Visual Salience Estimation of 3D Mesh Models

Xiang-peng Liu[1], Xing-qiang Yang[2], Yi Liu[2], Cai-ming Zhang[2]
1. Computer Department
Jinan Vocational College
12, Shungeng Road, Jinan, 250011
CHINA
2. School of Computer Science and Technology
Shandong University
1500, Shunhua Road, Jinan, 250101
CHINA
yxq@sdu.edu.cn

Abstract: - The visual salience is an important property of 3D mesh model. There are many metric, including methods based on geometry and ones based on images. It is difficult for the former to infer the direct relationship between geometry and visual stimuli, and the latter is affected by the viewpoint and light source. The visual salience of 3D mesh geometry elements, such as the vertex, edge and patch, is a basic issue which this paper concerns. This paper regards the brightness difference and the contour line as direct factors to stimulate eyes, and deduces the relation between these direct stimuli and the mesh model. The brightness contrast of 3D mesh geometry elements is determined by the model, viewpoint, and light. We treat the light source and viewpoint as variables and compute the maximum brightness contrast of geometry elements for any view point and light source. The maximum brightness contrast is determined only by the model, not the viewpoint and light. So it can be used for measuring the visual salience of the geometry element. The contour line is another important factor to vision. The probability of a geometry element appearing on contour lines is measured and is also treated as a metric of visual salience. Many results of experiments show that our metric accords with human eyes.

Key-Words: - Salient feature, Visual perception, 3D mesh model, contour line.

1 Introduction

3D mesh models have become a universal form to describe 3D shapes in the fields of industrial design, medical science, digital entertainment, etc. A lot of research work has been done in the fields of the representation [1], rendering and transmission of 3D mesh models. Now human visual perception has been incorporated into mesh processing and rendering, for examples, improving the performance of generating and transmitting visual data, simplification of the mesh, and embedding digital watermarking. The visual salience is used for describing regions of a 3D model which attract our attention, and can plays an important role to adjust the illumination and shading to enhance the geometric salient features of the underlying model[2-4]. It depends on not only the geometry of 3D model but also human visual system. This paper will study the former, that is, what kinds of geometry attract more attention of human vision, without taking into account the human factors such as goals of vision, personal history and experience. We place emphasis on salience of the local geometry elements, such as the vertex, edge and triangle patch, which are the basic elements to form the salience of the 3D mesh model.

There are rich literatures [3-4] on the research of the visual salience. Some methods based on the image even ask human involvement. Sarah Howlett etc [5] attempt to determine the salient by using an eye-tracking device to capture human gaze data and then investigate if the visual fidelity of simplified polygonal models can be improved by emphasizing the detail of salient features identified in this way. However it is not feasible to perform eye-tracking on every known object and that human intervene is just what we try to avoid. P. Lindstrom etc [6] introduce the notion of image-driven simplification, a framework that uses images to decide which portions of a model to simplify. Their method produces models that are close to the original model according to image differences. But it is dependent on view points. The literature[7] examines three different experimental techniques for measuring these fidelity changes: naming times, ratings, and preferences. They also examine several automatic techniques for predicting these experimental measures, including techniques based on images and on the models themselves.

It is convenient to measure the visual salience based on the geometry feature, which is widely used. The surface curvature gives a unique and viewpoint-independent description of a local shape. Gabriel Taubin [8] describes a method to estimate the tensor of curvature at the vertices of a 3D mesh. Peng [9] estimates Gaussian curvature at a vertex as the area of its small neighborhood under the Gaussian map divided by the area of that neighborhood. Alexander Belyaev [10][11] presents a method for detection of perceptually salient curvature extrema on surfaces approximated by dense triangle meshes. Lee etc [12] also shows the disadvantages of the curvature to describe the salience mesh, and they define mesh salience in a scale-dependent manner using a center-surround operator on Gaussian-weighted mean curvatures. Massimiliano e Corsini etc [13] present a new methodology for subjective evaluation of the quality of 3D objects. They derive two objective metrics from measures of surface roughness and assess their efficiency to predict perceptual impact of 3D watermarking. Hausdorff distance is often employed to measure distortions [14], which are sensitive to vision. However, it is a global methodology, and is not directly related to vision. Similarly, SNR and PSNR are faced with the same problems. Bian Zhe etc [15] bring up a method of quantifying small visual differences between 3D mesh models with conforming topology, based on the theory of strain fields.

