A Direct Segmentation Algorithm of Medical Volume Data Based on Fuzzy Transition

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***Abstract*—3D direct volume segmentation is a nodus and one of research hotspots in 3D medical data field processing. Through the analysis of physical properties of the medical data field, a direct segmentation algorithm of medical volume data based on fuzzy transition is put forward. Firstly, the existence of transitional regions and the feasibility of fuzzy segmentation in the medical data field are demonstrated. Secondly, middle region between-class that is difficult to distinguish is segmented into transitional regions so as to avoid either-or rigid segmentation in common segmentation algorithm. Finally, the experimental results shows that the algorithm not only decreases the segmentation difficulties of medical data field, but also satisfies the non-rigid segmentation requirements for the following rendering and at the same improves the anti-interference capability of segmentation.**

Keywords-Volume segmentation,Fuzzy transition,Transitional Region

I. INTRODUCTION

Due to such factors as imaging principle, partial volume effect, fuzzy tissue margin and others, 3D medical data field segmentation is a challenging subject all the time. People have offered a number of segmentation algorithms in the past over twenty years. However, the segmentation of medical data field still does not have general theory up to now because of complexity of human body structure, irregularity of tissues and organs as well as variation of different individuals. Although there is a large difficulty in segmentation for 3D medical data field, it is one of crucial techniques in processing the data field, analyzing and comprehending systems, and also is an important step to operate the visualization of data field. Only making accurate segmentation of data field can obtain a reasonable model for the following rendering. In a word, to realize the 3D visualization of medical data field, the primary task is to make correct and reasonable segment of image data[1].

The data of 3D medical data field as a processing subject is measured by medical instruments, which is affected by the precision of measuring equipment, environment and other unknown factors and appears an uncertainty resulting from the variation of measuring values of testing subjects in spatial regions (especially in the edge regions). In these sensitive regions of edges, it is very difficult to classify the substances correctly according to gray level while these regions are emphasized in many laboratories, so it is hard to ensure the precision that a regular fixed threshold is given to the substance classification. On the contrary, if the fixed threshold is not stated to separately display the regions of some features or properties in which the users of special subjects are interested within certain gray level range, it can provide more accurate information of this subject for more actual meaning.

There are two algorithms of medical data field segmentation at present: (1) an algorithm of edge regions based on discontinuity of gray level among regions; (2) an algorithm of regions based on similarity of gray level in internal regions. These two algorithms have a same hypothesis that the whole image consists of regions' union, which means no existence of the edge width. However, the research indicates that the hypothesis is not applicable in actual image, especially in some medical image, that is to say, the edge of actual image is a region, which not only features the edge—to separate different regions, but also the region— to have the width of edge without zero edge area of image, so we call this special region as an edge transitional region. The transitional region is between two different regions and its gray level of pixels is often between the gray levels of two corresponding regions' pixels, so its parts must stand out and be emphasized in many experiments and applications. Strictly based on substances, general volume rendering algorithm is classified to give each voxel the color value and the opacity, and voxel is either-or in substance classification, thus artificial factors lose the transitional feature in the edge transitional region of image[1,2,3].

The so-called feature [4,5] is the information contained in data set and helpful to explain the corresponding physical phenomena, so the feature is defined as a region of a target or a parameter in which the users are interested from the data field in actual application.

After the full argument to the existence of transitional region in medical data field at first, the transitional region is defined as the feature region in which the user is interested. And then a new segmentation algorithm for 3Ddatafield is presented which turns the segmentation threshold in the original algorithm to threshold region with certain width from point value to extract out edge transitional regions and non-edge transitional regions in 3D data field respectively, so it decreases the difficulty of the algorithm realization based on the medical data field itself and the fuzzy sets theory, and increases the segmentation precision and operability of the algorithm.

