin. This system is very efficient and doesn't need complicated camera [RBY*99] [CCF*00] [SSM00] or sensor calibration methods. We would only have to redo the measurements when the parameters of the projector are changed and the results of the projection would be immediate.

7. Projection test on the real model

To test the viability of the project and to find out values that can only be estimated in the field, we conducted two projection tests on the actual portico. We could only do tests on small items because we could not scan the entire portico or project on it because it is being restored.



Figure 4: Interactively adjusting the projection (with the data from the real projector in the upper left-hand corner). This is the image projected by the projector

7.1. Pre-test of projector qualities

We conducted the first test before beginning the 3D study to observe the quality of the projection of different colors and shapes on the portico, the need for more power, light reflection, what affects other light sources, pixel size, . . . The study on reflectance was not fundamental since the actual color of the stone is not the color that it will have after all of the items of the portico are cleaned. When it comes to color variation, we expect that reflectance will be even better when it is cleaned since the surfaces will be whiter and more homogenous.

7.2. System validation test

We conducted the second test at the end of the study to validate the model and to estimate if the system could work on a larger facility. The test consisted of three basic items: the chest of the Virgin, the projector, and a computer with the 3D application that creates the image that will be projected.

We only projected on the chest of the Virgin with the appropriate pixel size. We used the interactive adjusting application, using the Virgin as a reference for our virtual world and thus being able to appropriately calibrate the virtual projector or camera. (Figure 6)

We measured the real displacement of the projector with respect to the Virgin on the x, y, and z axes (position). At the same time, we took measurements of the three turning angles of the projector (orientation). Finally, we set the same focal length for the virtual projector as the real projector was set to. We entered all of this data into the application that was going to project the image onto the Virgin. Then, we set up a virtual camera with the same data as the real camera. If we projected this image, it would fit perfectly on the Virgin. From the point of view of the observers, you can appreciate



Figure 5: Conducting the validation test of the interactive adjusting application.

the chest of the Virgin fully polychromed and perfectly adjusted (thanks to the exact measurements taken and how it is defined in the virtual model). The restorers approved the polychromes. They think it is a good system and want to continue with the project, expanding it to the entire portico.



Figure 6: Statue of the Virgin with the projected polychrome

8. Conclusions

In this study we managed to virtually "restore" the chest of the Virgin without touching its structure and were able to

see the different types of polychromes that it had throughout the centuries. We conclude that the solution presented here is a good solution for the restoration objective that we had set (the restorers that attended the test confirmed this). The test was a success and all we would need to do is apply the system to the entire portico or the parts that they determine. This would be done when the current restoration work on.

8.1. Future Applications

Once the restoration work is finished and when the restoration conditions of the portico allow, we would carry out a project to expand the dynamic projection of polychromes for all of the items on the portico that the restorers did a polychrome study on through the dynamic, interactive projection on the model of the Virgin.

In the future, we would study the possibility of using motorized, computer controlled, or non-motorized "tracked" projectors to project on the statue or part of the portico that the user chooses in a system similar to the one used in [BES02]. This system could be applied to any restorable monument that has cultural heritage: churches, cathedrals, caves, ... where they want to get them back to their original condition in a non-invasive way using augmented reality.

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