Viewpoint Selection Based on Fechner Type Information Quantities for 3D Objects

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ABSTRACT

This paper proposes several algorithms for selecting viewpoints, based on information quantities, which provide representative views expressing a whole feature of 3D object. By defining a novel information quantity of Fechner type based on Fechner's law in psychophysics, we introduce shape information quantities depend on an area of face and depend on a length and sharpness of edge line in a polyhedral object. We then define viewpoint information quantities of several types obtained by summing up shape information quantities of the visible surface form a viewpoint. Representative views are obtained from viewpoints at local maximum of the viewpoint information quantity of each type. The face type and the edge type of algorithms are derived that compute viewpoint information quantities obtained from all visible faces and all visible edge lines respectively. Experimental results and estimation on polyhedral objects and triangular mesh representations of curved objects are presented.

Keywords Viewpoint selection, Fechner type information quantity, Shape information quantity, Viewpoint information quantity, Representative view, 3D object.

1 INTRODUCTION

Viewing a 3D object, we can obtain different features of the 3D object from different viewpoints. It is therefore important to select a good view (or viewpoint) that grasps a whole feature of 3D object and the viewpoint selection has various applications such as computer graphics, object recognition, data visualization, etc. Many previous approaches on the viewpoint selection, for examples [SK92, TFTN05, VFSH01], are 2D image based approaches using information taken from 2D image such as a projected area of object surface. A 3D model based approach, on the other hand, is available which searches for good viewpoint using the 3D model such as a surface model, a wire-frame model [KK88], and so on. An advantage of 3D model based approach is that it allows us to use 3D information lost in projected 2D images. One of such lost 3D information is a curvature-like feature of surface, which is obtained by the distribution of normal vectors of surface of a 3D model.

In pioneering researches [SK92, VFSH01] on general viewpoint selection, Shannon's entropy is utilized as an information measure to obtain good viewpoints in 2D image based approach. We however adopt a more natural approach for visual perception and introduce a novel information measure based on Fechner's law [P99] in psychophysics, which expresses the logarithmic characteristic of sensory response to stimulus.

In this paper, several algorithms for good viewpoint selection are proposed, which are applied from simple polyhedral objects seen in daily life to complicated polyhedrons containing polygonal expressions of 3D curved objects, by defining shape and viewpoint information quantities of Fechner type based on the 3D model based approach. The shape information quantity is defined based on a sensory amount obtained from an area of face or a length and sharpness of edge line of a polyhedron object, under the assumption such that a viewpoint (i.e. an eye) receives the light stimulus equivalent to the area of face or the length of edge line. Several viewpoint information quantities are then computed by proposed algorithms carried out various summations, which gather shape information quantities of visible surface of the object from a viewpoint. For viewpoint selection, these algorithms propose representative views (or viewpoints) given by local maximum values of each viewpoint information quantity. We then suppose that there exists a good view for user in the set of representative views. In the derivation of algorithms, we suppose a virtual 3D model of object having the virtual surface constructed from sensory amount (i.e. shape information quantity) instead of the real physical surface of object. This virtual model may be considered as an internal 3D model (3D object image) in the brain.

The remainder of this paper is organized as follows. Section 2 refers to related work. The information measure of Fechner type is defined in Section 3. Two main types of algorithms are derived for viewpoint selection of polyhedral objects. We then construct a face type algorithm in Section 3 and construct edge type algorithms in Section 4. These algorithms are applied to polyhedral objects and triangular mesh expressions of curved objects that are regarded as complex polyhedrons. Section 5 is devoted to experimental results and estimation. Finally, in Section 6, conclusions are presented.

2 RELATED WORK

Shannon's entropy is applied in various field of information processing and computer vision. Takeuchi and Ohnishi [TO98] expressed the intensity information of 2D image by Shannon's entropy and proposed an active vision system finding complex region in a 2D image. Shannon's entropy is also introduced for viewpoint selection. Sato and Kato [SK92] defined the object image entropy to yield a good viewpoint with a balanced distribution of visible faces in a projected 2D image. Vazquez et al. [VFSH01] formulated independently the viewpoint entropy, which is the same as the object image entropy, except for adding to it the projected area of background in a 2D image.

