JUDGING SPINAL DEFORMITY BY TWO CHARACTERISTIC AXES ON A HUMAN BACK

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Abstract Spinal deformity is a serious disease especially for teenagers and it is desirable for school children to be checked possible spinal deformity by moire photographic inspection method. The moire images of children's backs are visually inspected by doctors, which may cause misjudge because of a large amount of data they have to examine. A technique is proposed in this paper for automating this inspection by computer. Two characteristic axes, a potential symmetry axis approximating the human middle line and a principal axis representing the direction of a moire pattern are employed. Two principal axes are extracted locally on a back and their gradients against the potential symmetry axis are calculated. These gradients compose a 2D feature space and a linear discriminant function (LDF) is defined there which separates normal cases from suspicious cases. The LDF defined by 40 training data was employed in the experiment to examine 40 test data and 77.5% of them were classified correctly. This amounts to 88.8% if the training data is included.
Keywords spinal deformity, principal axes, potential symmetry, linear discriminant functions

1. INTRODUCTION

Spinal deformity is a serious disease especially for school children. It is compulsory in some areas in Japan that these children receive examination for their possible spinal deformity. For the examination, the most popular inspection method used is the employment of a moire photographic image of a human back. The moire image of a human back shows symmetry if he/she is normal with his/her spine, whereas it shows asymmetry if not normal. Doctors examine the degree of asymmetry visually on this moire image. This is actually tough work because they have to check a large amount of image data collected at schools and it is likely that the work may lead doctors to misjudgement. Therefore their visual task needs to be automated by computer.

There are several attempts to realize this automation. Batoushe[1] and Ishikawa *et al.*[2] reconstructed 3D shape of a back from its moire image to evaluate spatial distortion of the back. But the reconstruction is troublesome as well as time consuming, since it is preceded by thinning of moire stripes and the thinning can not usually be well performed. Employment of potential symmetry analysis is proposed by Ishikawa *et al.*[3] and Ishikawa *et al.*[4], in which they evaluate the degree of symmetry around the extracted axis of potential symmetry. Their techniques do not, however, well discriminate normal from suspicious cases yet in a practical sense.

In this paper, a new technique is proposed for automating the spinal deformity inspection based on a moire image of a human back. Two characteristic axes are employed for the purpose of representing asymmetry (in the sense of axial symmetry) of the moire image. They are the axis of potential axial symmetry which approximates human middle line and the principal axes of the moire image showing the principal direction of the image. Two principal axes are extracted at the region near shoulder blades and near waist. The angles principal axes and the axis of potential symmetry make are employed for classifying normal cases and suspicious cases with respect to spinal deformity. The proposed technique is shown its performance by the experiment employing 80 moire images of junior-high school children.

2. THE AXIS OF POTENTIAL AXIAL SYMMETRY

There are not a few shapes which are not symmetric but had better be understood that they have a certain kind of symmetry. For example, a human face is in its exact sense not symmetric between the left and the right half, but it is far much useful to understand it as it has 'potential' axial (or mirror) symmetry with respect to the middle line. These shapes are called shapes with potential symmetry and the technique for defining such axes or planes of potential symmetry is proposed by Ishikawa *et al.*[3].

The potential symmetry analysis technique is employed in this paper to define the middle line on a moire image of a human back. Namely the middle line is approximated by the axis of potential symmetry of the back and is denoted by A_S. The technique can be applied to the moire image of a back, since the moire image is never be exactly symmetric, even if a normal case. Figure 1 shows the location of the axis of potential axial symmetry.

3. THE PRINCIPAL AXIS

The principal axis of a shape is the axis to which direction the moment of inertia takes the value of

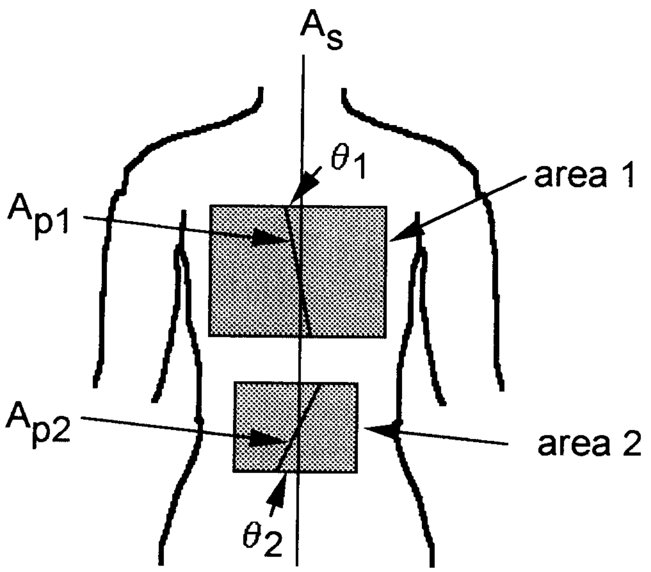


Fig.1 Expressing spinal deformity of a human back

extremum.

