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

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Abstract In the recognition of similar patterns like profile contours of human faces, feature measure plays important role. We extracted effective and general feature by B-spline approximation. The nodes and vertices of the approximated curve are normalized and used as features. Since the features have both local property of curvature extrema and global property by B-spline approximation, they are superior to those of curvature extrema of the profile contour. For the image data of six sets of 56 persons, some of which are ill-made, averaged accuracy rate of 97.6 % is obtained in recognizing combinational 333 test samples.

1. Introduction

B-spline is introduced[1-3] in the recognition of plane curves in view of the general recognition system and the desirable conditions of features. B-spline approximation (fitting) is applied under the criterion of least squares.

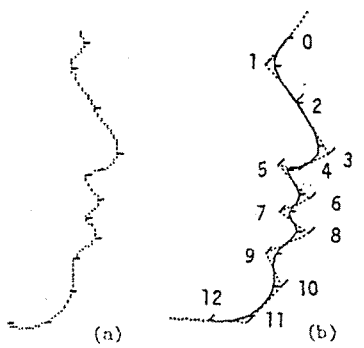
In the recognition of face images, many methods have been developed so far.[4-6] None of them, however, are suitable for the general recognition system. One representative work by Harmon et al.[5] got accuracy rate of 96 % in the recognition of profiles. but their method lacks in generality. In recognizing plane curves such as profiles, it is desirable to have such properties as (1) ability to characterize a curve, (2) high separability of classes, and (3) generality.

2. Features and Distance

Two points of nodes, vertices and knot points are used as the reference in normalizing approximated profile (B-spline curve). In the case of normalization by nodes, nodes of a curve are so arranged that node 1 (Fig.1) is the origin of Cartesian coordinates and the line connecting node 1 to node 9 coincides in the y-axis with normalized length. Feature selection is one of the important subjects in pattern recognition and must be evaluated eventually by the experimental results which feature or feature set is effective. We have taken x- and y-coordinate values of the points as feature set as they include implicitly the information of all the combinative features of length and angle of the points and have generality. In the selection of feature set, five feature sets are considered by the combination of normalizing reference and feature points. With the reference points of normalization by nodes, vertices and knot points, the coordinate values (x,y) of nodes, vertices, and knot points are taken as a feature set. The notation VN , for example, means that the reference points are taken from "vertices" and coordinate values of "nodes" are taken as the feature set. KK is the case where the reference points are taken from the knot points (on the original contour) and the coordinate values of knot points are used as features.

As for the number of features, two cases are compared: 16 for coordinate values of eight points made by CCE only, and 22 for those of 11 points by CCR plus auxiliary points.

Two kinds of distance are used to match standard and unknown pattern; Euclidean and Mahalanobis distance. In Euclidean distance, three types are considered and compared according to weight function for each features. They are denoted as follows:



(a) Profile contour and knot points.
(b) Nodes and vertices of B-spline curve

Fig.1 A Profile Contour and its Approximated B-spline Curve.

1) E_1, weight of unity for all features.

2) E_T, weight of inverse of total variance for each feature.

3) E_W, weight of inverse of within-class variance for each feature.

4) MAH, Mahalanobis distance, assuming that the variance-covariance matrix is same in all the classes.

3. Data Set

In approximation step, input data has been composed of 25 persons taken by CCTV camera once everyday for five days. We call these five sets of 25 persons (123 profiles) "SET A". Seven months later, profiles of 24 persons among 25 persons who are same as above are taken again. In this case, different data acquisition system, was used. We call this one set of 24 profiles "SET A1". Another seven month later, image data of 31 persons who are different from those of SET A are taken six times in a day with the same data acquisition system of SET A1. We call these 6 sets of 31 persons (186 profiles) "SET B". Another data set "SET T" is composed of total data by summing SET A, SET A1 and SET B, which results in six sets of 56 persons (333 profiles altogether).

