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Representation of Flat EEG Images via Fuzzy Limit

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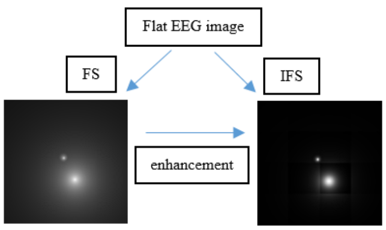
GRAPHICAL ABSTRACT



ABSTRACT

Sugeno type intuitionistic fuzzy generator is one of the ways to compute the non-membership value in an intuitionistic fuzzy set (IFS). In this paper, the Sugeno type intuitionistic fuzzy generator is extended to the concept of fuzzy limit in order to determine the hesitation value, namely π. The non-membership function λ, will influence the hesitation value, π and the results will be demonstrated in the form of images. Hence, by implementing the definition of fuzzy limit, different values of ε are used in obtaining the integer N that will determine the value of λ. Moreover, the relationship between hesitation and membership value will be demonstrated graphically.

Keywords: intuitionistic fuzzy set, hesitation degree, Sugeno fuzzy generator, Flat EEG

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1. INTRODUCTION

Various approaches have been introduced by researchers in modeling imprecisioness. One of the well-known and flexible methods in handling these imperfect nature of information is called fuzzy set which was introduced by Zadeh in 1965 [1]. Fuzzy set is a generalization of the classical set and characterized by a membership function. However, it is not absolutely perfect in assigning degrees of membership to the elements of a set. This drawback brings researchers to explore more on higher-order extensions of fuzzy set. One of the extensions that has gained a big interest in the area of imprecision is the intuitionistic fuzzy set (IFS) which was introduced by Atanassov [2]. IFS considers more uncertainties in terms of membership and non-membership functions. In IFS, the sum of membership and non-membership is not necessarily equal to one. Thus, there exists hesitancy in deciding the degree to which an element satisfies a particular property.

Fuzzy set has been implemented in diverse area such as in computer vision, machine intelligence, decision-making, and pattern recognition. However, the application of IFS in those areas especially in digital image processing is just beginning to develop. Chaira [3-5] is one of the researchers that works aggressively in the application of IFS in medical imaging. This is due to the fact that medical images contain a lot of uncertainties. Image degradation normally occurred during the acquisition stage or can be inherent by the image pixels. Hence, by enhancing the image quality, it will help in better diagnosis of certain diseases.

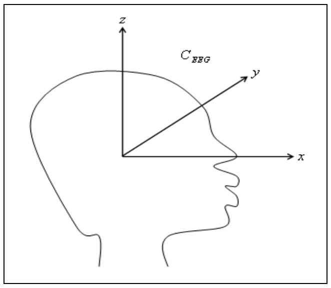
2. FLAT EEG

Flat EEG (fEEG) was developed by Fuzzy Research Group of UTM [6] which has been used purely for visualization. The main scientific value lies in the ability of flattening method to preserve information of recorded EEG signal during seizure. The 'jewel' of the fEEG method is that EEG signals can be compressed and analyzed. It is a method for mapping high dimensional signal, namely EEG into a low dimensional space.

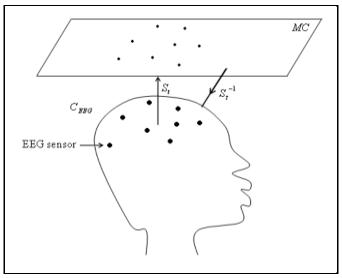
Fauziah's EEG coordinate system (Figure 1a) is defined as

$$C_{EEG} = \left\{ \left((x, y, z), e_p \right) : x, y, z, e_p \in \Re \text{ and } x^2 + y^2 + z^2 = r^2 \right\} \tag{1}$$

whereby r is the radius of a patient head.



(a)



(b)

Figure.1 (a) EEG Coordinate System, (b) EEG Projection

The mapping of C_{EEG} to a plane is defined as follows: $S_t : C_{EEG} \to MC$ (see Figure 1b) such that

$$S_t\left(\left(x,y,z\right),e_p\right)=\left(\frac{rx+iry}{r+z},e_p\right)=\left(\frac{rx}{r+z},\frac{ry}{r+z}\right)_{e_p(x,y,z)} \quad (2)$$

whereby $MC=\left\{\left(\left(x,y\right)_0,e_p\right):x,y,e_p\in R\right\}$ is the first component of FTTM. Both C_{EEG} and MC were designed and proven as 2-manifolds [6].

Furthermore S_t is designed to be a one to one function as well as being conformal. Details of proofs are contained in [6].

