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Unfolding a Point Cloud on Relic's Surface for Surface Pattern Visualization

Zepeng Wang Katsutsugu Matsuyama Kouichi Konno

Graduate School of Engineering, Iwate University

{xiaoxie@lk.cis., kmatsu@, konno@cis.} iwate-u.ac.jp

Abstract

Developable surfaces are important for representing and understanding geometric features of 3D models. Some methods are required that surface pattern of a relic should be easily observed in archaeology area. This paper introduces a system to visualize the development of relic's surface pattern based on points, which does not require reconstruction of a mesh model and relies only on the information of points to develop the relic's surface. After a point cloud of a relic is segmented to separate sections, points of each section are projected to a developable surface, then the points of relic's surface are unfolded into an image plane. In our method, the number of segmentations can be controlled by an archaeologist in an interactive interface. The more segmentations a point cloud is divided into, the higher precision the image plane is shown in adjacent area. To observe the surface pattern easily, a developed plane can be interactively rotated on the prime meridian, which is extracted from a relic's surface. This approach can help archaeologists move a specific area of interest to the center of the relics.

Keywords: Point cloud, Development, Surface pattern, Visualization, Relics

1 Introduction

With the development and cost reduction of three-dimensional scanning devices[1], archaeological survey records[2] are not limited to two-dimensional scale drawing[3, 4], photograph or rubbed copy. For a great number of relics, it has become easy to create a record of three-dimensional point clouds. In order to represent easily and understand the features of relics, archaeologists prefer to develop relics' surface for observing surface pattern[5].

Many traditional methods have been presented for archaeologists to observe the patterns, such as scale drawings, rubbed copies, photos, or exploded view of illustrations by tracing the surfaces[2]. These methods, however, have some problems. Scale drawing is carried out manually to measure the surfaces with a triangle ruler, divider, Mako and other tools[2]. Since there is some distortion in shape and size, a certain degree of error cannot be avoided. When a decorative pattern on pottery appears in a narrow area, surface measurement becomes more complicated. Even by a very skilled technical illustrator, the measurement takes a long time and efforts. The major disadvantage of scale drawing is quite subjective. There can be a case in which different archaeologists create different scale drawings with their own intentions and perspectives.

Currently, photos provide a simple and effective way to observe surface pattern. The images on cylindrical relics can be rolled out by using photographic techniques. But any photographic techniques[6] are influenced by ambient light. In addition, photographers have to decide a specific projection before the photographic process. As is the same as scale drawings, rubbed copies are also carried out manually. No matter how brush ink is applied directly on an object surface, or no matter what coated ink is used on paper, relics will be stained. A clear disadvantage of all traditional techniques is that they frequently require direct contact with the relic's surface. Recently, the method based on frustum rollouts[7] using high resolution 3D meshes is introduced. An object is projected onto a frustum's mantle and is developed into an image plane. Unfortunately, it requires reconstruction of a mesh model, which describes the geometry of an object in a list of 3D points and surface.

This paper proposes a method to visualize the development of relic's surface patterns based on points, and it does not require reconstruction of a mesh model and relies only on the information of points to develop the surface. A point cloud of a relic's surface is projected to a developable surface represented by a bilinear Bézier surface and it unfolded into an image plane. To observe the surface pattern easily, archaeologists can rotate on the prime meridian extracted on the relic's surface. It can help archaeologists move a specific area of interest to the center of the relics. With the implement of proposed method, effectiveness of our development method is confirmed.

Figure 1: Example of unfolded surfaces[8]

2 Related Works

2.1 Traditional Method

Scale drawing comes from graphics of engineering archeology. For charting subtle lines efficiently, the tool shaped like Mako is used, as shown in Figure 2. The pictures show how the scale drawing is performed to measure the surface patterns on the pottery surfaces.

