Recognition of Profile Contours of Human Face by Approximation — Approximation —

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Abstract From the viewpoint of general recognition system, B-spline is introduced for the approximation and recognition of human profile contours. Profile contour is approximated to the cublic B-spline curve by least square fitting so that B-Spline nodes nearly correspond with the curvature extrema of the contour. This method is designed for the spline to be good features in recognition, and also showed good approximation compared with the variants of B-spline appraximation.

1. Introduction

In computer vision, plain curve recognition which includes contours from silhouettes and line drawings is fundamental and has been well studied. As suggested by P.J.BESL et al.,[1] however, there are other components besides recognition for a general recognition system to have. The total system performance is expected to improve if the system components have close relationship with each other. From the standpoint of general recognition system which consists of low and high level processing, recognition (understanding), modeling and data base, we have recognized human by front contour of face profile. (we call front contour of face profile as profile hereafter.) The shape of profiles is simple and generally similar to each other, which makes it difficult to grasp the delicate differences between profiles.

The purpose of this work is to develope an effective method of approximation which provides good features to recognize similar patterns. Since B-spline curve has attractive properties,[2-6] such as predictability, variation diminishing and local support, it has been widely used in CAD, CAM and computer graphics. Once the vertices are given, B-spline generates the shapes of objects compactly. Therefore, the vertices are also used as a means of data compression in memory storage.[7] The properties and applications are just the components required in a general recognition system. The main problem is how to make the most of B-spline curve for recognition. We present B-spline mathematics and least squares fitting procedure of a plane curve briefly, and determine where the knots shall be set on the curve in the parameter space. Then one condition is set for the vertices to be qualified as features, which also improves the precision of approximation.

2. Data Acquisition and Preprocessing

Profile data of 25 persons are taken by CCTV camera once everyday for five days. Therefore, total data are composed of 5 sets of same 25 persons. Those persons are asked to look at front with no glasses and beard, eyebrow exposed and mouth closed. The sensory data are quantized to 256 X 256 pixels with 4 bit grey level.

In the preprocessing, we extracted edges and then the region of front part, as described in our earlier work[8-10]. The quality of resulting data are generally not good because strong contrast is not adopted and the grey level is low. Two profiles of fourth data set are deleted because of severe broken lines of the nose. In setting up the upper- and lower-boundary of profile, upper edge of eyebrow and jaw, variations were inevitable. Profile curve in the extracted region are then converted to string data, and smoothing is executed to reduce noise and to make the gaps of broken strings closer. The number of sample points in a profile is approximately 126. As a result, 123 profiles are processed hereafter. Fig.1 shows the profiles after preprocessing.

3. B-spline Approximation

Normalized, uniform, open B-spline curve of cubic degree (order 4) is selected for the profile. Assuming that B-spline curve is composed of m segments, and m+1 vertices $(V_0, V_1, \ldots, V_m)$ and m+1 knots $(u_0, u_1, \ldots, u_m)$ in the parameter space u of the curve length are given, the i-th segment of the B-spline curve is:

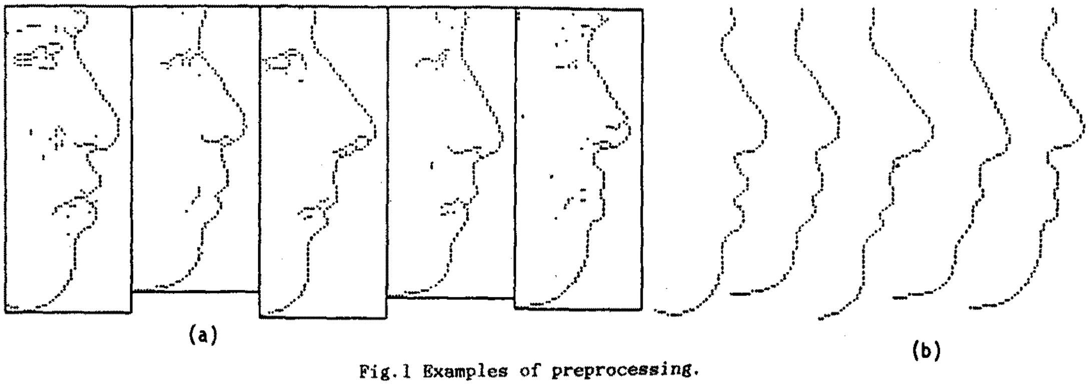


Fig.1 Examples of preprocessing.

$$P_i(S) = [x(s)\ y(s)] = \sum_{j=i-1}^{i+2} N_j(S)\, V_j = [S^3\ S^2\ S\ 1][C][V_{i-1}\ V_i\ V_{i+1}\ V_{i+2}]^T \quad (1)$$

$$[C] = 1/6 \begin{pmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{pmatrix}$$

$$S = (u - u_i) / (u_{i+1} - u_i), \quad 0 \leq S < 1 \quad (2)$$

where $N_j(S)$ is cubic basis function, and S is normalized parameter for the curve segment i, and T means transpose. For the generation of the terminal curve segments, two artificial vertices V_{-1}, and V_{m+1} are set as such:

$$V_{-1} = 2V_0 - V_1,\quad V_{m+1} = 2V_m - V_{m-1} \quad (3)^{[3]}$$

$P_i(0)$ for every segment is called node. Nodes and vertices are derived from each other.

