A comparison of ordinary fuzzy and intuitionistic fuzzy approaches in visualizing the image of flat electroencephalography

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Abstract. Medical imaging is a subfield in image processing that deals with medical images. It is very crucial in visualizing the body parts in non-invasive way by using appropriate image processing techniques. Generally, image processing is used to enhance visual appearance of images for further interpretation. However, the pixel values of an image may not be precise as uncertainty arises within the gray values of an image due to several factors. In this paper, the input and output images of Flat Electroencephalography (fEEG) of an epileptic patient at varied time are presented. Furthermore, ordinary fuzzy and intuitionistic fuzzy approaches are implemented to the input images and the results are compared between these two approaches.

1. Introduction

In this digital era, everything is seemed to be computerized due to the rapid development in advanced technologies. For instance, the environment of medical imaging has changed dramatically from analogue to digital technology. This is very important in assisting medical practitioners to diagnose different medical conditions without having to undergo surgical procedure to look into various organs and areas in the body.

One of the example is in diagnosing epilepsy. Epilepsy is a symptom that originates in the brain. It causes disturbances in electrical signaling in the brain and can be happened in a small area of the brain or it can affect the whole brain. A seizure is just a symptom of epilepsy, as not all seizures are caused by epilepsy. People with multiple seizures is said to have epilepsy. Epileptic foci refer to the location of the current sources which generate the corresponding magnetic fields. The main interest in this work is to visualize the path of ‘brainstorm’ in the brain that occur during seizure by using fuzzy and intuitionistic fuzzy image processing.

2. Basic concepts

In the previous study on fEEG by Zakaria [1], the data was collected from an epileptic patient by using the EEG. After that, the recorded EEG signal (see figure 1) was transformed into fEEG whereby fEEG is a method for visualization. The fEEG mapped high dimensional signal into low dimensional space.
The main scientific value lie in the ability to preserve information about the surface. Moreover, the EEG signals can be compressed and analyzed via the fEEG method. Figure 2 shows an example of fEEG for $t = 0$ to $t = 8$ of an epileptic patient.

Furthermore, in Abdy [2], the fEEG was transformed into digital fEEG in order to convert it in a form that can be stored in a computer. Next, the digital fEEG was transformed into image by the process of digitization and quantization. However, in the process of imaging and transformation such as fEEG, it is hard to avoid different kinds of noise during recording of the EEG signals. Uncertainty may arise within every transformations since the regions of clusters in fEEG are not always defined. Therefore, in dealing with uncertainty, fuzzy approaches are used in this work.

Fuzzy sets theory was introduced by Professor Zadeh in 1965 [3]. It aims to model the uncertainty which cannot be modelled by the classical sets. Since then, fuzzy sets has evolved tremendously in many areas including image processing. In 1983, Atanassov [4] introduced the extension of fuzzy sets which is known as intuitionistic fuzzy sets (IFS). It considers more uncertainties in terms of membership and non-membership functions.
3. Methodology
In this work, the fEEG input image is enhanced in terms of contrast enhancement. Initially, the fEEG input image is fuzzified to convert it from gray plane into a fuzzy plane. In fuzzy plane, the pixel’s value is denoted by the membership value which can take values in the closed interval [0, 1]. The membership value \( \mu_i(x) \) represents the degree of brightness or darkness of the pixels. After that, the membership value is modified by using the intensifier operator. Finally, the image is transformed back into gray plane via defuzzification process. The algorithms for fuzzy and IFS are described as follows:

3.1. Fuzzy Algorithm.
1) fEEG input image is fuzzified by using
\[
\mu_i \left( g_{ij} \right) = \frac{g_{ij} - g_{\text{min}}}{g_{\text{max}} - g_{\text{min}}}
\]
2) The membership value is modified by using intensifier operator
\[
\mu_i^{\text{enh}} \left( g_{ij} \right) = \begin{cases} 
2 \left[ \mu_i^{\text{mod}} \left( g_{ij} \right) \right]^2 & \text{if} \quad \mu_i^{\text{mod}} \left( g_{ij} \right) \leq 0.5 \\
1 - 2 \left[ 1 - \mu_i^{\text{mod}} \left( g_{ij} \right) \right]^2 & \text{if} \quad 0.5 < \mu_i^{\text{mod}} \left( g_{ij} \right) \leq 1
\end{cases}
\]
3) Finally, defuzzification is carried out by using \( I = 255 \times \mu_i^{\text{enh}} \left( g_{ij} \right) \).

