Cobb Angle Quantification for Scoliosis Using Image Processing Techniques

Raka Kundu
A.K.C.S.I.T, University of Calcutta, Kolkata-700009.
R&D, N.I.O.H,Kolkata-700090

Prasanna Lenka,
Ratnesh Kumar
R&D,N.I.O.H,Kolkata-90

Amlan Chakrabarti
A.K.C.S.I.T, University of Calcutta, Kolkata-700009

ABSTRACT
Measurement of Cobb angle is the standard technique used for scoliosis assessment. The challenging task in computerized method lies in totally automating the method of curvature measurement from digital X-ray images. In this paper we presented a method which automatically measures the Cobb angle from radiographs after selection of the end vertebrae of the curve. The image processing methods used shows an appreciable measurement of scoliosis curvature in digital X-ray image, reducing user intervention. The proposed method detects the inclination of the vertebra by identifying the lines of the endplate from edge image, helping in calculating the Cobb angle in the direction of the endplates automatically. An intra-observer and inter-observer assessment was performed over the radiographs using the manual and the proposed digital method. A level of improvement for Cobb angle measurement is achieved in the proposed computerized image processing technique in terms of estimating the vertebral slope and limiting user intervention.

General Terms
Biomedical Image Processing.

Keywords
Image Processing, Digital X-ray image, Scoliosis, Cobb angle.

1. INTRODUCTION
Scoliosis [1] is a three dimensional deformity that causes abnormal curve of the spine. It involves lateral curvature accompanied with vertebral rotation of the spine. Scoliosis is of several types based on the cause and age of the curve development. About 2% of female and 0.5% of male population can be affected by scoliosis. Adolesant idiopathic scoliosis is the most common form of scoliosis. Depending on condition and severity of the curve and chances of getting the curve worse, the treatment of scoliosis involves observation, bracing and surgery. The deformity of spine may be characterized by measurement of lateral curvature from anterior-posterior radiograph images. The standard in orthopedics for quantifying the degree of scoliosis is the measurement of Cobb's angle from radiographs. This measurement helps in understanding the stage of deformity, monitoring curve progression and management of scoliosis. Cobb angle below 25 degree is kept under observation with routine measurements. Cobb angle between 25-40 degree and that is still growing, a brace treatment is recommended. Bracing is not required for people who have finished growing the curve. A surgery is usually suggested for curvature having Cobb angle greater than 45 degree.

The Cobb angle measurement technique consists of selection of the end vertebrae which tilt more severely toward the concavity of the curve. Lines are drawn one from the upper endplate of the superior vertebrae and the other from the lower endplate of the inferior vertebrae of the curve. The angle *(θ)* formed by intersection of the two lines is considered to be the Cobb angle [Figure 1] which represents the measurement of lateral curvature. The normal measurement errors for Cobb angle magnitude quantification are due to selection of different end vertebrae and in estimation of the slope of the end vertebrae. Same selected end vertebrae may result in Cobb angle degree variation due to improper estimation of the vertebral slope. Manual method which includes drawing lines through endplates of vertebrae with use of pencil, scale and protractor on X-ray plate is less preferable as the lines may not run across right corners of the endplates leading to variation in Cobb angle quantification.

Technological improvement has increased the use of digital X-ray image for clinical purpose. To improve the reliability and accuracy of Cobb angle quantification method, several algorithms have been developed till date. In 2002 Chockalingam et al. [2] proposed a computer assisted Cobb angle measurement method which produces eight lines over the region of interest (ROI), resulting in eight equal segments. The observer needed to mark two points on each line where the line intersected the vertebra edge. The program then determined midpoint of each line and formed the spinal midline connecting these midpoints. The Cobb angle was quantified based on this midline. In 2007 a reliability assessment of Cobb angle was performed by Gstoettner et al. [3] for manual versus digital measurement tool. The Incoview software was used for this purpose where lines were drawn over the upper and lower endplates of the extreme vertebrae of the curve and the program measured the Cobb angle automatically. In 2008 Allen et al. [4] used an automatic Cobb angle measurement method which was based on active shape model and it also needed training set. In 2010 Tanure et al. [5] performed a reliability assessment of Cobb angle using manual and digital method. The digital method consisted marking the endplates of the superior and inferior vertebrae of the curve with the mouse. One dot on each extremity of each endplate was needed and the remaining steps of Cobb angle measurement were done automatically. In 2009 Zhang et al. [6] developed a new technique of computerized Cobb angle measurement method. The method needed contrast and brightness adjustment with ROI selection. Canny edge detection, fuzzy Hough transform were used to find the lines over the endplates of the vertebrae. The Cobb angle was calculated according to direction of these lines.