In the experiments, standard and unknown patterns are made by the combination of a given data SET. For example, if data SET A (123 profiles) is given, four data sets are used for standard pattern and the remaining one set is used as test sample. All the combination choosing 4 from 5 sets, resulting in 123 test samples, are tested, summed and expressed as $_5C_4$. When all the 123 samples are also tested using all 5 sets for standard pattern, it is expressed as "close".

4. Experiments 1

The main object of the experiments in this section is to see which metric and which feature set is the best. Given the data SET A, accuracy rates by three types of Euclidean distance are shown in Table 1. The results show that EUD_T is better than EUD_1, and EUD_W is the best for all the feature sets. As for the MAH, the results are shown in Table 2 together with the EUD_W for comparison. Accuracy rates of MAH are better than those of EUD_W.

Focusing on the open case by MAH, the best accuracy rate (99.2 %) is acquired in NN, NV, VN and VV with 22 features. With 16 features the results are almost same. This means that any reference and any feature set works equally well by MAH. On the other hand in EUDs, NN and NV are more effective than VN and VV. As a whole, NN is considered to be a desirable method in EUDs and all of the four feature sets work well in MAH. The only failure in the best results marked second candidate with slight difference.

One important result can be obtained by comparing NN with KK in Table 1 and 2. The features of KK are curvature extrema of original profile.

Method	open or close	Accuracy (%)		
		EUD_1	EUD_T	EUD_W
NN	open	78.0	88.6	92.7
	close	96.7	96.7	95.9
NV	open	80.5	86.2	91.2
	close	99.2	99.2	99.2
VN	open	74.0	82.9	83.7
	close	93.5	93.5	95.9
VV	open	75.6	84.6	87.8
	close	95.9	95.9	98.4
KK	open	73.2	86.2	90.2
	close	96.7	96.7	97.6

Table 1. Accuracy Rates of Euclidean Distance in Data SET A

Method	Num. of feat.	EUD_W		MAH
		Open (%)	Close (%)	Open (%)
NN	16	93.5	98.4	98.4
	22	92.7	95.9	99.2
NV	16	90.2	99.2	97.6
	22	91.2	99.2	99.2
VN	16	83.7	95.9	98.4
	22	83.7	95.9	99.2
VV	16	84.6	98.4	97.6
	22	87.8	98.4	99.2
KK	16	87.8	98.4	94.3
	22	90.2	97.6	96.7

Accuracy rates of MAH in closed case are all 100%.

Table 2. Accuracy Rates by MAH and EUD_W in Data SET A

On the other hand, NN uses features of approximated curvature extrema of B-spline. Since the two feature sets correspond to each other, absolute comparison is possible. In spite of the approximation errors of least squares the accuracy rates of NN are better than those of KK. The reason is analyzed as follows. The features of KK represent local characteristics of a curve. If the features have some variations in a class, the validity of local characteristics decreases. In NN case, however, a node is determined by its neighboring three vertices. Each vertex mainly shares the information of its neighboring four curve segments of original curve. Furthermore, nodes are approximately curvature extrema in a B-spline curve. Since the variations of vertices are smoothed by least squares approximation, the nodes are also smoothed even though they contain least squares error. The vertices and nodes acquired from the profile by approximation also characterize a curve. In other words, nodes and vertices have global properties as the features of a "curve" though they are "points". The two properties, local characteristics of smoothed curvature extrema and global characteristics, make the NN features robust to some variations in the curvature extrema of original curve in a class.

Next experiment is to check the influence of time deterioration and difference of data acquisition system. Taking SET A as standard pattern and SET A1 as test sample, Table 3 shows the results. While NN is better than KK as before, all the results are generally not good. Time deterioration might be one of the reasons, but it was cleared out that the effect of system difference is a major reason. Taking the system difference into consideration, however, NN of MAH caused only one failure, which means it is insensitive to some variations.

For the data SET B and SET T, almost of the results have same trends as those of SET A. In the case of SET T as shown in Table 4, best result of 97.6 % obtained in NV and VV by MAH. Half of ten failures by NN came from the data SET A1, which were taken by different data acquisition from data SET A. Two failures came from the variations around the mouth. Some people in data SET B opened and closed mouth irregularly.

