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3D Face Modeling from Ancient Kabuki Drawings

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Abstract

In this paper, we describe a system to reconstruct 3D face model from ancient Japanese Kabuki drawings. Because of the limitation of input, we deform the face model, which is compatible with MPEG-4 face animation standard, according to ancient drawings to get the 3D geometry, and then a texture mapping algorithm is used to map Kabuki make-up onto the reconstructed 3D face model. The deformation and texture mapping algorithms are based on multi-level radial basis function network, which is an extension of original radial basis function to achieve the smoothness and precision simultaneously. Experimental results show that the multilevel RBF method can solve the deformation and texture mapping problems quite well.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling: Modeling Packages I.3.7 [Computer Graphics]: Three Dimensional Graphics and Realism: Animation

1. Introduction

Kabuki is a traditional form of Japanese theater. It was founded early in the 17th century, and over the next 300 years developed into a sophisticated, highly stylized form of theater. There are abundant cultural legacies to describe the long history of this outstanding art, such as beautiful pictures of Kabuki dance which is called UKIYOE in Japan and Kabuki make-up. However, they are all traditional media and lack of interactivity: One can only view the static pictures. The aim of our research is to make use of such legacies to reconstruct and animate 3D Kabuki face model by means of Computer Graphics techniques. It is a new way to preserve the cultural heritage, and we think that it provides an interesting way for people to learn about Kabuki art.

To reconstruct the 3D face model of ancient Kabuki players, we need to consider how to generate precise 3D mesh and high quality texture mapping of Kabuki face. There are already abundant researchs on face modeling. They can be roughly categorized according to their input: multiple photographs [Par72, Par82, AS93, LKT97, NFN00, HL96], range data [LTW93, LTW95, Tan95], video [LZJC98], face model database [BV99].

Face modeling based on two orthogonal or multiple photographs try to make use of the correspondence of different photographs to compute the precise 3D shape and high quality face texture. Parke [Par72, Par82] presented to put a skin grid on the face and compute 3D coordinate of grid point to generate animation by interpolation. Many methods are introduced to automate Parke's method. Face detection technique is used to detect feature points on face [AS93], and deformation techniques, such as direct free form deformation and radial basis function, are also applied to adapt a generic facial model according to detected feature points [LKT97, PJHSS98, NFN00]. Besides 3D shape, researchers also stress the importance of creating high quality face texture. Basically, it's a blending of multiple views. According to [PJHSS98], face texture extraction can be divided into view-independent blending and view-dependant blending [PJHSS98, AS93, LKT97, PJHSS98, HL96], and its consideration includes self-occlusion, smoothness, positional certainty and view similarity. Face modeling from video provides not only the way to construct 3D shape of face but also the way to generate high quality texture map. Furthermore, they provide way to capture the motion of face to create high quality animation [LZJC98].

Range data is another important source for facial modeling. Lee et al. [LTW93, LTW95, Wat87] proposed a method to adapt a physics-based face model with animation structure to specific range data. Blanz et al. [BV99] presented to construct a face database and reconstruct 3D face model by the linear combination of the face models in database. All face models in this database are embedded into a vector space and PCA is used to find the principal eigenvectors to compress the data. Their method can deal with face recon struction from single photograph or multiple photographs by statistical gradient optimization.

Since our research is also related to texture mapping, we will make a brief introduction of the related work in texture mapping field. Basically, there are two kinds of texture mapping in CG now: 2D texture mapping and 3D texture mapping. 2D texture mapping is to map 2D texture image to the 3D geometry model to enhance the visual effect, so it needs 2D parameterization of 3D geometry model. 2D parameterization can be solved as a optimization problem or a scattered interpolation problem [MYV93, Lev01, TWBP03]. To map a 2D texture map to a 3D face model, some point constraints, such as eyes, mouth, and so on, should be considered. Levy [Lev01] presented a global optimization method to compute the texture coordinates for face texture mapping problem. Ying et al. [TWBP03] proposed to use single level RBF with regulation term to map face texture to 3D face model. Our paper also uses RBF to map face texture to 3D face model. However, we enhance the precision of single level RBF with multilevel RBF based on the adjustment of the length of radiuses. So, the precise alignment of feature points can be guaranteed, and the quality of mapping result is then enhanced.

