An Interactive Simulation of a Guided Articulated Needle in a Porous Structure

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Introduction

Recently, design of articulated mechanisms became popular due to technologies development.

This kind of device can be used in many applications such as redundant material removal from cavities in 3D printed mechanical parts, and substance transfer (e.g. drugs) into difficult to reach areas in the human body. Both examples represent delicate situations where extra caution is required in order to avoid or to minimize any damage to the body

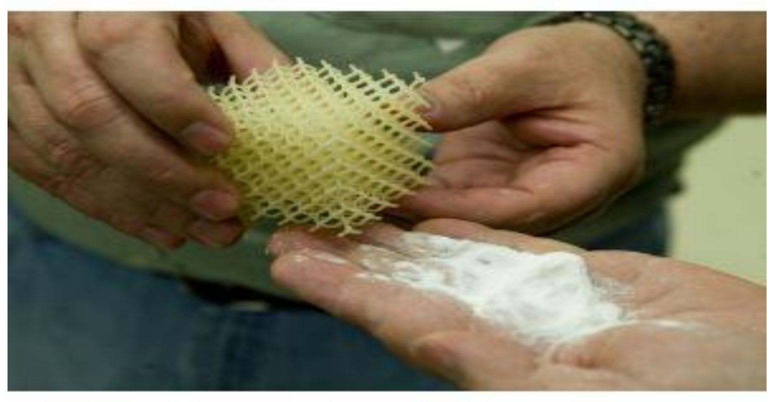

Fig 1: redundant material removal

Since an articulated needle has not yet been produced for practical usage, we propose an interactive-simulative application for guiding such a device in a porous structure. The application uses the outcome data of a geometrical pre analysis made on the structure.

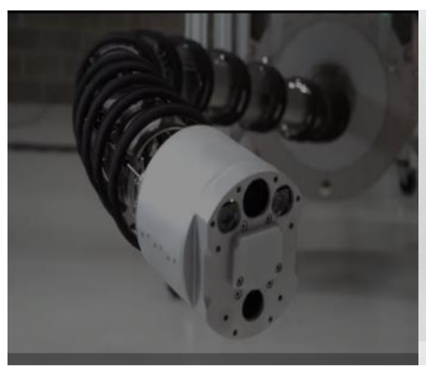

Fig 2: articulated robot

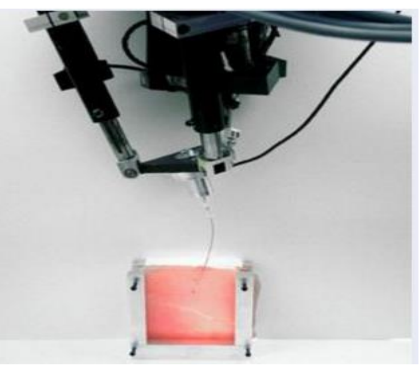

Fig 3: Shoham's flexible needle

Process

Creating the porous structure

⇓

Distinguishing between cavities and material

⇓

Finding the shortest tunnel between every couple of cavities with "clear view" between them

⇓

Finding the shortest path between selected pair of cavities

⇓

Finding a "clean" way inside a cavity from entry point to leaving point

⇓

Guiding an articulated needle according to the created pathway between two selected points

Implementation and methods

1. Creating the porous structure

The work begins with a 3D binary matrix, where the '0' elements represent the cavities and the '1' elements represent a material.

Two investigated types:

a) A solid structure filled with separated individual cavities (discrete pores).

b) A complex system of connected cavities.

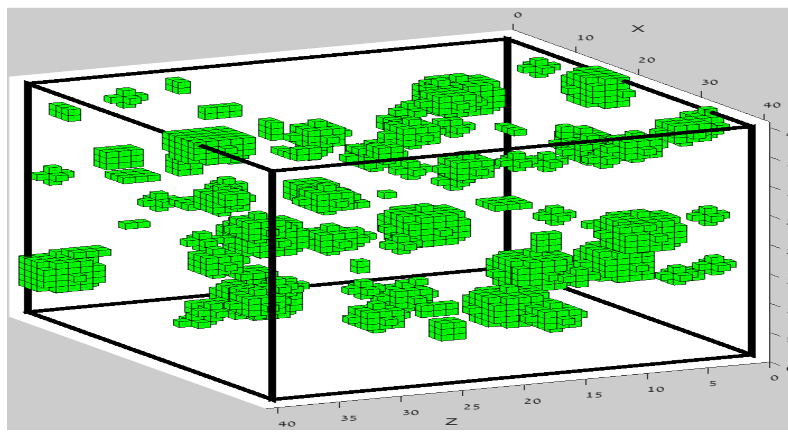

Fig 4: Self made discrete pores using the application features
*Second type of structure

