MEDICAL IMAGE SEGMENTATION USING THE WATERSHED TRANSFORMATION ON GRAPHS

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ABSTRACT

In this paper the usability of the watershed transformation on graphs for segmentation of Computer Tomography images in hyperthermia planning is examined. In the past the segmentation step was done using interactively obtained contours. Now the segmentation should be realized applying the watershed transformation on graphs. The question arises if the results of the watershed transformation are suitable for hyperthermia planning. The special requirements for the segmentation step in hyperthermia planning lead to particular problems. However, the comparison with the interactively obtained contours show that the watershed transformation results are suitable. Still, they do not provide an absolutely satisfying solution. We therefore propose an approach for further developments.

1. INTRODUCTION

For hyperthermia planning the first step is the acquisition of Computer Tomography (CT) images of the patient. The goal of hyperthermia treatment in cancer therapy is to heat up the tumor region locally without affecting the healthy tissue. The second step is the segmentation of these CT images. The segmentation result is then used to generate a tetrahedral anatomical grid model of the patient. Such a grid is required for the numerical simulation of the temperature distribution. To achieve an optimal therapeutic effect - high temperatures within the tumor and low temperatures outside - the temperature field distribution has to be optimized.

In the past the segmentation step was done using interactively obtained contours. The goal is to separate all relevant anatomical objects. Borders and the topological neighborhood relationship between tissues of different dielectric constants, e.g. bones, fat and muscle, should be especially located. The reason is that interfaces of tissues with high and low dielectric constants cause significant distortion in the temperature distribution. Additionally, every anatomical object region should be characterized by features that allow definite tissue classification. Since for hyperthermia planning a CT scan between 90 and 170 slices has to be completely segmented, interactively obtained contours are not suitable for a clinical routine solution. Additionally the drawn contours are not based on numerical image information and therefore they are not always completely exact.

The watershed transformation seem to be a more appropriate solution. An advantage of the watershed transformation is that this approach already results in the necessary information: closed contours and region characterization. Furthermore, applying the watershed transformation on graphs provides us directly with the required neighborhood relationship. First, the basic principles of the watershed transformation and the watershed transformation on graphs are described. Then the usability of this segmentation approach in hyperthermia planning is examined. Since the results are not completely sufficient, an extended approach based on the watershed transformation is proposed.

2. THE WATERSHED TRANSFORMATION ON GRAPHS

Using the geographical concept of watersheds to images the grayscale pictures are considered as topographic reliefs representing the elevation at a point by the numerical value. For the algorithmic computation we use the interpretation as an immersion process [1] [2]. Drilling holes in each regional minimum of the relief, the surface is immersed into a lake ensuring a constant water level in all the valleys of the graylevel mountains. Starting from the minima of the lowest altitude, the water will fill up the different valleys. At the end of this immersion procedure each minimum is completely surrounded by watersheds, which delimit its associated valley. The valleys correspond to the regions whereas the watersheds define the optimal contours of an image.

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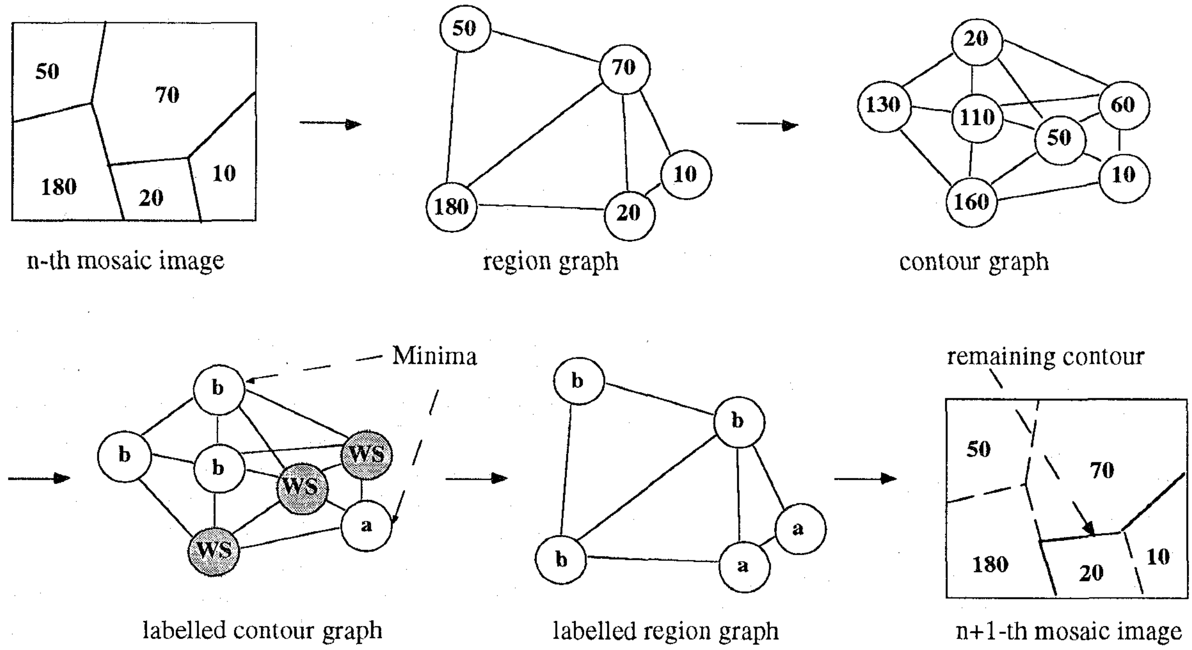

Fig. 1. The development of the next mosaic image with corresponding graphs.

