REALISTIC RENDERING OF MATERIAL AGING FOR ARTWORK OBJECTS

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ABSTRACT

Material aging has a significant effect on the realistic rendering of artwork objects. Small deformations of the surface structure, color or texture variations contribute to the realist look of artwork objects. These aging effects depend on material composition, object usage, weathering conditions, and a large number of other physical, biological, and chemical parameters. In this work we focus on local deformations due to corrosion/erosion and finally cracks mainly by modeling the behavior of displacements locally. Micro-profilometry provides the quantitative measurements of the surface texture and roughness at micro-metric level, which is used to obtain information about material changes over time in terms of its surface deformation. We present a method for simulating aging based on micro-profilometry measures taken on material sample plates during an emulated aging process. Subsequently, we use this model for realistic rendering of aged cultural artifacts.

***Index Terms*—** aging,distribution

1. INTRODUCTION

Material aging has a significant effect on the realistic rendering of cultural artifacts. Small deformations of the surface structure, color or texture variations contribute to a realist look of artwork objects. The distinctive crack patterns observed in many materials arise due to small-scale interactions among elastic strain, plastic yielding, and material failure. Stress gradients can be very large near the crack tip where the stress field often approaches singularity.

Modeling the effect of aging is a computationally intensive task . Therefore, tools are needed to expedite the aging simulation/emulation process. Several types of textures may be used to improve rendering. However, this process requires intensive user interaction which may not correctly capture subtle micro-deformations. Texture parameterization is a tedious task especially for non genus-0 objects that may introduce triangle mesh distortions [1].

The aging process depends on material composition, object usage, weathering conditions, and a large number of other physical, biological, and chemical parameters. Weathering for example, over long periods of time results in cracking and peeling of layers such as paint.

Material aging related visual effects are important for capturing realistic effects in computer generated images. Simulating and rendering such phenomena results in images which have a much higher degree of realism [2]. In this work we focus on local deformations due to corrosion/erosion and finally cracks mainly by modeling the behavior of displacement locally by studying the artificial aging process of sample plates [3].

Micro-profilometry provides the quantitative measurements of the surface texture and roughness at micro-metric level, which is used to obtain information about material changes over time in terms of its surface behavior.

To this end, we introduce a method for modeling and rendering the aging process based on micro-profilometry measures taken on material sample plates during an artificial aging process. In each step of the emulated aging process micro-profilometry measures are statistically analyzed and fitted by a normal (Gaussian) probability density function. This PDF is then used to determine regions where dents, bumps and cracks are plausible. Dents and bumps are approximated by radial basis functions parameterized to reflect material behavior. Cracks are modeled by paths simulating surface singularities. These mesh deformations are modeled by directly altering mesh geometry or through displacement maps for rendering efficiently the aging effect on cultural artifacts.

2. RELATED WORK

Aging depends on material composition, object usage, and other physical, biological, and chemical parameters. Aging phenomena often play a key role in realistic rendering. Their absence results to non-realistic surfaces, looking too clean and smooth. Each specific aging process is considered according to [4] as a challenging task in computer graphics, because of the often-complex underlying physics involved and

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the need for providing designers with usable tools.

Capturing aging in computer graphics is simulated by modeling object morphology changes such as cracks, fractures, patina, corrosion, erosion, burning, melting, decay, rotting and withering. Some approaches consider effects which influence the geometry of an entire object, instead of the surface appearance alone (see e.g. [5]).

In our work we propose a novel method for the modeling, prediction and rendering of small scale geometric deformations by studying the artificial aging effect on material sample plates.

While the simulation of fracture physics has been studied in computer graphics, reproducing fracture patterns observed in real-world materials remains a difficult problem. In [3] a high-poly mesh is dynamically produced locally to adaptively capture details wherever it is required by the simulation. Crack patterns observed in materials arise due to small-scale interactions between elastic strain, plastic yielding, and material failure. Stress gradients can be very large near the crack tip where the stress field often approaches singularity. In [6] the surface of wood is defined by values assigned to tetrahedral mesh vertices. Changes in the surface are achieved by value changes. We build on this background to model cracks.

[7] demonstrates how a Bayesian optimization method can determine the parameters of a fracture model patterns based on examples. In our method we use statistical fitting to derive material behavior pertinent to local deformation. Hence no examples are needed to model, predict and render such aging effects.