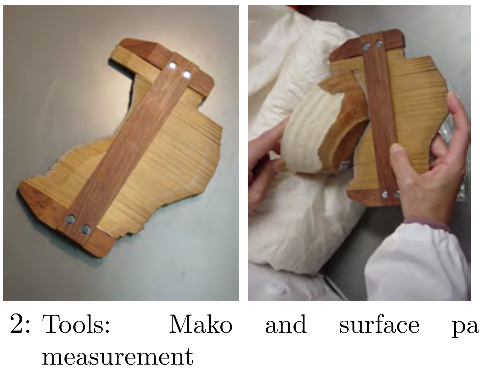


Figure 2: Tools: Mako and surface pattern measurement

When a rubbed copy is taken, a sheet of paper shown in Figure 3 is pressed against the uneven patterned surface or the characters carved on a vessel of metal or stone monument, and the ink is applied. There are two types of rubbing taking: dry copy and wet one. When a dry copy is taken, a dry paper is placed on the surface of an object and the special soft ink is applied on the paper surface. When a wet copy is taken, the paper is soaked in water and applied to the surface of an object and the object with the paper is left until the paper is semi-dried. Then a piece of cloth or brush is applied thoroughly and the patterns and characters are copied with ink. Figure 3 shows how a rubbed copy on the surface patterns on the pottery surfaces is taken.

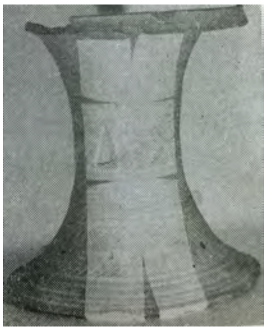


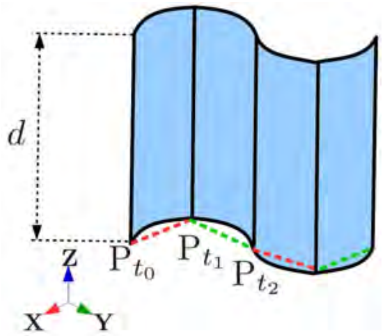
Figure 3: Rubbed copy[2]

2.2 Rollout Photography

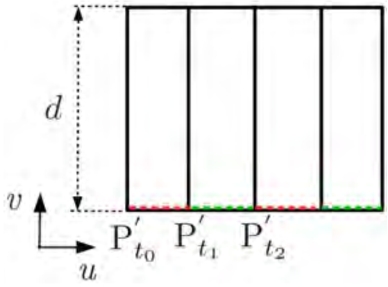
Rollout Photography requires a structured-light 3D scanner to acquire surface models, which contain a list of vertices, triangles, and its color information. The partial models scanned by different directions are merged and saved in a PLY 3D model[7]. For developing a relic's surface without inevitable distortions, an object is divided into a number of separate sections. Each section is projected onto a frustum's mantle, which is based on conical mantle, then it is developed onto a plane.

2.3 Developable Surface

The developable surface is a curved surface that can be developed into a plane without any stretch. In mathematics, one of the developable surface is a ruled surface, having Gaussian curvature K, which is equal to zero everywhere. Figure 4 shows how to develop a developable parametric surface. In Figure 4(a), a direct curve of a ruled surface is cut into 4 sections by given parameters. In the u direction, the length of the curve between points $\mathbf{P}_{t_0}$ and $\mathbf{P}_{t_1}$, whose parameters are t_0 and t_1 in a ruled surface, is equal to the distance between points $\mathbf{P'}_{t_0}$ and $\mathbf{P'}_{t_1}$, whose parameters are t_0 and t_1 of the image plane. In the v direction, the common distances d is defined in Figure 4(a) and (b).



(a) A ruled surface



(b) An image plane

Figure 4: A developable parametric surface

3 Our Unfolding System

3.1 Overview

In this paper, a visualization system for development of relic's surface patterns based on points is introduced. The flowchart of the system is shown in Figure 5. The process of the system

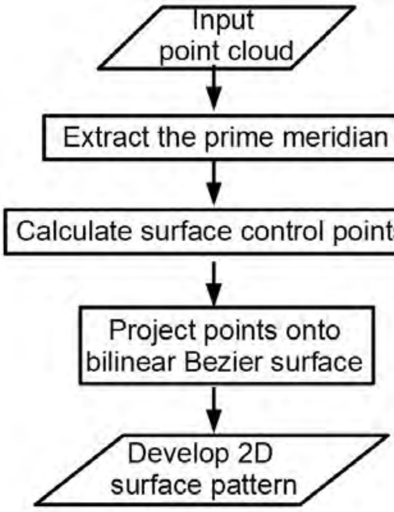


Figure 5: Flowchart of the system

is as follows.