Various applications of viewpoint entropy are carried out, such as image-based modeling [VFSH03], perception based illumination design [VS03], and volume visualization [TFTN05]. Weinshall and Werman [WW97] asserted two important measures such as the view likelihood, which is the probability for obtaining a characteristic view, and the view stability, which implies the stability of good viewpoint. Kamada and Kawai [KK88] provided, based on a 3D wire-frame model, the viewpoint obtaining cleared frame model without overlapping its edge lines using the normal vector of face from 3D model. Similarly using 3D models, Lee et al. [LVJ05] introduced the idea of mesh saliency applying mesh simplification and viewpoint selection.

Palmer et al. [PRC81] investigated the canonical view (or viewpoint) for an object using psychophysical measurements, which is assigned the highest goodness view and is first imagined in visual imagery of an object by people. Blanz et al. [BTB99] further investigated properties of canonical views for various objects including nonsense objects using computer graphics psychophysics. One of purpose of viewpoint selection techniques is to obtain good approximation of the canonical viewpoint for an object. Although visible shape of 3D object varies infinitely according to the viewpoint transference, human has qualitatively limited and stable views about the object in spite of viewpoint transference. This cognitive fact is explained by the concept referred as the view potential in psychology [RF86].

3 FACE TYPE ALGORITHMS FOR VIEWPOINT SELECTION

There exist 3D model representations for a polyhedral object such as the surface model and the wire-frame model based on faces and edge lines respectively. The entropy method uses 2D projected image of the surface model. According to these two models, we construct a face type and an edge type of algorithms for viewpoint selection.

Entropy Method and Assumptions

The entropy method for viewpoint selection of polyhedral objects such as the object image entropy [SK92] and the viewpoint entropy [VFSH01] is based on the assumption such that a good viewpoint depends on the largeness of number of visible faces and the uniformity of each visible area in given 2D image. Let T(z) be a set of visible faces from a viewpoint z. This entropy, denoted by H(z), is obtained from the visible area A(t) of face t ($\in$T(z)) as follows.

$$\mathrm{H}(\mathrm{z}) = -\sum_{\mathrm{t}\in \mathrm{T}(\mathrm{z})} \frac{\mathrm{A}(\mathrm{t})}{\tilde{\mathrm{A}}(\mathrm{z})} \log_2\left(\frac{\mathrm{A}(\mathrm{t})}{\tilde{\mathrm{A}}(\mathrm{z})}\right) \qquad (1)$$

where $\tilde{\mathrm{A}}(\mathrm{z}) = \sum_{\mathrm{t}\in \mathrm{T}(\mathrm{z})} \mathrm{A}(\mathrm{t})$. In case of the viewpoint entropy, T(z) contains the projected area of background in given 2D image. Takahashi et al.[TFTN05] used for volume visualization a modified version of Eq.(1) by dividing it with its maximum value of $\log_2 \mathrm{N}$, where N is the number of elements in T(z). The value of A(t) is computed by counting the number of pixels belonging to the visible area.

In the problem of viewpoint selection, it is generally difficult to define an objective criterion on the good viewpoint, since it has qualitative properties depending on subject and sensibility, etc. We therefore stand on the assumption such that instead of qualitative property we introduce measurable quantity representing a difference of each viewpoint, in a set of maximal vales of which a good viewpoint exists. The face type algorithm is constructed based on the following assumption. (1) A necessary condition of good viewpoint is to capture the whole feature of a 3D object and therefore it is necessary to provide visible surface of the object as large as possible. (2) We look at the object with referring to its 3D image (3D object model possessed in the brain) and search a good viewpoint int the brain such that it provides visible surface of this 3D image as large as possible. For realizing the above-mentioned assumption we introduce a novel information measure based on Fechner's law [P99], which is more natural measure for visual perception than mathematical measure based on the information theory.

