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GEOMETRIC INVESTIGATION OF LARGE 3D SPATIAL DATA FOR VIRTUAL MUSEUM APPLICATIONS

Abstract: This paper introduces a novel method of successful processing the large three-dimensional (3D) spatial data for Virtual museum design. Billion triangular faces are obtained from the 3D scanning process of national clothes. In order to avoid the filling holes problem we have included additional steps in post scanning process. Removing isolated vertices and all redundant faces, in the first step algorithm solves all topological error issues. This step also includes mesh optimization for two purposes: i) removing duplicated edges and faces and ii) mesh simplification for a precise unwrapped map. Algorithm in the next step performs texture creation and UVW mapping. Separated fields of the mesh faces contain rich and unique textures analogously to original national clothes. Separating these fields by color, texture and curvature features, we also achieved better rendering performance in the 3D web preview. This step is the final step in the presented algorithm. Classifying texture pixels in database in strict correlation to the real museum cloth and jewelry classifications, we have designed powerful software engine. Algorithm is crucial for the Virtual museum in order to allow the simple and efficient use and administration through user view and administrator panel.

Keywords: 3-D geometry, 3D modeling, 3D scanning, cultural heritage, digital archive, virtual musem.

1. Introduction

Digitization of 2D artwork is a mature field and is widely deployed in the museum and library communities. However, relatively few groups have tackled the problem of digitizing 3D artworks. In the field of clothing digitalization, according to our knowledge, there has been no similar project. This area is quite complex in geometrical and mathematical sense, due to complexity of three-dimensional (3D) meshes that represent a real cultural heritage models. Complexity of geometrical and topological representation of real cloth model is consequence of the physical characteristic of clothing material. In contrary to solid and rigid models, clothing models contain much curved areas that prevail in relation to flat and sharp surface regions. Although many research papers [1][2] have tried to solve clothing representation problems, this area is still in infancy.

Two notable examples of the successful 3D digitalization are results of the National Research Council of Canada (NRCC) and IBM. The NRCC efforts are interesting because they focus on building robust, field-deployable systems, and consequently their papers echo some of the same concerns raised in this paper [3]. The IBM efforts are interesting first because they scanned a statue under field conditions, and second because they used a structured-light scanner in conjunction with photometric stereo, producing geometry at 2.0 mm and a normal vector field at sub-millimeter resolution [4]. Although their resulting models are not as detailed as ours, their equipment is lighter-weight and therefore more portable.

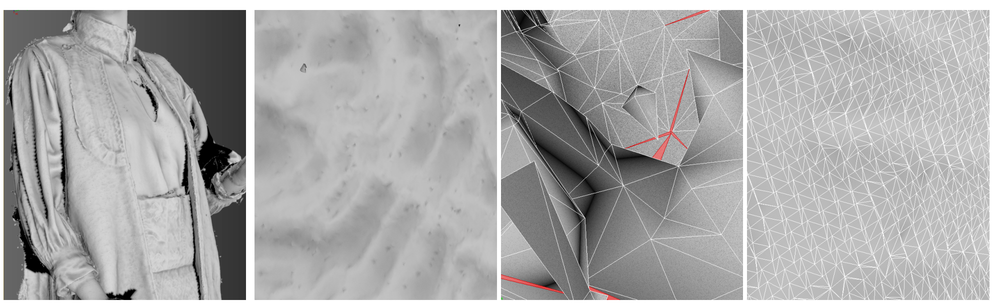
Recent improvements in laser rangefinder technology, together with algorithms for combining multiple range and color images, allow us to digitize accurately the shape and surface characteristics of many physical objects. As an application of this technology, a team of 30 faculty staff, and students from the Stanford University and the University of

Washington spent the 1998/1999 academic year in digitizing sculptures and architecture by Michelangelo [5]. This excellent research dealt with huge curved regions and detailed representation of each part of real models. It is not our aim to compare our project result with a genius work of Michelangelo, however our problem was closer to a difficulty that the sculptor had than to the problem with digital representation of his work.

2. Challenges

Analyzing the sculpting process, we can conclude that representation of real model depends on: i) quality of tools and ii) "sharpness" of sculptor's eye. Undoubtedly, Michelangelo had the second one with an excellent sculptor skill, but there was no tool that he could successfully shove in a hole of many wrinkles to made representation of real clothes. This issue is not solved even with modern laser tools today. In some cases modern technologies are helpless dealing with seemingly simple, convex models, as jewelry for example.