Employing watersheds to image segmentation the gradient of the image has to be interpreted as a relief. The original graylevel image is inappropriate because the amount of the graylevel elevation does not allow the unmistakable classification of valleys to regions and elevations to contours. The regions are obtained using the watershed transformation on the gradient image. Each region is then described by a grayvalue feature, for instance the average, achieving a so-called mosaic image. In general the selected region feature should be similar to the graylevels of the original image. In our environment several different features and combinations of these features are possible.

The watershed transformation results in regions with good located closed contours, but leads to a strong oversegmentation, i.e., the interesting contours cannot be seen clearly because of many irrelevant contours. We use the concept of the watershed transformation on graphs to reduce the effect of this oversegmentation. If every presegmented region of the mosaic image is represented by a region characterization and some region neighborhood is given, the problem can be interpreted exactly the same as for the original graylevel image. The idea is to apply the watershed transformation again on the mosaic image. In our environment we use two graphs for modelling purposes. A region graph represents the original image and a contour graph corresponds to the gradient image.

For a region graph the nodes describe regions and the arcs represent the neighborhood relationship between these regions. Every arc in the region graph - contour piece in the mosaic image - is represented as a node in the contour graph. The value of the node is the absolute difference of the two neighbor regions. Then each node is linked with the nodes of its two neighbor regions. The upper part of Figure 1 shows a mosaic image, the corresponding region and contour graph.

The watershed transformation is applied on the contour graph. The result is then a labelled contour graph, see lower part of Figure 1 with labels a, b and WS for watershed. In contrast to the original watershed transformation the problem is that the labelled contour graph cannot be easily represented as an image. The reason is that every node of the contour graph describes the contour between two regions. Therefore the labelled contour graph is used to label the region graph. Then this labelled region graph can be transformed into a new mosaic image (Figure 1). Besides a specialization of Vincent's [2] algorithm resulting in the same technique for graylevel images and graphs, the combination of region and contour graph provides a solution for the problems that appear when applying the watershed transformation on graphs [4].

The multiresolution segmentation planes are obtained by computing iteratively the mosaic image and applying the watershed transformation on the contour graph of this mosaic image. This process can be continued until only one region remains. The results are mosaic images of order n representing the n-th segmentation plane and showing regions that describe anatomical objects of different resolution at each plane. Therefore the required different anatomical objects are correctly segmented in segmentation planes of different order. An example can be found in [5].

For some objects the selection of the adequate plane can be based on an object description. At the moment we use tissue characterization for bones and fat. However, in general it is difficult to find good descriptions for all kinds of anatomical objects. A solution is to use these segmentation planes as basis for an interactive segmentation environment. The user can select the high and low contrast objects in different planes for a final image segmentation. If an object is separated into several regions the user has the possibility of merging these regions. For most images a sufficient segmentation result is achieved when applying these two actions. Furthermore, for diffuse objects the user has additionally the possibility to obtain contours interactively.

3. APPLICATION

For the application of the watershed transformation on graphs in hyperthermia planning the question is, if all tissue types or anatomical objects relevant to the numerical computation can be separated. In hyperthermia planning the main difficulty for the segmentation step is that the required object regions do not always correspond to the normally defined image regions. For instance, a segmentation approach should separate bones from marrow due to the fact that the grayvalues are completely different. In hyperthermia planning bones and marrow are seen as one object, since the marrow is within the bone and therefore does not affect the temperature distribution. On the other hand some contrastless objects are required for planning. For example, blood-vessels influence the temperature distribution and have to be considered for the numerical simulation. Unfortunately, these cannot be separated regarding only the image information, but an expert draws the vessel contours using a priori knowledge.

To answer the question if the watershed transformation results in a proper segmentation for hyperthermia the known problem is to determine an adequate reference segmentation. We decided to use interactively obtained contours by an expert as a reference segmentation. The main aspect for this choice is that in the past the segmentation step in hyperthermia planning was done using interactively obtained contours. However it should be noted that using interactively obtained contours is definitely not the best choice. The reason is that the contours of different experts can vary or even the contours of the same expert on different days. Besides the a priori knowledge the main reason for this variability is that these contours are not based on any computed image feature. However regarding the above specified requirements for hyperthermia planning the interactively obtained contours provide at least a segmentation that satisfies these requirements.