Fechner Type Information Quantity

Fechner's law expresses logarithmic characteristics of sensory organs, which is natural information measure for sensory amount or response to light stimulus from face and edge. Let Q be stimulus amount and R be sensory response, then the Fechner's law is expressed as,

$$\mathrm{R} = c \log \frac{Q}{Q_0} \tag{2}$$

where c is a constant factor and Q_0 is the lower limit of stimulus amount. Based on this relation, information quantity of the Fechner type, denoted by I, is defined as follows.

$$\mathrm{I} = \log_2 \left(\frac{q}{\gamma} + 1 \right) \tag{3}$$

where q (≥ 0) denotes physical or mathematical quantity as local stimulus of object surface, and γ (> 0) is a design parameter tuning the effect of q. Information quantity I takes a nonnegative value by adding 1to q / γ.

Face Type Shape and Viewpoint Information Quantities

Now consider a point p on an object surface the neighborhood of which is regarded as a face or a plane. An information quantity of face type at the point p is defined by letting the area S of its neighborhood be the quantity q of Eq.(3). We stand on the assumption such that the viewpoint looking at the neighborhood of point p receives light stimulus equivalent to the area S. This information quantity of face type determines the information received by the viewpoint at infinity that is perpendicular to the face or the plane. Thus the shape information quantity of face type, denoted by I_f, is expressed as

$$\mathrm{I}_f = \log_2 \left(\frac{\mathrm{S}}{\gamma_f} + 1 \right) \tag{4}$$

Based on this shape information quantity, a viewpoint information quantity is introduced which a viewpoint receives from the visible surface of object. The viewpoint information quantity gathers shape information quantities of visible surface according to the viewpoint location and direction of surface. As shown in Fig.1, a viewpoint z is defined on the viewpoint hemisphere that a 3D object is set at its origin.

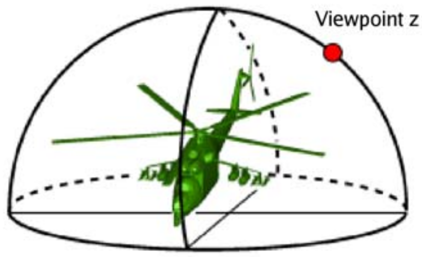

Figure 1: The viewpoint hemisphere

Let ζ(t,z) be an angle between the normal vector of face t$\in$T(z), where T(z) is a set of visible faces, and the view direction vector toward viewpoint z. Let S(t) be the area of face t. The step function g(x) is defined as g(x) = 1 (if x $>$ 0), = 0 (if x $\leq$ 0). If g(cos ζ(t,z)) = 1, then a face t is visible from the viewpoint z. An information quantity denoted by Γ(z,t), that the viewpoint z receives from a face t, is expressed as,

$$\Gamma(\mathrm{z},\mathrm{t}) = \mathrm{g}(\cos \zeta(\mathrm{t},\mathrm{z}))\zeta(\mathrm{t},\mathrm{z}) \log_2 \left(\frac{\mathrm{S(t)}}{\gamma_f} + 1 \right) \tag{5}$$

when the viewpoint z is just above the face t (i.e. ζ(t,z)=0), Γ(z,t) has the maximum value and coincides with the shape information quantity I_f of Eq.(4). The viewpoint information quantity of face type, denoted by Γ(z), is defined as the summation of shape information quantities, which the viewpoint z receives from all of its visible faces. Thus the information quantity Γ(z) is expressed as follows.

$$\Gamma(\mathrm{z}) = \sum_{\mathrm{t} \in \mathrm{T(z)}} \mathrm{g}\ (\cos \zeta(\mathrm{t},\mathrm{z}))\zeta(\mathrm{t},\mathrm{z}) \log_2 \left(\frac{\mathrm{S(t)}}{\gamma_f} + 1 \right) \tag{6}$$

Internal 3D Models

Face type viewpoint information quantity for a face is represented as $\cos \zeta \log_2 (\mathrm{S}+1)$ (where γ_f=1). Since the amount of light from face is supposed to be equal to S, an eye (a viewpoint) physically receives the light stimulus equal to S cos ζ,i.e. the visible area. In the case of $\log_2$(S+1)cos ζ, however, a shape information quantity $\log_2$(S+1) is the amount of sensory response and not the amount of light. In this model, a face has this sensory amount $\log_2$(S+1) instead of physical quantity of area S. This object model therefore has the virtual surface of sensory amount instead of actual surface of object.

