Reconstruction and Visualization of Cultural Heritage Artwork Objects

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Abstract. Cultural heritage artwork objects usually consist of multiple surfaces with details that become more apparent over time. The most common deformations concern the composition of materials, the use of objects. Reconstruction techniques are used for building 3D models of existing objects from sensor data such as laser scanner and photogrammetry data. Similarly, we can use additional types of sensor data for reconstructing (i) the micro-structure of the object (dents, bumps, cracks) or (ii) the material layers that lie underneath the external surface.

We report on the development of methods for digitally reconstructing and visualizing cultural heritage objects including their material consistency and their micro-structure.

Keywords: Material aging · Visualization tool · 3D reconstruction

1 Introduction

The protection of cultural heritage artifacts is an important but often very tedious and repetitive process. Each object has been crafted using several materials that age differently, a fact that can have a significant impact in its appearance as it ages. Archaeologists and curators bear the brunt of studying the aging process of each material and then apply that knowledge to restore artifacts to a prior condition or to prevent further decay.

The analysis, simulation, emulation and visualization process that is used to model the effect of aging requires highly detailed models of the solid objects and therefore demands a computationally intensive physical modeling simulation.

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3D reconstruction is the process of capturing the boundary surface and the appearance of real objects. This process can be accomplished either by active or passive methods.

Small deformations of the surface structure, and small color variations due to corrosion contribute to a realistic look of objects. Deformations observed in many materials arise due to small-scale interactions among elastic strain, plastic yielding, and material failure. According to Kider [1] the aging process depends on material composition, object usage, weathering conditions and a large number of other physical, biological, and chemical parameters which over long periods of time result in local deformations that are manifested through dents, bumps, cracks and layer peeling. Furthermore, sensor data from ultrasounds and non visible electromagnetic radiation (infrared, ultraviolet and x-rays) are used to reconstruct information regarding multiple material layers.

Subsequently, methods are needed for (i) the analysis of the aging process on sample materials (see Pfaff et al. [2]) the prediction of aging described as a set of surface micro deformations based on the results of the analysis (ii) for the realistic rendering of artwork objects and the visualization of the underlying material layers. Therefore we report on the development of (i) technique for reconstruction of artwork objects with all the macro and micro properties of the surface and the underlying material layers (ii) a powerful visualization tool for browsing a realistic rendered interior and exterior of a reconstructed artwork object. Figure 1 illustrates the reconstruction and visualization pipeline.

2 Related Work

Realistic rendering is one of the most important goals in computer graphics. A key role in realistic rendering is being played by the micro-structure of the surface of the object. This micro-structure is often modeled by local deformations that affect locally the geometry of the boundary surface of the object. Frerichs et al. [3] provide a thorough survey of such methods.

Small deformations such as cracks according to Pfaff et al. [2] are more likely in areas determined by local properties or by physical simulation which result in refining a high-quality triangle mesh. Glondu et al. [4] use a physically-based fracture to create a wide range of crack patterns. Dorsey and Hanrahan [5,6] observed that crack patterns in materials arise due to small-scale interactions between elastic strain, plastic yielding, and material failure.

Lee et al. [7] introduced a method for reproducing visually observable aging deformations by a simplified simulation process. According to Mérillou and Ghazanfarpour [8] determining the effect of an aging period on the visual appearance of an artwork object is a complex process.

El-Gaoudy et al. [9] and Rushmeier [10] noticed that it is of extreme importance the availability of information about the properties of material composition for manufacturing, or restoration.

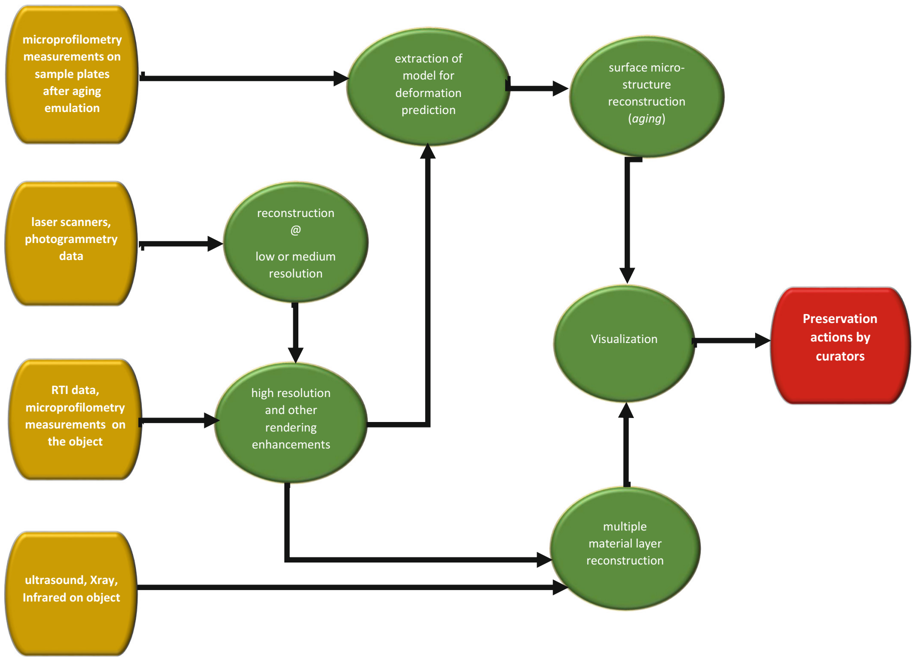


Fig. 1. Reconstruction and visualization pipeline.

