MEDICAL IMAGE COMPUTING AND INTELLIGENT MEDIA INTEGRATION AT IMI-COE: RESEARCH RESULTS AND FUTURE PROBLEMS

Kensaku Mori

Graduate School of Information Science, Nagoya University

ABSTRACT

This paper presents an overview of research results and future research directions related to medical image computing at the Intelligent Media Integration COE. In particular, we introduce Navigation-based Intelligent Computer Aided Diagnosis, called NavI-CAD, which assists diagnosis of medical images through the navigation of a human body. In the era of "whole-body scanning," it is important to develop CAD (Computer Aided Diagnosis) systems that can automatically detect multiple diseases occurring in several organs. Also it is important to develop a computer-assisted surgery system that use information contained in such medical images. Through the IMI COE project, we have been working on development of NavI-CAD, which fuses computer-aided diagnosis and a new diagnostic method, called *navigation diagnosis* enabling us to navigate inside a human body. The NavI-CAD system has many functions for assisting diagnostic processes by employing advanced visualization techniques. NavI-CAD has been extended to a system that assists with interventional procedures. In this short paper, we summarize the research results from the viewpoint of intelligent media integration, and outline future research direction.

1. INTRODUCTION

In the field of medical imaging, remarkable progress has been made in volumetric image scanners, such as multi-detector row CT scanners (MDCT) and MR (magnetic resonance) imaging scanners. For example, MDCT can acquire whole-body CT images in about twenty seconds with approximately 0.5 mm resolution. Although it is possible to acquire very high resolution medical images, the load on radiologists is significantly increasing, leading to strong demand for the development of computer-aided (or assisted) diagnosis systems (CAD system) for such images. Also, computer-assisted surgical systems are desired.

In the era of "whole-body scanning," it is important to develop a CAD system that can automatically detect many different diseases occurring in multiple organs. Such a CAD system is required to process functions that can recognize all organs contained in medical images and analyze all of the diseases occurring in these organs. The IMI COE and the collaborating project "Intelligent Assistance in Diagnosis of Multi-dimensional Medical Images" (the primary research area funded by the Grant-in-Aid for Scientific Research by the Ministry of Education, Culture, Sports, Science and Technology and led by Dr. Hidefumi Kobatake, the President of Tokyo University of Agriculture and Technology) are working on development of CAD systems for higher-resolution and higher-dimensional medical images covering the entire human body [1]. This system utilizes two kinds of databases (a) the digital atlas of human anatomy (DAHA); and (b) digital representation of diagnostic knowledge (DRDK). The DAHA is a computer-readable database that holds precise information about human anatomy. The DRDK is also a computer-readable database that stores information about diseases that are recognizable on medical images.

The goal of our research project at the IMI COE is to construct highly sophisticated CAD systems that can assist or augment diagnostic processes of physicians by efficiently and effectively presenting the results of medical image understanding and recognition obtained by using the DRDK and the DAHA. Intelligent information integration is attempted in this research. In this framework, our research group is trying in particular to develop a navigation-based intelligent computer aided diagnosis system (NavI-CAD) that fuses computer-aided diagnosis and a new diagnostic method called *navigation diagnosis*, which enables us to navigate inside a human body. NavI-CAD includes many functions for assisting diagnostic process by employing advanced visualization techniques. It integrates a wide range of information about anatomical structures extracted from medical images.

In this paper, we introduce examples obtained under the auspices of the IMI COE. Especially, topics related to NavI-CAD will be presented. Also, we discuss the meaning of nav-

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igation in NavI-CAD. The system of intelligent media integration will be reviewed from the process of lung and colonic cancer screening and treatment.

2. MEANING OF NAVIGATION

As described in the previous section, our research group is working on development of NavI-CAD, which fuses computer-aided diagnosis and navigation inside a human body. Navigation is vital keyword in NavI-CAD and in the framework of intelligent media integration, since clarification of navigation targets is expected to be an important point in explaining NavI-CAD, aimed for diagnosing multiple organs and diseases under the concept of intelligent media integration.

