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Recognizing Asymmetric Moire Patterns for Human Spinal Deformity Detection

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Abstract Recently, the number of techniques for analyzing medical images has been increasing in computer vision, employing X-ray CT images, ultrasound images, MR images, moire topographic images, etc. Spinal deformity is a serious problem especially for teenagers and medical doctors inspect moire topographic images of their backs visually for the primary screening. If a subject is normal, the moire image is almost symmetric with respect to the middle line of the subject's back, otherwise it shows asymmetric shape. In this paper, an image analysis technique is described for discriminating suspicious cases from normal in human spinal deformity by recognizing asymmetric moire images of human backs. The principal axes which are sensitive to asymmetry of the moire image are extracted at two parts on a subject's back and their angles are evaluated with respect to the detected middle line of the back. The two angles compose a 2-D feature space and inspected cases are divided into two clusters in the space by a linear discriminant function based on the Mahalanobis distance. Given 120 cases, 60 normal and 60 abnormal, the leave-out method was applied for the recognition and 75% recognition rate was achieved.

Keywords: symmetry, potential symmetry, spinal deformity, moire topographic image

1. Introduction

Recently, the number of techniques for analyzing medical images has been increasing in computer vision, employing X-ray CT images, ultrasound images, MR images, moire topographic images, etc. A number of automatic symmetry detection algorithms have been proposed[1,4], in which the algorithms based on the use of principal axes of objects(e.g.,[5]) offer the most general and practical way. It is, however, of no use when shapes under consideration have some asymmetry. Very few techniques[2] have been reported to date which cope with those shapes with approximate symmetry.

Spinal deformity is a serious problem especially for teenagers and medical doctors inspect moire topographic images of their backs visually for the primary screening. If a subject is normal, the moire image is almost symmetric with respect to the middle line of the subject's back, otherwise it shows asymmetric shape.

In this paper, an image analysis technique is described for discriminating suspicious cases from normal in human spinal deformity by analyzing moire images of human backs. The principal axes which are sensitive to asymmetry of the moire image are extracted at two parts on a subject's back and their angles are evaluated with respect to the detected middle line of the back. In order to detect the middle line, the technique for analyzing almost symmetric shapes[6,7] is employed. The two angles compose a 2-D feature space and inspected cases are divided into two clusters in the space by a linear discriminant function based on the Mahalanobis distance. Some experimental results are shown and discussion is given.

2. Moire Topographic Image

Moire topographic image describes the surface of a 3-D shape by a stripe pattern. Mainly it is used in the industrial and medical fields because it has an advantage that it does not come in contact with the object concerned. Employing moire images, Otsuka[3] classified abnormal patterns of spinal deformity into five main categories which are the right thoracic pattern, the left/right lumbar pattern, the alternate pattern and the high thoracic pattern.

3. Two Characteristic Axes

In this section, we refer to two characteristic axes employed in this study: One is the axis of potential axial symmetry, and the other is the principal axis.

3.1 The axis of potential axial symmetry

Various shapes having potential symmetry exist in nature. For example, though a human face is not exactly symmetric, it can be understood to have bilateral symmetry. In order to analyze such shapes with potential symmetry, we have already proposed a technique[6,7] which is presented in the following.

Assume that the original digital image is described by function $F(x,y)$,

$$F(x,y) = \{f(x,y) \mid (x,y) \in R\}.$$

The reflection image with respect to the y axis is represented by $F^r(x,y)$ where

$$F^r(x,y) = \{f^r(x,y) \mid (x,y) \in R^r\}.$$

Here R is a region of F and its reflected region R^r is denoted by F^r. Transformation matrix of the reflection image $F^r(x,y)$ can be written as

$$T = \begin{bmatrix} cos\theta & sin\theta & c_x \\ -sin\theta & cos\theta & c_y \\ 0 & 0 & 1 \end{bmatrix}.$$

Image $F^r(x,y)$ is superposed onto $F(x,y)$ by parallel translation $\mathbf{c} \equiv (c_x, c_y)$ and rotation θ to find the best coincidence according to Eq.(1):

$$D = \sum_{(x,y)\in S} \left| \frac{F(x,y) - T(F^r(x,y))}{S} \right| \qquad (1)$$

where $S = n\{R \cap R^r\}$. Note that the number of the elements of set A is denoted by $n(A)$. Following geometrical restriction is taken into account with respect to c_x, c_y, and θ;

$$c_y = c_x tan\frac{\theta}{2} \quad . \qquad (2)$$

When the superposed position realizing D of Eq.(1) is obtained, the normal bisecting the line segment connecting G, the centroid of F, and G^r, the centroid of F^r, is defined as the axes of potential symmetry. This axis is inclined by $\frac{\theta}{2}$ with respect to the vertical line. For effective usage of Eq.(1), the superposed area S needs be more than a certain threshold value.

3.2 The principal axis

Principal axes are calculated from the moment of inertia matrix I defined on an object. It is given by the following;

$$I = \begin{bmatrix} \mu_{02} & -\mu_{11} \\ -\mu_{11} & \mu_{20} \end{bmatrix}. \qquad (3)$$

Here μ_{pq} $(p,q=0,1,2)$ is the $(p+q)$th central moment. By solving the eigenproblem with respect to Eq.(3), the principal axes are obtained as its eigenvectors.

