Navigation Path Retrieval from Videobronchoscopy using Bronchial Branches

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Abstract. Bronchoscopy biopsy can be used to diagnose lung cancer without risking complications of other interventions like transthoracic needle aspiration. During bronchoscopy, the clinician has to navigate through the bronchial tree to the target lesion. A main drawback is the difficulty to check whether the exploration is following the correct path. The usual guidance using fluoroscopy implies repeated radiation of the clinician, while alternative systems (like electromagnetic navigation) require specific equipment that increases intervention costs. We propose to compute the navigated path using anatomical landmarks extracted from the sole analysis of videobronchoscopy images. Such landmarks allow matching the current exploration to the path previously planned on a CT to indicate clinician whether the planning is being correctly followed or not. We present a feasibility study of our landmark based CT-video matching using bronchoscopic videos simulated on a virtual bronchoscopy interactive interface.

Keywords: Bronchoscopy navigation, lumen center, brochial branches, navigation path, videobronchoscopy

1 Introduction

Lung cancer is a frequent and serious malignancy with a 5-year global survival rate in patients in the early stages of the disease of 38% to 67% and in later stages of 1% to 8% [1]. Early diagnosis has increased survival rates from 44% to 80% in men and from 28% to 52% in woman from the 70's to the 2000's [2]. This fact emphasizes the importance of early cancer detection and treatment with curative intention, and this is a challenge in many countries [3]. Computed tomography (CT) screening programs may significantly reduce the risk of lung cancer death, but diagnostic of solitary peripheral lesions is still suboptimal [4] and requires further surgical intervention. Such lesions can be diagnosed via bronchoscopy biopsy without risking complications of other interventions like transthoracic needle aspiration [5]. However, navigation with a flexible bronchoscope is a difficult task in case of solitary peripheral small lesions and according to the Am. Coll. Chest Phys., diagnostic sensitivity of lesions is 78%, but drops to 34% for lesions < 2 cm [4].

One of the main drawbacks of flexible bronchoscopy when exploring lung periphery is the difficulty to predict the correct pathway to a potential lesion.

In this sense, several technologies have been proposed to aid clinician in this task, such as CT Virtual Bronchoscopy (VB) or the analysis of pure videobronchoscopy information.

CT VB is a non-invasive method that can precede flexible bronchoscopy for navigating inside the respiratory tract to assess the optimal path to a lesion. VB is a computer simulation of the video bronchoscope image from the bronchoscope camera [3] which is created from the 3D CT volume, with the same view angle and zoom settings. During exploration, VBs should accurately guide the operator across the planned path to the biopsy point. To display the correct position of the bronchoscope and tools in the CT-derived maps (structural maps of airways), scope and tools position and orientation need to be tracked in real time. Standard protocols relying on fluoroscopy have a diagnostic yield around 60% and require repetitive radiation during intervention [6]. Existing alternatives like VB LungPoint (Broncus Medical, Inc), NAVI (Cybernet Systems) or electromagnetic navigation (inReachTM,SPinDrive) are far from meeting clinician expectations. Systems based on standard bronchoscopes (e.g. LungPoint, NAVI) require manual intra-operative adjustments of the guidance system [7, 8]. Electromagnetic navigation systems require the use of specific gadgets [9], altering the standard operating protocol and increasing, both intervention time and patient anxiety. Finally, they all require exhaustive personnel training and increase intervention complexity and cost.

In spite of increasing research interest, the potential of image processing in enhancing guiding capabilities has not been fully explored. In image-based/video-based tracking, the position of the bronchoscope tip is found by comparing and matching VB virtual view to the videobronchoscope current frame [10, 11]. Current solutions [12, 3] are mostly based on multimodal registration of CT virtual projections to the actual videobronchosocpy frame and are still far from reliable deployment [13]. A main disadvantage is that the view from the bronchoscope can be obscured by blood or mucus, causing the tracking between the video images and the virtual images to be disrupted. Also, the lack of depth and rotation information from the bronchoscope camera view hinders their performance.

An alternative to image registration is the use of anatomical landmarks as reference in coordinate systems [14]. The use of anatomical landmarks as reference systems is a fast alternative to volume-based registration methods for matching anatomical data across patients and 3D scans. Identification of bronchial tree key-points in, both, CT scans and videobronchoscopy frames should also provide accurate matching between off-line planed path and the current endoscopic navigation. Landmark extraction in interventional videobronchoscopy is challenging due to the large variety of illumination and camera position artifacts, as well as, the unpredicted presence of surgical devices. Recent works [15] have developed efficient video processing methods to extract airways lumen that minimize the impact of non-bronchial structures such as instrumentation, shines, folds and vessels.