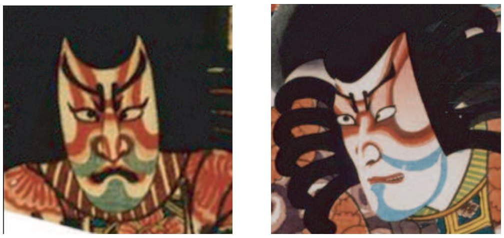


Figure 1: *Examples of Ancient Kabuki Drawings*

Unfotunately, the ancient players were from several hundred years ago. We can not find such kind of input mentioned above from the cultural legacies of Kabuki. Firstly, it is impossible to get their photographs. We can only get drawings of their face. Secondly, Kabuki player often use a special make-up style (see details in Section 4). Since this special make-up style is sometimes independently recorded, we must provide way to map make-up to the 3D face model. That means we can't always get 3D shape and texture at same time. To deal with the reconstruction problem, We design a procedure to deform the 3D face model compatible with MPEG4 face animation standard according to the UKIYOE to get the 3D geometry information, then a texture mapping algorithm is used to map the our special texture to the reconstructed 3D facemodel. Since our facemodel is compatible withMPEG4 standard, we can obtain the animatable structure automatically after deformation, and many subsequent applications can benefit from this, such as Virtual Environments, web applications, and so on [PF02, Bal98]. Radial basis function (RBF) [Orr96] is the base of our deformation and texture mapping algorithm, and we present a multilevel approach to enhance the precision of original RBF network to make it suitable to both deformation and texture mapping.

The remainder of this paper is organized as follows. Section 2 will describe the principle of multilevel RBF method. In section 3, we will introduce how to reconstruct 3D face model from ancient drawings. Kabuki make-up mapping is described in section 4, and we provide a conclusion and discuss future work in section 5.

2. Multilevel radial Basis Function Algorithm

RBF has been widely used in scattered interpolation, deformation, animation and so on, and we will show that it is also suitable to texture mapping. In the theory of RBF, a regulation term is usually used to guarantee the smoothness of the constructed surface [Orr96]. However, this also leads to the imprecision at data points. To solve this problem, we present a Multilevel RBF approach to achieve the precision and smoothness at the same time. Lee et al presented a multilevel B-Splines method to do scattered data interpolation [LWS97]. They built multilevel method by increasing the density of knots. However, our method is based on the adjustment of the length of radius in RBF.

2.1. Radial Basis Function Network

The definition of RBF network is the following:

$$y = \sum_i w_i h_i(x) \tag{1}$$

where $w = i$ is the weight coefficient and h_i is the kernel function. The kernel function is usually a Gaussian-like function determined by the center c_i and its radius r_i.

Given known pairs: (x_i, y_i) $i = 0, 1, \ldots, n-1$, we need to compute coefficients w_i so that the following least square function is minimum:

$$g = \sum_i (y_i - \sum_j w_j x_j)^2 + \lambda \sum_i w_i^2 \tag{2}$$

Taking derivative to w_i, We get:

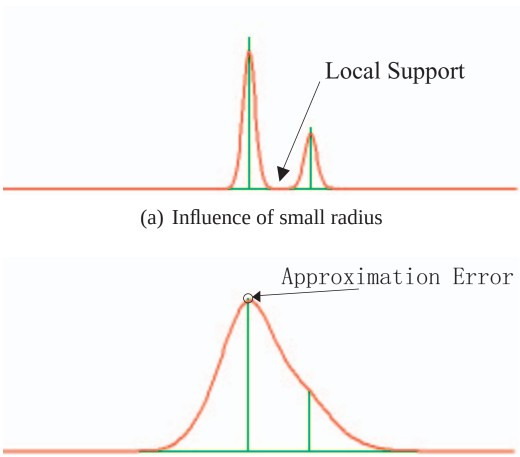
$$(\mathbf{H}^T\mathbf{H} + \lambda\mathbf{I})\mathbf{W} = \mathbf{H}^T\mathbf{Y} \tag{3}$$

In equation 3, $\mathbf{H}$ is called design matrix, where $\mathbf{H}_{ij} = h_j(x_i)$, and $\mathbf{W}$, $\mathbf{Y}$ are column vectors of w_i and y_i respectively. To select a good parameter λ, we adopt the global-ridge algorithm introduced in [Orr96] and the generalized cross-validation in [GHW79] as error criteria.

