

MERGING RATIO IMAGES BASED REALISTIC OBJECT CLASS RE-RENDERING

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ABSTRACT

The *Merging Ratio Image(MRI)* for realistic object class re-rendering is presented and applied to human face image. We focus on the Lambertian object class and utilize a uniform ratio image scheme—Merging Ratio Image—to merge the Expression Ratio Image, Ageing Ratio Image, and Illumination Ratio Image(Quotient Image), which exhibits a new facial model quality. Given a single face image and some other photorealistic face examples with distinct attributes, such as aged wrinkles, expressive feature motions, and certain lighting conditions, we generate expressive expressions, natural ageing, rejuvenating and varying illuminations with MRI rendering technique. Experimental results demonstrate the attractive properties of our method with some face examples from MPI Caucasian Face Database and AI&R Asian Face Database.

1. INTRODUCTION

Two main factors influence the images of Lambertian class object: appearance and illumination. Various techniques on re-rendering of realistic objects in natural scenes have been presented for visual task[1-10]. The appearance of a face object is always described by different attributes, such as expression, age(old or young)[4],gender, race, etc. Ignoring cast shadows, the concept of *Ratio Image*(or *Quotient Image*) defined in existing publications is capable of capturing detailed visual cues of facial expressive expressions or varying illuminations and mapping it from one object to another [5-7,9,10]. Limiting the type of objects to the class of human faces, in this paper, we exploit a uniform ratio image scheme, called *Merging Ratio Image(MRI)*, to combine the *Expression Ratio Image*, *Ageing Ratio Image*, and *Illumination Ratio Image(Quotient Image)* for realistic facial image transformation. The MRI re-rendering technique exhibits many attractive properties and new facial model qualities.

There has been a lot of related works. Liu et al.[5] proposed the expression ratio image to capture illumination changes of one person's expression and mapped it to other person's face to synthesize more expressive expressions. Zhang and Fu[6,7] defined a face ageing space and proposed the ageing ratio image based techniques to generate the aged and rejuvenated facial appearances. Wen et al.[8] presented a ratio-image based technique to use a radiance environment map to render diffuse objects with different surface reflectance properties. Shashua and Riklin-Raviv[9] proved that the quotient image is invariant to illumination conditions. They proposed the class-based re-rendering techniques for generating faces under varying illuminations. Stoschek[10] extended the technique and proposed a scheme for re-illuminating of faces at continuously changing pose angles or lighting directions.

2. MERGING RATIO IMAGES

2.1. Lambertian Object Class and Ratio Images

Object class(human face)[11,12, 3] is a set of objects with same shape but different texture. After pixel-wise correspondence[13,6,3], ignoring shadows, human face at the same pose(frontal, side, etc) can be defined as a class of object whose image space is represented by the Lambertian reflectance function: $\rho_i \cdot \mathbf{n}^T \cdot \mathbf{s}_j$, where ρ_i is the surface reflectance of object i , \mathbf{n} is the surface normal and \mathbf{s}_j is the direction of point light source j . We assume that all objects of the class have the same surface normal \mathbf{n} . Let y be the image of a Lambertian object y with the surface reflectance ρ_y and illumination direction \mathbf{s} , $y = \rho_y \cdot \mathbf{n}^T \cdot \mathbf{s}_y$, where $\rho_y = \sum_{i=1}^M \alpha_i \rho_i$ and $\mathbf{s}_y = \sum_{j=1}^N \beta_j \mathbf{s}_j$ with ρ_i and \mathbf{s}_j as the basis of the spanned spaces of ρ and \mathbf{s} respectively. As a basic result, three linearly independent vectors s_1, s_2, s_3 are sufficient for representing illumination space($N = 3$)[14,15,9,10].

