Principles of 3D Web-collections Visualization

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Keywords: Photogrammetry, 3D-modeling, Interactive Animation, Web Design, Polygonal Modeling.

Abstract: The paper introduces to approaches to solving the problem of creating realistic interactive 3D-web collections of museum exhibits. The article deals with the representation of 3D-models objects based on oriented polygonal structures and methods for 3D-models development based on photogrammetry, interactive videos, and editable surface method. The evaluation of the computational complexity of constructing realistic 3D-models is analyzed too. The calculation results for real museum exhibits are given. The paper describes approaches to the formation of digital collections in the integration environment of the digital library. One of the ways to form a multifunctional information resource is proposed as an effective solution to the problem of presenting digital collections of various memory institutions to general public users. One of such methods of forming a multifunctional information resource is implemented in the form of a virtual exhibition. The format of virtual exhibitions allows combining the resources of partners to provide general public users of collections stored in a museum, archive and library collections.

1 INTRODUCTION

In connection with the qualitative performance of modern data transmission networks growth, new opportunities are opening up for the information systems operating organization with a large amount of online information. Such information systems include digital libraries (DL), in the collections are represented digital objects of various origin (for example, print publications, multimedia objects). If several years ago a digital library's collection included just only text files were accepted by the achievement, then in modern realities collections of document scans and digital 3D-models of museum collections are already qualified normally.

To get to a whole new level of presenting objects from archives and museums in the digital library as three-dimensional objects it is necessary to develop existing approaches and methods for obtaining 3D-models, as well as create new ones.

However, in capture museum objects and integrating them into a united information resource are arise some difficulties. Such as:

- the creation of high-quality (in the context of visual sensation) digital 3D-models of museum objects;
- the development of methods for describing information objects which provide easy access to them;
- the integration of digital 3D-models of museum objects into thematic collections;
- the drill-down of information objects into the digital library environment to create interdisciplinary multimedia digital collections and virtual exhibitions.

At current, there is a limited supply of methods of digitizing museum objects. Particularly as regards the building of digital 3D-models and integrating them into a united information resource, and the providing digital 3D-models general public users with modern multimedia technologies. This is particularly true in science museums activities. For example for organizing subject exhibitions, research practice and supporting the academic programs.

These days there are two technologies used when 3D scanning museum objects: active and passive based on contact and contactless 3D scanning, respectively.

The use of these 3D scanning technologies allows creating a high-quality three-dimensional digital model of a museum object.

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Sobolevskaya, I. and Sotnikov, A.
Principles of 3D Web-collections Visualization.
DOI: 10.5220/0008184401450151
In *Proceedings of the 3rd International Conference on Computer-Human Interaction Research and Applications (CHIRA 2019)*, pages 145-151
ISBN: 978-989-758-376-6

The main shortcomings of the active scanning method are the processing complexity and the necessity to use high-resolution scanners when scanning small-sized objects. The main shortcomings of the contactless passive scanning method are the inability to scan the "deepenings" of an object or its defects, etc.

There is a section called "Virtual Exhibitions" on the many museums' websites. Each museum defines and interprets the concept of "virtual exhibition" by itself. Some museums place hundreds of printed and/or archival digital copies of documents in this section, other museums offer a full catalog created according to all the rules of multimedia technologies as a "virtual exhibition". Work on the creation and presentation of digital 3D-models museum objects has been conducted since the 1990s of the 20th century. In (Higuera, 1999; Hazan, 1999; Rao, 1999; Zheng, 1998; Johnson, 1997; Nicchiotti, 1997; Terashima, 1994) are described in detail methods for the formation and presentation of 3D-models museum objects in the digital space. The most difficulties in creating a digital 3D-model arise from the need to use large computational powers in the calculations. In turn, to represent the constructed model, specialized visualization software is required.

The development of multimedia and interactive technologies allows today:

1. To demonstrate the museum objects that are not included in the main exhibition of the museum (most of the museum items are in the museum storage).
2. To form a virtual museum content, significantly expanding the natural-science and cultural-educational knowledge space;
3. To provide the possibility of obtaining more detailed and more vivid (in an emotional sense) information about the object, phenomenon, historical event;
4. Turn the modern museum space into an educational and leisure center.

Thus, if multimedia technologies are a well-thought-out methodology of informational and educational nature the introduction of these technologies is not only justified but also is necessary in some cases. At the same time, not every science museum can turn its space into an entertainment and leisure center. In this case, it is possible to create a virtual exhibition space. Such a virtual exhibition can be created together with archives and libraries. Then these exhibitions could be built up on a digital library platform. A technological and fundamentally new resource is the digital library "Scientific Heritage of Russia" (DL SHR) [http://e-heritage.ru/index.html]. DL SHR allows solving the problems of creating and support of interdisciplinary virtual collections. DL SHR is implementing the open remote access to its funds for a general public user which significantly distinguishes this data resource from many other multimedia projects (Sobolevskaya, 2017).

