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An IEC-Based 3D Geometric Morphing System*

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Abstract - *3D geometric morphing is an essential technique to create attractive dynamic contents. There are two fundamental problems, the geometrical correspondence and the parameterization, to realize successful and aesthetically pleasing transformations between different 3D objects. Most prior research activities put emphasis on either of the two problems. In this paper, an approach to effectively resolve both problems is proposed. A 3D data representation called the layered round slices method is designed to resolve the correspondence problem and a 3D transformation technique called the image-based 3D transformation is invented for the parameterization problem. Interactive Evolutionary Computation (IEC) framework is applied to intuitively explore complex transformation parameters.*

Keywords: 3D morphing, geometric modeling, interactive evolutionary computation, computer graphics.

1 Introduction

Metamorphosis or morphing of graphical objects is an essential technique to create attractive dynamic contents. Figure 1 shows a 3D morphing example. It interpolates 3D geometries between two graphical objects, a source (a head data of a stone Buddhist image) and a target (a vase model) object. 2D image morphing techniques have reached some levels of production quality and have been utilized for some real-world applications such as commercial films [1]. 3D geometric morphing, however, still remains in an active research phase. The 3D geometric morphing techniques generally need to overcome the following two problems:

(1) the *geometrical correspondence* problem to generate an smooth interpolation between the source and the target object, and
(2) the *parameterization* problem to create appropriate and aesthetically pleasing transformation.

Most prior research activities put emphasis on either of the above two problems. We show an approach to effectively resolve both of them.

We propose a new 3D data representation technique called the *layered round slices method* to resolve the correspondence problem. Both the source and the target

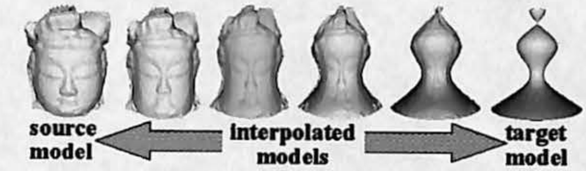


Figure 1: 3D morphing example.

model are converted into a set of 2D round slices and the correspondences between the models are established in a pair of slices. Existing methods only allow very similar shapes to be associated. Our slice-based method enables totally different shapes to be connected for smooth interpolation.

For the parameterization problem, we invented a new 3D transformation technique called the *image-based 3D transformation*. It treats the layered slices as a 2D gray scale image that retains geometrical profiles of the original 3D model. Users can easily process various 3D operations such as morphing, deformations, and blending by editing the 2D images. It simplifies a 3D transformation problem with a 2D image processing. *Interactive Evolutionary Computation* (IEC) [2] is integrated with these image-based 3D operations to encompass a wide variety of modeling styles.

2 Characteristics of Proposed System

Previous methods developed for the 3D morphing are classified into two categories, the volume-based method and the polygon-based method, depending on which data structure (volume or polygon) is used [3]. The volume-based method is superior to the polygon method in resolving the correspondence problem. However, it has many limitations to transform the 3D objects. Interpolation between the source and target shapes is too time consuming to generate real-time smooth transformation. In contrast, many useful transformation algorithms have been developed for the polygon-based representations. The polygon method, however, needs to generate a common polygon mesh between the source and target objects to construct a geometrically appropriate correspondence. The common polygon generation is only possible for a pair of very similar shapes or it requires manual interventions for shapes with different geometries and topologies [4].

