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Evaluation of Thresholding Techniques on 3D Fractal Dimension MRI Images

[1]Iqbal Jamaludin, [2]Mohd. Zulfaezal Che Azemin, [1]Liyana Musa, [1]Abdul Halim Sapuan,
[1]Zafri Azran Abdul Majid, [3]Azmir Ahmad, [4]Nor Azlina A. Rahman and [4]Mohamed Arshad Sideek
[1]Department of Diagnostic Imaging and Radiotherapy,
[2]Department of Optometry and Visual Sciences, Kulliyyah of Allied Health Sciences,
[3]Department of Basic Medical Sciences for Nursing, Kulliyyah of Nursing,
[4]Department of Biomedical Sciences, Kulliyyah of Allied Health Sciences,
International Islamic University Malaysia, Kuantan, Malaysia

Abstract: Currently, there are few textural measures being used to characterize the textual memorization of brain structures. Fractal Analysis (FA) application in medical field has been used to measure the occurrence of changes in the brain complexity for some diseased and normal aging brain. Within FA, there is Fractal Dimension (FD) which is an index of structural complexity. FD methods were classified into three major categories which are box-counting method, variance method and spectral method. Here in this study we used box-counting method to measure our FD due to its directness and automatic computability capabilities. We evaluated the impact of different thresholding techniques when quantifying the FD. We applied three different thresholding techniques on our brain MRI images: Otsu's method, midpoint method and hysteresis method. A total of 27 subjects (14 males and 13 females) aged ranging between 21-25 years old were voluntarily participated. The process of thresholding the images and computation of the FD values were done under MATLAB. There was a statistically significant difference between groups of thresholding techniques as determined by Friedman test with $\chi^2(2) = 48.667$ and $p<0.001$. Post-hoc Wilcoxon-signed ranked test with Bonferroni correction done where the p-value was set to 0.017. All three group pairs (midpoint vs. Otsu's, midpoint vs. hysteresis and hysteresis vs. Otsu's) were statistically significant different with $p<0.001$. Pearson's correlation showed moderate correlation ($r = 0.446$, $p = 0.02$) between hysteresis and Otsu's. Spearman correlation showed weak correlation which is not significant ($r = 0.256$, $p = 0.198$) for midpoint vs. Otsu's and ($r = 0.252$, $p = 0.204$) for midpoint vs. hysteresis. In conclusion, different thresholding techniques do have impact on FD values but with moderate correlation between them.

Key words: Box-counting, thresholding, fractal dimension, brain, magnetic resonance imaging, textual memorization

INTRODUCTION

Textual memorization: The brain is among the most complex organs in human body. It functions as a prime regulator for the human body to function properly and also the part which stores the memory for human. Over the years, variation in brain structures and its designated memory capacity have caught attention of researchers to dig deeper in order to understand their relation and connectivity. Memory is the power or process of reproducing or recalling what has been taught previously (Tranel and Damasio, 1995). If we look into cognitive psychology, memory is defined as a stored pattern of networked neural cluster in the brain for retaining and retrieving information (Wang, 2009). Memory has been classed as sensory memory, Short-Term Memory (STM) and Long-Term Memory (LTM) (Baddeley, 1999; Nevid, 2012).

Textual memorization involves comprehensive memory construction and retrieval process which may leave permanent changes in the brain structures. Currently, there are few textural measures being used to characterize the textual memorization brain structures. Fractal Analysis (FA) application in medical field has been used to measure the occurrence of changes in the brain complexity for some diseased and normal aging brain

Corresponding Author: Mohd. Zulfaezal Che Azemin, Department of Optometry and Visual Sciences, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Kuantan, Malaysia

(Farahibozorg *et al*., 2015). A study by Zhang *et al*. (2007) has proven that FA detected low White Matter (WM) volume in older patients as compared to young adults whilst Voxel-Based Morphometry (VBM) didn't detect any differences between the two groups. Their finding is in line with our previous research by Sapuan *et al*. (2015) which found that total grey matter volume of Huffaz was not significantly differed from the control group by using VBM.

