GENERATION OF LAYERS WITH VORONOI INTERIOR

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***Abstract* – In this study a new approach for construction of the 3-D Voronoi Diagrams is explained. This approach is mainly developed for the parts going to be manufactured by using additive manufacturing methods. Main motivations of the study are creating 3-D Voronoi diagrams with low computational cost and having advance control over the Voronoi structure.**

***Keywords* – Additive manufacturing, construction algorithm, path planning, robotics, voronoi diagram**

I. INTRODUCTION

Voronoi diagrams are the equally spaced of a n-dimensional space into regions wrt. norms to given set of objects.Voronoi diagrams have wide range of practical and theoretical application fields. 3-D Voronoi diagrams may be very useful to control the inner structure of the objects in generative design, since physical properties of the object can be changed by positioning the Voronoi centers. However, even-though there are many algorithms are available to construct 3-D Voronoi diagrams, practical implementation of them is still an issue due to computational cost. Moreover, controlling the layer properties of the additive manufactured object by using 3-D Voronoi diagrams are challenging since arranging points in 3-D space does not directly allow us to understand the layer dynamics of the objects.

In this study, an algorithm that can built 3-D Voronoi structure from the cross section of the boundary layer of the object is studied. Main motivations of this study are providing an algorithm that can built 3-D Voronoi structures with low computation cost, and advance control over the layers of the 3-D Voronoi structures. Moreover, continuous path planning and the G-Code creation for the additive manufacturing are also considered.

II. LITERATURE SURVEY

There are well known algorithms in the literature to construct the Voronoi diagrams. Generally those algorithms are focused on obtaining the diagram's itself or the obtaining the Delaunay triangulation to construct the Voronoi diagram. Most famous algorithm for the 2-D Voronoi Diagram is Fortune's algorithm. Bowyer–Watson algorithm is a solid option for generating a Delaunay triangulation for any number of dimensions, and Voronoi Diagram can be obtained by that Delaunay triangulation. The Jump Flooding Algorithm is an another option for obtaining approximate Voronoi Diagrams.

Lloyd's algorithm is an useful algorithm to construct of Voronoi diagrams with uniform area cells. Lloyd's algorithm is an iteration algorithm and at every iteration algorithm builds the Voronoi Diagram and select the new Voronoi points as the centers of the Voronoi cells.This kind of Voronoi Diagrams are also refered as Centroidal Voronoi tessellation.

In path planning Voronoi Diagrams usually used to avoid the obstacles for robots. However a continous path planning algorithm is offered by M. Özcan and U.Yaman at "A continuous path planning approach on Voronoi diagrams for robotics and manufacturing applications"(2019).

III. Algorithm

In this section main algorithm is explained.

A. Generating First Layer

In order to generate the first layer of the 2-D Voronoi Diagram. Define the boundary polygon and select desired amount of the Voronoi points from them. Create the Voronoi Diagram by using *scipy.spatial.Voronoi* command. Unfortunally, *scipy* does not offer bouded Voronoi diagrams. Thus, find the edges that goes to infinity at the output of the *scipy.spatial.Voronoi* and find the every intersection point of the boundary polygon with those infinite edges. Then, Lloyd's algorithm is used to obtain the Centroidal Voronoi tessellation.

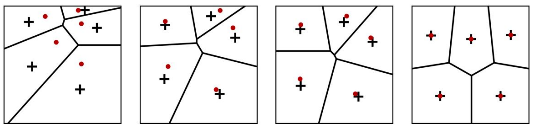

Fig. 1. Example of Lloyd's algorithm. The plus signs are the Voronoi Cell Centroids and red dots are the Voronoi Points

B. Generating Next Layers

In order to create the 3-D Voronoi Diagram from a 2-D Voronoi Diagram different methods may be considered. However, I selected to create the next layers by using the position of the Voronoi points, since main motivations of constructing the 3-D Voronoi Diagrams from 2-D Voronoi Diagram are having advanced control over the 3-D Voronoi Diagram and making this with low cost.Randomly assigning speeds to the cell edges would require excessive calculations and special events for some special situations. Moreover, controlling the 3-D structure does not seem easy with that method. However, we can control the structure if we can simply control the Voronoi points, and since building Voronoi Diagrams at 2-D is relatively simple, we can obtain 3-D Voronoi structures with low costs.

In order to transform the 2-D Voronoi Diagram to 3-D one, we must obey the rule that two neighbor 3-D Voronoi Cells shares a common surface and that surface is planar. This phenomena can be provided if all the Voronoi points moves according to some certain rule. I discovered this rule is: **Every Voronoi point of the 2-D Voronoi, should move towards or**

the reverse direction through a point on one of the inner edges of the Voronoi Diagram.. This point is named as **magnet point** in this study.

