'95 KACC (1995. 10. 23 ~ 25)

Analyzing Deformity of Human Backs Based on 3-D Topographic Reconstruction from Moire Images

Seiji ISHIKAWA*, Shin-ya TAKAGAMI*, Kiyoshi KATO*, Yoshinori OTSUKA**

*Dept. of Civil, Mechanical and Control Eng., Kyushu Institute of Technology
Sensuicho 1-1, Tobata, Kitakyushu 804, JAPAN
Email: ishikawa@cntl.kyutech.ac.jp

**Chiba Higashi Hospital
Nitonacho 673, Chuo-ku, Chiba 260, JAPAN

Abstract A technique is presented for evaluating spinal deformity of a human back by extracting a spinal line based on 3-D topographic reconstruction of the back from its moire image. A given moire image is differentiated by DOG filter to extract moire stripes. The stripes are then assigned labels and the labels are interpolated by the Lagrange polynomial to yield the undulation of the back which gives a relative 3-D shape of the back. A valley is searched on the undulation near the middle part of the back and the valley line is finally extracted as an approximated spinal line. The mean difference and the variance between the spinal line and the middle line are calculated and reported. Experiment is performed employing real moire images of junior-high school students' backs and some of the results are shown with discussion.

Keywords Medical image processing, 3-D reconstruction, Moire topography, Spinal deformity

1. INTRODUCTION

Spinal deformity is a serious problem especially for children and doctors employ moire topographic images of their backs to inspect it. If a subject's spine is normal, the moire image is almost symmetric with respect to the middle line of his/her back: If it has some deformity, the moire image shows asymmetry whose degree is evaluated visually by doctors. Automating this inspection routine is actually required, since the routine imposes too much load to the doctors because of a large number of examined subjects.

There are not many studies on automating spinal deformity inspection by computer, among which Ishikawa et al.[1] proposes the employment of a potential symmetry axis from a subject's rear moire image. Extracting deformed spinal line is also reported by Ishikawa et al.[2] where they employ the genetic algorithm based on the idea of local potential symmetry. These two techniques use moire images in a 2-D way and they do not use 3-D topographic information moire images provide. Batouche[3] recovers 3-D shape of a subject's back from its moire image and he makes a knowledge-based diagnosis system for automating the inspection. However there is no description on the performance of the system in the paper. for the purpose of primary screening, a simpler judgment strategy is likely to be successful than introducing such knowledge-base.

This paper proposes a technique for automating primary inspection of spinal deformity based on moire images. The technique reconstructs the 3-D shape of a subject's back from its moire image and extracts a valley line called a spinal line. Difference between the spinal line and the middle line is evaluated numerically by two indices for possible primary inspection. Performance of the technique is illustrated experimentally and some issues are discussed.

2. 3-D TOPOGRAPHIC RECONSTRUCTION FROM MOIRE IMAGES

In order to obtain moire images of an object, a moire camera is used. A moire camera projects a structured light through a specified lattice and the light reflected on an object is photographed over another lattice of the same structure as the one used for the structured light emission. The photographed image contains a moire pattern of the object each of the line stripes represents those positions on the subject of equal distance from the center of the lens of the moire camera.

Since a moire image contains distance information in the form of stripes, exact 3-D shape reconstruction can be performed. Here, in place of the exact reconstruction, relative undulation of a human back is recovered, since it is enough for extracting a valley line of the back which is regarded as a deformed spinal line.

The reconstruction procedure is shown in **Fig.1**. Given a moire image of a human back, the stripes are extracted by image differentiation employing DOG filter. The DOG filter is given by the difference of two Gaussian distributions $N(0,\sigma_e^2)$ and $N(0,\sigma_i^2)$ and the parameters σe and σi are given constraint $\sigma i/\sigma e=1.6$ so that the optimum filtering is realized. Zero-crossing pixels are chosen from the DOG filtered image in order to extract the moire stripes.

Labels are assigned to the obtained stripes. In **Fig.2**, the two points S_1 and S_2 correspond to the peak of scapulae and the nearest to the camera, whereas the point O corresponds to the caved point of the middle waist and the most distant from the camera. The xy coordinate system whose origin is O is defined as shown in the figure. Line $A(\equiv A_0)$ passes O and is parallel to line B connecting S_1 and S_2. Line A scans the back by parallel transformation until it reaches line A_N (and also line $A_{-N'}$). With respect to line A_i(i is integer and $-N' \leq i \leq N$), labeling is performed from the point $P(0, y_i)$ to the x direction by the procedure that the kth stripe on A_i (given by a black pixel) is assigned the number k. The same labeling proceeds to the $-x$ direction on line A_i. This labeling is effective within the range specified by R.