Let x be the image of a Lambertian object \mathbf{x} with the same pose of \mathbf{y} , we have $x = \rho_x \cdot \mathbf{n}^T \cdot \mathbf{s}_x$. The *Ratio Image* is defined by

$$R = \frac{y}{x} = \frac{\rho_y \cdot \mathbf{n}^T \cdot \mathbf{s}_y}{\rho_x \cdot \mathbf{n}^T \cdot \mathbf{s}_x}$$

If object \mathbf{x} and \mathbf{y} are in the same lighting conditions, the lighting direction vectors are the same, that is, $\mathbf{s}_x = \mathbf{s}_y$. If \mathbf{x} and \mathbf{y} are the same object with certain attributes (expression, appearance, age, etc), the surface reflectances are the same, that is, $\rho_x = \rho_y$.

Expression Ratio Images: Realistic facial expressions include many visual cues, such as shape deformation, feature motion, wrinkle, and illumination variation. Let two images x_n , y_e denote the neutral face and the expression face of the same object, the *Expression Ratio Image*[5] R_E is defined by

$$R_E = y_e/x_n = \rho_y \cdot \mathbf{n}^T \cdot \mathbf{s}_y / \rho_x \cdot \mathbf{n}^T \cdot \mathbf{s}_x.$$

Ageing Ratio Images: The speckle, wrinkle, and shape deformation of aged face are more remarkable than that of the expression face. Let two images x_r , y_a denote the rejuvenated face and the aged face of the same object, the *Ageing Ratio Image* R_A is defined by

$$R_A = y_a/x_r = \rho_y \cdot \mathbf{n}^T \cdot \mathbf{s}_y / \rho_x \cdot \mathbf{n}^T \cdot \mathbf{s}_x.$$

Illumination Ratio Images: Under certain illumination circumstances, the same class of face object(\mathbf{x} and \mathbf{y}) has similar point light sources and surface normals. The *Illumination Ratio Image* R_I (the *Quotient Image* in [9]) depends only on the relative surface texture, $R_I = \rho_y / \rho_x$.

2.2. Images Re-Rendering with Merging Ratio Images

To synthesize more realistic appearances of facial images, we merge the different Ratio Images to re-render a certain facial image. With the *Merging Ratio Images(MRI)*, a neutral face can exhibit natural expressions, ageing, and rejuvenating with varying illuminations. We need the following face examples to get the Ratio Images: (1). a non-expression (neutral) facial image A of face \mathbf{A} and its expression image A_E . (2). an aged facial image B_A of face \mathbf{B} . (3). three images C_1, C_2, C_3 of face \mathbf{C} under three linearly independent illumination conditions. (4). the average facial image I_{average} of a set of young face examples. After computing the pixel-wise correspondence, we have the vectorized representations (shape and texture are separated) of $A, A_E, B_A, C_1, C_2, C_3, I_{\text{average}}$ relative to

the reference image I_{average} , that is, $(S_A, T_A), (S_{AE}, T_{AE}), (S_{BA}, T_{BA}), (S_{C1}, T_{C1}), (S_{C2}, T_{C2}), (S_{C3}, T_{C3}), (S_{\text{average}}, T_{\text{average}})$.

Given a novel facial example I , we can generate expression face I_E , ageing face I_A , rejuvenating face I_R , illuminated face I_I or re-rendering face I' with all these natural effects. The vectorized representations are $(S_I, T_I), (S_{IE}, T_{IE}), (S_{IA}, T_{IA}), (S_{IR}, T_{IR}), (S_{II}, T_{II}), (S'_I, T'_I)$.