Based on these observations, Chen[16] use regression analysis to combine multiple properties into an analytical model that predicts where Schelling points are likely to be on new meshes. The literature[17] proposes a new computational model of visual attention for stereoscopic 3D still images.

Visual salience is the distinct subjective perceptual quality which makes some items in the world stand out from their neighbors and immediately grab our attention. The metrics based images use the contrast between pixels and their neighbors to describe the visual salience of a region. Unlikely, an image only display what we can see at one view point. Geometry features intuitively reflects the shape’s affection to human vision, however, it is difficult to find the direct relation between geometry features and their stimulations to vision. The approach based on geometry doesn’t consider how the model is displayed to people, for example, some concave area may be not visually salient although its curvature is big. This paper try to define the mesh salience based on what the eye can perceive, especially contrasts between items and their neighborhood. We do researches on not only the shape of the model but also how it appears to human vision.

2 Basic ideas

The colors in the image are direct stimulations to vision, and intensity of the stimulation is measurable. On the other hand, geometry features (such as curvature) are abstract concepts, and we cannot tell how much a geometry feature produces stimulation to our vision. In fact, geometry features always act on our vision in a form of image. So we attempts to convert the geometric shape into forms of images and measures their visual salience.

The contour line and brightness difference are direct factors to stimulate the vision in an image. They are determined by the geometry of 3D model, light source and viewpoint. We treat the light source and viewpoint as variables and deduce the maximum brightness difference of geometry elements for any view point and light source. Thus, the maximum brightness difference is determined only by the model, so it can be used for measuring the visual salience of the model. The contour line is a more important factor to stimulate human eyes, but a part of the model is not always on the contour lines. So the probability of a geometry element appearing on the contour line is measured and is also treated as a metric of visual salience.

The vertex, edge and triangle patch are the basic geometry element of 3D mesh model. It is an essential issue to study their visual salience. For a geometry element, let s be its visual salience in some image, and let p be the probability of s appearing, the average visual salience of the geometry element can be expressed as

$$\bar{s} = \sum_{for\ all\ images} p \cdot s$$

Notice that the p and s all depends on geometry, light source and view point. It is very difficult to compute this equation strictly, so next we will find a simple and reasonable way to obtain the visual salience based on this equation.

2.1 Visual characteristic quantity of 3D models

Human vision reconstructs the shape of 3D model according to the different grayscales of 3D model image. There are three possible situations of grayscales variation between adjacent pixels in an image of 3D model:

(1) The grayscale is continuous. This means the surface of the 3D model and the normal vector are all continuous. The more gradual the surface is, the less the grayscale variation is. For an edge, the brightness difference of its two side patches shows the visual salience of this edge. Most of 3D model can be thought as continuous when the triangle patches are small enough, see Fig.1 (1).

(2) The grayscale is not continuous, but the surface of model is continuous. Here the normal vector between two adjacent patches is not continuous, and there is a clear edge between them, see Fig.1 (2).

(3) The grayscale is not continuous, and the surface of model is not continuous too. Here the breaking of grayscale shows the contour line of the model. The two sides of the contour line are the model and its background respectively. The regions marked with circles in Fig.1 (1) and (2) are some examples of contour lines.

The brightness difference shows the concave or convex parts of the model. Especially, the contour line is a break on the grayscale, which describe the key shape of the model. The vision is stimulated by the contour line and brightness difference of the model, so we want to know what kinds of geometry elements often appears as contour lines and forms big brightness difference.

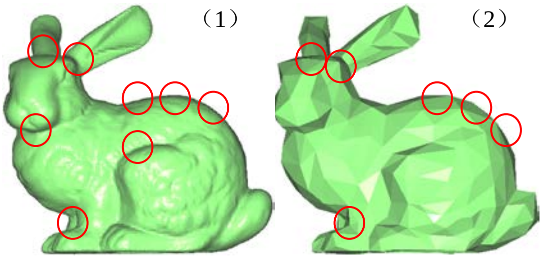


Fig.1 Continuity between two adjacent patches: The surface and normal are all continuous; the surface is continuous but the normal is not; neither is continuous.