The meaning of navigation as used in NavI-CAD includes not only the meaning of "navigation to a target point" but also that of "navigation through various axes." The former meaning is just like a GPS navigation system used in a vehicle or a vessel. We consider that navigation is performed in two types of spaces: (a) the physical space and (b) the semantic space (Fig. 1). The former space is spanned by (1) the space axis, (2) the time axis, (3) the intensity axis, and (4) the scale (resolution) axis. These axes are related to certain physical measures. The latter space is spanned by (5) the anatomical object axis and (6) the disease axis. In this case, navigation is performed in the semantic space constructed from the results of understanding and recognizing medical images. Polyp navigation in virtual colonography is a good example. Mixed-space navigation (mixture of physical- and semantic-space navigation) is also an important navigation type. In "Navigation-based Intelligent Computer-Aided Diagnosis," semantic-space navigation is important, a concept that corresponding to intelligent media integration.

Free fly-through in a virtual endoscopy (VE) system is classified as navigation in the space axis; guidance to a desired (target) point by automated fly-through or showing paths are also classified as navigation in the space axis. Navigation in the time axis means observation of time series of medical images such us 3D ultrasound images or 3D CT images of follow-up CT scanning for cancer care. Intensity-axis navigation means, for example, observation of 3D medical images by volume rendering with dynamic changes of transfer-function tables [2]. Scale-axis navigation means observing medical images while changing their resolutions such as seamless transition of medical images taken of the macro and the micro scales. On the other hand, anatomical-object navigation, for example, includes observation of multiple organs while changing target organs by following organ lists that a computer automatically generated by a computer, with target organs being specified by their anatomical names. Navigation of suspicious regions, such as follow-up of all of suspicious regions detected by an automated algorithm, is also classified as the semantic-space navigation. These suspicious regions are displayed not only by marking them on original images but also by showing additional semantic information such as their location described in anatomical terms.

As described above, navigation diagnosis means observing medical images while changing various parameters of various axes. In the sense of navigation-based intelligent computer aided diagnosis, it is important to navigate in both semantic and physical space.

3. NAVI-CAD AND IMI

In this section, we briefly introduce implementation examples of NavI-CAD, including one for the chest and one for the colon. The NavI-CAD system analyzes 3D CT images to extract the anatomical structure of a patient and to find abnormal regions. Then the system outputs analysis results to augment a physician's decision process. The NavI-CAD system also assists a physician during examination or surgical procedures by using a function of real environment sensing (such as endoscope guidance.)

3.1. NavI-CADs for Chest and Colon

3.2. Overview

NavI-CAD for Chest is a CAD system based on navigation diagnosis that targets the chest. NavI-CAD for Chest includes the following functions: (a) segmentation of organs in the chest area; (b) automated classification of the pulmonary arteries and veins; (c) automated extraction of lesions; (d) automated nomenclature of the bronchial branches; (e) intelligent path generation; (f) advanced visualization by integrating segmentation results; and (g) bronchoscope navigation by utilizing a bronchoscope-tracking method. Figure 2 shows a schematic framework of NavI-CAD for Chest. A detailed explanation of each function will be provided in another paper from this symposium.

NavI-CAD for Colon has similar functions [3]. It has been developing for assisting diagnosis of disease related to the colon, based on abdominal CT images (Fig. 3). NavI-CAD for Colon consists of the following functions: (a) generation of virtual unfolded views [7]; (b) visualization of intensity information beyond colonic walls; (c) automated detection of colonic polyps; (d) observation assistance of detected colonic polyps [10]; (e) integrated display; and (f) a user interface.

3.3. NavI-CAD and IMI

3.3.1. Anatomical structure recognition as a basis of information integration

NavI-CAD for Chest is implemented according to the concept of intelligent medial integration. The goal of medical image analysis is "maximum extraction of anatomical information from input medical images." To achieve this aim, NavI-CAD

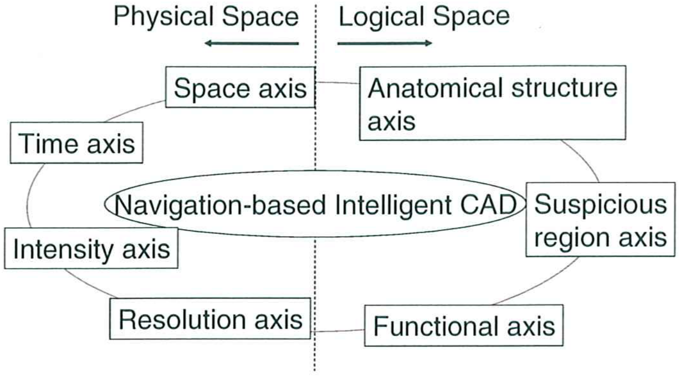

Fig. 1. Meaning of navigation used in the NavI-CAD.

