Outmost Surface Extraction from CT Images using Optimal Cutting Planes

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Abstract

Outmost directed surface extraction from CT images is the first task in the implants design. This paper presents a method based on moving optimal cutting plane to extract the outmost directed surface from CT images. To make the CT images understandable, dual contouring technique is employed to reconstruct the model. And then an optimal cutting plane is generated based on the designer’s selection on the reconstructed model. With the optimal cutting plane moving along the orientation of the bone, the relevant neighborhood are marked. After removing the interior surface, the outmost surface is obtained. Experimentally, the proposed method succeeds extracting the outmost surface from CT images.

Keywords: Bio-CAD, tissue engineering, surface extraction

1 Motivations

With the development of rapid prototyping technologies, the demands of customized medical equipments for individual patients have been increasing [1, 2, 3, 4]. A shape of the equipment consists of several pieces of surfaces some of which must fit to a surface of a bone of the patient. The surface of a bone can be obtained in the form of a triangular mesh generated from the CT images of the bone with iso-surfacing method. And it often contains the outmost surface and complex inner surfaces of the bone. Only the outmost surface is that we need as the medical equipment is attached to it in design. Generally speaking, the surface of the bone is closed and it is not so difficult to get the outmost surface by selecting the largest iso-surface of the bone. However, the outmost surface is often connected to the inner surface through small holes. Thus we have to remove the inner surfaces before we get the outmost surface.

In addition when a bone is articulated to other bones, the outmost surface can be connected to another bone part through a narrow region because of the limited resolution of CT images. We also have to cut the outmost surface at these narrow connections. Moreover, considering the aesthetic reasons, we hope the bone is cut by optimal cutting plane. To this end, an approach to extract the outmost surface of a bone using optimal cutting plane is proposed in this paper. After cutting off the desired bone from CT images with optimal cutting plane, the outmost surface is obtained by removing the inner surfaces with a simple method.

2 Proposed Method

CT images consist of points (voxels) arranged in the 3D grid structure. Each grid point p is assigned its CT value ρ(p). By defining a threshold μ of CT value we can distinguish a foreground (bone) part from the background where ρ(p) − μ ≥ 0 and ρ(q) − μ < 0 for the foreground point p and background point q respectively (Fig.1(a)). p is named boundary grid point. In this study, the CT model is generated by dual contouring techniques [5], in which a relation, named Grid-Mesh relation, is constructed. With this relation we can get the boundary grid point p from the four triangles and triangles from p as well (Fig.1(a)).

The basic idea of this study is that we first generate an optimal cutting plane based on user’s specification and get its relevant neighborhood (Fig.1(e)). And then evolve the optimal cutting plane in two directions along the bone and get the corresponding relevant neighborhood (Fig.1(f)). In this process, the most important thing is to keep the plane to be optimal cutting plane all the time. After the plane stops moving on condition like arriving at the narrow connections or on the user’s request, we get the relevant neighborhood (Fig.1(f)). In this procedure, the boundary grid points near inner surfaces are also obtained (Fig.1(I)). A simple method (Fig.1(d)) is used to remove the marked grid points close to inner surface (Fig.1(g)) and finally the outmost surface is obtained (Fig.1(h)) with grid-mesh relation.

2.1 Optimal cutting plane initialization

Let us consider a cutting plane π through q with normal v (see Fig.1(b)). The relevant neighborhood N(π) is a group of grid points {p_i} which meet the following requirements: (1) p_i is boundary grid point; (2) Euclidean distance from p_i to π is less than a given threshold δ; (3) p_i belongs to the same shape part as q if π encompasses multiple shape parts. Therefore, in Fig.1(b), only the blue and green points are the components of N(π). Different colors mean they are on the different side of π.

