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Feature-preserving Outermost-surface Polygonization from CT images

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ABSTRACT

This paper outlines a simple method for computing outermost-surface polygon data from CT images. The concept involves manipulating CT values of object void structures and the subsequent application of isosurface extraction algorithms. To identify void structures, a morphological closing operator is applied to input images, and differences between the input and closed images are computed. The method enables the creation of topologically simple isosurfaces because polygonization of the internal structure is prevented. In addition, sub-voxel accuracy is guaranteed thanks to the application of common methods for polygonization.

Keywords: isosurface extraction, outermost surfaces, void structure, morphology.

1. INTRODUCTION

Polygonal meshes representing medical and biological objects such as bones and brain parts are usually calculated from CT images of the target part, and are used in various applications such as surface inspection and attachment design [8]. In these applications, the point of interest is the outermost structure of the object in question. However, common methods [9] involve the polygonization of whole surfaces along with internal structural elements such as sponge part of skulls, resulting in complex topological structures. As these parts are usually unnecessary in the above applications, a method of extracting outermost surfaces only is required.

In outermost-surface extraction, the problem of eliminating the internal structure while at the same time preserving surface features is a challenge that can be simply addressed using mathematical morphology [9]. The application of a closing operator allows small voids to be filled, and their polygonization then becomes part of the process for the outermost surface. However, mathematical morphology usually involves a problem that small features on surfaces are lost in the binarization process. Although such morphology can be applied to greyscale images, the accuracy of the resulting polygonization is not guaranteed. Level-set methods and related variants (e.g. [12]) can be used to compute high-resolution outermost surfaces, although parameter tuning issues still remain.

This paper presents a simple method for computing high-resolution outermost-surfaces from CT images. The concept involves identifying internal structures known as voids from such images. To detect these structures, a closing operator is applied in mathematical morphology [9] to binarized images, the CT values of the void region are then replaced with sufficiently large values, and common polygonization methods (such as Marching Cubes algorithm) are finally applied to the modified CT images. As the CT values of void structures are modified, these regions are not polygonized.

The main advantage of the method is its capacity to simplify the topological structure of isosurfaces. As polygonization using the Marching cubes algorithm is faithful in terms of CT values, the results often include complex parts due to the structure of voids in the target object. This is prevented with the proposed method because it involves manipulating the CT values of these regions, which also helps to reduce the number of faces. In addition, the method calls on the use of the Marching cubes algorithm for polygonization and inherits several advantages, such as sub-voxel accuracy and intuitive parameter tuning. Moreover, the method is simple and easy to implement with GPGPU. Indeed, prototype implementation

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in this study resulted in a level of performance several times faster than CPU-based application.

The paper consists of five sections: Section 2 reviews related work, Section 3 describes the algorithm used, Section 4 outlines the results, and Section 5 gives the conclusion.

2. RELATED WORK

Marching cubes algorithm [10] represents a common approach to polygonization from CT images, whose voxels are individually examined to determine whether their values exceed a certain threshold. Isosurfaces are then constructed based on look-up tables of sign patterns for eight voxels in each cell. The vertex position of each triangle is computed based on linear interpolation of CT values, and sub-voxel accuracy is guaranteed. However, the polygonization applied in this method is faithful to CT values, and complex structures of biological objects are also polygonized. The resulting structures often have complicated parts that are difficult to remove in post-processing. Wood et al.[13] introduced topology simplification method based on Reeb graph by manipulating voxel value to remove handle. This approach is similar to ours in terms of CT value manipulation. However, their method focuses on removing handles of isosurfaces whereas our method removes geometric hollows in the objects.

