Chinese typeface generation and composition using B-spline wavelet transform

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ABSTRACT

In this paper, a new approach is introduced to generate and compose Chinese typefaces employing B-spline wavelet transform. Firstly, we model each area-based curved outline of the Chinese characters using a B-spline curve, which is determined by a set of control points. Secondly, the B-spline wavelet transform is used to represent the control points with several sequences of wavelet coefficients on several different scales. We then modify the details on different scales by editing them or by combining the coefficients obtained from different standard typefaces. Finally, the modified wavelet coefficients are reconstructed, resulting in a new curved outline for the character being processed. Experiments show that the proposed approach is capable of generating many special kinds of typefaces by applying different editing strategies on the wavelet coefficients.

Keywords: typeface generation, wavelet transform, B-spline curve

1. INTRODUCTION

With the explosion of the desk publishing, various kinds of Chinese typefaces have been extensively used. So far three basic techniques are commonly used to define Chinese characters which are bitmap, vector outline and curved outline. Among them, the curved outline approach is usually regarded as the best because it can be arbitrarily scaled, rotated or stretched without losing quality [1]. Recently, by using curved outline approach, some methods are proposed to automatically generate new Chinese typefaces and to combine two different style of typefaces[2].

Multiresolution analysis (MAR) using wavelet transform has been thoroughly investigated in the last decade. It has been widely used in various applications ranging from speech and image processing, to computer vision and numerical analysis. The wavelet analysis is, in some sense, better than the traditional Fourier transform in that it is better in representing details (or features) of the signals. A recent trend is to apply wavelet theory in the field of computer graphics. The key idea is that the curves and surfaces can be better analyzed and edited by using wavelet techniques.

In this paper, we use the MAR method to model the curved outlines of Chinese characters. Consequently, various kinds of new Chinese typefaces can be generated by editing those curved outlines in wavelet domain.

2. MULTIRESOLUTION CURVE ANALYSIS USING B-SPLINE WAVELETS [3,4]

Consider a discrete signal C^n, expressed as a column vector of samples $[c_1^n, c_2^n, \cdots, c_m^n]^T$. In our application, the samples c_i^n could be thought of as a curve's control points in $\mathbf{R}^2$. C^n can be expressed a low-resolution version C^{n-1} with a fewer number of samples m' ($m' < m$):

$$C^{n-1} = A^n \cdot C^n \tag{1}$$

where A^n is an $m' \times m$ matrix. Since C^{n-1} contains fewer samples than C^n, it is intuitively clear that some amount of detail is lost. The lost detail D^{n-1} can be computed by

$$D^{n-1} = B^n \cdot C^n \tag{2}$$

where B^{n-1} is an $(m - m') \times m$ matrix which is related to A^n. The pair of matrices A^n and B^n are called *analysis filters*. The process of splitting C^n into a low-resolution version C^{n-1} and detail D^{n-1} is called *decomposition*. If A^n and B^n are chosen

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correctly, then the original signal C^n can be recovered from C^{n-1} and D^{n-1} by using another pair of matrices P^n and Q^n, called *synthesis filters*, as follows:

$$C^n = P^n \cdot C^{n-1} + Q^n \cdot D^{n-1} \quad , \tag{3}$$

Recovering C^n from C^{n-1} and D^{n-1} is called *reconstruction.*

Note that the procedure for splitting C^n can be applied recursively to the new signal C^{n-1}. Thus, the original signal can be expressed as a hierarchy of lower-resolution signals $C^0,\cdots,C^{n-1}$ and details $D^0,\cdots,D^{n-1}$, as shown in Figure 1. This recursive process is known as a *filter bank.*

$$\begin{tikzcd}
C^n \arrow[r, "A^n"] \arrow[dr, "B^n"'] & C^{n-1} \arrow[r, "A^{n-1}"] \arrow[dr, "B^{n-1}"'] & C^{n-2} \cdots\cdots \arrow[dr, dotted] & C^1 \arrow[r, "A^1"] \arrow[dr, "B^1"'] & C^0 \\
& D^{n-1} & D^{n-2} & D^1 & D^0
\end{tikzcd}$$

(a) Decomposition

$$\begin{tikzcd}
& C^0 \arrow[r, "P^1"] & C^1 \arrow[r, "P^2"] & C^2 \arrow[r, dotted] & C^{n-1} \arrow[r, "P^n"] & C^n \\
D^0 \arrow[ur, "Q^1"] & D^1 \arrow[ur, "Q^2"] & D^2 \arrow[ur, dotted] & & D^{n-1} \arrow[ur, "Q^n"'] &
\end{tikzcd}$$

(b) Reconstruction

Fig.1 The diagram of wavelet decomposition and reconstruction

Since the original signal C^n can be recovered from the sequence $C^0, D^0, D^1, \cdots, D^{n-1}$, this sequence can be considered as a transform of the original signal, known as a wavelet transform.