2.2 Brightness Difference

For simplicity, we render the image with the simple illumination model, in which the ray of light is parallel, and only diffuse reflection is considered. This illumination model is enough to display the shape feature. The brightness of every patch is only relative to the intersection angle between its normal vector and the ray of light. So we can express the brightness of the patch below:

$$b = G(p, l, v)$$

Where p denotes a patch, l denotes the ray of light, v denotes the viewpoint, and b denotes the brightness of the patch p, and G stands for the illumination model. The brightness difference between two patches can be expressed

$$\Delta b = | G(p_1, l, v) - G(p_2, l, v) |$$

Δb is affected by the ray of light and the viewpoint. Different rays of light may make the brightness difference different. However, there exists the L and V, which makes the Δb maximum.

$$\Delta b_M = \max(| G(p_1, L, V) - G(p_2, L, V) |) \qquad (1)$$

Δb_M is related to the geometry only, and it doesn't depend on the ray of light and view point. So we regard it as a metric of visual salience of 3D models.

2.3 The contour line and view Point

The contour line reflects the shape feature of 3D model, to which human vision pays attention. An edge or a vertex is visually salient when they are on the contour line. A geometry element may appear on the contour line only when the view point is in some region that is denoted as contour-viewing region of a geometry element. The size of contour-viewing section depends on the local geometric shape of a geometry element. The bigger the contour-viewing region is, the more chance the geometry element is seen on the contour line. Some geometry elements never appear on the contour line, such as concave edges or concave vertexes, so they seldom give rise to eye's concern.

For an edge or vertex, it is on either a contour line or not. When it is on the contour line, it is certain to give rise to visual attention and we think the geometry element is most salient. When it is not on the contour line, the brightness difference that it produces can be used to measure its visual sensitivity.

Assume that V1 is the contour-viewing region of a geometry element, its non-contour-viewing region is V2, and V3 stands for the region in which the eye cannot see it. Then V= V1+V2+V3 indicates the entire space. Assume E is the brightness of a patch when the ray of light illuminates it perpendicularly, which is the brightest, and the brightness of background is 0, then the brightness difference between two sides of an edge is in the interval [0, E]. Let Δb_M is the maximum brightness difference when the viewpoint is in the region V2, the visual salience of an edge or vertex can be expressed as

$$S_v = \frac{V_1}{V} \cdot E + \frac{V_2}{V} \cdot \Delta b_M \qquad （2）$$

Just like the normal of patch, the size of the patch also affects the vision. Assume the total area of the adjacent patches of a geometry element is w, Sv can be instead by w·Sv. We focus on the vertex and edge of a patch in this paper. As for salience of a patch, it depends on its area and the salience of its boundary(edges and vertices).

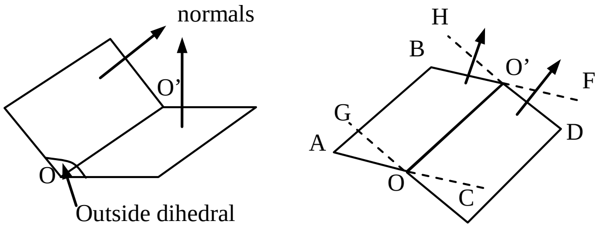
We will discuss the computation of the items in equation (2) in section 3.

3 Methods

Since edges and vertices are color boundaries in an image of the 3D model, we can assess the local visual salience of the model as long as we grasp the brightness contrast based on edges and vertices. In the following we will discuss the local visual salience by analyzing the grayscale features of edges and vertices in the image respectively.

3.1 The Visual Salience of Edges

The visual salience of an edge is relevant to its both side patches. If the outside dihedral angle of two adjacent patches is less than or equal to 180 degrees, the edge will not become a part of the contour lines. As is shown in Fig. 2(1), the edge OO' is the common part of two patches, it can never appears on the contour line no matter where the view point is. If the outside dihedral angle is greater than 180 degrees, as is shown in Fig.2(2), the edge OO' will probably become a part of the contour line. For example, if the viewpoint lies inside the dihedral AOG or the dihedral COE, see Fig.2(2), the edge OO' will appear on the contour line; if the viewpoint lies inside the dihedral EOG, it will not be on the contour line.



