A Framework for Working with Digitized Cultural Heritage Artifacts

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Abstract. In this paper, we present our work in designing, implementing, and evaluating a set of 3D interactive spatial measurement tools in the context of Cultural Heritage Toolbox (CH Toolbox), a framework for computer-aided cultural heritage research. Our application utilizes a bi-manual, spaceball and mouse driven user interface to help the user manage visualized 3D models digitized from real artifacts. We have developed a virtual radius estimator, useful for analyzing incomplete pieces of radial artifacts, and a virtual tape measure, useful in measurement of geodesic distances between two points on the surface of an artifact. We tested the tools on the special case of pottery analysis.

1 Introduction

Using digital models of cultural heritage artifacts, obtained through 3D scanner and modeling technology, has the following advantages. It is faster, cheaper, and safer to store, transport, search, sort, and re-arrange digitized models instead of the real pieces. Digitization is also beneficial for the computational analysis of these artifacts as it makes it easier to compute and verify the results.

Although the use of digitized models in cultural heritage research is beneficial, the adoption of such techniques is problematic because nearly all experts are trained for using the traditional methods. Thus, practitioners of the field cannot easily transfer their expertise with traditional tools to new software based tools without further education [1]. Similar problems arise in the medical field as well, where the disparency between computer tools and formal education methods is acknowledged. The generally preferred solution to this problem is to present a familiar interface to the underlying software system.

In the following subsections we will present two traditional tools, the tape measure and the bordimeter, and discuss their usage in the special case of archaeological pottery classification.

1.1 Tape Measure

The tape measure is used for determining the dimensions of a sherd and the surface distance between any two points on the sherd. These measurements are

used for classifying a piece, along with its weight and thickness. It is also used for measuring fracture lengths to aid in reconstruction. The main purpose of the tape measure is to find geodesic distances either on the surface, along the rim, if the sherd is part of the rim, or along the fractured edges.

The tool is used with two hands. The protrusion on the edge of the tape is fastened to one of the end-points of the distance to be measured, then it is held in place using one hand while the other hand pulls the measure and extends the tape to the other end-point. The measurement can be more easily read by locking the tape at the desired length. The tape measure is, in essence, an easier to use metered rope.

1.2 Bordimeter

A bordimeter, also called a rim chart, is a set of concentric circles drawn on a piece of paper or cardboard. It is used for estimating the rim radius of a vessel given a sherd belonging to the vessel's rim. The rim radius is used in calculating the rim size, which in turn helps archaeologists to assess a pot's usage. Radius estimation is also used in volume, and consequently capacity estimation. Both assessments help in the classification of the vessel.

The tool is placed on a flat surface, then a rim sherd is put rim-side down to find the best fitting circle, which is then used to estimate the radius. Because the bordimeter is a solid piece of paper, radius estimation cannot be done with pieces other then rim sherds.

2 Related Work

The most common approach in working with digitized cultural heritage artifacts is to use existing 3D modeling software. The problem is that effectively using these programs needs expertise with the software and user interface which the researcher may lack. They are also general purpose programs, mostly geared toward digital content creation, architecture, or technical drawing and thus may not mimic the traditional way cultural heritage researchers work with artifacts. Applications targetting specific archaeological tasks exist, but they are limited by their tight focus and cannot be easily extended to other domains in analytical cultural heritage research.

2.1 Geodesics

A geodesic curve is the shortest path between two points on a surface. Common areas of use include navigation, path-finding, motion planning and network optimization. It is also an important step in many computer graphics algorithms such as mesh parametrization, mesh segmentation and mesh editing [4–6]. Current graphics hardware all use a triangular mesh format to process and visualize 3D geometries, thus most geodesics research is done for the discrete case [7].

The Djikstra shortest-path algorithm is not sufficient to solve the discrete geodesic problem because the shortest path on a surface does not always follow along the edges of the mesh. The simplest solution is to augment the original mesh with extra points before running Djikstra. Lanthier et. al. [9] compare different ways of populating a mesh with additional vertices on existing edges, called Steiner points, and show that a bounded approximation to the geodesic can be obtained with this method. The error bound and complexity of the algorithm depends on the number and distribution of these Steiner points. An description of the algorithm using a fixed-point distribution scheme, which we used, will be presented in the next section. A survey of approximate algorithms can be found in [8].

