# Automatic Segmentation of Neck CT Images

Chia-Chi Teng[1], Linda G. Shapiro[1,2], Ira Kalet[2,3]
[1]*Department of Electrical Engineering,* [2]*Department of Computer Science & Engineering*
[3]*Department of Radiation Oncology, University of Washington*
*ccteng@u.washington.edu*

## Abstract

*In this era of cross-sectional imaging, it is useful to think of the neck in terms of adjacent anatomical spaces separated by fascial layers extended from the skull base to the thoracic inlet. Although these layers are not usually visible in CT or MR images, their locations can be inferred by knowing their relationships to various anatomical structures that are visible in cross-sectional images. Identifying these anatomical structures in the neck region can facilitate applications such as automated diagnosis by finding abnormality, or computer assisted radiation therapy planning by inferring cervical lymph node regions from these anatomical structures. We are proposing a system that can automatically segment the neck region from CT images by identifying the cranial and caudal bounding slices and then locating and labeling various anatomical structures in the region.*

## 1. Introduction

Malignant tumors in the head and neck represent a great epidemiological problem in western countries. Head and neck cancer accounts for approximately 3% of all cancer cases reported in the United State, or roughly 50,000 cases per year [1]. Due to the tumor position, the risk of developing lymph node metastases in the neck region is very high. Radiation therapy will be used as part of the treatment in a majority of the cases. Therefore a fast and effective system for creating a conformal radiation treatment of enlarged (i.e. potentially malignant) lymph nodes is essential. With a well-designed conformal plan, critical anatomical structures can be avoided while radiation dosage is maximized for the lymph node region. As imaging based cervical lymph node region classification is developed [2], a system that can identify those critical anatomical structures by segmenting patients' CT images with little or no user interaction is crucial to the success of implementing a fast and effective radiation treatment planning system.

Fully automatic segmentation in the neck region is particularly difficult, because many soft tissue anatomical entities are small in size and similar in density. Furthermore, they can be directly adjacent to each other or only divided by fascial layers that are not visible in CT images. The relative locations between anatomical entities can vary in different axial location. Little work has been done specifically for the neck images; one exception is the work of Kruegar et al [3] who implemented a semi-automatic system to segment neck CT images for pre-operative planning of neck dissections. We will focus on an automatic segmentation method for radiation therapy patients.

## 2. Dynamic Thresholding

Kobashi and Shapiro [4] proposed a knowledge-based method to identify anatomical structures that can minimize or eliminate the need for user interaction using constraint-based dynamic thresholding, negative shape constraints to rule out infeasible segmentation, and progressive landmarking that takes advantage of the different degrees of certainty of successful identification of each structure. Our experimental system is motivated by these techniques.

## 3. Cranial and Caudal Boundary

Williams and Smoker [5, 6] identify the neck in terms of adjacent anatomical spaces separated by fascial layers extended between skull base and thoracic inlet. Physicians often use these two landmarks to determine the range of CT image slices that are of interest for neck surgery or radiation treatment. Our first step is to identify the approximate locations of the skull base and the thoracic inlet in the CT image set.

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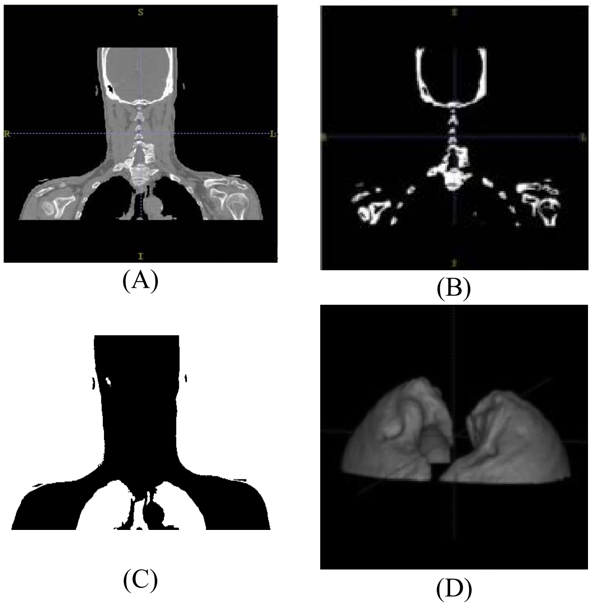


**Fig 1**. A typical mid-coronal plane of head and neck CT image set, (A) original grayscale, (B) dynamic thresholding result of bone structures, (C) thoracic cavity regions, (D) 3D mesh of thoracic cavity.

