Biomed Eng Lett (2014) 4:158-165
DOI 10.1007/s13534-014-0129-z

ORIGINAL ARTICLE

Automatic Extraction of Vertebral Endplates from Scoliotic Radiographs Using Customized Filter

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Received: 9 October 2013 / Revised: 15 April 2014 / Accepted: 7 May 2014

Abstract

Purpose The scoliosis diagnosing system needs radio-graphic information in terms of spinal curvature estimated using Cobb's definition. The evaluation process and treatment analysis depends on the reliability and reproducibility of the spine curvature in the frontal view.

Methods Manual identification of end vertebrae and other anatomical features required for the estimation of spinal curvature causes variability and unreliability at higher rate. This paper proposes an automated system to extract the required anatomical features using customized filter. The customized filter used in this paper is a combination of anisotropic, sigmoid and differential filter. Combination of these filters automatically extracts the anatomical features in terms of required vertebral endplates. Automatic identification of these endplates eliminates the human intervention involved in the quantification of Cobb angle.

Results and Conclusions Analysis of the results reveals significant difference between the observer variability between manual, computer assisted and computerized image understanding system in terms of inter and intra cross correlation coefficient ratio (ICCR).

Keywords Vertebral endplate, Cobb angle, Scoliosis, Diffusion filters, Sigmoid filters, Derivative filters

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INTRODUCTION

Scoliosis is a three dimensional spine deformity and its severity is measured by spinal curvature. Spinal curvature is one of the most significant quantitative parameters used for planning orthopedic surgical procedure and monitoring the progression of scoliosis. Despite the enormous advances in cross sectional imaging over the fast decades, radiograph remains the mainstay of diagnosis and evaluation of scoliosis [1]. The largest curvature in the scoliosis spine is known as the primary or major curve. A scoliosis curve may have more than one or several major curves [2]. For each curve there is a terminal and apical vertebrae. The terminal vertebra is the most tilted superior or inferior vertebra included in the curve. Careful attention in evaluation technique of scoliosis radiography is mandatory because small difference in rotation, magnification and other alterations in patient's position can significantly alter the spinal curvature measurement.

Severity of the spine curvature in the lateral view is quantified by Cobb angle [3]. Quantification of Cobb angle is based on the identification of upper endplate of superior vertebra and lower endplate of inferior end vertebra with ruler and pencil procedure. Cobb angle is obtained by measuring the maximal angle from the upper endplate of superior end vertebra to the lower endplate of inferior end vertebra. Cobb procedure is preferred because of its easier reproducibility, easier application and management of larger angles for more severe spinal curvature [4].

The methods for quantifying the scoliosis curvature are most acceptable, when they are completely automated or require minimal manual intervention. Early studies on computerized system have reported a potential decrease in measurement error relative to manual measurement attributed to elimination of variability of different manual protractors and use of wide diameter radiographic markers [5]. The amount of actual error in the measurement among the examiners was relatively

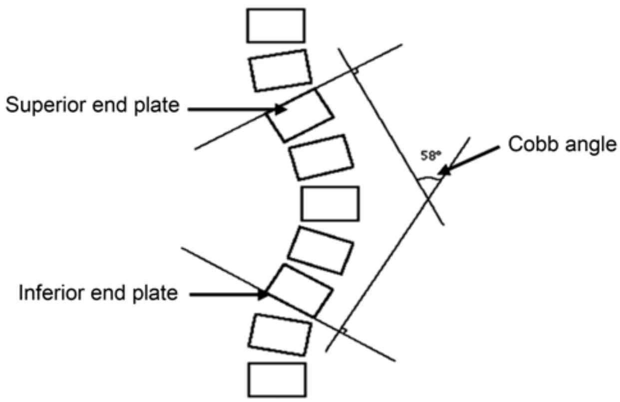

Fig. 1. Cobb angle calculation.

small when the end vertebrae were pre-selected. This confirms that, selection of end vertebra plays major role and it is the largest source of error as the required end vertebrae are embedded in the vertebral column between para-vertebral muscle masses.

Computer assisted systems are based on the geometrical features obtained by geometrical reconstruction of manually identified anatomical landmarks [6, 7]. In order to completely eliminate this human variability, this paper proposes a computerized image analysis and understanding system for reliable quantification of spinal curvature from scoliosis radiograph.

