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NEW APPROACH FOR EMPHYSEMA PATTERN DETECTION IN COMPUTED TOMOGRAPHY IMAGES

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Abstract

Texture experimental analysis is one of the biggest challenges in the field of computer vision and pattern recognition. Fractal dimension (FD) has proven to be a useful technique in this field to analyze texture patterns. On the other hand, it could be difficult to use this approach to construct descriptors since the fractal magnitude space usually fails in representing adequately the richness of detail present in a unique feature vector. This paper therefore proposes two new algorithms for pattern analysis and detection. The first method applies different Higuchi dimension methods for identifying regions or sections with emphysema pattern problem. The second approach investigates the importance of multi-fractal spectrum for efficient identification and analysis of emphysema patterns in high resolution computed tomography (HRCT) images. The proposed algorithms have been applied to identify the locations and corresponding quantity of the emphysema patterns in HRCT images. Experimental analyses of the results were investigated using statistical techniques to establish the relationship between the ground truth patches and the HRCT image slices. Results revealed that regions with higher FD values contained the presence of emphysema due to the image tissue complexities within the regions, while detection of emphysema failed in those regions with lower or minimum FD values.This research work therefore recommended that both Higuchi's dimension and multifractal techniques could be accurately used in detection and analysis of regions with emphysema diseases.

Introduction

Fractal dimension is a very important phenomenon in the theory of fractals and also in almost all applications involving fractals. Fractal dimension has the ability to characterize the irregularity of shapes, which other dimensions such as the topological dimension may not be able to represent. It is used to estimate the size and roughness of fractal sets; it is a number associated with a fractal that tells how densely the fractal occupies the underlying space. The computational methods that can be used for the estimation of fractal dimension are the box counting and the Higuchi methods. Fractal system can be subjected into the category of mono-fractals whose characteristics are represented by a single exponent called the fractal dimension. This concept can be generalized into a wider and more complex multi-fractal system characterized by a continuous spectrum of exponents (called the singularity spectrum or multi-fractal spectrum). A multi-fractal system can be described as a combination of several fractal systems collectively exhibiting a variation of fractal dimensions at different scaling exponents. However, it should be noted here that multifractal analysis has not been used to characterize or identify multiple self-similar structures in an image. Multifractal descriptor uses statistical distribution of irregularities in an image for texture feature descriptors in image analysis applications. So far, not much work has been done in multifractal approaches to biomedical image analysis (Jayasuriya, Liew & Law,2013; Soares et al.,2014). A method for

identifying the region of interest in a mammogram image was developed by (Stojić, Reljin &Reljin,2006), and in (Ding, Dai &Zhang,2014), a model for multi-fractal analysis has been proposed for automatic detection of micro-calcification in tissue images.
The proposed system would focus on detecting the emphysema patterns by identifying the patterns within the images using some of the characteristic parameters in the extracted features. These ideas can be achieved in various ways; the absolute differences in the overall mean values of the Higuchi's FD values between the normal tissue images and the histological images could be used. The regions with statistically significant absolute mean differences contain the emphysema patterns while the regions without significant differences have no emphysema patterns. In multi-fractal, the same approach can be used to differentiate between the regions with emphysema patterns and those regions without.

Literature Review

FD Applications in Identification of Region of Interest in HRCT Images

The applications of fractal dimensions have also been previously used to locate and identify regions of interest in various digital images (Iftekharuddin, Jia & Marsh, 2003; Jing, Zhang, & Yue,2003; Kiselev, Hahn & Auer,2003). Fractal dimension is a very good way of measuring the complexities within different areas in biomedical images. The regions with emphysema diseases are expected to be more complex when compared with those areas without the diseases and would have higher FD values. In (Vehel & Mignot, 1994), multi-fractal characterization of images has been used for edge detection, the process was achieved by smoothing process, which is known as the inverse of a classical approach. The good thing about this process is that the information is neither lost nor introduced. The results of the segmentation are very excellent. One of the limitations in this case is that the computational complexity is very high. In this paper, multi-fractal analysis was introduced to detect micro-calcifications. Multi-fractal analysis and segmentation can also be used to identify suspicious regions in an interactive manner. The problem with this approach is that the segmentation method that was introduced may not be able to detect patterns of diseases like emphysema since it is not visible like micro-calcification or other visible nodules.
Higuchi method of computing fractal dimension has been applied to diagnose patients with alzheimer disease. HRCT is more sensitive and effective than chest radiography in terms of scanning in measuring the type, extent and distribution of emphysema. Patients with early emphysema disease might still have the symptoms; this is the stage where HRCT is most useful.