In this paper, we propose to reproduce a bronchial navigation path by using the lumen centers as anatomical landmarks in both CT and videobronchoscopy.

Selection and tracking of such centers together with detection of branching points is used to do correspondences between VB planing and images of the current exploration. We present an exploratory study to test on the feasibility of a landmark base CT-Video matching on video sequences simulated on a VB interface platform. Our first results indicate that there is enough evidence supporting a guide system based on tracking of landmarks.

2 CT-Video Anatomical Matching

The bronchial tree has a tubular geometry and, thus, it is described as far as its central line (corresponding to the airway lumen center) and walls (luminal area) are extracted. In the case of bronchial navigation, the path can be described by means of the lumen center position and their branching points defining the bronchial tree structure.

Our CT-video path matching locates the current position of the scope by comparing the bronchial tree extracted from the CT used to plan the intervention to a bronchial structure generated from the tracking of lumen centers extracted from videobronchoscopic images during intervention time. Both anatomical structures can be computationally encoded by means of a binary tree [16] with nodes given by the bronchial branching levels. The matching between CT-video bronchial structures is then given by comparing the two binary trees.

2.1 Bronchial Anatomy encoding from the CT scan

The whole bronchial tree to be matched to the current exploration navigation path is encode from a segmentation of the CT volume as follows. First, the skeleton of the segmented CT volume is obtained using the method described in [17] which allows a pruning of skeleton spurious branches depending on the branch length. In order to ensure that we encoded the highest bronchial levels as possible, the branch pruning length was set to the maximum trachea radius.

The CT skeleton represents the center airway line and, thus, an ideal scope motion if the clinician follows a central navigation thought lung airways. In order to define the binary tree that encodes the bronchi branching anatomy, we identify the skeleton branching points and label each branch according to their bronchial level and orientation (left, right) with respect the splitting branch at the previous level. The binary tree top node corresponds to the tracheal entry point and it is labelled "1". At each new branch, two nodes are added labelled "1" or "2" depending on the anatomical branch orientation ("1" for left, "2" for right). We note that by using such a node labelling, a given path corresponds to a sequence of nodes traversing the binary tree.

Figure 1 shows the encoding in a binary tree of the bronchial anatomy from a segmented CT. We show the segmented CT scan (top-right image) and its skeleton that represents the center airway line (top-left image) and the final binary tree data structure for the first 3 bronchial levels (bottom-left). We have labelled the skeleton branching points according to their corresponding binary tree nodes, so that the green path would correspond to the node sequence $(1, 2, 1, 2, 1, 2, 1)$.

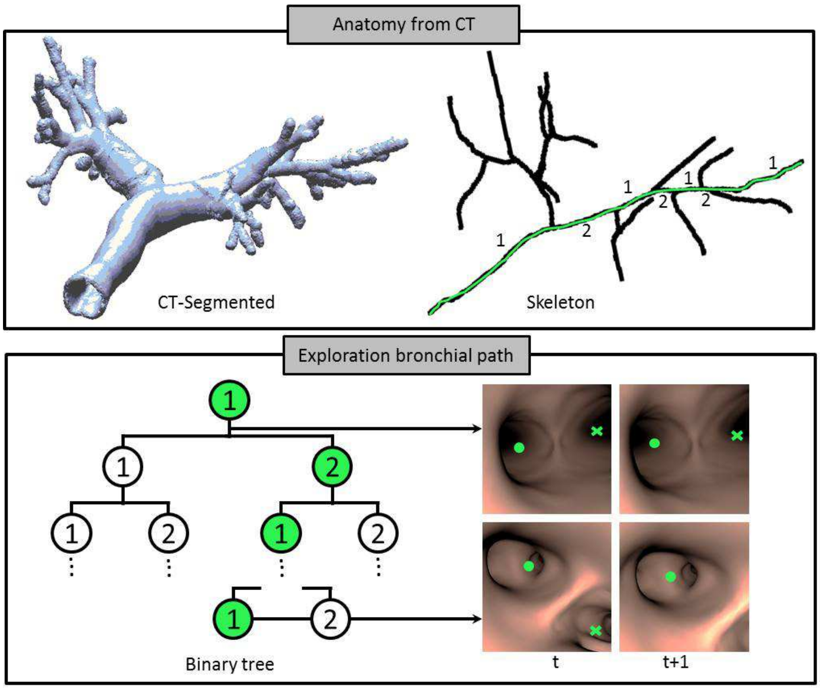

Fig. 1. CT-Video Anatomical Matching. Codification of the bronchial anatomy from CT branch points (top images) and binary tree coding for identification of the navigated path inside the bronchial tree (bottom images).