All that is needed for performing a wavelet transform is an appropriate set of analysis and synthesis filters A^j, B^j, P^j and Q^j. To construct these filters, we associate with each signal C^n a function $f^n(u)$ with $u \in [0,1]$, given by

$$f^n(u) = \Phi^n(u)\, C^n \quad , \tag{4}$$

where $\Phi^n(u)$ is a row matrix of basis functions $[\phi_1^n(u), \phi_2^n(u), \cdots, \phi_m^n(u)]$ called *scaling functions*. In our applications, the scaling functions are the endpoint-interpolating B-spline basis functions, in which case the function would be an endpoint-interpolating B-spline curve. The scaling functions are required to be refinable; that is, for all j in [1, n] there must exist a matrix P^j such that

$$\Phi^{j-1}(u) = \Phi^j(u) \cdot P^j \quad , \tag{5}$$

Let V^j be the linear space spanned by the set of scaling functions $\Phi^j(u)$. The refinement condition on $\Phi^j(u)$ implies that these linear spaces are nested: $V^0 \subset V^1 \subset \cdots V^{n-1} \subset V^n$, choosing an inner product for the basis functions in V^j allows us to define W^j as the *orthogonal complement* of V^j in V^{j+1}, that is, the space W^j whose basis functions $\Psi^j(u) = (\psi_1^j(u), \cdots \psi_{m-m'}^j(u))$ are such that Φ^j and Ψ^j together form a basis for V^{j+1}, and every $\psi_i^j(u)$ is orthogonal to every $\phi_i^j(u)$ under the chosen inner product. The basis functions $\psi_i^j(u)$ are called wavelets. We can now construct the synthesis filter as the matrix that satisfies

$$\Psi^{j-1}(u) = \Phi^j(u) \cdot Q^j \quad , \tag{6}$$

It is easy to prove that

$$P^j \cdot A^j + Q^j \cdot B^j = 1 \quad , \tag{7}$$

$$\left[\frac{A^j}{B^j}\right] = \left[P^j \mid Q^j\right]^{-1} \quad , \tag{8}$$

To construct our multiresolution curves from endpoint-interpolating cubic B-splines, we

1. For all j in [0, n], choose the $2^j + 3$ endpoint-interpolating cubic B-splines as the basis functions and construct their corresponding synthesis filters P^j.
2. Select $\langle f, g\rangle = \int_{-\infty}^{+\infty} f(u) \cdot g(u)du = 0$ as the inner product for any two functions f and g in V^j. This choice also determines the orthogonal complement spaces W^j.
3. Choose the set of 2^j *minimally-supported* functions that span W^j. This choice determines the synthesis filters Q^j. Together, the synthesis filters P^j and Q^j determine the analysis filters A^j and B^j by equation (8).

3. CHINESE TYPEFACE GENERATION AND COMPOSITION

3.1 Control points of B-spline curves

Each Chinese character is composed of several curved outlines. We represent such kind of an outline with a B-spline curve which can be expressed as a series of control points. Since we are going to apply multiresolution analysis on such a curve with wavelet transform described above, the number of the control points must be $2^j + 3$. In order to comply with such a length, we extend each curve with a resealed sampling interval. The extension procedure can be concluded as the following steps:

1. For a sampled curve with N space knot points, we first obtain a cubic B-spline curve $F^n(u)$ that pass all of the space knot points. $F^n(u) = (f_1^n(u), f_2^n(u), \cdots, f_N^n(u))$, where $f_i^n(u)$ is the jth B-spline curve that can be written as:

$$f_i^n(u) = \sum_{j=1}^{4} c_{i+j-2}^n N_{j,4}(u) \qquad i = 1,2,\cdots,N, \quad u \in [0,1], \tag{9}$$

   where $N_{j,4}(u)$ is the basis functions of cubic B-spline. c_{i-1}^n is the control points that determine the whole B-spline curve.
2. According to the real length of the curved outline, determine the decomposition levels n. Usually, $N \le L$ and $L = 2^n + 3$.
3. Resample $F^n(u)$ with a new sampling interval of $\Delta t = \frac{N}{2^n}$. Totally, 2^n new sample points are obtained. Consequently, we get a new series of N' space knot points with $N' = L$.
4. Similar to equation (9), we can get the new set of control points $c_{i'-1}^n (i' = 1,2,\cdots,N')$ with a length of $2^n + 3$. As a result, we have $F^n(u) = (f_1^n(u), f_2^n(u), \cdots, f_{N'}^n(u))$.

3.2 Wavelet transform for the curved outline

We decompose the control point sequence using the cubic B-spline wavelet transform as discussed in Section 2. The curve then can be represented with several series of wavelet coefficients $C^0, D^0, D^1, \cdots, D^{n-1}$ under different detail levels. By modify the wavelet coefficients, we can get different style of reconstructed curves. In Fig. 2, we show the reconstructed characters by removing only one stage of details of $D^{n-1}, D^{n-2}, \cdots,$ and D^0, respectively. It appears that the details on different scales have different influences on the reconstruction effects.

