A Shape Contour Description Method based on Chain Code and Fast Fourier Transform

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***Abstract*—A new shape contour description method based on eight-direction chain code and Fast Fourier Transform (FFT) is proposed. Firstly, chain code tracks shape boundary sequentially, according to the relationship between contour and chain-code projection-transform value. A constructed chain-code function of contour is transformed using FFT. After optimization, then a new Fourier Constant Factor Descriptor is proposed which is called FCFD. The descriptor is independent of initial point and has rotation, shift and scale (RSS) invariant properties. The results of experiments show that our shape contour description method based on FFT reduces computation and improves the efficiency of data processing effectively.**

Keywords-chain code; contour; FFT; RSS; FCFD

I. INTRODUCTION

Shape recognition of an object is an important research content in pattern recognition and machine vision, which is widely applied in many fields, such as image processing, intelligent safety monitoring, AGV cars, medical science, agriculture and so on. In the two-dimensional image space, the shape of the object is usually defined as an area surrounded by the closed contour curve. So there are two kinds of shape descriptors: contour-based shape descriptor and region-based shape descriptor [1,2]. And extracting contour cure of the object is one of the significant aspects for shape recognition. When the contour of the object is accurately described, the object can be further identified. In a word, the description of the contour is the key.

Nowadays there are many ways to describe the contour, such as references [3-5]. The evaluation criteria for contour description mainly include RSS invariant [6], initial point independence, and the memory size and speed of algorithm. Freeman chain code [7] is widely applied, mainly because it uses less data but stores more information, the image data are compressed efficiently. In this paper, eight-direction chain code projection transform is used as the marker function of contour, then the function is fast Fourier transformed. Furthermore, Fourier descriptor is optimized in the frequency domain. Finally, a FFT description method based on chain code is proposed. This method extracts the contour very well, solves the problems of RSS invariance and initial point independence, greatly reduces computation and improves the efficiency of algorithm.

II. EXTRACTING CONTOUR WITH CHAIN CODE

Chain code is a shape descriptor which is used to describe the boundary of an object, in this paper we use the eight-direction chain code [8], illustrated in Figure 1. The chain code values 0-7 represent eight directions. Searching by counterclockwise, 0 is the first one. Every time it rotates 45°, the chain code value adds one. These eight directions can show all the change directions of the object contour.

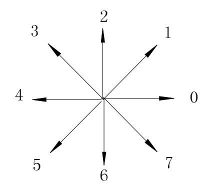

Figure 1. Eight-direction chain code

Let N denotes the number of pixels in the contour. The initial point is A_0, all the points and their coordinates are:

$$[A_0(x_0, y_0), A_1(x_1, y_1), \cdots\cdots, A_{N-1}(x_{N-1}, y_{N-1})]$$

With eight-direction chain code, the outline of an object is searched counterclockwise, and the chain code values of the contour CD_i are obtained:

$$\mathrm{CD}_i = 0, 1, 2, \cdots\cdots, 6, 7 (1 \le i \le N) \tag{1}$$

Define the length of chain code as follows:

$$|CD_i| = \begin{cases} 1 & ,CD_i=0,2,4,6 \\ \sqrt{2} & ,CD_i=1,3,5,7 \end{cases} \tag{2}$$

Because the length of chain code is fixed, the projective transformation of the chain code length in X axis and Y axis can reflect the coordinate changes of the contour when the initial point is determined. The method can reduce the storage space and depress the number of pixels needed by search. In two-dimension coordinate space, horizontal to right and vertical down are positive direction, horizontal to left and vertical up are negative direction. Let $X(i)$ and $Y(i)$ represent the projective values in X axis and Y axis which varies with the chain code. The values are shown in Table I ($1 \le i \le N$).

Table I. The projection value of the chain code in coordinate axis

CD_i	0	1	2	3	4	5	6	7
$X(i)$	0	-1	-1	-1	0	1	1	1
$Y(i)$	1	1	0	-1	-1	-1	0	1

The coordinates of contour points vary with the projection of chain code:

$$x_1 = x_0 + X(1), \qquad y_1 = y_0 + Y(1)$$
$$x_2 = x_1 + X(2), \qquad y_2 = y_1 + Y(2)$$
$$\cdots\cdots$$
$$x_{N-1} = x_{N-2} + X(N-1), y_{N-1} = y_{N-2} + Y(N-1)$$

According to the above equations, the contour can be constructed as follows:

$$h(\mathrm{n}) = x_n + y_n \times t, \qquad \mathrm{n} = 0,1,2,\cdots\cdots,\mathrm{N\text{-}1} \tag{3}$$

where $t = \sqrt{-1}$, N stands for the pixel number of the contour. $h(\mathrm{n})$ is called chain code function, which represents the contour.