An assumption for this model is then mentioned as follows. This virtual 3D surface model is supposed to be an internal model (3D image) of object that is possessed in the brain. If the retina captures a 2D image of some real object, a 3D object image corresponding

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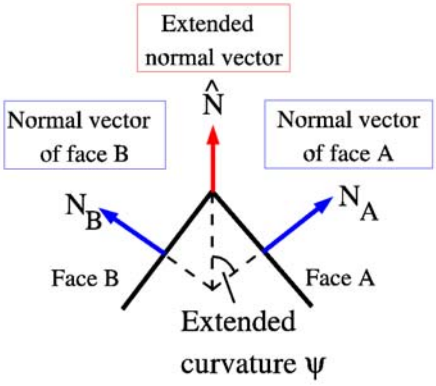

Figure 2: The extened normal vector and the extended curvature of edge line

to the retina image is called out in the brain. It is then supposed that the internal virtual viewpoint looks at this object image using the mental rotation in order to make matching with the retina image for the object recognition.

4 EDGE TYPE ALGORITHMS FOR VIEWPOINT SELECTION

The edge type algorithm is constructed based on the following assumption. Taking notice of curvature-like quantity of an object surface we suppose that there exists more information at a surface having a lot of changes of curvature-like quantity, that is, an uneven and irregular surface has more information than even surface such as a face and a plane. Therefore the shape information for an edge line of polyhedral object is defined using its length and sharpness.

Edge type Shape Information Quantity

In order to define the edge type information quantity, we should represent the sharpness of edge line. The curvature of face is zero and that of line direction of edge line is also zero. There is however no ordinary curvature defined mathematically on the vertical direction of edge line. It is then necessary to introduce a curvature of wide sense.

So we define an extended curvature on the vertical direction of edge line. Fig.2 shows a section vertical to the edge line at any point of edge. An extended curvature is defined as 1/2 of the angle between the unit normal vectors N_A and N_B of faces A and B respectively which intersect at the edge line. This extended curvature is denoted by ψ. We next define an extended normal vector of edge line as the normalized vector of the sum of N_A and N_B, which is perpendicular to the edge line. A shape information quantity for an edge is then defined using the length of edge line and the inner product $\cos\psi$ of the extended normal vector $\hat{N}$ of edge line and N_A or N_B. Thus the shape information quantity of edge type, denoted by I_e, is expressed as follows.

$$I_e = \log_2\left(\frac{L}{\gamma_e \cos\psi} + 1\right) \tag{7}$$

In Appendix, Eq.(7) is derived through the face type shape information quantity of Eq.(4).

Edge type Viewpoint Information Quantities

We now consider a classification of viewpoints for edges. When we look at an edge line, a neighborhood of edge line is also in sight. Two cases of viewpoint are therefore considered. One is (1) a viewpoint looking both faces that intersect at the edge line, and the other is (2) a viewpoint looking at least one of faces that intersect at the edge line. Viewpoint information quantities can be constructed corresponding to these cases. The cases (1) and (2) are called by the names as edge I and II types respectively in the following.

4.2.1 *Edge I Type*

It is considered a situation that an edge line can be perceived and its sharpness (i.e. the extended curvature) is also recognized, only when both faces of the edge line are in sight. This situation may be considered as the case that a robot, which has no 3D image and knowledge about edge or object, perceives an edge line and its sharpness.

