Emphysema Detection using a Density Mask

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Introduction

Emphysema is a condition of the lung characterized by permanent, abnormal enlargement of airspaces accompanied by destruction of their walls without obvious fibrosis. [1]

Emphysema can be detected by biopsy, pulmonary function tests, radiography, and Computer Tomography.

Detection by Pathology

This involves analysing lung tissue samples, and is conducted post mortem.

Detection by Pulmonary Function Tests

"Pulmonary function tests may demonstrate elevated lung volume, air trapping, reduced expiratory airflow and destruction of the capillary bed." [1]

Detection by Radiography

"The main radiographic manifestations of emphysema are over-inflation and alterations of the lung vessels."[1]

Detection by Computer Tomography

"CT scans, particularly high resolution (HRCT) scans are the most accurate means of detecting emphysema and determining its type and extent in vivo.

"On an HRCT scan. emphysema is characterized by the presence of areas of abnormally low attenuation which can be easily contrasted with the surrounding lung parenchyma, if sufficiently low window values are used." [1]
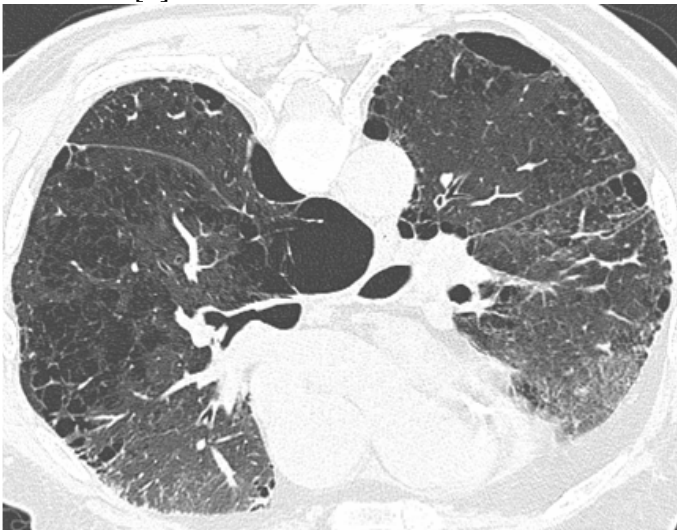

Figure 1 I100 , an HRCT image exhibiting emphysema

Research Aim

To develop automated process to recognize and calculate the area of the lung that is affected by emphysema.

Density masks from HRCT have been used successfully to recognize emphysema, and in earlier studies the results have been confirmed by biopsy[2] and pulmonary function tests [3].

Process Approach

To detect emphysema we need to:

1. Obtain an image

2. Obtain a density mask of emphysema

3. Obtain a frequency map of the density mask

4. Obtain a region map of emphysema

5. Remove Noise from the region map

Obtaining the Image

CT machines measure the attenuity of each cell in the slice matrix.

Attenuity is a measure of the absorption of X-rays energy relative to water.

$$Attenuity = K \times \frac{\mu_{water} - \mu_{cell}}{\mu_{water}}$$
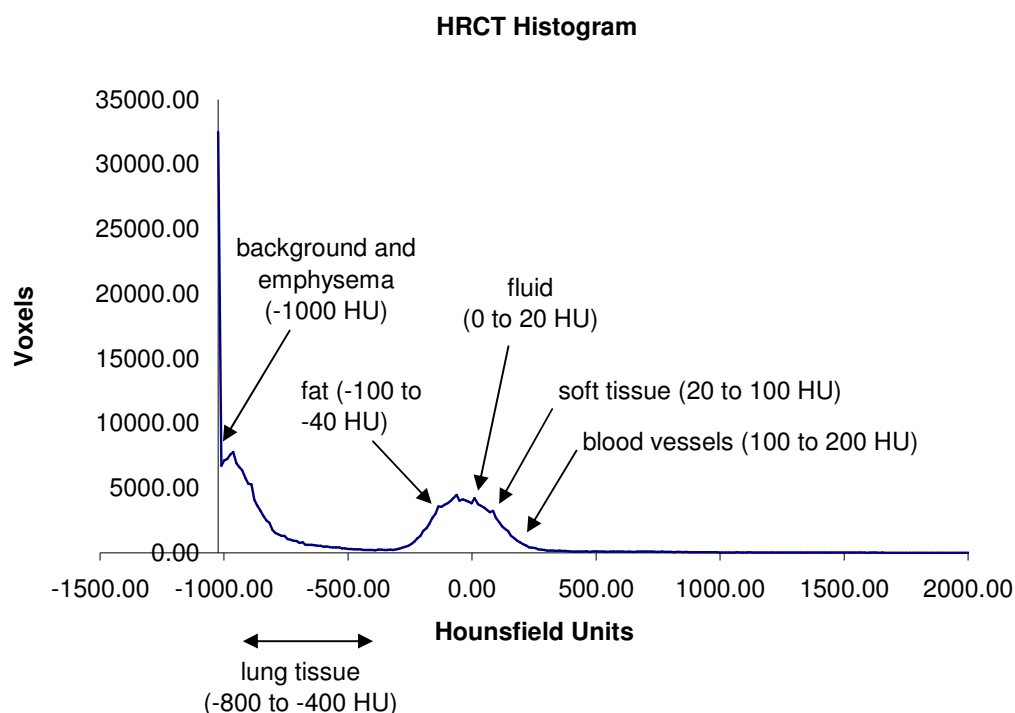
In practice when K =1000, the attenuity value is in Hounsfield Units.