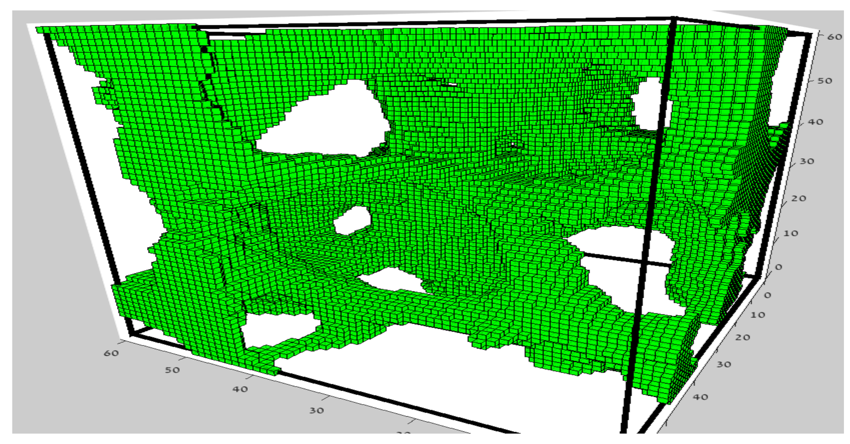

Fig 5: system of connected cavities Imported bitmap image of a 3D bone structure (from Yizhak Ben-Shabat Thesis

2. Segmenting the cavities

The cavities are then being segmented by applying a Connected Component algorithm on the binary matrix, in which neighbor elements are being labeled with the same value and color.

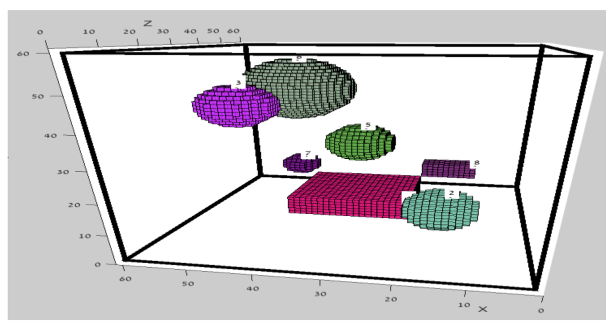

Fig 6: Segmented cavities

3. Calculating the shortest path between two cavities

The shortest path between two cavities is defined as the path which leads to the **minimal** penetration inside the material.

This is done by **exploiting other cavities in the way as a medium**.

a) Finding the shortest connection between each pair of cavities (hereinafter "tunnel").
Method: Nearest Neighbor algorithm a recursion done on a 3D binary tree