RELATED WORKS

The Cobb method [4] is the commonly utilized techniques for measuring Scoliosis. In 1979 Barry F Jefferies [6] stated that a change in curvature of 5 degree may be due to variations in measurement rather than true improvement or worsening of the curve. To eliminate these deficiency in the scoliosis evaluation, they started with a computerized program to identify and accept spatial data regarding the locations of thoracic to lumbar vertebrae. Computerized measurement provides better evaluation of true shape of the curve with reference point were located on standard posterioanterior (PA) radiographs from first thoracic to iliac crests using sonic digitizer.

In 2002 Cheung et al., started analysis [8] of scoliotic deformity by means of computerized digital analysis. This study was to determine the reliability of computerized measuring system. All the computerized methods are bounded with human intervention, either in deciding the endplates of vertebra or drawing the lines along those endplates.

The role of preselection of end vertebrae are discussed by Kuklo et al., in 2006. This comparison includes computer measurement of digitally acquired radiographs, manual measurement of hard copy and manual measurement of traditional films. To minimize previous identified errors manual measurement were performed with each examiner with same marking pencil. Examiners are allowed to alter brightness, contrast and magnifications of digital image to assist the measurement. To familiarize the examiner with software program each underwent an initial training period consisting of minimum 10 radiographs [7].

In 2007 Gstoettner et al., did the reliability assessment on the Cobb angle with manual versus digital measurement. They used inter cross correlation coefficient for the reliability assessment. Digital radiography does not improve the measurement accuracy. For Cobb angle measurement, definition of the end vertebra introduces the main source of error [5].

Allen et al., proposed a reliable Cobb angle measurement using active shape models in 2008 for idiopathic scoliosis [9]. They need a training set of radiographs representative of curves seen in scoliosis, to train the software to recognize the vertebrae and active shape models cannot significantly deviate from variations and thus can only generate shapes similar to the training set. During the training set the boundary of the object is identified by manually digitizing N landmarks around the perimeter of the object in an image.

In 2009 Hitesh Modi et al., [10] studied the reliability of Cobb angle between juvenile and adolescent idiopathic scoliosis. In their study two observers, independently measured the Cobb angle using computer based digital radiographs. Both the observers are given predefined level of upper and lower endplates. Because of the predecision of the upper and lower end vertebrae, there was no significant difference in the Cobb angle measurement.

For the pediatric orthopedic [11], Eiten et al., did the reliability analysis for the Cobb angle measurement using novel Picture Archiving and Communication Systems (PACS) computer software program. Their reliability relies on precise definition of bony landmarks for measurement angles, indexes and length of joints, limbs and spine. They concluded that most of the differences between specialist and non-specialist were insignificant. The correlation between the results according to the number of bony landmarks that needed to be identified was also insignificant.

Finally, technical report on Reliable Assessment of Cobb angle [1] using manual and digital methods says that Cobb angle in the PA view is an important parameter in the assessment of scoliosis. Technical advances allows increased use of digitized X-rays images in clinical practice. The computer assisted method is clinically advantageous and appropriate to assess the scoliotic curvature, but the end vertebrae selections are the unsolved problems.

EXTRACTION OF VERTEBRAL ENDPLATES

Extraction of vertebral endplates from the scoliotic radiograph involves different image processing techniques. Proposed work is based on the pipe-line structure of different filters, which is referred as customized filters. It is a combination of three different filters namely anisotropic diffusion, sigmoid and derivative filters as shown in Fig. 2.

Scoliotic radiographs are noisy in nature due to reduced radiation dosage as patient needs to be frequently monitored. It is difficult to mark exactly on the vertebral corners and furthermore repeatability cannot be assured. Usage of linear filters leads to mixing up of foreground and background, and causes blurring and smoothing of the required anatomical features along with removal of noisy pixels.

