Multiple texture mapping of alveolar bone area for implant treatment in prosthetic dentistry

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A B S T R A C T

Treatment using implants is frequently employed in prosthetic dentistry. In this method, determining the bone density of the upper and lower jaws is important. Generally, a dentist can recognize the condition of the alveolar bone to be manipulated using a cone-beam computed tomography (CBCT) image. However, communicating the data to the patient is a challenge because it is difficult for the nonprofessional person to interpret the image, which contains a distribution of pixels with similar density. We present an intuitive texture mapping method of the alveolar bone area for application in implant treatment. Our method aims to help patients better understand the treatment process by using a textured image that includes several different texture patterns that reflect the density of the alveolar bone area. We segment the area in accordance with the density of corresponding parts in the alveolar bone and the gingiva. By simplifying the boundary of each segmented region, the distribution of pixels with similar density on the alveolar bone area can be easily recognized. Next, the texture patterns for several segmented regions are mapped onto the alveolar bone area using the graph-cut algorithm, which is used for smooth texture mapping at the boundary of the segmented region. The result is an applied texture on the alveolar bone area that corresponds to the bone structure. Our method is helpful for facilitating communication and understanding of treatment using dental implants.

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1. Introduction

The alveolar bone, which supports the teeth, can perform the complete function of the teeth [1,2]. Tooth loss and gingival disease can cause collapse of the alveolar bone. An artificial tooth can be inserted using dental implants when a tooth is lost [3,4]. However, when the alveolar bone tissue has disappeared, a variety of problems can occur including improper insertion of the implant screws or tooth loosening after treatment. Therefore, the condition of alveolar bone is important because an implant is used to support dental prosthetics instead of a tooth in the alveolar bone. When a CBCT image of a jaw has been obtained, dentists usually examine the distribution of density to confirm the condition of the alveolar bone tissue. However, explaining the current state of treatment or surgical plans for future treatments to patients using the standard CBCT images is difficult because only those with specialized knowledge can interpret such images. Here, we provide a method for visualizing the density distribution of the alveolar bone using texture patterns. Our method can help nonprofessional people easily understand the structure of the alveolar bone. A patient's alveolar bone density during treatment using

dental implants can be intuitively visualized using our method. We can efficiently plan a schedule for treatment because our method enhances the patients understanding. For example, before an implant treatment, a dentist can use our texture mapping method to explain that the condition of the jaw should be enhanced before treatment due to poor alveolar bone health.

The density value of the alveolar bone is quantized into discrete levels with several predefined threshold values. We determine the density value range between the minimum and maximum values of a segmented area. Then, we divide the range evenly by the number of levels. The number of levels is determined by the user. We perform segmentation corresponding to the density of each area and then map bone texture patterns to their corresponding areas. However, different texture pattern shapes cannot be easily and smoothly connected on the seam boundary between different segmented areas because the pattern of the bone tissue is cancellous. The repeated texture continuously follows as a tile attached to the region when the target area for texture mapping is larger than the size of the texture. In order for the boundaries to appear naturally synthesized, deforming the boundary is necessary. Recently, the example-based texturing technique has been mainly used to generate a large version of the textured image using texture pattern analysis of the boundaries [5]. The example-based texturing methods are categorized into pixel-based approaches [6–10] and patch-based approaches [11–13]. The pixel-based method can

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connect the boundary region more naturally than the patch-based method. The pixel-based method analyzes the similarity of texture patterns using a pixel unit when two patterns are interconnected. However, the patch-based method analyzes the similarity using the patch unit, which is a set of pixels. The patch-based method is faster than the pixel-based method because it analyzes the texture pattern using a patch, rather than individual pixels. The minimal error boundary [14] and the graph-cut algorithm [15] are presented as patch-based methods. We selected the graph-cut algorithm for texture mapping on the alveolar bone area because its computation time is fast, allowing for appropriate communication between the dentist and the patient.

Our contribution is the application of a texture on the alveolar bone area that corresponds to the bone structure. Previous methods only visualize the density distribution of bone using a gray-scale or pseudo coloring technique. It provides non-intuitive result. We propose a novel method for visualizing intuitively the density distribution using mapping some texture patterns. Our method is helpful for facilitating communication and improving the patients understanding of treatment using dental implants. Dentists usually use density values from the CBCT image to confirm the inner condition of the bone. Alternatively, they can use a pseudo coloring method. Although these methods provide an exact view of the condition, the connectivity between several levels of the segment region is not sufficiently represented. However, we can visualize the inner structure of the bone using our texture mapping method.