(1) A prime meridian is defined from extracted points of the object's outline in the vertical direction.

(2) By using a defined guide curve and cross sections, the surface control points are calculated through segmentation of a point cloud.

(3) Projection onto the bilinear Bézier surface is introduced to develop a point cloud to an image plane.

(4) Projection filter is created for point reduction.

(5) To observe the only non-distorted place, the developed plane can be interactively rotated on the extracted prime meridian.

3.2 Prime Meridian Definition

To determine a reference line for developing a surface, points on the object's outline are extracted in the vertical direction as the prime meridian of the developed image plane. In Figure 6, the center axis of a point cloud coincides with Z-axis in the coordinate system. Points $\mathbf{Q}_i(x_i, y_i, z_i)$ nearby the cross section of XOZ plane are obtained if the both conditions of equation (1) are satisfied.

$$x_i \geqq 0, \quad |y_i| \leqq \epsilon \tag{1}$$

Where, ϵ is initialized as 0.01. The red line connected to $\mathbf{Q}_i$, is extracted as the prime meridian of the relic's surface. The point cloud of an object will be developed along this prime meridian.

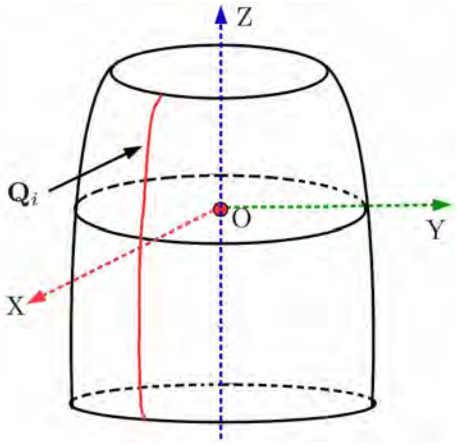


Figure 6: Prime meridian

3.3 Surface Control Point Definition

In this section, the control points of a Bézier surface are defined through segmentation of a point cloud. A guide curve is introduced to define the cross sections for calculating the control points. As shown in Figure 7, the red curve is extracted prime meridian. Meanwhile, the straight blue line is the defined guide curve, coinciding with Z axis.

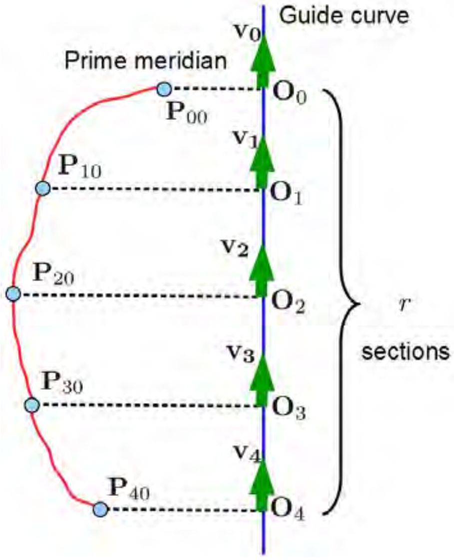


Figure 7: A guide curve

The guide curve is split into a variable r sections by step parameters. Since the guide curve coincides with the Z axis, the straight line $\mathbf{O}_0\mathbf{O}_4$ is divided into equal r (= 4) sections as shown in Figure 7. Points $\mathbf{O}_0$, $\mathbf{O}_1$, $\mathbf{O}_2$, $\mathbf{O}_3$ and $\mathbf{O}_4$ are equidistant split points. Green arrows $\mathbf{v_0}$, $\mathbf{v_1}$, $\mathbf{v_2}$, $\mathbf{v_3}$ and $\mathbf{v_4}$ are the tangent vectors of the guide curve at points $\mathbf{O}_0$, $\mathbf{O}_1$, $\mathbf{O}_2$, $\mathbf{O}_3$ and $\mathbf{O}_4$.

As a result, the cross sections are defined as the planes, going through the split points perpendicularly to tangent vectors $\mathbf{v_i}$. Points $\mathbf{P}_{00}$, $\mathbf{P}_{10}$, $\mathbf{P}_{20}$, $\mathbf{P}_{30}$ and $\mathbf{P}_{40}$, shown in Figure 7, are intersection points between the prime meridian and the cross sections. They are considered as control points on the prime meridian.

