Image and Vision Computing 20 (2002) 319–324
www.elsevier.com/locate/imavis

Applications of computer-aided rasterstereography in spinal deformity detection

Junaid Ahmed Zubairi*

Department of Mathematics and Computer Science, College at Fredonia, State University of New York, Fredonia, NY 14063, USA

Received 21 January 2001; received in revised form 10 October 2001; accepted 10 January 2002

Abstract

In this paper, a methodology developed for analyzing surface shapes using computer-aided rasterstereography is discussed and its applications in the field of medical science are highlighted. In this methodology, deviations are extracted from projected horizontal and vertical rasters and used in generating a profile of the surface under consideration. The magnitude and direction of deviations indicate 3-D properties of the surface. This technique is suitable for screening children for spinal deformities because it is simple, fast and non-invasive. It does not require very specific setup due to the reduction of errors using symmetry of the human back. The positive cases detected by the system can be referred to the physician for further diagnosis and treatment.

Keywords: Rasterstereography; Spinal deformity; Projected raster; Surface shape

1. Introduction

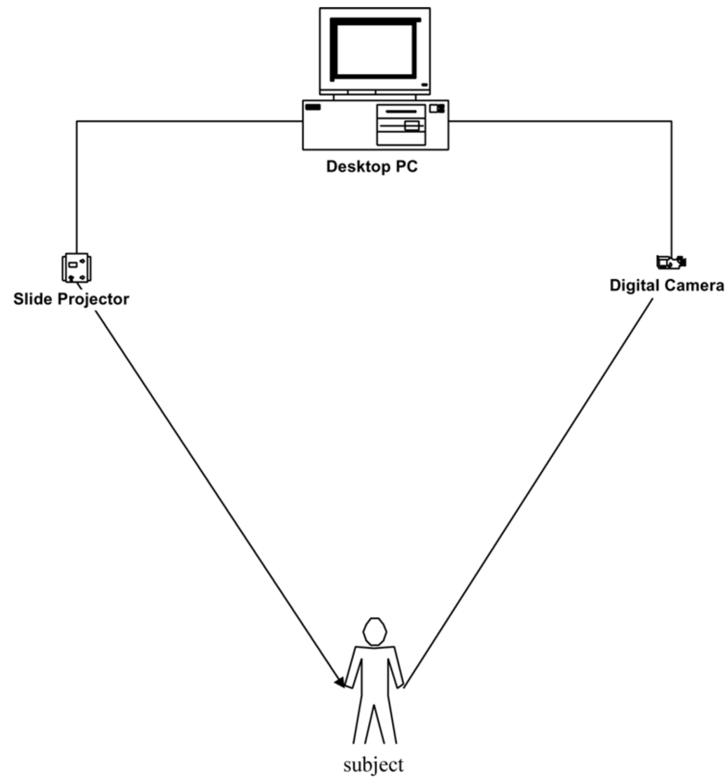
There is considerable interest in determining surface types and shapes from range and intensity images. Several methods have been employed to determine the surface types in the images [1–7]. For range images, one segmentation method for detecting various surfaces yields three types of surfaces [6], whereas other methods consider eight basic types of surfaces based on signs of mean and Gaussian curvatures [3]. Some researchers have used projected grid to determine the underlying surfaces using surface normals and curvature computations [8,9].

Surface shape detection methods can be applied to many fields including medical science. For example, physicians perform spinal deformity diagnosis using expensive equipment such as X-ray and ultrasound. These deformities include scoliosis and abnormal degrees of kyphosis and lordosis. Spinal deformity detection in childhood can lead to effective and early treatment. However, mass screening of school children for spinal deformity cannot be carried out using X-ray and ultrasound. These techniques are expensive and require considerable setup time for every child. Moreover, the presence of a physician on the spot is necessary to interpret the results. The X-ray involves the risk of exposing young children to radiation doses. We need an inexpensive, fast, automated and non-invasive technique to filter out the healthy cases and select the children suspected of having spinal deformity. Such cases can be referred to the physician for detailed examination and treatment. Several efforts have been made to provide non-invasive ways to detect spinal deformities [10–13]. Similar work at Oxford and other centers led to the development of commercial Integrated Surface Imaging System (ISIS) in 1980s and more recently, the video rasterstereography systems [14–16]. Some of these efforts are directed towards applying computer vision techniques to determine spinal deformity without adversely affecting the children. In computer vision research, two types of images are used for surface shape detection, namely the range image and the intensity image. Range images are depth maps obtained through laser range finders. Laser calculated depth maps might be used in expensive operating room equipment. However, these systems cannot be used as screening devices due to their high cost and specific setup requirements. On the other hand, most of the methods using intensity images are computation-intensive and need powerful computers to generate results in a reasonably short time.