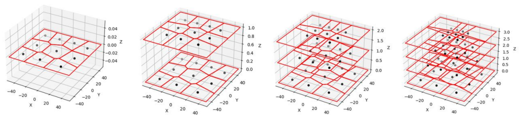

Fig. 2. Example of the Algorithm with 10 Voronoi nodes at every layer

One of the main advantages of this algorithm it provides easy manipulation of the rules for the creation and demolition of the cells. Some of the examples are shared below.

- Holding the magnet point but reversing the move of the Voronoi points through magnet points at every nth layer, results in symmetric structures at every n layer.

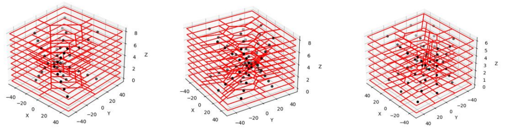

Fig. 3. Fixed Magnet Point and Reversing the Behaviour of the Voronoi Points at every nth ,(4th,4th,3th) layers respectively, with m,(3,7,8) Voronoi points

- Change the magnet point at every nth layer, which would make the new magnet point more or less denser wrt. Voronoi points.
- Calculate the area of the every Voronoi cell at new layer and find the standart deviation. Change the behaviour of the Voronoi points at a limiting standart deviation value would result a uniform structure.
- Cells with an area value at the below of the some threshold value can be demolished and the biggest cell can be divided into two just like mitotic division. This would results with non-uniform Vornoi cells.

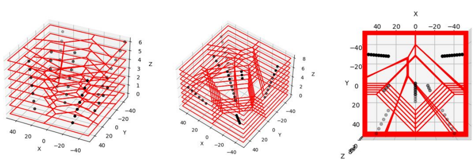

Fig. 4. Smallest Cell is destroyed and the biggest one is divided into two

Mentioned items are depends on the threshold values, which can be arranged according to results of the analysis of the objects. Moreover, thresholds can be fixed according the purpose of the object.

This approach successfully creates 3-D Voronoi Diagram since it provides the common surfaces of the Voronoi cells are planes. Moreover, this approach grants us advance control over the structure of the object.Initial layer is created as Centroidal Voronoi tessellation, however it can be modified according to the desired properties of the object. For example, high stress areas of the specific volumes of the objects can simply be supported by increasing the Voronoi point around that area and making every Voronoi point move towards the center of that point.

C. Varying Boundary Cross-Section

Created code is also suitable for the varying boundary cross-section.

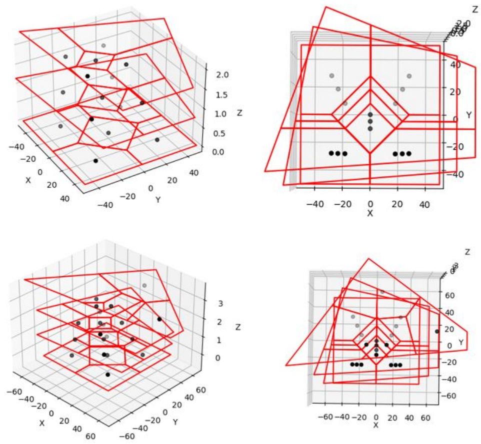

Fig. 5. Varying Boundary Layer at every layer with 5 Voronoi Points each layer

D. Path Planning

Unfortunately, I could not implement path planning algorithm due to lack of time. However, code already deposits every Voronoi cell for the every layer. Thus, recommended method for continuous path planning algorithm by M. Özcan and U.Yaman may be implemented easily.

E. G-Code

Unfortunately, again due to lack of time I could not implement path planning algorithm. However, I already created an successful G-code function for decided paths at Mini Project 2. It can be easily implemented after implementing path planning algorithm to this study.

IV. CONCLUSIONS

In this study, I offered a new approach to construct the 3-D Voronoi Diagram from a 2-D Voronoi Diagram. This approach provides advance control over the inner structure since manipulation of the position and the behaviour of the Voronoi points can be modified easiliy. Moreover, this approach can be combined with the analysis results to adjust the local Voronoi cell densities at layers. Study is compatibility with the varying boundary layer which means it can be used practically.

REFERENCES

[1] Özcan, M., and Yaman, U. (2019). A continuous path planning approach on Voronoi diagrams for robotics and manufacturing applications. Procedia Manufacturing, 38, 1–8. https://doi.org/10.1016/j.promfg.2020.01.001