EUROGRAPHICS Workshop on Graphics and Cultural Heritage (2016)
C. E. Catalano and L. De Luca (Editors)

3D object spatial- consistent texture maps appropriate for 2D image processing

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Abstract

The aim of this work is to generate a spatial-consistent UV maps of a 3D object's texture suitable for 2D image processing algorithms. An approach to produce such a fully spatially consistent UV mapping suitable for image processing based on the planar parameterisation of the mesh is presented. The mesh of a 3D model is parametrised onto a unit square 2D plane using computational conformal geometry techniques. The proposed method is genus independent, due to an iterative 3D mesh cutting procedure. The selection of the initial seed vertex for the mesh-cut is not essential for the parameterisation of the geometry, however it affects heavily the appearance of the obtained texture map. In this work we attempt to determine such a seed vertex, in order the UV map to be suitable for image processing. Having the texture of a 3D model depicted on a spatially continuous two dimensional structure enables us to efficiently apply well known image processing based techniques and algorithms. Our method is applied on a 3D digital replica of an ancient Greek Lekythos vessel.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Geometric algorithms, languages, and systems I.3.3 [Computer Graphics]: Picture/Image Generation—Bitmap and framebuffer operations

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1. Introduction

The research area of 3D signal processing is nowadays an active topic, due to its numerous subdomains and applications. 3D digital replicas of real world objects are used in different domains such as cultural heritage, game industry, industrial design, prototyping and medicine. The evolution of 3D acquisition techniques such as laser scanning, structure-from-motion and structure-from-light, that has led to the creation of numerous 3D digitised models, makes the need for development of techniques for visualisation, processing and utilisation of 3D surfaces (2D- manifolds) urgent. One of the common characteristics among most 3D digitisation methods is the generation of a spatial inconsistent (fragmented) texture map. This spatial inconsistency derives from the application of the optimum back- projection approach that takes under consideration the perpendicularity between the different mesh surface portions and the positions of the corresponding 3D digitisation viewpoint- planes. This spatial inconsistency leads not only to colour information scattering but also to poor exploitation of the UV- space due to the existence of unused areas (Figure 1). In this we generate a spatial-consistent UV map.

Our approach is based on computational conformal geometry, an interdisciplinary research field, that combines geometry, computer graphics and computer vision [GY08]. More specifically, one of the fundamental reasons that makes conformal geometry valuable, is that all surfaces (2D- manifolds) can be deformed into one of the three canonical spaces, which are the sphere, the plane and the disk (hyperbolic space), while being unaffected by the morphological complexity of their mesh. Another important merit of conformal mapping is that it is shape preserving. This is done by keeping the neighboring mesh triangle angles unaffected by applying only scaling transformations. Additionally, conformal mapping allows the reduction of a three dimensional problem to a two dimensional one, simplifying the processing challenges. The above mentioned characteristics of conformal mapping are exploited in order to transform an initial spatial non- consistent (fragmented) texture-map into a fully consistent (continuous) one [ICK*16]. Moreover our goal is to guide the mesh- cut, if there is the need to perform one, to pass through areas without texture information.

Our objective apart from the creation of a fully *spatial- consistent texture map* (SCTM) is to enhance in terms of preservation of the regions of interest (ROIs), a 3D model's texture map. Thus, we propose a method to primarily cut- open the mesh of 3D model by selecting a proper *seed vertex* in order to prevent the slicing of ROIs of the 3D model's texture.

DOI: 10.2312/gch.20161411

2. 3D model surface parameterisation

There are number of prerequisites related to the 3D model that need to be met in order to apply our approach. (i) the mesh of the 3D model has to be composed solely by triangles (*pure triangular mesh*), (ii) the mesh has to be 2D- manifold, that is a maximum of two triangles can share the same edge, (iii) the 3D model has to carry *per-Vertex* UV coordinates and (iv) the 3D model's mesh has to be connected and may not contain unconnected parts (e.g. a 3D scene where different mesh entities exist). We can have meshes with more than one boundary and an arbitrary number of genus. As an example we use a 3D digital replica of an ancient Greek Lekythos. It is a genus 1, 2D- manifold pure triangular mesh (Figure 1) that consists of 24,980 vertices organised into 42,400 faces and a texture image of 3,500 x 3,500 pixels.

