Multiresolution Image Morphing in Wavelet Domain

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Abstract

This paper presents a new view synthesis technique using the 2D discrete wavelet-based view morphing. The view morphing is completely based on pairwise images without the camera calibration and the depth information of images. First, the Fundamental Matrix related to any pair of images is estimated. Then, with the fundamental matrix, the pair of image planes is rectified to be parallel and their corresponding points lie on the same scanline, which gives an opportunity to generate new views with linear interpolating techniques. The pre-warped images are then decomposed into hierarchical structure with wavelet transform. Corresponding coefficients between two decomposed images are therefore linearly interpolated to form the multiresolution representation of an intermediate view. Quantization techniques [10,11] can be embedded here to compress the coefficients to reduce the morphing complexity. Finally, when displaying, compressed images are decoded and inverse wavelet transformed. A post-warping procedure is employed to transform the interpolated views to its desired position.

Keywords: Image morphing, Interpolation, Wavelet transform, Multiresolution, Virtual reality, Progressiveness

1. Introduction

View morphing [1], proposed by Seitz and Dyer in *SIGGRAPH'96*, introduces a new IBMR (Image Based Modeling and Rendering) method via image morphing technique. Different from the traditional image morphing concept where the two reference images may be very dissimilar in shape and radiometrics [8], and hence so is the intermediate images, view morphing emphasizes the physical reasonability, which means that the intermediate images should be shape-preserving. In other word, the results of view morphing should be same as the projective rendering mosaics from different viewpoints. View morphing algorithm can be summarized as a three-stage process: first, the pre-warp source and destination images are pre-warped into canonical configuration in the sense that the two image planes are parallel and corresponding points satisfy the scanline property. Second, intermediate images are generated by the image morphing techniques. Third, the intermediate sequences are post-warped into the original configuration. Compared to other IBMR methods, view morphing possesses the following advantages: very few reference images are required and no geometry information may be needed.

Image morphing is a well-received technique that generates a sequence of *in-between* images such that the source image is gradually changed into the destination image. The main problem in image morphing is to derive a set of warping functions from specified corresponding features in the source and destination images. The warping functions are 2D geometry transforms that distort the source image towards the direction of the destination image, and vice versa. The two distorted images are then cross-dissolved by properly interpolating their positions [7] and radiometric [8].

Mesh-based and field-based morphing are two commonly used image morphing methods. In the former approach, features are specified as a non-uniform control mesh, and a warp function is

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computed by a *Spline interpolation.* The disadvantage of the approach is that the controlling mesh at each step is complicated. The latter approach provides an easy-to-use interface to specify features, which are pairwise line segments in the source and the destination respectively. Each line has a field of influence. A warp is computed by taking the weighted average of the influences of line segments. Both of the approaches are very time-consuming. The computation time is proportional to the image resolution as well as the number of features. In addition, they suffer from influence of high frequency noise near the features. To accelerate the performance of the morphing and de-noise the influence near the features at the same time, wavelet transform is a good approach for its multiresolution structure and nice features in both spatial and frequency domain. There has been some work on 3D metamorphosis in frequency domain. For example, in [5], Wang and Arie introduced a wavelet-based volume morphing method to realize smooth transition between two volumetric data sets. Also, the Fourier transform has been used for volume morphing [6].

In this paper, we propose a fast view morphing method based on wavelet transform. This method preserves all the features in both spatial and frequency domain, while gaining a significant improvement in performance compared to spatial domain morphing.

2. Wavelet Domain View Morphing

Our approach, which can be viewed as an extension of *View Morphing* [1], consists of the following four steps:

Suppose that I_1 and I_2 are two reference images.

1. ***Rectification***: two transformation matrixes H_1 and H_2 are found so that $H_1 I_1$ and $H_2 I_2$ have parallel image planes and the corresponding points are on the same scanlines, *i.e.* their y coordinates are the same. This process guarantees that the interpolation be linear and shape-preserving.
2. ***Image morphing in wavelet domain:*** the two rectified images are first decomposed into pyramid structure by 2D wavelet transform. Next, using interpolation techniques to construct the coefficients of new views level by level.
3. ***Coefficients coding and decoding:*** wavelet coefficients can be quantizated to reduce the complexity and storage requirement, for example, *by Vector Quantization.* When displaying, they can then be decoded quickly.
4. ***Reconstruction:*** inverse wavelet transform is performed to generate new rectified views. The final views with correct position, orientation and radiometrics can be made through a post-warping process.