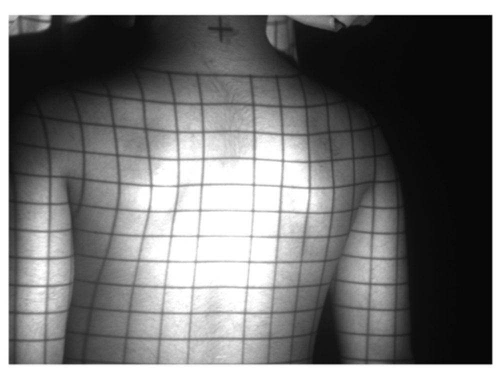
In this paper, a novel method to perform surface shape detection using computer-aided rasterstereography is presented. We show its application in spinal deformity detection using an ordinary PC, a digital camera and a slide projector. In this way, mass screening of

* Tel.: +1-716-673-4694; fax: +1-508-256-8324.
E-mail address: zubairi@fredonia.edu (J.A. Zubairi).

0262-8856/02/$ - see front matter
PII: S0262-8856(02)00026-4



(a)



(b)

Fig. 1. The experimental setup for spinal deformity detection.

school children can be done without the need for the presence of a physician. Only the positive cases detected by the system will be referred to the physician for further diagnosis and treatment. We also present some results from experiments conducted to detect spinal deformity in children. The rest of the paper is organized as follows. First, the experimental setup is introduced and a brief overview of rasterstereography is given. In Section 3, we discuss the steps involved in transforming the digitized image into a set of detected lines with all pixels recorded. The mathematical formulae of deviations are given and their applications in detection of spinal deformity are discussed. Towards the end, some results from the spinal deformity detection experiments are presented and discussed.

2. The experimental setup

For studying surface properties, simple optical techniques such as Moiré fringe topography and rasterstereography can be used. Moiré fringe topography is an optical and non-invasive technique that generates fringes in the 3-D space when two sets of equidistant lines interfere with each other. The height step between successive fringes increases outward with the numerical order. Moiré fringe topography

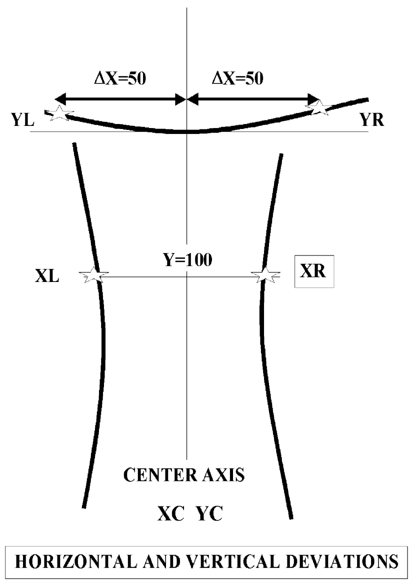


Fig. 2. An example of determining horizontal and vertical deviations of projected lines.

requires specific setup with exact distances in order to generate fringes of desired properties. In addition, Moiré technique generates a sparse depth map because the exact depth is known only on the pixels that fall on the fringes. The depth of other pixels is interpolated from known depths.

Rasterstereography is a photogrammetric technique similar to stereophotogrammetry. Its basic principle is that a curved surface distorts the image of two sets of mutually perpendicular lines projected on it. In stereophotogrammetry, two cameras placed at an angle to each other take synchronized photos of the object under investigation and later the photos are superimposed to recover the 3-D information. In rasterstereography, a projector that projects the raster containing the grid on the object under investigation replaces one of the cameras. The grid gets distorted due to curved surface of the object. Through the geometrical shape of the projection, a 3-D picture of the surface can be reconstructed. The study of this distortion provides information about the shape of the surface under consideration. Rasterstereography was selected for this work because of its advantages including its non-invasive nature, regular pattern of data, wide choice of storing options and simple setup.

Fig. 1 shows the setup for applications in spinal deformity detection. It includes a slide projector that projects a raster of equidistant lines on the subject's back. The crosshairs of the raster are aligned with the guide marks on the subject's back indicating the central axis. The straight lines are distorted due to the inherent curvature of the back surface. A digital camera digitizes the image of the distorted raster and transfers it to the PC. This image is filtered and processed by a line detection algorithm based on thresholding and chain coding principle [17]. This algorithm isolates the distorted lines from rest of the image and records them in a meaningful way so that further calculations can be facilitated. Since this algorithm numbers the lines in the order found in upper-left to lower-right scan, the image of the vertical raster is rotated 90° before being processed.