Let U(z) be a set of visible edge lines of object from a viewpoint z and θ(u,z) be an angle between the view direction vector and the extended normal vector of edge line u ($\in$ U(z)). Let ψ(u) be the extended curvature and L(u) be the length of edge line u. Moreover let ζ(u,z) and ζ'(u,z) be angles between the view direction vector and the normal vectors of both faces of edge line u, then both faces of edge line u are in sight if g(cos ζ(u,z))g(cos ζ'(u,z)) =1. The edge I type viewpoint information quantity, denoted by Ω_I(z), is defined as the summation of shape information quantities, which the viewpoint z receives from all of its visible edge lines. Thus the information quantity Ω_I(z) is expressed as follows.

$$\Omega_I(z) = \sum_{u\in U(z)} g\,(\cos\zeta(u,z))g(\cos\zeta'(u,z)) \\ \cos\theta(u,z)\log_2\left(\frac{L(u)}{\gamma_e\cos\psi(u)} + 1\right) \tag{8}$$

4.2.2 *Edge II Type*

Even though the case of viewpoint looking at least one of faces that meet at an edge line, the edge line is inferred at a margin of face and its sharpness is also speculated by the appearance of surrounding at the edge

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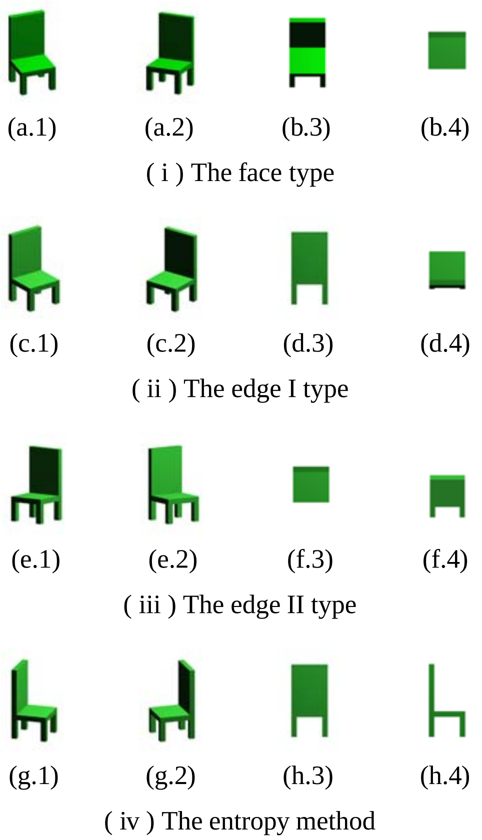

Figure 3: The 8 views of (a),(c),(e), and (g) are representative views and the 8 views of (b),(d),(f), and (h) are unrepresentative views of a chair by the face type, the edge I type, the edge II type,and the entropy type respectively.

line. This situation implies the fact that human (or a robot), which already has a 3D image and knowledge about edges or the object, can infer and perceives the edge line and its sharpness from such viewpoint. Under the assumption that the viewpoint receives a half of shape information quantity I_e of Eq.(7) when either face of edge is seen from the viewpoint, the edge II type viewpoint information quantity, denoted by $\Omega_{II}(z)$, is expressed as follows.

$$\Omega_{II}(z) = \sum_{u \in U(z)} \frac{1}{2}\{g(\cos\zeta(u,z))\ \cos\zeta(u,z) + g(\cos\zeta'(u,z))\ \cos\zeta'(u,z)\}\log_2\left(\frac{L(u)}{\gamma_e \cos\psi(u)}+1\right) \quad (9)$$

4.2.3 *Convex-Concave Information Type*

The edge I, II and the face type have following problem. The normal vector of surface is ordinary defined to have the direction toward outside from surface and the curvature-like quantity, such as $\cos\psi$, has

Figure 4: The view potential of a house

no sign. Faces and edge lines then cannot be determined whether they are convex or concave. Concave regions of surface are therefore regarded as convex regions, that is, the above-mentioned viewpoints are, as it were, equivalent to monocular stereopsis.

