Chapter 1

Introduction

1.1 General

The human body is one of the most marvelous creations - it is more complex than the most intricate man-made machines. Inside that, spinal column is a part of this complex anatomical composition also called the spine or the vertebral column, situated in the dorsal side of the human body. It starts from the base of the skull and extends to the pelvic region [7]. This flexible structure provides support to the body and also helps in three-dimensional movements. In healthy spine, natural curve occurs in the sagittal plane with a lordosis in the lower back and kyphosis in the upper back region. Spinal deformities are the group of disorders characterized by abnormal curvature of the spine. The spine disease in any pathology affects the spinal column and/or the spinal cord and spinal nerves [8].

Spine disease is very common, with many people undergoing spinal surgery every day. Degenerative spine disease is a general term for any pathology of the spine that occurs over a time due to both normal aging and wear and tear of the vertebral column. Spinal dysraphisms are due to abnormalities in the development of the spinal cord and/or vertebral column. Scoliosis is the most common spinal deformity and is described as an abnormal side-to-side
spinal curve [9]. Abnormal lateral curvature of the spine accompanied by axial rotation and sagittal curvature makes it a complex three dimensional deformity. A small degree of lateral curvature does not cause any medical problem, larger curves can cause postural imbalance and lead to muscle fatigue and pain. More severe scoliosis can interfere with breathing and lead to arthritis of the spine (spondylosis). Approximately 10% of all adolescents have some degree of scoliosis, though fewer than 1% have curves which require medical attention beyond monitoring. Scoliosis is found in both boys and girls, but a girl’s spinal curve is much more likely to progress than a boy’s [10].

Evaluation of scoliosis begins with case history and physical examination. Physical finding includes curved spine, abnormal shape of the ribcage and one shoulder may appear higher than the other [11] [12]. If the patient requires further examination, radiographic assessment is carried out. Two parameters are typically measured from radiographs namely the angle of curvature and the vertebral rotation [13]. Scoliosis result from morphological deformation of the vertebrae during developmental stage [14] [15]. Due to the complicated nature of developmental process of the vertebrae, various anomalies could occur [16]. In interpreting the imaging features of scoliosis, it is essential to identify the significance of the vertebrae, the curve type, degree of angulation, degree of vertebral rotation and longitudinal extent of the spinal deformity.

The treatment options depend on the severity and the age of a person. The decision to do nothing may be a reasonable decision depending on the age of the person and the predicted outcome [17]. Bracing has been proven to be an effective method to prevent curves from getting worse [18]. For those persons who already have a significant curve with a significant deformity, surgery can reduce the curve and significantly reduce the deformity. Surgery is reserved for teen and pre-teens who already have a curve around 40 degrees or more. Surgery arrests the progression of the deformity and wherever possible to straighten the curve without injury to the spinal cord [19].
Measurement of spinal curvature and vertebral rotation are important for measuring the progression of scoliosis [20]. Radiographs with posteroanterior (PA) view are used to measure the above mentioned parameters.