4. Classification Employing Two Axes

4.1 Extracting two axes

To evaluate the degree of asymmetry, the proposed technique employs aforementioned two characteristic axes that are obtained from a moire image. Since a human body is regarded as having potential axial symmetry, the axis of potential axial symmetry is extracted as the middle line from the moire image of a subject's back employing Eq.(1).

Two principal axes are extracted on the other hand from upper and lower rectangle areas containing shoulder blades and the waist, respectively(See Fig.1). The principal axes are calculated from the moment of inertia matrix given by Eq.(3) which is defined by the gray values in each rectangle area. Since the range of the gray values normally varies with respective images, their distribution is normalized so that the mean gray value is 0 and the standard deviation 1.

4.2 Classification method

In order to discriminate normal cases from suspicious cases, an index given by Eq.(4) is calculated from the two characteristic axes;

$$ad = |\theta_p - \theta_s|. \qquad (4)$$

Here θ_p is the angle of principal axis, and θ_s is the angle of the potential symmetry axis. The value of ad at the upper rectangle area and the lower rectangle area are denoted by ad_{upper} and ad_{lower}, respectively. They are called the characteristic angles.

The set of values ad_{upper} and ad_{lower} has a distribution in the 2-D feature space according to the number of analyzed moire images. The distribution is expected to be divided into two classes corresponding to normal and suspicious cases. Therefore the linear discriminant function(LDF) is defined on the 2-D feature space based on the Mahalanobis distance so that it can offer a rational border between the two classes. The LDF is the classifier for the spinal deformity detection.

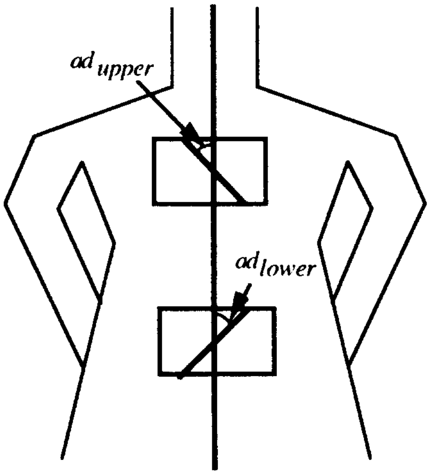

Fig.1 Two rectangle areas. cases.

5. Experimental Results

5.1 Hardware system

Photographs of the moire images have 256 by 256 pixels with 256 gray levels. They are fed into an EWS(SUN Sparc Station 10) by an image scanner through a personal computer.

5.2 Experiment

To define the middle line of a subject's body, the axis of potential axial symmetry is extracted employing GA, in which the number of individuals are 30, the mutation rate is 2%, and one point crossover is used.

In the experiment, 120 data(60 normal and 60 abnormal) are employed. The leave-out method is used to perform classification of these data: They are separated into three sets each with 20 normal and 20 abnormal cases and a set among them is

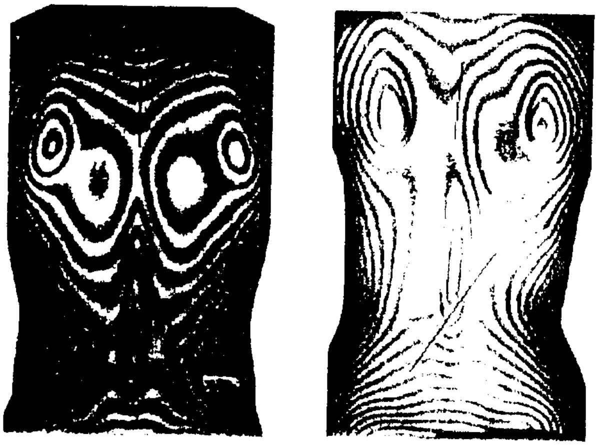
(a) Normal (b) Suspicious

Fig.2 Extracted axes.

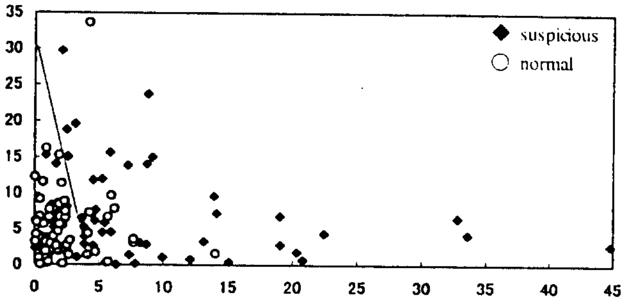

Fig.3 The 2-D characteristic space and the LDF.

Table 1 Classification rate.

Data	Data A	Data B	Data C	Average
A	87.5%	70.0%	62.5%	73.3%
B	70.0%	90.0%	67.5%	75.8%
C	72.5%	72.5%	87.5%	77.7%
				75.5%

used for training, i.e., for defining a LDF, whereas the other two sets for test. This is performed three times and the average classification rate is finally reported.

5.3 Result

Two of the analyzed moire images are shown in Fig.2. The left-hand side is a normal case whereas the right-hand side is a suspicious case. Fig.3 shows the 2-D characteristic space and Table1 shows the classification rates. On the average, we obtain 75.5% of classification rate.

6. Conclusion

This paper proposed a technique for classifying normal/suspicious cases for spinal deformity automatically from moire images of human backs. The proposed technique was examined its performance by an experiment and 75.5% of correct classification rate was achieved. Although the classification rate is not yet satisfactory for practical use, the rate may be increased by more careful choice of the two rectangle areas. Defining the rectangle areas on individual moire images might be another efficient way of increasing the classification rate. These remain for further study.

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