Mathematical morphology in image processing is a set of Minkowski sum operations for binary images, and is often used to remove noise in 2D images. For instance, dilation operators are used to compute expanded shapes by probing structural elements of the input shape, and erosion operators are used to compute shrunken shapes in the same way. A closing operator is a combination of these two types, computing dilation and then erosion. It is known that such operators can be applied to remove small holes efficiently and to simplify the topological structure of images, and the outermost surfaces of closed images can be extracted using the Marching cubes algorithm. However, morphology operators require binary images, whose accuracy is subsequently lost. In addition, unnecessary points often remain on concave surfaces after closing operator application. Their usage with greyscale images has also been studied [9], but the accuracy of the results from such application is not guaranteed. Similar operation can be applied to surface models known as surface offsets [1]. However, accuracy remains an issue, and related computation is usually unstable.

We can also find similar problem from the context of computational geometry. Alpha shape [2] produces results similar to those for outermost surfaces treated with a closing operator. An alpha shape is a generalization of a convex hull [11], and surfaces can be defined if a circumscribed sphere with a radius of r can be defined without any points inside the sphere. This enables the removal of internal mesh structures and significantly reduces the number of faces involved. However, the approach results in the filling of small features, and the surfaces produced are somewhat smooth. In medical application, small features are often important for analysis, which makes it difficult to use the approach directly. Surface features have also proven difficult to preserve in studies of other methods [3,4]. Lien and Amato proposed a method for decomposing input shapes into a set of convex shapes so that they approximates input shapes [7], however small features are also lost.

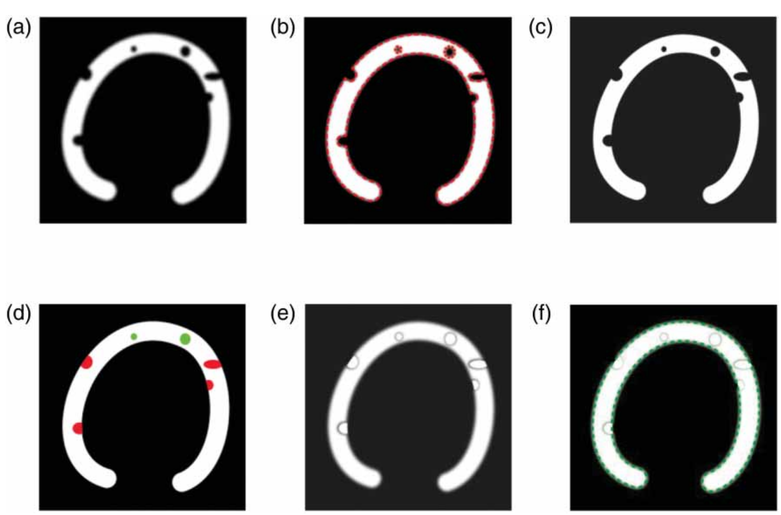

Fig. 1: An overview of our method in 2D. (a) Input image (b) isosurfaces of (a) (red). (c) Binarization result for (a). (d) Detection of void structure (drawn in red and green). (e) Manipulation of CT value of voids. (f) Isosurface extraction result for (e) (green).

Shrink wrapping approach [6] can also create similar results, however, the quality depends on the density of remeshing.

Active contour models provide efficient segmentation for greyscale images and other data. The use of a snakes algorithm [5] minimizes the energy function for explicit curves, and level-set methods [12] involve the tracking of fronts defined by implicit forms. These approaches are very flexible and allow the extraction of any boundary type by changing the energy function. However, parameter tuning is needed to extract the desired results.

Recently, Liu proposed an outermost surface extraction method for design of locking plate or attachment of bone [8]. Their method defines cutting planes on CT images in order to find outermost surface in 2D and they compute outermost surfaces by tracking the intersections. However, their method is designed for tubular-like objects and it is hard to apply the idea to general cases.

3. ALGORITHM

The objective here is to compute simply structured polygonal meshes and surface feature details from CT images. Given such images of the target object (Fig. 1 (a)), the proposed algorithm can be used to compute surfaces via the three simple procedures of void detection from binary images (Figs. 1 (c), (d)), CT value manipulation (Fig. 1 (e)) and polygonization based on the Marching cubes algorithm (Fig. 1 (f)). The resulting surface is simple because complex structures are filled, even though the result from the original image (b) is complicated. With this method,

Fig. 2: A 2D example of void extraction with smaller radius. (a) Dilation result to input image (black). Red circle shows structural element. (b) Erosion to (a). (c) Extracted void (red). Note that larger void is not filled in (c) because closing results does not fill there.