The PA radiograph have almost equal intensity in the vertebral body, pedicle, rib region, etc. Partial differential equation (PDE) based methods are one of the best mathematical techniques in image processing for convolution, median filtering, dilation and erosion. PDE based techniques are mainly used in smoothing and restoration process. PDE based image enhancement with diffusion type relates diffusion filters to vibrational image restoration technique. Diffusion process equilibrates concentration differences without creating or destroying mass. Equilibration property :

$$j = -D * \nabla u \qquad (1)$$

Concentration gradient ∇u causes a flux j which aims to compensate for this gradient. The relation between ∇u and j is described by the diffusion tensor D, a positive definite symmetric matrix. If the diffusion tensor is constant over the whole image of homogeneous type, a scale dependent filter is called as nonhomogeneous. Because of nonuniform distribution of intensity values in the radiograph, it is better to apply adaptive method to filter using nonlinear diffusion process. It was first introduced by Perona Malik by avoiding blurring and localization problem of linear diffusion filter. This method applies inhomogeneous process that reduces the diffusivity at those locations, which have larger likelihood to be edges [12],

Diffusion Process by Perona Malik is given by,

$$\partial_t u = div(g\|\nabla u\|^2 \nabla u) \qquad (2)$$

its diffusivity,

$$g(s^2) = \frac{1}{1 + \frac{s^2}{\lambda^2}} \qquad (3)$$

During smoothing, linear scale space method treats all spatial points and scale levels equally. It is preferred to work with region boundaries that should be sharp and should coincide with semantically meaningful boundaries at each resolution level and that intra region smoothing is better than the inter region smoothing. In-order to establish a smoothing scale space property for this nonlinear diffusion process, anisotropic nonlinear models are preferred.

The anisotropic filter is based on the numerical solution of a PDE describing the process of nonlinear anisotropic diffusion [12] as follows,

$$\frac{\partial f(x, y, t)}{\partial t} = div(g(\|\nabla f\|)\nabla f) \qquad (4)$$

where $f(x, y, t)$ represents the image function. The diffusion coefficient g is a decreasing function of the image gradient norm $\|\nabla f\|$. The diffusion process is inhibited around the edges where the image gradient is high. Different functions can be used giving perceptually similar results such as,

$$g(\|\nabla f\| = \frac{1}{1 + (\|\nabla f\|/K)^2} \qquad (5)$$

The parameter K controls the rate at which the diffusion coefficient decreases as the norm of the image gradient increases. The value of K is set in relation to the gradient strength of edges of the vertebrae in the region of interest which should be preserved during the diffusion.

Sigmoid filter is used to map the specific range of intensity into a new range by making very smooth and continuous transition for the minimum output level to the maximum output level.

These filters are widely used as a mechanism for focusing attention on a set of particular values and progressively attenuating the values outside the specified range. In proposed application attention is on the anatomical structures like vertebral boundary and it's endplate region. The sigmoid

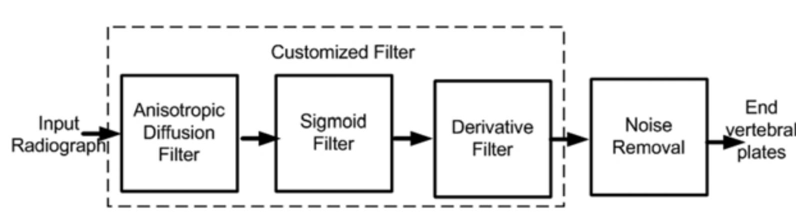

Fig. 2. Block diagram showing extraction of vertebral end plates.

equation is,

$$I' = (Max - Min).\frac{1}{\left(1 + e^{-\left(\frac{I-\beta}{\alpha}\right)}\right)} + Min \tag{6}$$

- Max : maximum output level specified by the user
- Min : minimum output level specified by the user
- α : extent of transition between the Max and Min values
- β : gray level value of pixels in input image around which the new intensity values are mapped

The non-linear filters and sigmoid filters retain the anatomical features after removal of noise from scoliotic radiograph as explained above. Using edge detection technique the preserved edges are extracted. The horizontal endplates of vertebrae are oriented in the horizontal direction along with some inclination in the same direction. The derivatives in the horizontal direction will extract the horizontal edges as well as any other edges oriented in the same direction.

