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Ultrasound imaging for human spine: imaging and analysis

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Abstract The results of ultrasound imaging of the human spine of a volunteer and the derivation of vertebral axial rotation (AR) and vertebral tilt (VT) are presented. The ARs and VTs were derived semi-automatically. In an ultrasound volume, the vertebral parts were enhanced using a length attribute filter, and localized using Robust Automatic Threshold Selection (RATS). Afterwards, a pair of two prominent regions of each vertebra was selected by ultrasound landmark points. Then, the centers of mass of these regions were used to calculate the ARs and VTs. The ARs and VTs were also determined manually based on the set of landmark points. The difference between the two methods determined the accuracy of the semi-automatic method. The overall results can be categorized into a confident, moderate, and less confident region, respectively, T3–T9, L3–L4, and other vertebrae. For the manual landmark determination, the confident region gave an error range of the ARs determination of $0^\circ\text{--}2.1^\circ/0.4^\circ\text{--}1.2^\circ$ (intraobserver/interobserver), and in the VTs determination it had the range of $0.3^\circ\text{--}3.2^\circ/0.2^\circ\text{--}1.9^\circ$ (intraobserver/interobserver). The difference between the results of semi-automatic method and the manual results was in the range -1.6° to 1.3° . The results confirm that ultrasound imaging is feasible to scan the human spine, and a semi-automatic method to derive ARs and VTs is also feasible.

Keywords Vertebral axial rotation · Vertebral tilt · Length attribute filter · Robust automatic threshold selection

1. Introduction

A drawback of using X-ray imaging to follow scoliosis progression is the radiation exposure. Therefore the number of annual images is limited. On the other hand, scoliosis progression should be examined frequently, because significant changes can happen within 1 month. Another drawback of radiograph imaging is that it gives 2D images while scoliosis is a 3D phenomenon. The assessment of the 3D information such as axial rotation and vertebral tilt is important to monitor scoliosis progression in

lateral and frontal direction and to decide the right treatment. As a result, the use of a freehand 3D ultrasound system was proposed [1].

The work described in this paper aimed to investigate the possibilities of ultrasound to image the human spine, to derive the axial rotation (AR) and vertebral tilt (VT) of each vertebra, and to introduce a semi-automatic method for this purpose.

2. Methods**2.1 Image acquisition and volume reconstruction**

A volunteer was positioned on a bed in prone position. Image acquisition was performed with the freehand 3D ultrasound system (FH3DUS) of the Institute of High Frequency Engineering, Ruhr-University Bochum, Germany. It was composed of a 2D ultrasound machine (Siemens Sonoline Omnia), an optical tracking system (Polaris from NDI) with active markers and a computer system. The positional accuracy of the 3D ultrasound system was reported to be 0.66 mm [2]. A 5 MHz curved array probe with an imaging depth of 90 mm was used. The ultrasound data was acquired via the SVHS-interface of the 2D ultrasound machine and a frame grabber card (IDS Falcon) with 25 frames per second (PAL-standard). The resulted frames were used to create an ultrasound volume in a volume reconstruction procedure. MRI images of the volunteer's spine in supine position were taken with a 1.5 T MR scanner (Siemens Avanto).

2.2 Recognizing the vertebral parts and calculating the vertebral axial rotation and vertebral tilt

The ultrasound volume was studied by two observers creating a pair of landmark points on the two prominent parts of each vertebra (US-LP). Each observer performed the measurements three times to obtain three sets of landmark points. The AR and VT of each vertebra were determined based on the pair of landmark points. In MRI images, three sets of landmark points (MRI-LP) were also created on the corresponding parts, and the ARs and VTs were calculated.

2.3 Calculating the vertebral axial rotation and vertebral tilt semi-automatically

A procedure to semi-automatically determine the ARs and VTs was developed. This procedure consisted of the following steps. The first step was the vertebral features enhancement. This step aimed to exclude elongated parts. It used a length attribute filter, a type of attribute filter in mathematical morphology [3, 4]. In its implementation, this filter employs a data structure called max-tree. Parts of the volume (3D regions) were grouped based on their spatial location and their intensity. Each node of the max-tree stored a 3D region and the attribute of this region. The length in longitudinal direction of each region was used as an attribute. In the filtering process, all nodes of the max-tree were inspected. The attribute of each node was compared with a length threshold range. The nodes which have longitudinal length outside the range will be removed. Several range values were evaluated to determine an optimum value.

The next step was the vertebral localization step. This step used the Robust Automatic Threshold Selection (RATS) [5–7] method to extract high intensity regions of the filtered volume, which were expected to contain the vertebral features. This method is a simple and fast method to extract objects from the background of noisy grey-level (intensity) images. Instead of using a global threshold value, this method determines a local threshold value to extract local object. The result of the application of RATS was a number of high intensity regions including the vertebral regions.

A pair of two prominent regions of each vertebra was selected by the US-LP. The centers of mass of the selected regions were used to calculate the AR and VT of each vertebra. The difference with the ARs and VTs derived from the US-LP determined the accuracy of the semi-automatic method.