Several algorithms giving an exact solution to the discrete geodesic problem have been proposed. The "single source - all destinations" algorithm described by Mitchell, Mount and Papadimitriou (MMP) uses the continuous Djikstra method and it has a worst case running time of $O(n^2 \log n)$, where n is the number of vertices. The MMP algorithm was recently implemented by Surazhky et. al. [11], who conclude that it performs much better than the worst case analysis suggests. An exact algorithm with $O(n^2)$ running time based on surface unfoldings was proposed by Chen and Han [12].

2.2 Circle Fitting

The problem of fitting a circle to a given set of co-planar points is called 2D circle fitting. It is a nonlinear least squares problem, which can be solved iteratively by reducing it to a set of linear least squares problems [3]. The numerical solution we used will be presented in the next section.

3 CH Toolbox

CH Toolbox is a 3D application framework for analytical cultural heritage research. It visualizes digitized models of artifacts in 3D and allows the user to analyze the pieces using a spaceball and mouse driven interface. It has a bi-manual user interaction scheme, where the mouse is used to switch between tools, toggle visualization modes and select the artifacts to be manipulated and the spaceball is used to translate and rotate the selected artifacts. Bi-manual interaction is a familiar human trait, and increases productivity in 3D manipulation tasks [13].

CH Toolbox is developed in C++, using the open-source scenegraph library OpenSceneGraph [14] that helps visualizations in OpenGL by providing an organizational hierarchy. The CH Toolkit and the interactive spatial measurement tools developed for it are available for all the operating systems that OpenSceneGraph supports. Our application runs in real-time on desktop PCs.

We developed a radius estimation and a surface distance measurement tool for the CH Toolbox. They are used interactively inside the framework and allow quick and precise measurements. The next subsections detail their implementation and usage.
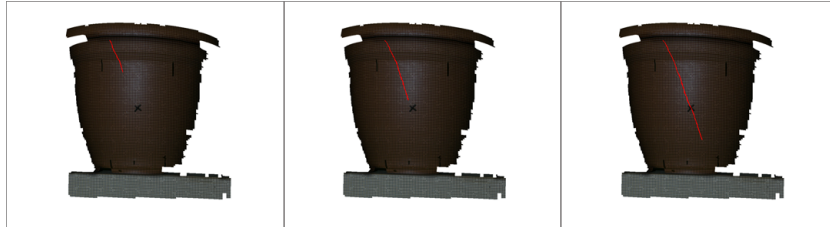
3.1 Virtual Tape Measure

The virtual tape measure is used for measuring the surface distance between two points on a model. The user fixes a point then moves the mouse to interactively visualize and measure geodesics originating from the start point as seen in Figure 1.

We solve the geodesic problem in the pre-processing stage before the artifact model is visualized inside the CH Toolbox environment. The approximate geodesic solution proposed by Lanthier et. al. [9] is used. The algorithm is as follows:

1. The original mesh is loaded and converted to a triangle mesh.
2. Original edges are sub-divided to create extra vertices, called Steiner points.
3. New edges are created between two Steiner points if they are adjacent on the same triangle edge or they lie on different edges of the same triangle.
4. The single-source all-destinations Djikstra is run for each vertex.

We used a fixed scheme to evenly add two Steiner points per edge, therefore 6 vertices and 27 edges are added to a triangle in the pre-processing stage. Lanthier et. al. [9] proved that the algorithm runs in $O(n^5)$ for the single-source all-destinations problem, where n is the number of triangles in the original mesh.

The geodesic is visualized by traversing vertices on the shortest path between the two end points of the tape measure. We choose to visualize the extra edges only if they lie on the shortest path solution, thus the tool has negligible impact on the interactivity of CH Toolbox. The bi-manual interaction scheme of the framework is also conserved while using the virtual tape measure.