2.2 Bronchial Path from Exploration Videos

The extraction of the navigated path has two different stages: lumen center tracking and matching of the center path to the CT bronchial tree.

Tracking of the lumen centers is based on an appearance and geometry likelihood map [18] that achieves maximum values at the center of the lumen. In case of multiple lumen at branch points, the map local maxima should correspond to each branch center. Local maxima are tracked across frames accounting for its spatio-temporal consistency to discard false detections.

In order to track local maxima, we keep a state vector that evolves across video frames and that contains, for each frame at time t the position in pixels of the NLM_t local maxima, $(X_t^i)_{i=1}^{NLM_t} = (x_t, y_t)_{i=1}^{NLM_t}$, the total number of frames each local maxima has hold, $(N_t^i)_{i=1}^{NLM_t}$, and the gap of consecutive frames that it has disappeared, $(G_t^i)_{i=1}^{NLM_t}$. The state variable is updated to incorporate the local maxima, NLM_{t+1}, at frame $t+1$, $(X_{t+1}^j)_{j=1}^{NLM_{t+1}}$, depending on their distance to the maxima at time t. If such distance is less than a radius R, the position X_t^i is updated using the closest point in $(X_{t+1}^j)_{j=1}^{NLM_{t+1}}$, otherwise the position is kept and new state vectors are added with the remaining maxima

found at $t+1$. That is, for the existing state vectors their values are updated as:
if $\exists X_{t+1}^j$ such that $d(X_t^i, X_{t+1}^j) \leq R$

$$X_{t+1}^i = X_{t+1}^j, \qquad N_{t+1}^i = N_t^i + 1, \qquad G_{t+1}^i = G_t^i$$

if $\forall X_{t+1}^j d(X_t^i, X_{t+1}^j) > R$

$$X_{t+1}^i = X_t^i, \qquad N_{t+1}^i = N_t^i, \qquad G_{t+1}^i = G_t^i + 1$$

and for the remaining $(X_{t+1}^j)_{j=1}^{NLM_{t+1}}$ that can not be matched to a previous state because, $d(X_t^i, X_{t+1}^j) > R$, $\forall j = 1, \ldots, NLM_{t+1}$ we create a new state with values:

$$X_{t+1}^j = X_{t+1}^j, \qquad N_{t+1}^j = 1, \qquad G_{t+1}^j = 0$$

We use a threshold on the length of the frame gap, G_t^i, and frame appearance, N_t^i, to decide whether a local maxima is a strong candidate or it should be discarded and eliminated from the final output navigation path. For the sake of notation simplicity, the position of the selected local maxima describing the final navigation path will be also noted by $(X_t^i)_{i=1}^{NLM_t}$.

In order to match the navigation path to the binary tree encoding CT bronchial anatomy, it suffices to identify frames traversing a higher bronchial level (binary tree level) and orient the entering branches allowing to chose the tree node. A given frame can be categorized from the multiplicity of the lumen centers as:

- Frame within same bronchial level if $NLM_{t+1} = NLM_t$.
- Frame approaching a bronchial level if $NLM_{t+1} > NLM_t$.
- Frame traversing a bronchial level if $NLM_{t+1} < NLM_t$.

Starting at the top node of the binary tree, each time a frame traverses a bronchial level, the tree level is increased and the path node sequence is updated by adding "1" or "2" depending on the entering branch orientation. The center point with highest likelihood is considered to be the scope current position and defines the entering branch. Its orientation (left or right) is defined by its relative position with respect the disappearing centers. If the x-coordinate is larger than the average x-coordinate of the vanishing points, we consider that the node is labelled "2" (right) and "1" (left) otherwise.

Figure 1 bottom, illustrates the identification of lumen centers (right images) and its matching to the binary tree (left image) representing exploration bronchial path. In right, lumen centers are plotted in green, crosses for strong center candidates and dot for the one corresponding to the scope current position. We show two representative cases of frame within same bronchial level (top images) and a traversing frame (bottom images). The node sequence associated to these frames is shown on the left tree in green.