Given the knots (u_i in eq.(2)), B-spline least squares is solved by differentiate E with respect to V_i and equate it to zero.

$$E = \sum_{i=0}^{m-1} \left[\sum_{j=1}^{n_i} \left\{ P_i(S_{ij}) - X_{ij} \right\}^2 \right] \quad (4)$$

where the curve is composed of discrete points X_{ij}, $i = 0,1,\dots,m-1$ as a curve segment, $j = 1,2,\dots,n_i$ as the number of points in i-th curve segment. S_{ij} is parameter value of X_{ij}.

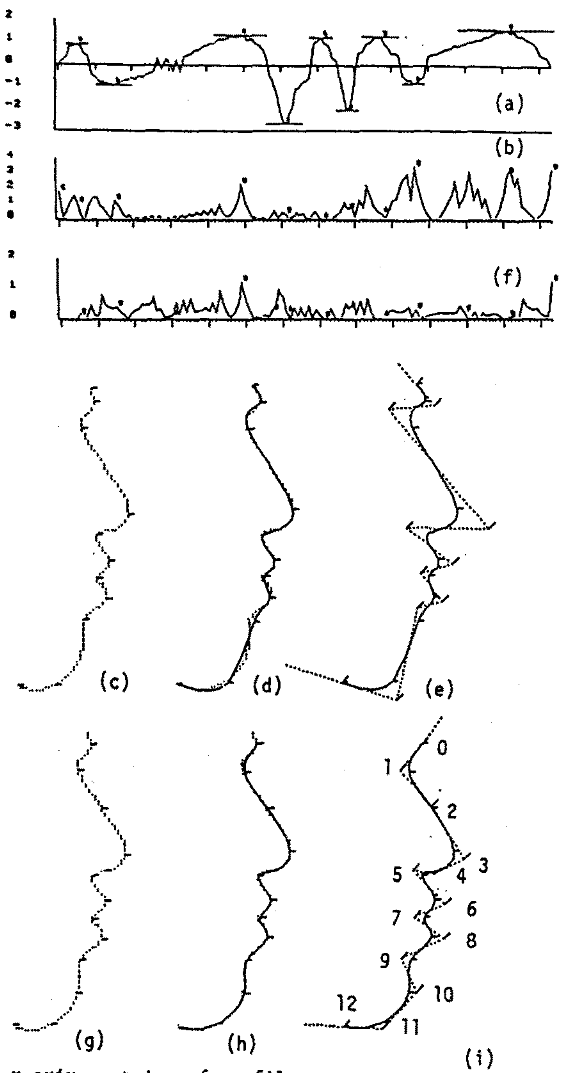
4. Curvature extrema and their Identification

Before the least squares fitting, the number of vertices and knot set should be determined. In other words, it is necessary to determine the number of curve segments and the position of segment boundaries in parameter space. As for the number of vertices concerned, it is a trade-off of good approximation and economy concerned. On the part of position of knots, it is a matter of approximation efficiency for the fixed number of vertices.

From the implication of a B-spline property, variation diminishing, the positions in parameter space whose curvature is extreme (CE) are set as knots. We extracted CE for the one set of profile data (25 curves), and determined nine characteristic curvature extrema (CCE) that almost of 25 curves commonly have stablely (Fig.2-c). Eight of 25 profiles that only have CCE are used to make a model for identifying CCE for all 123 profiles. For each CCE, three measures are stored as the model and used to identify all the CCE of 123 profiles: the sign of curvature, the average of normalized length from the first point of the curve to the i-th CCE, and its standard deviation. For 1107 CCE of 123 profiles, 38 errors were found. 25 errors of them were due to non-existence of corresponding CE. Non-existing CCE of right answers are estimated by the position of two neighboring CCE identified already. As for the wrong CCE, right answer were given so that further experiments could proceed.