At present, there is no common methodology for applying one or another computer-generated simulation method for storing the obtained volume models with the possibility of subsequent replication and providing users with the opportunity to inspect virtual copies in various projections. The development of a unified scheme for the application of computer-generated simulation methods for building 3D-models to create thematic 3D-collections of museum objects in the digital library environment and create thematic interdisciplinary virtual exhibitions is relevant.

The analysis and development of methods for generating 3D-models in the direction for obtaining a realistic representation of 3D-collections in the Web-space are open up opportunities for the formation of high-quality 3D-collections of museum objects. These methods allow to keep safe the originals and to increase access to the high-quality digital copies of museum exhibits.

2 MANUSCRIPT PREPARATION

Attempts to provide more complete information about the object than a simple graphic image began with the creation of stereo image technology.

The stereo image technology is based on the representation of the object images taken by cameras from different positions. With the advent of computer graphics technology, the development of this idea made a quantum leap. It became possible to store and present an object image not only from two fixed points but also from any point defined by the user.

It is clear, complete high-quality and detailed digital 3D-modeling of an object is a rather difficult task. This task needs the use of powerful computing resources and special equipment. Such modeling opens up new opportunities for the realizing of 3D-models, their presentation, and use. For example, if you have a high-quality 3D model built by dint of a 3D printer, you can get a copy of a museum object halfway around the world without risking damage or loss of the main artifact. This technology was used by the State Darwin Museum of Moscow to collection development with unique objects of digitized archetypes of the skeleton elements of a prehistoric man from the collection of the museum located in South Africa.

To map a three-dimensional object on a plane screen, you must project into the plane the three-dimensional object. This is possible using projection rays connecting the center of the projection, each point of the object. These projection rays are required to be orthogonal to the projection plane. This plane is called the pictorial surface. It is located between the displayed object and the observer, perpendicular to the visual direction. The points at which the projecting rays intersect the pictorial surface are the corresponding points of the projection.

The main method of representing 3D-models objects is polygonal modeling at the moment (Lyashkov, 2017). The principle of method consists in representing the object surface using the coordinates of points on the object surface and the normal vectors in them. This representation makes it possible to approximate the reconstructed surface with polygons with minimum error. In terms of the linear algebra, the 3D model is represented as related sets of nonplanar oriented triangles or more polygons. Affine space and a homogeneous coordinate system are used to represent elements of 3D objects.

The homogeneous coordinate system has the property that the object defined in these coordinates does not change when the same non-zero number multiplies all coordinates. The number of coordinates required to represent points is always one more than the space dimension in which these coordinates are used. For example, to represent a point in two-dimensional space you need 3 coordinates and you need 4 coordinates to represent a point in three-dimensional space (Weeger, 2018).

Thus, for example, for manipulating 3D models built in homogeneous coordinates to perform atomic operations such as rotation, elation, scaling is required square 4-order matrices. These matrices are applied to all elements of the model.

The polygons geometry and their quantity are the main parameters that determine the quality of a 3D object model. There are two approaches to determining the values of these parameters. Choosing an approach mainly depend on the computational power of the processors involved in drawing the models. The first approach is characterized by an increase in the number of polygons of minimal complexity (triangles), which is accompanied by an increase in the amount of data for displaying a 3D model.

The second approach is based on the construction of complex polygons that best fit the surface of the simulated object.

The visualization algorithm based on the formation of the Spline surface to form surfaces of non-analytical forms described by composed functions is one of the much-used tools in CASE systems and computer graphics programs. This is since the Spline is a differentiable curve. It contains vertices and segments, passes through two watchpoints an at least, and having watchpoints that are not on this curve. These points determine the Spline shape. At the same time, each Spline vertex has a surface tangent vector passing through the watchpoints. Each surface tangent vector has a so-called marker. This marker controls the curvature of the Spline segments at the entrance to the vertex. This surface tangent vector belongs to the same vertex at the exit from it. The most common types of splines used in 3D graphics are Bezier curves and B-splines. The use of splines in the methods of constructing 3D-models allows to increase the quality of the simulated surface, however, increases the complexity of the calculation, which requires large computational powers.

The construction of 3D models from a set of images by photogrammetry is a rather laborious task and requires rather bid computation power. For example, 124 photos of image processing at one of the cluster node MVS-10P (JSCC RAS) (Sotnikov, 2018) took 41 hours of calculations. Figure 1 shows a digital 3D-model of anthropological reconstruction constructed by photogrammetry by M.M. Gerasimov located in the State Biological Museum named K.A. Timiryazev.

