Image Morphing of Facial Images Transformation based on Navier Elastic Body Splines

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Abstract

In this paper, we propose a new image morphing algorithm which uses a Navier elastic body splines to generate warp functions for interpolating scattered data points. The spline is based on a partial differential equation proposed by Navier that describes the equilibrium displacement of an elastic body subjected to forces. The spline maps can be expressed as the linear combination of an affine transformation and a Navier interpolation spline. The proposed algorithm generates a smooth warp that reflects feature point correspondences. It is efficient in time complexity and smoothly interpolated morphed images with only a remarkably small number of specified feature points. The algorithm allows each feature point in the source image to be mapped to the corresponding feature point in the destination image. Once the images are warped to align the positions of features and their shapes, the in-between facial animation from two given facial images can be defined by cross dissolving the positions of correspondence features and their shapes and colors. We describe an efficient cross dissolve algorithm for generating the in-between images.

1 Introduction

Image morphing algorithms have been widely used in creating special effects for television commercials, music videos such as Michael Jackson's *Black or White*, and movies such as Willow, Indiana Jones and the Last Crusade [18]. Applications of image morphing in the entertainment industry date back to the old cross-dissolving process, which originated at Industrial Light and Magic (ILM). Cross-dissolving is the process of mixing the colours of a source image with a those in destination image to form new colours in an intermediate image.

The correspondence between the two images is established by an animator with pairs of points or line segments. In most feature based morphing algorithms, these features are defined manually using an interactive user interface. The user interface presents two images side by side such that correspondence points can be defined by alternately picking points in the two images.

Once the corresponding points from two given facial images are paired, we can construct a warping function to interpolate the position of the feature across the morphing sequence. A warp is a two dimensional geometric transformation which generates a warped image when applied to an input image. When two images are given, the image morphing process first establishes the feature correspondence between them. Based on these feature correspondence pairs a warping function is then constructed. The warping function distorts the images to align the positions of the features and their shapes. Finally, the in-between images can be generated by cross dissolving the colours at each corresponding pair of pixels in the warped images. Its can be obtained by interpolating the positions of the correspondence feature points. Therefore, the image morphing process should allow convenient feature specification, and show a predictable distortion which reflects the feature correspondence.

The rest of this paper is organized as follows. In section 2, we describe the relationship between our work and previously published work. The proposed algorithm based on the elastic body spline is discussed in section 3. The description of the cross dissolve algorithm to generate the in-between images is given in section 4. Some experimental results are discussed in section 5. Finally, conclusions and ideas for future works are discussed in section 6.

2 Related Work

Most of the literature on image morphing falls into three categories. One is mesh morphing, which is an early morphing technique. It was used by Industrial Light and Magic to create the special effects for the movie $''Willow''$ [18]. Wolberg [19] used a nonuniform control mesh and computed a warp by using cubic spline interpolation. Nishita [16] also used a nonuniform control mesh and computed a warp by using two dimensional free form deformation and a Bezier clipping algorithm. The deformation was performed by moving the control points of the mesh on the images. These methods have the drawback that they require a control mesh on an image whereas its features may have an arbitrary structure. Also, using the user interface to define the feature correspondence is very difficult and time consuming.

The second morphing category is called field morphing. This technique depends on pairs of lines, one line in a source image and a corresponding line in a destination image. Field morphing used by Pacific Data Images to create the morphing sequence in Michael Jackson's video clip *Black or White*[6]. The field warp mapping is specified by defining a weighted average of the influence fields around each of the features of the images to be warped. This algorithm, of course, simplifies the work of user interface but the warp generation is complicated and it suffers from unexpected distortions referred to as ghosts[6].

The last category is point based morphing. It is an important particular case of morphing where each feature is distinguished by a set of points in the image. The warp function can be derived by constructing the surfaces that interpolates scattered data points. Recently, two warping algorithms have been proposed which are based on radial basis functions [4] and thin plate splines[3,7] formulate warp generation as scattered data interpolation. These techniques generate a smooth warp that exactly reflects the feature correspondence. An energy minimization method has been proposed for deriving the warp function[14]. This method allows extensive feature specification primitives such as points, polylines, and curves. Internally, all primitives are sampled and reduced to a collection of points. These points are then used to generate a warp.

In this paper, we propose a new spatial image warping with scattered point interpolation based on a Navier elastic body spline to generate a warp function. The spline is based on a partial differential equation of Navier that describes the equilibrium displacement of an elastic body subject to forces.

