Exploration on Extracting Geometric Model by Topology Optimization Design

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Abstract. Topology optimization design is a way to achieve more efficient design with a minimal priori decision. However, due to the complexity of the solution obtained, topology optimization is usually limited to theoretical researches and can not be applied into actual manufacturing. As a new manufacturing method that is currently developing rapidly, additive manufacturing has made great progress in many fields. Additive manufacturing has fewer limitations on the shape and complexity of the design. And it is currently moving toward higher precision and larger dimensions. The combination of these two ways can solve the problem of topology optimization design well. However, the topology optimization design’s principle determines that it is difficult to transform into a 3D model that can be processed and manufactured perfectly. Based on the topology-optimized structure, this paper uses MATLAB to extract the geometric model and smooth it, which provides an effective method for extracting 3D models from topology optimization. Also, this paper puts forward an efficient method to optimize the structure and it gets a pretty good result in the simulation.

1. Introduction
Topology optimization is a mathematical method that optimizes material distribution over a given area based on given load conditions, constraints, and performance metrics. Seeing material as the optimization object, topology optimization can find the best distribution scheme in the design space. Compared with other traditional structural optimization methods, it has more degree of freedom and can obtain much more design space. At present, common topology optimization methods include homogenization method [1], variable density method [2], progressive structure optimization method [3] and so on. As for additive manufacturing, great progress has been made in recent years. Jacob Koffler from the University of California, San Diego, used additive manufacturing techniques to mimic the spinal cord scaffold of the central nervous system structure, which successfully helped the rat to recover its motor function [4]. Researchers at Tel Aviv University in Israel use the patient's own tissue as a raw material to complete heart building. Building complete heart structure is the world’s first. Both of these technologies are at the forefront of their respective fields, and additive manufacturing can be well solved for the problem of topology optimization. However, the process of transforming the topology optimization structure into a manufacturable 3D model is still not well implemented. This is because the topology optimization result is probabilistic information, which is theoretically optimal, but can not give the actual processing and manufacturing model [5]. To this problem, this paper obtains its geometric model by a method of boundary optimization and extracting the processed contours. At the end of the
model, the smooth processing and analysis of the model also have been carried out. What is more, the paper talks something about the future work.

2. Extraction of geometric models
This paper extracts the geometric model based on the results obtained by Erik Andreassen et al.’s topology optimization program [6]. Fig.1 shows the results of topology optimization under the conditions of Table 1. The Fig.1 has a fuzzy probabilistic part, and the fuzzy value at the model boundary is between 0 and 1 (1 means there must be, 0 means no). Firstly, the digital information of the model boundary is preprocessed to ensure that the boundary value is optimized without affecting the optimization performance. At the same time, the influence of the surrounding structure points is considered. Secondly, the geometric model is extracted by selecting the contour line at 0.5, and the selection of the interpolation method is explained.

Table 1. Parameter setting.

| % MATERIAL PROPERTIES | % MATERIAL PROPERTIES |
|------------------------|-----------------------|
| n elx = 90; | n elx = 15; |
| nely = 90; | nely = 30; |
| volfrac = 0.5; | volfrac = 0.5; |
| penal = 3; | penal = 3; |
| rmin = 2; | rmin = 2; |
| ft = 2; | ft = 2; |
| tic | tic |
| E0 = 1; | E0 = 1; |
| Emin = 1e-9; | Emin = 1e-9; |
| nu = 0.3; | nu = 0.3; |

Figure 1. Topologically optimized graph.

2.1. Boundary value optimization
In the optimization of the boundary value, the influence of the surrounding point values should be considered. The specific method is as follows: each element value is changed into a matrix of n^n, and each number in the matrix is the value of this element. Taking the influence of the surrounding point values into account, each element takes the value of its own sum with the surrounding values, and the result is shown in Fig.2.
2.2. Contour extraction

First adjust the results of the topology optimization (matrix), and use the linspace function and the griddata function to divide and interpolate. The specific code is shown in Table 2.

### Table 2. Extract geometric model.

| % | geometric model |
|---|-----------------|
| xPhys_1 = xPhys; |
| [a, b] = size(xPhys_1); |
| x = ones(a,1); |
| y = [1: b]; |
| y = y'; |
| X = kron (x, y); Y = kron (y, x); Z = xPhys_1 (:); |
| xx = linspace (1, a, 100); yy = linspace (1, b, 100); |
| yy = yy'; |
| zz = griddata (X, Y, Z, xx, yy, 'cubic'); |
| Figure |
| contour (xx, yy, zz, [0.5,0.50001]); |
| set (gca, 'ydir', 'reverse', 'FontSize', 16) |
| title ('the geometric model'); |
| axis equal; |
Among them, there are four kinds of interpolation methods: linear function, cubic function, nearest function, v4 function. The results are shown in Fig.4. After comparison, the cubic function with the shortest time and the smoothest curve is selected for interpolation.

![Image of different interpolation methods](https://via.placeholder.com/150)

**Figure 4.** Comparisons of different interpolation methods.

3. Optimization results and analysis

3.1. Optimized results

According to the optimization method in the section “Boundary Value Optimization”, we use different \( n \) values for optimization analysis, and the results are shown in Fig.5.

![Image of optimization results](https://via.placeholder.com/150)

**Figure 5.** Optimization results with different values of \( n \).
3.2. Analysis of optimization methods

It can be seen from Fig.6 that the value of n is not as large as possible, but instead presents a trend of superiority and inferiority. To further verify the universality of the conclusions, different topological optimization results are used for analysis.

The processed results show that our optimization method does solve the problem of non-smoothness very well, but it seems that each different size model has a corresponding optimal n value. In the structure of Fig.6 above, the optimum state is clearly reached when n=3. If the value of n is greater than or less than this value, the output model will become unsmooth, which will cause processing difficulties for the output model. Approximate in this model is as follows: the correspondence between the unit length and the optimal n value (seen in Table 3).

| Width  | n = 2   | n = 3   |
|--------|---------|---------|
| Width = 0~3.7 | Suitable | Not suitable |
| Width = 3.7~30  | Not suitable | Suitable |
| Width > 30     | Not suitable | Not suitable |

4. Conclusion

This paper extracts the geometric model of the topology-optimized structure by its contour through the MATLAB software. Aiming at the boundary value considering the influence of the surrounding points, a method of mean value is proposed, which can be seen in the simulation results to make the boundary smoother. On this basis, the optimization effect of the expanded matrix dimension n under different conditional models is studied. Finally, an optimal n-value approximation map of different width structures is given. Through the exploration of geometric model extraction, it is better to extend the model building of complex structures in the future. Therefore, the topology optimization method and the additive manufacturing technology are contacted, and the theoretical optimal topology optimization result is truly applied to the actual processing and production. In the future work, we can widely move this method to the 3D model, and perhaps artificial intelligence recognition can be applied to make the surface smoother and easier to manufacture. There is no doubt that these jobs will provide the basis for the perfect combination of topology optimization and additive manufacturing.

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