Automatic Spinal Deformity Detection by Two Characteristic Axes

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Abstract

This paper proposes a technique for judging spinal deformity from a moire image of a human back. The middle line and the principal axes of the back are extracted from the moire image and their difference is numerically evaluated. For the extraction of the middle line, the potential symmetry analysis technique is employed, whereas the principal axes are obtained from the moment of inertia matrix defined on the moire image. Experimental results are given and some issues are discussed.

1. Introduction

Spinal deformity is a serious problem for teenagers. Medical doctors inspect moire images of their backs for primary screening in schools. If a subject's spine is normal, the moire image is almost symmetric with respect to the middle line of his/her back. If a subject has spinal deformity, the moire image is distorted asymmetrically and the degree of asymmetry is evaluated visually by doctors. It is actually crushing effect on medical doctors to inspect a number of moire images. Therefore, automating the screening is strongly expected by medical doctors. There have been some studies on this automation until now [1, 2] , but none of them has yet been put into practice.

This paper proposes a technique for judging possible spinal deformity by extracting two characteristic axes from a subject's rear moire image. One of the characteristic axes is the middle line of human and the other axis is the principal axis. Difference of their gradients are employed for judging normal or suspicious with respect to spinal deformity. The experiment is performed employing real moire images of children's backs and the result is shown with discussion.

2. Characteristic Axes

2.1 Axis of Potential Symmetry

A shape is called to have potential symmetry, if it makes us associate with a certain kind of symmetry like a human hand. The shape which has potential symmetry may provide intrinsic information of the figure, if it is analyzed taking the original symmetry type into account. This analysis is originally realized in [3]. The technique is slightly modified in this paper.

Let us denote a digital image by $F(x,y)$, $(x,y)\in R$, and its mirror symmetric image by $F^r(x,y)$, $(x,y)\in R^r$. Here R is a region of F and its reflected region is denoted by R^r. Image $F^r(x,y)$ is superposed onto $F(x,y)$ by parallel translation $c(c_x,c_y)$ and rotation θ to find the best coincidence according to the formula

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

where $S=\mathrm{n}\{R\cap R^r\}$ and

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

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Note that the number of the elements of set A is denoted by n(A). The following restriction should be taken into account with respect to c_x, c_y, and θ [4];

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

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 axis of potential symmetry. This axis is inclined by $\theta/2$ with respect to the vertical line. For effective usage of Eq.(1), the superposed area S needs be more than a certain threshold value.

2.2 Principal Axis

The extreme value of the moment of inertia gives the direction of the principal axis of the object concerned. It coincides with the axis of symmetry, if the object is exactly symmetric. However, if the object has even a slight asymmetric part, the principal axis will never agree with the original symmetric axis.

Principal axes are calculated from moment of inertia matrix **I** defined on an object (or on its part). It is given by Eq.(3),

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

Here μ_{pq} $(p,q = 0,1,2,\cdots)$ is the $(p+q)$ th central moment. By solving the eigen problem of **I**, the principal axes are obtained as its eigenvectors.

3. A Technique of Detecting Distortion

The moire image of a human back is almost symmetric with respect to the human middle line, if his/her spine is normal. However, the moire stripes are distorted asymmetrically if he/she has spinal deformity. In order to evaluate this asymmetry in a numerical way, the proposed technique employs two characteristic axes obtained from the moire image of a human back. The flow chart of the entire procedure is shown in **Fig.1**.

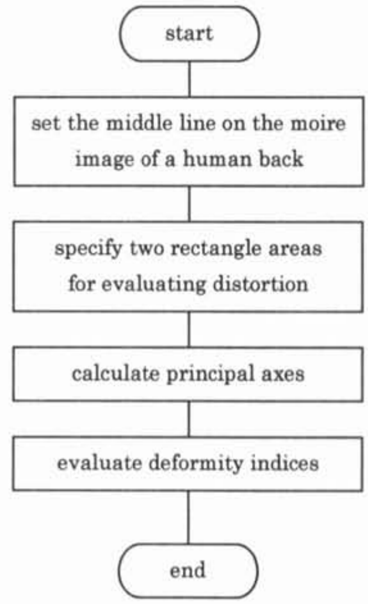


Fig.1 Flow chart of the procedure

In the first place, the axis of potential axial symmetry is extracted as the middle line employing the technique[3, 4] from a moire image of a subject's back. Two principal axes are extracted from upper and lower rectangle areas containing shoulder blades and the waist, respectively (See **Fig.2**). 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. The rectangle area itself is specified manually keeping the location symmetric with respect to the middle line. Its size is , however, specified by a user at the moment.

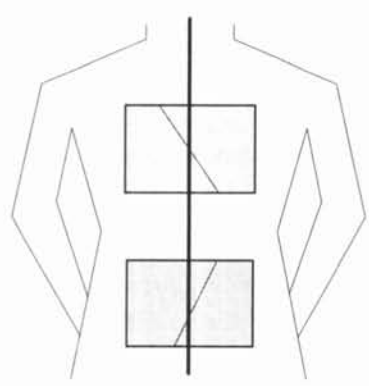


Fig.2 Two rectangle areas

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

$$ad = a_2 - a_1 \ . \qquad (4)$$

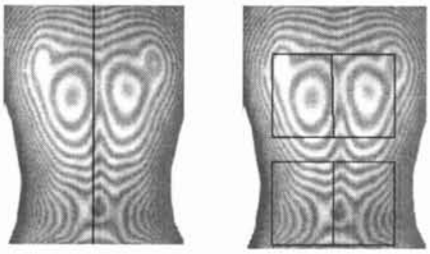
Here a_1 is the angle in degrees of the middle line, and a_2 is the angle in degrees of the principal axis. The values of ad at the upper rectangle area and the lower rectangle area are denoted by ad_{upper} and ad_{lower}, respectively. They are called characteristic angles.