3 Navier Spline Interpolation

The warping of scattered data points is a problem that appears frequently in science and engineering. The basic problem involves the construction of a reasonable interpolation function which goes through a set of data points. In recent years digital image warping has received a greatdeal of interest. It plays an important role in a wide range of applications including remote sensing, medical imaging, and machine vision as well as in computer graphics[3].

In remote sensing application[11,15] length distortions are caused by surface curvature and oblique viewing angles. For example, when a photo of the Earth's surface is transmitted from a satellite to ground, it is typically warped to correct the surface curvature. In medical imaging[5,12] image warping may be applied to the registration of medical data sets between various modalities, i.e. sensor types such as Computer Tomography and Magnetic Resonance Imaging, or between patients and an anatomical atlas. For example, one often wishes to compare two views of the same part of the anatomy acquired using the same imaging modality in order to detect differences. In computer graphics[3], image warping may be used to create an intermediate image for two given images. A well known example of image warping is a computer movie production technique called image morphing.

In this section, we propose a new algorithm for constructing the mapping function that interpolates scattered data points. It is based on the elastic body spline [2,9]. It allows each feature point in the source image to be mapped to the corresponding feature point in the warped image. The elastic body spline is based on partial differential equation by Navier [8,9,10,20] that describes the equilibrium displacement of an elastic body subjected to forces. Once image features are paired with correspondence points $\vec{p_i}$ and $\vec{q_i}$, we can construct the EBS transformation and use it as interpolation map from R^2 to R^2 relating the set of corresponding feature points.

In point based warping, a set of n point pairs $(\vec{p}_i, \vec{q}_i)$ are selected in the source and destination images. For instance, if $\vec{p}_1$ is the coordinate of a feature point in the source image, $\vec{q}_1$ is the corresponding point of the same feature in the warped image. The displacement between a pair of points is:

$$\vec{r_i} = \vec{q_i} - \vec{p_i}. \tag{1}$$

The coordinate transformation must be determined such that it matches the displacements $\vec{r_i}$ and interpolates them elsewhere. The coordinate transformation $C_{trans}(\vec{x})$ is defined by

$$C_{trans}(\vec{x}) = (f_x(\vec{x}) \ \ , f_y(\vec{x})) \tag{2}$$

$f_x(\vec{x})$ and $f_y(\vec{x})$ are elastic body splines that represent displacements and take the form:

$$C_{trans} = \sum_{i=1}^{N} K(\vec{x} - \vec{p_i})\vec{w_i} + A\vec{x} + \vec{b} \qquad (3)$$

$A\vec{x} + \vec{b}$ is the affine part of the EBS in which $A = [\vec{a_1} \quad \vec{a_2}]_{(2\times 2)}$ and $\vec{x} = [x \;\; y]^T$.

$K(\vec{x})$ is given by:

$$\vec{u}(\vec{x}) = K(\vec{x})\vec{w} \qquad (4)$$

where the coefficient, $\vec{w} = [w_1 \;\; w_2]^T$, is the strength of the force field. $\vec{u}(\vec{x})$ is the displacement of a point within the body from the original position $\vec{x}$.

Above, $K(\vec{x})$ is defined as:

$K(\vec{x}) = [r(\vec{x})^2(M_1)I - (M_2 - 5)\vec{x}\vec{x}^T]r(\vec{x})^2$,

$M_1 = 3\alpha ln[r(\vec{x})] - \beta, \qquad M_2 = 12ln[r(\vec{x})]$.

Here I is a 2x2 identity matrix, $r(\vec{x}) = |\vec{x}|$,

$\alpha = 12(1-k) - 1$,

$k = \frac{\lambda}{2(\lambda+\mu)}$ is Poisson's ratio, $\beta = 18(1-k) - 2$.

Equation(4) is the fundamental solution of the Navier equilibrium partial differential equations for the elastic body subjected to forces which serve as the constraint equations in the elastic body:

$$\mu\nabla^2\vec{u}(\vec{x}) + (\mu + \lambda)\nabla[\nabla.\vec{u}(\vec{x})] + \vec{F}(\vec{x}) = 0 \qquad (5)$$

where ∇^2 and ∇ denote the Laplacian and Gradient, respectively. μ and λ are the Lame coefficients which describe the physical properties of the elastic material. $\vec{F}(\vec{x})$ are the external forces distributed everywhere in the body; we should select these forces so that the warping of the elastic body spline is smooth. There are many different ways to derive the forces[5], such as using information from the input data, from external knowledge (i.e., interactively or from a knowledge base) or from some other processes. These forces should be selected to generate a smooth warp:

$$\vec{F}(\vec{x}) = \vec{w_i}r(\vec{x})^2 ln[r(\vec{x})], \qquad (6)$$

$\vec{F}(\vec{x})$ and $\vec{x}$ are all 2D vectors.

