Automatic Determining of Vertebrae from CT Images

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Abstract. Position of the spinal column and vertebrae on the CT images is one of the main features to determine position of a patient and his organs. In this paper we propose the algorithm to extract the spinal column and vertebrae with ribs from CT images and to estimate their coordinates as well as coordinates of human body in the coordinate system of a CT scanner.

1 Introduction

In recent decades remarkable improvements in diagnostic managements of oncology patients have been achieved. We became witnesses of a technological breakthrough in the field of diagnostic imaging, including the computerized tomography (CT), magnetic resonance imaging (MRI), angiography etc.

Over the past decade, the increasing technological sophistication of CT equipment has permitted excellent images with a limited dose of radiation which is currently equal to a plain chest X-ray (0,001 Gy). Modern CT scanners were equipped with special programs in order to save the information in DICOM files, to analyze images and to provide interactive measurements. The programs disclose internal object structures and compute a great number of organ parameters. They make easier interactive measurements of organ size and volume and identification of the character of the pathological mass.

At present there are a few special systems and complexes for the automatic diagnosis in medicine using imaging techniques. These systems, in general, belong to the diagnostic management of brain pathology. Image technologies also play the key role in the diagnosis of Pediatric malignancies. CT imaging more than any other imaging modality provides documentation of the tumor areas, and topography characteristics. It gives together with additional intravenous infusion of contrast (CT-angiography) extra data about the blood vessels of the tumor and surrounding tissue.

Now medical experts use vertebrae and ribs to figure out disposition of regions and organs of human body. The tasks of extraction of spine column, distinguishing and counting of vertebrae on CT images are usually carried out by medical specialists manually. This routing work takes significant time and efforts. Algorithms, which solve or even partly solve mentioned problems, seriously facilitate the work with CT datasets having from several dozen to hundreds images. A dataset of CT images of a patient is stored as 2D grayscale scans of body axial section written in the DICOM format.

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Medical experts very often need localization of parts of human body and human organs shown in 2D scans. For this purpose numbering of vertebrae is traditionally used.

We offer an approach to extract the spine column from CT images and distinguish vertebrae. It enables automatic segmentation of spine column region and automatic or semiautomatic separation of vertebrae. We offer our solution in the traditional decision making form as a prompt for the medical expert who can easily correct the result of automatic separation of vertebrae.

2 Formulation of Problem

Usually a dataset of CT images of one patient consists of 20÷100 scans. Distance between scans can vary from 0.1 to 1 centimeter. All images are stored as files in the DICOM format. Each DICOM file contains 3D coordinates of the top left corner of the 2D scan image relative to the coordinate system of the CT scanner.

One of difficulties for experts to work with the CT dataset consists in absence of interconnection of successive numbers of files and their real 3D coordinates. A CT scan can have arbitrary Z-coordinate relative to the human body Therefore, 2D scans should be ordered in regard to their space disposition before one begins to segment human organs.

DICOM pictures are represented as 16-bit grayscale images. Brightness of DICOM images of 2D CT scans corresponds to the Hounsfield units that characterize organ densities. Unfortunately, it is not referred to topograms. An appropriate transformation of DICOM images, especially topograms, into the standard 8-bit gray scale ones can help to get maximum accuracy of further steps. All images are provided with their 3D coordinates according to the coordinate system of the CT scanner.

Our task is to estimate position of vertebrae and vertebra in a 2D scan. The main steps of the offered decision rely on finding characteristic vertebra for comparing different investigation of one patient.

3 Vertebra Segmentation

Vertebra segmentation from CT pictures is an urgent task for many medical applications. It is widely used to control dynamic of conditions of the spine, to recognize its deceases and to treat them. Besides, this procedure is an intermediate step for segmentation of abdominal organs, such as the liver, kidneys, and spleen, from CT scan imagery [1]. Among semiautomatic and automatic approaches to the problem are model-based, discrete optimization, neural network, active contours, morphologic methods or their combinations [2-4] with or without of use a prior information etc. One of the difficulties of vertebra segmentation, often mentioned by authors of algorithms, consists in discrimination between the spine and ribs.

We propose a new automatic algorithm, which allows both: reliable automatic detection of the vertebrae on 2D CT images in DICOM format, and separation of ribs touching the spine. Also, detection of vertebrae on 256-color gray scale CT images is possible, as well. The algorithm does not need learning. It contains five main steps: image preprocessing, finding body section, reliable detection of round part of the vertebra, accurate segmentation of the bone, which image can break up into several parts and be touched by ribs, and discrimination between the spine and ribs.