III. FFT BASED ON CHAIN CODE FUNCTION

Regardless of rotating, scaling, shifting or initial point changing, the object should be unchanged, so does the contour descriptor. However, the chain code function does not have invariance. In order to make it invariant, next the FFT method is applied on chain code function, and then the FFT descriptor will be optimized.

A. FFT Algorithm

Because the chain code function $h(n)$ is discrete, $\mathrm{n} = 0,1,2,\cdots,\mathrm{N\text{-}1}$, $h(n)$ is converted by Discrete Fourier Transform(DFT), its DFT is described as:

$$\mathrm{H(k)}=\sum_{n=0}^{N-1} h(n) \cdot W_N^{nk}, k = 0,1,2,\cdots\cdots,N-1 \tag{4}$$

As W_N^{nk} has certain special properties, some terms of the DFT can be merged, so a long sequence of DFT can be divided into short sequences of DFT. As follows, $h(n)$ is divided into even and odd groups:

$$\mathrm{H(k)}=\sum_{r=0}^{[\frac{N}{2}]} \mathrm{h(2r)} \cdot W_N^{2rk} + \sum_{r=0}^{[\frac{N}{2}]} \mathrm{h(2r+1)} \cdot W_N^{(2r+1)k} \tag{5}$$

where $N = 2^Z$, N stands for the number of contour points.

Given $W_N^2 = W_{\frac{N}{2}}$, equation (5) can be changed as follows:

$$\begin{aligned} H(k) &= \sum_{\mathrm{r}=0}^{[\frac{N}{2}]} \mathrm{h(2r)} \cdot W_{\frac{N}{2}}^{\mathrm{r}k} + W_N^k \sum_{\mathrm{r}=0}^{[\frac{N}{2}]} \mathrm{h(2r+1)} \cdot W_{\frac{N}{2}}^{\mathrm{r}k} \\ &= M(k) + W_N^k N(k) \end{aligned} \tag{6}$$

Here, $M(k)$ and $N(k)$ only have $\frac{N}{2}$ points, the periods of $M(k)$ and $N(k)$ are both $\frac{N}{2}$, $W_N^{(\frac{N}{2}+k)} = -W_N^k$, so:

$$H(k+\frac{N}{2}) = M(k) - W_N^k N(k) \tag{7}$$

Then the DFT of N points is divided into two DFT of $\frac{N}{2}$ points as following:

$$\begin{cases} H(k) = M(k) + W_N^k N(k) \\ H(k+\frac{N}{2}) = M(k) - W_N^k N(k) \end{cases} \tag{8}$$

where $\mathrm{k}=0, 1, 2,\cdots\cdots,\frac{N}{2}-1$.

The FFT of the chain code function is described as:

$$H(k) = [H(0), H(1), H(2),\cdots\cdots, H(N-1)] \tag{9}$$

The multiplying times of DFT is N^2 , the add times is $N(N-1)$, so the calculating amount of DFT increases with the increasing number of points . The DFT of N points is changed into two DFT of $\frac{N}{2}$ points, which greatly reduces the calculating amount. And each DFT of $\frac{N}{2}$ points can be divided into two DFT of $\frac{N}{4}$ points. Given $N = 2^Z$, the DFT of N points is separated Z times until the DFT of 2 points is obtained.

Suppose $N = 4$, the process of FFT is as follows:

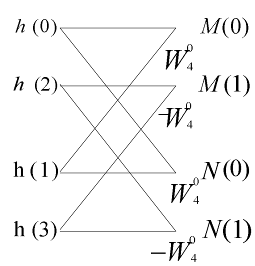

Figure 2. First step

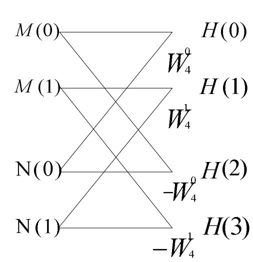

Figure 3. Second step

Figures 2 and 3 are known as the butterfly calculation, which consists of two steps, the multiplying times is

$\frac{N}{2}\log_2 N = 4$ and the add times is $N\log_2 N = 8$. By contrast, when DFT is used, the multiplying times is $N^2 = 16$ and the add times is $N(N-1) = 12$. Therefore, the application of butterfly calculation can save more resources if N is larger.