The next step in this procedure involves calculating deviations of the extracted lines from their original positions. The vertical deviations of horizontal lines are calculated at set distances from central axis in both directions. The horizontal deviations of vertical lines are computed by determining line pixels that fall on identical rows albeit different columns. Since the human back is symmetric, the deviations on both sides of central axis (spinal midline) are equivalent. Any spinal deformity would result in asymmetrical back leading to different deviations of projected rasters.

3. Steps in spinal deformity detection

As shown in Fig. 1, the horizontal and vertical rasters are focused on the subject and digitized images are obtained. The horizontal and vertical rasters are used separately as the deviations for both are determined independently. The density of lines in the projected rasters can be modified to adjust the resolution of the results. The slides used in these experiments had 1 mm spacing between lines. Raw image is filtered to remove noise and the image is converted to binary image using adaptive thresholding. The noise removal and adaptive thresholding procedures are done using image processing utilities. Since the image capture is done under identical lighting, the parameters of these procedures are not subject to large variations. Since the width of projected lines spans multiple pixels, skeletonization is performed to reduce the width of lines to single pixel only. Skeletonization is done through a C language function that reads the thresholded image and deletes outer pixels of lines until the lines are only single pixel wide. Outer pixels are taken off on both sides of lines to avoid shifting the line during this process. Skeletonization of curved lines may leave gaps that are filled by the next step, i.e. the algorithm to detect lines.

3.1. Detection of lines

The line detection algorithm is based on boundary chain coding (BCC) technique. The algorithm is applied to a thresholded image. A pixel's intensity value is checked to decide whether it falls on a line or on the background. The algorithm records all the pixels on the lines as BCC elements. Here, a BCC element includes an integer value that represents the direction of the next pixel on the line. The range of possible directions is coarsely quantized, where there are eight possible directions corresponding to each of the eight pixels that are adjacent to the center pixel in a 3×3 neighborhood.

The algorithm records the data for all the lines detected in a 3-D array where the 2-D represents the information of an

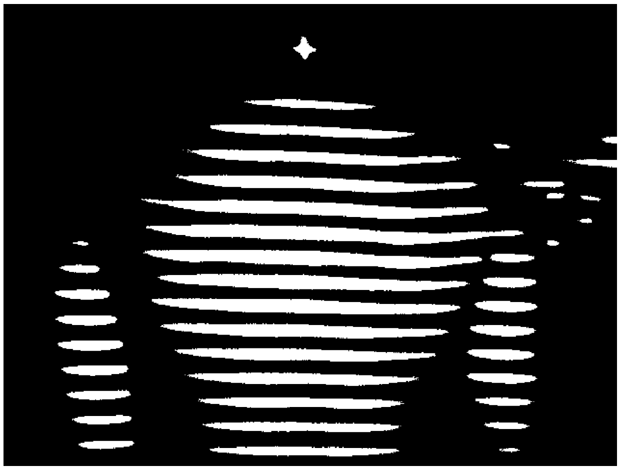


Fig. 3. Horizontal raster image.

individual line (e.g. location of the pixels and chain code direction) and the third D represents the identity of the lines.

The algorithm first does a search in a raster pattern to find out a start point on a line in the image. After getting to the start point on a line, certain pixels in its nearest neighborhood are checked one at a time, to determine the next point on the line. The process is continued until the complete line is detected. After detecting and recording the line, the algorithm then deletes the line from the image and continues to detect and record the next line in the image. The process is terminated when all the lines are detected and recorded.

3.2. Deviation parameter and its calculation

The deviation parameter is calculated for all the vertical lines located on both sides of the central axis and all horizontal lines orthogonal to it. Central axis is defined as the straight vertical line passing through the center of the image. In order to calculate the deviations, the lines to the right and left of central axis are paired together. Any unpaired line on

Fig. 4. Vertical raster image.

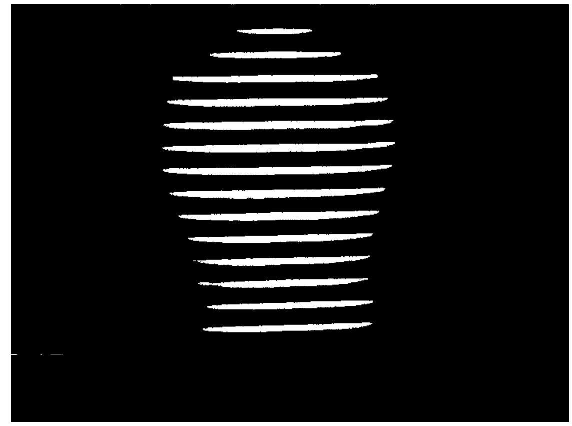


Fig. 5. Another subject's image with horizontal raster.