Limits of Hounsfield values:
     Dense Bone   = +1000 HU
     Water   =   0 HU
     Air   = -1000 HU

CT machines calibrate their results so that the values obtained for dense bone is +1000 HU, and the value for air is -1000 HU.
For tissue, the values obtained from the HRCT machine lie between -1000 HU and +1000 HU.

HRCT Histogram

Figure 2 histogram for I100
        (housfield units for different tissue see [6])

The data obtained from CT, is stored in a DICOM file.

Such a file contains the characteristics of the CT machine, image parameters, the slice thickness, the slice position, the pixel data, the image format, the patient orientation and patient statistics[4].

In particular for CT images, the pixel data is not the sample data obtained by the CT machine, as they are converted to conform with the storage requirements of DICOM (can only contain positive values, and there is a limit on the storage space allocated for each value).

The pixel data are converted to hounsfield units, using the equation [5]:

HousfieldValue = RescaleSlope*Value + RescaleIntercept

… where the RescaleSlope and RescaleIntercept are obtained from the DICOM file.

Obtaining a Density Mask

A density mask is a binary image that uses a narrow window of values.

Most emphysemous cells, have an attenuity of -1000 HU, but some emphysemous cells can have larger values, due to attenuity by surrounding tissue. The window used in this research used encompasses values falling between -1000 and -910 Hounsfield Units (HU).

Figure 3 density mask for I100

The density mask shows discrete cells which have emphysema.

The density mask values are not continuous because of hardware limitations and the presence of reticular tissue

Obtaining a frequency map

In order to determine which groups of HRCT cells have emphysema, the frequency of emphysemous cells in the surrounding cells was calculated for each cell.

Figure 4 frequency map for I100

The frequencies can be visualised by a grey scale image, where a grey value of 0 indicates a cell surrounded completely by emphysemous cells, a grey value of 255 indicates a cell surrounding by no emphysemous cells, and grey values in between these extremes indicate a percentage of the pixel neighbourhood that is emphysemous.

Obtaining a region map

A region map is obtained from the frequency map, by thresholding the frequency map, to keep cells which

are in a highly emphysemous regions and discarding cells which are not.

Figure 5 region map for I100

Removing noise

To increase clarity of the image, small clusters of cells are discarded.

