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Brain tumor segmentation using neutrosophic expert maximum fuzzy-sure entropy and other approaches

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ABSTRACT

Glioblastoma is the most aggressive and most common primary brain tumor in adult individuals. Magnetic resonance imagery (MRI) is widely used in the brain tumor diagnosis. This study proposes an approach called neutrosophic set – expert maximum fuzzy-sure entropy (NS-EMFSE), which is a successful edge detection approach, by combining two powerful approaches such as neutrosophic set (NS) and expert maximum fuzzy-sure entropy (EMFSE). Thus, a high performance approach is designed for Glioblastoma, which is the most difficult brain tumor segmentation and edge finding process. The proposed NS-EMFSE approach was designed to detect enhancing part of the tumor in brain MRI image. Using maximum fuzzy entropy and fuzzy c-partition methods, EMFSE determines the necessary threshold value to convert images into binary format. NS has been recently proposed as an efficient approach based on neutrosophy theory, and yields remarkably successful results for indeterminate situations. The proposed algorithm was compared to NS with Otsu thresholding (NS-Otsu), support vector machine (SVM), fuzzy c-means (FCM), Darwinian particle swarm optimization (DPSO). SVM, FCM, DPSO algorithms have been so far used for edge detection and segmentation in various fields. In this study, figure of merid (FOM) and jaccard index (JI) tests were carried out to evaluate the performances of these 5 edge detection approaches on 100 MRI images. These tests indicate which approach yields the best performance in enhancing part detection of the tumor in MRI image. Analysis of variance (ANOVA) was performed on FOM and JI data. As a result, the maximum values of FOM and JI results for the NS-EMFSE are 0.984000, and 0.965000, the mean values are 0.933440 and 0.912000, and the minimum values are 0.699000 and 0.671000, respectively. When these statistical results are compared with the statistical results of other 4 approaches, it is understood that the proposed method yields higher FOM and JI results. In addition, other statistical analysis results proved that the proposed NS-EMFSE performed better than other 4 methods.

1. Introduction

Glioblastoma-type cancers can spread rapidly and are generally likely to lead to a shorter lifespan [1]. In this type of cancer, despite the lack of effective therapies and progress in drug treatments, it is difficult to anticipate the progress of the disease [2].

MRI is widely used to diagnose potential intracerebral problems. It is of vital importance to optimally detect the edges of a tumor or tumors in an MRI image in terms of medical diagnosis and surgical planning. Today, the edges of a tumor/s in an MRI image are manually detected by a radiologist. However, this method is too time-consuming, and might risk overlooking some tumors in the image. As a result, from a medical perspective, it bears utmost importance to automatically detect the edges of a tumor or tumors in an MRI image. It is easier to detect the edges of some brain tumors such as meningiomas, it is more difficult to find brain tumors such as glioma and glioblastoma due to their poorly constrated, low brightness and diffused nature [1]. Therefore, this study focuses on tumor edge detection in MRI images with glioblastomas.

Various approaches have been proposed for tumor edge detection in MRI images such as neural network [1,3], watershed [4], entropy based [5], fuzzy c-means (FCM) algorithm [6], cellular automata [7], stochastic [8], level set [9], support vector machines (SVM) [10], random forests [11], Markov Random Fields [12] and so forth.

In this study, neutrosophic set - expert maximum fuzzy-sure entropy (NS-EMFSE) is proposed as an approach for an automatic tumor edge detection in an MRI image. The first element of the proposed approach, neutrosophic set (NS), is a contemporary approach dealing with the scope, origin and nature of neutralities.

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Additionally, NS is based on neutrosophy theory, which is a new philosophical branch [13], and is a recent method that successfully resolves indeterminate situations. Thus, it is widely used in various fields such as image processing, filtering, edge detection and segmentation. In the second element of the proposed approach, expert maximum fuzzy-sure entropy (EMFSE), the maximum fuzzy entropy and fuzzy c-partition can automatically detect threshold value at gray level [14]. The method benefits from maximum entropy method, and Sure was used as a type of entropy. This study combines our previous studies on NS [13] and EMFSE [14] to create a more efficient edge detection method. Because NS is a relatively new field of study, its use in the field of biomedical applications [15–18] is limited. In addition, EMFSE has never been used in any biomedical application.

For comparison with NS-EMFSE, NS with Otsu thresholding (NS-Otsu), SVM [19], FCM [20,21] and Darwinian particle swarm optimization (DPSO) [22] algorithms were used. The NS-Otsu approach was obtained using Otsu thresholding [23] instead of the EMFSE used in the NS-EMFSE approach.

An efficient statistical learning method, SVM [19] is widely used in various applications such as segmentation, edge detection and classification. Similarly, FCM [20,21] is an unsupervised technique used in image edge detection, object classification, data mining and machine learning [24]. It is particularly used for edge detection / segmentation in medical images. The particle swarm optimization (PSO) is a powerful machine learning technique. DPSO, which is obtained by adding additional features to the PSO, is an evolutionary algorithm [22]. Ref [22]. provides detailed information on DPSO. The PSO algorithm is frequently used for segmentation and edge detection in brain MRI images [25–27].

