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Automatic Judgement of Spinal Deformity from Moire Images Employing Asymmetry of Local Centroids Location

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Abstract

A technique is described for classifying abnormal cases and normal cases in automatic spinal deformity analysis by computer based on moire topographic images of human backs. Displacement of local centroids is evaluated statistically between the left-hand side and the right-hand side of the moire images. The technique was applied to real subjects images in order to draw a distinction between 60 normal and 60 abnormal cases. According to the leave-out method, the entire data was separated into three sets. The linear discriminant function based on the Mahalanobis distance was defined on the 2-D feature space employing one of the data sets containing 40 moire images and classified 80 images in the remaining two sets. The average classification rate was 87.9%.

1 Introduction

Spinal deformity is a serious disease for teenagers and screening has been performed at primary schools and secondary schools in Kanto, Japan, in order to realize early check of the illness. For the screening, moire topographic images of human backs are conveniently employed, since 3-D asymmetry of a back caused by spinal deformity is easily observed as an asymmetric 2-D moire pattern. In practice, orthopaedists inspect spinal deformity visually by the moire images before they proceed to X-ray check.

This inspection is tough work on account of a large number of moire images yielded by the screening at schools and automating the inspection by computer image processing has strongly been requested by doctors. Since moire imaging is much safer to a subject than X-ray imaging and it is also easily obtainable by a moire camera which is commercially available, every researcher tries to analyze a moire image of a human back in order to realize automatic diagnosis of spinal deformity by computer. Reported techniques to date[1-3] perform 3-D recovery of the undulation of the back and try to evaluate its geometrical asymmetry. The result is that they all suffer from their complicated image processing techniques and impractical processing time. Nothing worth discussing has been achieved for the automatic diagnosis of spinal deformity to date.

Unlike these techniques based on 3-D geometric analysis, the technique proposed in this paper simulates doctors' 2-D visual asymmetry inspection on a human moire image. The technique realizes simpler analysis of the moire image and therefore achieves much shorter processing time than ever. Asymmetry of the moire image of a human back is quantified by examining displacement of local centroids defined on the moire image. The technique is evaluated its performance experimentally by real subjects' moire images. Finally the result is discussed.

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2 Asymmetry Representation by Local Centroids Displacement

2.1 Extracting the area of interest

Let us denote a moire image of a human back by $I(x, y)$. 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 $0 \leqq y \leqq y_e$. The middle line is defined in the first place on $I(x, y)$. Since the moire pattern of a human back usually exhibits asymmetry, a potential symmetry axis[4] is extracted from $I(x, y)$ and the axis is regarded as the middle line of the back. Let the middle line be located at $x=m$.

The area of interest denoted by R is defined in the second place on $I(x, y)$ in the following way. Image $I(x, y)$ is binarized and histogram of the binarized pixels onto the x-axis is calculated. The locations having the minimum frequency value are found within $0 \leqq x \leqq m$ and $m \leqq x \leqq x_e$, and two such locations, $x=x_0$ and $x=x_1$, that are the nearest to the middle line are chosen from the respective ranges. The area of interest R is defined as the inside area of $I(x, y)$ discriminated by the two vertical lines $x=x_0$ and $x=x_1$. The area R excludes arms of the subject and takes subject's physical dimensions into account. See **Fig.1** for the procedure, where (a) is a binarized moire image, (b) histogram of the pixels (doubled in the direction of the y-axis for easier observation) and the discriminating two lines, and (c) the area of interest R.

2.2 Evaluating asymmetry by local centroids

Within the area of interest R, as shown in **Fig.2**, two square regions are defined at symmetric locations with respect to the middle line $x=m$. Length of its side a is defined by $a=\min\{x_1-m, m-x_0\}$. Let us denote the square regions of the left-hand side and the right-hand side at $y=j$ by R_j^l and R_j^r, respectively. Here $j=1,2,\ldots, N$. The center of gravity (or the centroid) of R_j^l and R_j^r are denoted by $G_j^l(\bar{x}_j^l, \bar{y}_j^l)$ and $G_j^r(\bar{x}_j^r, \bar{y}_j^r)$, respectively. The centroid $G_j^l(\bar{x}_j^l, \bar{y}_j^l)$ is reflected with respect to the middle line $x=m$ into the region R_j^r and denoted by $G_j^{lr}(\bar{x}_j^{lr}, \bar{y}_j^{lr})$. The Euclid distance denoted by D_j is calculated between $G_j^r(\bar{x}_j^r, \bar{y}_j^r)$ and $G_j^{lr}(\bar{x}_j^{lr}, \bar{y}_j^{lr})$. The mean μ and the standard deviation σ of the values D_j ($j=1,2,\ldots, N$) are employed for representing asymmetry of the moire image in R.