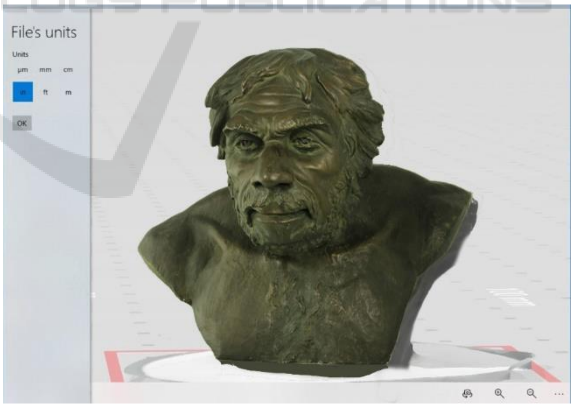

Figure 1: 3D model produced by photogrammetry.

The limitations of this method are:
- it is impossible to control the process of creating a 3D model;
- waiting for long-running operations for the processing of source data;
- need for sufficiently large computational powers.

Thus the problem of creating high-quality 3D models from a set of “flat” images requires solving the following tasks:

• maximizing performance of data processing. Both by increasing the powerful computing tools and the creation of effective algorithms and programs;
• reduction of model setup time.

These tasks remain relevant and their solutions involve the further development of methods for digital visualization of objects.

Modern video-processors can process a stream of data to draw graphical primitives. Modern graphics processors in addition to improved performance allow real-time execution of smoothing algorithm, approximation, and optimization of polygons, which leads to a decrease in the data volume of the 3D model and improved visual perception.

To create a virtual collection of 3D-models to provide it to general public users via the Internet is used the so-called interactive animation technology. This technology does not imply the building a full-fledged 3D model but is based on a programmatic change (scrolling) of a fixed set of object types (frames) using specialized interactive mapping programs that simulate a change in the point of view of the original object. To create such an interactive animation you need a set of pre-shot scenes that will be used as separate exposure frames (Figure. 2).

Figure 2: Images to create an interactive animation.

The technology of interactive animation was used, for example, in such projects as “Interactive walk around the Kremlin” or “Virtual walk through the garden of life”, dedicated to the 160th anniversary of I.V. Michurin (Kirillov, 2017).

Based on the same data set (individual exposure frames), a full-fledged 3D model can be constructed using photogrammetry methods, which were actively developed in the 70s for building a topographic map using space and aerial photographs. Photogrammetry uses methods and techniques of various disciplines, mainly borrowed from optics and projective geometry (Jo, 2017).

In the simplest case, the volume coordinates of object points are determined by measurements taken from two or more photographs taken from different positions. The main task, in this case, is to determine common points on two adjacent images. After creating an array of the seed point cloud is formed a set of rays. These rays pass through each common point and through the location point of shooting camera. The cross-cup of these rays determines the location of a point on the surface of the original object in space. More complex algorithms can use other, known in advance, information about the object: for example, the symmetry of the object's elements, which, in some cases, allows you to reconstruct the volume coordinates of object points from only one photographic image.

The algorithms used in photogrammetry are intended to minimize errors come about from obtaining a set of consecutive frames, as well as measurement errors. The Levenberg – Marquardt algorithm (Xu, 2018), usually solves the problem of minimizing the set of errors. This algorithm is based on nonlinear systems solving by the least-squares solution.

Objects that we encounter in life can be divided into simple and complex. A simple object is an object that can be described by a given (described by a given equation) surface of revolution not higher than cubic. An example of a simple object is parallelepiped, which is a brick or a cylinder, for example. A complex object is an object consisting of a combination of simple objects. An example of a complex object is almost any three-dimensional museum piece, such as a stuffed mammoth, or an archaeological finding in the form of an amphora.

Except for the described above some methods of modeling in three-dimensional graphics, working with 3D modeling is relevant to working with editable surfaces (Hernando, 2018).

There are several ways to create 3D models using editable surfaces.

These methods are based on the formation of a model consisting of:

1. Triangular faces. In this case, the variable parameters are the vertices of the triangles, their sides (edges), the entire surface of the triangle (used, for example, to overlay/change the texture) (Bowick, 1995);
2. Polygons. In this case, the variable parameters are the vertices of the polygons, their sides (edges), the entire surface of the polygon (Meilapredoviciu, 1991; Kulikajevas, 2019);
3. Combinations of triangular or quadrangular faces that are created by Bezier Splines (Schulz, 2011;

Barsanti, 2017). The two-dimensional Bézier Spline is defined by four points: two endpoints to which the ends of the curve are attached, and two control points that act as "magnets" for pulling the curve away from the line connecting the two extreme points (Dimas, 1999).