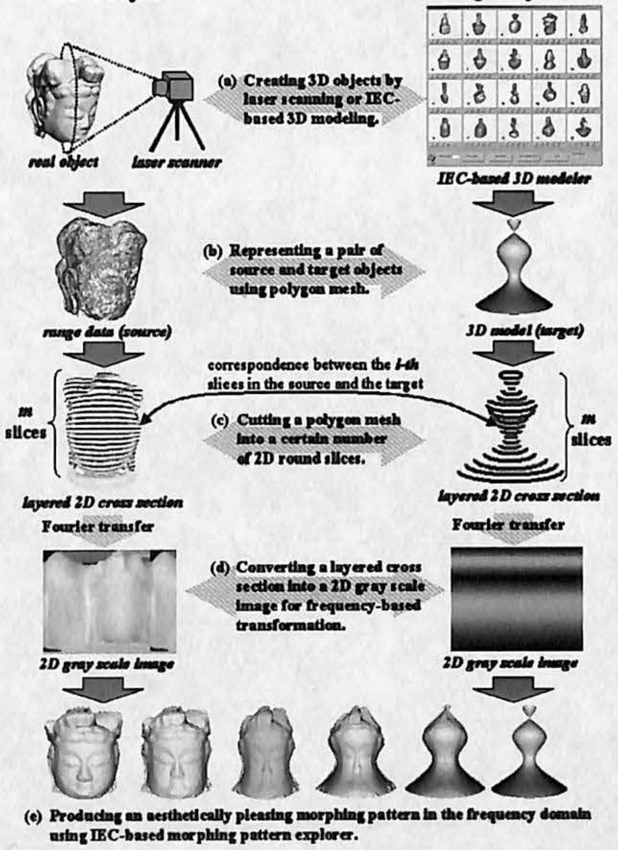


Figure 2: Functional overview of the proposed 3D morphing system.

The proposed method cuts a 3D object into a set of 2D round slices and interpolates between the corresponding slices [5]. It simplifies the 3D objects' correspondence with the 2D geometrical mapping by the slicing operation. It also makes smooth and various motions between the 2D slices possible by interpolating them in the frequency domain.

For the transformation problem, we applied an IEC framework to make the optimum parameter exploration an easy task. While the manual setup of the appropriate transformation parameters is a difficult task, the evaluation of any animation contents is quite an easy task. We can tell whether a morphing sequence caused by a particular set of the parameters is pleasant or not by just looking at the motion. Therefore, the optimum parameters are explored by using an interactive genetic algorithm with user-specified fitness values.

3 System Implementation

3.1 Functional Overview

Figure 2 shows the functional overview of the proposed 3D morphing system. To start production of the 3D morphing contents, a pair of the source and the target object needs to be created. The 3D model creation, however, is per se a bothersome process especially for novices. Therefore, the system provides some convenient options for the modeling process including the use of commercially available laser scanners [6] to easily digitize real object's shape and an IEC-based 3D modeler [7] to enable intuitive 3D model creation as shown in figure 2(a).

The modeling process produces a pair of 3D objects represented by the polygon mesh, a most common 3D file format, as shown in figure 2(b). Next, the system cuts the polygon mesh into a certain number of 2D round slices as shown in figure 2(c). Assuming that the number of slices is m, the source and target objects are identically cut into m slices. Then, the *i-th* (i=1,2,..,m) slice in the source naturally corresponds to the *i-th* counterpart in the target. Then, it converts these slices into frequency signals using a Fourier transfer and line up the signals to frame a 2D gray scale image as shown in figure 2(d). We employ the frequency domain approach to explore various 3D transformation parameters for the morphing, deformation, and blending using the IEC framework. It enables the 3D objects to transform in various manners between the source and the target shape as described in [8]. Finally, the IEC-based morphing pattern explorer generates fascinating motions through an interactive genetic algorithm according to the users' subjective preference.

3.2 Slicing Operation

Figure 3 illustrates the slicing operation. The system firstly fixes the coordinate system as shown in figure 3(a). It adjusts the y-axis position to pass through the object's center of gravity by recalculating all vertices of the polygon model. The system slices the model with a cutting plane orthogonal to the y-axis and produces a set of horizontally sliced cross-sections. A directional relationship between the y-axis and the 3D model determines a slicing angle. Figure 3(b) shows a case of the vertical slicing. This example spins the model 90 degrees counterclockwise before the slicing operation. The variable slicing angle is a useful function to create wider variety of motions as described in section 4.3.