An EEG signal during seizure of an epileptic patient (see Figure 2)

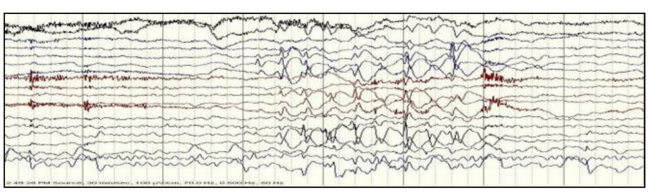
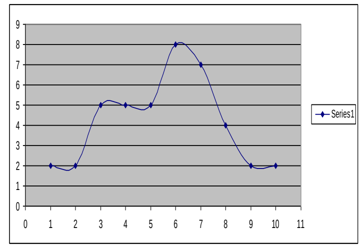
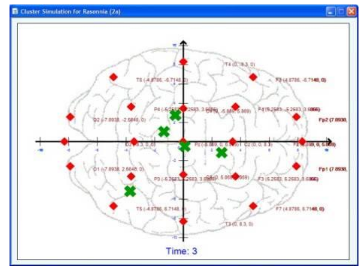


Figure.2 EEG Signal

can be compressed to Figure 3(a) and analyzed second by second as Figure 3(b)



(a)



(b)

Figure.3 (a) Compressed EEG Signal, (b) Analyzed EEG Signal

The EEG signal is transformed into low dimensional space via the flattening method. Furthermore, the fEEG is transformed into image by [7] via fuzzy approach. Figure 4 shows the transformation from EEG signal into image form.

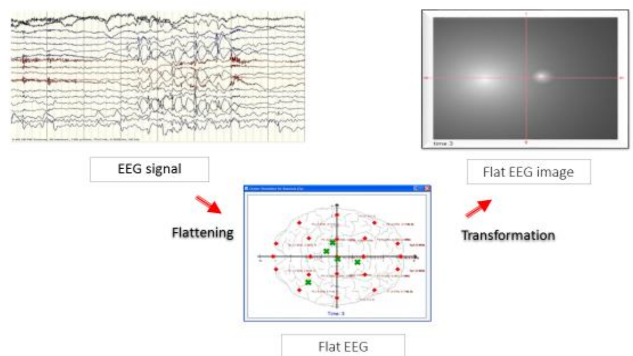


Figure. 4 Transformation from EEG signal into fEEG image

The fEEG undergoes some important steps in the transformation to image form as follows [7]:

a) fEEG is divided into pixels (see Figure 5)

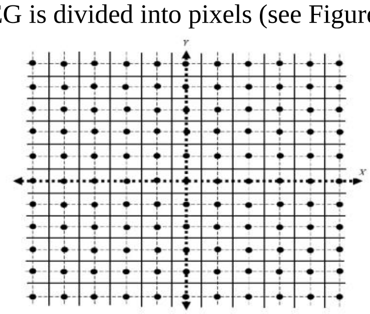


Figure.5 fEEG pixels [7]

b) The membership value for each pixel is determined in a cluster centre and the maximum operator of fuzzy set is implemented (see Figure 6)

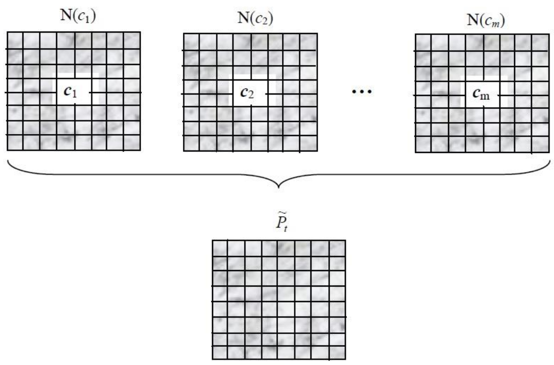


Figure.6 Fuzzy neighborhood of each cluster centre c_j of a fEEG [7]

c) The membership value of pixel is transformed into image data (see Figure 7)

Figure.7 fEEG image (input image) [7]

3. METHODOLOGY

In 2012, Chaira [3] proposed a method known as the window based enhancement scheme (WBES). This method is based on IFS which is aimed to enhance the contrast in medical images. Therefore, in this paper, the WBES is implemented on the fEEG image but with a slight difference in the initial step of the former method. In Chaira [3], the image is initially divided into 4 partitioned windows and fuzzification is carried out for each partitioned window. According to Chaira [3], a lot of noise is presented in the output image as the numbers of partitioned windows increased. Moreover, Chaira [3] used the formula $\mu_A\left(g_{ij}\right)=\dfrac{g_{ij}-g_{\min}}{g_{\max}-g_{\min}}$ to fuzzify the image. However, in this paper, fEEG image is initially fuzzified by using the method that is suggested by [7]. The fuzzification is applied to the entire image and later the image is divided into 4 partitioned windows. This method is known as the revised WBES version for fEEG. The revised algorithm is described as follows:

1. The entire input image is initially fuzzified by using the method as in [7]
2. The image is divided into 4 partitioned windows and enhancement is carried out for each partitioned window
3. The non-membership function is computed by using Sugeno type intuitionistic fuzzy generator as follows

$$\nu_A\left(g_{ij}\right)=\frac{1-\mu_A\left(g_{ij}\right)}{1+\lambda\mu_A\left(g_{ij}\right)},\quad \lambda>0 \tag{3}$$

4. The hesitation degree is given by

$$\pi_A\left(g_{ij}\right)=1-\mu_A\left(g_{ij}\right)-\frac{1-\mu_A\left(g_{ij}\right)}{1+\lambda\mu_A\left(g_{ij}\right)} \tag{4}$$

5. The mean of each partitioned window is calculated
6. The modified membership value is given by

$$\mu_A^{mod}\left(g_{ij}\right)=\mu_A\left(g_{ij}\right)-mean\ window\times\pi_A\left(g_{ij}\right) \tag{5}$$

7. Finally, the contrast enhancement is applied to each partitioned window by using the intensifier operator as given by Eq. (6)

$$\mu_A^{enh}\left(g_{ij}\right)=\begin{cases}2\left[\mu_A^{mod}\left(g_{ij}\right)\right]^2 & if \quad \mu_A^{mod}\left(g_{ij}\right)\le 0.5\\ 1-2\left[1-\mu_A^{mod}\left(g_{ij}\right)\right]^2 & if \quad 0.5<\mu_A^{mod}\left(g_{ij}\right)\le 1\end{cases} \tag{6}$$

Here, g_{ij} is the $(i,j)^{th}$ gray level of the image.

Furthermore, the non-membership function (see Eq.3) is generalized by using the concept of fuzzy limit.

Consider the definition of convergence of fuzzy number as given by [8]:

Definition [8]. A sequence $X=\{X_n\}$ of fuzzy numbers is said to be convergent to the fuzzy number X_0, written as $\lim_n X_n = X_0$, if $\forall\varepsilon>0,\exists n_0>0 \ni \bar{d}\left(X_n,X_0\right)<\varepsilon$ for $n>n_0$

From Eq. (3), as $\lambda\to\infty$, the non-membership function $\nu_A\left(g_{ij}\right)$ will approach zero as follows:

$\lim_{\lambda\to\infty}\nu_A\left(g_{ij}\right)=0$ if and only if

$\forall\varepsilon>0,\exists N\left(N\left(\varepsilon\right)\right)\ni\lambda>N\Rightarrow\left|\nu_A-0\right|<\varepsilon$

Now, by taking $N>\dfrac{1-\mu_A\left(g_{ij}\right)}{\varepsilon}-1$,

therefore $\lim_{\lambda\to\infty}\nu_A\left(g_{ij}\right)=0$ since

$$\forall\varepsilon>0,\exists N\left(N>\frac{1-\mu_A\left(g_{ij}\right)}{\varepsilon}-1\right)\ni\lambda>N\Rightarrow\left|\nu_A\left(g_{ij}\right)-0\right|<\varepsilon$$

Hence, by applying the concept of fuzzy limit as shown above, the value of N is determined.

4. RESULTS AND DISCUSSION

The aforementioned enhancement algorithm is applied on the image of EEG signal during epileptic seizure at time 1 with size 201x201. Different values of ε are used in order to obtain the value of N.

Here, some values of ε are 0.01, 0.02, 0.1, 0.2, and 0.5. For each particular ε, the maximum value of N will be chosen in determining the value of λ as given in Table 1.

Table.1 Values of parameters

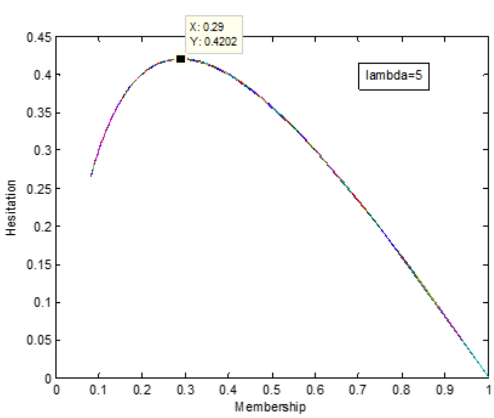
ε	N	λ
0.01	$N \geq 91$	$\lambda > 91$
0.02	$N \geq 45$	$\lambda > 45$
0.1	$N \geq 9$	$\lambda > 9$
0.2	$N \geq 4$	$\lambda > 4$
0.5	$N \geq 1$	$\lambda > 1$

For these particular values of λ, the maximum value of hesitation are presented in Table 2.