The first derivative operator follows some basic properties like; the first derivative of the gray level is negative at the leading edge of the transition, positive at the trailing edge, and zero in the areas of constant gray levels. The gradient of an image $f(x, y)$ at the location (x, y) is given by the two dimensional column vector. The gradient vector points in the direction of maximum rate of change of image f at (x, y). The magnitude of this vector is given by:

$$MAG(\nabla F) = [G^2x + G^2y]^{1/2} \tag{7}$$

are the rates of change of two dimensional function $f(x, y)$ along x and y axis respectively. A pixel position is declared as an edge position, if the value of the gradient exceeds some threshold value, because edge points will have higher pixel intensity values than those of surrounding. A simple way is to compare the gradient value of a point to a threshold value and the point is said to be on edge, if the threshold value is more than the gradient value of that point.

Based on the same principle as the gradient method, the Derivative Image Filter is used for computing the partial derivative of an image. In this the derivative of the image is calculated in the X-direction or in the Y-direction as specified by the user. Two different outputs are obtained when this filter is used, one containing edges in X-direction and other containing edges in the Y-direction. The image with derivative in X-direction can be used to obtain the spacing between two vertebrae, whereas the derivative in Y-direction can be used to extract the vertebral boundary from the input image. The output having derivative in X-direction can be used to calculate the Cobb angle between two vertebrae, which may help in classifying the degree of scoliosis the person is suffering from.

The above edge detection technique also leaves some unwanted structural elements, which may cause hindrance in further processing of the radiographs. It is eliminated by noise removal module in two stages viz., contrast enhancement and block erosion method.

Algorithm 1 Noise Removal/Edge Enhancement

1: Calculate the mean pixel value of the input image.
2: Subtract the mean value from each of the pixels in the image so as to eliminate unnecessary structures present in the image.
3: Apply Power transformation to the image, so that pixels having considerable grey level values are enhanced while no noticeable change is observed in pixels having small grey level values.
4: Enhance the image by multiplying it by a factor of 2.

The customized filter is automated and two iterations are performed in the sigmoid domain of the filter. The image passed through the anisotropic diffusion filter is iterated twice in the sigmoid filters so as to extract the vertebral boundary.

Usually edges present in the image have higher gray value then the rest of the image. This difference in the gray level value can be exploited through contrast enhancement of the desired image so as to differentiate between the present edges and the background information present in the image. The main motivation behind this algorithm is the noise present within the vertebrae is concentrated in a small area. A customized mask is used to isolate the horizontal vertebral boundaries in the image. In case of scoliotic vertebrae, the edges usually lie at an angle of 0^0 to 45^0 in the horizontal direction. Hence the following mask is designed to use as a structuring element (Fig. 2) in the block erosion technique. The proposed work fulfill the requirement using erosion procedure, by considering the structuring element in the horizontal direction as shown in Fig. 3.

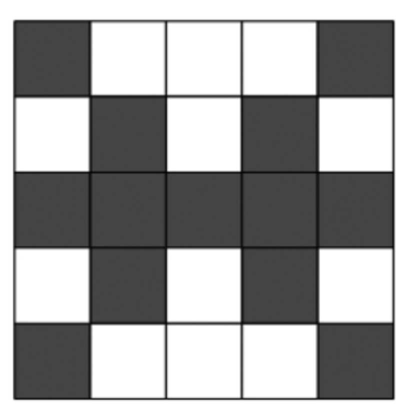

Fig. 3. Structuring element.

Erosion:
A and B as set in Z,

$$A \ominus B = \{z(B)_z \subseteq A\} \quad (8)$$

The erosion of A by B is the set of all points Z such that B translated by Z is contained in A.

In case of scoliotic radiograph, because of the twisting in the lateral direction, horizontal endplates of the vertebrae will have non-zero slope. This slope information are directly used for end vertebral identification. Manual determination of slope of horizontal endplates are time consuming and cumbersome. Hough transform perform this by transforming it into parameter space. The line represented in the image space is $y = mx + c$ and its corresponding representation is a point in the parameter space. An image with different N lines corresponds to a N- point slopes in the parameter space.

These horizontal endplates are nothing but horizontal lines, analysis needs its objective description. Any line in the image space can have objective description in the Hough domain through its slope form.