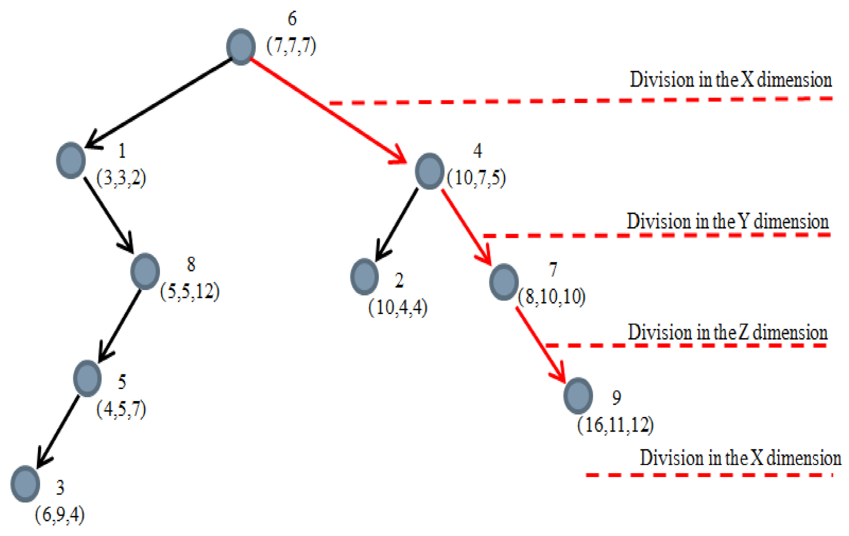

Fig 7: A 3D tree on which the recoursive NN algorithm is executed

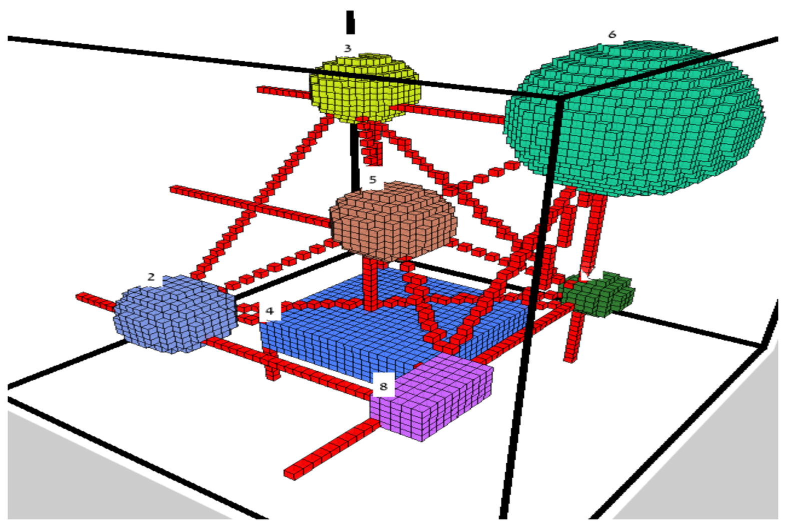

Fig 8: Step (a) result as all the cavities are connected in the shortest way

b) Once all the tunnels are defined, calculating the shortest path which is composed from tunnels.

Method: Dijkstra's Algorithm, where the path with the lowest sum of tunnel lengths is selected.

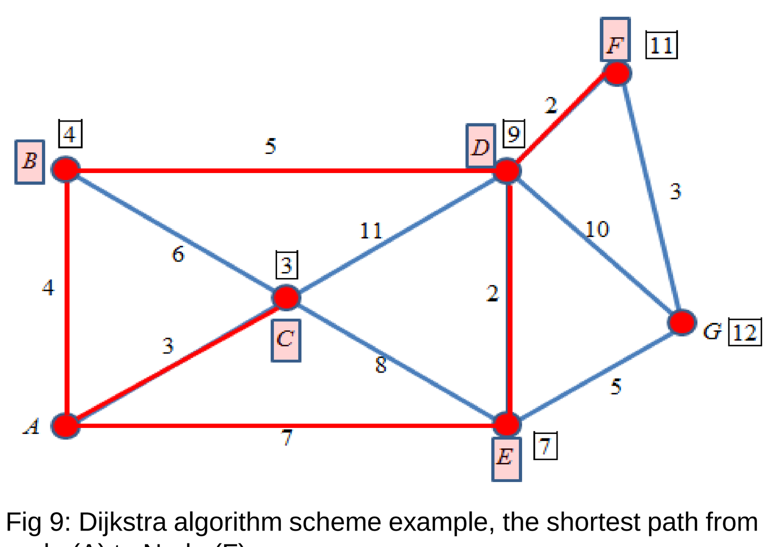

Fig 9: Dijkstra algorithm scheme example, the shortest path from node (A) to Node (F)

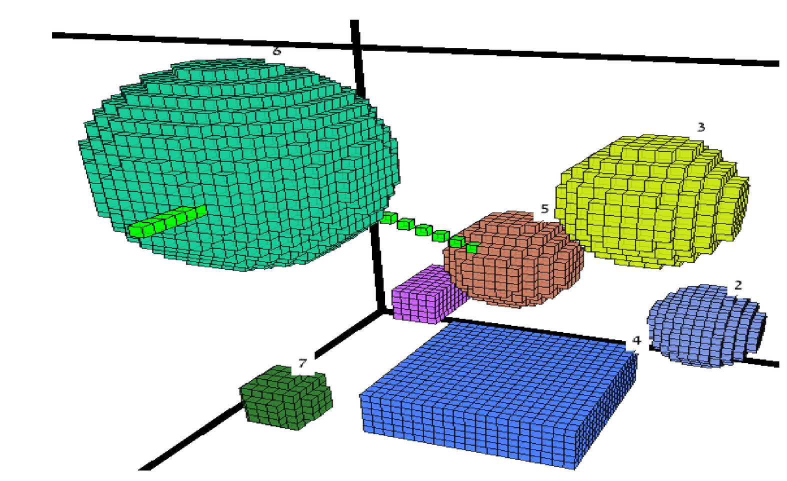

Fig 10: Step (b) result. The shortest way from the outside world (cavity 1) to cavity 5, exploiting cavity 6 as a medium

4. Obstacle bypassing

In this part we propose an algorithm for bypassing obstacles in a system of connected cavities (bone structure in this case) which also may be found inside a single cavity. The result is a voxel path which shows clearly the suggested bypass.