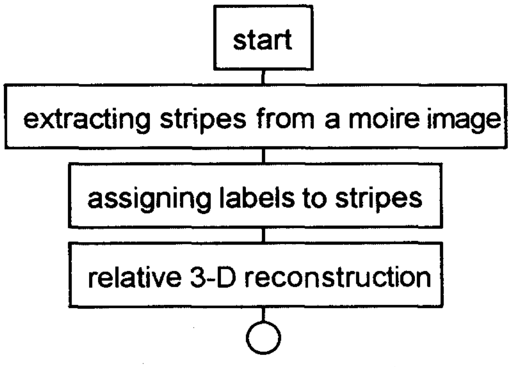


Fig.1 Reconstruction procedure.

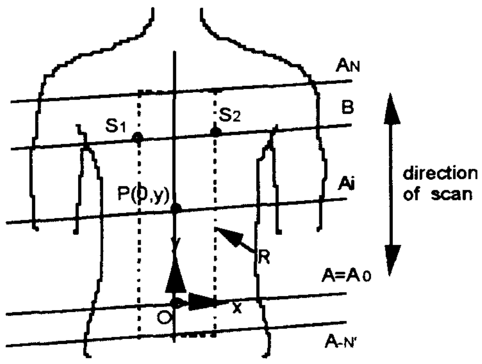


Fig.2 Labeling strategy.

This labeling is a little complicated. The above procedure is followed by reassignment of contradictory labels, guessing labels at discontinuous positions, etc., which will not be stated further in this particular paper.

In order to reconstruct relative undulation of the back, all the labeled pixels on line A are interpolated with their labels employing the Lagrange polynomial. This is necessary, since the pixels which the moire stripes do not pass through have no labels and therefore no information on their distances from the camera.

3. EXTRACTING A SPINAL LINE

In this section, extraction of a spinal line is described and its degree of deformity is defined

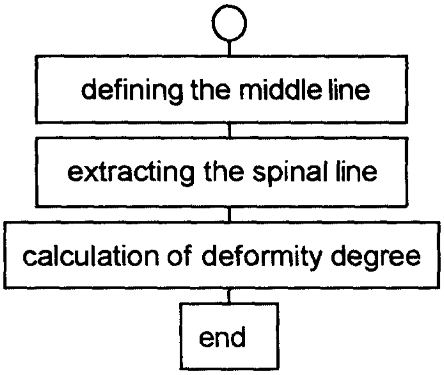


Fig.3 Numerical evaluation routine.

numerically.

The flow is shown in **Fig.3** from the definition of the middle line of a back to the calculation of the degree of deformity. The middle line is the intersection of the surface of a standing human body and the middle plane which is a vertical plane (called a sagittal plane) bisecting the body into the left and the right halves. The middle line is defined in this study as the vertical line bisecting the line segment that connects points S_1 and S_2 (See Fig.2).

On the other hand, the spinal line is defined employing the reconstructed shape of a back. As the result of the reconstruction, the back has undulation along the line A_i ($-N' \leq i \leq N$) in Fig.2. Let us denote the lowest pixel near the middle line on the undulation by $p(x, y_i)$. Then the set $S=\{ p(x, y_i) | -N' \leq i \leq N\}$ receives smoothing by median filter in this order and the sequence of the pixels are all become connected. This connected line provides the spinal line.

The obtained spinal line is evaluated its deformity with respect to the middle line by the following equations:

$$Bend1 = \frac{\sum_{i=-N'}^{N} \left| Centerline - Spine(i) \right|}{N + N' + 1} \qquad (1)$$

$$Bend2 = \frac{\sum_{i=-N'}^{N} \left(Centerline - Spine(i) \right)^2}{N + N' + 1} \qquad (2)$$

Here *Centerline* is the x coordinate of the middle line, whereas *Spine*(i) denotes the x coordinate of the spinal line at $y=i$. Obviously **Eqs**.(1) and (2) indicate mean and variance, respectively, of the two lines' horizontal difference.

4. EXPERIMENTALRESULTS

Experiment is performed on a workstation (SS10). Moire images of the backs of junior-high school students are provided by films which are scanned by an image scanner and fed into the workstation. The images are finally converted into 256 by 256 pixels digital images with 256 gray values. The employed language is C.

The proposed technique is composed of two main parts: The first part reconstructs relative 3-D shape of a back, while the second part extracts the spinal line and evaluates its degree of deformity employing two numerical indices. In the first part, the three main points S_1, S_2, and O in Fig.2 are specified interactively as well as some parameters used in the DOG filter. The second part is fully automated.

In the performed experiment, three normal cases are analyzed. In **Fig.4**, upper images illustrate the moire stripes extracted by the differentiation employing DOG filter, and the lower images show obtained spinal lines superposed onto the original gray moire images. For each case, the values of σe and σi, and the filter size $z \times z$ are given with respect to the upper images, while numerical reports are provided with respect to the lower images, *i.e.*, *bend1*, *bend2*, and the entire elapsed time T in seconds.

