User-guided Segmentation of Thoracic Computed Tomography Data for Electrical Impedance Tomography Image Reconstruction

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Abstract
Electrical Impedance Tomography (EIT) is a promising technique to visualize lung function, but it suffers from inaccurate thorax models. To easily generate such models in the presence of severe lung damage, we propose an interactive segmentation workflow that utilizes expert knowledge. Body shape, lung, ribs, heart and pathological lung tissue are segmented from CT scans to allow multi-material body models for EIT image reconstruction.

The workflow includes histogram-based thresholding, body shape extraction, ribcage and heart segmentation and uses well-known techniques like Connected Component Analysis and morphological operations as well as interactive algorithms like Geodesic Segmentation. Our method can deal with both human and pig body geometry and to our knowledge there is no other application that features a similar integrated workflow with planned expert user interactions while having the same potential for multi-material thorax segmentation.

Index Terms: 1.4.6 [Image Processing and Computer Vision]: Segmentation—Pixel Classification

1 Introduction
Electrical Impedance Tomography
Electrical Impedance Tomography (EIT) is a functional imaging technique that visualizes conductivity changes inside the body. It is now being used to monitor pulmonary gas distribution during mechanical ventilation of patients in intensive care [3]. The choice of body models is crucial for the quality of reconstructed images. The state of the art is a 2.5D model generated from a single slice segmentation [2].

Major problems of EIT are the low spatial resolution, noise and perfusion affecting the signal, poor image quality for patients that deviate significantly from the model (especially obese patients) and unclear correspondences of regions in EIT and CT.

Goals
The segmentation procedure presented here is intended to foster patient-specific model generation from semi-automatic multi-material segmentation of CT data. It is expected that image quality improves significantly and creating anatomical context for EIT becomes possible. Along with the individualization of EIT image reconstruction one of our long-term goals is to help justify the usefulness of EIT by providing anatomical context to assess EIT image quality.

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2 Segmentation Process Summary
Initial Segmentation based on Histogram Thresholding
After the user selects a start and end slice (to constrain the region of interest) and the data is smoothed using anisotropic diffusion (to reduce noise from metal artifacts), the log-histogram is computed. Several peaks represent structures like aerated lung, muscle/fat/blood tissue, bones and metal. An initial segmentation is...
computed by searching for local minima between peaks. These thresholds can be adapted by the user with immediate visual feedback.

**Thorax Shape Extraction**

Thorax shape is very important for Electrical Impedance Tomography image reconstruction, but it also allows to remove voxels outside the thorax which otherwise would interfere with automatic methods.

Morphological operations (majority and erosion filters) and Connected Component Analysis are applied to isolate the thorax structure. Its convex hull is then refined by scribbling: Foreground and background scribbles are drawn by the user and then processed by Geodesic Segmentation [1]. The initial segmentation is then updated with the new knowledge using inside/outside masks.

**Ribcage Segmentation**

The next step is to delineate the volume enclosed by the ribcage since important structures like aerated and pathological lung tissue, heart and aorta are located there. The user selects undesired components (e.g. metal objects inside the body), and if they cannot be properly separated by Connected Component Analysis, the user can draw regions that are then removed from the mask.

We locate those points on the contours inside the ribs’ convex hull that point towards its centroid. These points form the inner ribcage region which is complemented with the lung mask to complete the region of interest.

**Segmentation by Scribbling**

The heart is the largest non-lung structure inside the ribcage. It is connected to the thoracic wall and to the blood vessels, and sometimes touches the diaphragm. We draw scribbles inside the heart and also place foreground scribbles at undesired structures (see Fig. 2a). Geodesic Segmentation [1] then produces quite successful results from scribbles in very few slices (usually just one is sufficient).

The procedure is repeated for the descending aorta and for atelectatic or otherwise non-aerated lung tissue (Fig. 2b). Note that this last segmentation is almost impossible to achieve automatically and is therefore usually done by manual contour drawing.

![Figure 2: Scribble-based segmentation of inner-thoracic structures.](image)

(a) Successful heart segmentation (green) with four scribbles.

(b) Successful separation of atelectasis (green) from other tissue.

**Electrode Segmentation**

Since our pig data was recorded during animal studies with combined CT and EIT images we also have the opportunity to locate the 16 electrode positions explicitly. Knowing the electrode plane, its angle towards the transverse plane and the exact positions on the skin is very crucial for EIT image reconstruction and helps reducing artifacts significantly. We compute the contact location with the skin as well as the electrode’s orientation with respect to the skin boundary.

3 **Results**

![Figure 3: Segmentation results and 3D visualization for two datasets from a pig (top) and a human (bottom).](image)

Even though the implementation of our method is at an early stage, it works quite stable and delivers almost satisfactory results (in terms of model building for Electrical Impedance Tomography).

Fig. 3 (top) shows a pig dataset with partially atelectatic lung tissue and electrodes. In Fig. 3 (bottom) a human dataset with distinctive atelectatic lung tissue (light blue) is presented. The lung also contains a pneumothorax (purple) that is detected automatically due to its special characteristics.

Note that all of our results were computed without manually tracing any material boundaries (which still is the state of the art in clinical practice). This produces enormous time savings and minimizes the time a radiologist needs to deal with the data.

4 **Conclusion**

We presented our first results on semi-automatically segmenting thoracic CT data to generate patient-specific body models for EIT image reconstruction. We showed that even with very little user interaction, quite good results can be achieved, while the planned input of expert knowledge is crucial to the success.

We are currently conducting an evaluation comparing manually segmented lung data to our results in order to show the faster execution time of our method while maintaining the same high quality of segmentation. We expect that our medical partners will also report better usability than other (semi-)automatic methods.

**References**