Edge lines are then classified using a method for deciding whether an edge line is convex or concave, and convex or concave information quantities are defined on convex or concave edge line respectively. The viewpoint information quantity $\Omega_I(z)$ (or $\Omega_{II}(z)$) is therefore divided into convex and concave viewpoint information quantities denoted by $\wedge^+(z)$ and $\wedge^-(z)$ respectively. These information quantities are combined with a parameter α($0 \le \alpha \le 1$) and yield the convex-concave information type, denoted by $\wedge(z)$, as follows.

$$\wedge(z) = \alpha \wedge^+(z) + (1-\alpha)\wedge^-(z) \quad (10)$$

For above-mentioned viewpoint information quantities, that is ,$\Gamma(z)$, $\Omega_I(z)$, $\Omega_{II}(z)$, and $\wedge(z)$, the viewpoint z at a local maximum value of each viewpoint information quantity is regarded as a representative viewpoint that is a candidate of viewpoint selection.

5 EXPERIMENTAL RESULTS AND ESTIMATION

This Section presents experimental results and estimation based on correlation characteristic for polyhedral objects and triangular mesh expressions of curved objects. The experiment uses the algorithm of detecting visible faces [MT97] for the triangular expression in order to make the set T(z), and is carried out under 3600 viewpoints over the viewpoint hemisphere and $\gamma_f = \gamma_e$ =1.

Polyhedral Objects

Various 3D objects having edge lines of right angles are found in daily life. Fig.3 shows experiment results for a

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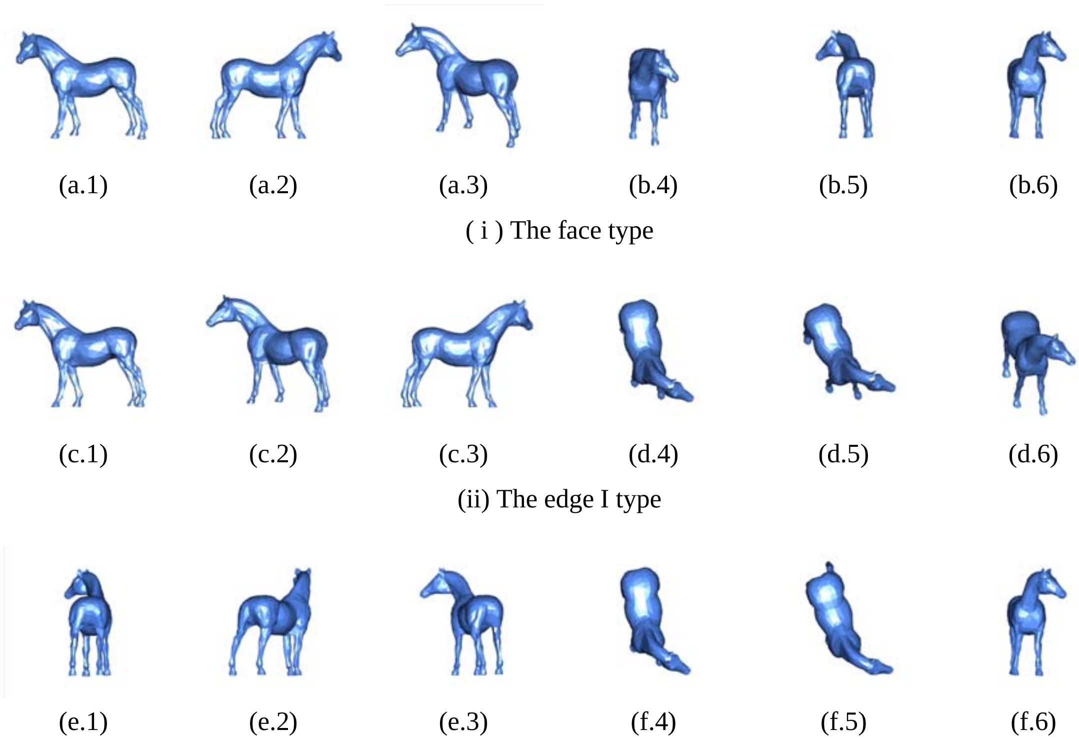

Figure 5: The 9 views of (a),(c),(e) are representative views and the 9 views of (b), (d),(f) are unrepresentative views of a horse by the face type, the edge I,and the entropy type respectively.

chair, which are viewpoints of the top two of local maximum values (representative views) and the last two of local minimum values (unrepresentative views) of each algorithm.

