Discrimination of Spinal Deformity Employing Discriminant Analysis on the Moiré Images

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Abstract: In this paper, we propose a technique for automatic spinal deformity detection from moiré topographic images. Normally the moiré stripes show symmetry as a human body is almost symmetric. According to the progress of the deformity of a spine, asymmetry becomes larger. Numerical representation of the degree of asymmetry is therefore useful in evaluating the deformity. First, displacement of local centroids and difference of gray values are evaluated statistically between the left- and the right-hand side regions of the moiré images with respect to the extracted middle line. We classify the moiré images into two categories i.e., normal and abnormal cases from the features, employing discriminant analysis. An experiment was performed employing 1,200 moiré images and 85% of the images were classified correctly.

Keywords: moiré topographic images, approximate symmetry, spinal deformity, discriminant analysis

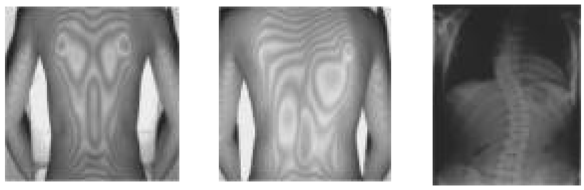
1. INTRODUCTION

Recently various imaging techniques have been introduced into medical fields [1-2] as useful tools for providing helpful information for visual inspections including X-ray computed tomography, ultrasound images, magnetic resonance imaging and moiré topographic images. In spinal deformity detection, forward-bending test or moiré topographic images used for visual inspection by doctors.

Spinal deformity is a serious disease mainly suffered during their growth stage. There are many causes of spinal deformity, but all of them are unknown. The most common type is termed “idiopathic” that show 80% of the spinal deformity. When one afflicted with spinal deformity, his/her spine often deforms in the shape of letter ‘S’ or ‘C’ and it causes oppression of inner organs such as lungs and a heart resulting in heavy lumber pain or fatigue. Fig.1 shows an example of the moiré images. In Fig.1, (a) shows a normal case, (b) shows an abnormal case and (c) shows a CT image. In 1977, the ministry of education of Japan started to direct examination of spinal deformity for school children. In order to check the presence of spinal deformity in its early stage, orthopedists have traditionally performed to children a painless examination called a forward-bending test. But this test is neither reproductive nor objective. Moreover the inspection takes much time when applied to medical examination in schools. To overcome these difficulties, a moiré method has been proposed which takes moiré topographic images of human backs and checks visually symmetry/asymmetry of the moiré pattern in a two-dimensional (2-D) way. Invention of the moiré method [3] largely raised efficiency of the school spinal deformity examination. One of the main reasons why the moiré method has gained its popularity among doctors is that symmetry/asymmetry of the subject back can clearly be observed by its moiré pattern. It is, however, medical doctors who examine the moiré images and visual examination of the large amount of moiré images collected from elementary as well as junior high schools. This causes exhaustion of doctors and therefore leads to misjudgment. There realization of automated spinal deformity inspection based on the moiré images has long been desired among orthopedists.

Automating judgment of possible spinal deformity by computer has been reported employing moiré images of human backs. A moiré topographic image describes an object’s three-dimensional (3-D) shape by a set of light-stripe patterns [4-11]. It is obtained from photographing the object using a moiré camera, which is commercially available. Since moiré topography contains depth information, most of the reported studies try to recover 3-D shape of the back by extracting moiré stripes and compare the right part of the back with its left part geometrically. Ishikawa *et al.* [12] and Kim *et al.* [13-15] proposed a novel technique for automating human spinal deformity detection based on the 2-D analysis method by computer. Despite these efforts, their approaches did not succeed, because of the difficulty of image processing in extracting the moiré stripes exactly. Thus they did not reach to the stage of classification experiments employing real data.