The second term in Eq. (2) is called regulation term. It is used to limit the values of coefficients so that the resulting RBF network doesn't fluctuate too much and generate a smooth curve or surface. This is suitable to machine learning or generate a smooth approximation from noisy input. However, in our case, we need the result from RBF network can pass the data points precisely. That means we need RBF network to interpolate, not approximate, in our application. For example, in texture mapping, the RBF network should compute precisely at corresponding feature points.

2.2. Multilevel Radial Basis Function Network

The center c and radius r of the kernel function h are the parameters to control the behavior of the RBF network. In many applications, the center is located at data points for convenience. We do the same in our reconstruction procedure. So, the radius r is the parameter that we can use to control the RBF network. We will analyze the influence of the radius to the RBF network first, and then explain why we choose the multilevel approach.



(a) Influence of small radius

(b) Influence of large radius

Figure 2: *Influence of radius length to RBF*

As illustrated in figure 2, there is a straight line and two points on it will be moved to new positions(two vertical green lines stand for the point movement and red curve represents the resulting curve computed by RBF). A small radius is selected first, and the result from RBF (Figure 2.a) shows that the middle regions between these two points are not affected. This is not a surprising result according to the local support property of RBF. But we need to point out that this is not suitable to interpolation application, and we can not use small radius to do texture mapping.

In figure 2.b, we choose large radius instead. Notice that the radius is large enough to let two points to influence each other. At this time, the middle region is influenced and interpolation is much better than the previous case. However, there are still approximation errors at the data points due to the regulation term. That means the resulting curve can not model the data points precisely. It will cause mismatching error, especially in texture mapping.

According to the discussion above, we can design a multilevel approach. First, large radiuses are selected to get an approximation and compute the approximation errors remained at data points, and then reduce the length of radius gradually to reduce the error to get the precise result at data points.We reduce the length of radius base on following reasons: a. the error can only be measured at data points, b. After we get a good approximation from large radius, we only need to adjust the curve or surface locally, and small radius means a small influence region, which means error at one data points will not spread to other data points. It leads to a more stable algorithm. The multilevel RBF can be written as:

$$y = \sum_j \left(\sum_i w_{ij} h_{ij}(x) + \lambda_j \sum_i w_{ij}^2 \right),\ r_{ij_1} > r_{ij_2},\ if\, j_1 > j_2 \quad (4)$$

In other words, our multilevel RBF algorithm can be described as following:

- Step 1: input data points and a error threshold
- Step 2: Calculate initial radiuses for each data point according to the distribution of data points(We adopt the following rule to compute the initial radius: Firstly, for each data point, compute the maximum distance between this point and other data points, secondly, use half of the maximum distance as the initial radius for this data point)
- Step 3: Levels = 0
- Step 4: Loop
- Step 5: compute coefficients w_{ij} for current level RBF network (with regulation term) and store the coefficients for current level
- Step 6: Compute the sum of the approximation error at data points, if the sum is less than the error threshold, stop the algorithm
- Step 7: Reduce the length of radiuses with formula: $r_{ij+1} = a * r_{ij}\ (a < 1,\ j = Levels)$
- Step 8: Levels = Levels + 1, goto step 4

Figure 3 shows the result of multilevel RBF for the same problem. Now the resulting curve (red curve in the figure) can model the data points precisely and smoothness is also guaranteed.

Figure 3: *The resulting curve from Multilevel RBF*

We would like to point out that this multilevel RBF approach is suitable for both compact support and global support radial basis function. Figure 3 shows the result of using compact support RBF in multilevel RBF approach. However, we can also adopt global support radial basis function in multilevel RBF method. It also improves the precision and smoothness is still guaranteed. Figure 4 illustrates some results of using global support radial basis function (Cauchy function) for multilevel RBF method in 2D case. In figure 4, black points represent the feature points and dash lines stand for the correspondence. With that correspondence, RBF can be used to find the corresponding point in right two figures to the red point in leftmost figure. The red points in right two figures are the result from multilevel RBF method and original single level RBF method.

It is obvious that our multilevel RBF approach can preserve the relationships between feature points better than the original RBF in an irregular case (notice that the feature points in right two pictures are arranged differently to the leftmost picture). In the first row of figure 4, multilevel RBF comes up with a correct result which is still inside the region of surrounding feature points, while original one level RBF generates a result outside of surrounding region. In second row, multilevel RBF also comes up with a better result. This feature of multilevel RBF builds a good fundament for both deformation and texture mapping.