The view potential for a house is shown in [RF86] to be classified into 8 views around the house, which are coincident with views obtained by the edge II type viewpoint information quantity as showed in Fig.4. The views of four corners in Fig.4 surrounded by the red frame are representative views obtained from viewpoints of local maximum value and the other four views are obtained from viewpoints of local minimum value. In viewpoints of local minimum value there exist generally views (or viewpoints), which keep the shape features of the object (e.g. Fig.3 (b.3)) and do not keep that of the object (Fig.3 (b.4)). The viewpoint of minimum value looking at just above the roof of house does not keep that of the house. The keeping of the shape features is thus a necessary condition of view potential.

Curved Objects

The polygon expression such as a triangular mesh expression for a curved object is a complex polyhedron and then the face type and the edge type algorithms can be applied to the polygonal expression. Fig.5 shows viewpoints of the top three of local maximum values (representative views) and the last three of local minimum values (unrepresentative views) of each algorithm

(α = 0.1) (α = 0.3) (α = 0.7)

Figure 6: The representative views of a cup which are given by the convex-concave information type.

for a horse (1850 meshes). In this experiment, the entropy method is computed by the triangular mesh 3D model of horse using A(t) =S(t)cosζ(t,z) for A(t) of Eq.(1), where S(t) is the actual area corresponding to A(t). An experimental result of the convex-concave information quantity $\wedge$(z) is shown in Fig.6. Functional viewpoints finding out a functional feature of object are obtained. As obvious from the figure, these viewpoints give some views by which we come to look gradually at the bottom of cup according to the value of α.

Correlation Coefficients and Estimation

We define a map which displays the distribution of viewpoint information quantity over (θ,ϕ) where θ and ϕ denote the azimuth angle and elevation angle of viewpoint respectively. An example for a cat is shown in Fig.7. Using this map, correlation coefficients among

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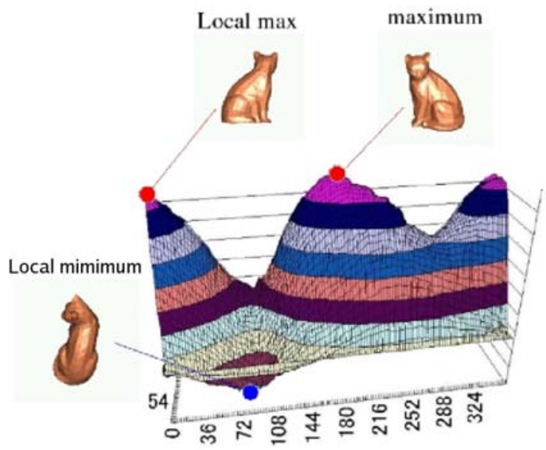

Figure 7: The map of viewpoint information quantity of the face type for a cat. Representative views at maximum and local maximum values and a unrepresentative view at local minimum value are shown.

maps of the algorithms for a chair and a horse are shown in table 1.

In the triangular mesh expression of curved object, large meshes and small meshes express small curvature parts and large curvature changes of a surface respectively. A area of triangle has a correlation with the sum of length of its edges and high approximation of curved object yields small extended curvature ψ and then cos ψ nears to 1 since a change of normal vectors between adjacent meshes(patches) is small. These conditions bring a high correlation between the face type and the edge type. This fact is shown in Fig.5 and the data of horse in Table 1. The edge II type is abbreviated in Fig.5 because it has very high correlation with the edge I type. The entropy method has however lower correlation with the others. The entropy grows larger at a part of uniform in size of meshes and this condition differs those of the face and the edge types.

On the other hand, for a polyhedral object the degree of correlation among the algorithms is slightly different for each other, witch is shown in Fig.3 and the data of chair in Table 1. Since all edge lines of chair have same right angles, cos ψ of Eq.(7) is a constant value and then the correlation between the face and the edge types depends on that of areas of faces and lengths of edges. The entropy method however depends on the uniformity of visible areas of faces and then gives different views with lower correlation from other algorithms.