When you create 3D models in practice, you must have to have the ability to move the control points ("sewing" of elementarily symmetric functions) by yourself on the computer screen. The peculiarity of this type of editable surface is the flexibility of controlling the shape of the object being created. This explains the usability of Bezier splines (Hu, 2017; Zimmermann, 2017);

4. Objects created using Boolean operations. Boolean operation is designed to create a new object based on two or more existing objects. As a result of applying the Boolean operations, a new object is formed as a combination of the original objects. The combining of the original object can be realized by addition operation, subtraction operation and intersection operation. The increase in the number of Boolean operators injections in one another leads to an increase in computational costs. Therefore it is almost impossible to create a three-dimensional model of a human head (especially a face) using this method (Wu, 2018; Sheng, 2018).

When forming a visual image of a 3D object it should not be overlooked the geometry, texture, and features of the source object. Each object can be modeled in several ways. When choosing how to create a digital model of a 3D object should not be overlooked several basic parameters: the parameter of the object creation time and resources consumption (the memory required to create and store the model). Therefore, one of the main tasks of the formation of 3D digital models is the task of optimizing the processes of modeling and visualizing objects. The method of photogrammetry makes it possible to build a high-quality 3D model with lower hard costs for added hardware in comparison with other visualization methods.

3 CONCLUSIONS

Based on the analysis and experiments using various scanning equipment, the advantages and disadvantages of various methods for constructing 3D models were identified. Namely:

- existing methods of creating a 3D-model of a real object have limitations in the construction of a full-fledged realistic three-dimensional model of an object that has a transparency surface, specular surface or light-absorbing surface;
- To build 3D-models with a light-reflecting or light-absorbing surface it is necessary to use special equipment. Namely, it is necessary to use a laser projector with a backlight grid and operating in such a wavelength range in which the "problematic" surfaces of the scanned object are opaque. Such a source of illumination of the reference grid should have a tuned working frequency for working with objects from various materials;
- Modern 3D-scanners are not allowed to obtain a polygonal mesh for building a 3D- model of a "transparent" object without applying a special "marking" means that absorbs light onto its surface. Such a scanning method is highly undesirable, for example, for museum objects;
- Photogrammetry method requires very significant computation efforts. Most of these efforts are paid and set on cloud storages are existed on a third-party file server. In addition to the method of photogrammetry, in particular, implies long-running operations for processing the source data when creating a 3D model, as well as the use of sufficiently large computing power.

When creating a digital 3D-model of a museum object the main task is its complete safety

Based on the research and findings, the technology for generating digital 3D-models of museum objects using photogrammetry was taken as the basis since this technology allows building a full-fledged 3D model of an object with a complex structure without using any special tools applied to the surface of the object being photographed. For visualization and presentation of a virtual collection of 3D-models of museum objects to general public users, the use of interactive animation technology is proposed.

Digital 3D-model is an object that can be linked by mutual links with other types of digital objects likes of text, archival, audio and video documents, etc. These links are stored on remote servers that can be accessed via the Internet. A multimedia object, which includes a set of digital 3D-models additional information associated with them can be integrated into some generic knowledge space. One of the effective means of integration and presentation of such information objects is the digital library.

One of the possible ways to solve the problem of presenting digital museum collections and, in particular, digital 3D-models of museum objects to general public users via the Internet offers a method of creating a virtual exhibition immersed in a digital library environment.

The results formed the basis of the technology of creating 3D-models for objects from the funds of the State Biological Museum named K.A. Timiryazev (GBMT) and the formation on their basis by means of the digital library "Scientific Heritage of Russia" of a virtual exhibition dedicated to the scientific activities of M. M. Gerasimov and his anthropological reconstructions [http://acadlib.ru/].

During the production process on the virtual project the collection of 3D-models of M.M. Gerasimov's anthropological reconstructions was created. Then this digital collection was downloaded into the environment of the DL SHR. The virtual exhibition is an example of intended use the integration of libraries, archives and museums resources into a unified thematic project.

The logic of virtualization of this exhibition is based on building links between the person (M.M. Gerasimov) to all elements of DL SHR, including with museum objects and collections.

This virtual exhibition combines the resources of libraries, archives, and a museum. In particular, this project offers the visitor to get acquainted with the history of anthropology, digitally printed publications on anthropology, photo and video documents related to the development of anthropology and anthropological reconstructions, as well as 3D models of M.M. Gerasimov's anthropological reconstructions, stored in the GBMT funds.

The research is carried out by Joint SuperComputer Center of the Russian Academy of Sciences – Branch of Federal State Institution “Scientific Research Institute for System Analysis of the Russian Academy of Sciences” within the framework of the State task 0065-2019-0014.

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