Next, the system extracts all polygons intersecting with the *i-th* cutting plane ($Y=y_i$) as shown in figure 3(c). Then, it repeatedly calculates a distance r_j (j=1,2,..,n) between the centered dot c and the point p_j (j=1,2,..,n) as shown in figure 3(d). The point p_j is an intersecting point between the straight line rotating every ϕ degree and the extracted polygons by the cutting plane. If $\phi = \pi/180$, the slicing operation on the *i-th* cutting plane yields a vector (r_1, r_2,.., r_{720}). If the number of slices is m, finally the slicing operation produces the following m vectors:

$$
\begin{aligned}
R_1 &= (r_1^1, r_1^2, \dots, r_1^{\frac{2\pi}{\varphi}}) \\
R_2 &= (r_2^1, r_2^2, \dots, r_2^{\frac{2\pi}{\varphi}}) \\
&\vdots \\
R_m &= (r_m^1, r_m^2, \dots, r_m^{\frac{2\pi}{\varphi}})
\end{aligned} \quad (1)
$$

3.3 Fourier Transfer of the Slices

The system converts the slice R_i (i=1,2,..,m) as defined in equation 1 into a frequency signal using a Fourier transfer. The Fourier series of a periodic function $F_i(\theta)$, with period T, is given by

$$F_i(\theta) = A_0^i + \sum_{n=1}^{\infty}(A_n^i \cos\frac{2\pi n\theta}{T} + B_n^i \sin\frac{2\pi n\theta}{T}) \quad (2)$$

where

$$A_0^i = \frac{1}{T}\int_0^T F_i(\theta)\, d\theta \quad (3)$$

$$A_n^i = \frac{2}{T}\int_0^T F_i(\theta)\cos\frac{2\pi n\theta}{T}\, d\theta \quad (4)$$

$$B_n^i = \frac{2}{T}\int_0^T F_i(\theta)\sin\frac{2\pi n\theta}{T}\, d\theta \quad (5)$$

The Fourier coefficients A_0^i, A_n^i, B_n^i are calculated by using a harmonic analysis to derive a Fourier series from equally spaced discrete data [5]. The initial terms of the coefficients in equation 2 are the low frequency components representing a rough shape of the 3D model. The rear terms are the high frequency components describing the smaller bumps on the model surface. The number of terms n in equation 2 is a variable. The smooth objects can be approximated by smaller n and the odd-shaped complex objects need to be declared by larger n. The slicing operation with larger m (the number of slices) and smaller ϕ preserves the geometric profiles of the complex shapes. The stone Buddhist head data as shown in figure 3 is created by slicing with m=200, $\phi = \pi/180$, and n=180.

Applying the above Fourier operations on all slices R_i produces the m Fourier series $F_1(\theta) \sim F_m(\theta)$. The original 3D model can be reconstructed by layering them.

3.4 Reconstruction of the 3D Model

The 3D model decomposed by the m Fourier series can flexibly be transformed by using filtering operations described in section 4. The model reconstruction procedure as illustrated in figure 4 visualizes the transformed model. The procedure recalculates the distance r_j using equation 2 with a rotation angle γ and stitches between the adjacent slices $F_k(\theta)$ and $F_{k+1}(\theta)$. Adjusting the angle γ enables the reconstructed model to be visualized in multiple resolutions.

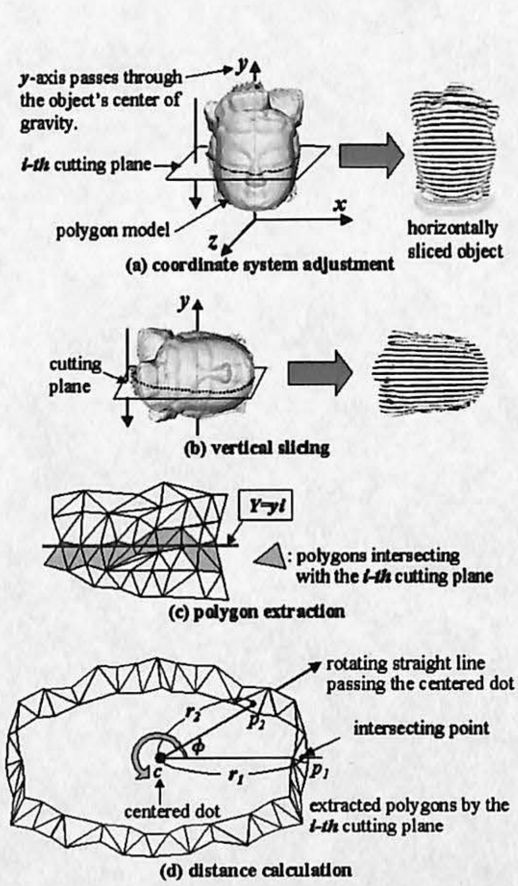


Figure 3: Object slicing operation.

