FUZZY EXPERT SYSTEM FOR EDEMA SEGMENTATION

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ABSTRACT

A method for segmentation of edema region in a computed tomography (CT) image of the brain is presented in this paper. The edema region is a dark region surrounding the intracerebral brain hemorrhage (ICH) region. Edema segmentation, in general, is difficult because of very subtle grayscale variations.

The proposed edema segmentation procedure consists of two major parts. Fuzzy feature extraction is performed in the first part of the procedure. Extracted features include local contrast and distance from ICH region. The fuzzy features are then input into the rule-based expert system as fuzzy facts.

In the second part, a fuzzy expert system is used to perform the actual segmentation. A set of rules is formulated to represent the knowledge about the possible image structure. The set of rules is constant and does not depend on the input image. The fuzzy facts extracted in the first part of the procedure are derived from the particular image to be segmented. Fuzzy-CLIPS software package has been used to derive a conclusion from the facts based on the rules. The conclusion represents the segmented edema region.

Experiments have shown that the method can be used for edema segmentation.

1. INTRODUCTION

A number of artificial intelligence techniques including neural networks, genetic algorithms, expert systems and fuzzy logic have been presented in biomedical image analysis in recent years. They have been used mostly for automatic analysis of medical images such as automatic segmentation of MR brain images [1, 2, 3], automated boundary extraction in echocardiographic images [4], labeling of medical images [5] and many others. A method for automatic segmentation of intra cerebral brain hemorrhage (ICH) from CT head images has been proposed in [6]. The localization of edema region has shown to be a particularly complex task. The edema region surrounds the hemorrhage region and is very hard to localize even for medical experts. The borders of the edema region are not well localized and the edema is just slightly darker than the brain tissue. All these facts make segmentation of the edema region very difficult. That is the reason why artificial intelligence techniques have been introduced in solving the edema segmentation problem.

The objective of this paper is to present an approach which combines two artificial intelligence techniques for segmentation of the edema region from CT head images containing ICH. This approach uses a rule-based expert system and a fuzzy logic and is implemented using the expert system shell Fuzzy CLIPS. Fuzzy CLIPS is fuzzy extension to CLIPS expert system shell. It can be used with fuzzy facts and fuzzy rules.

2. METHOD

The edema segmentation method proposed in this work is an extension of the previous work described in [6]. In the previous method a non-fuzzy expert system has been used for edema segmentation. The edema segmentation follows after the segmentation of the primary ICH region. The location of primary ICH region is used to determine the location of the edema pixels. The same procedure is used by the human radiologists.

The segmentation procedure is hierarchically divided into a global and a local segmentation. Block diagram of the segmentation procedure is shown in Figure 2.

The location of the ICH region is determined in the global segmentation step. The pixels that belong to the brain tissue are used as candidates for edema region. The global segmentation consists of two steps. In the first step the image is clustered into three clusters: dark, medium, and bright . This is done by the

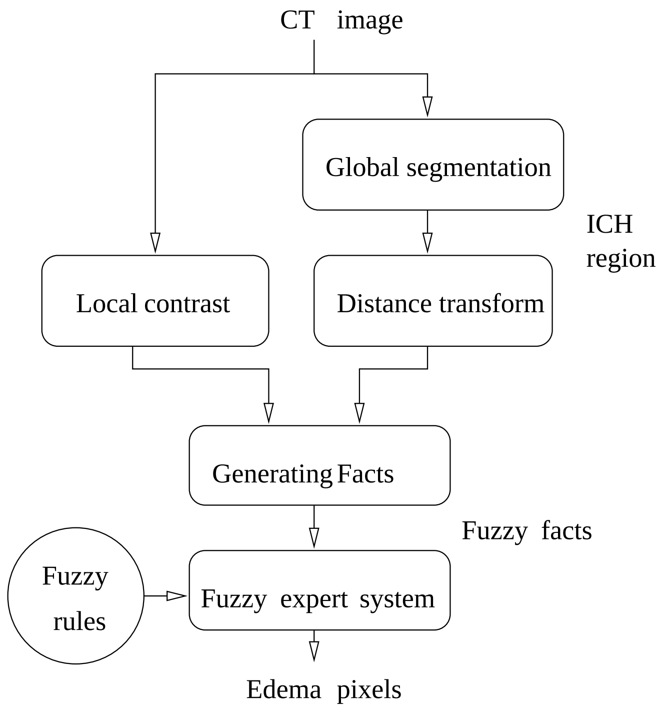

Figure 1: Block diagram of the proposed segmentation method.