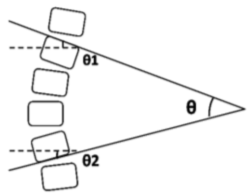

Figure 1: Representation of Cobb angle (θ = θ1+θ2)

In this work we have proposed a computer-aided method for Cobb angle quantification of scoliosis from digital X-ray image. The digital method requires only selection of the extreme vertebrae of the scoliosis curvature from the user and the rest of the process for measuring the Cobb angle from radiograph image was performed by the proposed image processing techniques. Based on Gaussian first order derivative operation a new horizontal edge detection algorithm has been developed which is effectual in the purpose of Cobb angle measurement. The proposed computerized technique aims in reducing the manual intervention and measurement error. The process helps in proper and easy assessment of scoliosis.

The organization of this paper is as follows. Section II consist the image processing algorithms applied in the subsequent steps of our proposed scheme of Cobb's angle measurement. Section III illustrates the results and statistical data. Concluding remarks and scope of future work are given in section IV.

2. MATERIALS AND METHOD

A series of 30 anterior-posterior radiographs from patients diagnosed with idiopathic scoliosis was obtained to perform the assessment of Cobb angle using manual and computerized method. Patients including female and male were chosen above the age group of 12 years. The study population included patients ranging from curvatures having small Cobb angle ($\theta \geq 2°$) to large Cobb angle ($\theta < 90°$) . MATLAB 7.9.0 (R2009b) software was used to develop the computerized program for quantifying the Cobb angle of spinal curvatures.

Objective of the proposed work [Figure 2, Figure 3] is to avoid user intervention and perform the Cobb angle quantification in a more reliable way. Prior to processing of the image the extreme superior and inferior vertebrae which tilt more severely toward the curve were selected by cropping the ROI. As digital X-ray images are highly prone to noise, we have used the Wiener filter [7] for smoothing the image. Next an algorithm for vertebral body horizontal edge detection was applied which mainly comprised of Gaussian derivative operation with a suitable thresholding and edge extraction scheme. This edge detection was followed by Hough transform to detect the slope of the vertebrae. Once the slopes of the vertebrae were selected the Cobb angle of the scoliosis curvature was calculated. Figure 2 gives a flow diagram of our proposed scheme and Figure 3 shows the overview of the scheme with help of some images.