II. THEORY BASE OF THE ALGORITHM

A. *Existence of transitional regions*

The existence of transitional region in 3D medical data field can be demonstrated by the image theory and the actual features of 3D medical data field. In the image theory: First, although continuous images contain ideal step-edge, the obtained discrete image still have the transitional region when taking sample according to Shannon Theorem, and its width is at least equal to the width of a pixel. In other word, as for image collection system that can be achieved physically, the collected images will be certain to have transitional regions. Second, the transitional region can be observed in actual image, which is fuzzy part of each region edge in the images, and if hatching line is made, it is obvious to see that the step-edge is slope-typed in our minds. Third, as for actual image collection system, the smoothness is its inherent feature so as to produce the transitional region in the image[6].

The following three conditions can demonstrate the existence of specific transitional region in 3D medical data field: First, some transitional property does exist in some medical phenomenon and some properties of human body tissues, for example, blood flow velocity has a slowing tendency from the middle of blood vessel to the blood vessel wall, and this transitional feature is unavoidable in the visualization of blood flow velocity; the densities of vertebral foramen and ethmoid sinus of human neck is between those of bone and brain tissue and have the transitional feature. Second, many results in the medical measuring instruments are the average value of internal measured pixels, which makes the data field in the organ or the tissue edge display the transitional feature, for example, volume effect in CT measuring experiment makes the measuring values of the measured pixels lie in the transitional region. Third, the interpolation pretreatment in 3D medical data field also makes the data in the organ or the tissue have the transitional feature. the transitional regions resulting from physical phenomenon itself or measuring instruments will be rendered in the following visualization process.

B. *Feasibility of fuzzy segmentation for medical data field*

As we known, 3D medical data field has a fuzzy property in nature: (1) Medical data field has an ambiguity of gray level: measuring values of CT in the same tissue are changeable in a large range. Taking femur, nasal sinus and teeth for example, their densities are very different; measuring values of CT in the same object are not consistent like the densities of femur's outer surface and internal borne marrow. (2) fuzzy property of geometry: large volume element of an edge usually contains two substances of edge and subject; it is difficult to clearly describe the relations among the edges, the corners and the regions of the subjects in the image. In addition, some pathological tissues have invaded its peripheral tissues to make their edges not be determined clearly. (3) uncertain results: if the human body is under a pathological situation, the normal tissues or parts may appear those structures which do not appear in a general situation, such as tumors on organs' surface and bone spurs on bone's surface. These structures under the pathological situation bring some difficulties for the data measurement and data model establishment. (4) The above-stated existence of edge transitional region in 3D medical data field also proves the fuzzy property of medical data field in nature.

III. DATA FIELD PRETREATMENT

The main title (on the first page) should be centered, and in Times 16-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two 12-point blank lines after the title. Each voxel's gray value (or color value) is given according to the people's habits or the users' requirements, and not owned by substances. Therefore, the difference of adjacent data has a certain meaning while the absolute value of each data is of no importance in the data field. This algorithm suggests that the function values of original 3D data field is within the range of 0-255 in the normalization integration, and processed data replaces original data to give the gray level value so as to provide a gray level field for the feature extraction, decrease the post-treatment memory demand and improve the post-treatment speed.

Although it is not simple for such problems as the time consumption that the data field turns 16-bit and 12-bit gray level images into 8-bit under the premise of keeping up the key information of the images in the process of the normalization pretreatment, the process is over in data format conversion of the pretreatment and any data field will be treated only once so as not to affect the efficiency of the whole algorithm.

