Dealing With Noise and Partial Volume Effects in Alzheimer Disease Brain Tissue Classification by a Fuzzy-Possibilistic Modeling Based on Fuzzy-Genetic Initialization

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ABSTRACT

Segmentation is a key step in brain imaging where clustering techniques are widely used, particularly the fuzzy approach which offers active and robust methods against noise and partial volume effect (PVE). To address those imperfections, this article suggests an automatic segmentation of brain tissues for magnetic resonance and functional images of Alzheimer's patients, based on an efficient and robust genetic-fuzzy-possibilistic clustering scheme for the assessment of white matter, gray matter and cerebrospinal fluid volumes. The proposed hybrid clustering process based on: 1) A fuzzy possibilistic c-means algorithm that models the degree of relationship between each voxel and a given tissue. 2) A fuzzy c-means algorithm to initialize the clusters centers, with subsequent optimization by a genetic algorithm. Each stage of the proposed clustering process is validated on real brain data and synthetic images of an Alzheimer's Disease Neuroimaging Initiative (ADNI) phantom. A performance comparison is made with the usual fuzzy techniques. The visual and quantitative results obtained with the proposed approach using various signal-to-noise ratios prove its effectiveness to quantify the tissue volume of images of different modalities types in the presence of noise and PVE. The effectiveness in terms of computational rate is also demonstrated.

KEYWORDS

Adni Images, Alzheimer Disease, Brain Tissues Classification, Fuzzy C-Means Algorithm, Fuzzy Possibilistic C-Means Algorithm, Genetic Algorithms, Possibilistic C-Means Algorithm, Real Images

1. INTRODUCTION

Because of the imperfection of medical information, the field of medicine has become a very attractive domain for the application of fuzzy set theory. This is due to the large imprecision caused by the Partial Volume Effect (PVE) and the uncertainty due to noise (Behroozi & Daliri, 2012). Recently, there has been considerable interest in the use of fuzzy clustering methods for medical image segmentation,

which retain more information from the original image than hard clustering methods (Vasuda & Satheesh, 2010). In hard clustering, each voxel of the image belongs to exactly one cluster or specific tissue, and a membership value of zero or one is assigned to it; in fuzzy clustering, each voxel belongs to every cluster, with its membership to each one varying between 0 and 1 (El-Melegy, Zanaty, Abd-Elhafiez & Farag, 2007). In medical images the complexity of tissue boundaries causes many voxels to contain a mixture of tissues (Links, Beach, L. Subramana et al., 1998). Fuzzy methods are better suited for this kind of situation.

In the literature on fuzzy clustering, the Fuzzy C-Means (FCM) clustering algorithm, proposed by Dunn (Dunn, 1974) and extended by Bezdek (Bezdek, J.C. 1981) is the best known and most used method. Although FCM is a useful clustering method, its membership results do not always correspond accurately to the degrees of belonging of the data, and it may be inaccurate in a noisy environment (Krishnapuram & Keller, 1993). To help address those weaknesses of FCM, methods stemming from possibilistic logic appeared.

Possibilistic logic was introduced by Zadeh (Zadeh, 1978) following its former works in fuzzy logic (Zadeh, 1965) in order to simultaneously represent imprecise and uncertain knowledge. Possibilistic logic is a weighted logic developed in the realm of artificial intelligence, with a view to develop a simple and rigorous approach to automated reasoning from uncertain or prioritized incomplete information. It enjoys properties that keep it close to classical fuzzy logic, although the introduction of weights (of different kinds) substantially increases its representation capabilities, especially for inconsistency handling (Dubois & Prade, 2004). Particularly, it has gained popularity recently in modeling and propagating uncertainty and precision in imaging applications (Pal, Pal, Keller & Bezdek, 2005).

To overcome the weakness of FCM against noise and PVE, Krishnapuram and Keller (Krishnapuram & Keller, 1993) proposed to relax the constraint of fuzziness and produce memberships that have a good explanation of the degrees of belonging for the data. They established the first Possibilistic C-Means algorithm (PCM) which used a possibilistic type of membership function to describe the degree of belonging. They showed that algorithms with possibilistic memberships are more robust to noise and outliers than FCM and its variants (Krishnapuram & Keller, 1993). However, Barni et al. (Barni, Cappellini & Mecocci, 1996) showed that the PCM algorithm is sensitive to initialization and generates coincident clusters. Timm et al. (Timm, Borgelt, Doring & Kruse, 2004) proposed then the possibilistic fuzzy clustering, and Pal et al. (Pal, Pal, Keller & Bezdek, 2005) proposed another Fuzzy Possibilistic C-Means (FPCM) that can avoid the coincident clusters of PCM while being less sensitive to noise than FCM.

Brain images are characterized by noise, intensity inhomogeneity, and weak boundaries. Therefore, the accurate segmentation of brain tissues is still challenging. The aim of this paper is to evaluate the effectiveness of fuzzy logic, especially possibilistic theory, at managing uncertainty and imprecision. The FPCM algorithm (Pal, Pal, Keller & Bezdek, 2005) was then chosen for the volumetric measurement of White Matter (WM), Gray Matter (GM), and Cerebrospinal Fluid (CSF) brain tissues, and for the computation of fuzzy tissue maps in images. The volume measurement of CSF, GM, and WM tissue plays an important role in computer aided neurosurgery, diagnosis (Yogita & Milind, 2016) and treatment of pathologies, and it may be of major interest in neurodegenerative disorders such as Alzheimer's Disease (AD), Parkinson's related syndromes, in WM metabolic or inflammatory disease, in congenital brain malformations or perinatal brain damage, and in post-traumatic syndrome (Saha & Bandyopadhyay, 2007).

Moreover, we propose a genetic-fuzzy process for the centers initialization of clusters. For this purpose, we use the FCM algorithm (Bezdek, 1981) to get the initial partition, and the Genetic Algorithms (GA) (Goldberg, 1996) to achieve optimization, before choosing the best score among all at the end. The integration of the genetic process allows to determine the appropriate cluster centers and the fuzzy corresponding partition matrix. This initialization process then allows to train the FPCM algorithm with the centers partition empirically obtained as opposed to randomly set, which

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