Figure 1: *Input vessel overview (left), spatial- inconsistent texture map (right).*

2.1. Workflow overview

The implemented approach is based on Geometry Images [GGH02], which is a parameterisation method applied on surfaces with arbitrary topologies. The basic idea is to topologically convert a surface into a genus zero disk, by cutting the surface along an appropriate set of edges [Mun00]. In this implementation we use the Iterative Cut Algorithm (ICA) proposed by Gu. According to ICA, an optimum mesh-cut has to pass through the *"parameterised mesh extremas"* (in our case vessel's appendages e.g. handles). An "extrema" of the parameterised mesh is a region that suffers from large geometric stretch. ICA is based on Floater's parameterisation that is shape preserving [Flo97]. Floater's parameterisation is selected and not a geometric stretch parameterisation, since the latter one would evenly distribute the stretch and therefore prevent the detection of an "mesh extrema".

ICA, has two stages, initially starting from a seed vertex it slices the mesh in a way that the mesh is topologically equivalent to a genus zero disc and afterwards begins augmenting the cut-path by iteratively parametrising the mesh using the current cut-path and detecting areas (triangles) that suffer from large geometric stretch and thus guiding the cut-path to pass through those areas. This process is performed until the overall mesh geometric stretch stops decreasing. The selection of the initial seed vertex for the mesh- cut is not essential for the parameterisation of the geometry, however it affects heavily the appearance of the obtained texture map. Therefore we attempt to enhance the passthrough of the mesh- cut by selecting a seed vertex that prevents the mesh- cut to pass through regions of interest (ROIs) of a 3D model's texture map. In order to identify ROIs, we apply the Scale-Invariant Feature Tranform (SIFT) algorithm [Low04] on the generated SCTM and extract the SIFT feature points. A square and size- deformable sliding window that scans the SCTM is used in order to detect the area with the smallest concentration of SIFT features. In this manner the new seed vertex to initiate the mesh- cut is defined. Thus, ROIs on the vessel's texture are preserved.

2.2. Initial spatial consistent texture map generation

Using the described workflow the mesh is parameterised onto a unit square along with its texture. The first step is to perform ICA, in order to topologically convert the mesh 2D- manifold into a genus zero disk. We map each vertex $v(X,Y,Z)$ in $\mathbb{R}^3$ from the initial mesh onto the unit square and has $v(x,y)$ coordinates in $\mathbb{R}^2$. The boundary of the unit square consists of the boundary of the initial mesh (if any) and the slice computed by ICA in order to convert the mesh into a topological disk.

Vertices along the slice are duplicated during the cutting phase. This is also true for the vertex attributes such as normal vectors and UV coordinates.

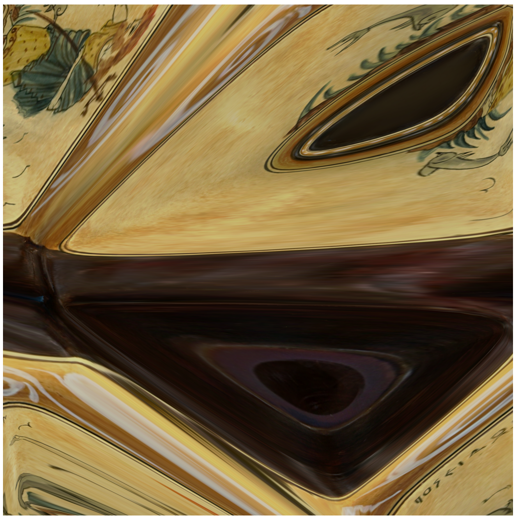

Figure 2: *Initial spatial- consistent texture map.*

Once the plane parameterised mesh is created, apart from the vertex spatial coordinates, we associate each vertex to new UV coordinates. Thus, we produce a mesh that is planar and also spatial- consistent in its interior. Such a parameterised planar mesh along with its new texture coordinates is depicted in Figure 2. Rendering the planar mesh with its texture map information, one can create a bitmap image that is referred as the *spatial- consistent texture map (SCTM)*. The highest possible resolution of the SCTM is related to the rendering capabilities of the graphics card and of course the resolution of the initial texture image. Figure 2 may exploit the whole

UV space but the appearance of the ROIs is scattered and therefore an enhancement procedure is necessary.

2.3. Spatial consistent texture map enhancement

The initial spatial consistent texture map exploits the total space of the texture map but may suffer from slicing ROIs and therefore not being suitable for image processing operations. This challenge is partially overcome by selecting an appropriate seed vertex to initiate the mesh- cut. As mentioned above, a mesh-cut has to pass through an "extrema" (in our case the handle of the vessel) and in combination with the fact that the ROIs on a vessel are not located close to the appendages (e.g. handles), it appears that it is sufficient to place the *seed vertex* on a region without any texture information.