(1) Not on the contour line (2) On the contour line

Fig. 2 An edge is on the contour line if and only if the outside dihedral is greater than 180 degrees.

The outside dihedral angle is denoted as α, then the variables V1, V2 and V3 in equation (2) can be calculated according to the following equation.

$$V_1 = \begin{cases} 0, & 0 < \alpha < \pi \\ 2\alpha - 2\pi, & \alpha \geq \pi \end{cases}$$
$$V_2 = \begin{cases} \alpha, & 0 < \alpha < \pi \\ 2\pi - \alpha, & \alpha \geq \pi \end{cases}$$
$$V_3 = \alpha \qquad (3)$$

When the viewpoint is located in the area V1, the edge is on the contour line, the maximum brightness difference between the edge's both sides is most salient and can be regarded as E. When the viewpoint lies in non-contour-viewing area V2, we need find out the light direction in which the brightness difference reaches its maximum. As a matter of convenience, the outside dihedral angles are divided into three categories: the acute angle, obtuse angle, and reflex angle. We will calculate brightness differences respectively in these three cases.

When α is an acute angle, the edge and its adjacent patches can't be seen unless the ray of light and the sight line both lie inside the dihedral. Fig.3 shows the section of outside dihedral AOB with the edge OO'. The normal vectors of two connected facets are supposed to be Na and Nb respectively, and the intersection angles between the two normal vectors and the ray of light is denoted as β_1 and β_2 respectively. Then the intensity of diffuse light of these two patches can be written as $E\cos\beta_1$ and $E\cos\beta_1$, and $\alpha = \pi/2 - (\beta_1 + \beta_2)$. The brightness difference can be represented as follow

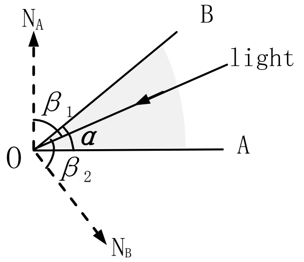
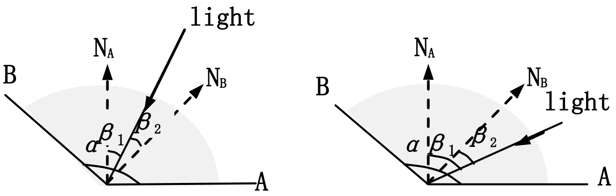


Fig. 3 the outside dihedral is acute

$$\begin{aligned} \Delta b &= | E\cos\beta_1 - E\cos\beta_2 | \\ &= \frac{E}{2} | \sin\frac{\beta_1 + \beta_2}{2} \sin\frac{\beta_1 - \beta_2}{2} | \\ &= \frac{E}{2} \cos\frac{\alpha}{2} | \sin\frac{\beta_1 - \beta_2}{2} | \end{aligned}$$

Since the ray of light is only inside the angle AOB when the edge is visible, the maximum of $|\beta_1 - \beta_2|$ can reach α, and the maximum brightness difference is $\Delta b_M = E\sin\alpha$.



(1) The ray of light is between two normals

(2) The ray of light is not between two normals.

Fig.4 The outside dihedral is obtuse

Fig.4 shows the section of outside dihedral AOB with the edge OO' when α is an obtuse angle. Here the ray of light is either between the two normal vectors or between one of the normal vectors and one of the patches. Fig. 4(1) and Fig. 4(2) indicate the two different cases respectively. In Fig. 4(1), just like Fig.3, here $\alpha = \pi/2 - (\beta_1 + \beta_2)$, so we still use equation (3) to find Δb_M. While in Fig.4 (2), the equation $\beta_1 - \beta_2 = \pi - \alpha$ holds. The brightness difference is then expressed as follows

$$\begin{aligned}\Delta b_M &= |E\cos\beta_1 - E\cos\beta_2| \\ &= \frac{E}{2}\left|\sin\frac{\beta_1+\beta_2}{2}\sin\frac{\beta_1-\beta_2}{2}\right| \\ &= \frac{E}{2}\cos\frac{\alpha}{2}\cos\left(\frac{\alpha}{2}-\beta_2\right)\end{aligned}$$

Considering $\beta_2 < \frac{\alpha}{2} < \frac{\pi}{2}$, the brightness difference reaches its maximum

$$\Delta b_M = E\sin\alpha \tag{4}$$

when $\beta_2 = \alpha - \frac{\pi}{2}$.