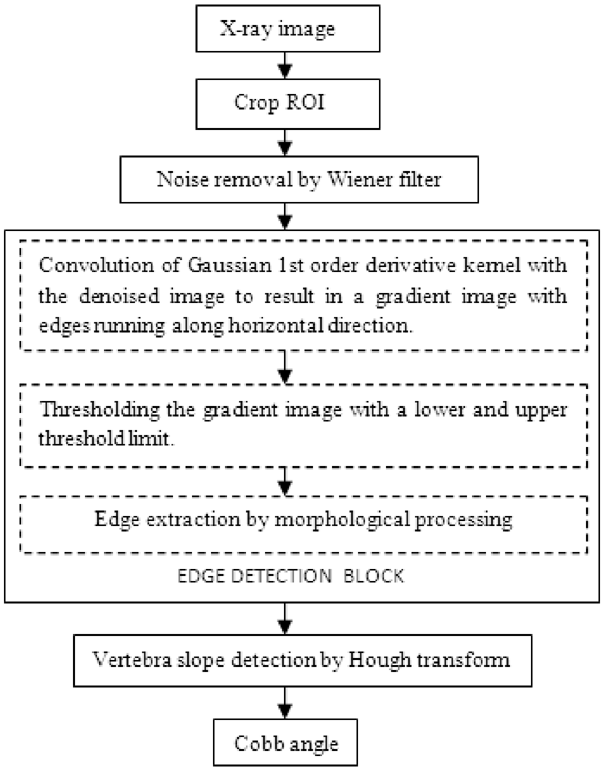

Figure 2: Proposed scheme for quantification of spinal curvature

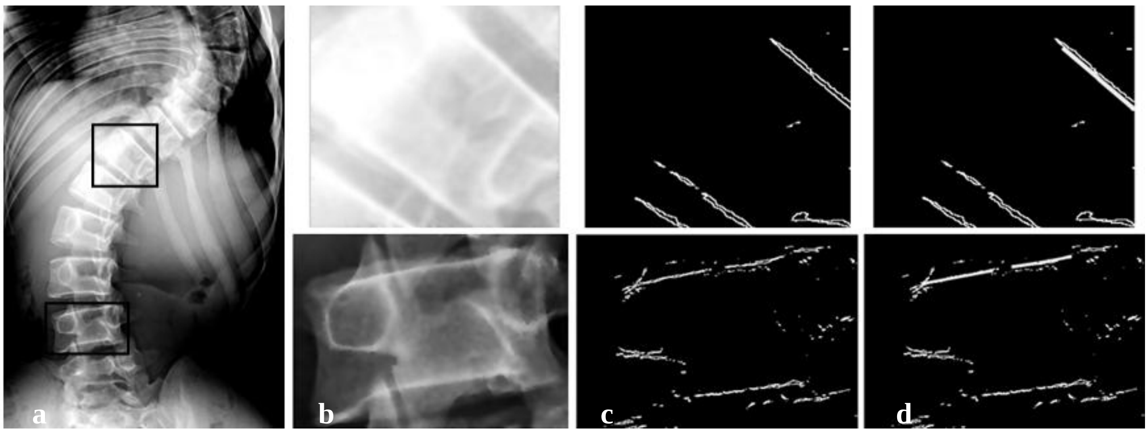

Figure 3: a-ROI selection, b-cropped and noise removed image, c-horizontal edge detected image based on Gaussian higher order derivative operator, d-endplate slope detection by Hough transform.

2.1 Edge detection

Edge detection is a requisite before Hough transform. Endplates of the vertebrae are not vertical edges, they are either horizontal edges or edges with inclination. Presence of vertical edges may produce erroneous result in Cobb angle quantification. A horizontal edge detection method is proposed as it is more suitable for detecting the endplates and slope of the vertebra for Cobb angle measurement in comparison the edge detected image containing both horizontal and vertical edges.

2.1.1 Obtaining Gaussian 1st order gradient image

The formulation of the proposed edge detection algorithm is based on the Gaussian function and its 1st order derivative operator. A common use of Gaussian function and its 1st order derivative can be found in Sobel edge detection and Canny edge detection algorithm [7, 8]. 1st order Gaussian derivative is used to get two kernels. These kernels are designed to respond to edges running along vertical direction and horizontal direction.

Figure 6: Denoised image

Figure 7: Gradient image obtained after convolution of the Gaussian 1st order kernel with the denoised image.

The equation of one dimensional Gaussian function is:

$$D(x) = \frac{1}{\sqrt{2\Pi\sigma^2}} * \exp^{\frac{-(x-\mu)^2}{2\sigma^2}} \qquad (1)$$

μ = mean, σ^2= variance.

With μ = 0

$$D(x) = \frac{1}{\sqrt{2\prod\sigma^2}} * \exp^{\frac{-x^2}{2\sigma^2}} \qquad (2)$$

The two dimensional Gaussian function is given by:

$$D(x,y) = \frac{1}{2\Pi\sigma^2} * \exp^{\frac{-(x^2+y^2)}{2\sigma^2}} \qquad (3)$$

For simplicity we drop $\frac{1}{2\Pi\sigma^2}$.

$$D(x,y) = \exp^{\frac{-(x^2+y^2)}{2\sigma^2}} \qquad (4)$$

$$D'_y(x,y) = \frac{\partial(D(x,y))}{\partial y}$$

$$D'_y(x,y) = -\frac{y}{\sigma^2} * \exp^{\frac{-(x^2+y^2)}{2\sigma^2}} \qquad (5)$$

A 3x3 convolution kernel of the derived Gaussian operator ($D'_y(x,y)$) with $\sigma = 0.9$ was chosen for the experiment. The kernel when convolved with the original digital deniosed image, results in estimating the gradient in y-direction. This helps in highlighting horizontal intensity discontinuities of the original image. Figure 6 and Figure 7 shows the denoised image and the resultant gradient image respectively. The horizontal gradient image obtained after convolution shows the clear structure of the end plates of the vertebra. This proves that the Gaussian 1st order operator is suitable for detecting meaningful intensity discontinuities of the digital X-ray image of vertebrae.

