Image-Guided Endoscopy for Lung-Cancer Assessment

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Abstract— **A system for virtual-endoscopic 3D medical image assessment and follow-on live endoscopy is described. The development and results focus on 3D CT images of the chest and lung-cancer assessment. Two stages are involved in the assessment. In Stage-1, the physician uses a series of tools for visualization and 3D central-axes analysis to build a guidance plan (a "case study"). Next, during Stage-2 endoscopy, the physician links the computer system and case study to the endoscope. The endoscopic video is registered to 3D virtual image data to give the physician "augmented reality" information to better perform the endoscopy. Results illustrate the system's utility for animal and human cases.**

I. Introduction

3D CT examination and endoscopy are both critical to assessing lung cancer [1]. Endoscopy often includes a procedure called Trans-Bronchial Needle Aspiration (TBNA), which is a minimally invasive approach to sample the tissue in the lymph nodes [2, 3]. In this procedure, a physician first *manually* examines a 3D CT scan to identify the location of possibly suspect lymph nodes. Then, using his *mental impression* of the 3D CT image, the physician guides an endoscope through the bronchial airways to the suspect sites to perform the TBNA biopsies. TBNA itself is a difficult procedure since the target lymph nodes are behind the airway walls and hidden from the endoscopic video [4, 5].

The development of 3D imaging technology, particularly the new area referred to as *virtual endoscopy*, leads to many image processing techniques that can help physicians combine the endoscopic video information with the 3D CT image [4, 6–8]. This paper proposes a paradigm for virtual guidance of endoscopy using a two-stage approach. Our efforts focus on the chest and lung cancer, although they are conceivably applicable to other areas such as colon cancer or coronary-artery disease. In the first stage, a physician uses the 3D image to pre-compute guidance data to suspect biopsy sites. In the second stage, done during live endoscopy, a guidance system combines the image-based guidance data, rendered suspect biopsy sites, and the endoscopic video to give the physician interactive virtual views. A multimode image-registration technique matches the virtual 3D CT view with live endoscopic video images [9]. This determines the endoscope's position relative to 3D CT coordinates, so that a suspect site extracted from the CT can be drawn on the video screen as a biopsy target.

Mori *et al.* developed a virtual endoscopic guidance system, which includes video-to-virtual CT registration [8]. The system does not include endoscope distortion correction, has not yet been tested in a live environment, and does not work at interactive rates. Bricault *et al.* devised a method that includes live registration of video and virtual CT images, but the method is restricted to bronchial regions at branch bifurcations [7]. McAdams *et al.* showed the usefulness of a virtual endoscopic system to live procedures, but the system lacks guidance information from a pre-computed path and does not register video to CT images [4]. Other authors have shown virtual endoscopy as a pre-procedure planning tool, but have not shown its applicability to live endoscopy procedures.

Our approach works for both initial 3D image assessment and subsequent live endoscopy. Section II overviews our two-stage procedure. Section III outlines the image-processing tools. Section IV gives animal and human results and concluding remarks.

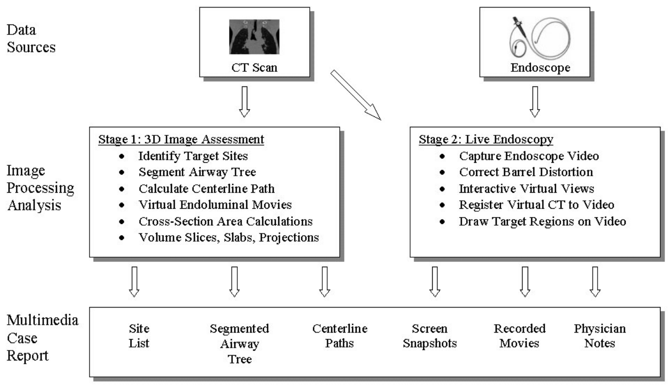

Fig. 1. Two-stage procedure for Image-Guided Endoscopy.

II. Two-stage Approach

Figure 1 depicts the two-stage approach, and Figure 2 shows the associated hardware. Stage-1 involves initial 3D image assessment. A preliminary analysis of the patient is done on a thoracic 3D CT scan image. The physician identifies biopsy sites such as lymph nodes. The airway tree is segmented using an adaptive searching technique, and guidance paths are created through the centerlines of the major airways [10]. These data serve as a road map for subsequent interactive virtual guidance. The physician can create endoluminal movies along a path to plan an endoscopic procedure. Also, the physician can assess supplemental 2D slice images, projection views, and thin-slab views for further planning [10]. All of these data are stored in a multimedia case study. The physician can refer to this one source