IV. DETERMINATION OF EDGE TRANSITIONAL REGION

Assume that the size of data field X is $M \times N \times K$ with $L+1$ gray level $\{0,1,\ldots\ldots\ldots L\}$, $\mu(x)$ means the membership function of $L+1$ gray level, if gray level of pixel (m,n,k) is x_{mnk} , its membership degree is $\mu(x_{mnk})$, $m = 0,1,\ldots. M, n = 0,1,\ldots.. N, k = 0,1,\ldots.. K$ show the brightness of pixel (m,n,k), and fuzzy rate $r(X)$, fuzzy entropy $E(X)$ and non-fuzzy rate $\eta(X)$ of the data field X all are to measure the image fuzzy property, whose definitions are Eq.1 and Eq.2 and Eq.3 respectively.

$$r(X) = \frac{2}{M \cdot N \cdot K}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{k=1}^{K}\min(\mu(x_{mnk}), 1-\mu(x_{mnk})) \quad (1)$$

$$E(X) = \frac{1}{M \cdot N \cdot K \ln 2}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{k=1}^{K} S_n(\mu(x_{mnk})) \quad (2)$$

$$\eta(X) = \frac{1}{M \cdot N \cdot K}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{k=1}^{K}[1-|2\mu(x_{mnk})-1|] \quad (3)$$

Shannon Function in Equ.2 is Eq.4.

$$S_n(\mu(x_{mnk})) = -\mu(x_{mnk})\log_2 \mu(x_{mnk}) - (1-\mu(x_{mnk}))\log_2(1-\mu(x_{mnk})) \quad (4)$$

From Eq.5 the equivalency of $r(X)$ and $\eta(X)$ is derived.

$$1 - |2\mu(x_{mnk}) - 1| = \begin{cases} 2\mu(x_{mnk}), & \mu(x_{mnk}) \le 0.5 \\ 2(1-\mu(x_{mnk})), & \mu(x_{mnk}) \ge 0.5 \end{cases} \quad (5)$$

If $\mu(x_{mnk}) = 0.5$, $r(X)$ and $E(X)$ take the maximum value, and if diverged, $r(X)$ and $E(X)$ come down the value. When $h(l)$ is the pixel quantity of l-gray level in image X, Eq.1 and Eq.2 are Equ.6 and Eq.7 respectively and in Eq.6 $T(l) = \min(\mu(l), 1-\mu(l))$.

$$r(X) = \frac{2}{MNK}\sum_{l=0}^{L} T(l)h(l) \quad (6)$$

$$E(X) = \frac{1}{MNK \ \ln 2}\sum_{l=0}^{L} S_n \mu(l)h(l) \quad (7)$$

The threshold is derived from the calculation of fuzzy rate $r(X)$. Fuzzy rate $r(X)$ of the image is determined by membership function $\mu(X)$. If membership function $\mu(X)$ is defined as S function, the geometry of S function and membership function figure of threshold segmentation are seen in Fig.1.

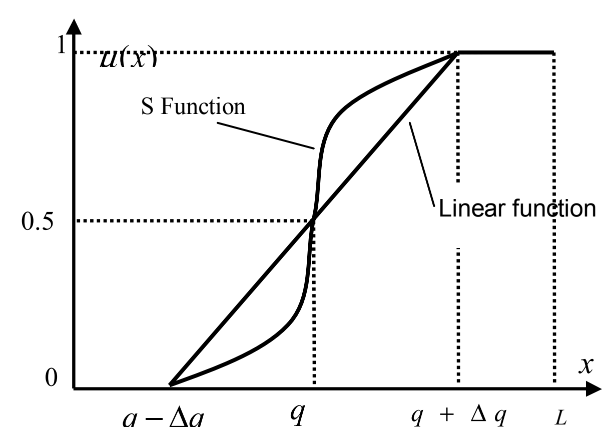


Fig.1 S function and membership function figure

The mathematical expression of S Function is Eq.8.