Emphysema can be measured by the presence of areas of abnormally low attenuation, which can be easily compared with surrounding normal lung parenchyma (Chabat, Yang &Hansell, 2003;Sørensen, Shaker, & Bruijne,2010; Mendoza et al.,2012; Nava et al., 2013). It can be sub-divided into three different classes: (i) centrilobular emphysema (CLE) (ii) paraseptal emphysema (PSE) and (iii) Normal tissue emphysema (NT) (Chabat, Yang & Hansell,2003; Masashi et al., 2008). The paper by (Masashi et al., 2008) comprehensively described emphysema diseases, different classification of emphysema and their properties. It was also discovered that features from HRCT images could generate important discriminative measures for identifying different classes of emphysema and the assessment of their severity. The Holder exponent of the local distribution of the intensity measure has been previously implemented and applied for the development of multi-fractal spectrum in CT images (Irini et al.,2000; Reljin & Reljin,2002; Hemsley & Mukundan,2009; Mukundan & Hemsley,2010; Khider et al.,2013; Ibrahim & mukundan,2014;Ibrahim & Mukundan,2015). The computation of a multi-fractal descriptor depends on the calculated Holder exponent and fractal dimension, which have been successfully used as a descriptor for efficient classification in biomedical images. A method for identifying the ROI in a mammogram image was developed by (Stojić, Reljin & Reljin,2006). In (Soares et al., 2014), a model for multifractal analysis has been proposed to assist the radiologist in diagnosing the breast cancer. In this research work, the regions with cancer nodule were identified and the developed system presented very good classification accuracy in differentiating the nodules locations between the regions with cancer and those regions without.
Dubey and Singh (Dubey, Singh, and Singh, 2016) introduced a novel feature descriptor for digital image indexing and retrieval purposes. Experimental performance analysis of the developed model using 168 patches from the emphysema database revealed an average retrieval precision (ARP) of 75% and average retrieval rate (ARR) of 88%. A similar image retrieval system using local gray scale invariant features was proposed by (Porto & Ornellas,2015) where they achieved an ARP of approximately 90% and an ARR of approximately 52%. However, the authors only used 37 HRCT slices containing the lower lung part. The Higuchi's dimension for different channels of EEG signals was applied to identify the regions with Alzheimer's disease (AD) (Stojić, Reljin, and Reljin,2006; Prince et al.,2015). The experimental results demonstrated that AD patients have significant lower Higuchi dimension values compared with the normal subjects. In (Marri & Swaminathan, 2015), multifractal analysis has been successfully used to separate EMG signals with fatigue conditions from those without fatigue conditions. The multifractal techniques extracted some characteristics features of EMG signals for this comparison and the results revealed that the strength of multifractality is very high as the differences between the EMG signals

with fatigue conditions and non-fatigue regions are highly significant. (Kara et al., 2017) applied Uroflowmetry test to evaluate urine flow rates and volumetric analysis of patients. Multifractal analysis has been applied for various applications in biomedical image analyses and the results accomplished so far demonstrated the strength and capability of multifractal features (Ibrahim & Mukundan, 2014). In this paper, the introduction of Higuchi's dimension would help us to identify the region of interest in the analysis of emphysema patterns while the multi-fractal analysis could be used to visualize those areas with severe problems using the appropriate image features.

Methodology

Experimental Design for Emphysema Detection

The details of the procedures involving the detection of emphysema regions using the Higuchi fractal dimension and the box counting are presented in Figure 1. The FD of subdivided images has been calculated using the Higuchi method and the box counting method. The Higuchi of each sub-image is computed for the normal image samples and portion with emphysema diseases. The magnitude of the differences in FDs between the normal tissue (NT) and the emphysema classes (CLE and PSE) would determine the complexity of the images in those regions. The second part of the algorithm uses the box counting method for computing the FDs in different regions of the images in order to generate the spectrum for areas with pattern problem.