An important aging technique that simulates the deformation of an object caused by repetitive impacts over long periods of time is discussed in [1]. The authors use adaptively refined meshes and mesh deformations to model aging due to heavy object usage. Another interesting approach describes the phenomenon of chemical aging in painting. Material aging is understood as changes of material properties with time, so usually observed as a gradual modification of some properties such as rigidity and strength [8]. These approaches can be used in conjunction with our method to extend the repertoire of aging affects.

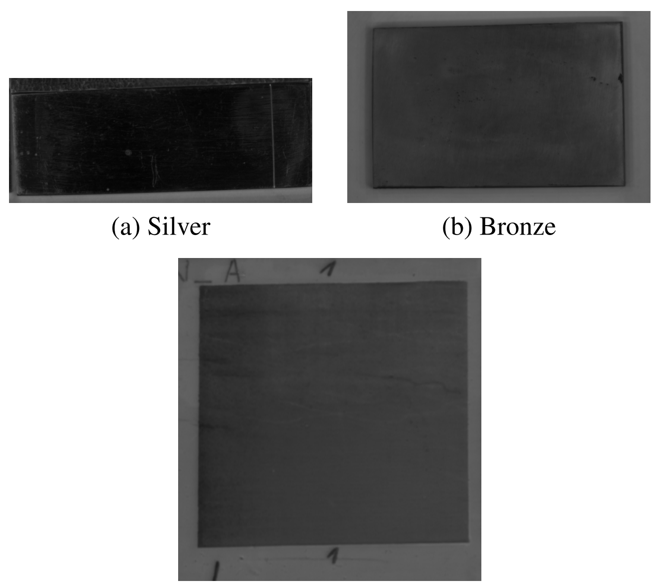
3. ARTIFICIAL AGING DATA ANALYSIS

Micro-profilometry, namely the acquisition of surface structure at micron or sub-micron scales, is routinely used for material inspection in engineering but is recently used experimentally in the cultural heritage field. Surface metrology of artifacts requires the design of a suitable device for in-situ non-destructive measurement along with reliable tools for effective analysis of materials [9].

So-called accelerated (artificial) aging tests are carried out for three major purposes. The first is to establish in a conveniently short time the relative ranking of materials, or physical combinations of materials, with respect to their chemical stability or physical durability. The second is to estimate or predict long-term behavior of material systems under expected conditions of use. Thirdly, processes of deterioration are speeded up in the laboratory to elucidate the chemical reactions involved (the mechanism of the degradation) and the physical consequences thereof. [9].

More specifically the aging process depends on material composition and can describe a number of methods used in computer graphics to simulate object morphology changes due to natural influences, such as cracks/fractures and local deformations. We will focus mainly on micro-profilometry data for our purpose. Areal micro-profilometry of the sample is obtained by raster scanning, i.e. collecting a set of line profiles along the scan direction and step by step along the sub-scan. The measurement of the sample is performed with the device placed in a vertical configuration, with the sample positioned perpendicularly to the laser beam of the probe. The sample is kept in a vertical position on a sample holder [9].

Micro-profilometry data consists of a sequence of distances between the lens and the target object, thus providing a digital representation of its surface through direct measurement of the surface heights. Several material features are detected by micro-profilometry such as surface cracks and other local deformations [9]. In this work we study 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 (see Figure 1) during the process of artificial aging.



(a) Silver (b) Bronze

(c) Egg Tempera

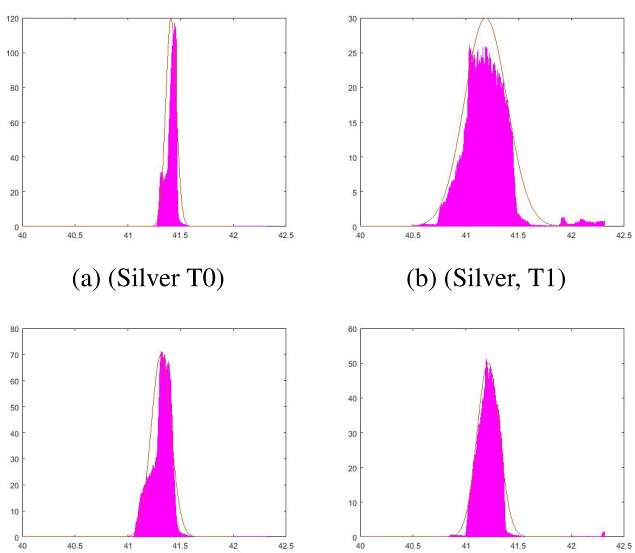
Fig. 1: Sample plates on which micro-profilometry measurements are conducted during an artificial aging process.