While the location of the skull base is not usually clear in the axial CT images, it is more easily identifiable in the coronal view. Fig 1 shows the mid-coronal plane of a typical head and neck CT image set. The skull base can easily be identified by the caudal extremum of the skull region. The thoracic inlet can be approximated by the superior apex of the thoracic cavity. Rather than trying to segment the thoracic cavity in many coronal planes to identify its apex in 2D, we chose to use the 3D intensity based region competition active contour (snake) method provided by the Insight Toolkit (ITK www.itk.org) to build the 3D meshes of the thoracic cavity. The active contouring can be automatically seeded by the 2D thoracic cavity region in the mid-coronal plane.

Identifying proper cranial and caudal boundaries is important as they can be used as references for relative locations for anatomical structures of interest. As we perform inter-subject image registration in a radiation therapy system [6], it is also imperative that each subject has the same region for alignment.

## 4. Segmentation

The system will try to locate the following anatomical structures that can be used as landmarks for lymph node regions in the head and neck, in the following order:

(1) Cervical spine,
(2) Mandible,
(3) Hyoid,
(4) Internal jugular vein,
(5) Common carotid artery,
(6) Sternocleidomastoid muscle.

This order is defined in accordance with the reliability of successfully detecting the structure. Each structure is associated with domain knowledge including:

(1) Relevant gray tone range, containing the threshold that should segment the structure correctly,
(2) Location relative to the cranial and caudal boundary and overall outer body contour extent described as a normalized range between [0, 1] in the axial, coronal, and sagittal directions.
(3) Location relative to other structures that can be found prior to this structure,
(4) Size in terms of area and extent,
(5) Shape constraints.

Segmenting soft tissues in the neck is in general very difficult because adjacent structures can be similar in gray tone with almost no distinct separation between them. We currently focus on the sternocleidomastoid muscle as it is the most prominent muscle in the neck. While part of the sternocleidomastoid muscle has distinct edges, it can be problematic as the sternal head comes into contact with other muscles and tissues and becomes difficult to separate.

We combine 2D segmentation and 3D active contouring for each anatomical structure we want to identify. For each structure, we first run the dynamic thresholding process to find 2D regions in axial slices according to domain knowledge. Then we run the 3D intensity based region competition active contour method (by ITK) to build the 3D model using those 2D regions as the seed. This two step process is then repeated for the next structure.

The dynamic thresholding algorithm is as follows. For each structure, the system iterates through a range of axial CT slices relative to the cranial and caudal boundaries according to the domain knowledge. The system first sets the initial threshold to the high end of the relevant gray tone range and performs a thresholding operation, morphological operations, and a connected components operation. It will check if