The equidistant points may not be obtained in some cases. In order to get over it, points on the prime meridian are approximated by a B-Spline curve[10]. There is a set of $n+1$ points of prime meridian, $\mathbf{Q}^0_0$, $\mathbf{Q}^0_1$, ..., $\mathbf{Q}^0_n$. In equation (2), a B-Spline curve of degree ρ defined by $n+1$ control points that passes through data points of the prime meridian in the given order. Parameter values $t_0, t_1, ..., t_n$ and knots u_0, u_1, ..., u_{n+p+1} can be obtained by equations (3) and (4).

$$\mathbf{C}(u) = \sum_{i=0}^{n} N_{i,\rho}(u)\mathbf{P}_i \tag{2}$$

$$t_k = \begin{cases} 0, (k=0) \\ \frac{\sum_{i=0}^{k} |\mathbf{Q}^0_{(i+1)} - \mathbf{Q}^0_i|}{\sum_{i=0}^{n} |\mathbf{Q}^0_{(i+1)} - \mathbf{Q}^0_i|}, (k = 1, ..., n-1) \\ 1, (k=n) \end{cases} \tag{3}$$

$$u_m = \begin{cases} 0, (m = 0, 1, ..., \rho) \\ \frac{1}{\rho}\sum_{i=j}^{j+\rho-1}(t_i), (m = \rho+1, \rho+2, ..., n) \\ 1, (m = n, n+1, ..., n+1+\rho) \end{cases} \tag{4}$$

In Figure 8, the pink points in each row section forms a circle. The top view of the pink points are shown in Figure 9. $\mathbf{O}_0$ is the center of the pink points in 0th row. In addition, the 0th row is on the cross section, which is orthogonal to and passing through the tangent vector of split point $\mathbf{P}_{00}$ at the guide curve. By dividing the circle of pink points into equal angluar sections, the surface control points are defined in a row. As shown in Figure 9, $\mathbf{P}_{00}$,$\mathbf{P}_{01}$,$\mathbf{P}_{02}$,$\mathbf{P}_{03}$,$\mathbf{P}_{04}$, $\mathbf{P}_{05}$ and $\mathbf{P}_{06}$ are the control points in the 0th row. In this paper,the process of dividing a point cloud into *row* × *column* sections can be controlled by users. The greater sections the point cloud of an object is segmented into, the closer the length of the developed image plane will be to the arc length of object's surface.

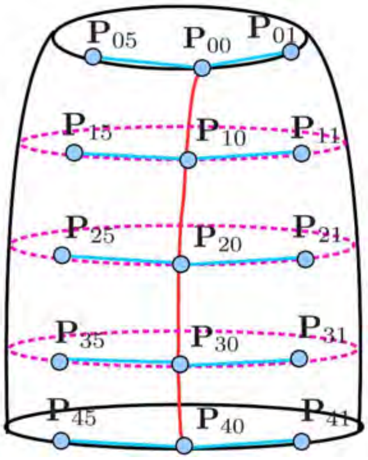


Figure 8: 3D model

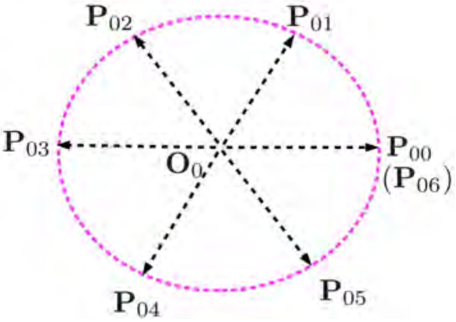


Figure 9: Control points definition in a row

3.4 Point Cloud Development

In order to develop a point cloud, projection to a bilinear Bézier surface is required. Surface control points of a bilinear Bézier surface are shown in Figure 8 with the blue points. The corresponding control points on the developed image plane are shown in Figure 10. Equation (5) tells us that a bilinear surface is obtained by blending the effects of the control points $\mathbf{P}_{ij}$, $\mathbf{P}_{(i+1)j}$, $\mathbf{P}_{i(j+1)}$ and $\mathbf{P}_{(i+1)(j+1)}$. They are weighted by the blending functions $(1-u)(1-v)$, $u(1-v)$, $(1-u)v$ and uv. The parameters of u and v are defined from