In Section 2, we describe the multiple texture mapping method for the alveolar bone area. The results are shown in Section 3. Lastly, we summarize and conclude our work.

2. Method

Fig. 1 shows the process of our method. Our texture mapping procedure consists of two steps. First, we segment the target area into several regions using defined density values, and we refine the segment area by removing tiny spots or holes in this region (we will refer to this procedure simply as "refinement"). In the second step, the level texture that corresponds to the density value for the segmented region is mapped. The graph-cut algorithm is used for smooth texture mapping at the boundary of the segment region because each level texture has a different pattern. After we complete the texture mapping for the nth level, we sequentially perform segmentation of the remaining area and texture mapping over the area that corresponds to the $n-1$ th level. By repeating this process for the number of levels, the bone density of several levels is efficiently visualized. This process covers the region of the previous level with the current level texture, as shown in Fig. 1, because the graph-cut algorithm connects different texture patterns, adjusting the boundary of the image to be overwritten based on the background image.

2.1. Segmentation for selecting an alveolar bone level

Before the segmentation and texture mapping steps, we must identify the alveolar bone in the CBCT image. To determine the bone area, we should select a range of the possible density values corresponding to alveolar bone because each CBCT image can have a slightly different density value with respect to alveolar bone [16–18]. We test the density values of pixels in the CBCT image by scanning horizontally and vertically to determine whether the values are within the threshold range for alveolar bone. This process of identifying the alveolar bone region is shown in Fig. 2.

The image is scanned horizontally and vertically. During horizontal scanning, we set the start position where the density value first increases to greater than the predefined density value of alveolar bone. We also set the end position where the density value decreases to less than that of alveolar bone (see the left of Fig. 2). We tag the pixels between the start and the end position as "IN", and the rest are otherwise tagged as "OUT". The same procedure is performed in the vertical direction. All of the pixels tagged as "IN" in both directions define the pixel set corresponding to the alveolar bone region, and this pixel set is suitable for texture mapping because no holes exist.

After selecting the alveolar bone area, we assign texture levels for each bone density threshold range (right of Fig. 2). The density range of the alveolar bone is divided into five levels by the user, and labels corresponding to each level are assigned (left of Fig. 2).

Fig. 3 shows the result of segmentation for three regions corresponding to the levels shown in Fig. 2. The current level may occur as a very small region because of "a non-uniform distribution of the density value (referred to as an "ignorable pixel set", IPS). Most occurrences of an IPS represent a cross section of the bone matrix rather than the cohesion of the adjacent bone tissue. Therefore, representing an IPS by the density of the adjacent region is not appropriate. In addition, the result of texture mapping does not provide good connectivity at the IPS boundary
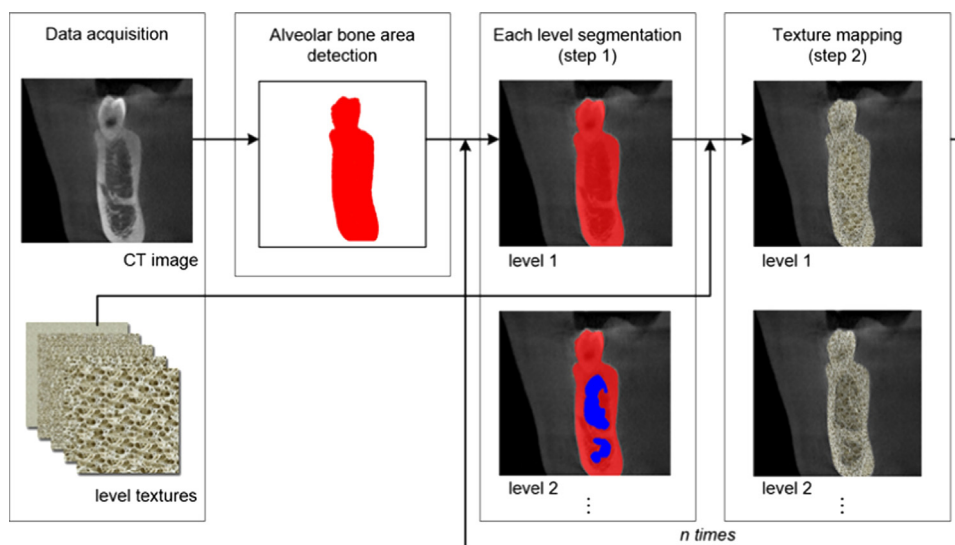

Fig. 1. The process of texture mapping. After locating the alveolar bone area, the segmentation and texture mapping steps are repeated n times.