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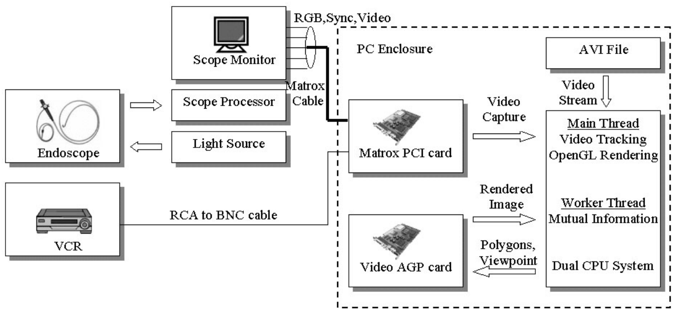

Fig. 2. Hardware diagram for Two-stage Image-Guided Endoscopy system.

to look at the input 3D CT data, endoluminal views of the airway tree, snapshots and movies captured during the endoscopy, and any notes recorded during the assessment.

During Stage-2, live endoscopy occurs. The physician uses the case study loaded into the computer system in tandem with the endoscope's video stream to perform the endoscopy. The computer display presents a rendered airway tree, the guidance path data, and local rendered endoluminal (inside the airway) views. The endoscopic video undergoes live distortion correction, so that its field of view matches that of the virtual endoscopy system's endoluminal renderings [11, 12]. An operator can interactively pick path points on the rendered tree, and a virtual endoluminal view appears at that location. This is helpful for guidance to the proper site. When the endoscopist is at the target site, he can turn on a 3D-image/video registration algorithm. The system performs an image registration to find the virtual viewpoint that best matches the current endoscopic video view (i.e., the real endoscope's current position). When the registration is complete, a virtual rendered image of the target site is drawn with the same field of view as the endoscope and the pre-computed biopsy sites are drawn on the live endoscopic video data. This gives the endoscopist a strong reference point to stick his needle, not available from raw endoscopic video, for performing an extraluminal biopsy.

III. Image Processing Tools

Figure 2 depicts the image-processing system. It is a PC-based software system with a large number of visual and analysis tools [10]. These tools include: 2D slice viewing, endoluminal rendering, projection viewing, 3D path analysis, 3D surface rendering, thin-slab viewing, airway cross-sectional area plotting, endoscopic video correction, and CT-video registration.

The system offers physicians considerably greater visual and analytical capability than standard manual assessment. Capability exists to take direct measurements

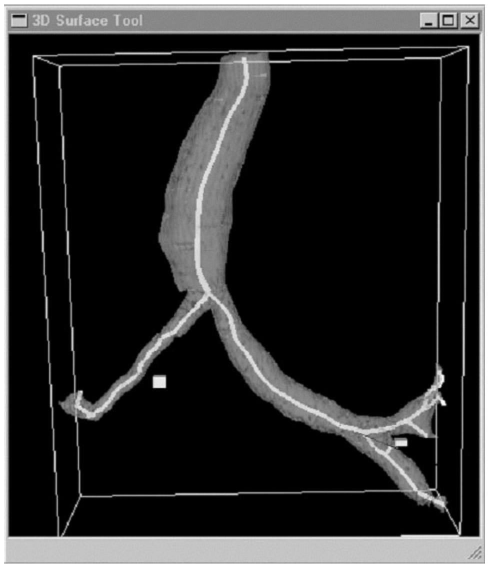

Fig. 3. The Surface-Render Tool shows a rendering of the 3D airway tree, target biopsy sites (small cubes), and automatically computed centerline guidance paths. This patient has a stent in the right-main bronchus, as indicated by the narrowed airway on the left side (image is viewed from the front).

of areas, segment out physical structures which may be hard to locate with visual inspection, and plan endoscopy. During Stage-2 endoscopy, video is captured to a PC through the RGB output connections from the endoscope. These signals are brought into a Matrox Meteor II frame grabber card at live video rates. Visual C++ 6.0 programs have access to the live video images by interfacing through the MIL (Matrox Interface Libraries) software package. Surface renderings of data are calculated on a 32MB AGP card using OpenGL commands. The virtual images are copied from the video card to the CPU for processing. Below we highlight some key system tools.

The Surface Render Tool (Figure 3) assists a physician in understanding his global position during endoscopy. It depicts a rendering of the segmented airway tree, guidance paths, and biopsy sites. The user can select points on the paths to command 3D virtual viewpoints to other tools in the system. The interactive viewpoint allows the physician to verify the endoscope location in the airway tree for the virtual views. As another global reference view, the Cube Tool (Figure 4) simultaneously depicts coronal (x-z plane), sagittal (y-z plane), and transverse (x-y plane) 3D CT image data, along with direction vectors superimposed on each view (and "floating in space") for the current viewing site.