Finally, the radiograph in the image space has horizontal morphometry of all the vertebrae which is under diagnostic region. Determination of superior, apical and inferior vertebrae depends on the horizontal inclination of all the end vertebral plates. For the normal spine in the PA view all vertebrae are stable with zero slope information. In case of scoliotic radiograph, because of the twisting in the lateral direction, horizontal endplates of the vertebrae will have non-zero slope. This slope information are directly used for end vertebral identification. Manual determination of slope of horizontal endplates are time consuming and cumbersome. Hough transform perform this by transforming it into parameter space. The line represented in the image space is $y = mx + c$ and its corresponding representation is a point in the parameter space. An image with different N lines corresponds to a N-point slopes in the parameter space. Evaluation of vertebral endplates are done using Hough transform on the retained horizontal endplates using Algorithm 2.

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HOUGH TRANSFORM

Extracted vertebral horizontal endplates are discontinuous in nature because of noisy radiographs. Definition of superior and inferior end vertebrae's are defined on the inclination of horizontal endplates of the vertebrae's. Quantification of extracted discontinuous horizontal endplates are challenging task in noisy radiographs. Generalized Hough transform fulfills the requirement by transforming it into the Hough domain. The representation of extracted horizontal endplates are shown in Figs. 5d and 6d. The quantified θ in the Hough domain with two extreme values (positive ($\theta_{superior}$), negative ($\theta_{inferior}$)) defines the superior and inferior endplates.

Algorithm 2 Hough Transform for detecting the lines

1: The input image is *MXN* binary array with edge pixels marked with ones and other pixels as zeros. Let ρ_d, θ_d be the array containing the discretized intervals of the parameter space.
2: Discretize the parameter spaces of ρ and θ using sampling steps δ_p, δ_θ yielding acceptable and manageable resolution of R, T in parameter space.
3: Let $A(R, T)$ be the counter array, initialized to zeroes.
4: For each pixel $E(i, j) = 1$, and for $h = 1... T$ let $\rho = isin(\theta(h)) + jcos(\theta(h))$
5: The output is a set of lines described by $\rho_d(k_p)$, $\theta_d(h_p)$

Analysis of the slope information yields end vertebral definition. Fig. 4a shows extracted end vertebral plates which comes under the diagnostic region. Fig. 4a shows the graph with X-axis in vertebral column and Y-axis represents

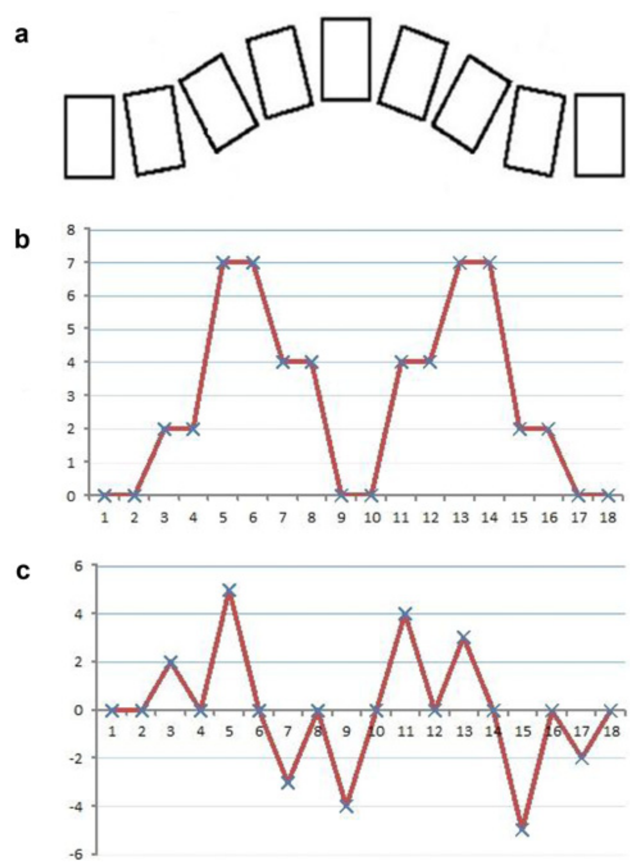

Fig. 4. (a) Vertebral column (b) Slope information (c) First order differentiation of slope.