Modifying Parameters

Emphysema Window

Using larger window to obtain a density mask can add more detail, but will also add more noise (non-emphysemous cells).
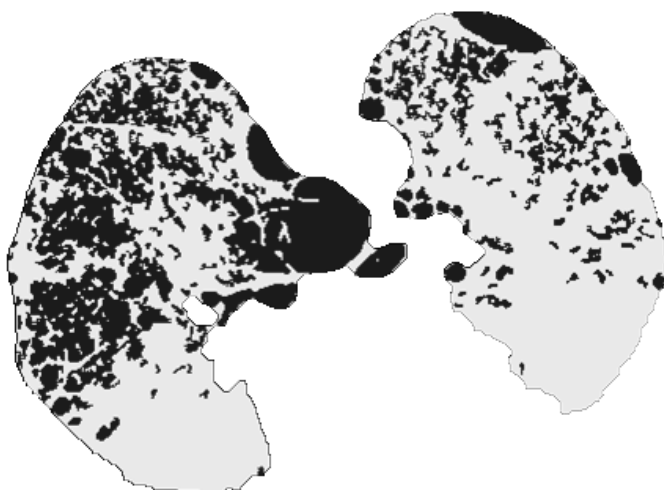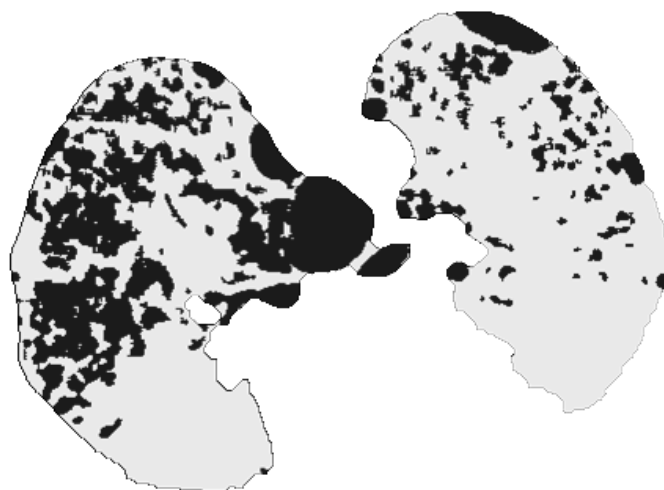

**Figure 6 I100 density mask
window of -1000 to -910 HU**

**Figure 7 I100 density mask
window of -1000 to -890 HU**

Neighbourhood Width

Using larger neighbourhoods to create the frequency map, can lead to *reduction* in noise, but will also lead to loss of detail.
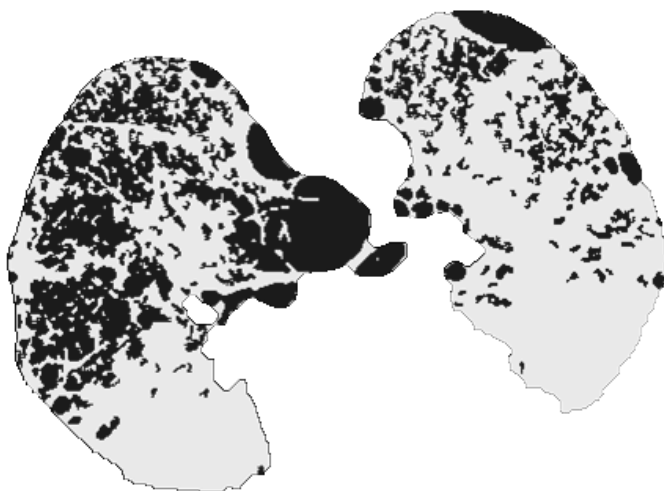
Figure 8 I100
neighbourhood width = 3,
frequency threshold = 55%,
noise limit= 10

Figure 9 I100
neighbourhood width = 5,
frequency threshold = 55%,
noise limit= 10

Frequency threshold

Applying lower thresholds to a frequency map, produces an emphysemous region map with more detail, but also more noise.

Figure 10 I100
neighbourhood width = 3,
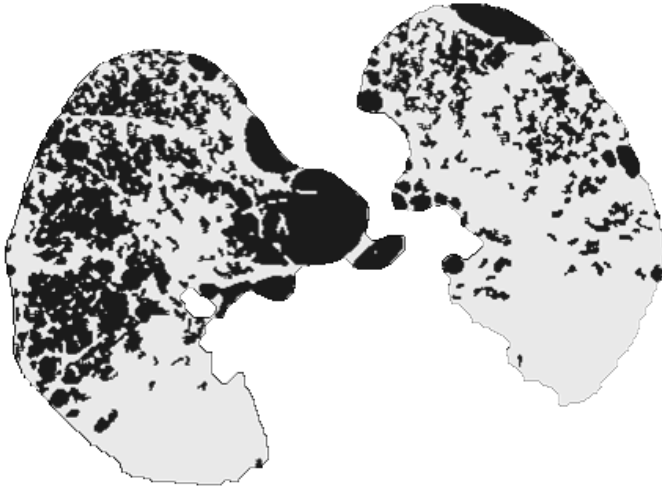**frequency threshold = 55%,**
noise limit= 10