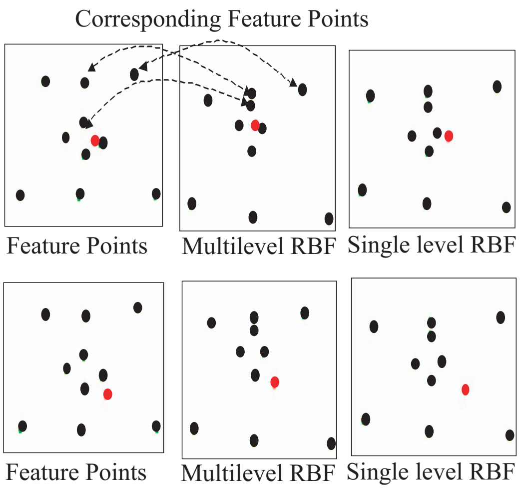
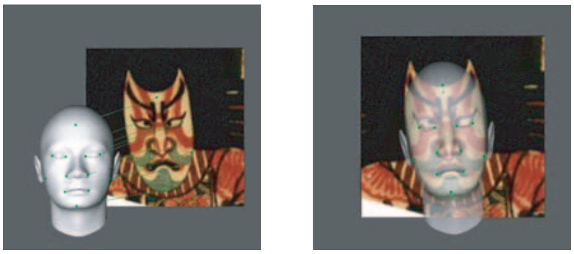


Figure 4: *Comparison in 2D case*

3. 3D FACE RECONSTRUCTION FROM UKIYOE

Because of the limitation we described in the introduction, our reconstruction strategy is to generate the 3D face model as precise as possible. The 3D face reconstruction procedure described in this paper is actually a registration and deformation procedure. Since the registration and deformation procedure can generate a 3D face model which matches the face in ancient drawing very precisely, the reconstruction result should be very similar to the real 3D shape of the face of Kabuki player in UKIYOE. After we get a precise match between the face model and the UKIYOE, the face model will be projected onto the picture to calculate the texture coordinates. Since our standard face model is compatible with MPEG-4 face animation standard, there are already feature points information in it, and each feature point is associated with influence region [Bal98]. Thus, it is easy for us to get the parameters for RBF network. There are also some other works in the deformation of MPEG4 face model [LP99], but our work is to use the deformation method to reconstruct 3D Face model of ancient player from UKIYOE.

After the user inputs a UKIYOE and a face model, our system starts with registering the face model to the UKIYOE. The purpose of registration is to get a rough match between UKIYOE and 3D face model, and the parameters of translation, rotation and scale will be estimated at same time. There are already many research papers on this topic [PJHSS98, BM92]. Since we let user to select feature points manually, the feature points in our case can‘t be too many. We choose traditional optimization algorithm, conjugate gradient, to solve this problem. Figure 5 illustrates the result, and the system also enables the user to adjust the transformation manually.



(a) Define feature points (b) Registration result

Figure 5: *Estimating transformation*

Multilevel RBF is used to deform the 3D face model to match the outline, eyes, nose and mouth of the face. The user can also specify arbitrary feature points in the region when the originalMPEG4 feature points are not enough to control the shape of 3D face model. Figure 6 illustrates the deformation result. As we can see, the deformation of mouth, nose, eyes and outline generate a precise match between face model and 2D UKIYOE. Final result after texture mapping is showed in figure 7.

Figure 6: *Deformation Result (Red points in the picture are feature points of the face model, user can drag these points to do deformation)*

By using the symmetry constraint in face model, we can

Figure 7: *Reconstruction result*

also reconstruct 3D face model from side view pictures (Figure 8). The feature points defined in MPEG4 face animation standard also facilitate the identification of symmetry constraint, for example, feature point 4.3 should be symmetric to feature point 4.4. Ref. [PF02] lists a lot of constraints between MPEG-4 feature points. They are also the constraints we consider in the reconstruction.

Figure 8: *Reconstruction from side-view kabuki drawings*

4. Kumadori Mapping

Kumadori is the name of the special face make-up style in Kabuki, which is usually viewed as the most distinctive feature associated with Kabuki. Kumadori uses bold lines to highlight the eyes, cheekbone and jaw line which helps to emphasize the emotional responsiveness of the character, and its color implies the personality of the character. Figure 9 illustrates some examples of Kumadori.