for Chest has several functions. The first function is segmentation. Since there are many organs in the chest area, it is necessary to segment the area to properly define individual organs. Segmentation results are especially indispensable in the case of semantic-space navigation. NavI-CAD for Chest can automatically segment several organs including lung regions, blood vessels, bronchi regions, arteries, and lung nodules. The system is also capable of automatically classifying pulmonary arteries and veins and automated division of lung lobes. Lung nodule extraction is achieved by combining thresholding and shape analysis, and automated classification of pulmonary arteries and veins is done by using distance features between bronchi and blood vessels. The lung region is divided into lung lobes by using fissure information extracted by enhancing sheet structures on CT images [4]. These segmentation results form basis of semantic integration of information contained in medical images and are used for various purposes.

NavI-CAD for Colon can automatically segment a lumen region of the colon, the medial axis of it, blood vessels related to the colon, and clonic polyps. These data are applied as basis data for information integration to augment a physician's decision-making process.

3.3.2. Understanding anatomical structure

Understanding anatomical structures is vital for intelligent information integration in NavI-CAD. To achieve this purpose, the NavI-CAD for Chest can automatically apply nomenclature to bronchial branches, performed using NavI-CAD's database for anatomical names of bronchial branches [5]. The nomenclature process is basically a graph-matching process of input tree structures of bronchi and tree structures stored in the database. Because there are many variations in branching patterns among the general population, we prepared several branching structure models in the database. These models are prepared for the right upper lobe, the right middle and lower lobes, the left upper lobe, and the left lower lobe. For each part of the lung, we prepare multiple models. The automated nomenclature process selects the model of best fit from these models based on deformation angles, which are angles for fitting branch models into input tree structures [5]. Figure 4 shows an example of tree models. Each of these models corresponds to a realization of the DAHA. The bronchus is quite an important organ in diagnosis of the chest, thus the precise recognition of bronchial branch names is necessary in NavI-CAD. For example, it is possible to describe the locations of lung nodules by using the anatomical names of bronchial branches related to them, since a physician usually uses the anatomical area name or the anatomical branch name related to an abnormal region. This is a step toward integrating all of the information in the anatomical space, considered as a type of intelligent media integration.

3.3.3. Intelligent path generation

NavI-CAD for Chest can find the best trans-bronchial path to an automatically detected nodule. The path generated by this function actually consists of two types of paths: (a) medial axis path defined on the medial axis of the bronchus; and (b) a set of anatomical names of regions that we should pass through through arrive at the destination (lung nodule) (Fig. 5) [6]. The former path corresponds to navigation in the space axis and the latter one corresponds to navigation in the anatomical structure axis. Furthermore it is possible to describe the locations of lung nodules that are automatically detected by using the anatomical name of a branch related to certain nodules. This method can also be used for path planning for TBLB. Since in practice, all of anatomical objects and procedures are described by using anatomical terms. Integration of path generation and anatomical name-finding is an important and useful function.