3. Epipolar Geometry And Fundamental Matrix

Since we concentrate on the uncelebrated cameras, the only information available is the images themselves. This is of great practice in applications where camera parameters may vary due to different conditions of image generation or may not be available at all. Based on the knowledge on stereo vision, the geometric relations between two cameras are described in projective terms rather than in *Euclidean*. This *epipolar* information is entirely contained in a 3x3, rank 2 matrix, called the *Fundamental Matrix* [2,12,13]. It is the key concept for image measurements as it contains all the geometrical information correlating two different images. To estimate fundament matrix, F, we need to know the correspondence between two images. We may interactively specify eight or more corresponding feature points instead. For a given point m in the first image, the projective representation l' of its epipolar line in the second image is given by

$$l' = Fm \qquad (1)$$

Since the point m' corresponding to m belongs to the line l' according to epipolar geometry, we have

$$mF'm = 0 \qquad (2)$$

Therefore, the parameters of F can be estimated by linear least-square method or nonlinear method relying on relation (2). We employ a linear method to fit an initial matrix F_0, and then use the non-linear iterative method to fine-tune a more stable and accurate solution of F.

To rectify the known image pair, we need to search for two transformations H_1 and H_2 such that the two warped images satisfy the scanline property. As described in [2], the necessary and sufficient condition that two images are properly rectified is that their fundamental matrix has the form:

$$F = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \qquad (3)$$

which is up to a constant scale. In [2], Beier and Neely introduced a method to search for the

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rectification transformation H_1 and H_2, based on epipolar constrains of F.

4. Wavelet Transform

Wavelet transform has been widely used in computer graphics, such as surface modeling, radiosity, raytracing, texture mapping, volume visualization and image compression. Wavelet transform possesses a nice feature in localizing image information in both spatial and frequency domain. In addition, wavelet transform provides a multiresolution hierarchical structure to image representation: it decomposes a function into a smooth approximation of the original function and a set of detailed information at different resolutions [5,9,10]. This leads to the progressiveness of the wavelet-based image processing techniques. In this section, we will brief wavelet transform and 2D-wavelet multiresolution decomposition.

Formally, the smooth approximation of a function $f \in L^2(R)$ at any resolution 2^i is a projection denoted as: $A_{2^i}: L^2(R) \to V_{2^i}$, $V_{2^i} \in L^2(R)$, and the detail of f at any higher resolution 2^j is a projection of f onto a subspace O_{2^j} of $L^2(R)$, which is denote as $P_{2^j}: L^2(R) \to O_{2^j}, j > i$. We can properly select the projection functions such that O_{2^j} are orthogonal to each other and V_{2^i}. For discrete functions, there are two sets of functions, which constitute the orthogonal basis of V_{2^i} and O_{2^j}, respectively. We call them wavelet function and scaling function denote as:

$$\psi_{j,n} = 2^{-j/2}\psi(2^j t - n)_{n \in Z} \tag{4}$$

$$\phi_{j,n} = 2^{-j/2}\phi(2^j t - n)_{n \in Z} \tag{5}$$

Using these two functions, the discrete signal and approximation resolution 2^j are respectively defined as:

$$(D_{2^j} f) = 2^{-j/2} < f(u), \psi_{j,n} > \tag{6}$$

$$(A_{2^j}^d f)_n = 2^{-j/2} < f(u), \phi_{j,n} > \tag{7}$$

Instead of calculating the inner products in equations 6 and 7, a pyramid algorithm is applied for the decomposition of the function. For 2D discrete image functions, this algorithm is applied sequentially along each dimension, where

$\widetilde{H}(n) = H(-n), \widetilde{G}(n) = G(-n)$ are low-pass and high-pass filters respectively, which impulse response is defined as:

$$H(n) =< 2^{-1}\phi(2^{-1}u), \phi(u-n) > \tag{8}$$

$$G(n) =< 2^{-1}\psi(2^{-1}u), \psi(u-n) > \tag{9}$$

5. Morphing In Wavelet Domain

Due to the spatial localization properties of wavelet, it is possible to exploit traditional field morphing method in each of the subband images in the of wavelet domain. We need to locate positions of all the feature lines.

5.1. Energy Distribution of a Point

A simple way to determine the feature lines of source and destination images in the wavelet domain is to scale coordinates of x- and y-direction of the features by a factor of ½.

Unfortunately, experiments show that not all wavelets preserve this spatial property because DWT is not a point-based transform, but a vector-based transform. Therefore, each coefficient in wavelet domain may be influenced by many pixels in image space relying on the length of band-passing filters. On the contrary, each pixel in image space will contribute to many coefficients in wavelet domain. In other word, we must know the distribution of energy of a point after wavelet transform. Figure 1 illustrates the energy distribution of a point under different wavelet transforms. We transform an image with only one point into wavelet domain and observe its energy distribution. The higher the energy of a coefficient, the darker it shows.