$$(1).\text{Expression: } \begin{cases} S_{IE} = S_I + \eta_E \cdot (S_{AE} - S_A) \\ T_{IE} = \mu_E \cdot T_I \cdot R_E \\ R_E = T_{AE}/T_A \end{cases},$$

$$(2).\text{Ageing: } \begin{cases} S_{IA} = S_I + \eta_A \cdot (S_{BA} - S_{\text{average}}) \\ T_{IA} = \mu_A \cdot T_I \cdot R_A \\ R_A = T_{BA}/T_{\text{average}} \end{cases},$$

$$(3).\text{Rejuvenating: } \begin{cases} S_{IR} = S_{\text{average}} + \eta_R \cdot (S_I - S_{\text{average}}) \\ T_{IR} = T_{\text{average}} + \mu_R \cdot (T_I - T_{\text{average}}) \end{cases},$$

$$(4).\text{Illumination: } \begin{cases} S_{II} = S_I \\ T_{II} = (\beta_1 T_{C1} + \beta_2 T_{C2} + \beta_3 T_{C3}) \cdot R_I \\ R_I = T_I / \sum_{k=1}^3 \beta_k T_{Ck} \end{cases},$$

$$(5).\text{Merging: } \begin{cases} S'_I = S_{IE} + S_{IA} - S_I \\ T'_I = (\beta_1 T_{C1} + \beta_2 T_{C2} + \beta_3 T_{C3}) \cdot R'_I \\ R'_I = T_{IE} T_{IA} / \left(T_I \cdot \sum_{k=1}^3 \beta_k T_{Ck} \right) \end{cases},$$

$$\text{or } \begin{cases} S'_I = S_{IE} + S_{IR} - S_I \\ T'_I = (\beta_1 T_{C1} + \beta_2 T_{C2} + \beta_3 T_{C3}) \cdot R'_I \\ R'_I = \left[T_{\text{average}} + \mu_R \cdot (T_{IE} - T_{\text{average}}) \right] / \sum_{k=1}^3 \beta_k T_{Ck} \end{cases},$$

where scalars μ, η respectively control texture rendering and shape deformations. According to (S'_I, T'_I) , use forward warp[16,6] to reconstruct the re-rendered face I' .

3. EXPERIMENTS

We choose the face examples from MPI Caucasian Face Database[3] and AI&R Asian Face Database[7] to demonstrate our method. Figure 1 illustrates the results of expression transformations coupled with ageing and rejuvenating. The neutral face of the first person is from MPI. Four expressions are synthesized from four ERI captured from AI&R V1.0 (Expression) database. The



Figure 1: Expression transformation coupled with ageing and rejuvenating. The four synthesized expressions for MPI face are smile, angry, moue, and cool. The three synthesized appearances for AI&R face are smile plus ageing and rejuvenating.

neutral face of the second person is from AI&R. We generate the smile face (middle face of the right three images) firstly and then synthesize the rejuvenating effect (left) and ageing effect (right). Figure 2 shows the results of ageing and rejuvenating transformation with the neutral frontal examples in AI&R V2.0(Ageing) database. Figure 3 illustrates the attributes merging effects with MRI for both MPI face and AI&R face. First row shows the ageing faces after expression synthesis of the MPI face in Figure 1. Second row shows the re-illuminated faces in the first row. The last two rows show the re-illumination effects of the AI&R face in Figure 1 after expression, ageing and rejuvenating transformation. We generate four images under four different lighting directions for each of the three images.

4. CONCLUSION

We have presented a *Merging Ratio Image(MRI)* based Lambertian object class re-rendering method. MRI merges the *Expression Ratio Image*, *Ageing Ratio Image*, and *Illumination Ratio Image* to capture detailed changes of object appearance and illumination. For realistic facial image transformation, given some photorealistic face examples with distinct attributes, we acquire *MRI* and map it to a single face image to generate expressive expression, natural ageing, rejuvenating and varying illuminations. The proposed technique can be extended to 3D facial model and be embedded into a system for facial animation or image processing, with high quality of performance.

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Figure 2: Ageing and rejuvenating transformation with two neutral frontal faces in AI&R V2.0(Ageing) database.



Figure 3: *Merging Ratio Image* based facial image re-rendering for MPI face and AI&R face in Figure 1. Top two rows show the ageing faces and re-illuminated ageing faces after expression transformation. Last two rows show the re-illuminated AI&R face.