Fractal dimension: The development of FA was originally initiated by Benoit B. Mandelbrot in his book: The Fractal Geometry of Nature in 1983 (Zhang *et al*., 2007). Since that, the application of FA has widened to all aspects of life including in the medical imaging (Ieva *et al*., 2013). Among application of FA were macroscopic (i.e., anatomic) and microscopic (i.e., histological) images as well as high-resolution radiological imaging (i.e., MRI) (Esteban *et al*., 2010). Apart from disease detection and measuring the aging effect, FA also capable of estimating the topological complexity of an object. It leads to FA being proposed as a surrogate marker of the degree of brain damage in several psychologic and neurological alterations (Ieva *et al*., 2013).

Within FA, there is Fractal Dimension (FD) which is an index of structural complexity (Farahibozorg *et al*., 2015). FD contains specific information about geometric structure of the fractals (Anisheh and Hassanpour, 2009). FD methods were classified into three major categories which are box-counting method, variance method and spectral method (Azemin *et al*., 2016). Here in this study, we used box-counting method to measure our FD due to its directness and automatic computability capabilities (Balghonaim and Keller, 1998). Measurement of the FD was done by placing a progression of boxes in descending size, box size, over the images and calculate the number of boxes, count that cover the images. Estimation of the FD is obtained from the gradient of log (count) versus log (box size) (Peitgen *et al*., 1992).

In this study, we are interested in evaluating the impact of different thresholding techniques when quantifying the FD. As compared to our previous research by Sapuan *et al*. (2015) where we used VBM, we hypothesised that the application of FD will give notable differences value between different thresholding techniques. We applied three different thresholding techniques on our MRI images: Otsu's method (Otsu, 1979), midpoint method (Xu *et al*., 1997) and hysteresis method (Xie *et al*., 2013). The brain MRI images (Sapuan *et al*., 2015) were first segmented where the process of segregating the images into several components accordingly with respect to their composition and regions (Hassanpour and Yousefian, 2010). The process of thresholding the images and computation of the FD values were done under MATLAB. We then ran certain statistical test to our FD values. The finding of our study will be discussed thoroughly throughout this study.

MATERIALS AND METHODS

Subject recruitment: The images for this study were obtained from our previous research by Sapuan *et al*. (2015). A total of 27 subjects (14 males and 13 females) aged ranging between 21-25 years old were voluntarily participated. Among inclusion criteria for the subjects were they must be right-handed, free from any medical illnesses no reported cases of past head injury not under psychiatric treatment and not on treatment for endocrine and neurological disorder. All subjects were in their tertiary education at the same public university. Subjects were assessed for any contraindication to enter the MRI system (claustrophobic, presence of metallic implant in the body, presence of cardiac pacemaker, etc.) prior their enrolment. Approval from the local ethical committees (IREC) was sought and approved prior conduction of this study. The study adhered to the ethical principles by Declaration of Helsinki and was registered in Malaysian National Medical Research Registration (NMRR) with research identification number NMRR-14-107-19576. Subjects were given prudent explanation regarding the purpose, objectives and research methodology prior them agreeing to participate and signing the written informed consent.

Image acquisition: The brain MRI images of the subjects were acquired using 1.5 Tesla Siemens Magnetom Avanto scanner (Siemens Medical Solutions, Erlangen, Germany). Details of imaging acquisition, image realignment, segmentation and normalization according to Montreal Neurological Institute (MNI) were described deliberately in our previous research by Sapuan *et al*. (2015).