Given a digital image $f(x,y)$ of the size $N \times M$, the $(p+q)th$ moment m_{pq} of $f(x,y)$ is given by

$$m_{pq} = \sum_{x \in N_n} \sum_{y \in N_m} x^p y^q f(x,y) \quad , \qquad (1)$$

where $p,q \in N$, $N_n = \{1,2,\cdots,N\}$ and $N_m = \{1,2,\cdots,M\}$.

The centroid of $f(x,y)$ denoted by (x_c, y_c) is

$$(x_c, y_c) = \left(\frac{m_{10}}{m_{00}}, \frac{m_{01}}{m_{00}} \right) \quad , \qquad (2)$$

which leads us to the definition of the central moment μ_{pq}, *i.e.*,

$$\mu_{pq} = \sum_{x \in N_n} \sum_{y \in N_m} (x - x_c)^p (y - y_c)^q f(x,y) \qquad (3)$$

The moment of inertia matrix is then given by

$$I = \begin{bmatrix} \mu_{02} & -\mu_{11} \\ -\mu_{11} & \mu_{20} \end{bmatrix} \qquad (4)$$

By solving the eigen problem of I, the eigenvectors are obtained which give the principal axes of $f(x,y)$.

In the technique presented in this paper, as shown in Fig.1, a principal axis A_{p1} calculated on area 1 near shoulder blades and a principal axis (A_{p2}) on area 2 near the waist are employed and their respective angles θ_1 and θ_2 defined by

$$\theta_1 = grad(A_{p1}) - grad(A_s)$$
$$\theta_2 = grad(A_{p2}) - grad(A_s) \qquad (5)$$

are used to represent the deformity of the moire image.

In order to calculate the principal axis on each area, the contrast at the area must be normalized, since the contrast usually varies from one moire image to another. The normalization is performed in the following way. The mean μ and the variance σ^2 of the image $f(x,y)$ whose area is specified by a rectangle of the size $N' \times M'$ are given by

$$\mu = \frac{1}{N'M'} \sum_{x \in N_n'} \sum_{y \in N_m'} f(x,y) \quad ,$$
$$\sigma^2 = \frac{1}{N'M'} \sum_{x \in N_n'} \sum_{y \in N_m'} (f(x,y) - \mu)^2 \quad , \qquad (6)$$

where $N_n' = \{1,2,\cdots,N'\}$ and $N_m' = \{1,2,\cdots,M'\}$. Using μ and σ^2, new contrast values are calculated by

$$f'(x,y) = \frac{1}{\sigma}(f(x,y) - \mu) \quad (7)$$

This distribution has the mean 0 and the variance 1^2. It is further transformed into $f''(x,y)$ by an appropriate positive constant a and b as

$$f''(x,y) = af'(x,y) + b \quad (8)$$

so that it can be represented as a digital image.

4. Classification By A Linear Discriminant Function

As was mentioned in the former section, two angles θ_1 and θ_2 are employed as features. Therefore points $\{(\theta_{k1}, \theta_{k2}); k = 1,2,\cdots,K\}$ are scattered in the $\theta_1\theta_2$ orthogonal coordinate system. Here K is the number of available moire image data. This distribution is classified into two classes by a linear discriminant function (LDF). Let us denote the class which contains normal cases by C_n, its centroid and variance by P_n and σ_n^2, respectively, and the class containing suspicious cases by C_s, and its centroid and variance by P_s and σ_s^2, respectively. If we denote a LDF by

$$g(\theta_1, \theta_2) = p\theta_1 + q\theta_2 + r \quad (9)$$

with constants p, q and r, an unknown (θ_1, θ_2) is classified in the following way;

$$g(\theta_1, \theta_2) < 0 \rightarrow (\theta_1, \theta_2) \in C_n$$
$$g(\theta_1, \theta_2) \geq 0 \rightarrow (\theta_1, \theta_2) \in C_s \quad (10)$$

The LDF is defined as a normal of line segment P_nP_s intersecting at P which is equidistant from P_n and P_s in the sense of Mahalanobis distance, *i.e.*

$$\frac{P_nP}{\sigma_n} = \frac{P_sP}{\sigma_s} \ .$$

5. Analyzing Procedure

Flow of the entire procedure from image acquisition to final judgment is given in Fig.2. Given a moire image of a subject, rectangle areas, area 1 and area 2, are manually specified on the image. Then each area receives contrast normalization and calculation of the principal axis from its moment of inertia matrix. On the other hand, the potential symmetry analysis technique[3] is applied to the entire moire image to define the middle line. Employing these axes, the angles θ_1 and θ_2 are calculated. The values of θ_1 and θ_2 obtained from a set of training data are scattered in the 2D feature space and they are clustered into two classes by 2-means method. A LDF is then defined on them. This LDF is finally employed for classifying a set of test data into normal and suspicious classes according to (10).