In this paper, we propose a technique for automatic spinal deformity detection from moiré topographic images. Normally the moiré stripes show symmetry as a human body is almost symmetric. According to the progress of the deformity of a spine, asymmetry becomes larger. Numerical representation of the degree of asymmetry is therefore useful in evaluating the deformity. In the first place, once the original moiré image is fed into computer, the middle line of the subject’s back is extracted on the moiré image employing the approximate symmetry analysis. In the second place, regions of interests (ROIs) are then automatically selected on the moiré image from its upper part to the lower part. Finally, displacement of local centroids and difference of gray values are evaluated statistically between the left- and the right-hand side regions of the moiré images with respect to the extracted middle line. We classify the moiré images into two categories i.e., normal and abnormal cases from the features, employing discriminant analysis.



(a) (b) (c)

Fig.1 Example of moiré image and its CT image: (a) shows a normal case; (b) shows an abnormal case; (c) shows a CT image.

2. EXTRACTION OF THE MIDDLE LINE AND SET OF THE ROI REGIONS

2.1 Definition of middle line

There are many shapes having approximate symmetry; *e.g.*, human faces, partially broken objects which originally had symmetry, symmetric shapes with asymmetric texture. All of these are understood as noisy symmetric shapes or the shapes possessing approximate symmetry. Minovic *et al.* [16-17] proposed a technique for defining the axis of symmetry on the shape having approximate symmetry by finding the largest symmetric subset on the shape using its mirror reflected image. This technique plays an important role in the definition of the middle line of a human back.

In the present technique, the approximate symmetry axis is employed for defining the middle line (see [17]). In capturing a moiré image, however, a subject is asked to lean forward on a position supporter so that his posture keeps vertical. On account of this nature, the approximate symmetry axis of the subject can be understood vertical on the moiré image.

2.2 Setting the region of interests

In the next stage, we extract the region of interests from a given moiré image. The region of interests is extracted in the following way.

Let us denote a moiré image of a human back by $f(x,y)$. The origin O of the xy-coordinate system is located at the lower left corner of the image. The ranges of the coordinates are $0 \leqq x \leqq x_e$ and $0 \leqq x \leqq y_e$. The middle line is defined in the first place on $f(x,y)$. Since the moiré pattern of a human back usually exhibits asymmetry, an approximate symmetry axis is extracted from $f(x,y)$ and the axis is regarded as the middle line of the back. The middle line is located at $x=m$ (See Fig.2 (a)).

The region of interests denoted by *ROI* is defined on $f(x,y)$ in the following way. Image $f(x,y)$ is binarized and histogram of the binarized pixels onto x-axis is calculated. The locations having the minimum frequency on the histogram are searched within $0 \leqq x \leqq m$ and $m \leqq x \leqq x_e$, and two such locations, $x=l$ and $x=r$, that are the nearest to the middle line are chosen from the respective ranges. The area *ROI* excludes arms of the subject and takes subject's physical dimensions into account. The regions of interests (ROIs) are automatically selected by this processing.

3. EVALUATING ASYMMETRY BY LOCAL CENTROIDS AND DIFFERENCE OF GRAY VALUES

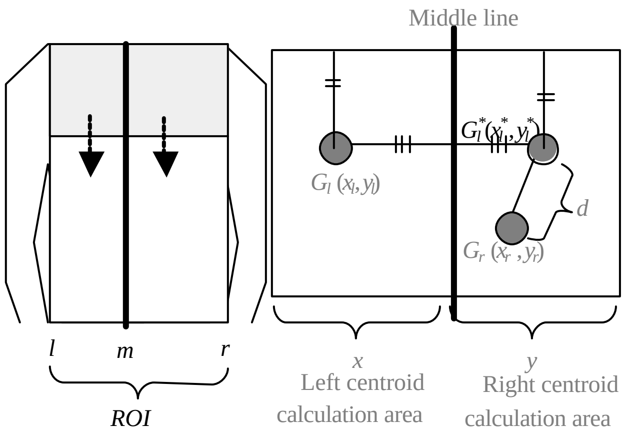
Within the region *ROI* and at a certain position y, two rectangle areas are defined as shown in Fig.2(a) at symmetric locations with respect to the middle line $x=m$. The width a of the rectangle area is defined by

$$a = \min\{r-m,\ m-l\}. \quad (1)$$

On the other hand, height of the area is defined empirically. The degree of asymmetry D is calculated by following way.