Since the desired bone of a CT model is decided by the user, so the initialization of optimal cutting plane is based on the user’s specification. Starting from the mesh specified by the user, we get the related boundary grid point m. And the optimal cutting plane π^* is a plane through m with normal v^* which makes the cut of the bone best represent the shape of the bone. v^* is got by the following equation:

\[ v^* = \arg \min_{v \in \{v_i\}, |v| = 1} \sum_{p_j \in N(\pi(m, v))} < v, n(p_j) > \]

where N(π(m, v)) denotes the relevant neighborhood of optimal cutting plane through m with orientation v.

Based on the experimental results, i = 35 is enough. We mark N(π^*)(Fig.1(e)) and next is to evolve the optimal cutting plane along the bone and get all the corresponding relevant neighborhood during the evolution.

2.2 Optimal cutting plane evolution

The basic idea for evolving the optimal cutting plane is shown in Fig.1(c). We move the optimal cutting plane π_t in its normal direction v_t with distance d_t and get π_{t+1}. Please note v_{t+1} = v_t + v_d...
at this moment. We get $N(\pi_{t+1})$ and calculate the approximate center $o_{t+1}$. As we know if the orientation of bone does not change, the vector from $o_t$ to $o_{t+1}$ is nearly the same as $v_t$. But they are different if the orientation of the bone changes. Based on this fact, we evolve the optimal cutting plane with the following procedure:

Step 1: get $\pi_{t+1}$ with normal $v_t$ through $u$ which is got by the follow equation:

$$u = o_t + v_t d$$

Step 2: get $N(\pi_{t+1})$ and $o_{t+1}$:

$$o_{t+1} = \frac{1}{n} \sum_{p_j \in N(\pi_{t+1})} p_j$$

where $n$ is the number of grid point $p_j \in N(\pi_{t+1})$.

Step 3: get the vector $\lambda$ from $o_t$ to $o_{t+1}$ and calculate the angle $\theta$ between $\lambda$ and $v_t$, where $\theta = \angle(\lambda, v_t)$.

Step 4: Given a threshold $\delta$, if $\theta < \delta$, go to Step 5. Otherwise, we recalculate $\pi_{t+1}$ with normal $v'$, namely $u = o_t + v'd$. $v'$ is got from the vectors between $\lambda$ and $v_t$ and satisfies $\theta < \delta$.

Step 5: mark $N(\pi_{t+1})$ and check the stopping conditions. If stopping condition occurs, stop evolution. Otherwise go to Step 1.

With the proposed procedure, we evolve the optimal cutting plane along the bone and guarantee the new plane is almost the optimal cutting plane. After the stopping conditions occur, we get all marked grid points (Fig.1(f)) in which those close to inner surface are contained. The inner surface is remove by canceling the mark of those grid points.

### 2.3 Inner surface removal

Usually, the normal of outmost surface is outward while inward for the inner surface. With this fact, the basic idea of inner surface removal is shown in Fig.1(d). We check the grid points close to inner surface in each evolution after we get $N(\pi_{t+1})$. In the figure, the green point is the approximate center of $N(\pi_{t+1})$. The dot product of the vector from the center to the grid points near outmost surface is always a large positive value while small or even negative value for those near inner surface and small holes. After canceling the mark of those grid points, we remove the inner surface as the surface is got by grid-mesh relation. The result of Fig.1(f) is shown in Fig.1(g). Although not all the mark of the grid points near inner surface are canceled because of the irregular of the bone, we can get the outmost surface by simply selecting all the connected surface (Fig.1(h)).

### 3 Conclusion and Discussion

In this paper, an approach to extract the outmost surface from CT images is proposed. We first generate an optimal cutting plane based on user’s specification. And then move the optimal cutting plane along the bone while keeping the plane to be the optimal cutting plane is the most important thing. The outmost surface is got after removing the inner surface. Experimentally, the proposed method succeeds extracting the outmost surface from the CT images.

Improvements should be made to refine the proposed method. The evolution is not so accurate. Sometimes it cannot guarantee the plane is an optimal cutting plane because the method is shape prior. In addition, the algorithm for inner surface removal is not so robust. The outmost surface may be removed if model is highly concave. So in the future we would to make the proposed method more reliable.

### References