2.1.2 Thresholding

A thresholding is applied to the gradient image to get the solid elements and avoid the unnecessary information of the gradient image. An upper and a lower threshold value are used in our experiment. The threshold limit can be adjusted to yield proper results for Cobb angle quantification. Figure 8 shows the image obtained after applying the thresholding operation to the gradient image.

Figure 8: Thresholded image

2.1.3 Morphological operation

A simple morphological operation [7] is used here for obtaining the edge image from the threshold image.

$$E = T - (T \ominus B) \qquad (6)$$

Where, *T* is the threshold image, *B* is the structuring element and *TΘB* denotes erosion of *T* by *B*. Figure 9 explains operations of equation 6. A visual assessment of the prior and post process of morphological operation are shown in Figure 10 and Figure 11 respectively.

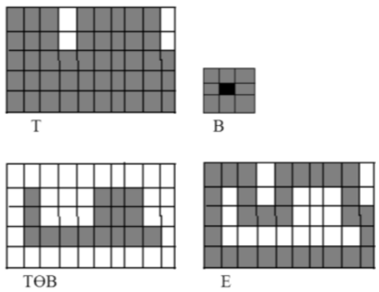

Figure 9: Edge extraction by morphological process

Figure 10: Threshold image before morphological operation

Figure 11: Edge image after morphological operation

The edge image of Figure 11 proves that our proposed technique of edge detection gives distinct visualisation of the endplates of the vertebra. For further illustrating the effect of using our proposed edge detection technique rather than Sobel horizontal edge detection, we demonstrate Figure 12 and Figure 13. In Figure 12 we show the magnified edges of the vertebra after applying sobel edge detection, where as Figure 13 shows the magnified version of the same edges obtained by our proposed technique. Comparing these two figures it can be easily found out that our proposed tecnique(Figure 13) generates edges with more continuous edge pixels and hence proves to be a better technique as compared to soble for the purpose of detecting endplate lines by Hough transform.

2.2 Hough transform

Hough transform [10, 11] is a method to detect straight lines. $x_i cos\theta + y_i sin\theta = \rho$ is the normal representation of a line in *x-y* plane. The parameter ρ is the distance between the line and the origin, θ is the vector angle from the origin to the closest point of the line and (x_i, y_i) is a point on the line which passes through a certain point (ρ_k, θ_k) in ρ-θ plane which is referred as Hough space.

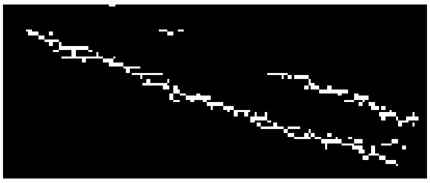

Figure 12: Horizontal Sobel edge detection with discontinuous edge pixels.

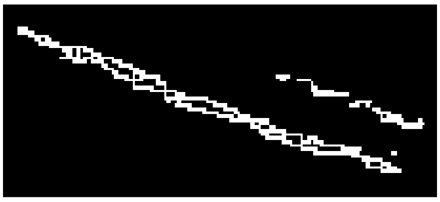

Figure 13: Proposed horizontal edge detection with continuous edge pixels.

All points (x_1, y_1), (x_2, y_2) in the *x-y* plane, passing through a common intersecting point (ρ', θ') in the Hough space will belong to a particular line. If in *x-y* plane we have *n* points lying on the line *L* then, in the Hough space there are *n* sinusoidal curves (each of this curve represent as a point in *x-y* plane) passing through the same point (ρ', θ'). So, identifying line passing through a group of points in *x-y* plane is reduced to identifying the point of intersection of the sinusoidal curves in the Hough space. The illustration is given in Figure 14.