Method	EUD_W (%)	MAH (%)
NN	16 (66.7)	23 (95.8)
KK	15 (62.5)	20 (83.3)

Number of test samples : 24

Table 3. Results of Time Deterioration and Difference of Data Acquisition System.

	Num. of feat.	EUD_W (%)		MAH (%)	
		Open	Close	Open	Close
NN	16	88.3	94.6	96.1	99.7
	22	90.0	95.8	97.0	100
NV	16	88.9	95.5	95.8	99.7
	22	88.8	96.4	97.0	100
VN	16	82.0	89.2	96.7	100
	22	81.9	90.4	97.6	100
VV	16	85.0	94.3	95.5	99.7
	22	85.5	92.5	97.6	100
KK	16	88.0	94.9	95.2	100
	22	88.8	95.8	94.2	100

6 sets of 56 persons (333 samples) are tested.

Table 4. Accuracy Rates in Data SET T.

5. Experiments 2

The object in this section is to show the contribution of global and local properties of NN to the recognition experimentally. The global and local properties are investigated by exchanging the features of standard pattern and test samples between NN and KK. First, standard patterns are made of KK features and the features of test samples are made of NN features. This method is expressed as KK_NN. NN_KK is the opposite case. The results of NN_KK and KK_NN methods for the data SET A, are shown in Table 5 together with NN and KK again.

The difference, NN - KK, means the total improvement of rates by using NN method compared with KK and marked with "1)" in the table. As for the NN_KK method, the features of test samples have no global information while the standard pattern has. The difference, NN - NN_KK, can be considered as the portion increased by global information. On the contary, the difference bet-

Method	EUD_W		MAH		
	rate	dif.	rate	dif.	
NN	92.7	2.5	99.2	2.9	1)
KK	90.2		96.3		
NN_KK	85.4	7.3	93.5	5.7	2)
KK_NN	87.8	-2.4	93.5	2.8	3)

1) NN - KK : Total improvement.
2) NN - NN_KK : Portion of global information.
3) KK - KK_NN : Portion of local variations.

Table 5. Accuracy Rates by Exchanging Feature Sets between NN and KK in data SET A.

ween KK_NN and K_K can be considered as the portion decreased by local variation. In local variations, two components can be considered. One is the approximation error which operates as a negative factor. The other is the smoothing component that operates as a positive factor.

In all data SETs, the sum of two differences, marked by "2)" and "3)" in the tables is positive, which means NN method contributes to the rates in spite of some approximating errors. This trend corresponds with the result of total improvement. Paying attention to the difference 3), the value is increasing from -2.8, 0.0 (SET B) to 1.5 (SET T) according to the number of profiles for standard pattern increase. This indicates that approximation process gets smoothing effect rather than approximation errors as the number of profiles for standard pattern increases.

6. Separability and Reliability

As for the separability, the ratio of within-class variance to between-class variance for each feature of NN and KK is compared. In case of data SET A, only four of 22 features of KK have slightly bigger ratio than those of NN. For the remaining 18 features, the ratio of NN features is bigger than those of KK with clear a difference. This also shows that the separability of NN features is improved by the global property of nodes. Reliability of the results of recognition is arbitrary defined as a function of the difference between the first and second candidate. Reliability also coincides with the result of accuracy rates.

7. Conclusions

It is a well known property in computer graphics that a change of a vertex affects only "local" parts of a B-spline curve. In the recognition, however, the vertices and nodes have "global" property as well as local property after least squares fitting. Making the most of B-spline properties, we have obtained 97.6 % of accuracy rate for 333 test samples. Furthermore, our method is suitable for a general recognition system which also includes processing, data base and applications such as CAD, CAM, computer graphics and measurements. The features (nodes and vertices) used in recognition could be also used in those fields as they are. The generality of this method can be extended in the recognition of three-dimensional curves and planes.

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