B. The Optimized of FFT Descriptor

Chain code function $h(n)$ is fast Fourier transformed, then the frequency domain function $H(k)$ is obtained, its frequency domain spectrum consists of amplitude spectrum $|H(k)|$ and phase spectrum $\varphi(k)$. $|H(k)|$ represents the size of signal, $\varphi(k)$ represents the phase curve varies with the frequency domain. In order to make Fourier descriptor have RSS invariant and initial-point independent, frequency domain analysis and optimization are followed:

1) When the object rotates ω degrees, contour function $h(\mathrm{n})$ is changed into $h(\mathrm{n})\cdot\exp(j\omega)$, its discrete Fourier function is described as:

$$\begin{aligned} H_r(k) &= \sum_{n=0}^{N-1} \mathrm{h(n)}\cdot\exp(j\omega)\cdot W_N^{nk} \\ &= H(k)\cdot\exp(j\omega), \qquad k = 0,1,2,\cdots\cdots,N-1 \end{aligned} \tag{10}$$

From equation (10), it can be seen that $|H(k)|$ remains the same and $\varphi(k)$ changes when the object rotates ω degrees. If $H_r(k) = |H(k)|$, then $H_r(k)$ is rotation-invariant.

2) When the object is scaled m times, $h(\mathrm{n})$ is changed into $h(\mathrm{n})\cdot m$. Its discrete Fourier function is described as:

$$\begin{aligned} H_s(k) &= \sum_{n=0}^{N-1} \mathrm{h(n)}\cdot m\cdot W_N^{nk} \\ &= H(k)\cdot m \qquad ,k = 0,1,2,\cdots\cdots,N-1 \end{aligned} \tag{11}$$

From equation (11), it can be seen that frequency domain signal $H(k)$ changes into $H(k)\cdot m$, and $H_S(1) = H(1)\cdot m$, let $H_s(k)' = \frac{H(k)}{H(1)}$, while $\frac{1}{H(1)}$ is a constant. Let $H_s(k) = k_0\cdot H(k)$, $k_0 = \frac{1}{H(1)}$, then $H_s(k)$ is scale-invariant.

3) When shifting happens, coordinates of x and y change, essentially, the value of $h(\mathrm{n})$ changes, suppose the new value is $h(\mathrm{n})+\alpha$, its discrete Fourier function is described as:

$$\begin{aligned} H_t(k) &= \sum_{n=0}^{N-1} (\mathrm{h(n)}+\alpha)\cdot W_N^{nk} \\ &= H(k)+\alpha\cdot\delta(n) \\ &(k = 0,1,2,\cdots\cdots,N-1) \end{aligned} \tag{12}$$

Where $\delta(n)$ is impulse function, it has value only when $n = 0$, so n ranges from 1 to $N-1$, then $H_r(k)$ is shifting - invariant.

4)When the initial point of searching changes, suppose the chain code function becomes $h(\mathrm{n}\text{-}\mathrm{n}_0)$. According to the theory of Fourier transform:

$$F[f(t-t_0)] = F(\omega)\cdot\exp(-j\omega t_0)$$

Then:

$$\begin{aligned} H_f(k) &= \sum_{n=0}^{N-1} \mathrm{h}(\mathrm{n}\text{-}\mathrm{n}_0)\cdot W_N^{nk} \\ &= H(k)\cdot\exp(-j2\pi n_0 k/N) \\ &(k = 0,1,2,\cdots\cdots,N-1) \end{aligned} \tag{13}$$

From equation (13), it can be seen that the amplitude of $H(k)$ remains the same, and the phase changes, so let $H_f(k) = |H(k)|$.

According to 1) - 4), Fourier descriptor can be optimized, then FCFD with RSS invariance and initial point independence is obtained, given $k_0 = \frac{1}{H(1)}$, then $FCFD(k)$ is described as:

$$\begin{aligned} &FCFD(k) = k_0\cdot|H(k)| \\ &(k = 1,2,\cdots\cdots,N-1) \end{aligned} \tag{14}$$

The contour with N points is written as:

$$\begin{aligned} C &= \{FCFD(1), FCFD(2), \ldots\ldots, FCFD(N-1)\} \\ &= \{1, FCFD(2), \ldots\ldots, FCFD(N-1)\} \end{aligned} \tag{15}$$

Overall, the contour described by FCFD has RSS properties and initial point independence. Meanwhile the algorithm efficiency is improved.

