Fractal Analysis in Digital Medical Image Processing

University of Sussex

Omar Sultan Al-Kadi[1]*, Des Watson[1]

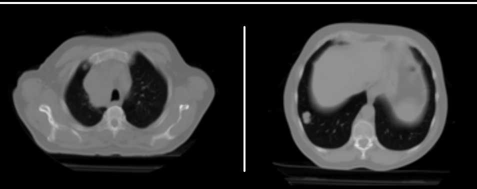


Figure A: Original Images of Lungs

Figure A represents two real case images of lungs, where the upper right side of the left lung in the left image and the lower left side of the left lung in the right image is affected with cancer. The two images are transformed to the Fractal Dimension (FD) using Box counting algorithm; after choosing the appropriate size of operation box and scaling factor. The results represent different outputs for the same (original) two images, but their display depends on choosing the appropriate parameters. Figure B, D and E are displayed using the slope of the FD regression line, while figure C is displayed using the FD intercept.

FD slope

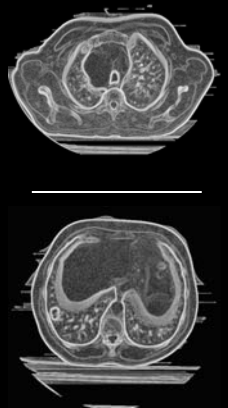


Figure B: Fractally Transformed Images (scaling factor 1)

FD Intercept

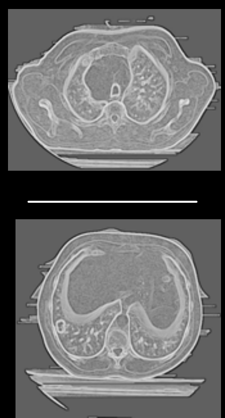


Figure C: Fractally Transformed Images (scaling factor 6)

FD slope

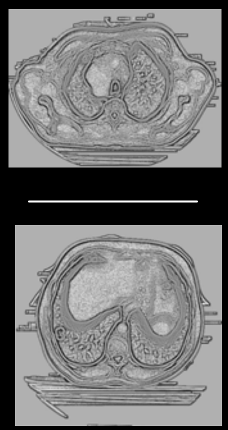


Figure D: Fractally Transformed Images (scaling factor 6)

FD slope

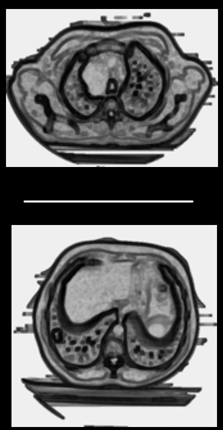


Figure E: Fractally Transformed Images (scaling factor 7)

Fractal Dimension (FD)

The word fractal stems from fracture which means broken, that is, we break a specific shape into smaller self-similar pieces which resemble the original (mother) shape at different scales. Unlike the classical Euclidean geometry which deals with integer dimensions (lines, circles, etc.), fractals are used to describe objects which do not have an obvious integer dimension — in-between dimensions— like the Sierpinski triangle, Koch snowflake, and many others. In theory, the FD of a structure examined should have invariant self-similar fragmented and irregular shapes at all scales of measurement reaching to infinity. Yet, in biological structures this could be true for a finite number of scales, as in the case of lung airway branching which can have self-similarity for some scale, of course also depending on the resolution and depth of acquired image intensity.

$$\text{Fractal Dimension (FD)} = \frac{\log(\text{Number of self-similar pieces})}{\log(\text{Scaling Factor})}$$

Objective

The aim of this research is to use Fractal Dimension to investigate its impact on cancers for the purpose of tumour type differentiation, and for different imaging modalities (both CT and MRI). Texture relevant to medical imaging:

- May give some indication of vascularisation when image contrast agent is present.
- Useful diagnostic tool for physicians.

Methodology

1. Patient is injected with a contrast agent.
2. A sequence of DICOM images is acquired using CT scan.
3. DICOM acquired images are transformed to the Fractal Dimension (FD) using Box counting algorithm at different scales, then using least square linear regression the FD slope and intercept are computed.
4. Afterwards, cancer locations which become more obvious now are easily identified by a Region of Interest (ROI).
5. The average FD is computed for the set of sequence of fractally transformed DICOM images for each ROI and compared with intensity average for the same region before FD processing.
6. Finally, the maximum and baseline average FD for each slice in each sequence will be computed which will classify the type (aggressive or non-aggressive) and stage of the examined lung tumour.

Results

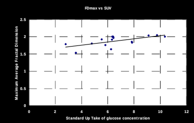
Advanced stage tumours tend to have a higher Fractal Dimension as compared to early stage tumours.

After transforming 16 different sets of sequences of DICOM images which correspond to 16 patients and extracting ROIs for the tumour areas, it was noticed that more than 80% (13 cases) of the cases the maximum FD_{avg} (i.e. the highest averaged value the FD can reach in any of the examined slices referring to an individual case) tend to have a higher value as compared to the remaining 3 cases. Above in Figure A, after FD processing the left image had a max FD_{avg} value of 2.0461 while the image on the right was 1.2906; given that the left image is late stage aggressive tumour while the one in the right image is an early stage tumour.

Using Spearman Rank order correlation test, the maximum FD_{avg} and the baseline FD_{avg} were correlated with the corresponding lung tumour stages which gave a correlation coefficient of 0.52 and 0.537 with a significance level of 0.0465 and 0.0387 for 2-tailed p-value; respectively.

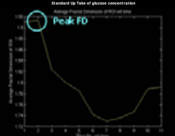
High Correlation in-between max FD_{avg} and Standard Uptake Values (SUVs) of blood glucose concentration in lung tumours

Comparing the obtained FD_{avg} values for all set of image sequences with the Standard Uptake Values (SUVs) of blood glucose concentration in the same examined lung tumours, it was shown that the maximum FD_{avg} has also a strong correlation with the SUVs. Hence we can indicate the stage and aggressiveness of the examined tumour from the blood glucose concentration only.



FD_{avg} is inversely proportional with time for aggressive tumours

The aggressive tumour cases which showed the highest FD_{avg} values were inversely proportional with time, which is, they started high and with time the curve descended to a trough after starting to slightly ascend again at the end. The non-aggressive cases behaved inversely.



Conclusion

Given that blood vessels in the lungs have a fractal form, so when we inject the patient with the contrast agent it will certainly enhance the intensity as we are viewing the image from a FD perspective (everything which is a fractal will be enhanced). So we expect for the FD_{avg} to increase with time reaching to a maximum before the contrast agent starts to fade away. This is true for non-aggressive cancers ROI, as the blood vessels in that region still maintain some of its fractal characteristics. While in the aggressive regions, the general shape of the blood vessels has been altered and deformed in a way it becomes completely rough, resulting in some loss in the original blood vessels' fractal characteristics. This increase in roughness contributed to the increase of the computed maximum FD_{avg} value in the aggressive cases as compared to the non- aggressive cases. Hence, Fractal analysis of CT images of lung tumours provides additional information about likely tumour aggression that could potentially impact on clinical management decisions.

[1] *Department of Informatics*
* *e-mail: o.al-kadi@sussex.ac.uk*