3 Experimental setup and results

In order to explore the feasibility of the proposed anatomical matching, we have tested our methodology on virtual explorations of a CT volume from a patient

	Case1	Case2	Case3	Case4	Case5
GT	112121	11112	12112	1222	11111
NaviPath	112121	1112-	122–	1222	11111

Table 1. Node code for GT and navigation paths for the 5 virtual explorations

coming from Hospital de Bellvitge [19]. The CT volume was segmented using the software AMIRA and a triangular mesh in .obj format was created for navigation path simulation [19]. Virtual explorations were exported generated using the simulation software Unity, which allows the modelling of the scope camera and an interactive camera point of view navigation. Unity virtual explorations were in .bmp video frames for the extraction of the bronchial path based described in Section 2.2. The camera position inside the bronchial tree was also exported to define the codification of the Ground Truth path in the binary tree.

A total number of 5 virtual explorations were defined starting from the trachea and following different branching paths and bronchial levels. The binary tree node coding for the ground truth camera position was compared to the coding extracted from the virtual videos. Node path coding has been compared in terms of True Positives Nodes (TPN) and True Path Representations (TPR). For a given exploration, a node is considered to be a TPN if its label indicating the chosen branch ("1" for left, "2" for right) coincides with the GT node label at the corresponding bronchial level. If all nodes are TPN, then the whole path has been correctly encoded and it is considered a TPR.

Table 1 shows the node codes for GT and navigation paths (NaviPaths) extracted from the 5 virtual explorations. A dash indicates that the tracking algorithm stopped because it reached a leave node of the binary tree mainly due to a wrong choice in an earlier branch. The total number of TPN is $19/24 = 80\%$ and in $3/5 = 60\% = TPR$ cases the whole path was correctly encoded. Navigation errors are mainly due to either not having a complete visualization of the branch or having a upper/lower branch. Figure 2 shows the qualitative results for the 1st case (top images)which is all nodes TPN and the 3rd case (bottom images) having only the first nodes as TPN. We show the CT skeleton in solid black line, the GT path in blue and the navigated path in green. We also show a snapshot of the simulated video with the tracheal lumen centers plotted in green, crosses for strong center candidates and dot for the one corresponding to the scope current position. In the third case we show the snapshot of the branch point not detected because center miss-detection (red cross).

The failing in the third case arises at the 3rd level of the left bronchial tree that has a lower branch that can not be visualized in bronchoscopic explorations in central navigation, so, our algorithm loses this sort (upper/lower branches) of branch points.

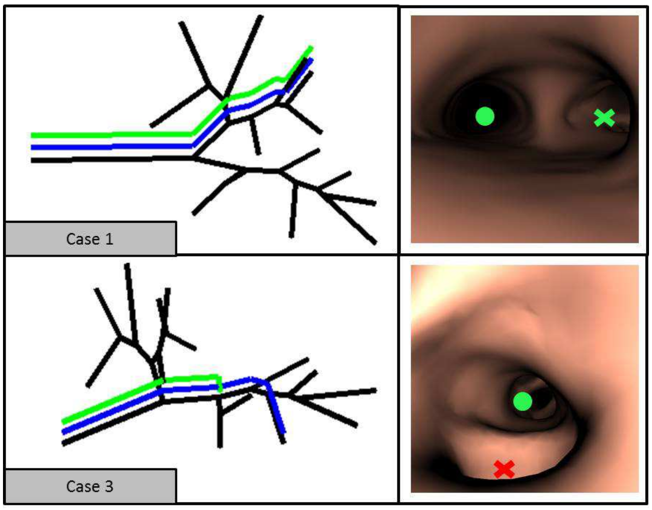

Fig. 2. Qualitative results for the 1st (top) and 3rd (bottom-right) cases.

4 Conclusions and future work

Diagnostic of solitary peripheral lesions in lung cancer can be diagnosed via bronchoscopy biopsy without risking complications of other interventions. New endoscopy techniques (virtual bronchoscopy assisted procedures or electromagnetic techniques) can reach an overall diagnostic yield of 70%, but still could be improved if technology would be able to better detect and guide the bronchoscopist to the target lesion. This paper presents a novel lumen center tracking as a landmark in order to know in which part of the bronchial tree the camera is situated. Preliminary results in virtual images show the feasibility of retrieving a navigation path from anatomical landmarks tracking and encourage further research to enable the use of this strategy in a real images.