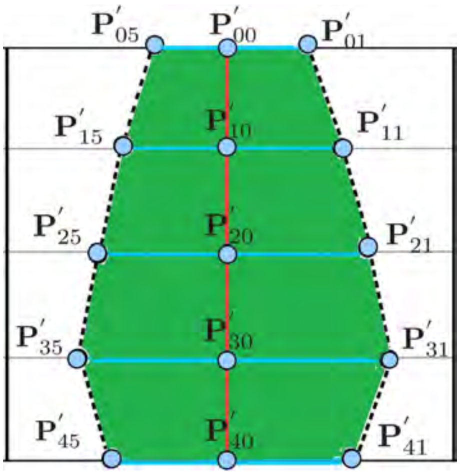


Figure 10: Development control points along the prime meridian

0 to 1.

$$\begin{aligned}\mathbf{P}(u,v) = {} & (1-u)(1-v)\mathbf{P}_{(i+1)j} \\ & + u(1-v)\mathbf{P}_{(i+1)(j+1)} \\ & + (1-u)v\mathbf{P}_{ij} + uv\mathbf{P}_{i(j+1)}\end{aligned} \tag{5}$$

In Figure 6 and 9, a point cloud is segmented into 4×6 sections by using the surface control points. Figure 10 shows the developed surface control points along the prime meridian. $\mathbf{P}_{ij}$ are developed to $\mathbf{P}'_{ij}$ $(0 \leqq i \leqq 4,\ 0 \leqq j \leqq 6)$. In addition, distance between $\mathbf{P}_{ij}\mathbf{P}_{i(j+1)}$ and $\mathbf{P}'_{ij}$ $\mathbf{P}'_{i(j+1)}$ are equal. The distance between surface control points $\mathbf{P}_{i0}$ $\mathbf{P}_{(i+1)0}$ and $\mathbf{P}'_{i0}$ $\mathbf{P}'_{(i+1)0}$ are also equal along the prime meridian. In the same manner, in each segmentation of a Bézier surface, there are the same parameters (u, v) on a projection point and its corresponding developed point. As a result, the areas adjacent to prime meridian are the only non-distorted place. In Figure 10, green areas are not distorted.

3.5 Projection Filter

In order to reduce points projected to a bilinear Bézier surface, a filter is introduced. Figure 11 shows point $\mathbf{Q}$ of a relic surface projected to a bilinear Bézier surface $\mathbf{Q}'$. Point $\mathbf{O}$ is defined as the center of the section points. The parameter for projection $\mathbf{Q}'$ can be calculated as (u', v').

Since distance $|\mathbf{QQ}'|$ is shorter than $|\mathbf{QO}|$, the distance between point $\mathbf{Q}_i$ of the relic's surface and its corresponding projection point $\mathbf{Q}'$ is calculated as D_i. Besides, the max distance is defined as D_{max}. The projection filter is related to the distance, ranging from 0 to 1. Therefore, the parameter of each point is set as γ_i, calculated by Equation (6). The minimum value in the range can be arbitrarily set by the user.

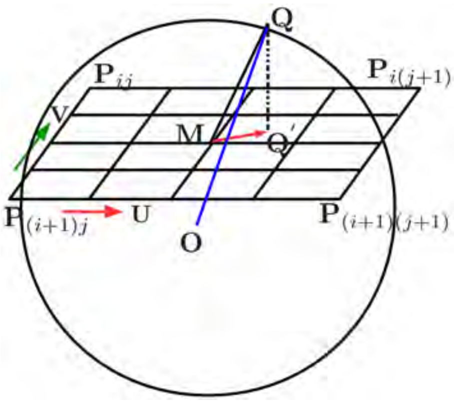


Figure 11: Projection to a bilinear Bézier surface

$$\gamma_i = \frac{D_i}{D_{max}} \tag{6}$$

3.6 Unfolded Pattern Rotation on Extracted Centerline

In cartography, a map can be rotated around the earth's axis. The same idea is introduced to our system. In our method, the unfolded areas adjacent to prime meridian are the only non-distorted places. In order to freely observe non-distorted areas, rotating the developed image plane around the prime meridian is proposed. The objective of this process is to freely present to the observer a planar representation of the object's characteristics. The extracted centerline of the object surface is defined as the longitude.