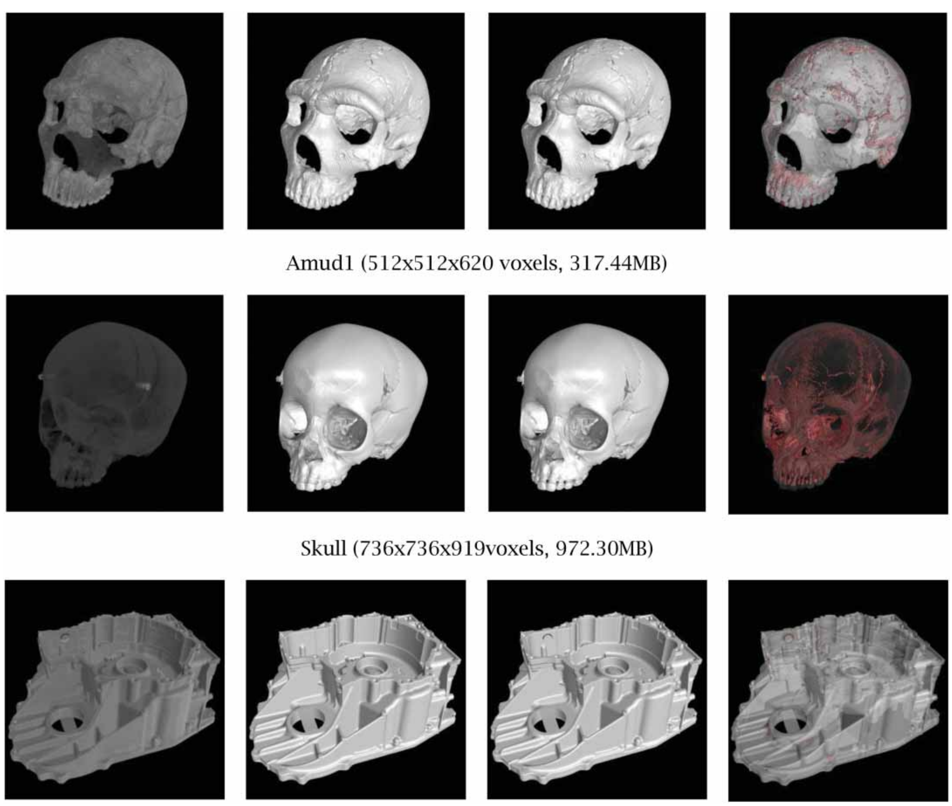

Fig. 3: Results. From left to right: Input CT images, Our results, Marching cubes result for the original images and detected void structure (red).

the user specifies the two parameters of t (the polygonization threshold) and r (the radius of the sphere or structural element).

3.1. Void Detection from Binary Images

Void is a small cavity of the objects. We can find these voids not only in bones but also on bone surface as dents. In addition, some of dents are connected deeply such as blood vessels, since they are running there. Connected component labeling algorithm can extract only isolated voids drawn in green in Fig. 1 (d) and a main objective of this step is also to detect the dent structure.

Our detection algorithm is based on morphological closing to binary images of the input. In order to obtain binary images, we apply a simple binarization with threshold t or threshold value used in Marching cubes algorithm. In the closing step, we use sphere with radius r as structural element. We first apply dilation operator to the images in order to fill void structure and apply erosion operator to remove expanded region. Void structure can be extracted by taking the difference between the closed image and the input binary images.

Radius of sphere depends on the size of extracting voids and smaller radius may fail to fill large empty region by dilation operator (Fig. 2). For example, at least radius d is required for filling void with thickness $2d$ spaces. However, larger radius sometimes detects concave surfaces as void. This can be estimated by previewing input image.

