

University of Groningen

Imaging the human spine using ultrasound

Purnama, I Ketut Eddy

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2007

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Purnama, I. K. E. (2007). *Imaging the human spine using ultrasound: a preliminary study to follow scoliosis progression*. [s.n.].

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Scoliosis is a three-dimensional deformation of the spine which is recognized in the frontal view by the presence of a lateral curvature. This curvature is characterized by an axial rotation of the vertebrae. The axial rotation in the thoracic region will move and deform the attached ribs resulting in an asymmetrical rib cage. In some cases, the lungs are deformed causing a decrease of lung capacity and in turn results in difficulties in breathing. The spinal deformation can also cause a change in voice and in back pain.

Early detection and treatment of scoliosis is needed to prevent progression of the scoliotic curve. The most common imaging method to examine the existing curvature is X-ray imaging. However, it has two major drawbacks: the radiation exposure and the 2D character of the obtained images. The radiation issue restricts the number of images which may be taken annually. On the other hand, scoliosis progression should be examined often, because a sudden increase of the curvature could occur. The 2D issue comes from the fact that X-ray image provides only 2D data. Since scoliosis is a 3D phenomenon it should also be examined in 3D. Deriving the 3D rotation such as the axial rotation from the X-ray image only gives the estimated rotation or apparent rotation.

In this thesis, the use of ultrasound is proposed as an alternative way to image the human spine, and a preliminary study to follow scoliosis progression is performed. In clinical practice, B-mode ultrasound imaging has never been reported to have a detrimental effect. The 3D orientation of the vertebrae and the 3D curvature of the spine are derived from the 3D ultrasound image (ultrasound volume). The 3D vertebral orientation is determined by the axial rotation and vertebral tilt. For practical reasons the feasibility study was applied on a volunteer instead of a patient with a scoliotic spine.

This thesis is started with the basic understanding about the ultrasound imaging of the human spine (**Chapter 2**). Basic ultrasonic imaging consists of the description about the image resolution, how to improve the ultrasound image quality, and reflection issues. In addition, the parts of the vertebra that can be captured by ultrasound in a transverse (axial) scan in the posterior scanning approach are mentioned. Two types of 3D ultrasound systems, 3D probe and freehand, are described. This chapter also contains the explanation of the imaging protocol, the coordinate system, the imaging planes, and the scanning approach used throughout this thesis. Finally, this chapter describes the sources of error in an image acquisition using ultrasound, particularly using a free-hand 3D ultrasound system.

The following chapters are divided into **three parts**. **The first part** which consists of **Chapter 3** describes a sequence of image acquisition and volume reconstruction procedures to acquire a 3D ultrasound image (ultrasound volume) of the spine of a volunteer. *In the image acquisition procedure, a freehand 3D ultrasound system was used*¹. This system can capture long or large structures and even the whole body. It is only limited by the volume which can be detected

¹Italics indicate new procedures to the context of this thesis

by the tracking system. In the experiment, the freehand 3D ultrasound system of the Institute of High Frequency Engineering, Ruhr-University Bochum, Germany was used. It was composed of a 2D ultrasound machine, an optical tracking system with active markers to determine the position of the ultrasound probe, and a computer system. Due to computer memory limitations, six scans of six overlapping segments were performed; each segment was scanned in a single ultrasound sweep. The stream of ultrasound frames consisting of the screen captures of the 2D ultrasound machine was stored in a file along with the 3D position and 3D orientation of the frames. In the volume reconstruction procedure, the non-textual parts of the frames were placed in a volume. *To handle multiple segments, two additional sub-procedures, volume segment alignment and volume segment compounding, were developed.* These sub-procedures were performed after the two well known sub-procedures from literature: the bin-filling and hole-filling. In the hole filling sub-procedure, *the use of olympic operation was proposed* and compared with the common operation, median and average; in the bin-filling and volume segment compounding sub-procedure, the average operation was used. The results confirm that the freehand 3D ultrasound system is an appropriate system to scan the human spine. In the volume reconstruction procedure, the proposed two sub-procedures are necessary since the displacement values of volume segments are higher than the positional accuracy of the freehand 3D ultrasound system that was used in the image acquisition procedure. The quantitative evaluation shows that, statistically, the olympic operation is better than the mean and median operations although they are not much different in terms of grey level values.

After obtaining the ultrasound volume of the human spine, the **second part** of this thesis which consists of **Chapter 4** describes the experiment to determine the feasibility to derive manually the 3D orientation of the vertebrae and the 3D curvature of the spine; the 3D orientation is determined by the axial rotation and vertebral tilt.