The elastic body spline coefficients are computed by solving the following linear system:

$$W = L^{-1}Y \qquad (7)$$

where

$$L = \begin{pmatrix} (K)_{2n\times 2n} & (P^T)_{2n\times 6} \\ (P)_{6\times 2n} & (O_2)_{6\times 6} \end{pmatrix}_{(2n+6)\times(2n+6)}$$

O_2 is a 6x6 matrix of zeros. K and P are defined by:

$$K = \begin{pmatrix} K_{11}(\vec{x}) & K_{12}(\vec{x}) & \cdots & K_{1n}(\vec{x}) \\ K_{21}(\vec{x}) & K_{22}(\vec{x}) & \cdots & K_{2n}(\vec{x}) \\ K_{31}(\vec{x}) & K_{32}(\vec{x}) & \cdots & K_{3n}(\vec{x}) \\ \cdots & \cdots & \cdots & \cdots \\ K_{n1}(\vec{x}) & K_{n2}(\vec{x}) & \cdots & K_{nn}(\vec{x}) \end{pmatrix}$$

$$P = \begin{pmatrix} x_1 I & x_2 I & x_3 I & \cdots & x_n I \\ y_1 I & y_2 I & y_3 I & \cdots & y_n I \\ I & I & I & \cdots & I \end{pmatrix}$$

where I is the 2×2 identity matrix. Y in Equation (7) is given by:

$$Y = \begin{pmatrix} \vec{f_1}^T & \vec{f_2}^T & \cdots & \vec{f_n}^T & \vec{0} \end{pmatrix}_{(2n+6)\times 1}$$

$\vec{0}$ is a vector of 6 zeros. The EBS coefficients are:

$$W = \begin{pmatrix} \vec{w_1}^T & \cdots & \vec{w_n}^T & \vec{a_1}^T & \vec{a_2}^T & \vec{b} \end{pmatrix}_{(2n+6)\times 1}$$

The elastic body spline can be evaluated by using Equation (3) as the interpolation function that interpolates scattered data points that satisfy $f(\vec{p_i}) = \vec{q_i}$ if and only if L is not singular.

4 Deformed Cross-dissolves

In-between images can easily be implemented using a sequence of interpolation between the source and the destination images. Given two images I_s and I_d, with variable $\alpha \;\epsilon\; [0,1]$, an in-between image I_α is created such that I_α is similar to I_s at $\alpha \longrightarrow 0$ and similar to I_d as $\alpha \longrightarrow 1$. We assume that the variable α varies from 0 to 1, so that the source image I_s continuously changes to the destination image I_d. The in-between images I_α are defined by interpolating a new set of feature points from their positions in I_s and I_d.

Let W_s be the warp function which specifies the corresponding point in I_d to each point on I_s. When it is applied to I_s, W_s has to distort I_s to match I_d in the positions and shapes of features. Let W_d be the warp function from I_d to I_s. It is required to map the features on I_d to the features on I_s when it distorts I_d. The in-between images can be defined using the following deformed cross dissolve function:

$$I_\alpha = [1 - K(\alpha)]W_s^\alpha(I_s) + K(\alpha)W_d^{1-\alpha}(I_d) \quad (8)$$

Here, $K(\alpha)$ is the transition control defined on the image. It determines how fast each point on I_s moves to the corresponding point on the destination image I_d. Also, it determines how much the colour of each point on I_s is reflected on the corresponding point in $I(\alpha)$. $K(\alpha)$ controls the rate of transition in Equation 8. For the colour transformations, linear interpolation cannot defined on the distorted images $I_d(\alpha)$ and $I_d(\alpha)$ but on the given images I_s and I_d, respectively. Hence, we used the transition control $K(\alpha)$ to attenuate the colour intensities of I_s and I_d before applying the warp function. The transformation of positions and colours can be independently handled by specifying a different transition function for each. We can verify that $I_{\alpha=0} = I_s$ and $I_{\alpha=1} = I_d$.