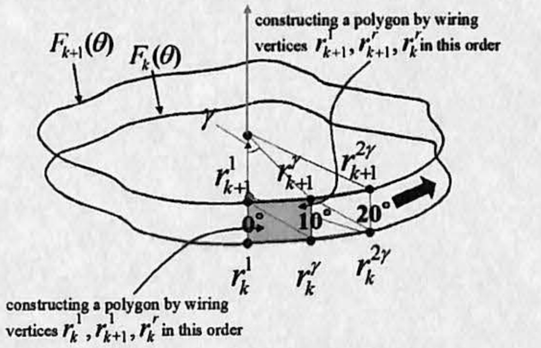


Figure 4: Model surface reconstruction by sewing neighboring slices.

3.5 2D Gray Scale Image Generation

The created layered Fourier slices can be treated as a gray scale image. Figure 5 shows how the layered slices associate with the image. The image resolution matches with the size of the reconstructed distance vector ($m \times 2\pi/\gamma$) and the gray scale value of each pixel corresponds to the distance value r_i^k . As a result, the image is an identical expression of the reconstructed original 3D model. Then, the image can effectively be

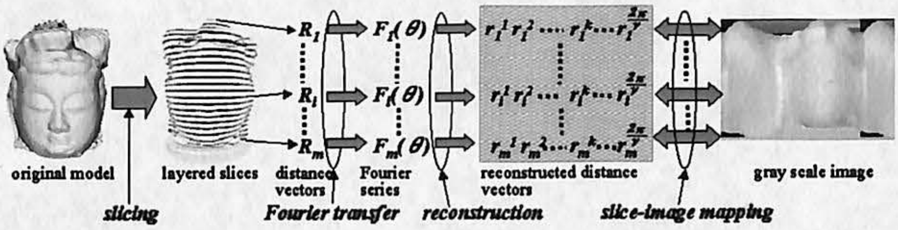


Figure 5: Association between layered slices and 2D gray scale image.

Figure 6: Image-based modeling interface.

used for exploring various geometric transformations as described in the next section.

4 Image-Based 3D Transformation Empowered by IEC

4.1 Interface for Image-based 3D Transformation

Commercial 3D modeling tools demand the users to enter exact parameter values to process any 3D geometric transformations. Beginners especially consumes enormous amount of time to master them. There are some advanced methods to ease the complex 3D transformations such as the free-form deformation (FFD) [9]. The FFD allows the users to directly manipulate and deform the 3D model rather than entering the parameter values. However, the direct 3D manipulation using standard 2D pointing devices like mouse is not an easy task to perform.

We developed a new method, called the *image-based 3D transformation*, to solve the transformation problem by using the standard 2D pointing devices. It enables the users to activate various 3D transformations through the 2D image retouch operations. Figure 6 shows the developed interface for the method. It consists of two windows and a pop-up menu. The main window displays the 3D model and the image window shows the corresponding gray scale image. The image completely matches with the geometrical structure of the 3D model as described in section 3.5. If the user points a specific pixel in the image, the corresponding vertex on the model surface is apparently indicated as shown in figure 6. A specific region on the 3D model can easily be selected by indicating the identical part in the image as shown in

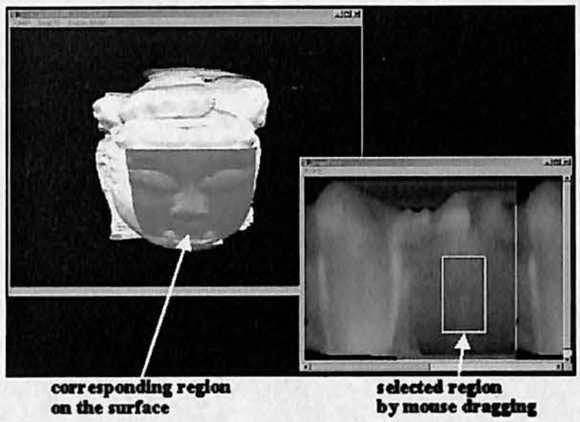


Figure 7: Region selection with the interface.

figure 7. This region selection function drastically simplifies the 3D surface selection and manipulation with the standard 2D pointing devices. Various 3D operations described in section 4.2 are initiated for the selected region through the pop-up menu.