6 CONCLUSIONS

This paper presents several algorithms for viewpoint selection based on the assumption that there exists a good viewpoint for user's purpose in a set of representative viewpoints, obtained at local maximum of the viewpoint information quantity, which are supposed to receive maximal amount of light stimulus from visible faces or visible edge lines determined by the viewpoint. Two main types of algorithms are derived based on faces or edge lines of a polyhedral object. The face type algorithm computes the viewpoint information quantity that is a sum of shape information quantities of all visible faces and the edge type algorithm similarly computes that of all visible edge lines from a viewpoint. Both types of algorithms give viewpoints with higher correlation for triangular mesh representations of curved objects and however provide different viewpoints with lower correlation for polyhedral objects. These characteristics of the algorithms shown for polyhedral objects are remained to investigate.

Table 1: Correlation coefficients among various types for a chair and a horse.

Chair	Edge I	Edge II	Entropy
Face	0.7284	0.7636	0.4718
EdgeI		0.8473	0.6478
EdgeII			0.6691

Horse	Edge I	Edge II	Entropy
Face	0.9331	0.9333	0.5133
EdgeI		0.9969	0.7753
EdgeII			0.7766

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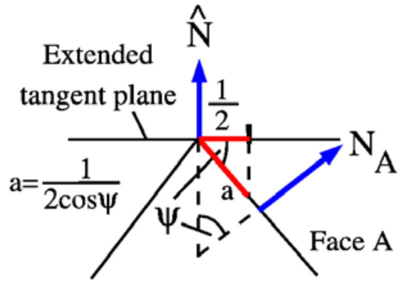
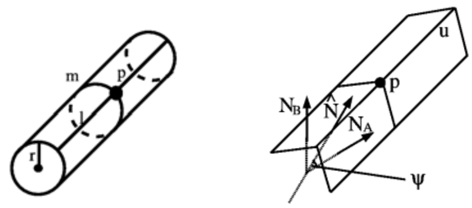
A DEERIVATION OF SHAPE INFORMATION QUANTITIES OF EDGE TYPE

As shown in Fig.A1, a plane, which contains edge line and is perpendicular to the extended normal vector $\hat{N}$ at a point of edge line, is referred as an extended tangent plane of edge line. Let a be an area of some region in the face A, then a is viewed as the area a' (a'= a cos ψ) from the viewpoint at infinity which is perpendicular to the extended tangent plane. Suppose the visible area a' is 1/2 i.e. a half of unit area, then the actual area a is obtained as a =1/2cos ψ. This quantity 1/cos ψ is regarded as the curvature-like quantity perpendicular to the edge line and the curvature-like quantity of edge line is 1 since its extended curvature is 0.



A.1 The extended tangent plane and the curvature-like quantity 1/cos ψ



(a) the right cylinder (b) the edge region of polyhedron

A.2 The correspondence between curvature 1/r and extended curvature ψ of a right cylinder and an edge region of polyhedron respectively.

Thus the existence of two extended curvature on an edge region is shown as Fig.A2, based on the correspondence between an edge region and a right cylinder. A straight-line l and a circumference m of radius r are intersected at a point p over the surface of cylinder and they have curvature 0 and 1/r as shown in Fig.A2(a). Similarly there exist the extended curvature ψ (curvature-like quantity 1/cos ψ) and straight-line of extended curvature 0 (curvature-like quantity 1) at a point p over edge line shown in Fig.A2(b).

There exists a neighborhood of edge line whose area is L/cos ψ that is the product of 1/cos ψ and length L of edge line. This neighborhood of area L/cos ψ is in sight from the viewpoint above edge line. By substituting the area L/cos ψ into Eq.(4), the shape information quantity of edge line is derived as follows.

$$\log_2\left(\frac{L}{\gamma_e \cos\psi}+1\right) \quad (A.1)$$

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