5. DISCUSSION

The three normal cases were successfully analyzed. Calculated deformity indices, *bend1* and *bend2*, provide reasonable values.

However, there is a certain difficulty in obtaining moire stripes images shown in the above row of Fig.4. As the result of differentiation of original images, there happen discontinuity of a single stripe, touch of two stripes, *etc*. Therefore guessing a label or reassigning the label for consistency of a stripe concerned is individual tough work. In order to make it easier, careful choice is required of the parameters for DOG filter. Automating this choice is likely to be difficult, since, for example, the size of DOG filter directly depends on the density of the moire stripes whose automatic recognition may again need differentiation.

6. CONCLUSION

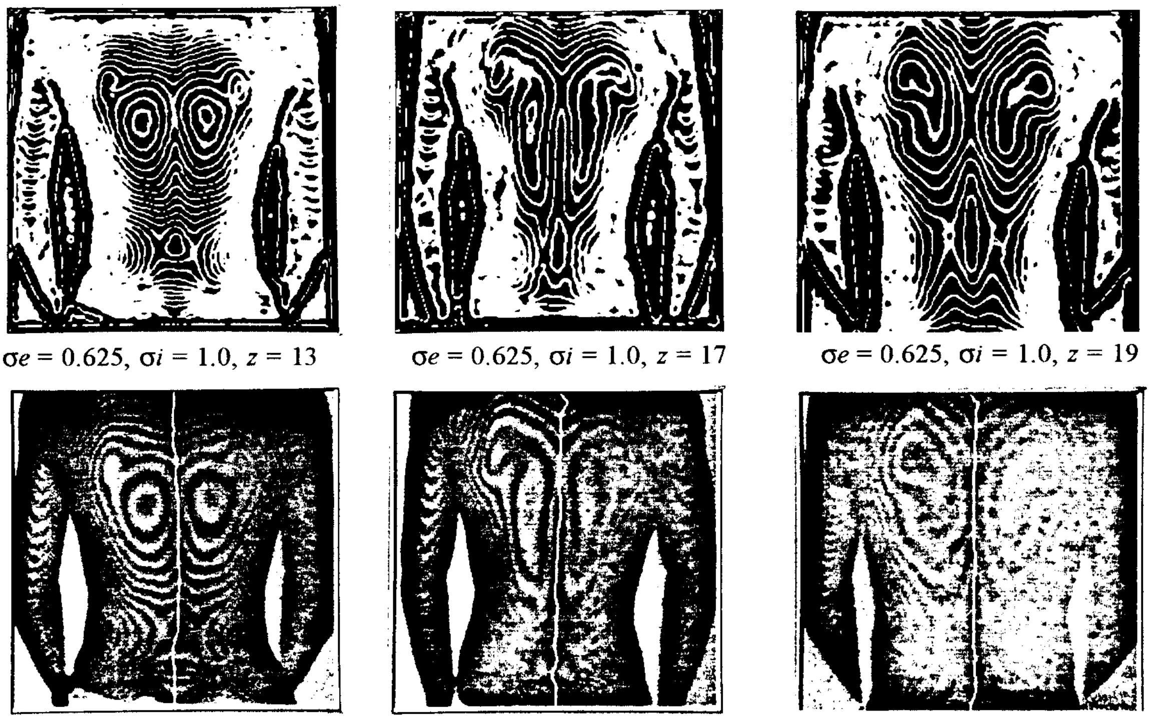
A technique was proposed for automatic inspection of spinal deformity from the moire image of a subject's back. Relative 3-D shape of the back was recovered and a valley line on the shape was extracted as a spinal line. Deformity of the spinal line was numerically compared with the middle line of the back. Performance of the technique was shown by experimental results. To realize the automatic primary inspection, further experiment employing a number of normal/abnormal cases need be done.

REFERENCES

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

[2] S. Ishikawa, H. Ueno, K. Kato, Y. Otsuka, "Automatic analysis of spinal deformity from moire images", *Proc. Int. Conf. Automat.*, Indore, 1995. (to appear)

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



$\sigma e = 0.625$, $\sigma i = 1.0$, $z = 13$ — $\sigma e = 0.625$, $\sigma i = 1.0$, $z = 17$ — $\sigma e = 0.625$, $\sigma i = 1.0$, $z = 19$

bend1= 1.63, *bend2*= 3.65
T= 26.1 s
(a)

bend1= 1.67, *bend2*= 4.33
T= 40.7 s
(b)

bend1= 0.91, *bend2*= 1.41
T= 49.8 s
(c)

Fig.4 Experimental results.