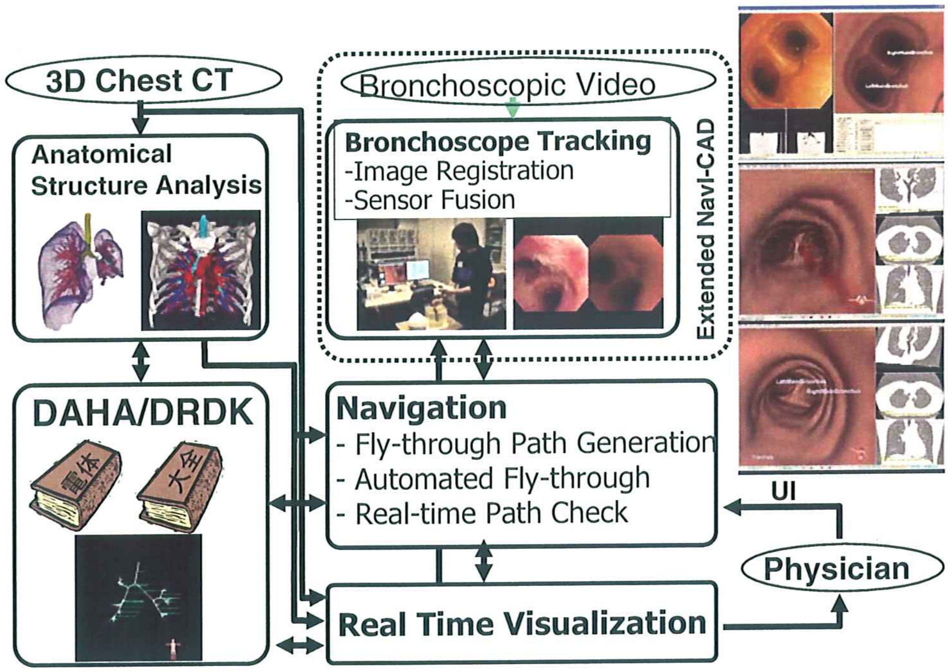

Fig. 2. Schematic illustration of NavI-CAD for Chest.

3.3.4. Integrated display based on anatomical information

NavI-CAD for Colon has the following functions for assisting observation of CT images [3]: (a) direct jump to polyp candidates detected by the method shown in the previous section; (b) assistance for understanding polyp shape by rotating the viewpoint of a VC view around the detected polyp; and (c) detection of unobserved regions. All NavI-CAD views including unfolded views [7], VC views, colon CPR (Curved Planner Reconstruction) views, outside views of the colon, and MPR (Multi-Planner Reconstruction) views, are completely synchronized through the integrated display function. Integrated display is achieved by integrating anatomical data extracted from 3D CT images. Special human interface devices, such as a joystick or a shuttle controller, can be connected to NavI-CAD for Colon to enable efficient reading.

3.3.5. Fusion with real endoscope

NavI-CAD for Chest has functions not only for computer-aided diagnosis for 3D medical images but also for assisting bronchoscopic examination or intervention. Here, to enable us to use NavI-CAD for Chest as a guidance system for bronchoscopic examination, we have implemented a function for automated tracking of a bronchoscopic camera. This bronchoscope tracking is based on image registration between real bronchoscopic (RB) views and virtual bronchoscopic (VB) views derived from preoperative CT images [8]. For each frame of the RB video, we find the viewpoint and the view direction of the VB system that can generate a VB image that is most similar to the real one. The position and direction found in this process are represented in the coordinate system of the preoperative CT images. It is possible to track RB camera motion by iterating this process for all frames of the RB video. RB examination can be assisted by displaying data described above in synchrony with RB motion (Fig. 6).

To improve tracking robustness, we are investigating the use a positional sensor attached at the tip of the bronchoscope. A tiny electro-magnetic positional sensor is now commercially available, which sensor can be inserted into the working channel of a bronchoscope. However, the tracking accuracy of this sensor is insufficient due to ferromagnetic material in place use around the sensor. To solve this problem, we have developed hybrid tracking system that uses both sensor tracking and image-based tracking [9]. In this method, the sensor output is used as an initial guess for image-based tracking, and by performing image-based tracking after sensor tracking, it is possible to obtain very high accuracy while reducing the computational cost (Fig. 7). This is also a type of intelligent medial integration (registration of segmentation results and real environment sensors).

Real colonoscope tracking is also one of challenging problems. because the colon exhibits high deformation during colonoscopic examination, we have to compensate for this deformation when tracking the tip of the colonoscope. Registration of a real (optical) colonoscope and a virtual colonoscope is an exciting problem, since it is just an issue of intelligent media (optical and virtual) integration. Further research is needed.