Thresholding techniques: In this study, we explore three common thresholding techniques which were Otsu's method (Otsu, 1979), midpoint method (Xu *et al*., 1997) and hysteresis method (Xie *et al*., 2013). While many researchers previously employed thresholding techniques to binarize their images, details explanation regarding their techniques were not given or no known to the researchers. Otsu's method is an automatic threshold selection technique which is used for picture segmentation (Otsu, 1979). This method, apart free from supervision and doesn't require any estimation of statistical measure for its parameter is also very simple to use. It only utilizes the zeroth and the first-order of the grey-level histogram cumulative moment (Otsu, 1979). Midpoint method is the application of thresholding value of 0.5 which will convert the images into binary levels (Rikxoort *et al*., 2010). Hysteresis method on the other hand has improved the single-value edge thresholding method. This method requires specification of band intensity during thresholding, rather than depending on single cut-off (Pridmore, 2001).

Fractal dimension measurement: We measured the FD value of our images using the box-counting function under MATLAB Version 7.12.0 (The MathWorks Inc., Natick, MA, USA). We followed the research from Liu *et al*. (2003) where the calculations of FDs were done by applying box-counting application on the images where they select the threshold to be as A+(B-A)/3 (A is the maximum peak intensity of Gray Matter (GM) while B is the minimum valley intensity of White Matter (WM)). The values of the FD in the research were obtained from the whole structure hence, making it 3D acquisition. The effect of different thresholding techniques on the brain MRI images can be seen in the result section.

Statistical analysis: We conducted Saphiro-Wilk test to examine the normality of FD values obtained earlier. Repeated Measured Analysis of Variance (RM-ANOVA) will be used for normally distributed data while Friedman test will be used if the data was not normally distributed. In order to analyse the difference in mean FD values, we used Friedman test since our data failed the assumption for normality by Shapiro-Wilk test. Post-hoc Wilcoxon-signed rank test was done to determine which thresholding techniques (Otsu's method, midpoint method or hysteresis method) had statistically significant different of the mean FD values.

Pearson's correlation test was conducted to the pair of thresholding technique that was normally distributed while Spearman correlation test was conducted on the pair of thresholding technique that was not normally distributed. Lastly, we performed Bland-Altman plot test to analyse the agreement between different thresholding techniques used. All statistical analysis above was done using Statistical Package for the Social Sciences (SPSS, Version 12.0; IBM-SPSS, Chicago, IL) except Bland-Altman plot test where we used Microsoft Excel 2010. All $p<0.05$ were considered to be statistically significant difference.

RESULTS AND DISCUSSION

Shapiro-Wilk test was done to test normality of the data for the three thresholding techniques (Otsu's, midpoint and hysteresis). The p-value for Otsu's and hysteresis were 0.379 and 0.293 showed the data in these two techniques were normally distributed. The p-value for midpoint technique is 0.006 showed that data for midpoint technique was not normally distributed. The mean and standard deviation for FD values of those three techniques can be seen in Table 1.

Table 1: Summary of FD values based on thresholding techniques

Technique	Mean FD	SD	N
Otsu	2.3860	0.0019	27
Midpoint	2.1157	0.0796	27
Hysteresis	2.3909	0.0047	27

Table 2: Post-hoc Wilcoxon-signed ranked test for different thresholding techniques

Groups	Midpoint vs. Otsu's	Hysteresis vs. Otsu's	Midpoint vs. hysteresis
z-value	4.541	4.037	4.541
p-value	0.001	0.001	0.001

Table 3: Pearson's correlation test for hysteresis vs. Otsu's

Tests	Values
r-value	0.446
p-value	0.020

Table 4: Spearman correlation test for midpoint vs. Otsu's and midpoint vs. hysteresis

Variables	Values
Midpoint vs. Otsu's	
r-value	0.256
p-value	0.198
Midpoint vs. hysteresis	
r-value	0.252
p-value	0.204

Friedman test was conducted to determine the impact of thresholding techniques manipulation between Otsu's, midpoint and hysteresis. There was a statistically significant difference between groups as determined by Friedman test with $\chi^2(2) = 48.667$ and $p<0.001$. Since, there was statistical significant difference shown by Friedman test, we proceeded with Post-hoc Wilcoxon-signed ranked test to determine the pair of group that differs from others.