After each artificial aging process, we statistically analyze the microprofilometry measurements from each sample plate. We have used the maximum likelihood estimation (MLE) which is a method for estimating the parameters of a statistical model given observations, by finding the parameter values that maximize the likelihood of making the observations given a specific family of probability distribution functions. Given a statistical model (possibly multi-dimensional) we determine the set of values of the model parameters that maximize the likelihood function. This process determines a probability distribution function that best fits a random set of input data.

The method of maximum likelihood is based on the likelihood function $L(\theta; x)$. We are given a statistical model, i.e. a family of distributions $f(.;\theta)|\theta \in \Theta)$, where θ denotes the multi-dimensional parameter for the model. The method defines a maximum likelihood estimate (MLE):

$$\theta \in arg_{\theta \in \Theta} max L(\theta; x). \tag{1}$$

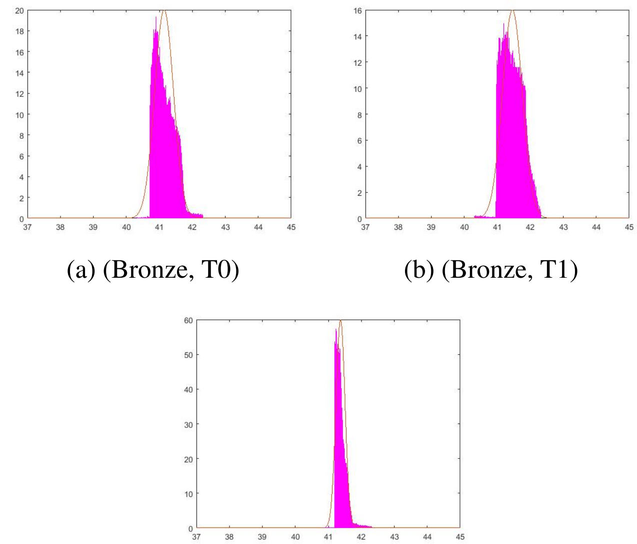
We derive the MLE distribution for each pair of (type of material, artificial aging time) and we determine the parameters of the Gaussian pdf that best fits each set of micro-profilometry measurements. Figures 2, 3 and 4 illustrate the measurements and the fitted distribution for silver, bronze and egg tempera respectively for various time instances of the artificial aging process.



(a) (Silver T0) (b) (Silver, T1)

(c) (Silver, T2) (d) (Silver, T3)

Fig. 2: Micro-profilometry measurements and pdf fitting for silver plate.



(a) (Bronze, T0) (b) (Bronze, T1)

(c) (Bronze, T2)

Fig. 3: Micro-profilometry measurements and pdf fitting for bronze plate.

4. ARTIFACT AGING SIMULATION AND VISUALIZATION

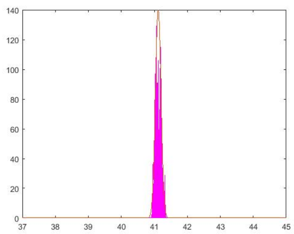
Relating results from accelerated aging to those obtained in actual-use conditions is difficult because laboratory tests do not reproduce all the exposure stresses experienced by materials exposed in actual-environment conditions. Although artificial aging have been used as a research tool in the past decades. However, there are still several open problems regarding the significance and accuracy of the results [9]. However, data from artificial aging of sample metal plates is sufficient to create a plausible realistic model intended for computer graphics applications.

In this section we further analyze the data from the artificial aging process and we use them to predict the occurrence of local deformations.

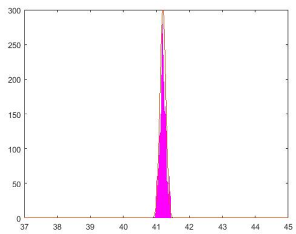
Material failure in metals manifest itself mainly by local deformations. We distinguish two types of such deformations: cracks and dents/bumps. We have studied (i) when and where such deformations come up, and (ii) their geometric structure and (iii) how we can represent such deformations in terms of surface mesh operations.

