Automatic segmentation of tumor-laden lung volumes from the LIDC database

Walter O'Dell

Departments of Radiation Oncology and Biomedical Engineering, University of Florida, Gainesville FL

I. Introduction

Recent advances in stereotactic radiotherapy technology [1] have renewed motivation for the early, computer-aided detection and diagnosis of small lesions in the lung, especially in regards to surveillance for metastatic disease to the lung in high-risk patient populations [2]. The segmentation of the lung parenchyma is often a critical pre-processing step prior to application of CAD of lung nodules. Segmentation of the lung volume can dramatically decrease computation time and reduce the number of false positive detections by excluding from consideration extra-pulmonary tissue. Of particular challenge is to preserve tumorous masses attached to the chest wall, mediastinum and major vessels. In this role, lung volume segmentation comprises an important CAD step that can adversely affect the performance of the overall CAD algorithm. An automated lung volume segmentation algorithm has been developed for tumor-bearing lungs with the goals to maximally exclude extra-pulmonary tissue while retaining all true nodules. It is applied here to the CT datasets compiled by Lung Image Database Consortium (LIDC) [3].

II. Methods

The first 100 LICD data sets were downloaded through https://wiki.cancerimagingarchive.net/display/Public/LIDC-IDRI.
A sequence of operations and parameters were empirically derived and/or created to accomplish the objectives.

1. Threshold to -370 Hu (Hounsfield units). Most of lung space is black (grayscale value = 0).
2. 3-D flood-fill the region outside body (fill in as white from all edge pixels).
3. Invert and crop the 3-D image set to all white pixels (to speed up subsequent tasks).
4. Re-invert and scale image to 128 (lungs now black; previously filled regions are medium-gray).
5. Perform 2-D flood-fill of internal lung spaces. Also determine the first 2-D slice at which the hemi-lung may appear as multiple disconnected crescent-shaped regions around the diaphragm and abdominal organs.
6. Determine the last slice at which the 2 hemi-lungs are connected.
7. Perform 3-D flood filling downward in patient's right hemi-lung from the slice below the last connection of hemi-lungs. 3-D filling is needed to include all disconnected crescent-shaped regions around the diaphragm.
   Perform 3-D flood-fill downward on left hemi-lung from the lowest slice where all disconnected regions of the left hemi-lung will be captured. Filling in 3-D from a more cranial slice may cause flood-fill leaking into the bowels, so is avoided.
8. To prevent 3-D flood-fill leaking into the trachea and major vessels, perform 2-D flood-fill of upper slices beginning at the slice above where the 3-D downward filling began, and advancing upward through the slices.
9. Separation of hemi-lungs. In each slice where the hemi-lungs are connected, perform image Erosion operations of successively larger disk size until the hemi-lungs have become separated. To achieve more equal bisection of the left and right hemi-lungs:
   i. On each hemi-lung separately, perform image Dilation using the same, final element size.
   ii. Perform a gradient operation independently on the dilated left and right hemi-lungs.
   iii. Add the two resulting edge images. Compute the line segment that intersects the upper and lower intersection points and impose this segment as a void onto the original image.
10. Crop the 3-D image volume to include both of the now-isolated left and right hemi-lung volumes plus a 6-pixel margin.
11. Perform a 2-D image Opening on each slice using a 2-pixel-radius disk element to remove CT reconstruction artifacts.
12. Perform 2-D image Closing on each slice using a 3-pixel-radius disk to snip small attached nodules.
13. Create a 2-D snake for each hemi-lung surface (all but hilar region) on each slice to remove larger attached nodules.
14. Clear (set to white) all pixels within 10 pixels internal to the optimized snake. Thereby snipping from the edge all objects of the largest diameter (15-20 mm) of interest. The lung volume is now white (255).
15. Remove any snake-generated internal lung 'holes' by scaling the lung mask to 128 (lung volume now grayscale value 128); 3-D flood-filling the space outside the lung mask; thresholding to 129 (lung volume now black); gray-scale inverting and thresholding to 25. The lung volume now white again.

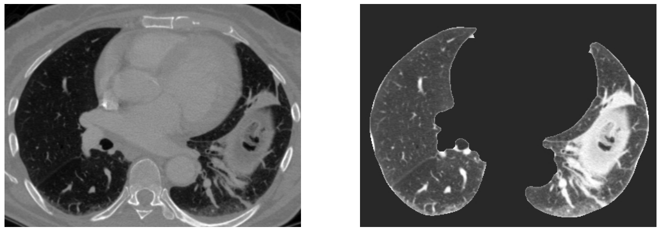

Figure 1. Original image slice [Left] and final masked lung volume [Right] shown at a lower-thoracic axial CT slice location (slice #204 out of 525) in LIDC study #0034. The segmentation outcomes at each major step for this dataset at this slice location are depicted in Figure 2. A large abdominal tumorous mass is seen protruding into in the left hemi-lung (right side of image). Airspace of the bowels is seen as voids within the center of the protruding mass.