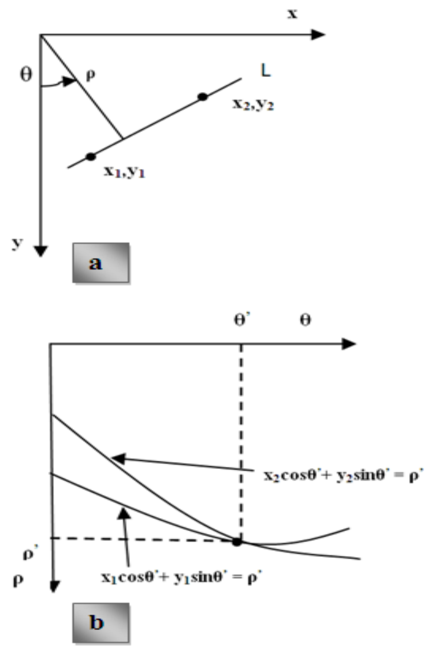

Figure 14: (a) Representation of a straight line L in x-y plane where (x_1, y_1), (x_2, y_2) are the points lying on the line L. (b) The point of intersection (ρ', θ') in Hough space corresponds to the line L passing through points (x_1, y_1) and (x_2, y_2) of the x-y plane.

The edge image obtained prior to Hough transform is horizontal edge image. End plates of the vertebra are not ideal straight line but are close to straight line. These endplates represent the longest line in the vertebra edge image. Selection of straight line with maximum group of (x_i, y_i) points passing through a particular (ρ_k, θ_k) will help in calculating the slope of the vertebra from the edge image. After getting the slopes from the respective upper extreme vertebra and lower extreme vertebra edge image, the required Cobb angle $(\theta = \theta_1 + \theta_2)$ of spine curvature is calculated.

3. RESULTS AND DISCUSSION

After illustration of Cobb angle magnitude measurement technique, the effectiveness of the method can be demonstrated through the experimental results. Figure 15 shows a sequence of images where the slope of the vertebrae is detected automatically from selected ROI. Here, the directions of line segments of the vertebral endplates are correctly identified for proper Cobb angle quantification. However as the vertebral body are complex in structure, the proposed technique in some cases failed in estimating the proper lines of the vertebrae. The success rate of the proposed technique is 80%-90% which implies that it can be accepted.

Figure 15: Edge image with identified slope of the vertebrae using the proposed technique.

An intra observer and inter observer assessment test was carried out to evaluate the validity of the proposed method. Two examiners, E_1, E_2 performed the experiments manually and using the image processing technique as mentioned above. The results of the measurement are grouped into four category based on magnitude of Cobb angle. S_1 *(<10°)*, S_2 *(10°- 25°)*, S_3 *(25°- 40°)*, S_4 *(>40°)*. The test results are given in Table 1 and Table 2 in terms of mean absolute deviation (MAD).

Table1: Intra observer variation

Group	No.	E1 Manual MAD	E1 Digital MAD	E2 Maual MAD	E2 Digital MAD
S_1	10	1.75°	1.53°	1.5°	0.93°
S_2	7	1.5°	0.89°	2.05°	1.35°
S3	7	2.17°	1.87°	2.58°	1.91°
S_4	6	2.58°	2.27°	2.5°	2.85°

Table2: Inter observer variation

Group	No.	Manual MAD	Digital MAD
S_1	10	1.13°	1.19°
S_2	7	2.28°	1.64°
S3	7	3.37°	2.19°
S_4	6	3.71°	2.31°

Reported statistical data of Table 1 and Table 2 of Cobb angle show that the mean intra observer variability for manual method was 2.1° and for digital method was 1.7°. Whereas, the inter observer variability for manual method was 2.62° and for digital method was 1.83°. The results reflect a good impression and prove that the proposed digital method was better than the manual method for Cobb angle degree measurement and produced small variability.

Thus the proposed method reduces one step of Cobb angle measurement by automatically selecting slope of the endplates of vertebrae and consequently reducing the measurement error of Cobb angle magnitude. This serves the aim of measuring the Cobb angle.