Post-hoc Wilcoxon-signed ranked test results shown in Table 2. Bonferroni correction was done where the p-value was set to 0.017. Median (IQR) of Otsu's method, midpoint method and hysteresis method were 2.3850 (2.3875-2.3847), 2.1363 (2.1717-2.0974) and 2.3906 (2.3932-2.3873). All three group pairs were statistically significant different with $p<0.001$ and $Z = 4.541$ for midpoint vs. Otsu's and midpoint vs. hysteresis while $Z = 4.037$ for hysteresis vs. Otsu's.

To check the correlation between each pair, we conducted Pearson's correlation for hysteresis vs. Otsu's pair while Spearman correlation was done on midpoint vs. Otsu's and midpoint vs. hysteresis pairs. Result for Pearson's correlation shown in Table 3 and result for Spearman correlation in Table 4.

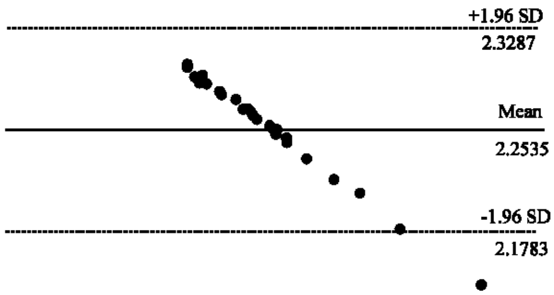

Fig. 1: Bland-Altman plot for midpoint vs. Otsu's. (FD mean difference of 0.1504 between upper limit and lower limit); Blind-Altman test for midpoint vs. Otsu's

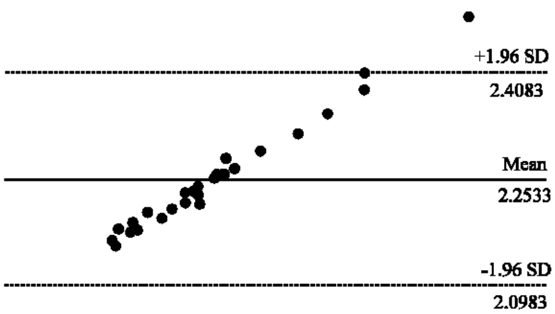

Fig. 2: Bland-Altman plot for midpoint vs. hysteresis. (FD mean difference of 0.31 between upper limit and lower limit); Blind-Altman test for midpoint vs. hysteresis

Pearson's correlation result in Table 3 showed moderate correlation (r = 0.446) which is significant with p = 0.02 between hysteresis and Otsu's. Spearman correlation result in Table 4 showed weak correlation which is not significant (r = 0.256, p = 0.198) for midpoint vs. Otsu's and (r = 0.252, p = 0.204) for midpoint vs. hysteresis.

Bland-Altman test plots were done to measure the agreement between two methods of midpoint vs. Otsu's, midpoint vs. hysteresis and hysteresis vs. Otsu's. The tabulation of the plot can be seen in Fig. 1-3.

As we can seen from Fig. 1-3 previously, the FD mean difference between midpoint vs. Otsu's, midpoint vs. hysteresis and hysteresis vs. Otsu's were 0.1504, 0.31 and 0.0114, respectively. The range between upper limit and lower limit is known as 95% limit of agreement where 95% of the differences between two measurement methods were expected to be included within that 95% limit of agreement (Rikxoort *et al*., 2010). Those results also shown that agreement of methods between hysteresis vs. Otsu's was better than midpoint vs. Otsu's and midpoint vs. hysteresis as the range of its upper and lower limits was smaller (0.0114) as compared to those two (0.1504 and 0.31).