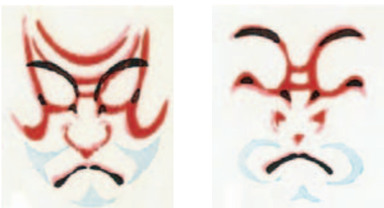


Figure 9: *Examples of Kumadori*

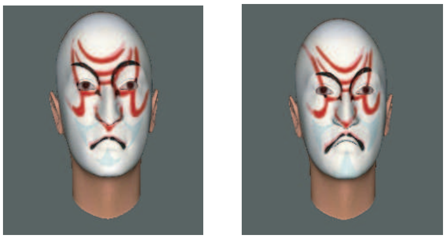
Mapping Kumadori to the 3D face model also starts with defining corresponding feature points. The user only need to define feature points at eyes, mouth, nose and some other feature points to roughly surround the Kumadori (see figure 10. green points are corresponding feature points). To use multi-level RBF to solve the texture mapping problem, we only need to treat the feature points on the reconstructed 3D face model as x_i and their corresponding feature points on the Kumadori picture as y_i in Eq. (4). Then, multi-level RBF can be used to compute texture coordinates for every 3D point on the face part of the reconstructed 3D face model.

Figure 10: *Feature points for Kumadori mapping*

Ref. [TWBP03] also adopts RBF to solve texture mapping problem, and they point out that RBF network with regulation terms is suitable for texture mapping. However, our mapping problem is more diffi- cult since we need to preserve the curve shape in Kumadori, and the correspondence is not obvious in our case. Furthermore, our multilevel RBF can enhance the precision of RBF network, which is very important to texture mapping problem. Another reason for us to adopt RBF is that we can base our system on the same algorithm, which brings us cleaner software architecture. Fig. 11 shows that multilevel RBF can generate precise match and the mapping result is much better. Figure 12 illustrates the results of our texture mapping algorithm by using two Kumadoris in figure 9 as texture.

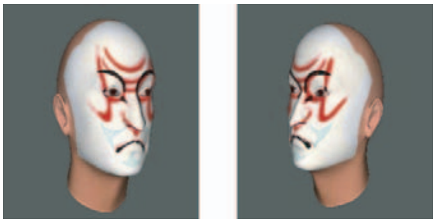
To demonstrate the ability of our texture mapping algorithm, we also apply it to map some special make-up patterns in Peking opera to the reconstructed 3D face model. Figure 13 illustrates the results.

There are some Kumadoris that were acquired from the face of ancient famous Kabuki players. They are treated as treasure of Japanese culture. Figure 13 shows the procedure of how to acquire the Kumadori and one Kumadori acquired from the eighth Danjuro who was a famous player about three hundred years ago. Mapping such kind of kumadori to the 3D face model is of special meaning to people. Since this ancient Kumadori is acquired by putting a paper on the face of the player (see figure 14), it is quite similar to cylindrical projection. So, we decide to project the deformed 3D face model to a cylindrical plane. This step can also be viewed as a 2D Parameterization of 3D Face model. Figure 15 illustrates the projection result. The red triangles are of face part of the face model. Please notice the irregular deformation at the mouth part. In Kumadori picture of figure 15, the mouth is very close to the nose. It is caused by the acquisition method of this Kumadori. The result shows that multi-level RBF approach can handle this quite well.

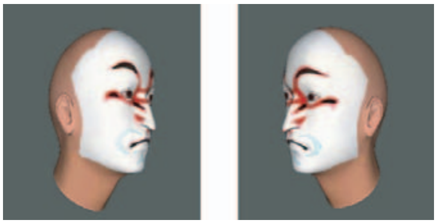


(a) Multilevel RBF (b) Single level RBF

Figure 11: *Comparing mapping result*



(a)



(b)

Figure 12: *Kumadori mapping results*

5. Conclusion

A 3D reconstruction method from ancient drawings of Kabuki player has been described. It is based on multilevel radial basis function algorithm. The reason we present multi-level RBFmethod is to achieve the smoothness and precision simultaneously, which is very important in texture mapping. Experimental results prove the effectivity of our method.

There is a new research hotspot on investigating how to apply CG techniques to the field of cultural heritage. Our face modeling system can be classified into that research, which provides a new way to interact with cultural heritage. The reconstruction result is not a precise 3D reconstruction of original face comparing to other reconstruction methods, but it provides interesting results and other applications can be based on the reconstruction result of our method.

Many problems are still remained to be solved. The hair of kabuki player will be added to improve the visual effect, and animation techniques will be applied to mimic the expressions in Kabuki. We also plan to find way to render the Japanese traditional costume used in Kabuki realistically.

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