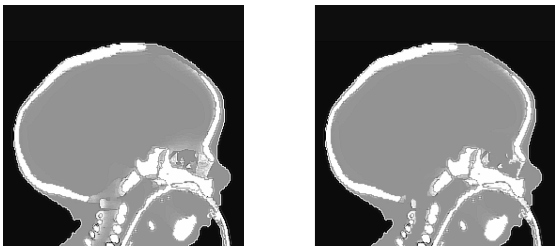
$$\mu(x) = \begin{cases} 0 & 0 \le x < q - \Delta q \\ 2[(x-q+\Delta q)/2\Delta q]^2 & q - \Delta q \le x \le q \\ 1 - 2[(x-q-\Delta q)/2\Delta q]^2 & q < x \le q + \Delta q \\ 1 & q + \Delta q \le x \le L \end{cases} \quad (8)$$

However, $\mu(X)$ is determined by window width $c = 2\Delta q$ and parameter q. If Window Width c is chosen, $r(X)$ is only related with parameter q, and parameter q that $r(X)$ takes the minimum value is usually corresponding to the valley point of the histogram. At this time, the region with a certain width at the center of parameter q is chosen as segmentation threshold. When calculating $r(X)$ via Eq.7, the effective part is the pixel that gray value is distributed among the region $[q - \Delta q, q + \Delta q]$. While parameter q changes, $r(X)$ will changes along with it and $r_q(X)$ is recorded as the image fuzzy rate as the parameter is q. If the histogram of image gray level appears peak-peak distribution, $r_q(X)$ will be calculated for each q. Theoretically, some q_0 can be found and make $r_q(X)$ minimum so as to take the central value in the segmentation region as q_0. If the image gray level appears a multi-peak distribution, using the above methods can obtain several q to make $r_q(X)$ take the minimum value, and can determine the segmentation of threshold region in order to implement the multiple-threshold segmentation.

q (or q_0) that the fuzzy threshold method makes $r_q(X)$ get the minimum value is the segmentation threshold to make the either-or classification in the image. If the segmentation plane is a straight line, the region with a certain bandwidth is the segmentation threshold at the center of q (or q_0) and makes the segmentation cross section have the region with a certain width in order to separately extract the edge transitional region and non-edge transitional region.

V. EXPERIMENTAL RESULTS

Under SGI Iris4D workstation environment, using C language made an experiment of CT volume data of $128 \times 128 \times 128$ data size for this algorithm. The direct segmentation result of 3D data field is usually difficult to display the intuitive segmentation plane result as 2D segmentation, so this experiment would display the segmentation result after rebuilding the image according to the voxel casting algorithm. The experimental result shows that this algorithm had the following features: (1) As for the algorithm feasibility, on the basis of the actual image, this algorithm turns the substance classification into the extraction of edge transitional region, thus it is easier to implement than common segmentation algorithm. (2) As for the image quality, this algorithm does not carry out the either-or classification on the edge transitional region voxel, which does not damage the transitional property of edge transitional regions and remained physical features of data field on the transitional region. Therefore, the edge transitional region can be observed clearly in the final visualized image result. Fig. 2(a) is the implementation result of this algorithm to display the vertebral foramen and the ethmoid sinus in the transitional region clearly. Fig. 2(b) is the implementation result of common segmentation algorithm not to display the vertebral foramen and the ethmoid sinus in the transitional region in the image obviously due to the disappearance of voxel transitional property in the edge transitional region during the segmentation.



(a) (b)

Fig. 2 Comparison on Algorithm Implementation Effect

VI. ALGORITHM ANALYSIS AND CONCLUSION

The segmentation algorithm for 3D medical data field based on feature regions of data field is build upon two respects: (1) the existence of the transitional regions in the medical image; (2) the transitional region is emphasized in many medical practices and is required for the independent segmentation. This algorithm has the advantages in its feasibility and precision. At first, as for the algorithm feasibility, it is simpler and easier to find out the image transitional region than to do the accurate image edge. And then, as for the algorithm precision, the real image edge is limited within the range of the transitional region in order to ensure the algorithm precision technologically. As a result, in either the gray level or the region, both can guarantee the range of accurate segmentation line (or plane) for the confirmation of transitional region, so there is a little probability to appear very large segmentation variation. In other word, this algorithm has the strong anti-interference capability.

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