CHAPTER 7

THREE DIMENSIONAL VISUALIZATION
OF MALIGNANT NODULES

7.1 INTRODUCTION

The essential organ of respiration in humans is the lungs. The anatomy of the human lungs is shown in Figure 7.1; it has five distinct partitions called lobes. The lobes are separated by the lobar fissure. Lobar fissures are the boundaries of the lung lobes, where the vascular and bronchial trees are absent. The right lung consists of the superior lobe, middle lobe and inferior lobe, which are separated by a right horizontal fissure and right oblique fissure. The left lung consists of superior and inferior lobes, which are separated by a left oblique fissure (Esomomu et al. 2013). In general, the functions of the lobes are relatively independent of one another, with no major airways or vessels crossing the lobar fissures (Wei et al. 2009). The Figure 7.2 shows the shapes (irregular shapes) and positions of malignant nodules in the lung lobes.

Figure 7.1 Anatomy of human lung (Wei et al. 2009)
Radiographic imaging plays an important role to detect and diagnose the abnormalities in the lungs. Lung nodules are the round shaped growth in the lungs (Austin et al. 1996). In people less than 35 years of age, the probability that a lung nodule cancerous is less than 1%, whereas above the age of 50 years, half the lung nodules in people are malignant (cancerous). The other factor that increases the lung cancer includes, smoking history, occupation, medical history, shape and growth (Lee et al. 2005). The primary radiographic imaging tool for lung nodule detection is Computed Tomography (CT), which has replaced the earlier film-based projection radiography (Wang et al. 2011). The cancerous nodules can grow double in size on an average of every four months. The growth can be evaluated through a series of CT scans over a period of time.

Initial stage of treating lung cancer is surgical removal of the diseased portion of the lung lobe or treating it with chemotherapy or radio therapy or sometimes combinations of these. For this, the surgeons need to know the exact location and volume of the cancerous nodules in the lung.
lobes. In current clinical practice, surgeons read stacks of CT images for assessing the spatial relationships among anatomic structures of lung cavities, specifically identifying the diseased portion of the lung lobes. Reading CT slices is highly subjective task and requires enormous mental work to map the anatomic structures from the 2-D images onto the 3-D actual lung cavities. This leads to long planning times, heavy workload and low accuracy in the predicted surgeries. The 3-D Computer-Aided Diagnosis (CAD) systems help the surgeons to visualize the actual location of the cancerous nodules in the lung lobes, by reconstructing the 2-D CT slices in 3-D.

This chapter is organized as follows. Section 7.2 elaborates subjects and methods and section 7.3 gives the experimental results and discussions. This is followed by summary of this chapter in section 7.4.

7.2 MATERIALS AND METHODS

7.2.1 Study Population

In order to detect the actual location of the lung malignant nodules of patients (stages I and II), who have confirmed through the CAD systems using HNFS and FACMM with SVM, visualized 10 (5 stage I and 5 stage II) cancerous patients’ (Mean±SD age=62.5±9.8 years) images in 3-D. Of these 10 patients, 7 were males (Mean±SD age=65.14±8.96 years) and 3 were females (Mean±SD age= 57.88±10.03 years).

7.2.2 3-D CAD Visualization System using MIMICS

The 3-D CAD visualization system was carried using MIMICS (Developer Version 18.0, Materialize, Belgium) software (Ilavarasi and Anburajan 2011). It is an image processing software for 3-D design and modeling developed by Materializes. It calculates 3-D models from 2-D stacks image data such as CT, Magnetic Resonance Imaging (MRI) and
ultrasound through image segmentation. The Region Of Interest (ROI) of the image is selected in the segmentation process and converted into a 3-D model using an adapted marching cubes algorithm that takes the partial volume effect into account, leading to very accurate 3-D model (Wiener 1949).