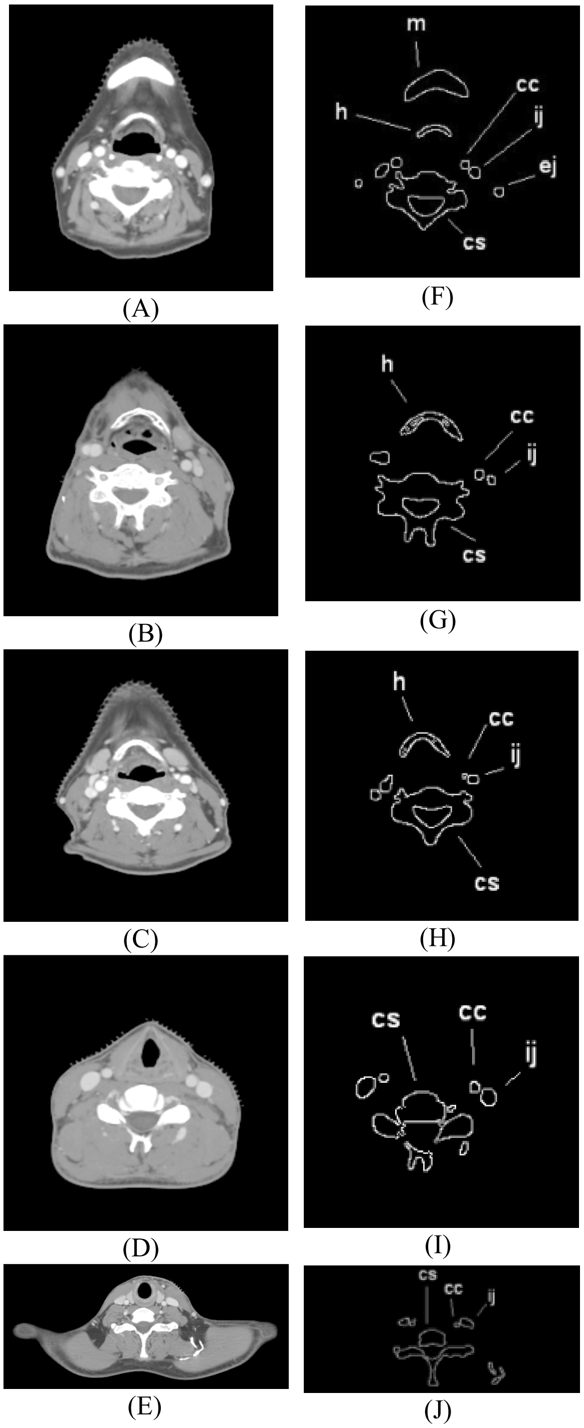


**Fig 2**. Result samples of dynamic thresholding for bone structures and blood vessels, cervical spine (*cs*), mandible (*m*), hyoid (*h*), common carotid artery (*cc*), internal jugular vein (*ij*), and external jugular vein (*ej*). (A) - (E) are selected sample CT slices from five different patients at various axial locations, (F) – (J) are corresponding dynamic thresholding results.

there is any region that satisfies the constraints. Candidate regions that overlap with other known structures are excluded. If multiple regions satisfy all the constraints, we choose the one with most overlap with the resulting region of the previous axial slice, or the region with largest area. The threshold is then reduced by a single step (value 5 is currently used) and the same procedure is repeated. This process continues until the low end of the relevant gray tone range or candidate regions are successfully found. After exiting this loop of repeated thresholding, if candidate regions are successfully found, we will continue with the active contour process. Fig 2 shows contours of structures extracted by the dynamic thresholding process at various axial locations in five different sets of patient CT images.

Since some axial slices may yield successful segmentation results and other do not, we use 3D active contouring to build 3D models from the partial segmentation results. Those 2D regions are used to seed the initial model. The final threshold values for each anatomical entity from the dynamic thresholding process are used to preprocess the raw CT images and isolate the intensity ranges of interest for the active contouring process.

This two step process is repeated for each of the anatomical structures we want to find according the predefined order. Fig 3 shows an example of step by step results of this iterative process. Fig 3A – 3B shows results for cervical spine segmentation, 3C – 3D for mandible, 3E – 3F for hyoid, 3G – 3H for jugular veins, 3I – 3J for carotid arteries, and 3K – 3L for sternocleidomastoid muscles. The left column shows the results of dynamic thresholding, where not all axial slices have successfully segmented 2D region. The right column shows the corresponding results of 3D active contouring using results from the left column as seeds.

## 5. Experiment and Results

The test images are CT scans performed at the University of Washington Medical Center using a General Electric CT scanner. Ten sets of CT images in which all of the slices are 512×512 pixels are used. Slice thickness varies between 1.25 mm and 3.75 mm.