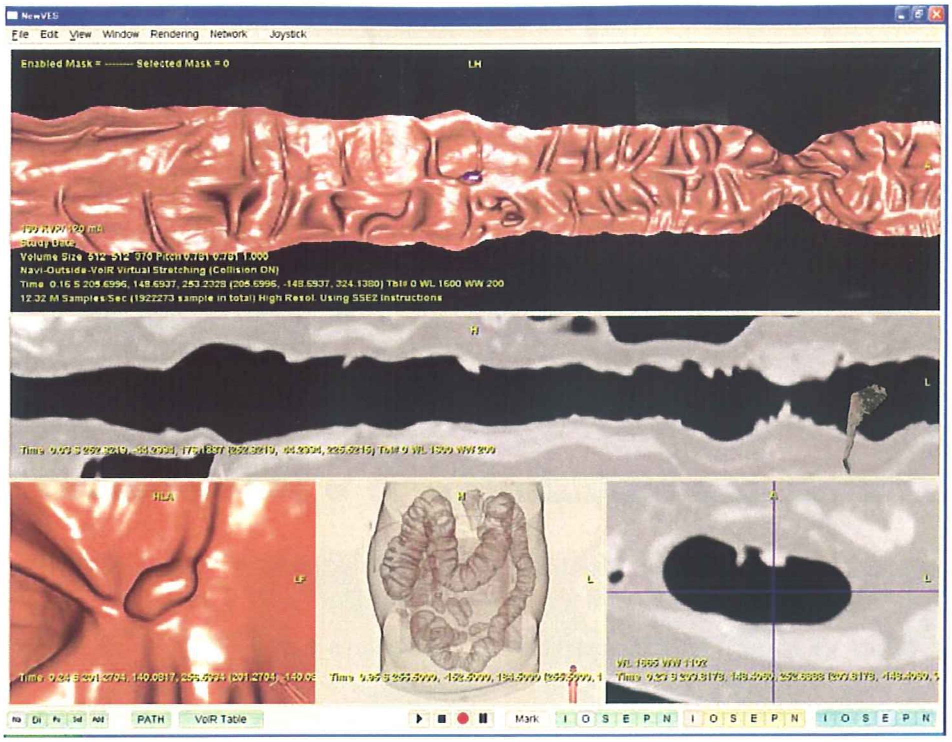

Fig. 3. A screen shot of NavI-CAD for Colon.

4. FUTURE CHALLENGES: TOWARD REAL INTELLIGENT MEDIA INTEGRATION IN MEDICAL IMAGE COMPUTING

In this short paper, we have demonstrated our research results related to medical image computing at the IMI COE, with two NavI-CAD systems introduced as those implemented under the concept of intelligent medial integration. However, there are many problems left to solve, which we would like to summarize below.

Although NavI-CAD integrated all of the data extracted from medical images based on anatomical information, this integration is not sufficient, since NavI-CAD used only local anatomical information, not global anatomical data. To construct complete CAD systems, we need to use global anatomical information, which means whole-body anatomical information. In addition, the concept of level-of-detail should be introduced here, because there are a lot of anatomical structures in a human body. NavI-CAD can be used at all of stages of a medical procedure (Fig. 8), but to support such procedures it is necessary to develop computer-assisted systems based on anatomical information integration.

Fusion with real-world information is also another significant challenge in the field of medical image processing. After the detection of abnormal regions, patients are referred to treatment or surgery. In such situation, real patient information captured in the examination or operating room should be seamlessly integrated with virtual information (data obtained from medical images) (Fig. 8). Real endoscope tracking is one example of this fusion. However, much information is recorded in an operating room, and it should be completely integrated. Such information includes not only images (video and medical imaging modalities) but also audio data. All kinds of information gathered in an operating room, including the behavior of surgeons and assistants, images from intraoperative imaging devices, vital-sign monitors, and videos of surgical areas, should be captured and shared for better surgery. For this purpose, it is necessary that the system's computer understands surgery conditions and thereby output appropriate information to augment the medical staff's decision-making process.