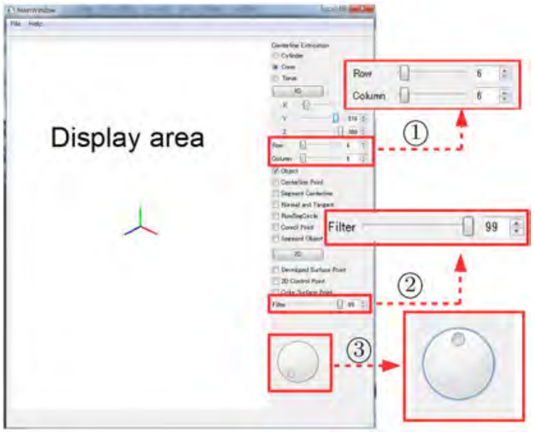
4 Experimental Results

In our experiment, three kind of point clouds of relics were examined, as shown in Figure 12. In order to satisfy the users for observing relic's surface patterns, points were manually deleted in the marked areas in Figure 12 (a) and (c), where there were no patters or points on the object's surface.

(a) Jommon pottery (b) Pottery (c) Replica of ring-headed pommel

Figure 12: Experimental relics

The interface of our system is shown in Figure 13. The number of segment parts in rows and columns can be controlled by modifying the sliders ①. To reduce points projected to a Bézier surface, the minimum value of the projection filter will be arbitrarily set by using the sliders ②. Different views of a developed image plane can also be rotated by the jog dial ③. Our system runs on 64-bit Windows 7 with Intel Core i7 CPU 3.40 GHz and 16.00GB RAM. The processing time for development a 3D point cloud of the relic's surface to an image plane depends on the number of points and segments.



Row 6
Column 6
Filter 99

Figure 13: Interface of development system

4.1 Unfoldment Result

Figure 14, 16 and 18 show the extracted prime meridians of the point clouds, shown with the red lines. The surfaces of these three relics are developed, containing 149,251, 193,590 and 651,912 points respectively. In Figure 13, the users can freely control the row and column sliders to segment point cloud. Two point clouds are segmented into 6*6 sections, as shown in Figure 15 and 17. In Figure 19, a point cloud is segmented into 20*6 sections. There are no distortion in blue and black areas in the middle, adjacent to the prime meridian.

In Figure 15, 17 and 19, the marked areas by the red circles show the developed image plane before and after rotation. In Figure 18, the red line is the defined guide curve that is a B-Spline one obtained by approximating the points on the prime meridian. The guide curve is split into twenty sections by using the step parameters. The green lines are the tangent vectors on the split points. It is obvious that the pink points lie on the cross section, which are orthogonal to the tangent vectors.

4.2 Rotation on Extracted Centerline

In our relic's surface visualization system, a jog dial for range control is provided to rotate the developed image plane around the prime meridian. The least distortion is measured in both sides of the prime meridian. Figure 15, 17 and 19 show the results of rotation. After rotating the developed image plane, the marked areas by the red circles are moved to the non-distortion areas.