5 Results and Discussion

Fig.1 and Fig. 2 show an example of image warping result based on elastic body splines. Fig. 1 shows the source and target images with a set of points selected between the two coordinate systems respectively. Fig. 2 represents the warping result of the elastic body spline with different Poisson's ratio, 0.4 and 0.5, respectively.

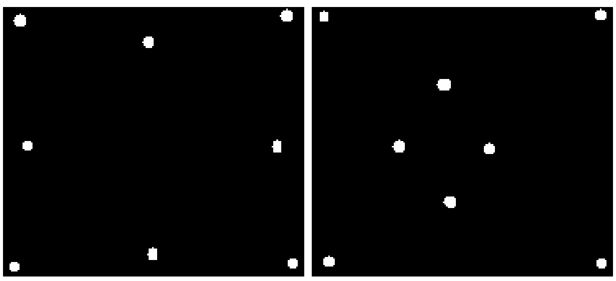

Fig. 1 Source and target correspondence points

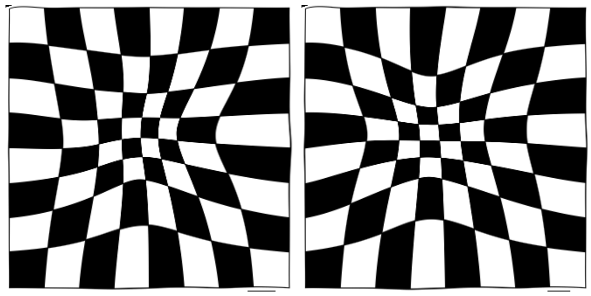

Fig. 2 Warping with $\alpha = 0.4$ and $\alpha = 0.5$

Fig. 3 shows the intermediate image between two facial images. The source image is in the left and the destination image is in the right. The intermediate image was generated using our algorithm. In Fig. 4 two different animal facial images are cross dissolved to generate a series of in-between images. The source image is in the upper left corner of the sequence, and the destination image is in the lower right corner. The other frames show the generated in-between images. Fig. 5 shows another animation morphing result. The source image is the leftmost image in the first row and the destination image is the rightmost image in the third row. The others are the generated in-between images.

Now, we will examine the time complexity of previous morphing algorithms and compare them with our algorithm. Examining Equation (7) and Equation (3) of Section 3, the complexity time of our algorithm is $O(n^3)$ for Equation (3) and $O(nG)$ for Equation (7), where G is the number of pixels in the image, n is the total number of feature points specified. The complexity time of Beier and Neely's method[6] can be estimated to be about $O(\mu G W_1)$, where μ is the number of the feature lines and W_1 is amount of computation required for one pair of feature line. The complexity time of Lee's algorithm[14] is $O(rW_2(G))$, where r is the number of relaxation required on each of a grid, W_2 is the amount of computation required for one relaxation on the finest grid, which is apparently proportional to G. However, in their methods, all pixel points constitute unknowns, so that the entire set of pixel points must fully converge to a tolerable level before the solution is visible as the warped image. The complexity time for thin plate spline algorithm[3,7] is $O(G + \nu^3)$, where is ν is the number of defined points and G is the total number of pixels. Compared with all discussed morphing methods, we found that with around one hundred and fifth points, our algorithm adequately gives a satisfied shape interpolation. The computation speed of our method is also fast enough for an interactive environment.