The Video Match tool is involved during Stage-2 endoscopy to (1) track the position of the endoscopic video relative to the virtual 3D-image (CT) world and (2) provide target site information to the endoscopist (see Figure 5). When the physician selects a path point

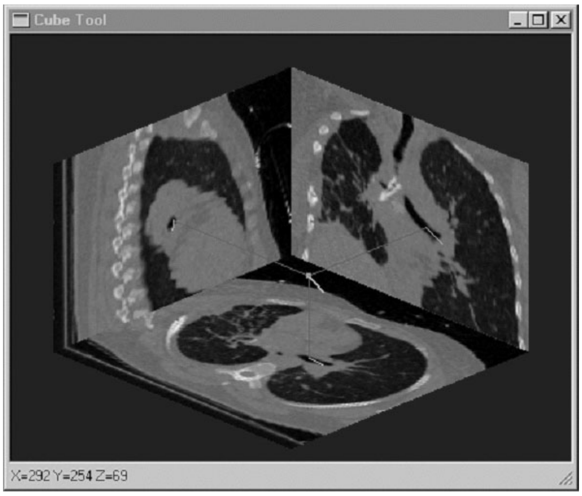

Fig. 4. The Cube Tool gives the orientation of the procedure path relative to the coronal (x-z plane), sagittal (y-z plane), and transverse (x-y plane) slice views. Direction arrows appear on the view for further orientation.

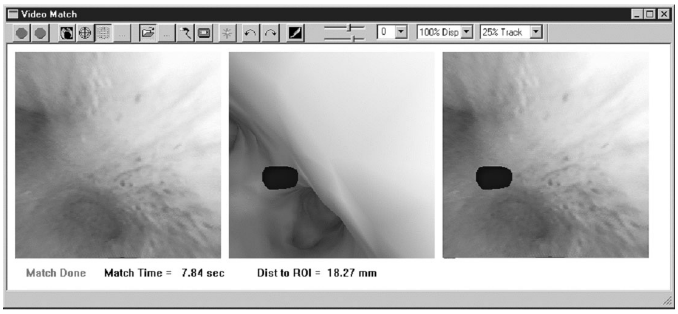

Fig. 5. The Video Match Tool. On the left is the live endoscopic video stream. In the center is the matching virtual endoluminal rendering from the 3D CT data. The matched endoscopic video view is on the right with a rendered target site (from the registered CT) drawn on it.

on the Surface Render tool (Figure 3), the virtual endoluminal rendering appears in the Video Match tool (Figure 5, center). The endoscopist then moves the endoscope "close" to this virtual site (Figure 5, left). A mutual-information-based image registration algorithm then performs a 3D spatial search of the virtual (3D CT) viewpoint that best matches the video frame. This algorithm, described in [9], is rapidly able to perform multimodal registration of the two different image sources (virtual 3D rendering and endoscopic video).

When the registration is complete, any previously defined target site ROIs appearing in the 3D CT (as defined for the Case Study in Stage-1) are then rendered onto the endoscopic video. The fused video image (Figure 5, right) gives hidden biopsy site information to the endoscopist, not available by raw endoscopy only. This gives the physician visible spatial information to plan a needle incision.

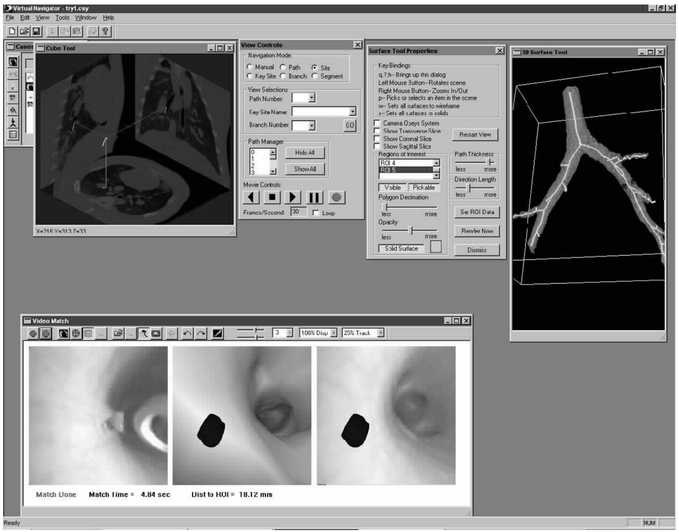

Fig. 6. A composite view of the image guidance system during a live pig study. The Cube tool in the upper left shows the virtual endoscope's position and orientation relative to the three orthogonal slice views, coronal (x-z plane), sagittal (y-z plane), and transverse (x-y plane). The Surface Render tool in the upper right shows centerline paths, airway tree and biopsy ROIs. By picking a point on a path, this sets the virtual view in all the other tools to this point. This is how an initial viewpoint is set before video-virtual CT optimization. The Video Match screen shows a matching video-virtual CT view after registration. The biopsy target is drawn relative to the virtual viewpoint and placed on the video view for live procedure guidance.