5. CONCLUSION

This paper presented an overview of the research results related to medical image computing at the Intelligent Media Integration COE. In particular, we introduced a Navigation-based Intelligent Computer-Aided Diagnosis system (NavI-CAD) that uses medical images of navigation through a human body to assist with diagnosis. We described intelligent media integration of NavI-CAD for Chest and NavI-CAD for Colon, showing several examples. Furthermore, we discussed the meaning of navigation using NavI-CAD, and reviewed in-

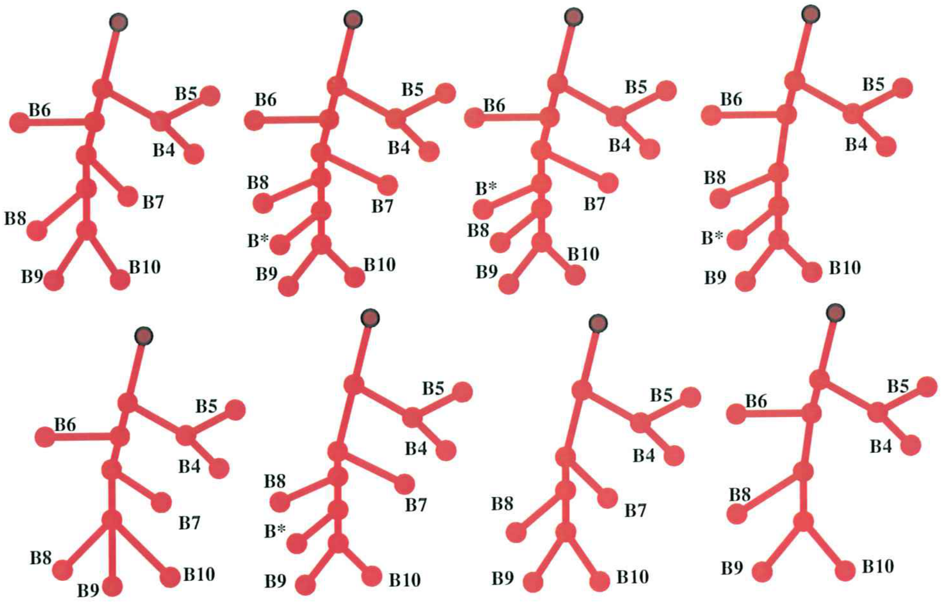

Fig. 4. An example of bronchial branch models.

telligent media integration from the aspect of lung and colonic cancer screening and treatment. We also outlined future research directions under the concept of intelligent media integration.

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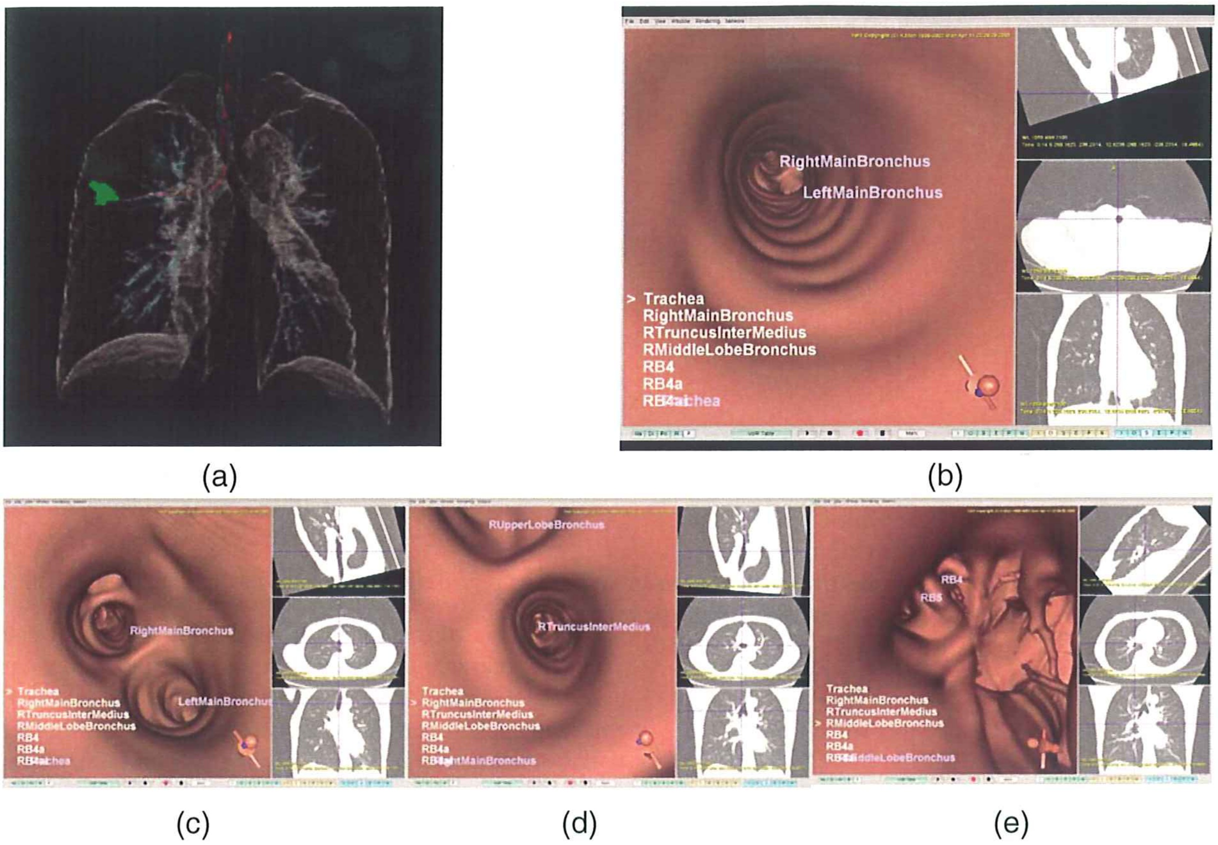