3.2. IFS Algorithm.
1) fEEG input image is fuzzified by using
\[
\mu_i \left( g_{ij} \right) = \frac{g_{ij} - g_{\text{min}}}{g_{\text{max}} - g_{\text{min}}}
\]
2) The non-membership function \( v_i(x) \) is computed by using Sugeno type intuitionistic fuzzy generator
\[
v_i \left( g_{ij} \right) = \frac{1 - \mu_i \left( g_{ij} \right)}{1 + \lambda \mu_i \left( g_{ij} \right)}, \quad \lambda > 0
\]
3) The hesitation degree is obtained by using
\[
\pi_i \left( g_{ij} \right) = 1 - \mu_i \left( g_{ij} \right) - \frac{1 - \mu_i \left( g_{ij} \right)}{1 + \lambda \mu_i \left( g_{ij} \right)}
\]
4) The mean of the image is calculated
5) The modified membership value is given by
\[
\mu_i^{\text{mod}} \left( g_{ij} \right) = \mu_i \left( g_{ij} \right) - \text{mean} \times \pi_i \left( g_{ij} \right)
\]
6) The contrast enhancement is applied by using the intensifier operator
\[
\mu_i^{\text{enh}} \left( g_{ij} \right) = \begin{cases} 
2 \left[ \mu_i^{\text{mod}} \left( g_{ij} \right) \right]^2 & \text{if} \quad \mu_i^{\text{mod}} \left( g_{ij} \right) \leq 0.5 \\
1 - 2 \left[ 1 - \mu_i^{\text{mod}} \left( g_{ij} \right) \right]^2 & \text{if} \quad 0.5 < \mu_i^{\text{mod}} \left( g_{ij} \right) \leq 1
\end{cases}
\]
7) Finally, defuzzification is applied via \( I = 255 \times \mu_i^{\text{enh}} \left( g_{ij} \right) \)

In the algorithm, \( g_{ij} \) is the \((i,j)\)\textsuperscript{th} gray level of the image.

The fuzzy method is based on Chaira [5] whereas the IFS is based on Chaira [6] with slight modification. In Chaira [6], window based enhancement scheme (WBES) is applied to the medical images. However, in this work the revised version of WBES is implemented.
4. Results

The aforementioned algorithm is implemented on fEEG input image for $t = 1$ to $t = 4$ of size 201x201 (see figure 3). There are two clusters of electrical current sources for $t = 1$, $t = 2$ and $t = 3$. Meanwhile, for $t = 4$ there are three cluster centres that can be observed. The brightness represents the strength of the electrical potential. Figure 4 shows the output images by implementing fuzzy approach. Whereas the output images for intuitionistic fuzzy approach are presented in Figure 5 and Figure 6 with different value of parameter $\lambda$. Furthermore, to measure the similarity between the input and output images, the structural similarity index measure (SSIM) is used for comparisons. The similarity measurement consists of three components which are the luminance, contrast, and structure. The best value of 1 is achieved if the input and output images are the same [7]. The results are displayed in Table 1.

![Figure 3. fEEG input images.](image1)

![Figure 4. fEEG output images by fuzzy approach.](image2)
Figure 5. fEEG output images by intuitionistic fuzzy approach, $\lambda = 0.01$.

Figure 6. fEEG output images by intuitionistic fuzzy approach, $\lambda = 1$.

Table 1. SSIM performance comparisons.

| Time, $t$ | Fuzzy | IFS, $\lambda = 0.01$ | IFS, $\lambda = 1$ |
|-----------|-------|---------------------|------------------|
| 1         | 0.2966| 0.2965              | 0.2598           |
| 2         | 0.3971| 0.3956              | 0.3366           |
| 3         | 0.4967| 0.4958              | 0.4958           |
| 4         | 0.4697| 0.4680              | 0.3908           |
From Table 1, it shows that there are not much different for similarity measurement between fuzzy and intuitionistic fuzzy approaches. For intuitionistic fuzzy approach, the SSIM values for \( \lambda = 0.01 \) are closer to 1 compared to \( \lambda = 1 \). This is because as the value of \( \lambda \) increase, the value of hesitation \( \pi \) is also increase.

5. Conclusions
In this work, the input image of fEEG is enhanced through contrast enhancement by fuzzy and intuitionistic fuzzy approaches. It shows that both approaches are able to produce fEEG images with darker background compared to the input image. The spread of the electrical potential has been reduced resulting in smaller area of the vague boundaries.

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