4.1. Cracks

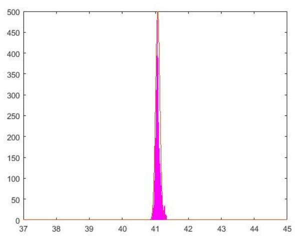
By studying the data from micro-profilometry (MP) measurements during the artificial aging process on sample plates we have observed the following: (i) cracks occur where extreme deviations from the mean value (distance from the metal plate plane) are obtained. Since MP data follow a normal distribution this means that we can model the frequency of cracks



(a) (Egg Tempera, T0)



(b) (Egg Tempera, T1)



(c) (Egg Tempera, T2)

Fig. 4: Micro-profilometry measurements and pdf fitting for egg tempera plate.

based on the standard deviation of the fitted distribution, (ii) cracks are more likely to occur when bumps or dents are present, and (iii) the geometry of the crack depends on the geometry of the existing object and the local deformations that have occurred in previous aging steps. In this work we have modeled (i) and (ii). We determine the parameters of (i) and (ii) manually by examining the MP measurements against the reconstructed mesh of the artificially aged sample plate. To this end, we have used a state of the art visualization tool. The direction and length of a crack is an issue that requires further investigation. In this work we select a random direction and a length that depends on the aging step and the MP distance. The direction and length determine a path on the mesh (see Figure 5).

Next we are going to summarize a method on how to create a crack in an area. According to the analysis outlined above we conclude in selecting an area that is more prone for a crack to appear at a given time instance.

4.1.1. *Dents and Bumps*

In this section we study local deformations which are formed around specific point of the surface, namely dents and bumps.

By studying the data from micro-profilometry (MP) measurements during the artificial aging process on sample plates we have observed the following: (i) dents/bumps occur where large deviations from the mean value (distance from the metal plate plane) are obtained. Since MP data follow a normal distribution this means that we can model the frequency of dents/bumps based on the standard deviation of the fitted distribution, (ii) dents and bumps are created around a vertex and present themselves by translating the neighboring vertices of the mesh (see Figure 6) towards the normal vector direction and (iii) the attenuation of the displacement in the neighborhood follows an RBF function. In this work we have determined the parameters of (i) and (ii) manually by examining the MP measurements against the reconstructed mesh of the artificially aged sample plate. To this end, we have used a state of the art visualization tool. For (iii) we use a radial basis function (RBF) which is a real-valued function whose value depends only on the distance from a point, called a center, so that $\phi(v, v_i) = \phi(||v - v_i||)$. We use as norm the Euclidean distance and as attenuating function the inverse quadric ($r = ||v - v_i||$):

$$\frac{1}{1 + (\epsilon r)^2}$$

Algorithm 1 Compute Cracks

procedure COMPUTE-CRACKS
  MPdist $\leftarrow$ compute MP data fit distribution
  CT $\leftarrow$ compute crack theshold
  myMesh $\leftarrow$ import your mesh
  for each vertex v_i of $myMesh$ **do**
    rand $\leftarrow$ random number according to MPdist
    if $rand \geq CT$ **then**
      Choose a random direction d_c
      Compute crack length l_c
      Starting form v_i determine a path p_i
      from v_i of length l_c towards d_c
      Along p_i create a wedge
  end for

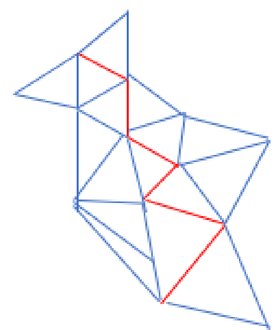


Fig. 5: An example of a crack path

5. TEST CASE

Explain setting and figure ...

Algorithm 2 Compute dents and bumps

procedure COMPUTE-DENTS-BUMPS
  MPdist $\leftarrow$ compute MP data fit distribution
  CT $\leftarrow$ compute crack theshold
  DBT $\leftarrow$ compute dent/bump theshold
  myMesh $\leftarrow$ import your mesh
  for each vertex v_i of $myMesh$ **do**
    rand $\leftarrow$ random number according to MPdist
    if $rand \geq DBT \wedge rand < CT$ **then**
      translate v_i in the direction of the normal
      translate neighbors of v_i attenuated by an RBF
  end for

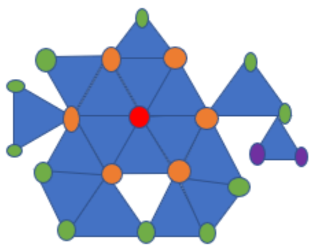


Fig. 6: An example of vertex neighborhood

(a) (b) (c) (d)

Fig. 7: (a) original object (b) simulating first artificial aging process (minor sparse deformations) (c) simulating second artificial aging process (medium more frequent deformations) (d) simulating third artificial aging process (medium frequent deformations).

6. CONCLUSIONS

We report on the design and development of a method based on micro-profilometry measures taken on material samples during an artificial aging process and we apply them to visualize the aging effect on cultural artifacts.

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