Fig. 5. Intelligent path generation to a lung nodule in NavI-CAD for Chest. (a) Target nodule; (b) generated path and a set of branch names; (c)-(e) screen shot of generated path.

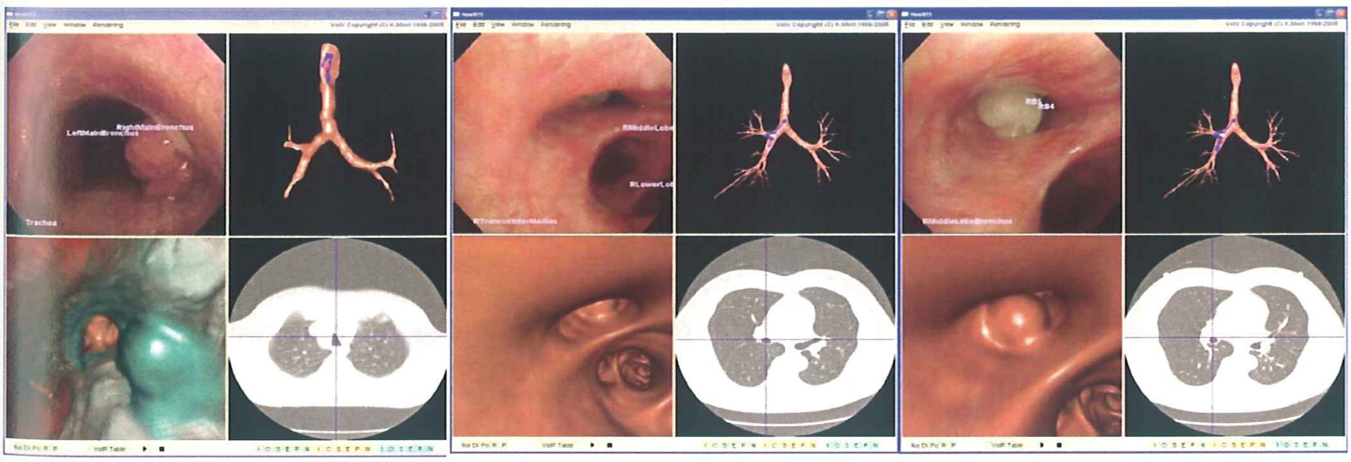

Fig. 6. Examples of real bronchoscope navigation.