The evaluation of spinal curvature in the PA plane is primarily focused on the measurement of scoliosis [21]. Cobb angle has become the basis for quantifying the magnitude of scoliosis curve. Precise measurement of vertebral rotation is most valuable for better understanding of the mechanism of progression of the three dimensional deformity, which is quantified using Nash-Moe procedure [2]. Manual measurement of Cobb angle consists of selection of end vertebrae which tilt with more severity towards the concavity of the curve. Grading of vertebral rotation are based on identification of apical vertebra and its pedicle position. Sources of errors for manual measurement of Cobb angle are wrong definition of end vertebrae and incorrect drawing of lines along the endplates. Measurement of errors is even higher in vertebral rotation because of difficulties in identification of apical vertebra and pedicles inside it. A significant part of the study reported that manual identification of end vertebrae and other anatomical features required for estimation of spinal curvature and vertebral rotation causes variability and unreliability at higher rates [22] [23]. Evaluation of Cobb angle is affected by many factors such as radiographic markers of wide diameter, selection of end vertebrae and bias of different observer, inaccurate protractor and image acquisition [24]. Similarly, for vertebral rotation, apical vertebra and its pedicle marking are the required anatomical landmarks. In classification procedure, errors in identifying radiographic landmarks and using the resulting measurement in identifying the pattern of deformity provide numerous opportunity for both technical and judgmental errors [25]. Reliability problems with respect to scoliosis classification system have been identified, but the sources of unreliability are still unsolved problems. These include observer errors in interpreting or memorizing the criteria for assigning curve types.
Digital radiography facilitates software assisted evaluation of radiographs to replace traditional pencil and ruler measurement. Currently, the radiographs are the most cost effective imaging modality for diagnosis of scoliosis. Computerized analysis of scoliosis evaluation identifies the end vertebrae as those having the highest tilt relative to horizontal baseline through the apex of the curve. Computerized method performs this by the reference points located on standard radiograph from first thoracic to iliac crest. Reference information such as the location of vertebral bodies was introduced using sonic digitizer. The computerized method with image stitching involves the computerized stitching of radiographs of the thoracic and upper lumbar region with radiographs of the lumbar and lower thoracic spine. Graphical tools were provided for evaluation and display of the Cobb angle. Digital measurement with picture archiving and communication system (PACS) needs the precise definition of bony landmark for quantification of scoliosis [23]. PACS systems are integrated with computer software such as TraumaCad software. Finally, reliability of the computerized systems is influenced by experience of the individual using the computerized tool, magnitude of the curve and image quality.

Computerized system with image characteristics are introduced using active shape models (ASM). This method has been implemented in two stages. First stage is to train the set of radiographs to recognize the vertebrae shape and subsequently identify the superior and inferior end vertebrae. Training was achieved with ASM. Training creates two models, the object shape and object appearance model. After training by deformity shape models and comparing the image with appearance model, the active shape algorithm iteratively converges to the target object in the image. During training the boundary of the object is identified by manually digitizing $N$ landmarks around the perimeter of the vertebra. The measurement was not accurate for more severe curve due to limited number of samples used during training stage. Chockalingam worked with automatic measurement of Cobb angle [26]. In this method it
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automatically generates eight horizontal lines over the region of interest (ROI) by dividing the spine image into equally spaced regions. Users set two points on each line where it intersects with the vertebral edge. The accuracy of this method depends on how well the edges of the vertebrae are identified. Due to continuous screening in case of scoliosis, it is difficult to work with high dosage radiographs to get noise free radiographs. This reduction in radiation results with noisy radiograph. In case of a noisy radiograph it is very difficult to identify the vertebrae edges. Fuzzy Hough transform is applied to identify the vertebral edges in the noisy radiographs [27]. This method automatically measures the Cobb angle on the spinal PA radiographs after the preselection of top and bottom vertebrae. This method starts with the edge detection by Canny operator. Fuzzy Hough transform was used to find the line structure in the vertebral edge images. Here no training set is required, but preselection of top and bottom vertebrae itself causes 50% inter- and intra-observer error [28].

The manual measurement used in classification procedure includes Cobb angle, curve end point and range of lateral bending and vertebral tilt. In computerized classification procedure, the observer needs to be trained, to mark the vertebral body and sacral landmark.

Computerized systems were developed to analyze digitized radiographs, to improve the reliability of measurement for diagnosing scoliotic radiographs. Digital radiograph analysis offers many advantages, such as fast and efficient image storage, easy access for comparison and follow up and application of digital image processing techniques capable of improving the quality of radiographs. It also supports a systematic way to reduce the impact of errors related to human subjectivity. A significant part of study which evaluated the reliability of the digital methods in calculation of spinal curvature, vertebral rotation and classification failed to consider some aspects that are relevant in clinical practice without preselected anatomical features like end vertebrae,
central sacral line (CSL), etc. [29]. This thesis aimed to provide insight into the pointed aspects by the computerized method using advanced image processing algorithms.

Computerized image understating method tried to address the different aspects related to anatomical features and analysis. Extraction of the anatomical features is supported by the computerized image analysis. Computerized image understanding results in an automated diagnosis, which is the primary objective of this research.