4.2 3D Operations Using Image Filters

This section exemplifies some useful 3D operations realized by 2D image filters. Some real-world objects are very difficult to measure by using the laser scanners such as cottony stuffed objects. A smoothing filter is a convenient tool to levigate the shaggy surface without simplifying the surface geometry. Figure 8 shows an example that applies a median filter on a measured stuffed bunny.

Figure 9 shows an example of the edge emphasis. It selects the nose in the image and activates an edge emphasis filter on the nose. Although the FFD [9] can also realize this kind of transformations, our method significantly eases the pointing, selection, and actual transformations via simple image filtering.

Our method can efficiently cooperate with various special effect filters embedded in the commercial photo retouch tools. Figure 10 shows some transformations produced from the filtered images edited by using the Adobe Photoshop. The use of the commercial tools amazingly widens the possibility to generate interesting transformations.

4.3 IEC-Based 3D Morphing

The image-based 3D operations described in the previous two subsections can accelerate the 3D contents

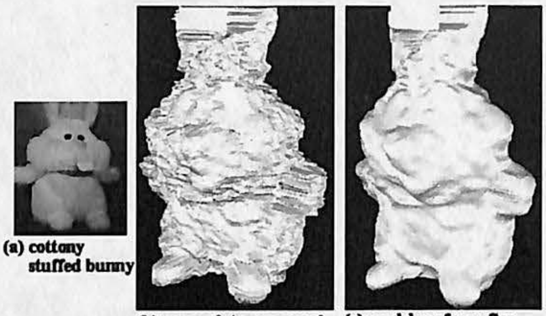


Figure 8: An example of smoothing function using median filter.

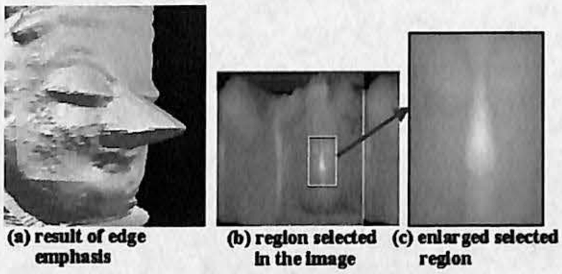


Figure 9: Display result of edge emphasis.

creation for wide range of users from beginners to professionals. The IEC framework enables the users to create further complex and unforeseen solutions for CG contents [10][11]. We applied the IEC on the morphing transformations.

Figure 11 shows a snapshot of the IEC-based morphing pattern explorer. The users can easily examine multiple morphing patterns one by one via a simple interface even if they have little knowledge and experiences of the 3D morphing design. They only need to subjectively specify the degree of "likes or dislikes" for each generated motion by rating a fitness value on a scale of 1 to 5 (the worst to the best corresponds to 1 to 5), and request the explorer to discover more preferred transformations based on the rates. This "rating-discovery" process is iterated until they find a satisfactory result.

The user can check each morphing pattern by operating the manual slider as shown in figure 11. A position of a yellow triangle indicates an interpolation coefficient and the interpolated model is redrawn when the users change its position by mouse dragging operation.

The morphing parameters searched by the prototype IEC explorer include a 3D object type (laser scanned or manually modeled object), an interpolation method (linear or non-linear method), additional transformations such as rotation, and an object-cutting angle. Figure 12(a) demonstrates a morphing example created by using a pair of laser scanned head models with linear interpolation. Figure 12(b) exhibits another example produced by different cutting angle for an identical object. Figure 12(c) gradually blends detailed bumps on a target object's

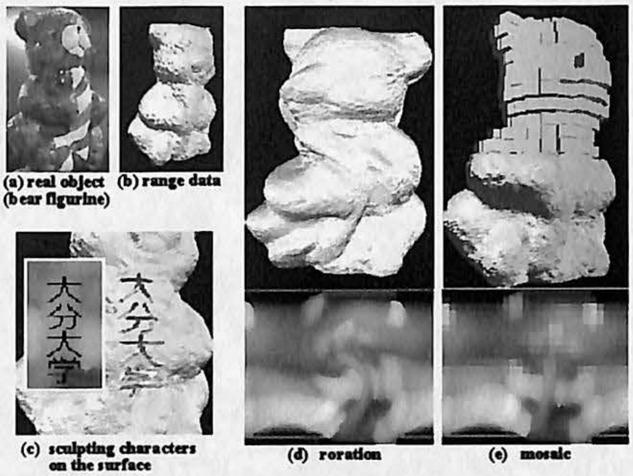


Figure 10: Model transformations using a commercial photo retouch tool.