Let us denote the rectangle areas of the left-hand side and right-hand side at $y=i$ by A_i^l and A_i^r, respectively. Here $i=1,2,\cdots,N$. The centroids of A_i^l and A_i^r are denoted by $G_l(x_l,y_l)$ and $G_r(x_r,y_r)$, respectively. The centroid $G_l(x_l,y_l)$ is reflected with respect to the middle line $x=m$ into the region A_i^r and denoted by $G_l^*(x_l^*,y_l^*)$. The distance D between $G_l^*(x_l^*,y_l^*)$ and $G_r(x_r,y_r)$ is calculated by

$$D = \sqrt{(x_l^* - x_r)^2 + (y_l^* - y_r)^2}\ . \quad (2)$$



(a) (b)

Fig. 2 Region of Interest and calculation area: (a) Region of Interest; (b) Calculation area.

The mean μ and the standard deviation s of the values D ($i=1,2,\cdots,N$) are employed as the features representing the degree of asymmetry of the moiré image in the *ROI*. They are obtained from

$$\left.\begin{aligned} m_D &= \frac{1}{N}\sum_{i=1}^{N} D \\ s_D &= \sqrt{\frac{1}{N}\sum_{i=1}^{N}(D-m_D)^2} \end{aligned}\right\}. \quad (3)$$

On the other hand, difference of gray values is evaluated statistically between the left- and the right-hand side regions of the moiré images with respect to the extracted middle line. The difference of gray values g is calculated by

$$g = |g_l - g_r| \quad (4)$$

where g_l is mean value on the left-hand side regions and g_r is mean value on the right-hand side regions. The mean μ and the standard deviation s of the values g ($i=1,2,\cdots,N$) are employed as the features representing the degree of asymmetry of the moiré image in *ROI*. They are obtained from

$$\left.\begin{aligned} m_g &= \frac{1}{N}\sum_{i=1}^{N} g \\ s_g &= \sqrt{\frac{1}{N}\sum_{i=1}^{N}(g-m_g)^2} \end{aligned}\right\}. \quad (5)$$

4. CLASSIFICATION BY DISCRIMINANT ANALYSIS

Discriminant analysis is used to determine which variables discriminate between two or more naturally occurring groups. It is a statistical tool for determining linear combinations of independent variables. In this paper, we classify the moiré images into two categories i.e., normal and abnormal cases from the features, employing discriminant analysis. In the discriminant analysis, four features are employed as a feature value *i.e.*, μ_D, σ_D and μ_g, σ_g from the eq. (3) and (5). In this study, each case is classified into the abnormal group if its discriminant score is below zero, and classified into the normal group if the discriminant score is above zero.

The leave-out method is employed in the classification to exclude biased data sampling. Classification rate r[%] is defined as follows:

$$r = \frac{k}{n} \times 100 . \quad (6)$$

Here k is the number of the data which classified correctly, n is number of the employed data.

5. EXPERIMENTAL RESUALTS

According to the above mentioned procedure, experiment was done employing 1,200 real moiré images (600 out of 1200 images are normal cases, whereas remaining 600 are abnormal cases). The image size is 256×256 pixels with 256 gray levels and they are provided by floppy disks.

Table.1 shows experimental results. They are respectively separated into six subsets each containing 200 images (100 normal cases and 100 abnormal cases). Six subsets containing normal cases are denoted by $S_{ni}(i=1,2,\cdots,6)$ and those containing abnormal cases are denoted by $S_{ai}(i=1,2,\cdots,6)$. A set S_i is defined as $S_i=S_{ni}\cup S_{ai}$ $(i=1,2,\cdots,6)$. Then, according to the leave-out method, the set S_j $(j=1,2,\cdots,6)$ is chosen as a training set and the set $S_k\cup S_l$ $(k\neq j,\ l\neq j,\ k\neq l)$ as a test set. Small rectangle areas in the region of interest *ROI* are defined at 19 individual positions which are mutually 10 pixels apart vertically. In the average, classification rate of 85% was achieved. The processing time of a single moiré image is 1.2 second in average on a Pentium III (1GHz) personal computer running FreeBSD.

