基于数学形态学的牙科 CT 图像分割

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摘 要 文章提出一种基于数学形态学的牙科 CT 图像分割方法。采用形态学重建与滤波技术处理图像，从人的口腔图像中提取出牙齿信息。初步结果表明所提出的方法可灵活用于从口腔图像中分割出需要的牙齿信息。

关键词 牙科；CT；图像分割；数学形态学

Dental CT Image Segmentation Based On Mathematical Morphology

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Abstract This paper proposes a generic scheme for dental CT image segmentation, which is based on mathematical morphology. The implementation of morphological reconstruction and filtering techniques is used to process the image, with the aim of identifying teeth within the oral cavity from a human specimen. Initial studies using dental CT images have demonstrated the feasibility of the proposed scheme for segmenting teeth from the surrounding biological matter.

Keywords Dental; CT; image segmentation; mathematical morphology

1 Introduction

In modern society, for many people teeth are regarded as one of the most important anatomical structures associated with the human face. The alignment of teeth is essential for the appearance of facial beauty and overall oral health. The ability to obtain high quality images via non-invasive techniques is of crucial importance for many medical imaging applications, such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and digital mammography. Such imaging modalities have proven to be invaluable tools, which have assisted greatly in advancing our understudying of human anatomy within the realms of research, medicine and dentistry.

The ability to conduct non-destructive examinations has been recognized as an indispensable tool. Thus, the application of CT imaging, has become common practice within the field of dentistry, where computer assisted procedures such as, surgical pre-operative planning have received much attention in recent years[1,2,3]. Examples of their applications include: postmortem identification of the deceased[4] and diagnosis of dental syndromes[5].

Currently, approaches to image segmentation can be divided into two main groups, often referred to as low-level segmentation and model-based segmentation, respectively. Low-level segmentation, represents the majority of clinical applications, and such an approach relies completely upon the assessment of local shapes within a given image, such as identifying specific

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structures i.e. bone structure from CT images based on homogeneity and intensity of X-ray radiation values. Conversely, model-based segmentation approaches employ use of a variety of information i.e. shape, size and texture. An essential pre-processing stage in the segmentation of images is the accurate detection of the edges of an image. The edge of a given image is defined as the boundary where distinct intensity changes or discontinuities occur. In recent years, various image segmentation algorithms based on mathematical metrology (MM)[6,7,8] have been proposed. An example of such algorithms is the pseudo top-hat transformation[9], which has been developed for the extraction of smooth edge features in dark regions of an image. This approach to image segmentation is based on basic MM operators with which to sharpen small gray-level changes. Here in this paper, we present a novel technique based on MM for conducting dental CT image segmentation, with the aim of extracting teeth from surrounding biological structures.

The remaining sections of this paper are organized as follows. In section II, the morphological operation employed by the proposed segmentation scheme is introduced, with a detailed breakdown of the fillhole operator, which is used to roughly reconstruct the target. The procedure of carrying out the proposed scheme and the results are presented in section III. A discussion section is provided in section IV, and finally, the paper is concluded in section V.

2 Methodology

2.1 Basic Morphological Operators

Amongst the wide variety of image processing techniques, mathematical morphology (MM) is a relatively new and powerful tool, which is based on concept of set theory. The MM technique extracts object features by interacting with a structuring element (SE), which corresponds to another image much smaller in size than the image being processed. The basic MM operators are erosion and dilation, denoted by $\odot$ and $\oplus$ respectively and defined as[10]:

$$A \odot B = \bigcap_{b \in B} A_{-b} = \{x \mid (x+b) \in A, b \in B\} \tag{1}$$

$$A \oplus B = \bigcup_{b \in B} A_{-b} = \{x \mid x = a+b, a \in A, b \in B\} \tag{2}$$

where A is a binary image being processed and B is the SE. Erosion and dilation can also be denoted by $\varepsilon_B(A)$ and $\delta_B(A)$, respectively. Intuitively, erosion can be considered as a contracting procedure while dilation can be imagined as expanding. In binary image processing, erosion is the union of the central pixel of B, if B is fully contained in the object. Hence, any target or structure that cannot contain the SE will be removed by erosion. Dilation on the other hand, is found by placing the center of the SE over each target pixel of the original image and then taking the union of all the resulting copies of the SE. The cascade combination of erosion and dilation results in another pair of two popular MM operators, opening and closing:

$$A \circ B = A \odot B \oplus B \tag{3}$$

$$A \bullet B = A \oplus B \odot B \tag{4}$$

where $\circ$ and $\bullet$ denote opening and closing, respectively. Opening recovers the structures that are shrunk (not removed) by erosion, while closing fills the small holes and gaps of the object while keeping its broad shape. This pair of operators forms the basic morphological filters.