2.4 Displaying the curvature

A curve that connected the middle point of the centers of mass of the left and right region of each vertebra represented the 3D curvature of the spine. The projection of this curve to a coronal plane (anterior-posterior view) gave the information about the lateral deviation, and the projection to a sagittal plane (lateral view) gave the information of the degree of the kyphosis and lordosis of the volunteer's spine.

3. Results

An ultrasound volume which contained the images of all thoracic and lumbar vertebrae was obtained from the image acquisition and volume reconstruction procedures. The transverse processes in the thoracic region and superior articular processes in the lumbar region appeared. The laminae in several vertebrae and the head of the ribs in the thoracic regions also appeared. Figure 1

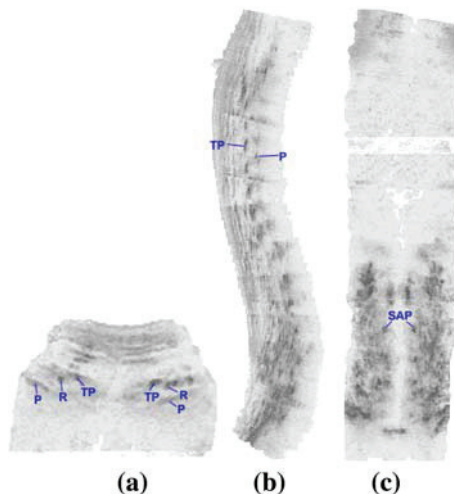


Fig. 1 The axial **a**, sagittal **b**, and coronal **c** cross section images of the ultrasound volume resulted from the image acquisition and volume reconstruction procedures. The transverse process (*TP*) and superior articular processes (*SAP*) of the vertebra, rib (*R*), and pleura (*P*) are visible

shows the axial, sagittal, and coronal cross section images taken from the resulted volume.

In the ultrasound volume, the landmark points were created on the transverse processes (T1–T10), laminae (T11–T12), and superior articular processes (L1–L5). The region of thoracic vertebra T3 until T9 gave an intraobserver (AE) and interobserver (EE) error range of the ARs determination of 0°–2.1° (AE) and 0.4°–1.2° (EE). In the VTs determination the range was 0.3°–3.2° (AE) and 0.2°–1.9° (EE). The difference between the results of semi-automatic method and the manual results was in the range –1.6° to 1.3°. The region of the lumbar vertebra L3 and L4 presented bigger errors, and the other thoracic and lumbar vertebrae showed the biggest errors. In the MRI images, the results derived from T3 until T9 were: 0°–7.8° (AE of ARs), 0.4°–4.6° (EE of ARs), 0°–4.1° (AE of VTs), and 0.2°–2.8° (EE of VTs).

The results of the application of different length threshold values to the original image (Fig. 2a) are shown in Fig. 2b until Fig. 2d. In Fig. 2b, the skin and muscle which cover the inner structures were removed. In Fig. 2c, the muscles (high intensity clouds in the lower part in Fig. 2b) were also removed. The pleura (the chain of high intensity regions in the upper part in Fig. 2b, c) were excluded as shown in Fig. 2d.

Figure 2e shows the result of the application of RATS to the volume of Fig. 2d. The number of 3D regions was reduced significantly while most of the regions of the vertebral features remain.

The regions selected by the ultrasound landmark points are shown in Fig. 2f. A curve which connects the middle point of the centers of mass of the two regions of each vertebra represents the 3D curvature of the spine. Its projection to a coronal plane and sagittal plane are shown in Fig. 2g, h, respectively.

4. Conclusion

The results confirm that ultrasound imaging is feasible to scan the human spine. Based on the resulted errors, the region of thoracic vertebra T3 until T9, L3 and L4, and the other thoracic and lumbar vertebrae can be categorized, respectively, as a confident, moderate, and less confident region regarding the recognition of the vertebral features. The differences are mainly caused by the presence or absence of muscles and other soft tissues. The confident region showed the smallest intraobserver and interobserver error in determining the axial rotation and vertebral tilt. MRI images that were aimed to be used for validation had comparable