4. Experimental Results

Experiment is performed employing the moire images of junior-high school students' backs. Photographs of the images are digitized into 256 by 256 pixels images with 256 gray levels by an image scanner connected to a personal computer and they are fed into a workstation (Sparc Station10) via network lines. The proposed technique is corded into a program by C language and it is implemented on a workstation to analyze specified moire images.

Two of the experimental results are shown in **Fig.3**. On the left-hand side, the original moire image with the detected middle line is shown, while on the right-hand side, the moire image with the obtained principal axes and the values of ad are given. Figure 3a is a normal case and Fig.3b is a suspicious case which is referred to as an alternate pattern. The average elapsed time for extracting the two axes is approximately 2 minutes by Sparc Station 10.

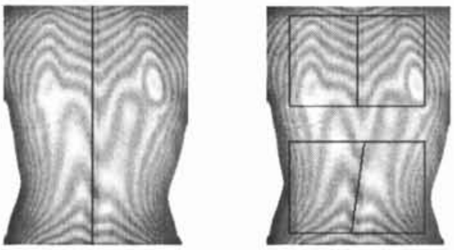
Forty data, 20 normal and 20 suspicious, are employed in the experiment. A feature space of the characteristic angles is shown in **Fig.4**. The horizontal axis is the values of ad_{upper}, and the vertical axis is the values of ad_{lower}. As shown in Fig.4, the horizontal axis does not contribute to differing normal cases from suspicious cases in this experiment. Therefore the vertical axis is solely employed in the experiment for separating the both cases. The result is given in **Table 1** where two respective thresholds are used to divide the scattered data into two classes on the ad_{lower} axis. In Table 1a, the threshold for ad_{lower} is chosen so that all the suspicious cases are correctly classified. Then the total classification rate is 80%. In Table 1b, on the other hand, the threshold is chosen to achieve 100% of correct classification of normal cases. The entire classification rate then becomes 90%.



$ad_{upper} = 0.21$

$ad_{lower} = 0.33$

(a)



$ad_{upper} = 1.62$

$ad_{lower} = -8.30$

(b)

Fig.3 Experimental results: (a) a normal pattern, and (b) an alternate pattern.

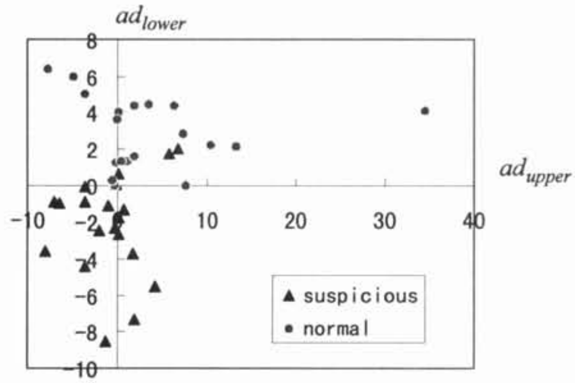


Fig.4 Characteristic angles

Table 1 Classification rates

	threshold	suspicious	normal	total
(a)	1.98	20(100%)	12(60%)	80%
(b)	-0.01	16(80%)	20(100%)	90%

5. Discussion

The proposed technique was examined its performance by an experiment and 90% of correct classification rate was achieved. The experiment is still under way employing a number of data to find the best threshold value for the classification.

Employment of two characteristic axes seem to work well, since the gradient of the principal axis is highly sensitive to asymmetric distortion of the moire image concerned, while detection of the middle line is likely to be stable because the moire image analyzed is not very asymmetric. The rectangle areas need careful choice, however, since the gradient of the principal axis depends on its location and size. One may need to specify them taking account of a subject's height, the girth of his/her breast and that of his/her waist.

Although the variable ad_{upper} was not used for classification in the performed experiment, it should be employed for future experiments, since the area containing shoulder blades are actually taken into consideration in medical doctors' visual inspection. Effective use of ad_{upper} largely depends on appropriate choice of the rectangle area near shoulder blades.

In the performed experiment, classification between normal and suspicious was a primary concern. The suspicious cases are, however, separated into five typical patterns and they are likely to be recognized by the gradients of the principal axes at the two rectangle areas. Automatic separation among these suspicious cases is also within the scope of this study.

6. Conclusion

A technique was proposed for detecting spinal deformity automatically from moire images of subjects' backs. Two characteristic axes were employed, i.e., the middle line on a subject's back approximated by the axis of potential symmetry and the principal axes calculated from the moment of inertia matrix. Their angular differences were employed for discriminating suspicious cases from normal cases and some experimental results were shown. Automatic rectangle areas specification and the employment of the pattern information of the area surrounding the shoulder blades need to be investigated. Separating possible spinal deformity into individual cases also remains to be studied.

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., Ueno, H., Kato, K., Otsuka, Y. : "Automatic analysis of spinal deformity from moire images", *Proc. Int. Conf. Automat.*, 213-216(1995).

[3] Takeda, T. Ishikawa, S., Kato, K. : "Employing symmetric subsets for identifying asymmetry of human skulls", *Proc. IAPR Workshop on Machine Vision Applications*, 338-341(1994).

[4] 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).