2.2 Morphological Reconstruction

Morphological reconstruction algorithms are powerful tools for target identification. For the unique objective of the present paper, the reconstruction based operator of fillhole[10] is used. According to the definition, a hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image. In most cases, some pixels in the target may be classified as background according to their pixel values, hence holes are formed. The fillhole operator fills these holes so that the entire target region can be separated from the background. The fillhole operator works by executing the following steps:

- Determine the marker image, f_m, used in the morphological reconstruction by erosion. f_m keeps the pixel values of the original image, f_o, if the pixel is not connected to its border;
- Calculate the geodesic erosion of f_m with respect to f_o:

$$\varepsilon_{f_o}^{(1)} = \varepsilon^{(1)}(f_m) \vee f_o \tag{5}$$

where $\varepsilon^{(1)}(f_m)$ is the elementary erosion of f_m, $\vee$ denotes the point-wise maximum between the two images;

- Calculate the reconstruction by erosion of the original image f_o from the marker image f_m, which is denoted by $R^{\varepsilon}_{f_o}(f_m)$ and defined as:

$$R^{\varepsilon}_{f_o}(f_m) = \varepsilon^{(i)}_{f_o}(f_m) \tag{6}$$

where i is such that $\varepsilon^{(i)}_{f_o}(f_m) = \varepsilon^{(i+1)}_{f_o}(f_m)$, i.e. the iteration of geodesic erosion of f_m with respect to f_o reaches stability.

3 The Segmentation Scheme and Results

The original image used in the present work, have been obtained from a prototype CT system (see Fig. 1), developed by the Shenzhen Zhong Ke Tian Yue Technology Limited Corporation. This device consists of a head phantom (RS-108T, RSD, USA) and a rotational C-arm, a flat panel amorphous silicon detector (PaxScan 2520D, Varian, and USA) comprising of a 1920×1536 array. The specifications of the system also include a pixel pitch of 127 µm and an active detector area of 23.8×19.0 cm^2. The CT system is capable of providing a maximum power of 384 W and generates an X-ray tube current of 3.2 mA. In addition the X-ray source for this CT system can be configured to operate in the range of 40 kV to 120 kV, as a result it is capable of producing two different focal spot sizes corresponding to 0.3 mm and 0.6 mm, respectively.

The CT image has been produced from circular cone-beam scans consisting of 360 X-ray projections, using the prototype CT device described above. The X-rays have been generated with initial parameter settings of 60 kVp, 0.2 mA, and an exposure rate of 1 second per projection. Such X-rays are directed onto a standard head phantom, distributed over a 2π solid angle. The source-to-object and source-to-detector distance settings were fixed at 460 mm and 600 mm, respectively. Shown in Fig. 2 is the original reconstructed dental CT image, which has been reconstructed using classical FDK algorithm[11]. The observed annulus encompassing the region of interest is the result of truncation effect, caused by the limited phase-space coverage of X-ray beams during the scanning process.

In order to establish the object of interest from the background, the gray scale image is converted to a binary one so as to roughly separate the object from the background. The threshold needs to be selected carefully so that it can not only separate the object but also be adaptive to various CT data. An efficient approach adopted in this paper is to determine the threshold based on the histogram of the image. As shown in Fig. 3, the histogram has two peaks–The first one corresponds to the CT background whilst the second one corresponds to the biological matter surrounding the teeth. The threshold is therefore automatically set at the right hand side of

Figure 1. Prototype dental CT system

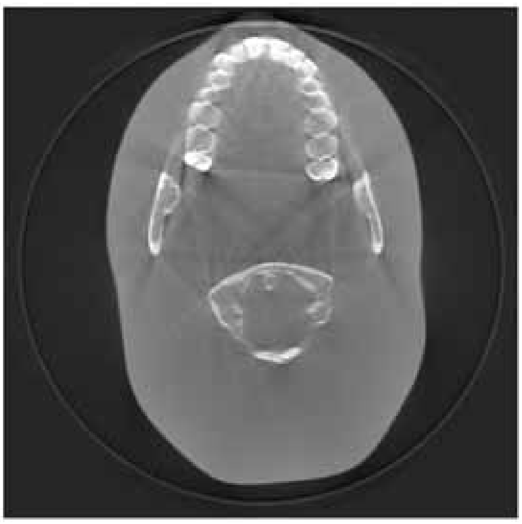

Figure 2. Original gray scale image

the second peak. However, as decayed teeth may have the same gray value as the oral cavity, a single threshold almost always results in the problem that part of the surrounding matter is recognized as teeth, or part of teeth is separated as the background. Therefore, in the present analysis, we have employed two threshold values and both resulted binary images are used for further processing. The binary image of Fig. 2 is shown in Fig. 4 with the threshold value set to 145 and 164, respectively.

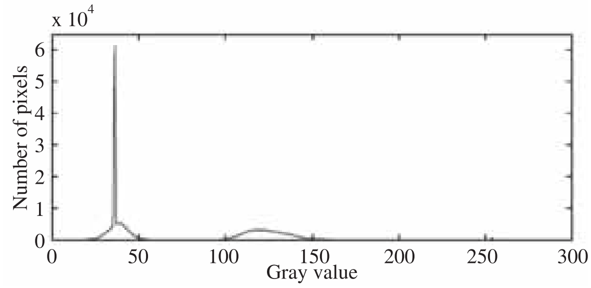

Figure 3. The histogram of the image

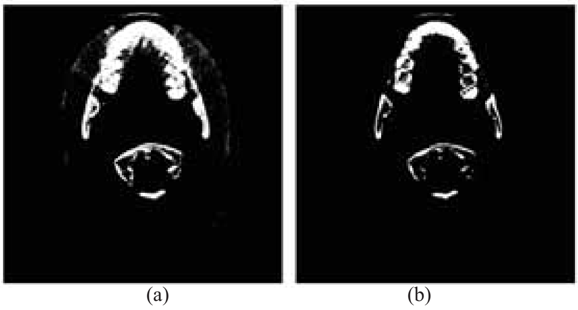

Figure 4. Converting the gray scale image to a binary image.