Using Altec EVA 3D scanner with the scanning steps from 0.5 to 1.7 mm, we obtained good quality of model in the sense of real model geometry representation. Moreover, resolution of 3D mesh exceeded our needs in relation to ethnological purpose. Actually, precision of the our scanner, i.e. available scanning steps are not small enough to represent a weaving fabric for texture analyzing, but ethnological purpose includes combination of unique clothing elements without detailed texture analysis. Although, we have obtained very precise 3D meshes, difficulties are reflected firstly in huge and complex topologies with many topological and geometrical errors. Processing of these huge models and error removal required significant computation time and use of expensive and high performance computers.



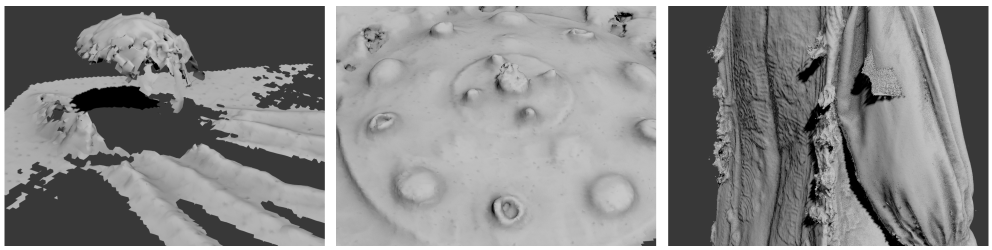
a) b) c) d)

Figure 1: Examples of topological and geometrical errors obtained from 3D scanner: a) scanned 3D model of a national costume, b) crossing faces, c) open edges and unstructured elongated faces, and d) duplicated scanning steps.

Examples of topological and structural errors, obtained from 3D scanning process, are shown in Figure 1. Small dark triangles in picture b) are triangular faces of 3D mesh that non-contiguously intersect regular faces. These faces are "confusing" in the optimization phase of computations. Moreover, probability of erroneous computation of face and vertices normal is pretty large. This would generate the problem with correct surface representation, and then cause incorrect perceptual definition. Open edges (Figure 1. c) define boundaries in cases of homogenous 3D mesh structures and all simplification processes, including the decimation [6][7] for increasing hardware rendering.

Due to the precise synchronization of two consecutive scans, numerous of vertices are inserted into the mesh geometry twice (Figure 1. d). As neighbors, these duplicated vertices are positioned very near to each other and generate elongated faces with internal angle close to zero [8]. Consequently, this type of mesh topology usually causes incorrect computations and very often crashes of software applications. On the other hand, corrections of these topological errors are extremely hard, bearing in mind that our models contain on average approximately more than ten million faces[1].

Another issue that scanning process causes is reflection of metal surfaces, pieces of glasses and specially hair detection inability. Next figure (Figure 2.) illustrates the mentioned type of difficulties.



a) b) c)

Figure 2: 3D scanning errors: a) undetectable metal reflection, b) transparent surfaces, and c) furry, hairy and threadlike surfaces.

In order to solve the above mentioned problems we need to avoid automatic software filling holes process, which is actually efficient dealing with small structured holes and open edges, but slow and inefficient to create big missed areas of the surface. Hence, we need algorithm with additional modeling steps, instead scanning and post scanning processes that produce incorrect, insufficient and even a wrongly structured 3D meshes.

3. Proposed algorithm

Due to the purpose of Virtual museum requires good „Ethnological" instead good „Geometrical" results, we adapted scanning process to achieve the perceptual quality of the model. Namely, the final goal of all scanning and processing steps is the correct web presentation, which actually represents the Virtual museum. Bearing in mind this fact, we designed an algorithm that avoids complex and inefficient post-scanning computations.

Anisotropic and irregular meshes contain boundary vertices and also topological errors such as isolated vertices and elongated faces. For these types of meshes „imperfections" such as boundary vertices and elongated faces can be very common. However, 3D scanning process should regularly build an isotropic mesh. A distance between all consecutive vertices is determined by the scanner hardware. This fact encourages us to treat mentioned vertices and faces as topological errors together with isolated vertices, which are already treated as errors. Thus, firstly we need find, select and eliminate such errors from mesh. The both sets of vertices of the mesh M : topological errors E_M , and boundary vertices B_M we calculated using our algorithm [9].