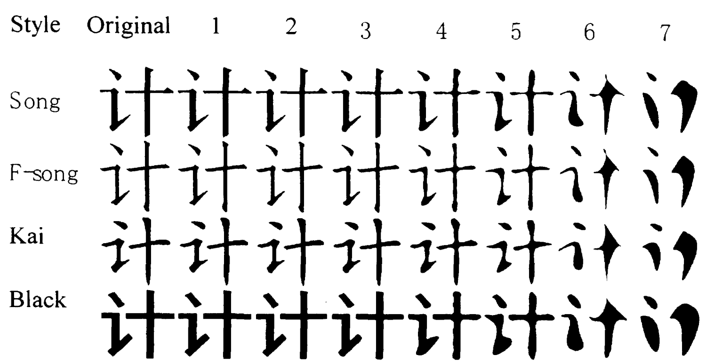

Fig. 2 Reconstructed Characters by Removing Multi-level Details

3.3 Chinese typeface generation and composition

The Chinese typeface generation and composition methods can be summarized as the following steps:

1. Segment each Chinese character into several separate areas, each of which can be represented with a close-up curved outline. For each curved outline, process with Step 2~6.
2. According to those stated in Section 2, extend the curved outline into a cubic B-spline curve with $2^n + 3$ control points.
3. Decompose the sequence of control points C^n using cubic B-spline wavelet transform, resulting in C^0 and the detail information $D^0, D^1, \cdots, D^{n-1}$ on different scales.

4. On some detail levels, replace the detail information with a new value of

$$D^j_{New} = \sum_{i=1}^{4} r_{ij} D^j_i \tag{10}$$

where $D^j_i (i = 1,2,3,4)$ are four different kinds of given typefaces and $r_{ij} (i = 1,2,3,4)$ are their corresponding weights. Usually, $0 \le r_{ij} \le 1$ (i = 1, 2, 3. 4).

5. By combining C^0 with the new detail information D^j_{New}, we can reconstruct a sequence of new control points C^n_{New} with a length of $L = 2^n + 3$.
6. Resample the curve $F^n_{New}(u)$ determined by C^n_{New}, leading to a new curved outline with $\Delta' t = \frac{2^n}{N}$.
7. Fill all the separate areas surrounded by the curved outlines, resulting in a new Chinese character.

We can get different types of Chinese characters by using different modification strategies on the wavelet coefficients, i.e., by giving different values to the weights of r_{ij}. In the experiments described below, we use $0 \le r_{ij} \le 1$ (i = 1, 2, 3, 4; j = 1, 2, 3, 4) to represent the weights for four standard Chinese typefaces of Song, F-song, Kai and Black styles on the first four stages of decomposition levels, respectively. In Fig. 3, some results of the Chinese words "计算机" (meaning *Computer*) are given. Table 1 gives the coefficients of the combined typefaces.

Table 1 Coefficients for different typefaces. (a) for second row, right of Fig. 3; (b) for third row, left of Fig. 3.

r_{ij}	i=1	i=2	i=3	i=4
j=1	0.3	0.3	0.3	0.3
j=2	0.1	0.1	0.1	0.1
j=3	0.3	0.3	0.3	0.3
j=4	0.3	0.3	0.3	0.3

(a)

r_{ij}	i=1	i=2	i=3	i=4
j=1	0.3	0.3	0.3	0.3
j=2	0.3	0.3	0.3	0.3
j=3	0.1	0.1	0.1	0.1
j=4	0.3	0.3	0.3	0.3

(b)

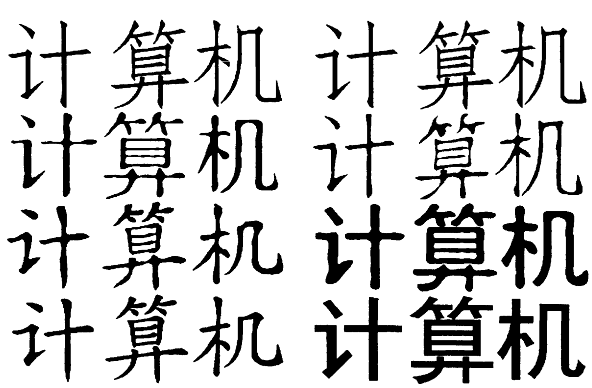

Fig. 3 Chinese typefaces composition results. First row, left: standard Song style; First row, right: standard F-song style; Last row, left: standard Kai style; Last row, right: standard Black style. Second row, left: all r_{ij} = 0 with C^{n-1} from Song style; Second row, right: C^{n-1} from F-song style and see Table 1(a) for the coefficients of r_{ij}; Third row, left: C^{n-1} from Kai style and see Table 1(b) for the coefficients of r_{ij}; Third row, right: all r_{ij} = 0 with C^{n-1} from Black style.

4. CONCLUSION AND DISCUSSION

In this paper, a new technique of cubic B-spline wavelet transform is used in the processing of Chinese characters. The central idea is to use a special characteristic of wavelet transforms, often refereed to as the function of "mathematical microscope". By extracting the detail features on multilevel scales, we can modify these details or combine the details extracted from different given typefaces. As a result, the features of the Chinese characters are modified, resulting in some new kinds of Chinese characters.

For the real application of our method, there still remains some pre-defined assumptions: 1. The number and the topologic structures of the separated areas should be the same. 2. The tracing directions of the corresponding curves of different typefaces should also be the same[2].

5. ACKNOWLEDGEMENTS

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