Fig. 3 Intermediate image

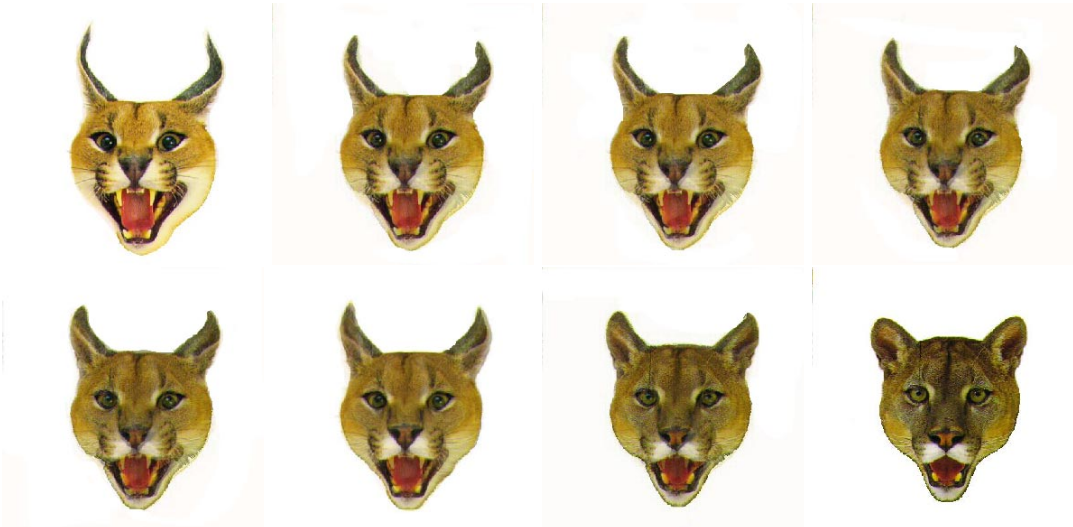

Fig. 4 Animated In-between images

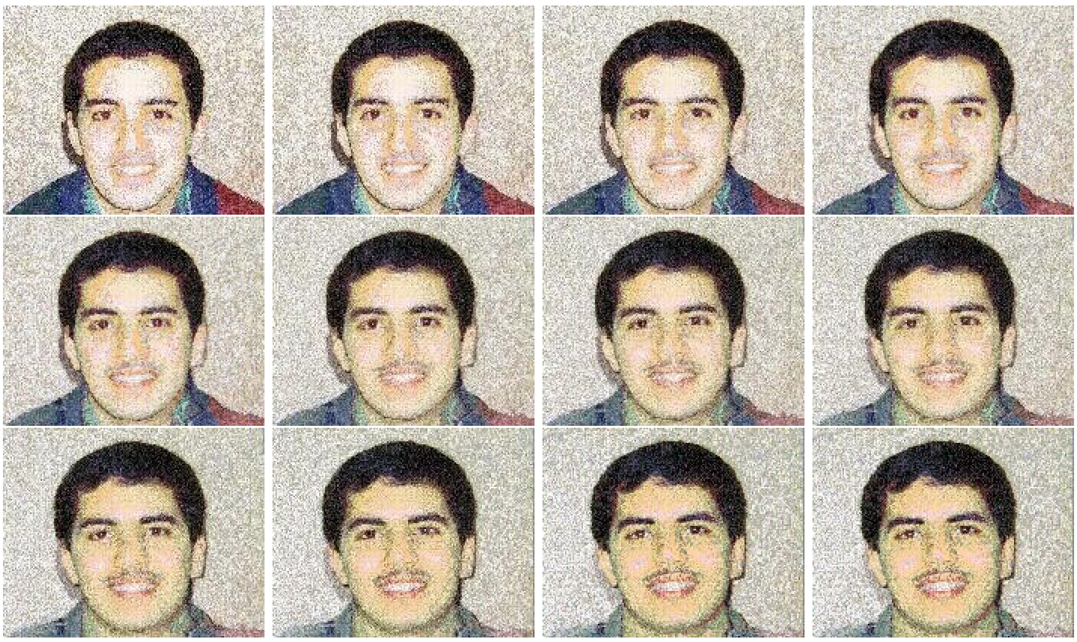

Fig. 5 Animated In-between images

6 Conclusion and Future Work

In this paper, we have proposed a new image morphing algorithm which uses elastic body spline to construct an interpolation map from R^2 to R^2 constrained by a set of corresponding feature points. The EBS is a technique for geometric transformation in 2D and 3D that is motivated by a physical model for the deformation of elastic materials. It is efficient in time complexity and smoothly interpolated morphed images with only a remarkably small number of specified feature points. It allows each feature point in the source image to be mapped to the corresponding feature point in the warped image. To generate the in-between images, we have described an efficient cross dissolve algorithm.

Our future work will be extended to apply the proposed method to the interpolation of intermediate planar slices in medical data sets. Since the proposed algorithm depends only on the distance between pairs of points, it can easily be extended to volume deformation applications, such as registration of volumetric data.

We should note that, the most tedious part of image morphing is to establish the correspondence of features between images by an animator. Algorithms from computer vision may be employed to reduce human intervention, such as active contour model[1,13] or active net model[17]. An edge detection algorithm can provide important features on images, and image analysis techniques may be used to find the correspondence between detected features. One of the most challenging problem in image morphing is to develop an efficient method for specifying features and their correspondence, especially when morphing between two given image sequences.

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