Figure 11 I100
neighbourhood width = 3,
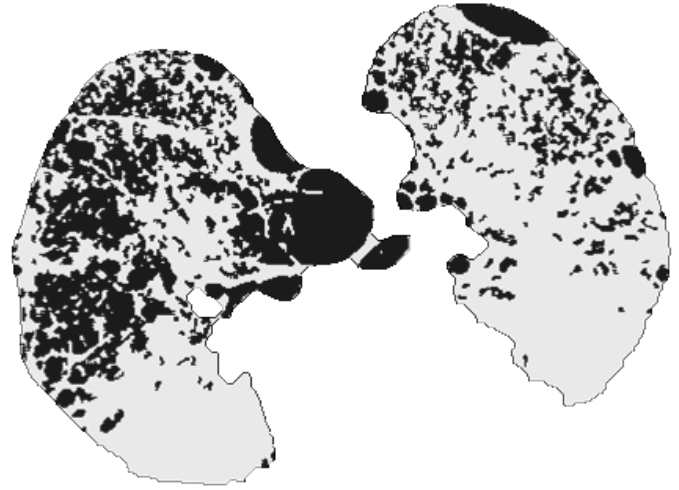**frequency threshold = 65%,**
noise limit= 10

Noise Limit

Changing the noise parameters, limits how much noise appears in the region map.

Figure 12 I100
    neighbourhood width = 3,
    frequency threshold = 55%,
    noise limit= 10

Figure 13 I100
    neighbourhood width = 3,
    frequency threshold = 55%,
    noise limit= 6

Optimum Parameters

Different combination of results were presented to our consulting radiologist, Peter Wilson, who found that the results produced with a neighbourhood width of 3 (i.e. a 3x3 neighbourhood) and a frequency threshold of 55% to be the most acceptable in detecting emphysema.

Problems and Solutions

Connected Regions

The following algorithm was used to find the connected (pixels in the same region).

> A label map is generated with all the pixels set to 0 (background region).
> The original image is scanned left to right top to down.
> When a significant pixel is encountered, the labels for the surrounding pixels are checked.
> If no neighbouring pixels are assigned a label, the current pixel is assigned a new label.
> If some neighbouring pixels are labelled, the current pixel is assigned the lowest positive label.
> This process is repeated (using the label map of the previous iteration), until all neighbouring pixels have the same label.
> Because neighbours get relabelled with the lowest possible label, some labels disappear.
> So it is necessary to remap the labels to another set of consecutive labels.

Preserving Details at the edges

Emphysemous pixels at the edges of the lung, can be lost from the final region map because the frequency of the neighbourhood is thresholded. At the edges, much of the neighbourhood is non-lung regions, which

will lower the frequency of the edge cells.
To prevent this bias, the frequency is calculated according to the neighbourhood of cells within the lung.

Lung map is inaccurate

To obtain an accurate percentage of lung area affected by emphysema, it is important to obtain an accurate lung map.

The lung segmentation algorithm currently used, gives a good approximation, but is larger than the lung. Such a value then cannot be used to make a confident diagnosis of lung disease.

However a better lung segmentation algorithm is currently being developed, and when completed will replace the current one.

Ground Glass Opacity Detection Using a Density Mask

Ground Glass Opacity is the appearance of hazy opacity in HRCT.
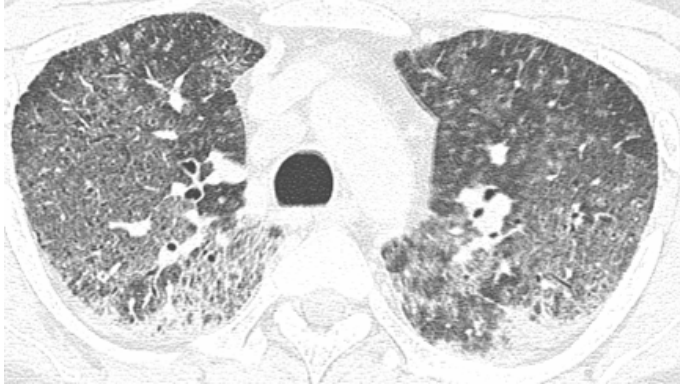
Figure 14 an HRCT image exhibiting Ground Glass Opacity (P22_S1_Im5)

It is caused by fibrosis or inflammation, and is associated with many conditions including pneumonia, pulmonary oedema and pulmonary haemorrhage. [8]

A density mask can be obtained for GGO using a different window setting (-200 to 250 HU) than for emphysema.