The rest of this paper is organized as follows: edge detection approaches are given in Section 2. The approaches for performance evaluation of edge detection are given in Section 3. Experimental results are presented in Section 4. Finally, conclusion is given in Section 5.

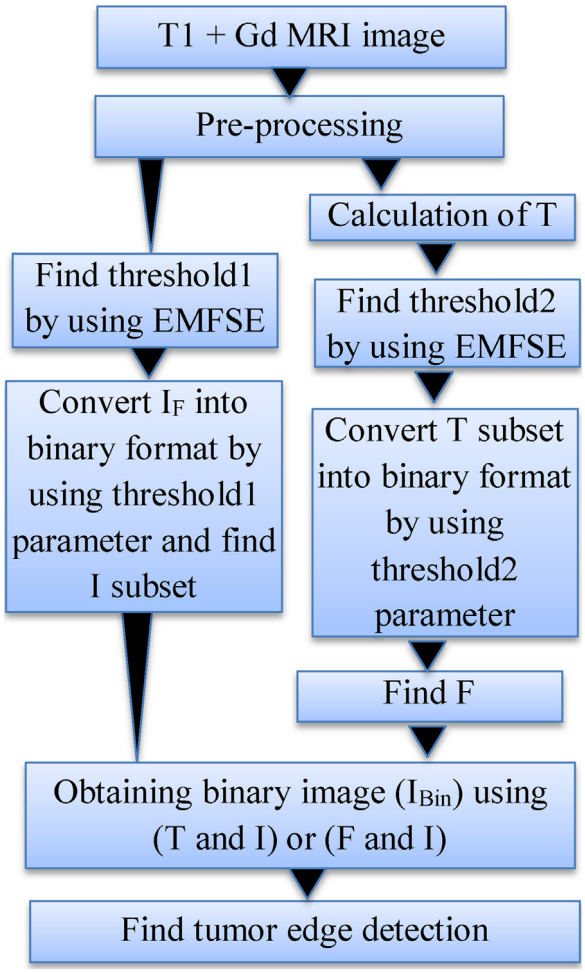

Fig. 1. Converting NS domain of MRI image by using NS-EMFSE.

2. Material and methods

2.1. MRI database

Images in The Cancer Genome Atlas (TCGA) Glioblastoma Multiforme (GBM) collection [28,29] in The Cancer Imaging Archive (TCIA) were used to test the performance of the proposed NS-EMFSE approach. TCGA-GBM collection contains pre-operative MRI images. TCGA-GBM offers open access data for researchers studying brain tumors. Therefore, no ethics committee is required to use the data in this collection. TCGA-GBM offers a rich radiological archive with skull-striped MRI images in NIfTI format in its T1-weighted pre-contrast (T1), T1-weighted post-contrast (T1- gadolinium (Gd), T2, and T2-FLAIR sequences. It is possible to find computer-assisted and manually corrected segmentation ground truth (GT) labels. The proposed NS-EMFSE approach detects enhancing tumor in MRI images. Because T1-Gd sequence is used to collect information about the enhancing and non-enhancing tumor, 100 pieces of 2D slices MRI image (T1-Gd sequence) were used in this study.

2.2. Neutrosophic image

A new approach introduced by Florentine Smarandache, neutrosophy theory is based on a number of disciplines such as neutrosophic logic, neutrosophic probability, neutrosophic set, and neutrosophic statistics [30]. In NS, events are converted to three subsets as True (T), False (F) and Indeterminacy (I). This approach can be used to model indeterminate situations and resolve them successfully [30]. Stock market or weather forecast can be given as examples of indeterminate situations in daily living [30]. Therefore, NS has been widely used in image processing applications. The flow diagram for the conversion of MRI images into NS domain using the proposed NS-EMFSE approach is shown in Fig. 1. This approach pre-processes MRI image at the beginning. Afterwards, EMFSE is used to find I subset in binary format and T and T subsets in binary format as well. This is followed by binary image (I_{Bin}) of the MRI image. Finally, the edges of enhancing tumor are detected.

2.3. Expert maximum fuzzy-sure entropy (EMFSE)

In EMFSE approach, the maximum fuzzy entropy and fuzzy c-partition methods are used to automatically detect threshold method at gray level [14]. In addition to this, Sure entropy was used for maximum entropy as well as c-partition. In this study, EMFSE algorithm is used to convert T, F and I subsets in to binary format [14].

An image has N – gray level ranging from r_0 to r_{j-1}, $W = \{r_0, r_1, \ldots, r_{J-1}\}$. The threshold values obtained from EMFSE correspond to cross points of the fuzzy set as show in Fig. 2. Pixels in this algorithm are divided into two groups as dark and bright groups. For this purpose, two fuzzy sets as dark and bright groups in W are