Chudnovsky and Preston [11] discuss the background for modeling the kinematics of aging deformations. Various simulation techniques have been used for material aging. For example, Yin et al. [12] studied the surface of wood which is modeled by values assigned to tetrahedral mesh vertices. On the other hand, Paquette et al. [13] present an aging technique that simulates the deformation of an object caused by repetitive impact strikes over long periods of time.

Modern rendering techniques and hardware are capable of capturing aging phenomena efficiently (see e.g. Kider [1]).

Gomes et al. [14] propose a multi step pipeline for the 3D reconstruction technique of cultural heritage artwork objects. This pipeline is based on high res photos and laser scanner data for mesh generation, partial view registration, mesh parametrization and diffuse texture generation. Our pipeline goes beyond this pipeline by incorporating, very high resolution geometry based on microprofilometry measures, surface micro-structure data (aging), multiple material layers, and detailed material properties using RTI data.

3 3D Reconstruction Techniques

3D reconstruction mainly focuses on reproducing an object by capturing surface geometry information and color. Digital reconstruction of cultural heritage objects is a challenging task since it requires capturing details at the level of micrometers for the external surface.

While there are many steps that compose a 3D reconstruction pipeline, the most important are (i) the acquire of raw color and (x, y, z) information, (ii) the alignment of 3D data into a common reference frame in a process known as registration, (iii) the mesh integration stage where data from all acquired 3D views are combined and finally (iv) a 3D model with its textures is generated as the final result.

3D reconstruction produces 3D models that are used for rendering the object using appropriate software and hardware. These models are composed using 2D and 3D multi-modal measures, which are then analyzed and combined to derive a high fidelity model of the surface of the object by using texturing and surface reconstruction techniques.

Multiple sensors are used to provide the data required for each model. For the outer surface reconstruction of the models, photogrammetry techniques, as well as laser scanning can be used to obtain a low or medium resolution triangulated mesh representing that surface. Micro-profilometry is used to obtain higher resolution data for a surface which can be used to extract texture maps that can reproduce this high resolution information efficiently using the rendering pipeline. Finally texture maps that contain information about the color of an area as well as the specular, roughness and albedo values of a material, are generated by RTI measurements (see Fig. 2).

(a) (b) (c)

Fig. 2. Multistep high definition 3D reconstruction technique.

4 Reconstructing the Surface Micro-structure and the Underlying Layers

In this section we outline methods for deriving a model for simulating aging based on micro-profilometry measurements taken on material sample plates (Costabel et al. [15]) during an emulated aging process (Moutafidou et al. [16]). We mainly focus on local deformations due to corrosion/erosion and finally cracks by modeling the behavior of displacements locally and observe the results by realistic rendering.

The first type of deformations that we would like to predict are dents or bumps. They commonly occur in areas around a specific point of the surface. According to micro-profilometry measurements on simple metal plates, we have observed that they mainly occur where large deviations from the mean value (distance from the metal plate plane) are obtained and then model their occurrence on real world artwork meshes that we have derives by the methods of Sect. 3.

The second type of deformation that we study is a crack. It's very common for a crack to start occurring where extreme deviations from the mean value are obtained. Since micro-profilometry data from sample plates follow a normal distribution, we can model the frequency of crack occurrence based on the standard deviation of the fitted distribution on sample plates which basically means that cracks are more likely to occur in areas where extreme bumps or dents are present.

For every new aging step the following repeatable process is carried out. Each artificial aging process is being studied by (i) statistically analyzing the micro-profilometry measurements from each sample plate according to maximum likelihood estimation (MLE) which is based on the likelihood function, (ii) finding the parameter values that maximize the likelihood of making the observations given a specific family of probability distribution functions, (iii) determine the set of values for the model parameters that maximize the likelihood function and finally (iv) determine the parameters of Gaussian pdf that best fits each set of micro-profilometry measurements.