When α is reflex angle, the result is just like the acute or obtuse angle, so it's unnecessary to give more details. Now we can obtain the visual salience of the edges according to equations (1), (2), (3) and (4).

3.2 Visual salience of vertices

The visual salience of the edge is revealed by its two side patches. Similarly, the visual salience of the vertex is expressed by the brightness difference among its adjacent patches. Just like the edge, we discuss the visual salience of the vertex based on whether it is on the contour line and brightness difference it produces in rendering.

The vertex is not on the contour line.

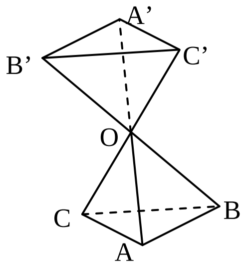


Fig. 5 contour-viewing region of a vertex

All the patches connected to a vertex are front faces when the vertex is not on the contour line. As shown in Fig.5, the region OABC is a solid angle and the region O'A'B'C' is the vertical angle of solid angle O. When the viewpoint lies inside the region O'A'B'C', all the patches and edges connected to O can be seen, and the vertex O is not on any the contour lines. Suppose the number of edges connected to a given vertex is n and the maximum brightness difference between two sides of each edge is Δb_{Mi} ($0 <= i < n$). Then the maximum brightness difference of a vertex can be written as

$$V_M = Max(\Delta b_{M\,i}), \quad 0 <= i < n \tag{5}$$

The vertex is on the contour line.

At least one patch connected to the vertex is the back face when the vertex is on the contour line. The contour-view area is all the regions excluding the solid angle of O and the vertical angle. The maximum brightness difference is E among patches connected to the vertex O. Let θ_v be the solid angle of the vertex O, the contour-viewing area and non-contour-viewing area in equation (2) can be represented as

$$\begin{aligned}V_1 &= \begin{cases}4\pi - 2\theta_v, & 0 < \theta_v < 2\pi \\ 0, & \theta_v >= 2\pi\end{cases} \\ V_2 &= \begin{cases}\theta_v, & 0 < \theta_v < 2\pi \\ 4\pi\text{-}\theta_v, & \theta_v >= 2\pi\end{cases} \\ V_3 &= \theta_v\end{aligned} \tag{6}$$

Then we can calculate the visual salience of a vertex according to the equation (2), (5) and (6).

3.3 Visual salience of patches

Just as the vertices and edges, the visual salience of patches is determined by the brightness contrast of the connected patches. For the triangle patch, the visual sensitivity of the three edges is denoted by S_1, S_2 and S_3 respectively, and the visual sensitivity of the triangle patch can be represented as

$$S_\Delta = Max(S_1, S_2, S_3)$$

3.4 Local salience and shape features of 3D models

We have discussed local salience of 3D models, including vertices, edges and patches, which are the basic visual salience completely based on the local brightness contrast. Local salience hardly reflects the shape of the 3D model. In fact, it is the shape feature that raises the visual attention. However, the salience of vertexes, edges and patches are key facts to form the meaningful shape.

A group of significant local features may make meaningful shape when linked together. Based on the calculation of local salience, we can display certain edges and vertices with the visual salience greater than a threshold and form the feature shape. Fig.8 in the next section shows the experimental results.

4 Experiments and Results

To test the rationality of visual salience based on the contour line and brightness difference, we performed the following experiments.

Display the visual salience of vertices. We use Bunny and Buddha to test visual salience of vertexes. The values of visual salience of all the vertexes are mapped into the interval [0, 1], and each vertex will be matched with a specific color according to the value of its visual salience. The colors range from red to yellow, and then to blue gradually as the visual salience decreases. The red color indicates the highest visual salience while the blue color indicates the lowest visual salience. Fig. 6 shows the distribution of visual salience of the vertexes on Bunny. Each vertex is displayed as all of its adjacent edges which are half of their length. The part of Bunny's ear and feet are marked as red due to its salience, but the part of its neck and leg are marked as blue because these regions are concave.