6. CONCLUSIONS AND DISCUSSIONS

In this paper, a technique was proposed for analyzing a moiré image of a human back in a 2-D way in order to automate the primary screening of spinal deformity inspection. This approach seems promising compared with existent other attempts which analyze moiré images in a 3-D way.

The present technique focused its attention on the displacement of local centroids location and difference of gray values in order to describe the degree of asymmetry of a moiré image. Some other features were as well employed for the experiments, such as difference of areas [13], inclination of the principal axes [15], *etc.*, between the left part and the right part of the moiré images. But no features except for the displacement of local centroids location achieved satisfactory results. Further development and improvement of the features describing asymmetry might result in higher classification rate in the present automatic inspection.

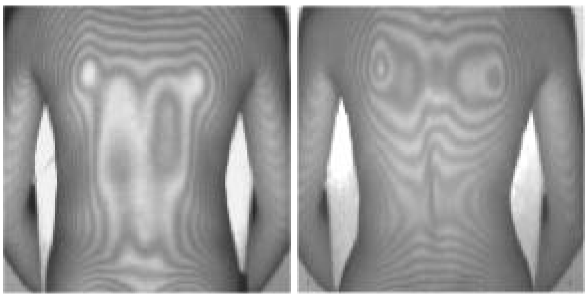
The classification rate of 85 % is achieved in the experiment. In more detail, 77.8% of normal cases were recognized correctly and 91.8% of abnormal cases were recognized correctly. In this point, the present technique misclassifies normal cases as abnormal at a higher rate than abnormal cases as normal, which should be strictly avoided.

Figure 3 illustrates examples of misclassification. In Fig.3(a), a normal case is classified into abnormal, whereas an abnormal case is classified into normal in (b). This is because gray values distribution in the rectangle regions unfortunately affected symmetrically when the local centroids were calculated. To escape from this difficulty, some other asymmetry features independent to local centroids displacement should be taken into account in conjunction with it. The issue remains for further study.

The proposed technique for automatic spinal deformity detection aims at being introduced in the primary screening stage mainly performed at schools to release doctors from tough work of visual inspection of a large number of moiré images of subjects' backs and to realize objective judgment. Since objectivity of the moiré method in spinal deformity inspection is well recognized among orthopedists in Japan, it is expected that putting the present technique into practical use will result in further spread of the moiré method especially in school screening.

The reported experiment is still continuing in order to put the present technique into a practical use. Sufficient number of test data needs to be employed. However there is a difficulty in collecting abnormal moiré images, since abnormal cases do not reveal themselves very often among all the collected cases. Sufficient abnormal data as well as sufficient normal data are indispensable to defining a reliable discriminant function.

From the database consist of 200 normal moiré topographic images and 200 abnormal moiré topographic images, the results were a sensitivity of 0.81 at a specificity of 0.92. Furthermore, False Positive Fraction (FP) of the 0.08 and False Negative Fraction (FN) of the 0.18 were achieved under the Receiver Operating Characteristic (ROC) analysis.



(a) (b)

Fig.3 Examples of misclassification: (a) Normal case classified into abnormal;
(b) Abnormal case classified into normal.

Table.1 Obtained classification rates [%]

Training Data \ Test Data	S_1	S_2	S_3	S_4	S_5	S_6	*Ave*
S_1	—	91.5	89.5	83.5	87.5	84.5	87.3
S_2	89	—	86	92	82.5	78	85.5
S_3	76.5	87	—	86.5	90.5	79.5	84
S_4	72	83.5	94	—	87	77	82.7
S_5	77.5	88.5	87	85	—	83	84.2
S_6	74.5	86	86	85.5	91	—	84.6
						Average	84.72

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