Note that wavelet transform introduces negative coefficients, so the coefficients in the wavelet domain have been absoluted. Even so, some influenced coefficients are not visible because their energies are too low and can be neglected. As shown in figure 1, the shorter the filter, the nearer the energy distribution is collected to the ideal position whose coordinates are equal to that of the point in image space scaled by a constant of ½ level by level. Inversely, the smoother the wavelet, the larger the regions of energy influenced. Also note that these regions may be disconnected.

5.2. Feature Lines of Different DWT

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So far we have observed that different wavelet selection may influence the determination of positions of feature lines in baseband as well as detail bands. To obtain feature lines accurately and adaptively, we design a simple algorithm that can quickly determine new positions consistent with the original line positions in the sense that the new control point of a line would not be selected at a unreasonable position.

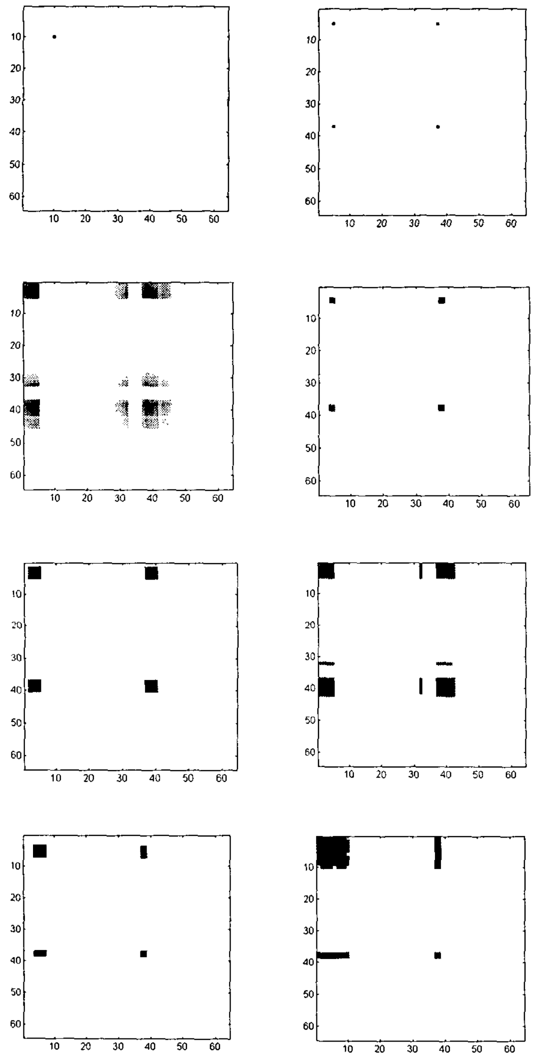

Figure 1. Energy distributions of a point with different wavelet transforms

Feature lines search algorithm:
for each multiscale level
for each line and each end point of it

1. *Transform the point image into a particular wavelet domain, which size is the same as that of the source and the destination.*
2. *Select four new points from approximated band and detail bands respectively to represent position of current considered end point.*
3. *In each subband, create a new line segment corresponding with current processing line.*

end %for line
end %for level

There are several criteria to select control points of the new lines from non-zero coefficients of the DWT transformed point image in different subbands, such as selecting position of minimum energy, maximum energy, energy mean, and absolute maximum energy coefficients. Our experiment shows that the criterion based on the absolute maximum energy coefficients (i.e. selecting the darkest point as new feature control point) leads to the best search performance.

5.3. Warping of the Wavelet Coefficients

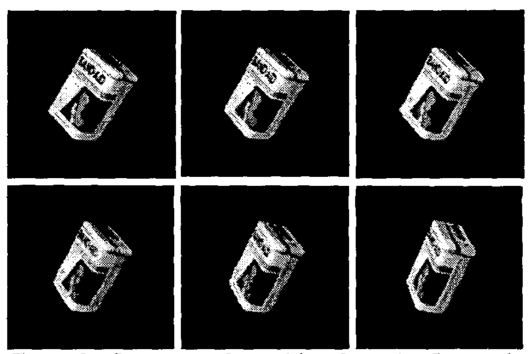

Figure 2. Sequence of transition from the first to the last

Once we have determined four new sets of feature lines in each subband and on a specified level, it is obvious that we can compute wavelet coefficients to generate the distorted source or destination images by directly applying field morphing algorithm in wavelet domain. In-between images are obtained by interpolating values of wavelet coefficients of the distorted source and destination, and then transforming by the inverse wavelet the in-between images to the image space. Figure 2 shows a sequence of in-between images, the first and last image are the source and destination respectively.