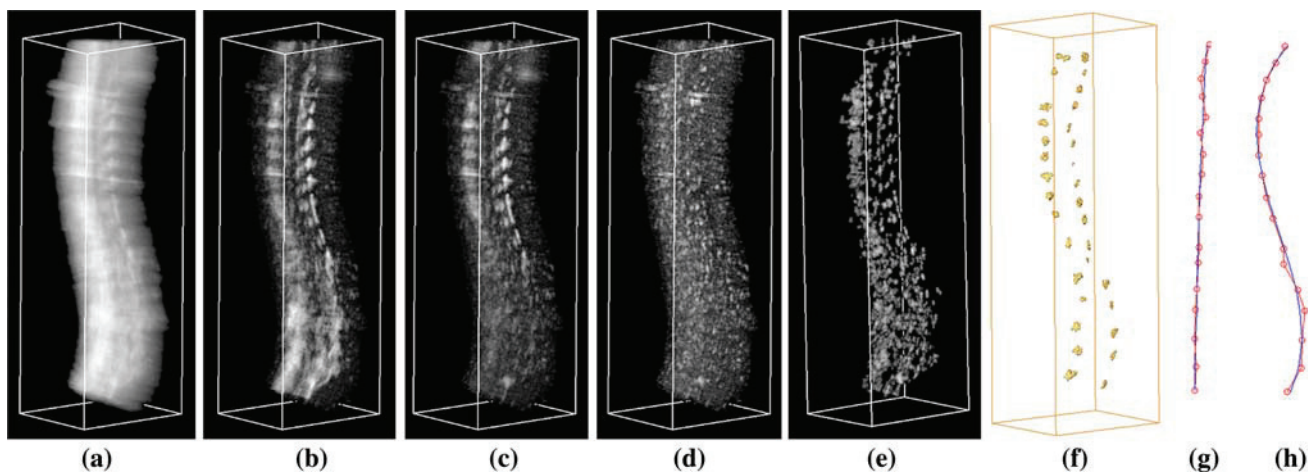


Fig. 2 The non-vertebral parts of the original images (a) are removed using a length attribute filter: the elongated parts such as skin and muscle (b), the muscles in the lower part (c), and pleura

(d). The result of the vertebral feature localization using Robust Automatic Threshold Selection is shown (e)

intraobserver and interobserver error. Hence, the validation can not be performed. A semi-automatic method appears to be feasible in deriving the axial rotation and vertebral tilt of each vertebra.

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Analysis of texture features for registration of DRR and EPI images

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Abstract The aim of our research is to analyse the importance of texture information for registration of a DRR (Digital Reconstructed Radiograph) and EPI (Electronic Portal Image) medical images. In our research, texture features are extracted by Laws texture coefficients and used for computing registration criterion functions. The proposed feature based approach is compared to the commonly used approach, where a registration criterion function is computed directly from intensity features, i.e. grey values. For this purpose we observed accuracy of registration, the distinctiveness of local extrema and the distinctiveness of a global extremum of the criterion functions. These parameters are essential to achieve a correct image alignment. Our results show that for the given image modalities we can expect more robust and more correct registration when texture based criterion function instead of intensity based one is used.

Keywords Image registration · Texture analysis · Criterion function

1. Introduction

The aim of our research is to analyse the importance of texture information for registration of a DRR (Digital Reconstructed Radiograph) and EPI (Electronic Portal Image) medical images. These two image modalities are present in radiotherapy treatment. By correctly matching the two modalities, it would be possible to verify the positioning of the patient during radiation therapy and automatically adjust the positioning if necessary.

There are mainly two approaches to solve the problem of registering multi-modal images: (1) by extracting simple features from images (such as salient points or contours) and register these features (i.e. feature matching); or (2) by using the original gray value information from images (i.e. intensity matching), and match the images by optimizing some intensity-based similarity measure [1, 2]. Feature based registration algorithms involve geometrical information from both images, which is extracted during the pre-segmentation. Precise segmentation of anatomical geometrical features is a tedious and subjective task and, furthermore, difficult to automate. On the other hand, intensity based registration can easily be automated. However, intensity values for DRR/EPI image modalities due to 2D representation of 3D data, do not comply with some global intensity relationship, expected by intensity-based registration approaches. Consequently, intensity based registration is not reliable.

In the paper we propose an alternative registration approach, based on texture features. This approach couples advantages of intensity-based registration with advantages of feature-based registration. It does not require explicit pre-segmentation and relies on structural information obtained from original images.

In order to test the proposed registration approach, a comparison of the criterion functions for both intensity and texture features is discussed. The experiments have been carried out on five sets of 2D DRR and EPI images of pelvis (Figs. 1, 2).

2. Materials and methods

Texture feature based registration requires, first, extraction of texture features from both of the images. In our approach we extracted Laws texture coefficients. Laws [3] developed a set of 2D

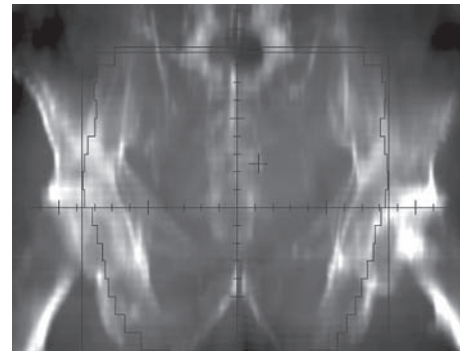


Fig. 1 DRR image of pelvis. The reference image of resolution: 490×375 pixels

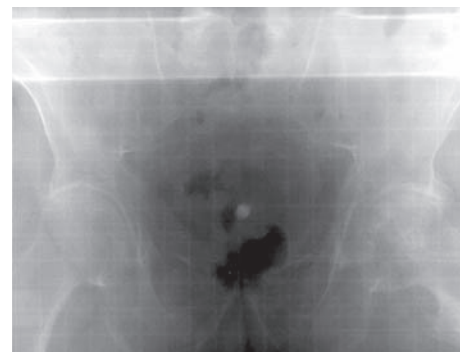


Fig. 2 EPI image of pelvis. The floating image of resolution: 490×375 pixels