IV. SIMULATION AND EXPERIMENTAL RESULTS

In this paper, the simulation is achieved using MATLAB 7.11. Processor: Intel Core 2 Duo T8100 2.10GHz, Memory: 2G ddr2 667MHz, Operating System: Microsoft Windows 7 ultimate. Firstly, we verify the chain code function which can extract the contour perfectly and the FCFD which has RSS invariance and initial point independence. Then we compare the calculating efficiency of FCFD, respectively using DFT and FFT.

A. The Verification of Invariance

The binary image of a maple leaf (200×200) is chosen as the sample. Figure 4. (a)-(e) represent the maple leaves which have the same shape but different size, rotation or initial point: (a)-(d) have the same size, (b)-(c) rotate 30° and 90° respectively, (d) shifts, (e) scales:

Figure 4. Maple leaves of the same shape

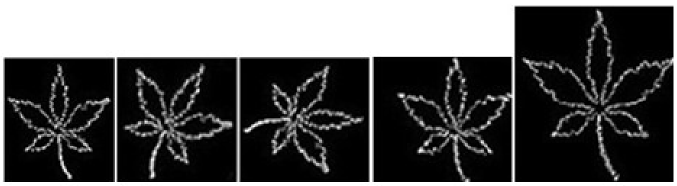

Figure 5. Maple contours extracted by chain code

In Figure 4, (a)-(e) show the maple leaves of the same shape. Their contours are extracted with chain code and shown in Figure 5. From Figure 5, it can be seen that the chain code function can accurately describe the contour, but can't keep invariant.

During the following experiment, FFT algorithm is applied on the chain code. Next the Fourier Descriptor is optimized in frequency domain. Finally, the first eight FCFD values of (a)-(e) in Figure 4 are shown in Table II:

Table II. FCFD of (a)-(e) in Figure 4

Leaf	$FCFD1$	$FCFD2$	$FCFD3$	$FCFD4$	$FCFD5$	$FCFD6$	$FCFD7$	$FCFD8$
a	1.0000	0.0226	0.0127	0.0095	0.0082	0.0081	0.0099	0.0189
b	1.0000	0.0224	0.0123	0.0094	0.0078	0.0075	0.0090	0.0181
c	1.0000	0.0219	0.0122	0.0089	0.0076	0.0078	0.0093	0.0183
d	1.0000	0.0227	0.0125	0.0093	0.0081	0.0080	0.0097	0.0185
e	1.0000	0.0218	0.0121	0.0091	0.0077	0.0076	0.0094	0.0182

From Table II, it can be seen that the FCFD of (a)-(e) in Figure 4 are extremely high similar, which proves that the contours of the maple leaves can be well described by the FFT algorithm based on chain code. Furthermore the invariance is obtained.

B. The Efficency Comparision between DFTand FFT in calculating FCFD

The same maple leaf (493×493) is taken as the sample, the number of contour points is 2051. Given different number of contour points (K), the time used by DFT and FFT for chain code function are compared in the following table (unit: second):

Table III. Compare the efficiency of DFT and FCFD

The Number of Contour Points	$FCFD-DFT$ (time)	$FCFD-FFT$ (time)	ΔT	Promote Efficiency
K=64	0.000073	0.000069	0.000004	5.47945%
K=128	0.000088	0.000072	0.000006	6.81818%
K=256	0.000091	0.000083	0.000008	8.79121%
K=512	0.000125	0.000091	0.000034	27.2000%
K=1024	0.000169	0.000105	0.000064	37.8698%
K=2048	0.000351	0.000152	0.000199	56.6952%

From Table III, it can be concluded that, the application of FFT on chain code function can significantly improved the efficiency. In addition, the promote efficiency increases with the rise of K.

V. CONCLUSION

The experiment results show that this method is feasible. The fast Fourier invariant factor descriptor based on chain code not only has rotation, shift, scale invariance and independence with the initial point, but also improves the search efficiency. The contour extraction method can still be improved to increase the algorithm efficiency, which will be studied in the future.

ACKNOWLEDGMENT

This work is fully supported by Key project in Science and Technology pillar program of Tianjin (10ZCKFGX00400) and National Innovation Experiment Program for University Students (091006008). The authors are grateful for the anonymous reviewers who made constructive comments.

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