Contrary to the precise curvature estimation in a data hiding purpose [10], the error elimination from scanned meshes requires the local featured curvature estimation. Values of the local Gaussian curvature κ_G as well as main curvature κ_H define important shape characteristics, but on the other hand extreme high and low values may describe mesh

[1] Our models are dressed dolls of human with 1.7 m height and approximately 0.7 m width. We have chosen "L" scanning mode using 1.7 mm wide scanning steps.

irregularities such as pick on an elongated face, or a hole in some smooth region respectively. Thus, after the definition of sets E_M and B_M, we calculate discrete Gaussian and normal main curvature that are expressed respectively in terms (1.1) and (1.2):

$$\kappa_G\left(\mathbf{v}_i\right)=\frac{1}{\mathrm{A}}\left(2\pi-\sum_{j=1}^{f}\theta_j\right) \tag{1.1}$$

$$\mathbf{K}\left(\mathbf{v}_i\right)=2\kappa_{H_i}\mathrm{n}_i=\frac{1}{2\mathrm{A}}\sum_{j\in N_1(i)}\left(\cot\alpha_j+\cot\beta_j\right)\left(\mathbf{v}_j-\mathbf{v}_i\right) \tag{1.2}$$

where f is a number of adjacent triangle faces, θ_j is an angle of j-th adjacent triangle, and A denotes an area of the first ring of triangles around the vertex $\mathbf{v}_i$. Mayer *et al.* [11] suggest mixed region A that include a Voronoi region for sharp triangles and half (or quarter) of region for obtuse angles. However, in our recent work [12] we presented the better result using a barycentric region:

$$\mathrm{A}_B=\frac{1}{6}\sum_{j\in N(i)}\left(\cot\theta_{ij}+\cot\alpha_{ij}\right)\left\|\mathbf{v}_i-\mathbf{v}_j\right\|^2\sin^2\theta_{ij} \tag{1.3}$$

where α_{ij} is an angle in vertex $\mathbf{v}_{j-1}$ if triangle of interest is given as $(\mathbf{v}_i,\mathbf{v}_{j-1},\mathbf{v}_j)$. In order to achieve a better convergence we may calculate this area as:

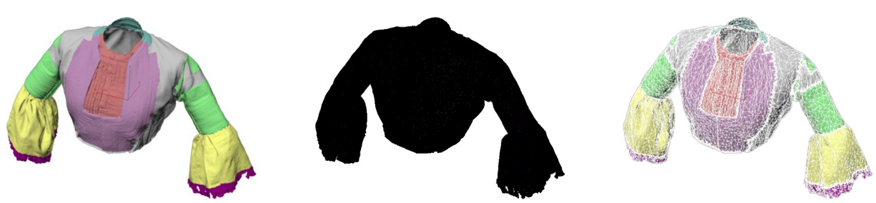
$$\mathrm{A}_T=\frac{1}{2}\sum_{j\in N_1(i)}\cot\theta_{ij}\left\|x_i-x_j\right\|^2\left(\frac{1}{3}\sin^2\theta_{ij}+\frac{1}{4}\right) \tag{1.4}$$

Our algorithm in the next step eliminates vertices that meet the following requirement:

$$v_i\in E_M\vee v_i\in B_M\vee\left(\kappa_{\mathrm{G}}\left(v_i\right)\geq\mathrm{L}_1\wedge\left(\kappa_{\mathrm{H}}\left(v_i\right)\leq\mathrm{L}_2\vee\kappa_{\mathrm{H}}\left(v_i\right)\geq\mathrm{L}_2\right)\right) \tag{1.5}$$

where L_1 and L_2 denote defined limits of the Gaussian and main curvature values respectively, and these values may be obtained by averaging the estimated curvature values, or using Fitting quadric method for global curvature computations [13]. In some cases collinear vertices that meet the criterion $\kappa_G\left(v_i\right)=0\wedge\kappa_H\left(v_i\right)=0$ can also be removed from the mesh and thus additionally reduce the density of mesh model before optimization.

Due to the high percentage of error vertices in the scanned mesh, after elimination of such vertices the mesh model contains much less faces than source mesh without any perceptual and even geometric changes. Drastically reduced number of mesh faces enables us to perform an additional modeling and texturizing steps that are shown in Figure 3.