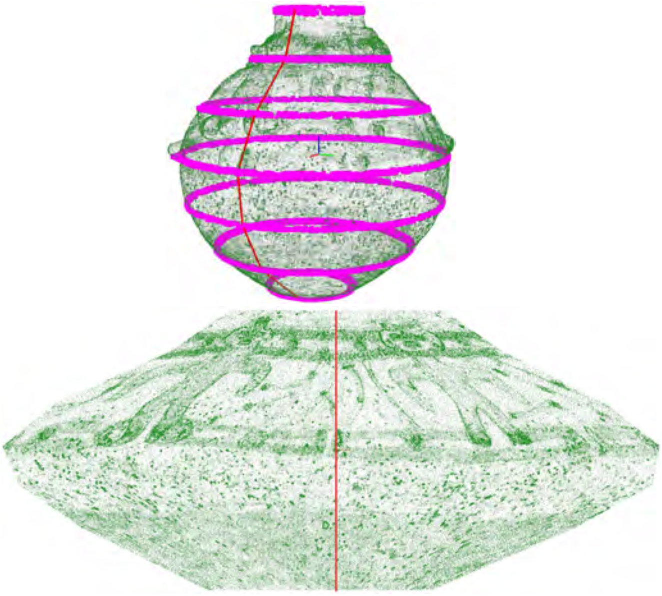


Figure 14: Extracted prime meridian and developed plane

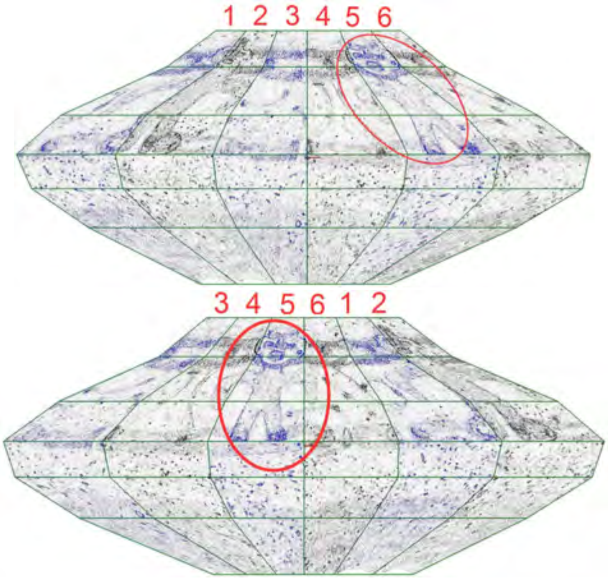


Figure 15: Point cloud segmented into 6*6 sections and rotation

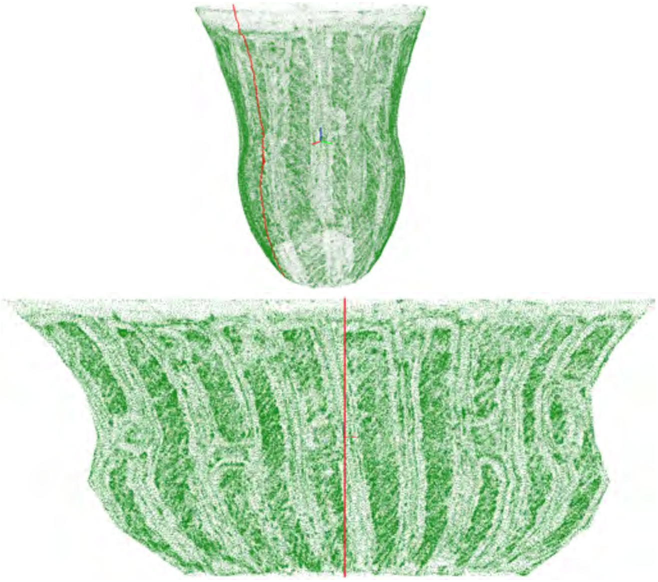


Figure 16: Extracted prime meridian and developed plane

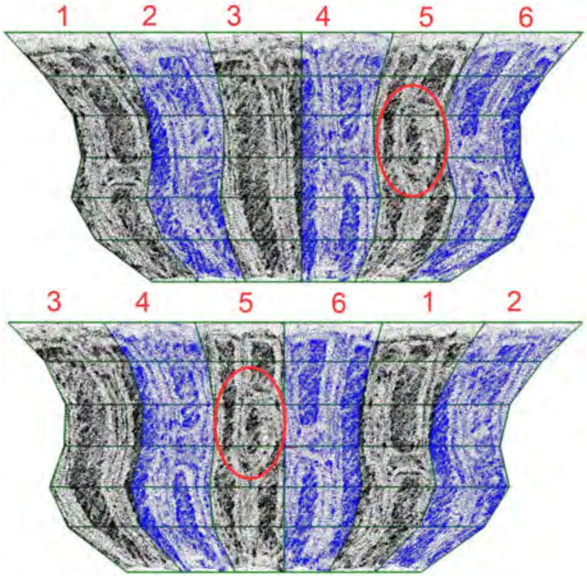


Figure 17: Point cloud segmented into 6*6 sections and rotation

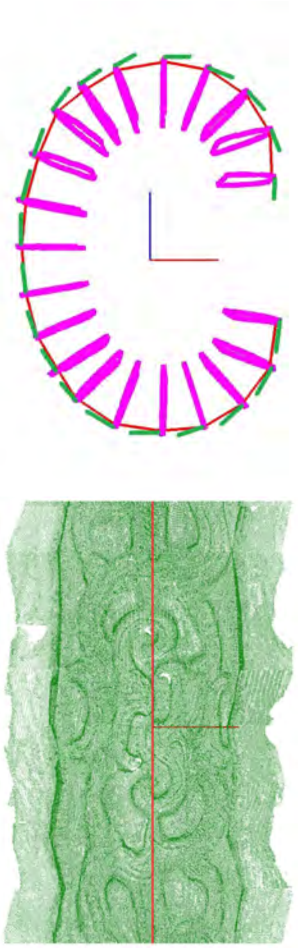


Figure 18: Extracted prime meridian and developed plane

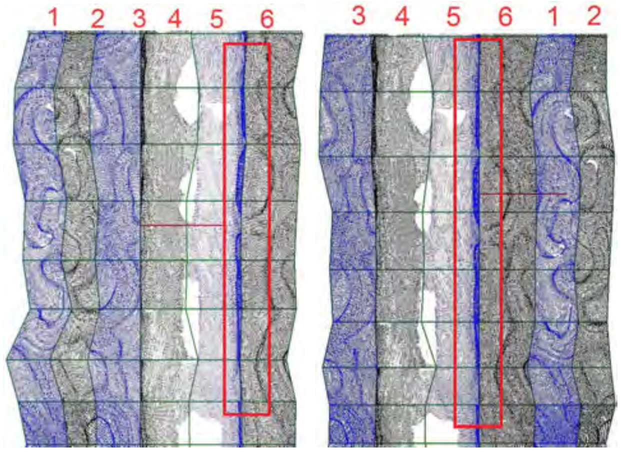


Figure 19: Segment point cloud into 20*6 sections and rotation

5 Conclusions and Further Work

In this paper, the development system of relic's surface patterns based on points is proposed. The measured points on a relic's surface are segmented into separate sections and each section is projected to a developable surface of a bilinear Bézier surface. The points on a relic's surface are developed onto an image plane according to the u-v coordinate system.

In the process of development, the number of segment sections can be set by using the sliders of the interactive interface. The segment sections are brushed in different colors and it becomes easier to view the development areas. In addition, the distance based on the filter slider is created to reduce the number of points projected to a bilinear Bézier surface. To help archaeologists to observe a specific area of interest, the unfolded image plane can be rotated around the prime meridian by the jog dial. Comparing to the tradition developments of relics' surface pattern, our visualization system requires less money, time and energy.

We will introduce the characteristic lines to the developed image planes as the future work.