The neighbourhood width used to generate the frequency map needs to be much larger (neighbourhood width =7) and the frequency threshold needs to be much lower(frequency threshold = 15%) (because a larger neighbourhood is used).
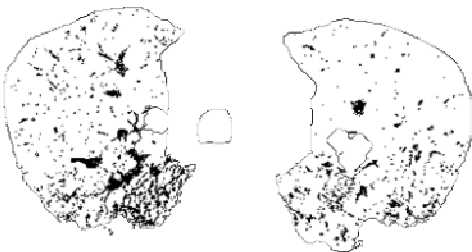
Figure 15 GGO desity mask for P22_S1_Im5

Results are modest compared to emphysema.

Figure 16 GGO region map for P22_S1_Im5

Lung Segmentation algorithm is not suitable to segment the lung affected by GGO

Software Environment
The Images were processed using plugins that can be executed under the image processing software, ImageJ version 1.31.
ImageJ can be downloaded from http://rsb.info.nih.gov/ij/

Programs Developed

Plugin	description
AdjustWindow_.java	If called with "ggo" as the argument, a density mask for ground glass opacity is produced. If called with "emphysema" as the argument, a density mash for emphysema is produced. If called without an argument, the image is displayed with a window of 1500, and window centre of -400.
BatchReport_.java	Generates an html report, using the results generated in Batch_
Batch_.java	Used to apply different settings to many images without user intervention.
ColorTable.java	Defines the colours used to represent the different types of regions. (DIS_LUNG, NOT_LUNG, and NORM_LUNG).
Connected.java	Given a Boolean region map, Connected returns an array of regions(array of pixel indices)
Divider_.java	Divides a large region into smaller regions. Used for experimentation.
LungsExt_.java	Extends the lung mask out for a specific number of pixels
LungMap_.java	Generates a lung map from an image that does not show ground glass opacity.
LunMapGGO_.java	Generates a lung map from an image that exhibits ground glass opacity.
ShowDisease.java	Called by ShowEmphysema and ShowGGO. ShowDisease calls AdjustWindow with the appropriate parameters, and calls either LungMap or LungMapGGO, and further process the image in the manner described above, in "Process Approach".
ShowEmphysema_.java	Available for convenience. It calls ShowDisease with the arguments appropriate for emphysema detection.
ShowGGO_.java	Available for convenience. It calls ShowDisease with the arguments appropriate for ground glass opacity detection.

Programs Used

LungsSegment.java

This output of this plugin was processed by LungMap and LungMapGGO, to generate a lung map. Unfortunately it is not perfect. The mask generated by it is larger than the lung, includes non-lung features, and image artefacts, and does not include areas affected by ground glass opacity.

Figure 17 HRCT image exhibiting GGO (P22_S1_Im5)

Figure 18 Output from the LungsSegment plugin (for P22_S1_Im5)

References

[1] Philippe A. Grenier, chapter 21, Chronic Airflow Obstruction *Grainger & Allison's Diagnostic Radiology*, Volume 1, 4th Edition, 2001, Churchill Livingstone.

[2] NL Muller, CA Staples, RR Miller, and RT Abboud, "Density mask". *An objective method to quantitate emphysema using computed tomography, Chest*, Oct 1988; 94: 782 - 787.

[3] M Kinsella, NL Muller, RT Abboud, NJ Morrison, and A DyBuncio. *Quantitation of emphysema by computed tomography using a "density mask" program and correlation with pulmonary function tests*, Chest, Feb 1990; 97: 315 - 321.

[4] Medical Information FAQ, *http://www.dclunie.com/medical-image-faq/html/part1.html*

[5] DICOM Imaging Pipeline Model, Cor Loef, *http://dicomwg12.org/image_presentation/genpixel.ppt*, Philips Medical Systems,

[6] Heggie, Applied Physics of Imaging, 4th Edition , 2002, St Vincents Hospital Melbourne

[7] David Hansell, chapter 4, High Resolution Computed Tomagraphy of the Lung, *Imaging of Diseases of the Chest*, 3rd Edition, 2000, Mosby