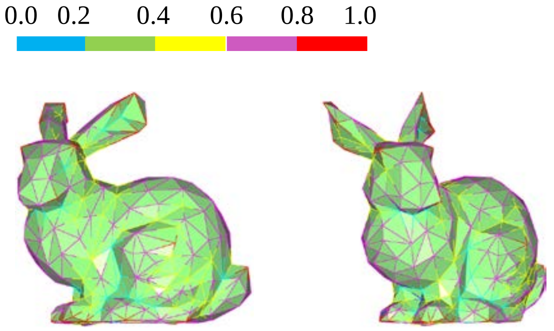
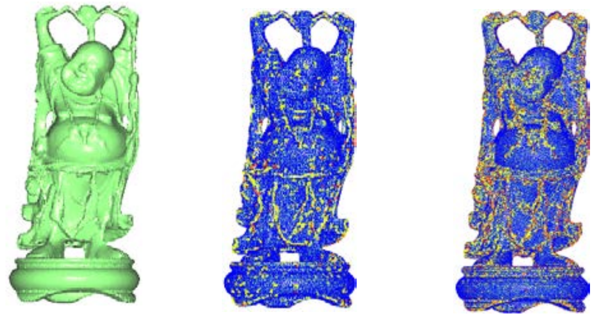


Fig. 6 The vertexes are displayed in different colors according their visual sensitivity.

(1) Bunny (3) Visual salience of vertexes (5) Visual salience of edges

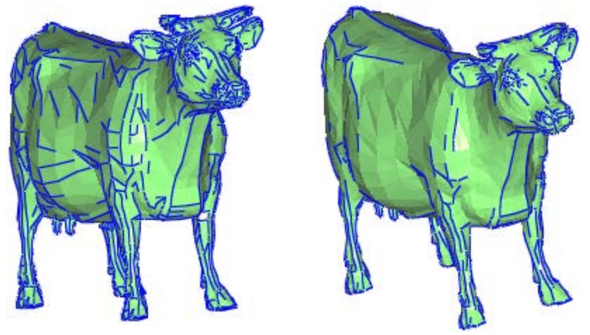


(2) Buddha (4) Visual salience of vertexes (6) Visual salience of edges

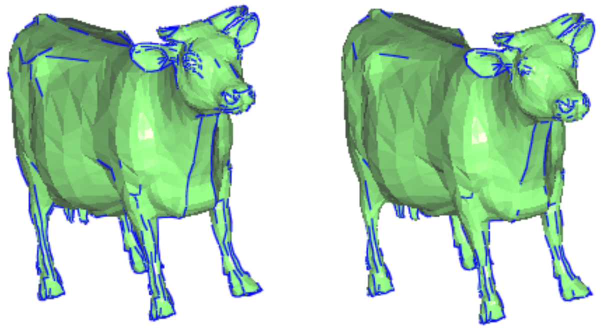
Fig. 7 The visual sensitivity of edges and vertexes of Bunny and Buddha

Fig.7 (1) and (2) are the high resolution models of Bunny and Buddha. Fig. 7 (3) and (4) are the visual salience of all of the vertexes in the high resolution model of Bunny and Buddha.

Display the visual sensitivity of edges. The visual salience of edges of Bunny and Buddha is displayed the same way as the vertexes, shown in Fig. 7(5) and (6). Compared with current researches, we pay attention to the contour lines of a 3D model. Those edges or points which "often" appear on the contour lines are extracted to be regarded as salient parts.



$S_v > 0.2$ $S_v > 0.3$



$S_v > 0.4$ $S_v > 0.5$

Fig. 8 Edges at different level of visual sensitivity are displayed respectively

Display the shape features of 3D models. Though vertices, edges, and patches can produce strong visual effect through local brightness contrast, they can't constitute meaningful shape features, such as a segment of curve which is impressive to the vision. However, if these local features are connected together, they will produce more intensive stimuli. In Fig. 8, we highlight the edges with visual salience greater than a series of thresholds, such as 0.2, 0.3, 0.4 or 0.5.

Through Fig. 8, we can find that a group of edges with some visual salience are prone to express characteristic curves of the model.

5. Conclusion and future work

Since edges and vertices describe the most basic features of 3D models, it is of significantly fundamental meaning to study their visual effect. In this paper, we have examined visual effects of vertices and edges by analyzing their brightness difference under different viewpoints and light directions, and established the quality relationship between geometrical feature and visual effect. The point of this method is to take the brightness and contour line which can be perceived by human eyes as the factor of visual stimulus. Compared with metrics based on the geometry, our method has more direct evidence. Compared with metrics based on image, our method is easy to implement. Furthermore these local features produce fine descriptions of shape feature in 3D models.