Acknowledgements

The basic concept of our method has already been presented in NICOGRAPH 2015[19] and we extended the concept in this paper. We are extremely grateful for lots of efficient advice from the paper reviewers.

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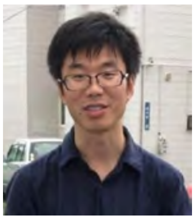
Zepeng Wang



Zepeng Wang is currently a Ph.D student in Faculty of Engineering at Iwate University. He received the BE degree in College of Information Engineering from Northwest A&F University in 2009. He earned the ME degree in Faculty of Engineering at Iwate University. His research interests include information visualization,interactive systems and computer graphics.

Katsutsugu Matsuyama

Katsutsugu Matsuyama is cur- rently an assistant professor at Iwate University. His research interests include computer graphics, information visualization and interactive systems. He received BE, ME, DE degrees in computer science from Iwate University in 1999, 2001 and 2005, respectively. He was a research associate at Future University-Hakodate from 2005 to 2011.

Kouichi Konno

Kouichi Konno is a professor of Faculty of Engineering at Iwate University. He received a BS in Information Science in 1985 from the University of Tsukuba. He earned his Dr.Eng. in precision machinery engineering from the University of Tokyo in 1996. He joined the solid modeling project at RICOH from 1985 to 1999, and the XVL project at Lattice Technology in 2000. He worked on an associate professor of Faculty of Engineering at Iwate University from 2001 to 2009. His research interests include virtual reality, geometric modeling, 3D measurement systems, and computer graphics. He is a member of IEEE.