Image preprocessing is performed by version of the region growing algorithm leaving only the largest connected component of the CT image, which always is the body section, and removing all other artifacts and noisy clusters. After, the region of interest (ROI) is found as the bounding box of the body section.

Simple prior information on round shape of a vertebra frontal is used to detect its location in the image. The shape of matching window is drawn in Fig.1b. Despite of the simple form of prior information practically all vertebrae were detected by the chosen window.

Then, top boundary of the vertebrae is determined (Fig.1c). Further outlining of the vertebra boundary is started from the lowest pixel of the bone (Fig.1d), since 2D slice CT image of this one piece bone can contain different number of separate pieces.

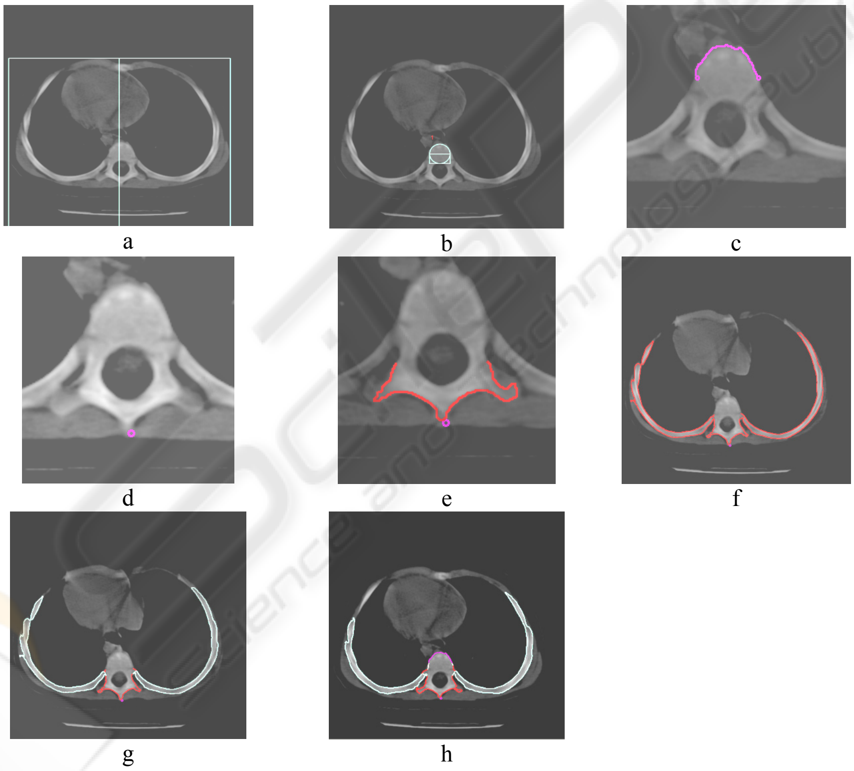

Fig.1. Steps of performance of the algorithm.

The lower boundary of the vertebrae is found after binaryzation of the CT image at values 1000 -1200 of Hounsfield units corresponding bones of human body. It allows outlining bottom part of the vertebra, possibly, with touching ribs. Outlined part of the vertebra without touching rigs is depicted in Fig.1e, and with them – in Fig.1f.

The algorithm analyzes bottom part of the outlined boundary and recognizes whether it contains rib frontiers.

In case of recognized touching ribs the algorithm estimates their contact points with the vertebrae and removes rib frontiers from the bottom boundary. Removed rib frontiers are shown in Fig. 1g by aquamarine color. The final segmented image with removes ribs colored in aquamarine can be seen in Fig.1h.

This algorithm was tested by CT-images of children and included in software for monitoring of mediastinal and retroperitoneal tumors. It is allow to detect description of organs position by vertebrae geometrical coordinates. This information is very usefulness for extraction 3D patterns of organs by module-based segmentation algorithms.

4 Definition of Vertebra Orientation

One of the basic feature of analysis CT Images is a topology of organs in body. For quality topology analysis It is necessary to define body orientation. For solving this task the algorithm of orientation definition was developed.

Orientation is determined on bone elements and the vertebra by using threshold segmentation. For the CT image histogram of brightness is divided into three gauss-like shape classes. On their position we can determine the location of the bodies (fig.2).