A MIMICS accepts stacks of 2-D CT slices and reconstructs them into a 3-D lung model, from which the original lung cavities of human beings can be seen. The flow diagram of such a 3-D CAD visualization system is shown in Figure 7.3. It is a semi-automatic method uses two stage approaches for cancerous nodule detection and localization. In the first stage, stacks of 2-D CT slices are combined to make 3-D model of the lungs. In the second stage, cancerous nodule is segmented from the lung lobes. The reconstructed 3-D model of lung has soft tissues (lung region), which are surrounded by rib cage. The ROI of this work is focused on the cancerous nodule segmentation; hence the lung region is segmented from the rib cage for further analysis. Then the lungs are partitioned into lobes. Further, cancerous nodule is segmented from the lungs. Various measurements like height, length, breadth, and volume of the cancerous nodule are made. Finally, cancerous nodule is superimposed on the lung lobes to show its exact location in 3-D.
The series of steps involved in lung lobe segmentation and 3-D visualization of cancerous nodule are given below:

7.2.2.1 **Histogram analysis**

In two dimensional image processing context, the histogram normally refers to the frequency of occurrence of gray level values in an
image. However in three dimensional image processing context, it gives the frequency of occurrence of voxel (volumetric pixel) values in a stack of 2-D CT slices. The Hounsfield Unit (HU- a measure of tissue density based on X-ray attenuation in Computed Tomography scanners) is used to measure the voxel values. Human lungs consist of soft tissues which are surrounded by rib cage. The HU of soft tissues (lungs) are different that of HU of rib cages for the lung images. Therefore it is possible to segment the lungs from the rib cage based on the histogram (voxel distribution) analysis.

7.2.2.2 Thresholding and region growing for rib cage segmentation

The next step after the histogram of an image is thresholding technique. Thresholding plays vital role in image analysis based on HU. Although the HU of bones (rib cage) and soft tissues vary by huge amounts, they remain fairly constant among patients. Thus, by selecting the proper threshold values, the ribs can be segmented from the lungs. The voxel values of lungs and rib cage are distributed in the range between -1023 HU and 3071 HU. On the images, the areas of rib cage is bright (high voxel value) and the areas of soft tissues are dark (low voxel value). The volumetric pixels corresponding to the rib will have similar values. Therefore it is possible to segment the rib region from the lungs by proper choice of voxel value (threshold).

The purpose of region growing allows to grow the similar region (similar voxels) to make the 3D model. The segmented rib region using thresholding technique can be combined with the region growing (grow the rib region by the proper choice of voxel value) to produce 3-D model of the rib cage. The segmented rib cage appears with unique color in its 3-D model.
7.2.2.3 Segmentation of lungs and Lobes

The ROI in this study is focused on detection and localization of malignant nodules in the lungs. After the segmentation of ribs, the lungs will be segmented by dynamic region growing technique. The volumetric pixels corresponding to the soft tissues (lungs) will have similar values in nature. The dynamic region growing technique segments the lungs by the proper choice of seed value (similar to voxel of lung region). This avoids the computation of processing anatomic structures outside the lungs. Then the 3-D model is computed for the segmented lungs. The segmented lungs appear with unique color in its 3-D model.

The segmented lungs are then partitioned into lobes by extracting the lobar fissures in the stack of 2-D CT slices. In most of CT images, fissure regions generally appear as the regions with an absence of vascular and bronchial trees. The lobar fissures are the boundaries of lung lobes, which separate all the five lobes in the human lung. Thus, the lobar fissures in stack of 2-D lung slices need to be extracted for lung lobe segmentation. By segmenting the lung lobes later the location of the malignant nodules can be detected. The lobe segmentation is carried out separately for all the lobes by multiple slice edit and edit mask techniques on 2-D CT slices. The multiple slice edit allows editing the multiple CT slices and edit mask allows segmenting the each lobe by extracting the lobar fissures. Then 3-D model is created for all segmented lobes. All the segmented lung lobes appear with unique colour in the 3-D model.

7.2.2.4 Malignant nodule segmentation and its measurements

The malignant nodules grow in uncontrolled manner, when compared to benign nodules. The rate of growth can be analyzed through CT scan over the period of times. The malignant nodules can spread to the other
organs and kill them. Finally, it leads to patient’s death, if it is not treated. Therefore it is necessary to locate the malignant nodules for the effective treatment; thereby it increases the survival rate of the patients with lung cancer.

The malignant nodules can be segmented from the lung region of 2-D CT slices by dynamic region growing technique. The dynamic region growing technique allows, selecting the malignant nodule by the proper choice of seed value (similar to voxel of malignant nodule). The 3-D view is calculated for the segmented malignant nodules. The segmented malignant nodule appears with unique colour (different colour with that of the lobes). The segmented malignant nodule can be superimposed along with the lung lobes to show its actual location in 3-D. Further, the malignant nodules’ height, length, breadth and volume are measured using measurement tools.