IV. Results and Discussion

Figure 6 shows an example composite view from a live pig study. The pig underwent 3D Electronic Beam Computed Tomography (EBCT) scanning to give a 512x512x120 3D CT image ($\Delta x = \Delta y = 0.4102$mm; slice thickness $\Delta z = 1.5$mm). During Stage-1 (3D image assessment), the airway tree, central axes, and biopsy sites were defined and saved in the Case Study. Next, during Stage-2 (live endoscopy), the endoscopist was guided to a biopsy site – see Figure 6. Figure 7 gives a complete two-stage example of a human case. A 3D helical CT scan was done to give a 404x424x142 3D CT image ($\Delta x = \Delta y = 0.609$mm; slice thickness $\Delta z = 1.2$mm). As before, the case study was defined. Figure 7 gives an example composite shot during endoscopy.

The final paper will give more details. Our follow-on efforts entail more human validation and automated detection of suspect sites, such as lymph nodes, isolated cancer nodules, and airway wall thickenings.

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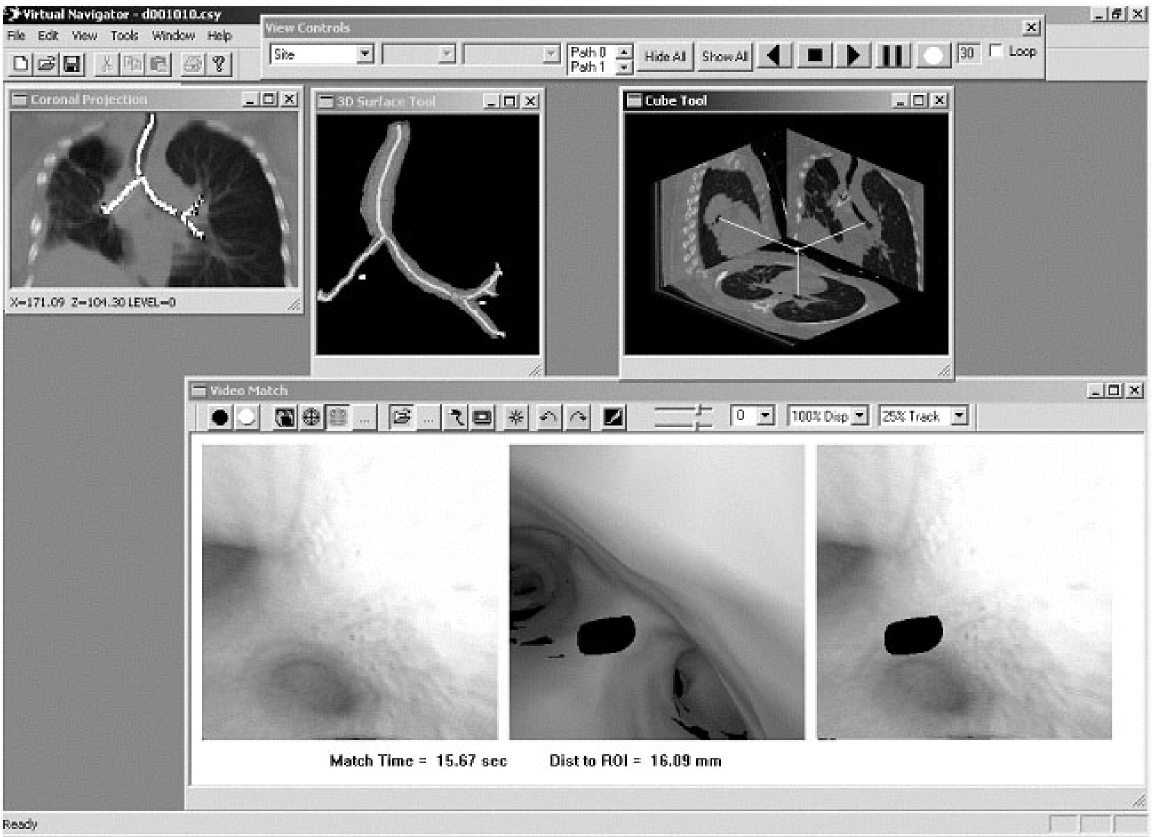

Fig. 7. A composite view of the image guidance system during a human endoscopy. The upper left display shows a weighted-sum 2D coronal projection of the 3D CT image, calculated from averaging the intensity values of all the coronal slices. The computed centerline paths are included in the display. The Cube tool in the upper right shows the virtual endoscope's position and orientation relative to the three orthogonal slice views (coronal, sagittal, and transverse). The Surface Render tool in the upper middle shows centerline paths, airway tree and biopsy ROIs. By picking a point on the path, an initial viewpoint is set before video-virtual CT optimization. The Video Match view depicts a matching set of video and virtual shots after registration. The biopsy target is drawn relative to the virtual viewpoint and placed on the video view for live procedure guidance.