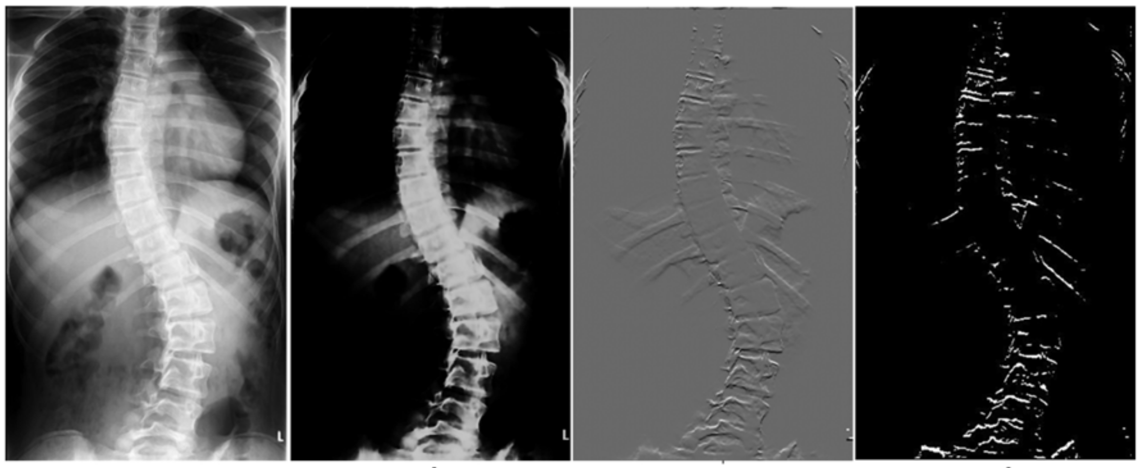

Fig. 5. (a) Input radiograph (b) Customized Filter 1 ouptput (c) Derivative filter output (d) Noise removal output.

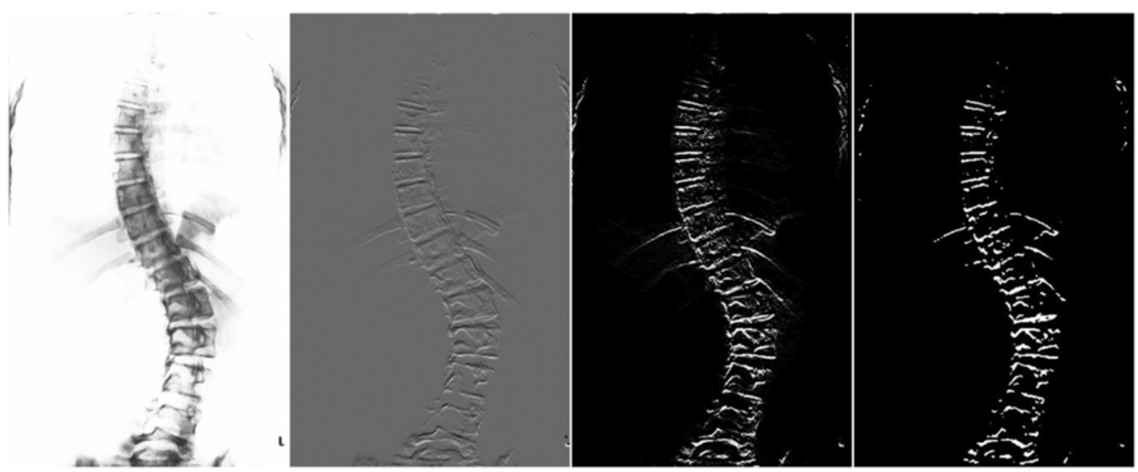

Fig. 6. (a) Customized filter-2 output (b) Derivative Filter output (c) Contrast stretching output (d) Noise removal output.

the angle. First order differentiation of the slope is represented in Fig. 4c. From Fig. 4c it is clearly visible that first zero crossing represents the superior end vertebra, second zero crossing for apical vertebral and finally third zero crossing for inferior vertebra. The slopes of superior and inferior vertebrae are named as $\theta_{superior}$ and $\theta_{inferior}$ respectively. The Cobb angle is calculated using Eq. (9).