1.2 Thesis Outline

The required parameters for objective evaluation of scoliosis are spinal curvature, vertebral rotation and classification. Estimation of spinal curvature and vertebral rotation are based on vertebral body deformity. Classification is based on whole vertebral column deformity. Automatic extraction of these required vertebral body and whole vertebral column are proposed in this thesis using different image processing algorithms as shown in Figure 1.1.

In the preprocessing stage, the radiographs are given to nonlinear filters for highlighting the required anatomical features using anisotropic diffusion filtering as shown in Figure 1.1(a). After removal of noise it is fed to the segmentation algorithm to extract all vertebral boundaries, which falls in the diagnostic region of the radiograph. Model based segmentation procedure failed because of variation in vertebral body from person to person as well as normal to scoliotic spine. These variations in vertebral bodies are handled using gradient vector field active contour model (ACM), as shown in Figure 1.1(d). Identification of vertebral bodies (superior, inferior and apical vertebrae) with respect to spinal curvature estimation is based on its horizontal boundary. To erode the other boundary region, morphological operations are used with structuring element along the horizontal direction, as shown in Fig-
Figure 1.1: Block diagram of thesis contributions
The slopes of these horizontal endplates are obtained using Hough transform. The computerized method will automatically decide superior and inferior end vertebra using this slope information. Based on the slope of the identified superior and inferior end vertebra computerized system will estimate the spinal curvature as per Cobb definition as shown in Figure 1.1(h).

The computerized method identifies apical vertebra based on the slope information and it is given to extract the pedicle boundary. The pedicle boundaries are extracted using Geometric ACM, with initialization inside the expected boundary. Extraction of pedicles from the preselected apical vertebra is shown in Figure 1.1(k). Computerized method will divide the whole apical vertebral boundary into six equal regions; it will show the displacement of the pedicles within the different regions. The position of the pedicles within the divided region is found using computerized method and that will grade the apical vertebral deformity, in terms of Nash-Moe procedure [2].

The computerized scoliosis classification requires CSL and medial axis (MA) [30]. These two anatomical features are embedded within the spinal boundary. Separation of complete spinal boundary from the given radiograph with rib cabs and pelvic region needs exact specification of ROI. This ROI depends on twisting of the spinal column in left as well as in right region. This is extracted using gray level profiles and this have some noise, which is eliminated using fast fourier transform (FFT) [31] interpolation as shown in Figure 1.1(c). The CSL and MA are bounded within this extracted vertebral column and it is described in terms of boundary of the extracted vertebral column. Only the boundary of the spinal column is retained using boundary descriptors as shown in Figure 1.1(e). The computerized method will extract the CSL and MA without any human intervention as shown in Figure 1.1(g). These two anatomical parameters are supplied to rule based algorithm, which follows King’s definition for scoliosis classification.
1.3 Organization of the Thesis

Chapter-2 is a background covering spine anatomy, spinal disorder, modalities used for diagnosis, materials and methods, literature review and statistical methods for verification of results.

Chapter-3 is a problem definition covering significance of the proposed research, objectives and scope and verification and validation of the research.

Chapter-4 is the first contributed chapter covering first objective of the thesis. This chapter proposes an automatic method to estimate the spinal curvature using image processing techniques.

Chapter-5 is the second contributed chapter covering second objective of the thesis. This chapter proposes a method to estimate the vertebral rotation. Initially apical vertebra is extracted using image processing and pedicle position within that is found using computerized method.

Chapter-6 is the third contributed chapter covering third objective of the thesis. This chapter proposes a completely automatic scoliosis classification system as per King’s definition. Initially image processing methods are applied to extract CSL and MA line. The final classification is based on CSL and MA as input to the computerized method.

Chapter-7 is the last chapter of the thesis covering conclusion and future works. All the contributions of this research along with a general conclusion are given in this chapter. As the future work we have suggested usage of the proposed work for other types of spinal disease like lordosis and kyphosis along with 3D spine reconstruction for any type of spinal disorder.