The local salience is the foundation for researches on the global salience. For the future, we will explore the relationship between the local salience and the global salience, and study the estimation methods for the global salience of 3D models.

References:

[1] Hoppe, H. , *Progressive meshes. ACM SIGGRAPH Proceedings*, 1996, pp. 99-108.

[2] Yongwei Miao, Jieqing Feng, Renato Pajarola, *Visual salience Guided Normal Enhancement Technique for 3D Shape Depiction*, Computers & Graphics, Vol.35, No.3, 2001, pp. 706–712.

[3] O. Le Meur, P. Le Callet, D. Barba, & D. Thoreau, *A coherent computational approach to model bottom-up visual attention,* IEEE Transactions on Pattern Analysis and Machine Intelligence. Vol.28, No.5, 2006, pp. 802-817.

[4] V. Navalpakkam & L. Itti, *Search goal tunes visual features optimally,* Neuron, Vol.28, No.4, 2007, pp. 605-617.

[5] Sarah Howlett, John Hamill,and Carol O'Sullivan, *Predicting and Evaluating salience for Simplified Polygonal Models*, ACM Transactions on Applied Perception, Vol.2, No.3, 2005, pp286-308.

[6] P. Lindstrom and G. Turk, *Image-Driven Simplification*, ACM Transactions on Graphics, 19(3), 2000, pp. 204-241.

[7] Watson B, Friedman A, McGaffey *A Measuring and predicting visual fidelity*, Proc. SIGGRAPH'01, Los Angeles, USA, August, 2001, pp.213-220.

[8] Taubin, G., *Estimating the tensor of curvature of a surface from a polyhedral approximation.* Proceedings of IEEE International Conference on Computer Vision, 1995, pp. 902.907.

[9] Peng Jingliang, Li Qing, K. C.-C. J. Z. M., *Estimating gaussian curvatures from 3d meshes, Proceedings of the SPIE,Human* Vision and Electronic Imaging VIII. 2003, pp. 270–280.

[10] Kouki Watanabe, Alexander G. Belyaev, *Detection of salient curvature features on polygonal surfaces*, Computer Graphics Forum,20(3), 2001, pp. 385-392.

[11] Shin Yoshizawa, Alexander Belyaev, Hideo Yokota, Hans-Peter Seidel, *Fast and Faithful Geometric Algorithm for Detecting Crest* Lines on Meshes, 15th Pacific Conference on Computer Graphics and Applications (PG'07), 2007, pp.231-237.

[12] Chang Ha Lee, Amitabh Varshney, and David Jacobs, *Mesh salience*, *ACM* Transactions on Graphics, Vol .24, No. 3, 2005, pp. 659-666.

[13] Massimiliano Corsini, Elisa Drelie Gelasca, Touradj Ebrahimi, and Mauro Barni, *Watermarked 3-D MeshQuality Assessment*， IEEE TRANSACTIONS ON MULTIMEDIA, VOL. 9, NO. 2, 2007, pp. 247-256.

[14] Massimiliano Corsini, Elisa Drelie Gelasca, Touradj Ebrahimi,and Mauro Barni, *Watermarked 3-D Mesh Quality Assessment*， IEEE TRANSACTIONS ON MULTIMEDIA, VOL. 9, NO. 2, 2007, pp. 247-256.

[15] Bian Zhe, Hu ShiMin Martin Ralph R, *Evaluation for small visual difference between conforming meshes on strain field* in Journal of Computer Science and Technology，Vol. 24，No.23，2009, pp.65-75

[16] Xiaobai Chen, etc. Schelling *Points on 3D Surface Meshes*, ACM Transactions on Graphics (TOG) - SIGGRAPH 2012 Conference Proceedings Vol. 31 No. 4, July 2012.

[17] Wang J, Dasilva MP, Lecallet P, Ricordel V, *Computational Model of Stereoscopic 3D Visual salience*. IEEE Trans Image Process. Jun;Vol.20, No.6, 2013, pp. 2151-65.