First of all, features or anatomical parts that appeared prominently in the ultrasound volume were recognized and selected. They were the transverse processes in most of the thoracic vertebrae, the superior articular processes in most lumbar vertebrae, and the laminae in the thoracolumbar region. The next step was to place landmark points in the centers of mass of the two equal vertebral features. The appearance of the vertebral features in the ultrasound volume was not clear. This volume resulted from the use of the average and olympic operations in the volume reconstruction procedure (Chapter 3). In order to improve the appearance, *in Chapter 4, the maximum operation in the volume reconstruction procedure was introduced.* The idea of using the maximum operation is based on the theory that the maximum ultrasound echo comes from a specular reflection from a surface when it is perpendicular to the ultrasound beam. The results prove that the maximum operation, which was used in the bin-filling, hole-filling, and volume segment compounding sub-procedure, gives an improved appearance of the vertebral features. Visually, the landmark points were more confidently created in the volume resulting from the maximum operation. *New methods to calculate*

the axial rotation and vertebral tilt using the two landmark points are introduced. The axial rotation is the angle between the line that connects the two landmark points and the left-right axis after projection of those lines to the axial plane; the vertebral tilt is the angle between the same lines, but after projection to the coronal plane. A way of deriving the 3D curvature of the spinal column is also introduced. The curvature is derived by connecting the midpoints of the two landmark points of all vertebrae. Validation was performed by comparing the results of the measurements in the ultrasound volume with the corresponding results in the MRI volume of the same volunteer. Since the volunteer was in a different position while performing the ultrasound and MRI scanning procedure, the validation was restricted to compare per vertebra the axial distance, the distance between the two landmark points. The measurements of the axial rotation and vertebral tilt of the region of thoracic vertebra T4 - T9 gives an intraobserver/interobserver error range of 0 - 2.1° / 0 - 1.9° and 0.7 - 3.2° / 0.1 - 2.3°, respectively. Validation error of the axial distance measurements in this region of the ultrasound volume gives an intraobserver/interobserver error range of 0 - 2.7 mm / 0.2 - 1.3 mm. It appears that determining the axial rotation and vertebral tilt is feasible in the region of the thoracic vertebrae T4 - T9. The determination is also feasible in the region of lumbar vertebra L2 - L4, but in a more complex manner.

The **third part** covers the next three chapters. It describes a sequence of procedures to derive the 3D vertebral orientation and 3D spinal curvature *semi-automatically*. Synchronizing with the manual approach, this information was calculated from two points on two equal vertebral features appearing in the ultrasound volume. The points are the centers of mass of the features. The use of points of the vertebral features instead of their areas is motivated by the fact that the exact boundaries of the vertebral features are difficult to obtain. To determine the centers of mass, the areas should first be extracted. Extracting these areas is not trivial due to the appearance of non-vertebral features that have the same properties as the vertebral features. Non-vertebral features are for instance ribs and pleura that have a high intensity or even higher than the vertebral features; layered muscles especially in the lumbar region also have a comparable intensity. *A new strategy to extract the vertebral features is introduced. The extraction is done by first to exclude as many non-vertebral features as possible, then to select the vertebral features using landmark points.* The next two chapters describe the procedure to exclude the non-vertebral features. **Chapter 5** describes spinal image enhancement procedure. To enhance the spinal image in the ultrasound volume, the use of length attribute filter is introduced. This filter utilized the length of structures in longitudinal direction as a criterion to remove non-vertebral features. The filter employed max-tree data structure to store the ultrasound volume. In the filtering process, all nodes of the tree were evaluated, and only the nodes with the corresponding areas within a certain range of the longitudinal length remained. To find the optimal values of the range, the landmark points were used. Quantitative evaluation delivers 6 - 11 mm as the optimal longitudinal range. The upper bound of the range removes the non-vertebral features which are extended in lon-

itudinal direction such as skin and muscles. This range also removes the ribs and pleura which have a length slightly larger than the vertebral features. The lower bound removes the small features. The filtering procedure gives a significant decrease in the number of areas. Most of the areas are the areas of the spurious objects. So another method is necessary to localize the areas of the vertebral features by suppressing the number of areas of the spurious objects. These areas remained because the longitudinal length of these areas was within the filtering range. **Chapter 6** describes a procedure to localize the vertebral features. Three methods based on a technique using threshold were selected: Bernsen, Niblack, and Robust Automatic Threshold Selection (RATS). Visually and quantitatively, the RATS gives the best result. In the quantitative measurement which utilized the landmark points, this method delivers less number of areas and maximum number of remaining landmark points. It means that this method preserved all of the expected areas of the vertebral features and removes most areas of the spurious objects.

Chapter 7 describes the procedure to determine semi-automatically the 3D orientation of the vertebrae and the 3D curvature of the spine. For each vertebra, areas of the two equal vertebral features were selected by the landmark points from the ultrasound volume resulted from the vertebral features localization procedure (Chapter 6). Then, using the same methods as described in Chapter 4, the centers of mass of these features were used to derive the axial rotation and vertebral tilt of the vertebra, and the 3D curvature of the spine. In the quantitative evaluation, the results of the axial rotation and vertebral tilt measurements using the centers of mass were verified with the corresponding results derived using the landmark points. The errors are in the range of $0.4 - 3.3^\circ$ and $0.1 - 2.9^\circ$, respectively, which are acceptable. The accuracy is defined by how close the centers of mass approached the corresponding landmark points which were manually created on the centers of mass of the vertebral features. The accuracies in the region of thoracic vertebra T4 - T9 were in the range of 0.8 - 2.2 mm.

In conclusion, in this thesis a new idea to image the human spine using a freehand 3D ultrasound system is presented. The necessary framework and its related issues are presented and studied, leading to the conclusion that the idea is feasible. Potential improvements are identified. The result provides a basis towards the aim to follow scoliosis progression using ultrasound.