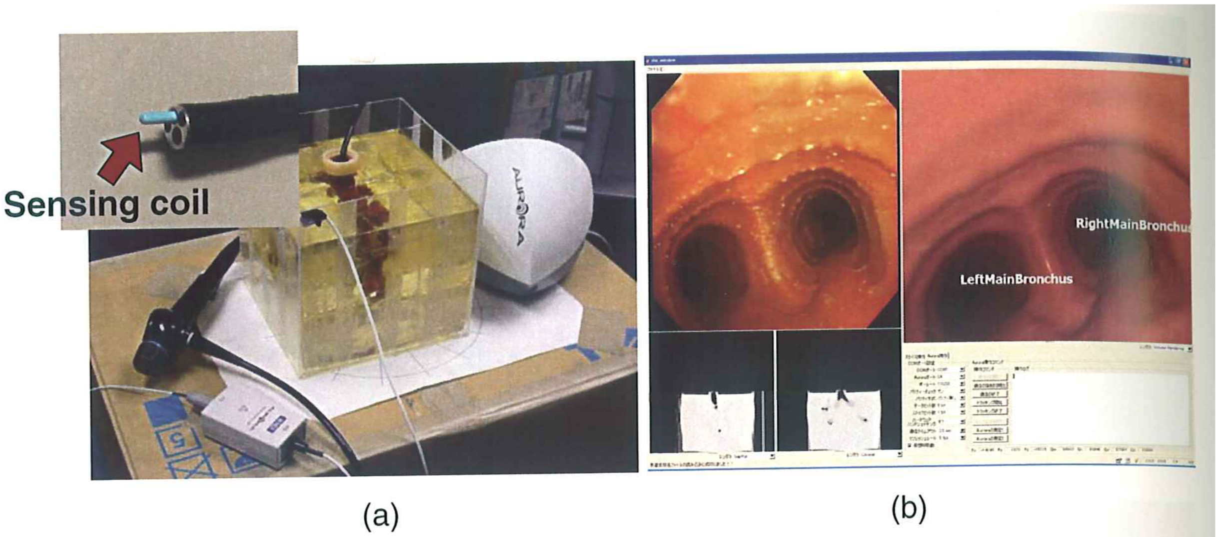

Fig. 7. Bronchoscope tracking using electro-magnetic sensor and image registration. (a) Overview of electro-magnetic sensor; (b) a screen-shot of hybrid tracking using sensor and image registration.

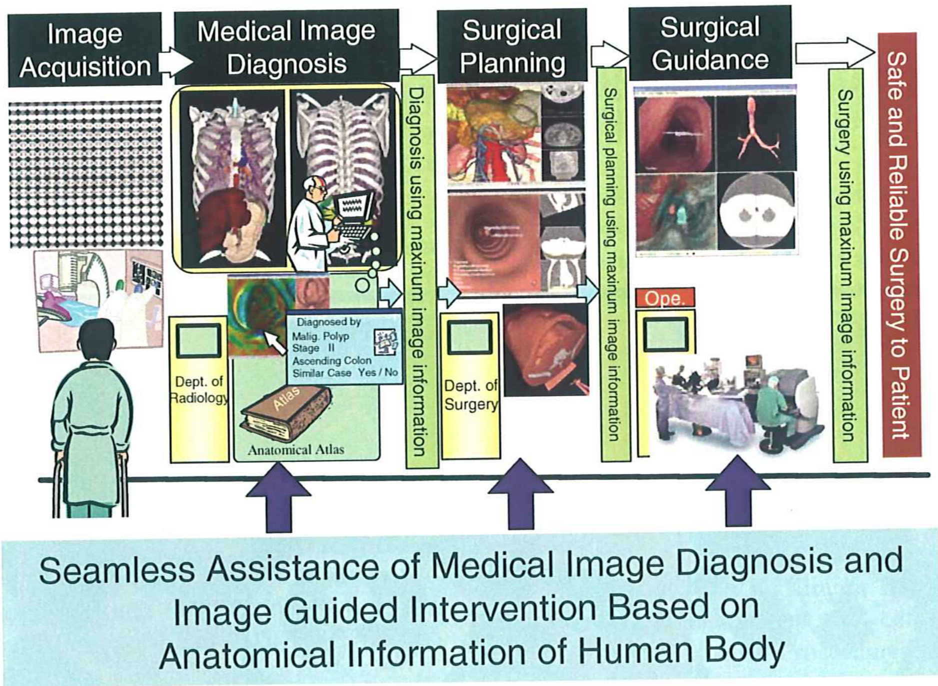

Fig. 8. NavI-CAD supporting all stages of a medical procedure. Anatomical information integration is necessary for this purpose.