While this system does not require user input to locate structures on axial CT slices, it is not yet able to locate all structures in all tested patient CT data sets. This is mainly due to random abnormalities caused by neck dissection or tumor.

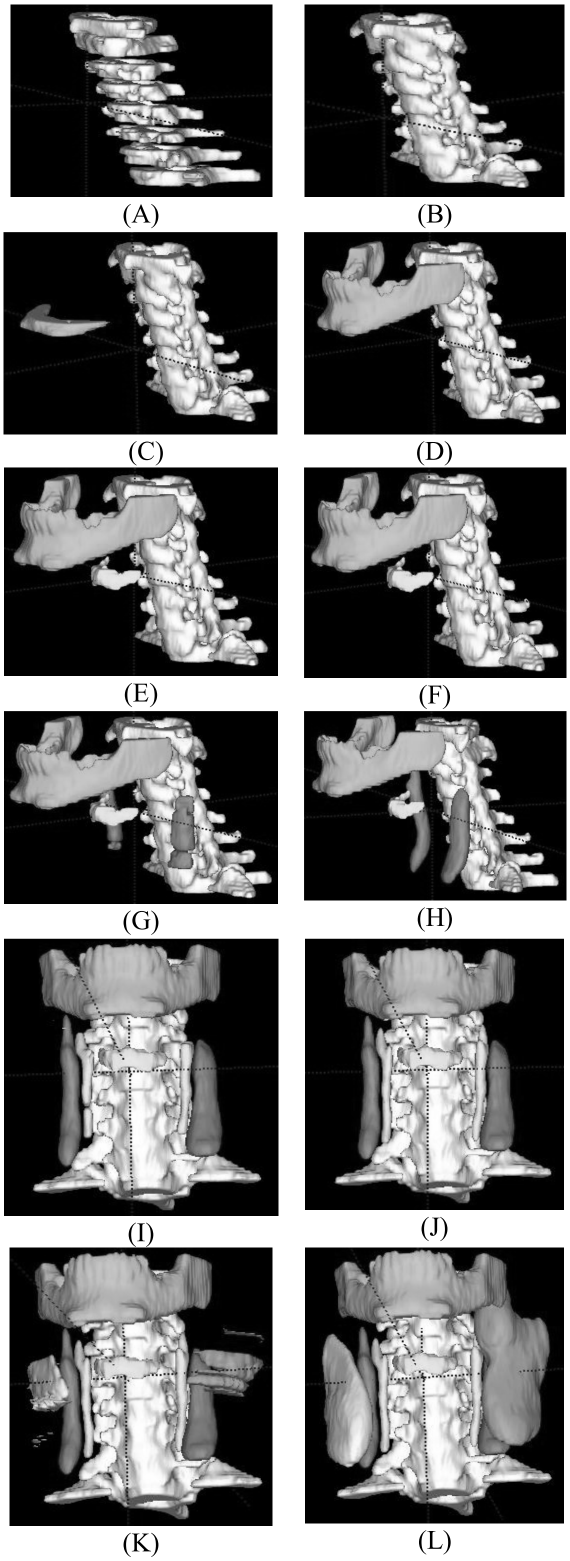


**Fig 3**. Example of step by step results, left column shows dynamic thresholding results, right column shows 3D active contour results.

## 6. Conclusions

Automatic segmentation of CT images is a challenging problem for which a knowledge-based approach can be useful in certain classes of applications. For a head and neck radiation therapy planning system which looks for a known set of landmarks, it may produce sufficient results.

We will acquire up to thirty more sets of head and neck CT images to evaluate these methods on a broader domain of patient data and make adjustment accordingly. This work will also be integrated into a radiation therapy planning system [6] for future clinical evaluation. We will continue to evaluate this method on more soft tissue structures in the neck. Applications such as automatic tumor identification can also be developed by observing shape and intensity abnormality or asymmetry of these anatomical structures.

## 10. References

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