either side is not processed further. On the central axis, at each point, the distance is measured in terms of number of pixels to the first line detected on both sides to obtain its absolute difference. For example, referring to Fig. 2, if the central axis has the current coordinates as (x_c, y_c), a line on the left has coordinates as (x_l, y_l) and the corresponding line on right has the coordinates (x_r, y_r), then on a given row

$$\Delta h = |(x_c - x_l)| - |(x_r - x_c)| \quad (1)$$

The calculation of Δh is repeated for selected rows (as per desired granularity of results) and on each row, all lines on both sides are considered. As an example, Fig. 2 shows the location of XR and XL pixels for row number 100. Similarly, for a horizontal line, the rows YL and YR intercept this line at the distance of $\Delta X = 50$ from the central axis.

The deviations of the horizontal lines are calculated as Δv. Using the same example as that mentioned earlier, Δv can be calculated for a given column as

$$\Delta v = y_l - y_r \quad (2)$$

4. Results and discussion

In this section, some results of using computer-aided rasterstereography in spinal deformity detection are presented. The image is acquired with projection of vertical and horizontal rasters on the back of the subject according to the setup in Fig. 1(a). The grid is aligned with the central axis with the help of guide marks as in Fig. 1(b). Since it is difficult to stop the movement of the child standing without any support, a stabilizing frame was added in the setup. This frame had a metallic base and two metallic bars about 5 ft in height were attached on both sides of the base. The child was asked to stand on the base, hold on to the metallic bars, and hold breath in order to reduce any errors due to the movement during picture taking. The room had no light except the slide projector light to avoid getting noisy images. It is possible to have lines shifted because of slightly tilted subjects. However, the subject's back is

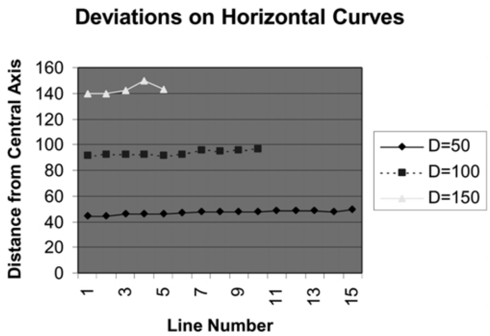


Fig. 6. Horizontal raster deviations.

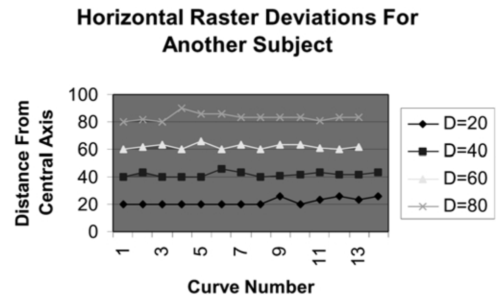


Fig. 8. Horizontal raster deviations.

taken as reference for computing deviations of projected lines, thus minimizing the effect of line shifts. The effect of line shifts is minimized due to the facts that all lines will shift from their original positions in the same direction and deviations are determined as per Eqs. (1) and (2).

The children screened were between 5 and 8 years of age. The results were developed using the Global Lab image processing system and its associated utilities as well as the software written in C language [18]. Fig. 3 shows the image obtained from projection of horizontal raster and Fig. 4 shows the image obtained from the projection of vertical raster. Fig. 5 shows the pre-processed image obtained from projection of horizontal raster on another subject.

Deviations were computed in terms of number of pixels on a 640×480 image for Figs. 3–5, respectively, using Global Lab's utilities, the C program written during this project and manually. The Δv and Δh values were found to be insignificant. Insignificant deviations have one or two empirically defined characteristics:

1. The values are less than 8% of the pixel row/column dimensions.
2. The deviations occur only in one dimension and the other dimension is not affected.

When both the horizontal and vertical raster show large deviations in a specific area, spinal deformity is detected. It was concluded from this example that the subject does not have any spinal deformity problem.

Figs. 6–8 show horizontal and vertical deviation plots. In Fig. 6, the ordinate represents the distance from the central axis on both sides and deviations for different values of D are shown in for respective curves.

In Fig. 7, the ordinate represents row numbers whereas the deviations are plotted for various curves. In Fig. 8, horizontal deviations are plotted for another subject. On a VGA scale of the image, the deviations are less than the empirically suggested value of 8% and larger deviations are not persistent on both rasters.