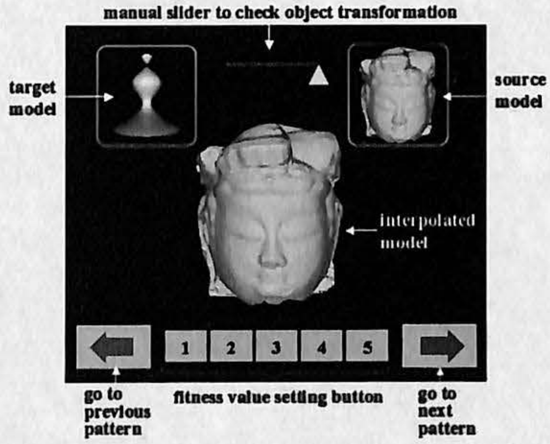
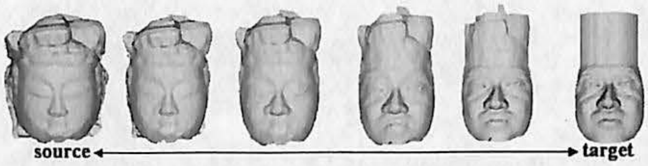


Figure 11: IEC-based morphing pattern explorer.

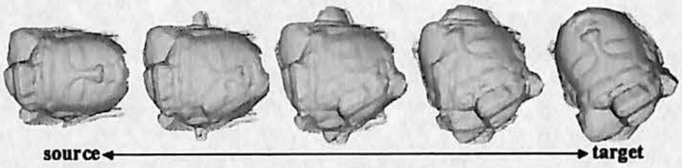
surface (the stone Buddhist image) with a rough shape of a source model (the speaker) in the frequency domain. Figure 12(d) warps a target (the stone Buddhist image) over a rotating source model (the bear figurine). These are only small set of examples created by using the prototype morphing explorer. The IEC-based exploration seems to easily produce many other variations for complex transformations.

5 Conclusions

In this paper, we proposed an approach to intuitively support the dynamic contents creation using a 3D morphing technique. The proposed system simultaneously attacked two issues, the geometrical correspondence and the parameterization that have not been able to resolve in a single system. We have been applied the IEC framework with other CG contents creation such as the lighting design [10] and the 3D geometric modeling [11]. Our preliminary experiment shows that the morphing or 3D transformation

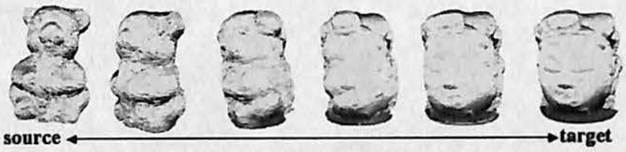


(a) a morphing example between the stone Buddhist image (source) and the human face with the cylinder type hat.



(b) a morphing example between the stone Buddhist images with different cutting angles.

(c) blending a rough shape of the speaker with detailed bumps on the stone Buddhist surface in the frequency domain.



(d) warping the stone Buddhist image over the rotating bear figurine.

Figure 12: Explored morphing pattern examples by IEC.

design is another promising application of IEC. Although the current experimental results are preliminary, we would like to conduct more comprehensive experiments to prove the effectiveness of the proposed method in the near future.

From the system performance point of view, the object slicing operation is a time-consuming process. It takes a few minutes to cut an object from a specific angle depending on how fast computer to use. Because all the other processes can run in real time, the performance improvement of the slicing operation is a critical issue to realize higher interactivity. It is also possible to build other mathematical extensions such as extrapolation to produce further interesting transformations.

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