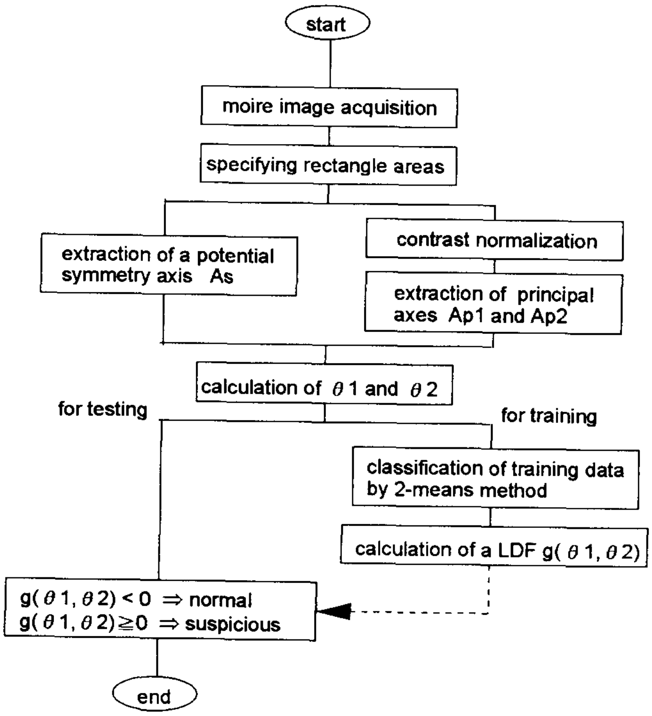


Fig.2 Flow of the procedure.

6. Experiment

An experiment is performed employing moire images of children's backs.

The image data are provided by negative films. They are scanned on an image scanner and fed into a workstation via a personal computer. Each image has 256 × 256 pixels with 256 gray values in the workstation.

Two moire images are shown in Fig.3, where (a) is a normal case and (b) is a suspicious case. Two rectangle areas can be observed there along with the detected principal axes and the potential symmetry axis. Values of θ_1 and θ_2 are also given.

In the experiment, 40 training data containing 20 normal and 20 suspicious cases were used to define a LDF which was given by

$$g(\theta_1, \theta_2) = 1.42\theta_1 + \theta_2 - 7.05 \quad . \quad (11)$$

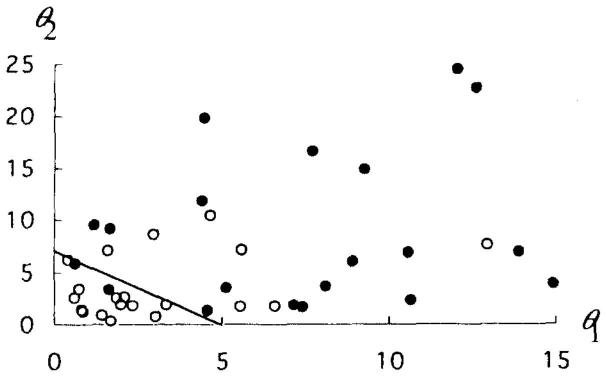
$\theta_1 = 2.47^\circ$ $\theta_2 = 0.68^\circ$

(a)

$\theta_1 = 0.35^\circ$ $\theta_2 = -14.17^\circ$

(b)

Fig.3 Moire images of human backs and obtained characteristic axes



○ *normal*

● *suspicious*

Fig.4 The feature space and the LDF

This LDF was applied to another 40 data containing 20 normal and the same number of suspicious cases for examining performance of the LDF. Distribution of the 40 data in the feature space is shown in Fig.4 along with the LDF. Thirty-one cases out of 40 test data were classified correctly, while 71 out of 80 (containing training and test data) were exactly classified. The classification rate is therefore 77.5% in the former and 88.8% in the latter.

7. CONCLUSION

A technique was proposed for automating spinal deformity inspection by computer based on moire images of human backs.

The features for judging possible spinal deformity had better be extracted in a simpler manner if the technique is to be put into practice. In this sense, calculation of two characteristic axes in the proposed technique is simpler than other techniques already proposed.

Although the classification rate is not yet satisfactory for pratical use, the rate may be increased by more careful choice of a LDF based on larger amount of training data. This remains for further study.

REFERENCES

[1] Batouche, M.: " A knowledge based system for diagnosing spinal deformations: Moire pattern analysis and interpretation" , *Proc. 11 Int. Conf. Patt. Recogn.*, 591-594, 1992.

[2] Ishikawa, S., Takagami, S., Kato, K., Otsuka, Y.: " Analyzing deformity of human backs based on 3-D topographic reconstruction from moire images" , *Proc. '95 Korean Automat. Control Conf.*, 244-247, 1995.

[3] Ishikawa, S., Kosaka, H., Kato, K., Otsuka, Y.: " A method of analyzing a shape with potential symmetry and its application to detecting spinal deformity" , *Computer Vision, Virtual Reality and Robotics in Medicine*, 465-470, Springer, 1995.

[4] Ishikawa, S., Ueno, H., Kato, K., Otsuka, Y.: " Automatic analysis of spinal deformity from moire images" , *Proc. Int. Conf. Automat.*, 213-216, 1995.