3.2. Modification of CT Values of Void Structure and Polygonization

This step fills void region by higher CT values than threshold, since CT values of void region is almost same as that of air. Replacing CT value must be larger than threshold t. Finally, Marching cubes algorithm with threshold t is applied to the modified images.

4. RESULTS AND DISCUSSION

Fig. 3 shows examples of our method for fossil skulls (Amud 1), Skull and Transmission cover. From left to right, the input CT images, our computation result, isosurface from the CT images are shown. In addition, the right most images shows internal structure of the object in red. We confirmed that our method could remove this structure by our method although surface quality is preserved. Indeed, the numbers of faces of Amud 1 and Skull data are 85 and 60 % of original faces, respectively. Since transmission cover involves lower number of voids, reduction ratio is about 1% of original mesh. However, in this case, over 180, 000 unnecessary faces are reduced.

Since our method manipulates CT values of void structure, surface quality is equivalent to that of Marching cubes. From Fig. 3, it is hard to find visual difference between results by our method and common methods. Indeed, geometric error is almost zero everywhere as shown in Fig. 4. Note that filled part involves relatively large errors because isosurfaces of original images do not exist there.

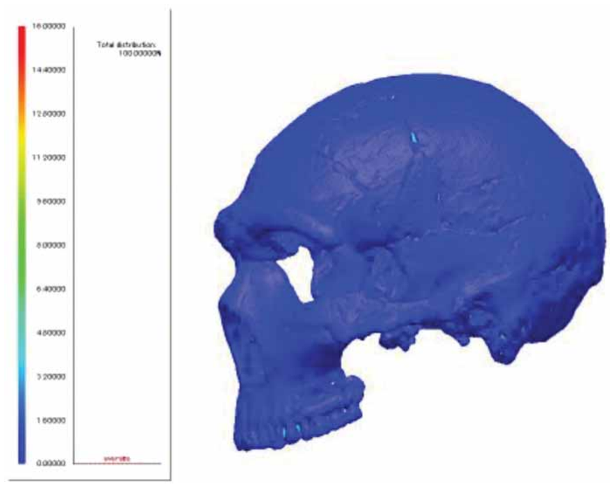

Fig. 4: Comparison with isosurface from original images (unit: voxel size (1 mm)). Color shows distance to the original model.

Computation time is also summarized in Tab. 1. Our prototype system uses OpenCL for void detection. All experiments are measured on Windows PC (CPU : Core i7-3960 processor (3.30 GHz), RAM: 32GB, GPU : GeForce GTX 680). The table tells us that about one third of total computational time is used for void

	Parameters		#triangles		Time (sec.)			
Data	t	r	Ours	MC only	Void	Manip.	MC	Total
Amud1	−430	4	3,780,280	4,414,470	58.48	2.94	110.36	171.78
Skull	13,000	10	10,538,128	17,939,444	317.90	18.72	740.29	1,076.91
Transmission Case	2,500	6	17,709,574	17,883,592	192.90	9.22	349.36	551.48

Tab. 1: Statistics. In time column, “Void”, “Manip.” and “MC” denote computation time for void detection, CT value manipulation and Marching Cubes respectively.

detection. In fact, our implementation is not fully optimized yet and computation time can be improved.

5. CONCLUSION AND FUTURE WORK

This paper has presented a simple method for outermost polygonization from CT images. Our method polygonizes CT images with modification of CT values at void part. As a result, we can compute quality surfaces equivalent to Marching cubes algorithm and they are much simpler than that of original images. These meshes can be used for medical applications efficiently.

This method involves some future work. A major issue is difficult to distinguish void structure or surface features. Although our method detects these voids by closing operator, we distinguish the voids by size or we do not consider their shapes. We would like to improve void detection so that surface features can be classified completely. Second is a memory usage. Since our current implementation is not optimized yet, memory usage is still large. For instance, peak memory usage of skull data is 3402.98 MB (7.17 byte/voxel). It must be improved in the future work.

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