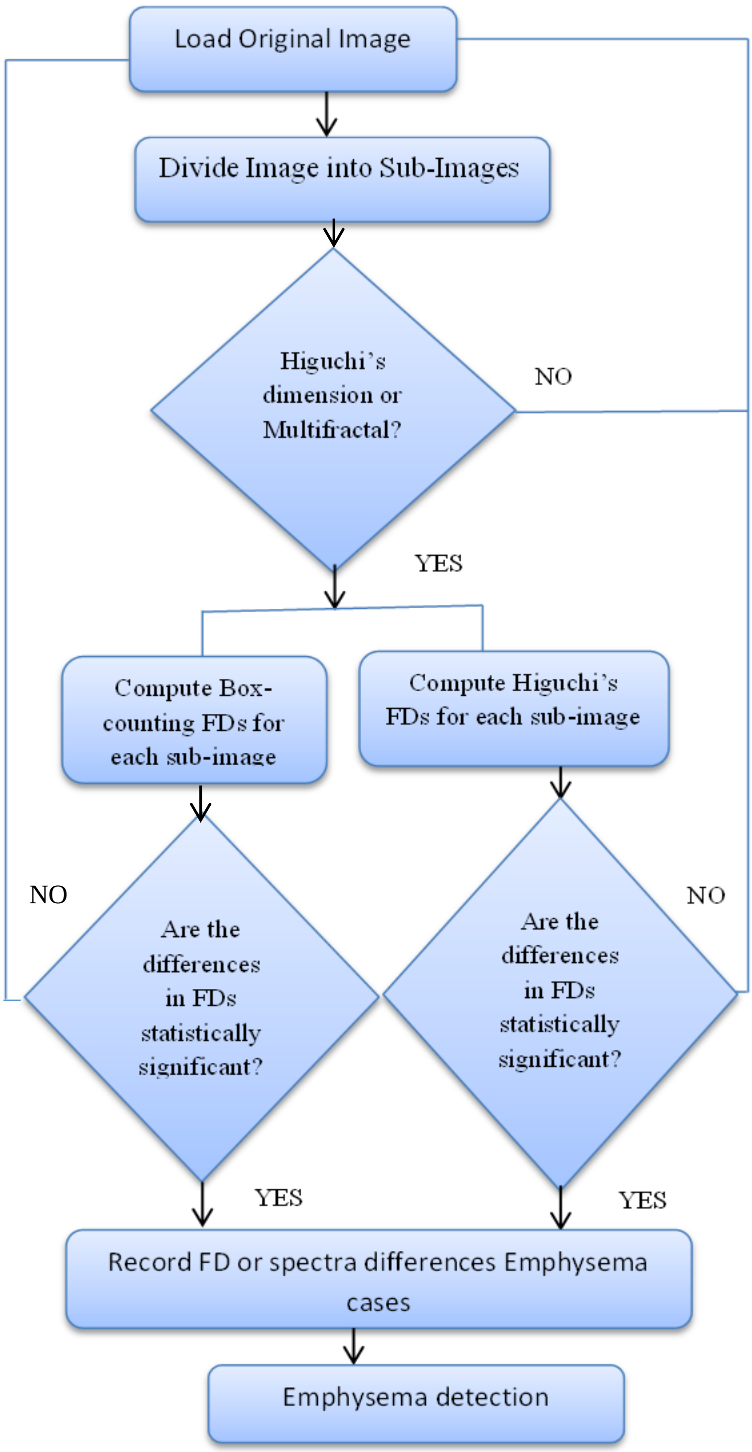

Figure 1: Development of emphysema pattern detection in HRCT image

The deviation in the FDs between the NT and other classes in both approaches is the key to measure the tissue complexities that determine the quantity of emphysema patterns in a particular region. This process can be achieved by the calculated Higuchi fractal dimension for each sub-image across the slice and the corresponding absolute difference.