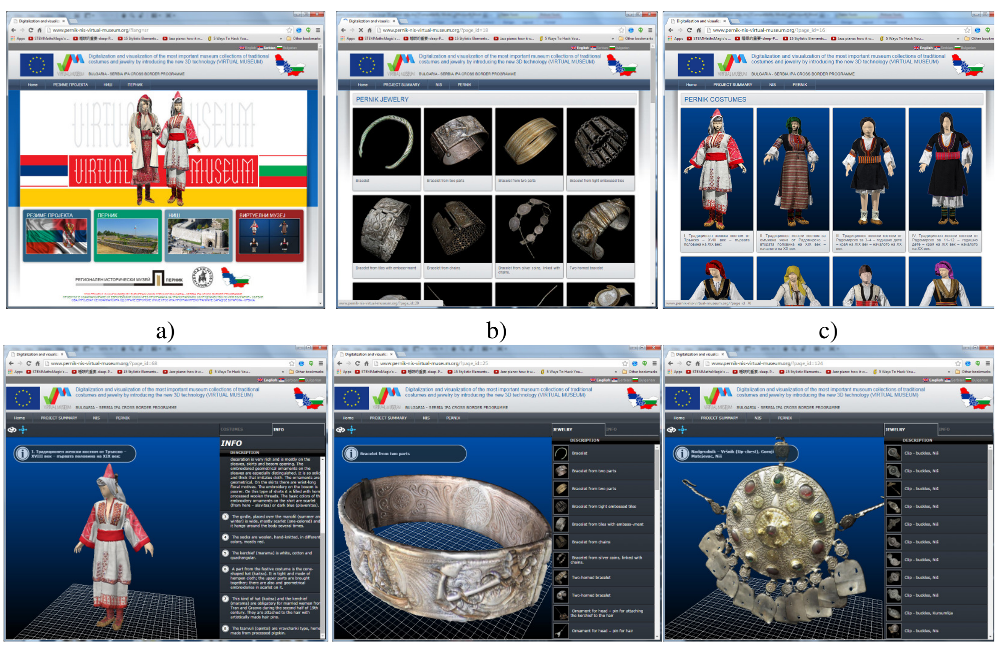
a) b) c)

d) e) f)

Figure 3: Additional operations: a) face selection, b) wired view of high-density mesh, c) simplified 3D mesh model used Pro Optimizer [14], d) and e) UVW mapping, and c) the final high-density mesh model, mapped by acquiring existing map from low-density mesh model.

4. Virtual Museum – Web Application

The Virtual Museum (VM) Web Site [15] is designed to host all relevant information for studying, classification and systematization of Serbian and Bulgarian cultural heritage that includes traditional costumes and jewelry, which are exhibited in the museum of Nis and Pernik. The most relevant VM site feature is an interactive display of 3D models. To achieve a smooth interaction and normal rendering FPS (Frames per second) the scanned models are optimized for Web display. More precisely the number of polygons of the originally 3D models is significantly reduced. Depending on the model geometry the polygon reduction factor varies, and in some cases reaches 1:100.



a) b) c)

d) e) f)

Figure 4: Virtual Museum Web Site screenshots, a) home page, b) jewelry selection, c) costume selection, d) costume 3d view, e),f) jewelry 3d view

Figure 4. shows various parts of the screenshots of the Virtual Museum Web Site. The user navigates to a specific 3D model starting from the home page. The user first chooses between the Virtual Museums of Pernik and Niš. In the second step the user chooses between

traditional costumes and jewelry. The user is then presented with all available models. Finally the user selects a specific model by clicking on a rendered thumbnail image after which the user enters the interactive 3D model viewer. The user can then rotate and zoom the 3D model by using mouse drag actions.

The key technologies used by the Virtual Museum are as follows:

- HTML5 – By using this technology the Virtual Museum Web site can provide a rich multimedia content without the need to install additional plug-ins while maintaining compatibility with all modern Web browsers.
- Web CMS (Content Management System) - This technology enables the user to easily administrate the content of the Virtual Museum Web site without the need to possess any expert knowledge related to Web technologies (HTML,PHP, Javascript etc.).
- WebGL – This technology provides support for OpenGL ES API within the Web browser thus enabling creation of interactive 3D content within a Web application. At the same time this is the key technology which drives the main 3D feature of the Virtual Museum Web Site.

5. Conclusion

We presented a method of successful processing of large three-dimensional spatial data for Virtual museum design. In order to avoid filling holes problems in post scanning process we have included more additional steps in 3D data processing. Our algorithm in the first step solves all problems with topological errors, by removing isolated vertices and all redundant faces. Next step defines process of texture creation and UVW mapping. Separating fields by color, texture and curvature features, we achieved better rendering performance in the 3D web preview. This step is the final step in the presented algorithm. Classifying texture pixels in database in a strict correlation to the real museum cloth and jewelry classifications, we have designed a powerful software engine. Algorithm is crucial for the Virtual museum in order to allow a simple and efficient use and administration through user view and administrator panel.

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