Paper Review

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May.2, 2020

Title: Anatomical Mesh-Based Virtual Fixtures for Surgical Robots

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Source: IROS 2020 (pending)

Summary

Many surgical operations, for example, mastoidecotmy on patients require high precision from surgeon's manipulation while carefully avoid hurting some fragile anatomical tissues, such as facial nerves. And a surgical robot could be very useful to achieve this aim. In order to let the robot assistant help surgeons to stop at critical tissues, virtual fixture algorithms are developed.

This paper presents a dynamic constraint formulation to provide protective virtual fixtures of 3D anatomical structures from polygon mesh representations. The proposed approach can anisotropically limit the tool motion of surgical robots without any assumption of the local anatomical shape close to the tool. Using a bounded search strategy and Principle Directed tree, the proposed system can run efficiently at 180 Hz for a mesh object containing 989,376 triangles and 493,460 vertices. The proposed algorithm has been validated in both simulation and skull cutting experiments. The skull cutting experiment setup uses a novel piezoelectric bone cutting tool designed for the da Vinci research kit. The result shows that the virtual fixture assisted teleoperation has statistically significant improvements in the cutting path accuracy and penetration depth control.

Critique

Pros

- This virtual fixture algorithm is the first time to consider the local anatomical structure information and can deal with arbituary shape represented by polygon mesh. By using several sorting conditions, it filters the large number of planes and find only those plane constraints that are active.

- This method is more efficient and reliable comapred with previous methods which model anatomical structures using general geometric shapes (such as modeling facial nervers as cylinders), which are not practical, rejecting the potential complexity of anatomical tissues.
- In conclusion, practical application in surgical scenario can be expected based on this work.

Cons

The algorithm is still not robust enough.

1. The inequality constraints are protecting the tissues so well that it preventing the surgical tool to enter any region within the anatomical structure. This can be too strict because sometimes surgeons may want to violate some of the constraints in order to perform the operation.
2. The algorithm is assuming the tissue to be static, it hasn't considered the case in which local tissue is deformed or bended due to the contact of the surgical tool, violating some of the constraints.
3. Currently, the algorithm only considered the tool tip point to be critical. But in real surgery scenario, not only the tool tip, but also quite a ratio of the tool shaft may enter patients body. The algorithm hasn't considered the possible intervention between the tissue and the rest of the tool shaft other than the tip point.

Relevance

The active plane constraint alogrithm developed in this paper was the fundamental algorithm of my work. Improving the algorithm's performance and making the algorithm pratically meaningful is the goal of my project.

Spedifically, I'm going to deal with the 1st and 3rd cons of this paper mentioned above, making the algorithm more compatible and robust, accelerating the application of the virtual fixture algorithm in practical usage.