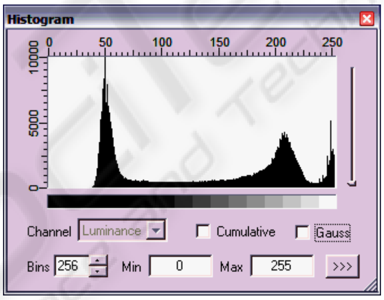

Fig. 2. Histogram of brightness for the CT images.

Position of the last local minimum is determined by the watershed thresholding method with smoothing of the histogram. Bone fragments carved this thresholding. However, there is a geometric noise on binary image. These noises correspond to the soft tissue and acquisition errors. Removal of such errors is performed through several steps. The first step is to remove small noise, which is performed by analyzing the size of objects and thin clamped to the edge of objects. This removal is realized by analyzing the image boundaries (Fig.3).

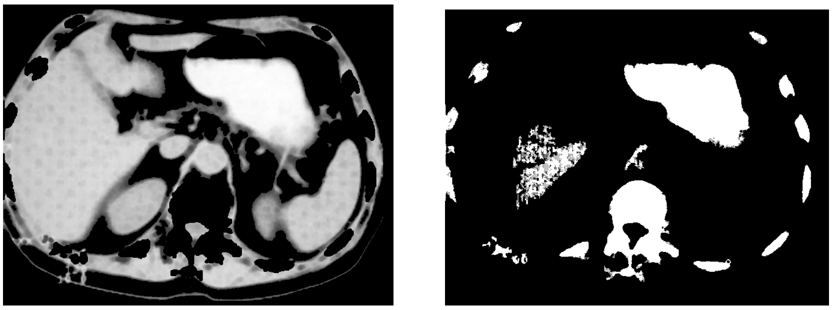

Fig. 3. Source CT image and Image with remote small object.

Spatial position of bone on the slice is used for definition of bone regions. Practically all bone elements are placed along the edges. So the overall operation with convex contour on all elements of the image is used for them to determine. Objects are saved, if they cross the convex contour.

To determine the remaining elements of the bone dilatation increases convex contour. Analysis of the factor of shape for all elements of the bone tissue determines the element that corresponding to the vertebra. Then the morphological open operation is performed with a high depth, which allows to get a round object. Center of gravity is calculated as a binding element.

Another element of the anchor is the center of gravity for the convex object.

Based on these coordinates calculated line corresponding to the slice orientation (Fig.4)

Fig. 4. Images from the orientation axis, the arrows indicate the centers of mass of a convex region and the vertebra.

Further detection of organs regions is carried out based on the watershed. On the basis of the subtraction of very smoothed watershed lines from the original image and regions binarization separate organs are defined.

Such analysis allow to define topology properties organs and body that can be used for monitoring and diagnostic task.

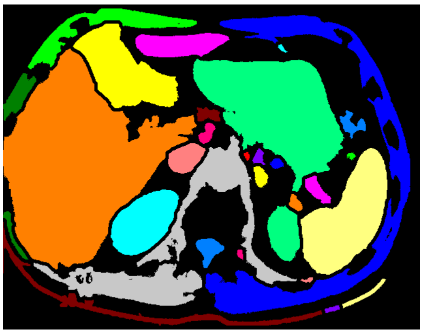

Fig. 5. Regions corresponding to different organs.

5 Conclusions

The presented algorithms allows automatic and semiautomatic extraction of the spine column and thoracic vertebrae from datasets of CT images stored in the medical DICOM format. It enables of reliable extraction and separation of thoracic vertebrae in order to number them relative to the bottom human vertebra with ribs.
In turn, it gives possibility for the medical expert to know the number of the vertebra he sees in the current 2D scan image.
A new unsupervised algorithm to segment vertebrae in 2D CT images has been presented. It allows reliable finding this bone and its automatic extraction. The algorithm does not use prior information on the spine shape. The results of tests showed possibility of automatic extraction of vertebra from CT images. In order to be applicable to practical extraction the algorithm needs following feasible improvements in order to: process correctly images, which do not contain the vertebra; process in special way CT images of patients that took contrast agents; test shapes of outlines contours.
The drawback of the algorithm is its real applicability to separate and number only thoracic but not lumbar and sacral vertebrae.

Acknowledgements

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