(a) The threshold is set at 145. (b) The threshold is set at 164

Both binary images contain biological matter i.e. tissue in the oral cavity as well as teeth. Therefore, the next step is to determine the region that corresponds to the teeth. In order to do so, the fillhole operator, as defined in section II-B, is employed. The results are shown in Fig. 5. Due to the fact that identification of teeth and non-teeth components within the image is not ideal, several connected components are formed in the image, among which the largest one corresponds to the object. Hence, for each image, the largest connected component is extracted in order to roughly separate the object of interest. The largest connected components of the images are given in Fig. 6. In this figure, only part of the image is illustrated.

It can be seen that when the threshold level is set to 145, all structures corresponding to teeth and some of the surrounding matter are detected as the object of interest to be segmented, while setting the threshold level to a value of 164 leads to certain sections of the teeth being associated with the non-teeth components. Therefore, in the current segmentation scheme we have adopted an approach to ascertain which structures within the entire image should be considered as objects of interest, and which are irrelevant structures to be regarded as background. This is achieved by examining the difference between binary images, constructed with the two different threshold values and taking an average of the pixels between the two. The resulting averaged image

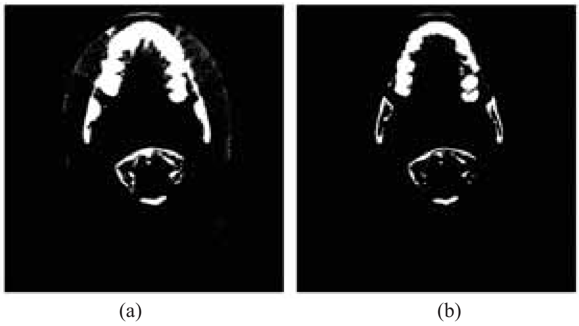

Figure 5. Results of applying the fillhole operator to the two images obtained in Fig 4, respectively

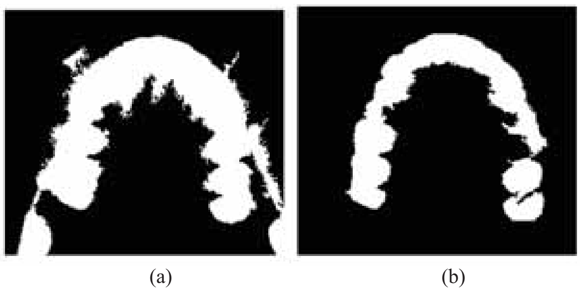

Figure 6. The largest connected components of the two images obtained in Fig. 5, respectively

Figure 7. The averaged binary image of the two images shown in Fig. 6

containing some gray pixel regions is displayed in Fig. 7. If a gray pixel is surrounded by white pixels, it will be kept. Otherwise, it is deemed as background structures and consequently removed. The obtained image, as shown in Fig. 8, is the so-called mask image, which is used for object segmentation. If the pixel has value 1 in the mask image, the corresponding pixel in the original image is retained; otherwise, the corresponding pixel in the original image is set as the background. The final result of image segmentation is illustrated in Fig. 9, which shows the teeth structures separated from that of non-teeth structures.

Figure 8. The mask image obtained from Fig. 7

Figure 9. The final result of image segmentation

4 Discussions

The CT image used in the present study has been produced from a prototype CT device developed by the Shenzhen Zhong Ke Tian Yue Technology Limited Corporation. The CT system is a relatively low cost device, which can result in obtained X-ray images being far from idealized quality. Nonetheless, the proposed scheme is able to segment teeth from other biological matter, which provides better inputs for further image processing.

MM algorithms include only addition, subtraction, maximum and minimum operations without any multiplication and division. These operations are processed in a recursive form and at regular intervals. Thus, hardware implementation of MM algorithms could be extremely simple, which means that it has great potential to be mapped onto hardware, embedded in the CT scanner and implemented in real time.

5 Conclusion

This paper has proposed a novel MM-based scheme for CT image segmentation of teeth. An adaptive thresholding strategy has been developed for converting the gray scale CT image to a binary one. The fillhole operator, which is a special case of morphological reconstruction, is applied to the binary image so that the region of interest can be roughly separated from the other structures within the image. Although the segmentation results obtained through the proposed scheme is at the moment far from ideal, it has nevertheless demonstrated its feasibility as a potential tool for dental CT applications. Much more work is still required to refine and improve the MM-based scheme before it can be successfully applied to real-world applications.

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