K-means clustering algorithm. In the second step of global segmentation algorithm regions obtained by the clustering are fed into the expert system which determines membership of those regions into tissue classes. The tissue classes are skull, brain, and ICH.

The local segmentation is done in the following way. For the pixels belonging to the brain tissue that are within some distance from the ICH region two features are calculated. The first feature is the distance from the ICH region. The second feature is the local contrast. The extracted features are fuzzified and fed to fuzzy expert system. The distance measure used is the check board distance. Negative value of local contrast is used because edema region is always darker than its surroundings. For each pixel one fact was generated containing fuzzy descriptions of pixel features.

The fuzzy expert system is an expert system that uses the fuzzy logic while a conventional expert system uses Boolean logic. In fact, it is a collection of membership functions and rules that are used to reason about data. As opposed to the conventional expert systems, which are mainly oriented to symbolic reasoning, the fuzzy expert systems are oriented toward numerical processing. For that reason, the fuzzy expert systems are more suitable for solving problems in image processing than the conventional expert systems. In the inference process, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy set to be assigned to each output variable for each rule. The rules that are used for segmentation of the edema region determine the membership value to the edema region for each pixel in the neighborhood of the hemorrhage region.

1. Rule 1: **if** distance is close **and** pixel is darker than background **and** pixel is adjacent to hemorrhage or edema **then** edema belonging is high

2. Rule 2: **if** distance is close **and** pixel is darker than background **and** pixel is adjacent to hemorrhage or edema **then** edema belonging is medium

3. Rule 3: **if** distance is far **and** pixel is darker than background **and** pixel is adjacent to hemorrhage or edema **then** edema belonging is medium

4. Rule 4: **if** distance is far **and** pixel is darker than background **and** pixel is adjacent to hemorrhage or edema **then** edema belonging is low

Three fuzzy variables are used in the above set of rules. The first variable is d which denotes the pixel's distance to the hemorrhage region. Two fuzzy sets correspond to this variable: close and far.

$$\begin{array}{lcl} close(d) & = & Z(d,a,c) \\ far(d) & = & 1 - close(d) \end{array} \tag{1}$$

where a and c are parameters of the standard Z function, defined as follows [7]:

$$Z(u,a,c) = 1 - S(u,a,c), \tag{2}$$

where $S(u,a,c)$ is defined as:

$$S(u,a,c) = \begin{cases} 0, & u \le a \\ 2(\frac{u-a}{c-a})^2, & a < u \le \frac{a+c}{2} \\ 1 - 2(\frac{c-u}{c-a})^2, & \frac{a+c}{2} < u \le c \\ 1, & c < u \end{cases} \tag{3}$$

The second variable b measures the ratio between the pixel intensity and the average pixel intensity in a neighborhood of the pixel (negative local contrast) as shown in the Equation 4.

$$b = 1 - \frac{f(m,n)}{\frac{1}{M}\sum_{(i,j)\in N} f(i,j)} \tag{4}$$

where $f(m,n)$ denotes pixel intensity, N is a set of point coordinates in the neighborhood of the point (m,n), and M is the total number of points in the neighborhood.

Two fuzzy sets can be assigned to the b variable: darker and not darker.

$$\begin{array}{lcl} darker(b) & = & S(b,a,c) \\ notdarker(b) & = & 1 - darker(b) \end{array} \quad (5)$$

The third variable e denotes the pixel membership to the edema region. The three fuzzy sets can be assigned to this variable: high, medium, and low.

$$\begin{array}{lcl} high(e) & = & S(e,a,c) \\ medium(e) & = & \prod(e,a,c) \\ low(e) & = & Z(e,a,c) \end{array} \quad (6)$$

where the $\prod$ function is defined by:

$$\prod(u,d,b) = \begin{cases} S(u, b-d, b), & u \le b \\ Z(u, b, b+d), & u > b \end{cases} \quad (7)$$

Other features used to characterize a single pixel are the pixel's coordinates that can be used to determine which pixels are adjacent to each other. The membership functions defined on the input variables are applied to their actual values to determine the degree of truth for each rule premise. If a rule's premise has a nonzero degree of truth then the rule is said to fire. It is possible to have more than one rule fired for a particular pixel. The influence of the fired rule on the pixel belonging to edema region is proportional to the degree of truth of the rule premise. The type of inference method which is used in this particular expert system for edema segmentation is commonly referred to as MAX-MIN method. In MIN part of inferencing, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth. This corresponds to the traditional interpretation of the fuzzy logic AND operation. In the MAX part of inference process, all of the fuzzy sets assigned to each output variable are combined together to form a single fuzzy set for each output variable. The combined output fuzzy set is constructed by taking the pointwise maximum over all of the fuzzy sets assigned to the output variable by the inference rule. Once the combined fuzzy set is obtained it has to be defuzzified in order to get only one value for the pixel membership to the edema region. There are several methods which can be used for defuzzification but one has shown best results. It is the AVERAGE-OF-MAXIMA method, which returns the average of the variable values at which the maximum truth value occurs. If the maximum truth value occurs in J points $X_1, X_2, \ldots, X_J$ then result is :