$$\theta = tan^{-1}\left(\frac{|\theta_{inferior} - \theta_{superior}|}{1 + \theta_{superior} * \theta_{inferior}}\right) \quad (9)$$

RESULTS

PA radiograph's of 250 patients with idiopathic scoliosis is used for study from KMC medical center Karnataka India. These radiographs are taken in a conventional standing posture at a fixed distance of 228 cm from X-ray source with knees fully extended and upper limbs resting on two arm support. These PA radiographs includes thoracic, thoraco lumbar and lumbar scoliosis with all classes of scoliosis. For the present study, JPEG compressed radiographic images of 256 gray levels with size 925 pixel height by 475 pixel wide are used. For these radiographs, correct Cobb angle estimation was taken by experts from KMC Manipal. We have grouped the given radiographs into different groups of 10 – 12 images set, based on the approximate range of spinal curvature (0^0 – 20^0 (G1), 20^0 – 40^0 (G2), 40^0 - 60^0 (G3)), which includes all different types of scoliosis radiographs. This study is based on 5 different observers on each group individually by three different measurements (manual, computerized and proposed).

The manual quantification of diagnosing parameters involves inter and intra observer error because of human judgments in the end vertebral definitions, as well as while drawing the lines along the vertebral endplates with ruler and pencil procedure. The computer assisted method increased the reliability range up to some extent under the constraint of vertebral endplate definition by manual judgment. The proposed image understanding system supports the quantification process without human intervention during vertebral endplate definition and drawing procedure. Here we first extracted the required features like vertebral endplate using image processing technique, so that the error involved in the end vertebral definition is completely eliminated. These endplates are fed to the Hough transform module for angle estimation.

Extraction of the end vertebral plate is supported by proposed customized filters. Sigmoid filter is applied to differentiate between vertebral regions from the rib-cab. Output from sigmoid filter is initially non-uniform and as a result of which the transition portion from darker region in the image to lighter region is not very clear. To reduce these irregularities in the original radiograph, anisotropic edge preserving diffusion is performed on the input image. Customized filter-1 uses sigmoid filter only once and filter-2 uses sigmoid filter iteratively. In Customized filter-2 sigmoid alpha in the 2nd iteration of the sigmoid filter is given as negative to obtain the negative of the image and increase the clarity of the image so as to detect the edge boundaries, because after 1st iteration, the output image loses its intensity considerably. Using the present filtering approach, the spine can be extracted successfully from the rib cage region of the radiograph, but there will be some loss in the vertebrae information after the 2nd iteration is performed. This information can be read from the output of the 1st iteration and the finer details which were not visible after the 1st iteration can be observed after performing the 2nd iteration. The iterative method is a user-friendly approach relative to the pipelined filtering method mentioned earlier, as in that filter, the user has to decide a suitable value for each of the parameter so as to obtain the desired output. The resultant image is shown in Figs. 5b and 6b. We can notice that only vertebral boundaries are highlighted not the ribs. Using derivative filters the vertebral boundaries are extracted from the retained edge part. The reason for the selection of the derivative filter is to retain only the horizontal derivatives and its related inclination in the same removal direction. Figs. 5c and 6c shows only the horizontal derivatives with some noise. The noise removal works with enhancement followed by block erosion technique. The output in the Figs. 5d and 6d shows the clear vertebral boundary endplates that is used to identify the superior and inferior vertebra. Extracted end vertebral plates are fed to the Hough transform module to identify the superior and inferior vertebra as shown in Fig. 7. Output of the Hough transformations are fed to the computer assisted system to automatically quantify the spinal curvature.