For the comparison we use the drawn contours as reference and segment the same image using the segmentation environment of the watershed transformation. Besides the selection of objects, here mainly the merging of regions is sometimes necessary due to the fact that some object regions are disregarded in hyperthermia planning. It should be noted that using the watershed transformation it is in general possible to obtain a more detailed segmentation result than the reference contours, for example little pieces of fat within muscle. Some results can be found in [5]. Moreover, for the comparison we did not determine contours of no contrast objects, like these of blood-vessels, interactively, which is generally possible in the segmentation environment of the watershed.

The comparison leads to the conclusion that the watershed transformation results in a segmentation which can for most objects be used for hyperthermia planning. However the special requirements for planning lead to additional interactions or for contrastless boundaries where the watershed transformation fails, to the necessity to obtain these contour pieces interactively, for instance the vessels or the boundary between liver and muscle. Regarding the necessary user interaction, the advantage compared with interactively obtained contours is that here complete object regions are selected. This provides quicker and more reproducible segmentation results for the computation of the hyperthermia plan.

4. FUTURE DEVELOPMENTS

In the last paragraph it has been stated that the watershed transformation is in general suitable for hyperthermia planning. However, regarding an efficient application it is still too time consuming. Here especially, the amount of CT slices - 90 to 170 - and the above mentioned special requirements are of significance. The advantage of the application in hyperthermia planning is that the scanned body parts are quite the same - mainly the abdomen and pelvis. Of course the scans vary slightly - besides women and men, through more slices, other gantry and so on - from patient to patient due to several reasons, for instance different patient's height and different physicians. Despite this variability the remaining a priori knowledge about the CT scan can now we used to control the segmentation. First, similar to the action of a physician a global

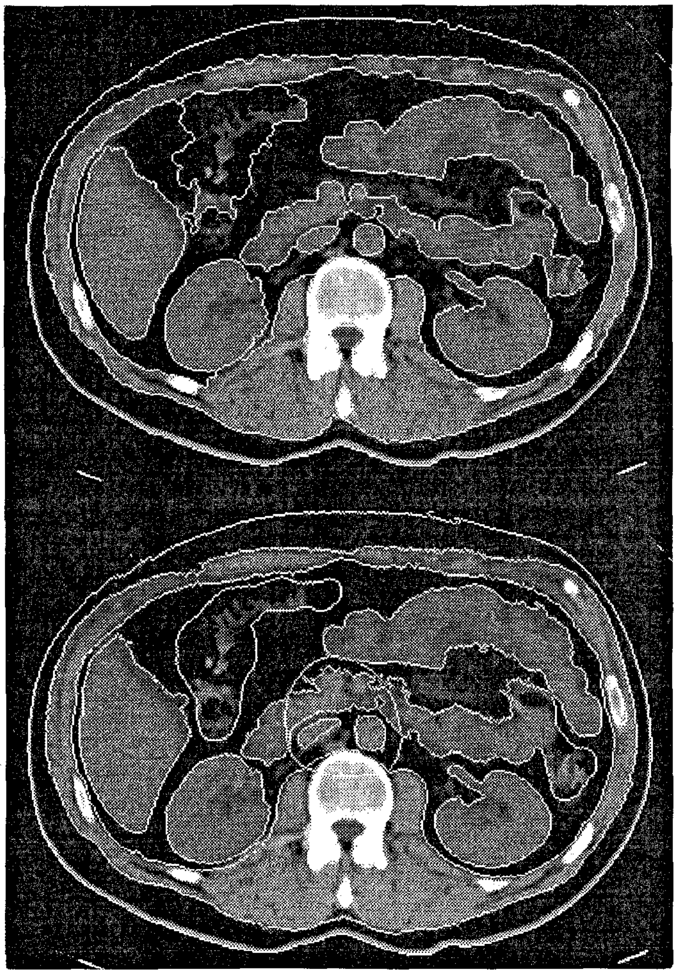

Fig. 2. The upper images show the result of the watershed transformation, the lower the interactively obtained contours.

orientation is required. This can then be used to apply locally an optimized segmentation strategy.

For a global orientation a simple registration - translation, rotation and scale - technique between the bones within the current CT scan and the bones of a model CT scan is used. It should be noted that a deformation is not necessary here, since the goal is a global orientation and not an exact fitting. The bones are chosen as basis for the registration mainly due to two aspects. First, since the scanned patient has tumors some anatomical objects can be changed or displaced. Besides bones missing due to surgery, in general the bones do not change. Second, the bones in the pelvis and abdomen area vary only slightly between different patients. They are especially characteristic. Even the size of the pelvis between patients of different heights is frequently the same. Additionally a simple threshold value is adequate to segment the compact bones.

Based on the global orientation body parts and areas in which certain anatomical objects should lie can be determined. This knowledge can then be used to apply the watershed transformation with optimal feature combinations for certain body parts. Moreover using the global orientation areas in which certain anatomical objects should lie can be delimited. The selection of the adequate segmentation plane can then be made using several model features of the expected object in this area. In every plane the features are compared with the model features and the plane which fits best is chosen. The features can vary depending on the expected objects from simple grayvalues up to shape parameters or even shape models.

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