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The source images are obtained from Seitz's database.

6. Reconstruction and Progressiveness

In the previous sections, we have discussed how to generate the multiscale representation for interpolated views in wavelet domain. In this section, we will address the issue how the views are reconstructed from the hierarchical representation.

6.1. Post-warp

To reconstruct the intermediate views in the image space (spatial domain), we need to inversely transform the morphed images from the wavelet domain to the spatial domain and then transform these images from the canonical configuration to the original coordination system.

A simple but effective approach for this is to select four control points of a quadrilateral in two original images separately, and then linearly interpolate the intermediate quadrilaterals. Any two quadrilaterals can derive a transformation, which warp one image into the shape of another. Therefore, two original images are warped toward a same intermediate image and then cross-dissolve the radiometric to generate the final morphed images.

6.2. Visibility Analysis

Due to the varying of viewpoints, some points of the scene may become invisible in some views. This gives rise to the problems of holes and folds appearing in the synthesized images. A fold is caused when multiple points are projected to the same position. It is relatively easy to be resolved. The common method is using Z-Buffer techniques. Whereas holes are more difficult to be resolved because we may have insufficient information at the hole position in either of the two original images. Traditional method uses known neighboring points for interpolation; however, it usually gives "ghost" appearing in the synthesized image. In our approach, we try to recover a conceptual surface, which can be used to predict the information at holes and folds.

6.3. Progressiveness of the Wavelet Domain Morphing

Our view morphing scheme possesses a nice feature for distributed and web-based applications. First, with the multiresolution property of wavelet transform, we can obtain a coarse morph on the top level. The morph can be progressively refined level by level. This feature is very suitable for distributed and web-based image and video applications, especially for distributed and Internet IBMR applications. Second, with the rich and effective wavelet-based image compression techniques [9,11], a compression scheme may be embedded in wavelet domain, such as GFA. This would reduce a large number of data transmitted and the decoding and rendering can be performed at the receiver side.

7. Experiment

Compared with field image morphing, wavelet-based image morphing can accelerate morphing process because wavelet analysis can be viewed as a sub-sampling of the original image and it is known that field morphing algorithms depend on the resolution and the number of feature lines. Also, since DWT transforms images into the frequency domain, some frequency-based analysis can be embedded, such as quantization [9], thresholding [11], de-noising, etc. An interesting effect that can not obtain from the spatial image domain based morphing method was mentioned in [3]; that is changing the transition rate of different frequency bands. For example, we can let the low frequency band change quicker and high frequency band slower, or vice versa. An experiment result is shown in figure 3. It is known that high frequency part of an image corresponds to the detail of the image. On the other hand, low frequency part is related to the global information of the image. So varying transition rate of different frequency bands, we can obtain some progressive effect.

A disadvantage of wavelet based image morphing is that the quality of the morphed images are not as good as that of traditional method. This accounts for sub-sampling of DWT, but not wavelet itself. We compare our results with the half size image morphing result from traditional field morphing algorithm and find that the results are the same. To improve quality of the wavelet-based morphing, we may replace the high frequency of wavelet morphed images with its corresponding high frequency part of traditional morphed images. An alternative method is to zoom in the original image and then select feature lines to generate a more accurately specification. Of course, we can also get feature lines via an animator.

8. CONCLUSION

In this paper we describe an effective view morphing method, in which the main image

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processing was performed in the wavelet domain. We discuss the influence of using different kinds of wavelet. We also give different strategies with respect to different wavelet families. Our method requires no camera calibration, which is superior for the IBMR system and communication applications.

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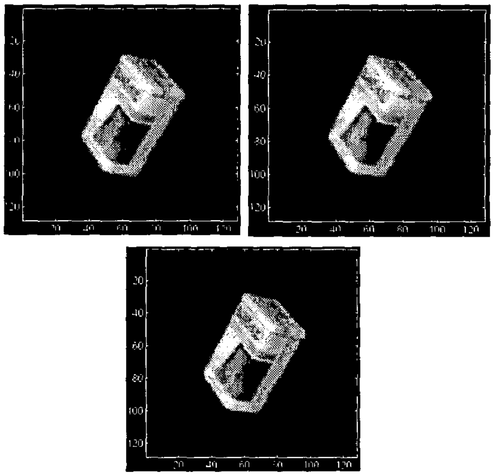

Figure 3. Morphing result using biorthogonal wavelet: Spline (1,1), Spline (3,3) and Spline (3,9)

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