Results and Discussion

The results of the experiments, which show the group means and the corresponding p-values for each experiment, are shown in Figure 2. The visual representation of the multi-comparison results demonstrating the graph of the estimates with comparison intervals between the group means of the normal tissues of the ground truth images and that of the image slice sub-regions are presented in Figure 2.

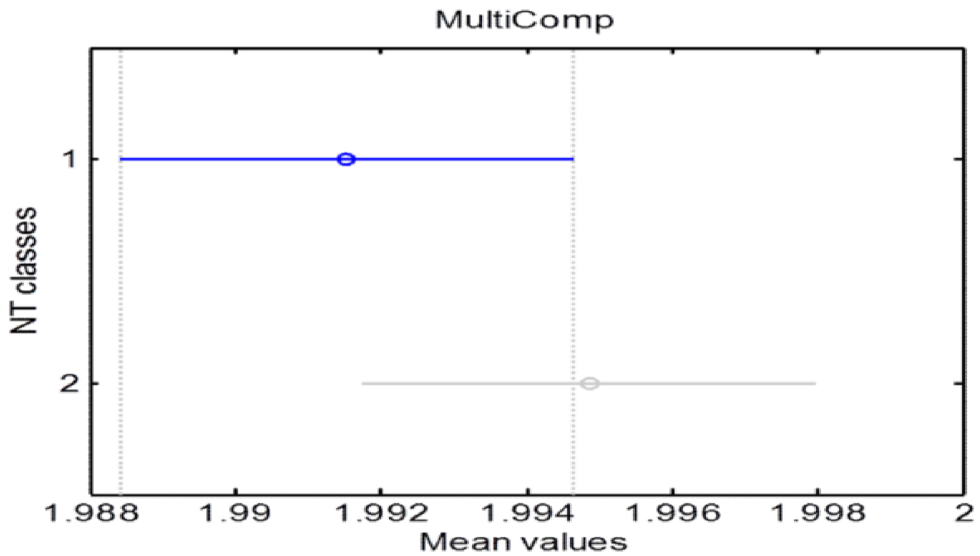

Figure 2: Group means between normal tissues of ground truth and sub-regions of slices

Each emphysema image was subdivided into 12 sub-images and the differences in FD for each sub-image was calculated between the normal image and emphysema patterns. The calculated Higuchi fractal dimension for each sub-image across the slice and the corresponding absolute differences are presented in Table 1. The results presented in Table 1 show that the FD differences between the normal and emphysema images (CLE and PSE) range between 0.0258-0.7082 and 0.0105-0.3525 for NT-CLE and NT-PSE respectively. It is noted that the differences in FDs values are statistically significant at some regions but not statistically significant in some other regions. The differences in the FDs within the regions that are statistically significant using the analysis of variance (ANOVA) indicate the presence of emphysema, with a p-value < 0.0001. The NT-CLE range of FD differences detects more emphysema patterns than the regions with NT-PSE range. Although, very large FD differences in both CLE and PSE show the presence of large emphysema in the images. This result also indicates that a large number of image subdivision is important for detection and location of emphysema images. Take for instance, it was verified experimentally when the whole HRCT image was divided into four sub-images that the differences in FD was not much between the Normal and that of emphysema images but an increase in the number of image subdivisions could improve the detection accuracy since emphysema will usually occupy small position within the images. The reason for estimating the FD of different parts of the HRCT images is because higher FD values could be associated with tissue complexity due to the presence of emphysema. In all cases, parts of the image with emphysema showed significantly higher FD values compared to the regions without FD values.

Table 1:
Higuchi FDs of Emphysema Images

FD of emphysema images using Higuchi dimension method					
M. Locations	NT-FD	CLE-FD	PSE-FD	|(NT-CLE)|	|(NT-PSE)|
E11	1.114	1.0734	1.145	0.0406	0.031
E12	1.3131	1.5	1.0299	0.1869	0.2832
E13	1.2569	1.3059	1.0661	0.049	0.1908
E14	1.0982	1.0724	1.2018	0.0258	0.1036
E21	1.0982	1.8064	1.4507	0.7082	0.3525
E22	1.4198	1.507	1.3635	0.0872	0.0563
E23	1.5987	1.3909	1.5404	0.2078	0.0583
E24	1.5478	1.4341	1.4494	0.1137	0.0984
E31	1.1505	1.1799	1.161	0.0294	0.0105