7.3 EXPERIMENTAL RESULTS AND DISCUSSION

The input stacks of 2-D lung CT slices are fed to the input of MIMICS software. First, the histograms of the stacks of 2-D slices are calculated. The histogram analysis shows the volumetric pixel values corresponding to the soft tissues (lung region) and rib cage was distributed between -1023 HU and 3071 HU, which is shown in Figure 7.4.

Figure 7.4 Histogram analysis
The voxel values corresponding to the rib cage are selected using thresholding technique and combined with region growing to make the 3-D model for the rib cage (green color), which is given in Figure 7.5. Then, the dynamic region growing is performed by proper seed value and 3-D view is computed for the segmented lungs (brown color), which is illustrated in Figure 7.6. The same procedure is repeated with proper seed value to segment the malignant nodule (red color), which is shown in Figure 7.7.

Figure 7.5 Segmented ribs

Figure 7.6 Segmented lungs
The series of steps involved in the segmentation of malignant nodule is summarized in Figure 7.8.

Lungs were partitioned into lobes by multiple slice edit and edit mask techniques, which is given in Figure 7.8 (a). The right lung was divided into superior lobe (cyan color), middle lobe (yellow color) and inferior lobe.
(pink color). The left lung was partitioned into superior lobe (blue color) and inferior lobe (green color). Then the malignant nodule was segmented from the lung region by dynamic region growing and superimposed to show its actual location in the lung lobes (via transparent view), which is shown in Figure 7.8 (b). It is evident from Figure 7.8 (b) that, the malignant nodule is located in the right superior lobe. The segmented cancerous nodule is shown in Figure 7.8 (c). Further, malignant nodule height, length, breadth and volume were calculated using measurement tools. The locations of the malignant nodules detected for the 10 initial stage patients, who confirmed with CAD systems using HNFS and FACMM and SVM are given in Table 7.1. It is evident from table 7.1 that, the implemented 3-D CAD visualization system can aid the surgeons to know the location of the malignant nodule (in the lobes), its height, length, width and volume before they plan for the surgery (Appendix 8), thereby it reduces actual surgical time.

### Table 7.1 Various measurements of malignant nodules

<table>
<thead>
<tr>
<th># Patient</th>
<th>Malignant nodule location (in lobes)</th>
<th>Measurements of the malignant nodules</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Height (mm)</td>
</tr>
<tr>
<td>#1</td>
<td>Right-superior</td>
<td>12.5</td>
</tr>
<tr>
<td>#2</td>
<td>Right-superior</td>
<td>15.2</td>
</tr>
<tr>
<td>#3</td>
<td>Left-superior</td>
<td>12.4</td>
</tr>
<tr>
<td>#4</td>
<td>Middle</td>
<td>9.8</td>
</tr>
<tr>
<td>#5</td>
<td>Left-inferior</td>
<td>8.3</td>
</tr>
<tr>
<td>#6</td>
<td>Right-inferior</td>
<td>8.7</td>
</tr>
<tr>
<td>#7</td>
<td>Left-inferior</td>
<td>10.2</td>
</tr>
<tr>
<td>#8</td>
<td>Middle</td>
<td>9.7</td>
</tr>
<tr>
<td>#9</td>
<td>Left-superior</td>
<td>10.4</td>
</tr>
<tr>
<td>#10</td>
<td>Right-superior</td>
<td>12.4</td>
</tr>
</tbody>
</table>
7.4 SUMMARY

In this chapter the 3-D visualization of the CAD system was developed using MIMICS software. The thresholding, region growing, dynamic region growing and edit mask techniques were successfully created 3-D views for the ribs, lungs, lobes and malignant nodules. The developed visualization system was applied on 10 patients with initial stage (stages I and II) of lung cancer. In all the ten cases, the implemented CAD system successfully located the malignant nodules in the lung lobes. Further, the measured height, length, breadth and volume of the malignant nodules can help the surgeons before planning the surgery. This concept attracts MIMICS and its segmentation algorithms towards 3-D visualization systems.