4. CONCLUSION

This work proposes an efficient image processing technique for Cobb angle measurement from digital X-ray image of spine. The technique automatically identifies the direction of the endplates of the vertebrae and minimizes user intevention. Proper adjustment of parameters of the technique produce a good result. The results show that our proposed technique reduces the intra observer and inter observer variability, by proper extraction of the endplate of the vertebrae with use of a new edge detection method formulated from Gaussian function. Thus the proposed work can be helpful in diagnosis and treatment of scoliosis by quantifying the Cobb angle in an easier, fast and reliable way. The future work for Cobb angle measurement will be in reducing the user judgement and to produce a totally automated Cobb angle quantification method.

5. ACKNOWLEDGMENT

This project is done as a collaborative research work between A.K.Choudhury School of Information Technology, University of Calcutta and Dept. of Rehab Engineering, National Institute for the Orthopaedically Handicapped, Kolkata.

6. REFERENCES

[1] Eeuwijk A. H. W. V., Lobregt S., Gerritsen F. A. 2006 A novel method for digital X-ray imaging of the complete

spine.

[2] Chockalingam N., Dangerfield P. H., Giakas G., Cochrane T., Dorgan J. C. 2002 Computer-assisted cobb measurement of scoliosis. Eur Spine J 11: 353-357.

[3] Gstoettner M., Sekyra K., Walochnik N., Winter P., Wachter R., Bach C. M. 2007 Inter-and intraobserver Reliability assessment of the cob angle: manual versus digital measurement tools. Eur Spine J 16: 1587-1592.

[4] Allen S., Parent E., Khorasani M., Hill D. L., Lou E., Raso J. V., 2008 Validity and Reliability of Active Shape Models for the Estimation of Cobb Angle in Patients with Adolescent Idiopathic Scoliosis, Journal of Digital Imaging,Vol 21, No 2, 208-218.

[5] Tanure M. C., Pinheiro A. P., Oliveira A. S., 2010 Reliability assessment of Cobb angle measurements using manual and digital methods. The Spine Journal 10: 769- 774.

[6] Zhang J., Lou E., Le L. H., Hill D. L., Raso J. V., Wang Y., 2009 Automatic Cobb Measurement of Scoliosis Based on Fuzzy Hough Transform with Vertebral Shape Prior, Journal of Digital Imaging, Vol 22. No 5: 463-472.

[7] Gonzalez, R.C., R.E. Woods, Digital Image Processing, Publisher – Pearson Education.

[8] Maini R., Aggarwal H., Study and Comparison of Various Image Edge Detection Techniques. International Journal of Image Processing, Vol. (3): Issue (1)

[9] Daghameen K., Arman N., 2007 An Efficient Algorithm For Line Recognition Based on Integer Arithmetic.

[10] Lee K., 2006 Application of the Hough transform, University of Massachusetts, Lowell.

[11] Duda R. O., Hart P. E., 1972 Use of the Hough transform to detect lines and curves in pictures, Published in the Comm. ACM, Vol 15, No. 1: 11-15.

[12] Shea K.G., Stevens P. M., Nelson M., Smith J. T., 1998 Masters K. S., Yandow S., A comparison of manual versus computer-assisted radiographic measurement. Intraobserver measurement variability for Cobb angles, Spine, 23(5):551-5.

[13] Wills B. P. D., Auerbach J. D., Zhu X., Caird M. S., Horn B. D., Flynn J. M., Drummond D. S., Dormans J. P., Ecker M. L., 2007 Comparison of Cobb angle measurement of scoliosis radiographs with preselected end vertebrae: traditional versus digital acquisition, Spine, 32(1):98-105.

[14] Mezghani N., Phan P., Mitiche A., Labelle H., Guise J. D., 2010 A computer-aided method for scoliosis fusion level selection by a topologicaly ordered self organizing Kohonen network. International Conference on Pattern Recognition, IEEE Computer Society.

[15] Chen W., Edmond H., M., Le L., H., 2011 Using Ultrasound Imaging to Identify Landmarks in Vertebra Models to Assess Spinal Deformity. 33rd Annual International Conference of the IEEE EMBS.

[16] Xu Z., Pan J., Zhang S., 2007 A Novel Automatic Framework for Scoliosis X-Ray Image Retrieval. Proceedings of International Joint Conference on Neural Networks.