III. Results

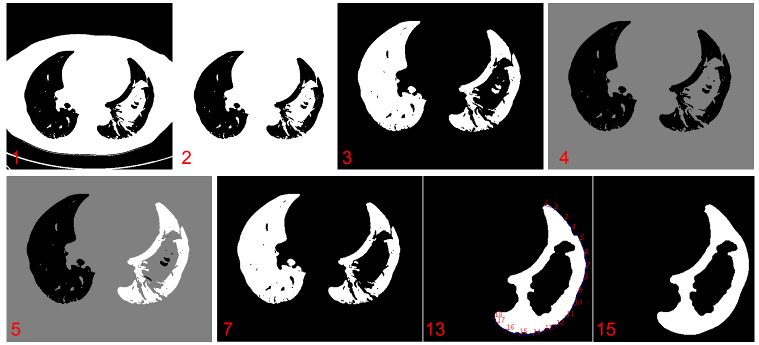

Figure 2. The output following each major step for LIDC study #0034. This dataset contained a large tumor in the abdominal and thoracic space, posing a particular challenge to the task of separating the lung volume from the bowels. The numbers for each sub-image correspond to the process flow chart. This dataset did not exhibit connection between the hemi-lungs, therefore the disconnection step #11 is not represented. Steps that do not affect the slice shown (#204/525), such as 2-D flood-filling of the more cranial slices, are not depicted.

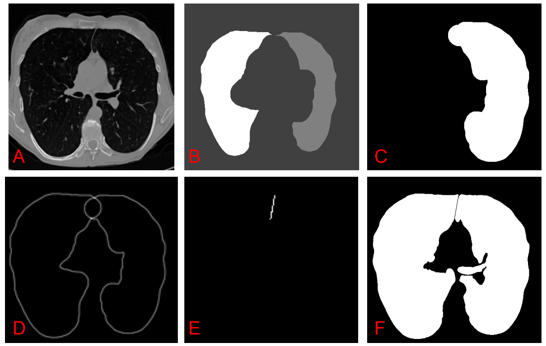

Figure 3.The output following each sub-step to disconnect the hemi-lungs (step #9) in LIDC study #0089. [A] This dataset contained a large region of connection between the left and right hemi-lungs, anterior to the heart. [B] Shown is the slice after performing Erosion with a 29-pixel 2-D disk - the minimum size to achieve hemi-lung separation. [C] Following Dilation with the same-sized disk. [D] Summing of edge images after independently Dilating both hemi-lungs. [E] Line segment drawn between the upper and lower intersecting points. [F] Mask of the bisection line applied to the step #8 image.

IV. Conclusions/Future work

A lung volume segmentation scheme was developed using an objective, uniform set of procedures and parameters to retain all nodules of interest while excluding the extraneous surrounding tissue. The algorithm was developed and tested on the first 100 datasets from the public LIDC database. The nodules of interest consisted of all nodules identified by ¾ of the expert readers and being of non-trivial size (<20 mm), and included nodules attached to vessels, the chest wall or the mediastinum. The algorithm consists of a series of thresholding, morphological, filling and snake-based procedures. The segmentation of each LIDC patient dataset took, on average, <5 minutes using a Mac Pro workstation.

V. References

1. **Okunieff, P., Petersen, A.L., Philip, A., Milano, M.T., Katz, A.W., Boros, L., and Schell, M.C., "Stereotactic body radiation therapy (SBRT) for lung metastases," Acta Oncol. 45(7), 808-817 (2006).**
2. **Milano, M.T., Katz, A.K., Zhang, H. and Okunieff, P., "Oligometastases Treated With Stereotactic Body Radiotherapy: Long-Term Follow Up of Prospective Study," Intl. J. Radia. Oncol. Biol. Phys., Jan. 2012.**
3. **Clarke, L.P., Croft, B.Y., Staab, E., Baker, H., and Sullivan, D.C., "National Cancer Institute initiative: lung image database resource for imaging research," Acad. Radiol. 8(5), 447-450 (2001).**

VI. Acknowledgements

Walter O'Dell received funding for this work through the University of Florida Shands Cancer Center.