The moire images employed are separated into two groups, *i.e.*, the training set $S_T=\{I_{Tk} \mid k=1,2,\ldots, M_T\}$ and the test set $S_S=\{I_{Sk} \mid k=1,2,\ldots, M_S\}$. The feature vectors (μ_k, σ_k) obtained from $I_{Tk} \in S_T$ are plotted on the 2-D feature space and the linear discriminant function L is defined on it employing the Mahalanobis distance. The images in S_S are classified by the line L into normal cases and abnormal cases of spinal deformity on the feature space. The leave-out method is employed in the classification to exclude biased data sampling.

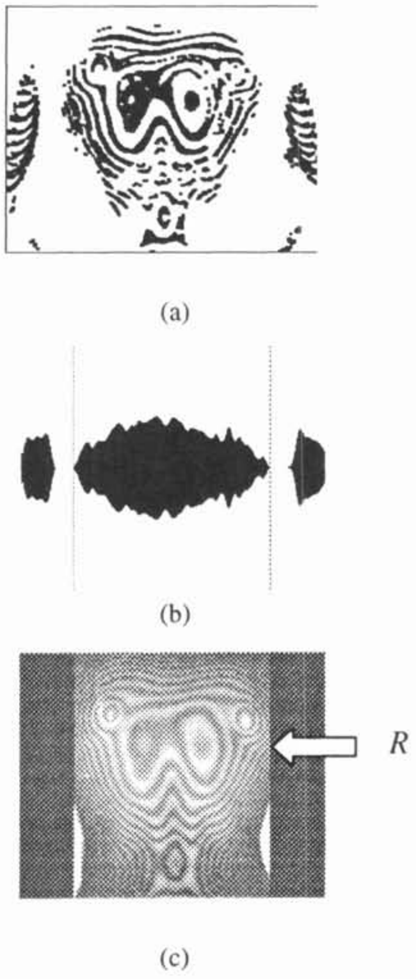


Fig.1. Extracting the area of interest: (a) Binarized moire image; (b) histogram on the x-axis and two discriminating lines; and (c) the area of interest R.

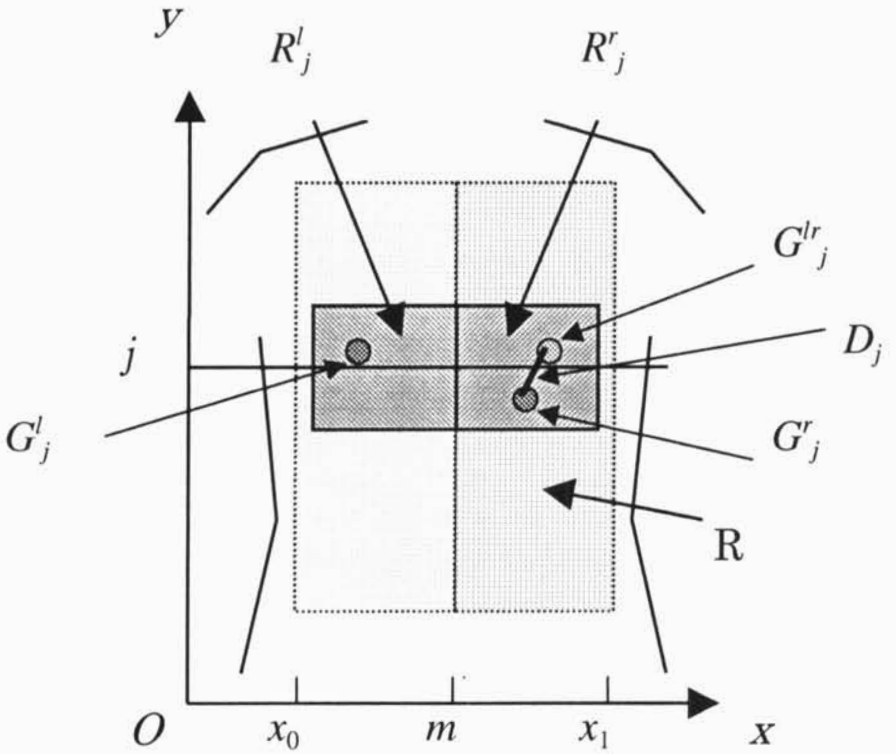
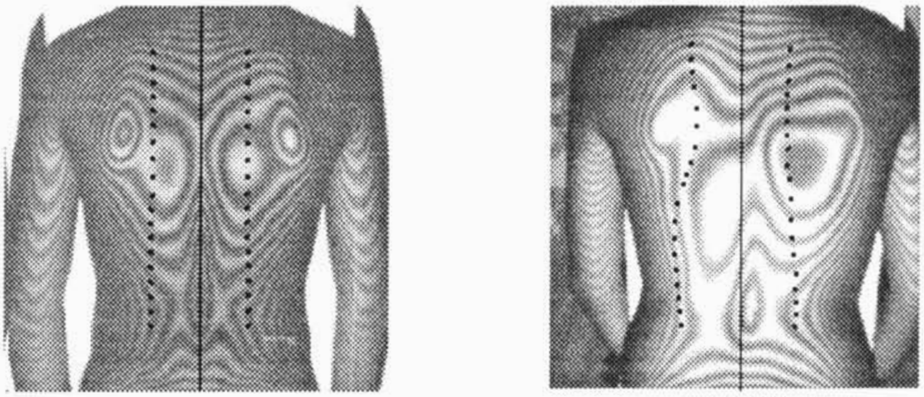