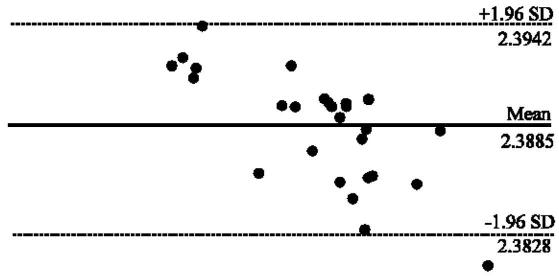

Fig. 3: Bland-Altman plot for hysteresis vs. Otsu's. (FD mean difference of 0.0114 between upper limit and lower limit); Blind-Altman test for hysteresis vs. Otsu's

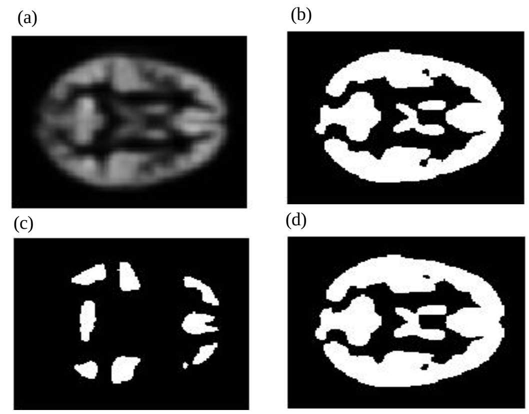

Fig. 4: a) Normal brain MRI image without any thresholding technique applied; b) Otsu's method; c) Midpoint method and d) Hysteresis method

Figure 4 shows the effect of thresholding manipulation on brain MRI images between Otsu's method, midpoint method and hysteresis method. Image was taken at slice number 60 from 121 slices.

In this research, we aimed to evaluate the impact of three thresholding techniques (Otsu's, midpoint and hysteresis) manipulation on the images and calculated FD and to determine if there were any association or correlation between two different thresholding techniques manipulation. Those thresholding techniques were chose due to their directness, user-friendly, easy to perform on MATLAB interface and well established method. We found those techniques not only affect the FD values of the brain images but also alter the MRI images (Fig. 4). The method differs from Squarcina *et al*. (2015) where they used global and local thresholding techniques in their research. They measured FD values for each slice of the brain MRI images in 2D while we measured the whole brain volume in 3D. They also avoid the segmentation process, unlike ours, resulting in the FD measurement of the images in grey-scale level, not at binarization level. As result, their FD values ranging between 1.29 and 1.66 while our FD values ranging between 2.1157 and 2.3909. Our finding is concurrent with Liu *et al*. (2003) where their FD values ranging between 2.540 and 2.596 showing consistent results for 3D acquisition of FD.

We found moderate correlation between Otsu's and hysteresis method. However, the correlation is not interchangeable. This may due to no variation in our subjects which were healthy young adults, aged ranging between 21 and 25 years old and were strongly right-handed. Zhang *et al*. (2007), Liu *et al*. (2003) and Squarcina *et al*. (2015) are together with other researchers in their previous study mostly compared the brain structures between normal and abnormal condition by using FD. However, they were interested in the effect of diseases or pathologies upon brain structural changes, while we interested in evaluating the effect of textual memorization brain structures. Most of previous studies known to the researchers didn't conduct Bland-Altman plot test to measure the agreement between two different methods, unlike ours.

We used images from our previous brain MRI acquisition which had undergone segmentation, normalization and smoothing in accordance to MNI, Sapuan *et al*. (2015) and Liu *et al*. (2003) stated that it will be more appropriate to do new acquisition of the raw data, rather than just resampling the data from previous study. This was impossible for us as we had limited access to the MRI facility during our research. Further improvement should include using newly acquired raw data of MRI images. We would also like to suggest the usage of 3D box-counting techniques to be used in the future instead of 2D in measuring the FD. Previous research by Zhang *et al*. (2007) and Esteban *et al*. (2010) reported better FD measurement obtained from 3D box-counting as compared to 2D box-counting. Impact of other thresholding techniques on images can also be explored in the future. Images that have been thresholded may also be analysed visually by experienced radiologist.

CONCLUSION

Different thresholding techniques do have impact on FD values but with moderate correlation between them. Other thresholding techniques should be explored in future with variance of subject's profile.

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