5. Setting B-spline knots

Usually profile is not well approximated by the vertices acquired by setting knots on CCE. Additional vertices (we call auxiliary vertices hereafter) are needed to improve the precision of approximation. Furthermore, as CE of a curve are important in object recognition and description, so CE on a B-spline curve must be important. If



x axix : string of profile curve
*: points of curvature extrema
(a) curvature (b) squared error
(c) curvature extrema(-)
(d) B-spline curve and nodes(-)
(e) vertices(/) and nodes(-) of B-spline curve
(f-i) same as (a-e) with auxiliary vertices added.

Fig.2 Results of appreximation and node features(i)

the nodes or vertices can play such a important role as CE, it must be very convenient for recognition, description and application. To meet the both needs, better approximation and recognition, the side length of vertex polygon should be taken into account.

In an ideal case where the lengths of two sides stretching from V_i in vertex polygon are equal, node N_i is CE of cubic uniform B-spline curve. Since it is impossible and not economical to insert knots to make all the side length of vertex polygon equal, we permit some deviation from the ideal CE within threshold T. For a side length l_{i-1} connecting V_{i-1} and V_i, if we want the deviation error of N_i within one tenth of l_{i-1}, the neighboring side length l_i should satisfy the condition (Appendix).

$$0.4 \le l_i / l_{i-1} \le 1.6 \qquad (5)$$

If the above condition is not satisfied, auxiliary vertex is needed on the longer side. The knot position for the auxiliary vertex is determined to the point dividing the longer curve segment by the ratio of its neighboring curve segment i-1 to i+1. In some cases in the profile, however, successive insertion occurred. To avoid this, auxiliary vertex is inserted in l_i when following condition is satisfied.

$$l_{i-1}/l_i < 0.4 \text{ and } l_{i+1}/l_i < 0.4 \qquad (6)$$

6. Results

For all 123 profiles, 72 had auxiliary vertex on the nose line and 49 on the jaw (Fig.2-i, number 2 and 10) by the condition (6). There are some deviations around the nostril. While nostril curve segment changes rapidly, CE was not extracted there because of its short span. As a result, profile is approximated by 14 vertices: 9 from CCE, 2 terminal points, 3 from nose line, nostril and jaw. The result of approximation is quite satisfactory as shown in Fig.2(f-i) and Table 1.

7. Conclusion

Profile contours of human faces are approximated by cubic B-spline curve under the criterion of least squares. There, the relationship between the curvature around a node and the side length of vertex polegon is analyzed, and a condition is set so that nodes are nearly curvature extrema of the contour. The result of approximation is satisfactory and shall be used in recognition.

Method	Averaged Square Error	Variance
1	0.237	0.055
2	0.372	0.109
3	0.247	0.059
4	0.254	0.060
5	0.422	0.141
6	0.605	0.179

1: Adopted method.
2: Knots are set on CCE only.
3: Weighted by the number of sample points.
4: Weighted by the curvature of each sample points.
5: Each knot is set on equidistance.
6: Interpolation.

Tabel 1. *Average of Squared Error for a Sample Point.*

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Appendix

Derivation of condition (5):

If vertices V_{i-1}, V_i, V_{i+1},.. are given, from eq.(1), $P_i(0)$ is

$$1/6\ V_{i-1} + 2/3\ V_i + 1/6\ V_{i+1}$$
$$= 2/3\ V_i + 1/3\ (V_{i-1} + V_{i+1})/2 \qquad \text{(a-1)}$$ [5]

Eq.(a-1) indicates that $P_i(0)$ is the point one third the way along the straight line joining V_i to the mid-point of the line joining V_{i-1} and V_{i+1}. If we assume an ideal case where the two side lengths are same and unity, as in Fig.a-1, $P_i(0) = [0\ 2\cos\theta/3]$. If the vertex V_{i+1} moves to W with same direction and x times longer, then $P_i(0)$ moves to Q.

$$W = [x\sin\theta\ (1-x)\cos\theta],$$
$$C = 1/2\ [(x-1)\sin\theta\ (1-x)\cos\theta], \text{ hence}$$
$$Q = 1/6\ [(x-1)\sin\theta\ (5-x)\cos\theta] \qquad \text{(a-2)}$$

The deviation d from $P_i(0)$ to Q is required within a threshold T,

$$d = |Q - P_i(0)| = 1/6\ |x - 1| \le T \qquad \text{(a-3)}$$

In the case of T = 0.1,

$$0.4 \le x \le 1.6$$

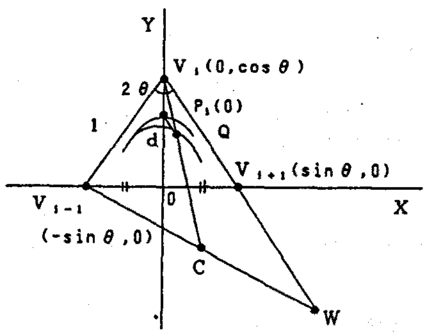

Fig. a-1