Before having a method ready to perform on true explorations, several issues should be improved. One of the processing tools we will include will be the use of Kalman and particle filters for the centers tracking [20]. Another issue is to enlarge the computational description of the bronchial tree to handle branches going to upper/lower lobes.

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References

1. H. Brenner, "Long-term survival rates of cancer patients achieved by the end of the 20thcentury: a period analysis," *The Lancet*, vol. 360, no. 9340, pp. 1131–1135, 2002.
2. B. Møller, "Cancer incidence, mortality, survival and prevalence in norway," *Yearly report*, 2005.
3. P. J. Reynisson, H. O. Leira, T. N. Hernes, E. Hofstad, and et. al, "Navigated bronchoscopy: a technical review," *JBIP*, vol. 21, no. 3, pp. 242–264, 2014.
4. E. F. Donnelly, "Technical parameters and interpretive issues in screening computed tomographyscans for lung cancer," *JTI*, vol. 27, no. 4, pp. 224–229, 2012.
5. A. Manhire, M. Charig, C. Clelland, F. Gleeson, R. Miller, H. Moss, K. Pointon, C. Richardson, and E. Sawicka, "Guidelines for radiologically guided lung biopsy," *Thorax*, vol. 58, no. 11, p. 920, 2003.
6. F. Asano, N. Shinagawa, and et. al., "Virtual bronchoscopic navigation combined with ultrathin bronchoscopy. arandomized clinical trial," *AJRCCM*, vol. 188, no. 3, pp. 327–333, 2013.
7. R. Eberhardt, N. Kahn, and et. al., "Lungpointa new approach to peripheral lesions," *JTO*, vol. 5, no. 10, pp. 1559–1563, 2010.
8. F. Asano, Y. Matsuno, and et. al., "A virtual bronchoscopic navigation system for pulmonary peripheral lesions," *Chest*, vol. 130, no. 2, pp. 559–566, 2006.
9. T. R. Gildea, P. J. Mazzone, and et. al., "Electromagnetic navigation diagnostic bronchoscopy: a prospective study," *AJRCCM*, vol. 174, no. 9, pp. 982–989, 2006.
10. L. Rai, J. P. Helferty, and W. E. Higgins, "Combined video tracking and image-video registration for continuous bronchoscopicguidance," *IJCARS*, vol. 3, no. 3-4, pp. 315–329, 2008.
11. D. J. Mirota, M. Ishii, and G. D. Hager, "Vision-based navigation in image-guided interventions," *Annual review of biomedical engineering*, vol. 13, pp. 297–319, 2011.
12. K. Mori, D. Deguchi, and et. al., "Tracking of a bronchoscope using epipolar geometry analysis and intensity-basedimage registration of real and virtual endoscopic images," *Medical Image Analysis*, vol. 6, no. 3, pp. 321–336, 2002.
13. X. Luó, M. Feuerstein, and et. al., "Development and comparison of new hybrid motion tracking for bronchoscopicnavigation," *Medical image analysis*, vol. 16, no. 3, pp. 577–596, 2012.
14. J. Garcia-Barnes, D. Gil, L. Badiella, F. Carreras, S. Pujades, E. Martí, *et al.*, "A normalized framework for the design of feature spaces assessing the leftventricular function," *TMI*, vol. 29, no. 3, pp. 733–745, 2010.
15. C. Sánchez, J. Bernal, F. J. Sánchez, M. Diez, A. Rosell, and D. Gil, "Toward online quantification of tracheal stenosis from videobronchoscopy," *IJCARS*, vol. 10, no. 6, pp. 935–945, 2015.
16. R. Bayer, "Symmetric binary b-trees: Data structure and maintenance algorithms," *Acta informatica*, vol. 1, no. 4, pp. 290–306, 1972.
17. R. Van Uitert and I. Bitter, "Subvoxel precise skeletons of volumetric data based on fast marching methods," *Medical physics*, vol. 34, no. 2, pp. 627–638, 2007.
18. C. Sánchez, J. Bernal, D. Gil, and F. J. Sánchez, "On-line lumen centre detection in gastrointestinal and respiratory endoscopy," in *MICCAI-CLIP*, vol. 8361 of *LNCS*, pp. 31–38, 2014.
19. A. P. P. Cabras, J. Rosell and et. al., "Haptic-based navigation for the virtual bronchoscopy," in *IFAC*, vol. 18, pp. 9638–9643, 2011.
20. S. Haykin, *Kalman filtering and neural networks*, vol. 47. John Wiley & Sons, 2004.