In order to detect ROIs on the SCTM image, SIFT local features and their location are extracted. SIFT feature locations are defined as maxima and minima of the result of difference of Gaussians function applied in scale space to a series of smoothed and resampled images. The algorithm uses a technique to eliminate low-contrast feature points and thus keep only the strong and important points of interest.

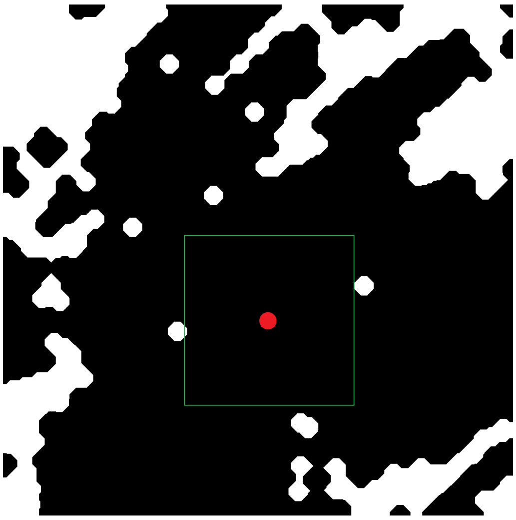

Figure 3: *Binary image depicting ROIs and the centre of the selected window to place the seed vertex.*

We generate a binary black image with the same resolution with the initial SCTM and place white dots in the locations the SIFT features. A dilation process with an octagon kernel is performed, followed by a morphological closing on the white regions of the binary image. A removal phase of all small ROIs is then implemented. As small ROIs we define single SIFT feature points (orphaned). Finally, an erosion process with a smaller kernel is applied to diminish the dilation effect over ROIs on the image, resulting in (Figure 3).

Once the binary image is created, we identify a square window of maximum size that does not contain any white regions. Finally, we define the new *seed vertex* as the vertex that lies closest to the centre of the window. Initiating the parametrisation procedure with the new *seed vertex*, enables the generation of an enhanced SCTM, in terms of ROIs preservation, as shown in Figure 4.

Figure 4: *Enhanced SCTM.*

3. Texture- based vessel object recognition

To demonstrate advantages of the enhanced SCTM, we chose an example of the object recognition domain. SIFT, a fully invariant algorithm with respect to four parameters namely zoom, rotation and translation of the affine transformation, is commonly used to address such a problem. However the parameterisation procedure used for the mapping introduces distortions on the triangle angles, making the feature matching procedure non trivial. For this reason we use ASIFT, a variant of SIFT, that takes into consideration the two remaining parameters of the affine transformation matrix, i.e. angle defining and camera axis transformation [YM11]. We used as a query object an ortho snapshot of Poseidon captured directly from the 3D model. The results of the application of ASIFT on the initial SCTM (Figure 2) and on the enhanced SCTM (Figure 4) are shown in Figures 5 and 6 respectively.

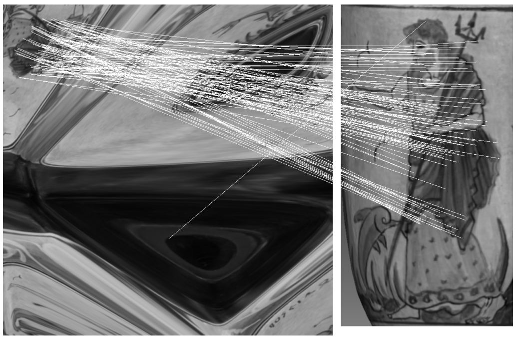

Figure 5: *104 ASIFT feature point matches.*

In the enhanced SCTM case, the number of feature point matches increased significantly.

Figure 6: *244 feature point matches.*

4. Conclusions

Having the texture information of a 3D model visualised in a spatial-consistent form enables us to practice well known operations that derive from the image processing domain. An enhanced mapping of a 3D model's texture information in a *spatial- consistent* form improves the applicability of these algorithms. In the near future, we would like to apply more elaborated techniques for defining optimum mesh- cut paths for 2D image processing.

Acknowledgement

This work was partially funded by the European Union's Seventh Framework Programme (FP7/2007-2013) in the context of the program "ARIADNE", grant agreement no. 313193. Furthermore the above mentioned procedure was partially implemented using OpenGI, an open-source library for parameterizing triangular meshes [Rau11]. Moreover the 3D model used as a case study is part of the *3D Pottery Content Based Retrieval Benchmark Dataset* created by the Multimedia Research Group of the Athena Research-Xanthi's division [KPL*10].

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