Fig.2. Area of interest *R* on the subject's back and the regions for specifying the centroids.


(a)

(b)

Fig.3. Examples of local centroid locations on the moire images: (a) A normal case; and (b) an abnormal case.

Table 1. Obtained classification rates.

Training data	%		Test data	%
S_1	90.0		$S_2 \cup S_3$	87.5
S_2	95.0		$S_3 \cup S_1$	86.3
S_3	82.5		$S_1 \cup S_2$	90.0
-	-		**Average**	87.9

3 Experimental Result

The moire images employed in the experiment contain 60 normal cases and 60 abnormal cases. They are respectively separated into three sets each of which contains 20 images and denoted by S_{Ni} for normal and S_{Ai} for abnormal (i=1,2,3). The set S_i is defined by $S_i= S_{Ni} \cup S_{Ai}$. Chosen S_i as a training set, *i.e.*, $S_T=S_i$, $S_S=S_j \cup S_k$ (j, $k \neq i$) are used as a test set. The area of interest R is defined at 19 individual positions which are mutually 10 pixels apart vertically. Employed parameters are therefore as follows: N=19, M_T=40, M_S=80.

Experimental result is shown in **Table 1**, where classification rates are given by percentage. Examples of local centroids location are depicted in **Fig.3**. The processing time of a single moire image is 12 seconds in average by Sparc Station 20.

4 Discussion

By the experiment employing real moire images of human backs, 87.9% of classification rate was achieved in average. To the best of our knowledge, this is the first experimental report employing real as well as substantial image data. The paper therefore holds its significance in this respect. Although the achieved classification rate is not yet enough to put the proposed technique into practice, the result makes us expect future automation of spinal deformity inspection by computer.

One of the advantages of the present technique is that feature extraction is simple and therefore computation time is shorter than any other techniques reported to date. The computation time can be improved further by the employment of the latest PC.

On the other hand, the present technique is sensitive to the location of the middle line, since the local centroid of the left-hand side square region is reflected with respect to the middle line in order to calculate the displacement with the local centroid of the right-hand side square region. Larger asymmetry in the moire image might result in inexact position of the middle line. On this issue, we are planning to settle the middle line visually on the stage of taking a subject's moire image. This may contribute to obtaining better results in the experiment.

Nine abnormal cases out of 60 were classified as normal. This is a vital situation compared with the reverse case that normal cases are classified as abnormal. All of the nine cases are obviously visible of the asymmetry of moire patterns and yet extracted local centroids spread on the image almost in a symmetric way. This may be because gray values distribution in the square regions unfortunately operated symmetrically when the centroids were calculated there. The size and the location of the square regions need be elaborated experimentally.

5 Conclusion

A technique was presented for analyzing spinal deformity by computer based on moire images of human backs. Asymmetry of local centroids were statistically evaluated. The technique was examined by 120 real moire images and 87.9% of the classification rate was achieved. The technique needs further improvement to obtain higher classification rates.

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