Fig. 1. Screenshot of the tape measure in action
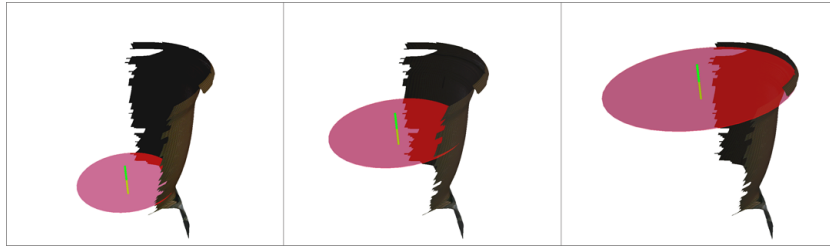
3.2 Virtual Bordimeter

Virtual Bordimeter is a radius estimation tool for digitized artifacts. A best fit circle is computed and displayed interactively as the user moves the mouse over visualization of the artifact model as seen in Figure 2.

The tool works as follows:

1. The plane defined by moving the mouse is intersected with the model to obtain a set of points on the plane.
2. The average of the points is taken as the initial estimate for the circle.
3. The circle is fit iteratively using least squares fitting to these selected points (see Figure 3).
4. The center and the radius of the circle is computed.

Even if the least squares solution does not converge, the iteration for fitting the circle is stopped after a certain number of steps to maintain interactivity. We found that the solution converges in sufficient time if the points are not nearly linear. Otherwise, a warning message is displayed. This is not a problem with our test case since archaeological pottery has a curved surface.

The circle and its center is visualized in addition to the text display of the location of the center and its radius because it helps the expert to visually verify the suitability of the numeric solution as the rotational axis of the artifact. During the measurement process the expert can use the spaceball to move and orient the model. She can also change the transparency of the circle visualization to prevent it from obscuring the artifact.

Fig. 2. Screenshot of the virtual bordimeter in action
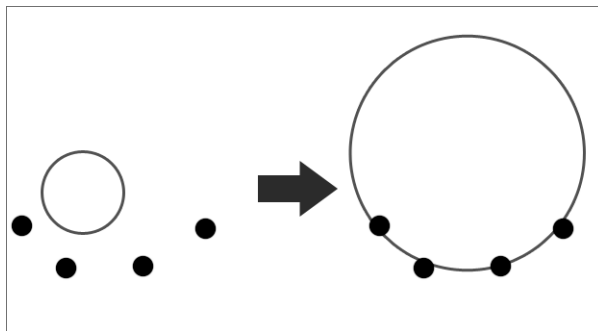
Fig. 3. Circle fitting

4   Results

We tested the surface distance algorithm on a Pentium IV 2.6GHz PC with 1GB RAM and a dual Xeon 3.4GHz workstation with 4GB RAM. For a sherd mesh with 17K triangles, our algorithm takes 16 seconds on the Pentium IV and 14 seconds on the Xeon as seen in Table 1. The number of extra vertices and edges, and its impact on performance is also reported. Although the perfomance is not adequate for real-time interaction, our interviews with cultural heritage experts show that the it is acceptable for real world use cases [1].

Table 1. Performance of approximate geodesic algorithm

Model	Vertices	Faces	Stn. points	Stn. edges	time 1 (s)	time 2 (s)
Sherd	9183	17696	62967	427304	16.2003	14.0507
Sphere	25502	50986	178502	1230534	47.5673	41.2052
Sphere	102302	204552	716102	4938138	202.2870	175.5850

We also compared rim estimations and surface distances measured on a real pot with the approximate results we got using our virtual tools on a sherd mesh (Table 2). The error rate of the geodesic is very small, and it is consistent with the bound proven by Lanthier et. al. [9]. Again, the error was found to be acceptable by experts [1] although it includes the error from the 3D scanning process as well.

Table 2. Error rate of virtual tools

Tool	Real (cm)	Virtual (cm)	Rel. error
Tape	15.35	15.44	0.6%
Bordimeter	12.74	12.17	4.5%

5   Conclusion and Future Work

Our contribution is the development of a platform for interactive computer-aided cultural heritage tasks. We implemented measurement tools that archaeologists daily use in real life by adapting algorithms developed for other computational geometry tasks. The algorithms we chose are suitable for use in a real-time interactive environment.

Accuracy problems of the radius estimation tool must be further researched. We suspect the relatively high error rate is due to errors in the 3D scanning technology we used. Our tools should be tested with models obtained from other scanning technologies.

CH Toolbox was approved by the cultural heritage experts who have seen it. We plan to release CH Toolbox as an open-source application to aid researchers in the cultural heritage domain.

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