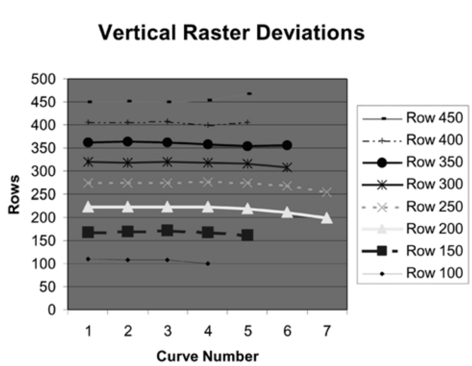


Fig. 7. Vertical raster deviations.

5. Conclusion

A methodology for the detection of spinal deformities in children of school going age is presented. This methodology is based on computer-aided rasterstereography using ordinary PC, digital camera and slide projector. It offers great promise in serving as a 'front-end' screening system for school-age children. The absence of false negative results is a pre-requisite before deploying any such technique in the field.

Acknowledgements

This research has been supported through a grant from the Research Center, International Islamic University Malaysia. I express thanks to Dr Ajmal Ansari and Dr AKM Mostafa Kamal for their help and Dr James McKenna for reviewing this paper.

References

[1] W.E.L. Grimson, From Images to Surfaces, MIT Press, Cambridge, MA, 1981.
[2] E. Hall, J. Tio, C. McPherson, F. Sadjadi, Measuring curved surfaces for robot vision, Computer 15 (1982) 42–54.
[3] P.J. Besl, R.C. Jain, Invariant surface characteristics for 3D object recognition in range images, Computer Vision, Graphics and Image Processing 33 (1986) 33–80.
[4] P.J. Besl, R.C. Jain, Segmentation through variable-order surface fitting, IEEE Transactions on Pattern Analysis and Machine Intelligence 10 (2) (1988) 167–192.
[5] T. Fan, G. Medioni, R. Navatia, Segmented descriptions of 3-D surfaces, IEEE Journal of Robotics and Automation RA-3 (6) (1987) 527–538.

[6] R. Hoffman, A. Jain, Segmentation and classification of range images, IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-9 (5) (1987) 608–620.

[7] A. Matsumoto, H. Saito, S. Ozawa, 3-D reconstruction of skin surface from photometric stereo images with specular and inter reflections, Proceedings of the IEEE International Conference on Control, Automation, Robotics and Vision, ICARCV'96, December 1996, pp. 778–782.

[8] Y.F. Wang, A. Mitchie, J.K. Aggarwal, Computation of surface orientation and structure of objects using grid coding, IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-9 (1) (1987) 129–137.

[9] N. Shrikhande, G. Stockman, Surface orientation from a projected grid, IEEE Transactions on Pattern Analysis and Machine Intelligence II (6) (1989) 650–655.

[10] S. Willner, Moiré topography for diagnosis and documentation of scoliosis, Acta Orthopaedica Scandinavica 50 (1979) 295–302.

[11] E. Heirdolzer, W. Frobin, Rasterstereographic measurements and curvature analysis of the body surface of patients with spinal deformities, Proceedings of First International Symposium on Moiré Topography and Spinal Deformities, 1981, pp. 267–276.

[12] M.A.K. YousufZai, A.K. Syed, J.A. Zubairi, Computer based analysis of human gait using Moiré fringe topography, Proceedings of the International Workshop on Computer Vision and Parallel Processing, IEEE and Q.A. University, Pakistan, 1995, pp. 60–71.

[13] M. Batouche, R. Benlamri, M.K. Kholladi, Computer vision system for diagnosing scoliosis using Moiré images, Computers in Biology and Medicine 6 (4) (1996) 339–353.

[14] E. Hierholzer, Calibration of a video rasterstereographic system, Photogrammetric Engineering and Remote Sensing 60 (6) (1994) 745–750.

[15] B. Drerup, E. Hierholzer, Back shape measurement using video rasterstereography and 3-dimensional reconstruction of spinal shape, Clinical Biomechanics 9 (1) (1994) 28–36.

[16] T. Huysmans, B. Haex, R. Van Audekercke et al., Measurement and analysis of the back surface for the three-dimensional evaluation of sleeping postures using video rasterstereography, 12th Conference of the European Society of Biomechanics, Dublin 2000.

[17] AKM M. Kamal, S.J. Steiner, A simple, fast and robust boundary detection algorithm based on chain coding principle, Proceedings of ICARCV'96, vol. 2, December 1996, pp. 1003–1007.

[18] J.A. Zubairi, AKM M. Kamal, A methodology for spinal deformity detection using computer aided rasterstereography, Proceedings of the IEEE International Conference on Intelligent Processing Systems, ICIPS'97, October 1997, pp. 1528–1531.