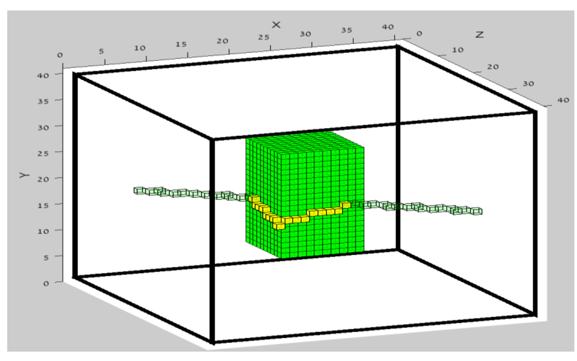

Fig 11: The obstacle bypass is constructed by yellow voxels

5. Simulation of the Articulated Needle

Once the porous structure analysis is done, the interactive simulation application may be used in order to manipulate and maneuver the needle and plan its route through the structure.

Several features are provided for this purpose in order to supply the user with rich controlling abilities

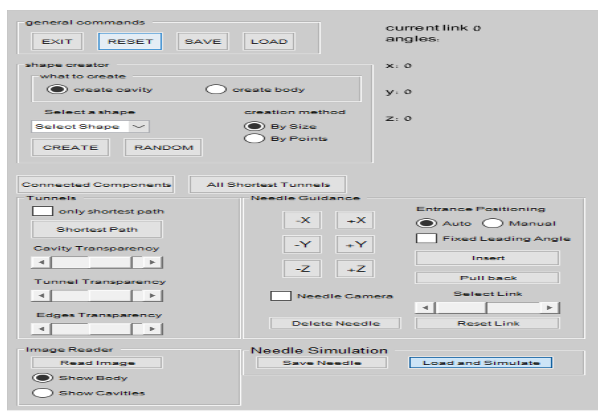

Fig 12: Application control panel

Discussion

In this work, some problems remained unsolved. Among them: (a) finding the ideal obstacle bypass. (b) Physical matters such as the needle material-penetration mechanism.

Further optimization of the application: In cases where the structure is very complex and the created path does not require the display of all the structure's details, it is possible, as proposed by Ben Shabat and Fischer, to select a suitable level of detail (LOD) for a certain region in the needle's pathway.

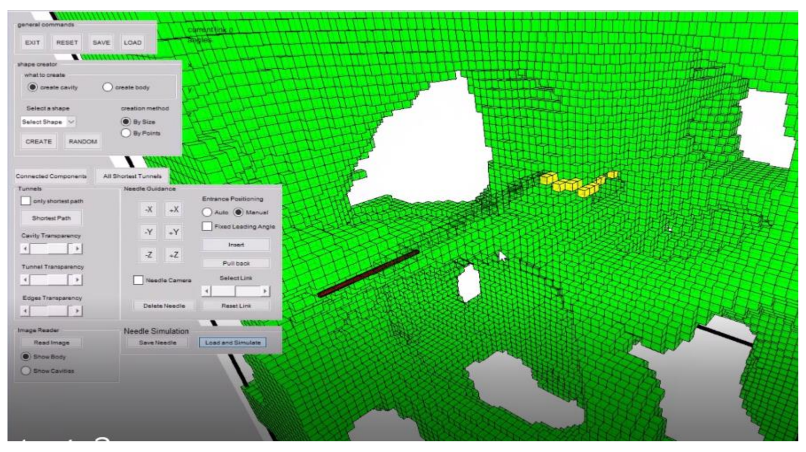

Fig 13: The red needle travels in the structure according to the user instruction

Conclusion

In this work, a practical method has been proposed for guiding an articulated needle in a porous structure, based on a pre analysis of the structure.

Several algorithms were used in order to create a path which avoids the damaging of the structure or at least bring the damage to the minimum. Since porous structures contain a lot of data, the used algorithms were also selected for their ability to reduce the complexity.

In the future it is proposed to implement the proposed method on a real articulated needle and to demonstrate its abilities in practice.

Acknowledgments

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