$$x = \sum_{j=1}^{J} \frac{X_j}{J} \quad (8)$$

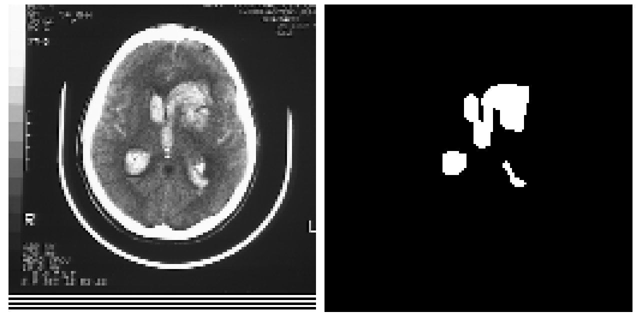

Figure 2: Original CT image (left), and ICH region (right) in the same image obtained by the global segmentation algorithm.

After the pixel membership to edema region has been obtained the next step is to determine the threshold for this membership which would provide whether the pixel is in the edema region or not. Taking lower threshold value increases the number of pixels recognized. The approach used in our work is to use multiple threshold values to obtain different results. The most appropriate of them can then be selected by the human expert.

3. RESULTS AND DISCUSSION

The original CT image in resolution 128×128 is shown in Figure 3 (left). The local contrast feature for the expert system is computed from this image. The ICH region obtained by the global segmentation is shown in Figure 3 (right). This image is used to compute distances required for the expert system.

Only the pixels whose distance form the ICH was smaller than 8 were used as candidates for edema region. For example, in the Figure 3 there were 2015 candidates from which 2015 facts are derived. Using FuzzyCLIPS [7] it takes about 230 seconds to run fuzzy expert system on this data using Sun Ultra Sparc 1 workstation.

Figure 3 shows results of the applied method for two values of defuzzification threshold. On the left is result with threshold to fuzzy membership variable set to 40 percent of maximum membership, and on the right threshold is set to 60 percent. In the first case 21 percent of candidate pixels were assigned to edema region and in the second case 10 percent. In such a manner it is possible to produce several versions of segmented edema region so that medical expert can make a final selection. The segmentation results obtained by fuzzy expert system are not perfect because there is a lot of pixels classified as edema which are not connected to other edema pixels. In most cases, the edema

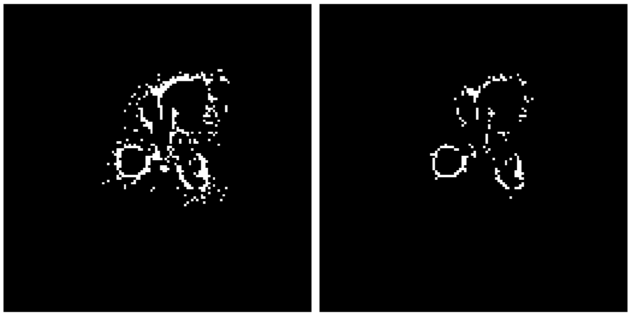

Figure 3: Edema regions obtained by two values of the defuzzification threshold.

consists of a single connected region. This happens because no rules based on pixel neighborhood are used in the procedure. However, there is a simple solution to this problem by doing morphological post processing on the edema binary image. The morphological opening by a small disk-shaped structuring element would remove the extra small regions and connect larger regions.

To improve the speed of the algorithm it should be coded in some compiled and not interpreted language. However, for the development phase an interpreted language as FuzzyCLIPS is satisfactory.

4. CONCLUSION

The fuzzy expert system has shown to be a good choice for solving image processing problems that cannot be easy modeled by conventional image processing techniques. An expert system can be used to formulate expert knowledge which is difficult to utilize in conventional algorithms.

The expert system rules utilize the concept of linguistic variables which are associated to fuzzy term set where each term represents a specific fuzzy set (high, low, medium). They are easy to understand and modify which provides possibility for introducing new rules for modeling of edema region in future work. For instance it is possible to add rules based on the shape of the edema region.

5. REFERENCES

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