The overall result in Table 1 has been very good in terms of detecting emphysema pattern; the regions that clearly indicate the presence of emphysema are those where the Higuchi FD differences are statistically significant. Detections of emphysema in CLE image can be observed in different regions compared to PSE image and they are of different quantities since the quantity of emphysema detection directly depends on the magnitude of the FD differences between the normal and the emphysema images. The exact position of the emphysema can be identified by using the FD differences as in Table 1, changes in FD between the normal and emphysema images in cell locations (1, 2 and 2,1) are statistically significant in PSE image and only cell location 1,2 in CLE image. These significant differences indicate the presence of emphysema patterns in these locations. The remaining locations fail to show the presence of emphysema since the changes in FD vary only in the range of 1-2% and the variations in FD are not statistically significant. Generally speaking, FD values in cell locations in normal images are less than the CLE images and that of the PSE images.
Though, this is not true in some locations, but in most cases as presented in Table 1, the higher the complexities of the image tissues, the higher the FD values of the corresponding locations and thus the higher the presence of emphysema in that location. On the other hand, the regions with higher FD values or greater spectra would detect more emphysema than the regions with lower FD values or smaller spectra. This is an indication that the fractal dimension in the case of emphysema CT regions has singularities degree higher than the normal case or the regions without emphysema. The higher FD values or multi-spectra with larger high and width in some sub-images are due to the complexities of the tissue in that region due to the presence of emphysema pattern. The degree of the singularities exponent can also be used to determine how severe the presence of emphysema in the region is. It has been noted that the spectra of all sub-images without emphysema are exactly the same such that any deviation of a spectrum away from the normal spectrum would indicate the presence of emphysema in that region. Similarly, the process of detecting emphysema in CT images can be achieved with calculated multi-fractal spectra as presented in Figure 3. Distinct deviations can be observed between the spectra of the normal image and that of pathological images in terms of the minimum and maximum values of alpha and falpha. This deviation is an indication of the presence of emphysema in that sub-image as can be seen in Figure 3.

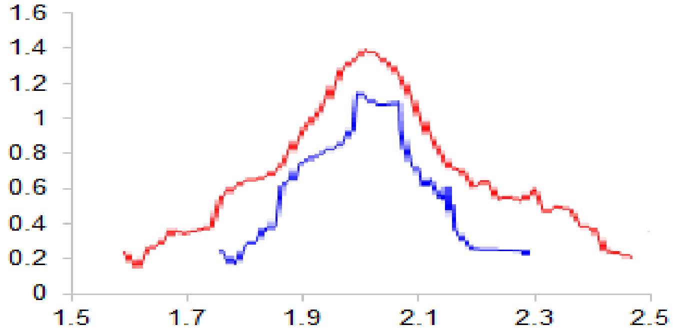

Figure 3: Deviation of multifractal spectra in detection of emphysema patterns

Conclusion

The research work in this paper has presented some of the applications of fractal dimension in CT emphysema images. The Higuchi fractal dimension of the CT image has been used to identify and detect some of the regions of the image with the presence of emphysema. It was discovered that the regions with higher FD values contain the presence of emphysema due to the image tissue complexities within the regions, while the detection of emphysema fails in those regions with lower FD values. The multi-spectra obtained from the multi-fractal dimension computation showed the effectiveness of the global descriptions for identification and detection of ROI in HRCT images. Useful features from the image textures displayed excellent performance and demonstrated to be a very good measure and accurate enough to separate the regions with emphysema patterns from the regions without. The results also show that multi-fractal spectrum of the CT images could also be used to detect the presence of emphysema as it is in line with the performance of the Higuchi's dimension. Further research work could be done in this area by applying better methods in terms of accuracy and efficiency for calculating the fractal dimension of the CT images or improving the computational accuracy and time complexities of the algorithms. This research approach can also be further extended by applying Higuchi's method in form of a multi-fractal framework, such that the multi-fractal spectra of digital images can be calculated using the Higuchi's dimension and this can probably improve the recognition accuracy.

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