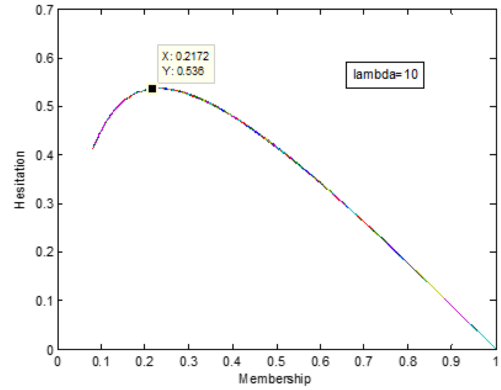
Table.2 Value of hesitation π for some λ

λ	π
2	0.267949
5	0.420204
10	0.536675
46	0.745406
92	0.812095

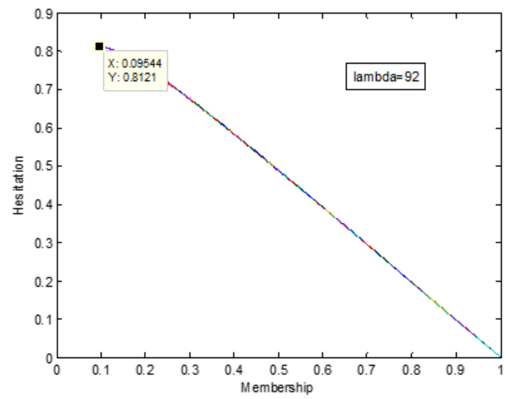
Figure 8 shows the relationship between hesitation and membership values for $\lambda = 5$, $\lambda = 10$, and $\lambda = 92$.



(a)



(b)



(c)

Figure.8 Hesitation vs membershipvalue for (a) $\lambda = 5$, (b) $\lambda = 10$, (c) $\lambda = 92$

Figure 9 shows the images of fEEG. Figure 9(a) is the input image obtained by implementing fuzzy set approach [7]. Whereas Figure 9(b), 9(c), 9(d), 9(e), and 9(f) are the images resulting from the IFS approach with different values of λ.

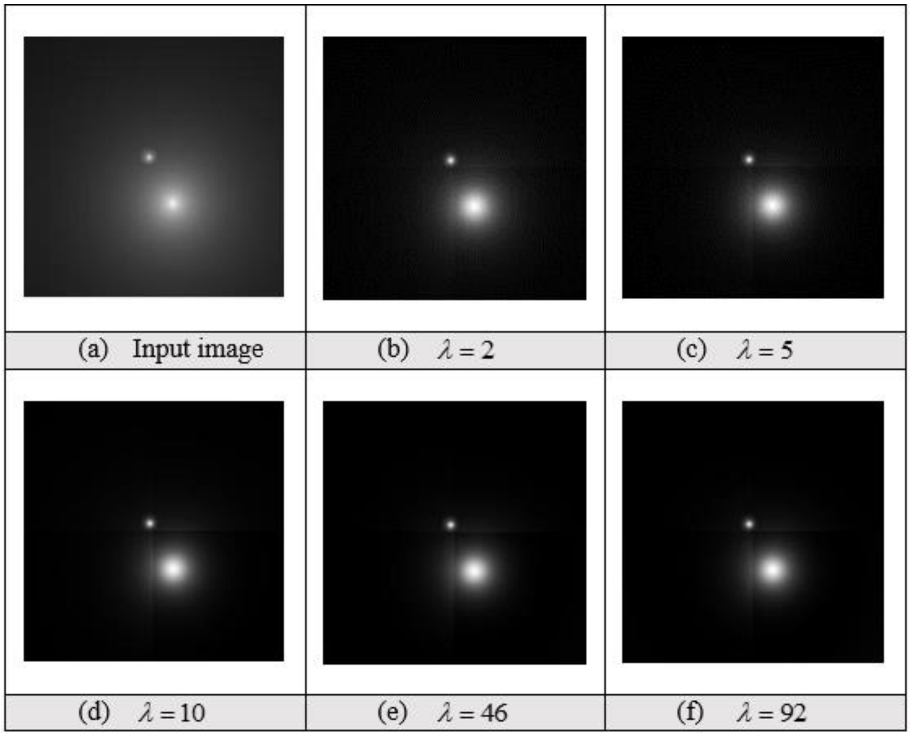


Figure.9 fEEG image during epileptic seizure at time 1 with size 201x201, (a) Input image, (b), (c), (d), (e), and (f) Enhanced image by using IFS with different values of λ.

5. CONCLUSION

In this paper, the enhanced images of fEEG are obtained by implementing the IFS approach. Moreover, the application of fuzzy limit shows that the deteriorating of fEEG images still can be obtained for any smallest value of ε.

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