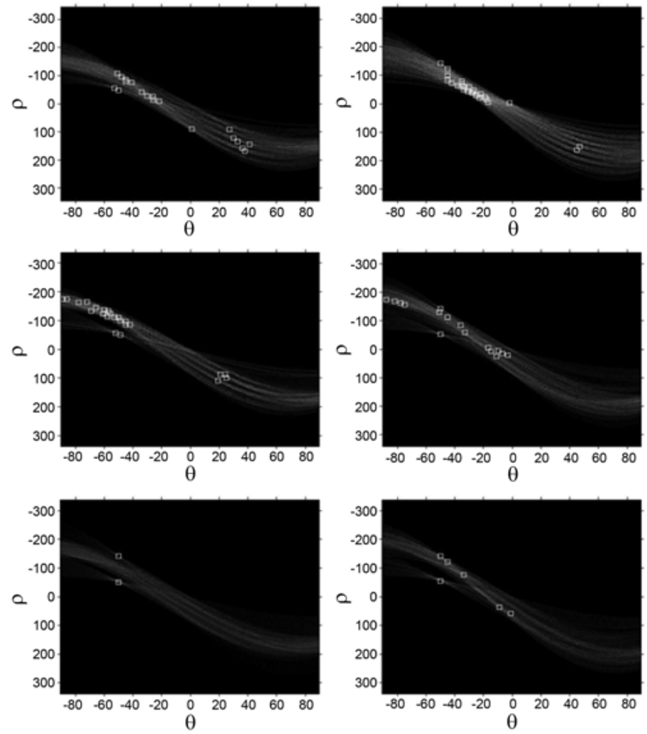

Fig. 7. Hough Transform for Group-2.

DISCUSSION

The spinal curvature in terms of Cobb's angle is the significant parameter for scoliosis evaluation. On the other hand computerized measurement makes the interpretation of images more objective, thus increasing the reliability and repeatability of the evaluation. However, errors may be introduced during initialization of end vertebral definition. To stay away from these manual interventions is currently the most challenging task in the development of computerized image understanding system. The validity and reliability of radiographic measurements or radiographic process measures may be even more critical for attempts to correlate radiographic and clinical outcome measures. Several studies have evaluated the association between process and outcome measure. The radiographic parameters with the worst reliability represent the greatest area for potential improvement, if the source of measurement of variability can be discerned and corrective. We attempted this problem with image understanding system. Initially we applied image processing for enhancement and noise removal. Further, we applied image analysis for extraction of the vertebral endplate as information. This extracted end vertebral information is supplied to the computer assisted system to increase the reliability of the measurement.

The reliability of the proposed system is compared with state-of-the-art techniques. The inter and intra observer error

Table 1. Reliability of the proposed system with the computerized and manual methods.

	Proposed			Computerized			Manual		
Group	Mean	Std deviation	ICCR	Mean	Std deviation	ICCR	Mean	Std deviation	ICCR
G1	1.9	2.2	0.97	3.2	2.9	0.90	3.85	3.45	0.87
G2	2.0	2.3	0.96	2.9	2.6	0.92	3.70	3.10	0.89
G3	1.8	2.0	0.98	2.9	2.6	0.92	3.90	3.20	0.85

is measured in terms of ICCR. The traditional manual measurement was based on human judgment of vertebral endplates and then manual landmark on those identified end vertebrae. Finally, with the ruler and pencil, they will quantify the spine curvature in terms of Cobb's angle. The computer assisted system works on the identified end vertebrae and landmark. The proposed system supplies end vertebral plates (i.e., in terms of horizontal slope of vertebral endplates) to the computerized system, thereby subjective error during identification of end vertebral plates is completely eliminated. The Table 1 gives reliability of the proposed system with the manual and computer assisted method. The change in reliability parameter between manual and computer assisted system is due to use of ruler, pencil and drawing. Change in reliability between image understanding (i.e., proposed technique) and computer assisted technique reflects advantages of automated identification of vertebral endplates using image processing.

CONCLUSION

This paper proposed extraction of vertebral endplates from scoliotic radiograph using image processing technique. The inter and intra observer error during measurement of scoliotic curvature in terms of Cobb's angle is drastically reduced. The proposed work is a better tool for assessing extent of scoliosis and useful in deciding further treatment.

ACKNOWLEDGEMENTS

Authors are grateful to experts from Department of Orthopedics, Kasturba Medical College, and Manipal India for evaluation of the experimental results.

CONFLICT OF INTEREST STATEMENTS

Anitha H. declares that she has no conflict of interest in relation to the work in this article. Karunakar A. K. declares that he has no conflict of interest in relation to the work in this article. Dinesh K. V. N. declares that he has no conflict of interest in relation to the work in this article.

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