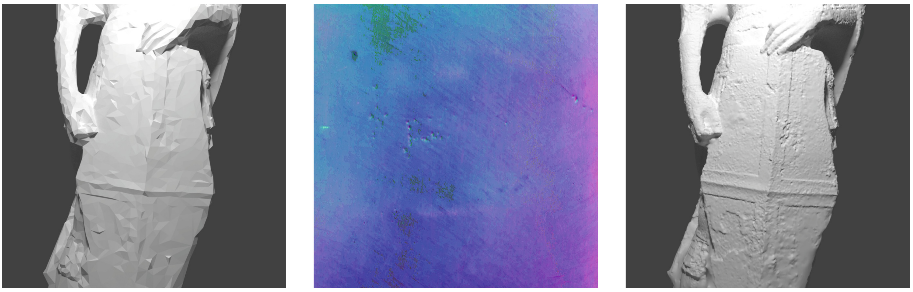
The results of the above process is utilized to predict aging on reconstructed artwork objects made by the same material. More specifically Moutafidou et al. [16] focus on the detection of such patterns within sets of data drawn from micro-profilometry measures taken on material samples such as silver, bronze or egg tempera plates during the process of artificial aging.

Finally, we derive not only the surface of the objects but also volumetric information of the interior of the solid object. Multiple sensors are used to provide the data required for each model. Ultrasound, infrared and x-ray measurements provide information for reconstructing details of the inner layers, including geometry and thickness.

5 A Visualization Tool for Artwork Objects

Most archaeologists work is based on the observation of existing cultural heritage artifacts in their current state, combined with the knowledge gathered from experience on how different materials age. The main goal of our work is to adopt a state of art approach from artificial material aging, and rendering so that people involved in curatorial work and in preservation tasks will be able to understand exactly the nature of aging and act accordingly. In this way, it is necessary to have tools that produce and visualize digital representations and models of visual surface appearance and material properties, to help the scientist understand how they evolve over time and under specific environmental conditions.

Material models mainly consist of surface geometry (including normals), material color, reflectance distribution and other light related material properties. Micro-surface modeling on the other hand, is based on a hybrid method that combines material aging models, multiple material layers and physical models. With all this available data for the model there is a need for an appropriate viewer that can visualize all the details. The 3D Viewer needs to be able to render the details provided by all types of sensors while being fast. Figure 3 illustrates the improvement of the rendering result if you added a normal map texture. Figure 4 illustrates the improvement of the rendering result if you added a normal map texture, and other texture maps to improve quality. For that reason, we have developed a rendering tool which is capable of visualizing efficiently all the surface details and the underlying layers.



(a) pure mesh (b) normal map (c) final result

Fig. 3. Example of adding a normal map texture in a low poly mesh to enhance the final result.

Our visualization tool is built on top of a multi-fragment renderer using vertex and fragment shaders. The outcome is a fast visualization tool that given the scanned geometry and material model is able (i) to portray the appearance of the artifact in the future when specific effects are applied and (ii) to visualize and analyze the underlying material layers.

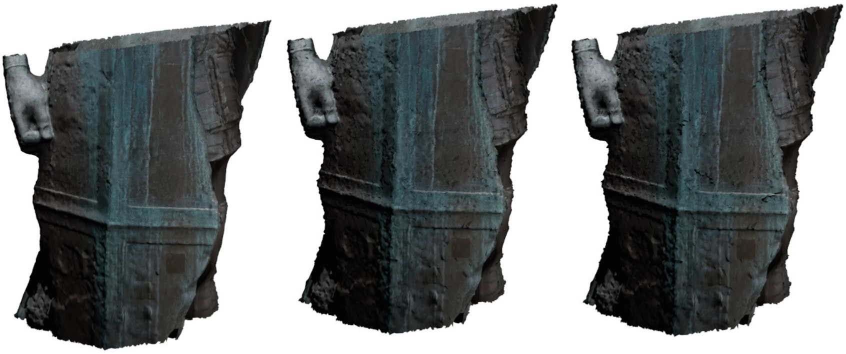
We have conducted artificial aging experiments with several types of sample plates (bronze, silver, egg-tempera). Furthermore, we have analyzed the micro-profilometry data and derived the distribution function for each pair of (sample plate, time instance). For several artwork objects we have applied an algorithm to create an aging effect such as dents and bumps as well as cracks based on the distribution function. The first algorithm refers to bumps. In this case we conducted bumps and dents in the original object. More specifically based on the original object (Fig. 5a) we derive a confidence interval to compute the number of the deformation. The result is 154 bumps and 99 dents (Fig. 5b). On the other hand we have studied cracks. Based on the same path we conduced cracks based on the previous model (Fig. 5b). In this case we are going to create a new aging step with bumps, dents and cracks. The result is 231 new bumps, 139 new dents and 4 cracks (Fig. 5c).

(a) Geometry

(b) geometry and normal map

(c) geometry and all texture maps

Fig. 4. Rendering original geometry, then enhancing using texture maps.



(a) original object in T0 (b) in T3 with simulated local deformations (c) in T3 with local deformations and cracks

Fig. 5. Simulating local deformations and cracks using data from micro-profilometry measurements on sample plates.

6 Conclusions

We have reported on the design and development of a tool for reconstruction and visualization appropriate for cultural heritage artifacts.

We present a method for predicting and enhancing the aging effect in cultural heritage artifacts. Furthermore, based on multi-modal sensor data we have developed a method for reconstructing and rendering multiple material layers.

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