OCT as tool for laser ablation monitoring applied to cholesteatoma

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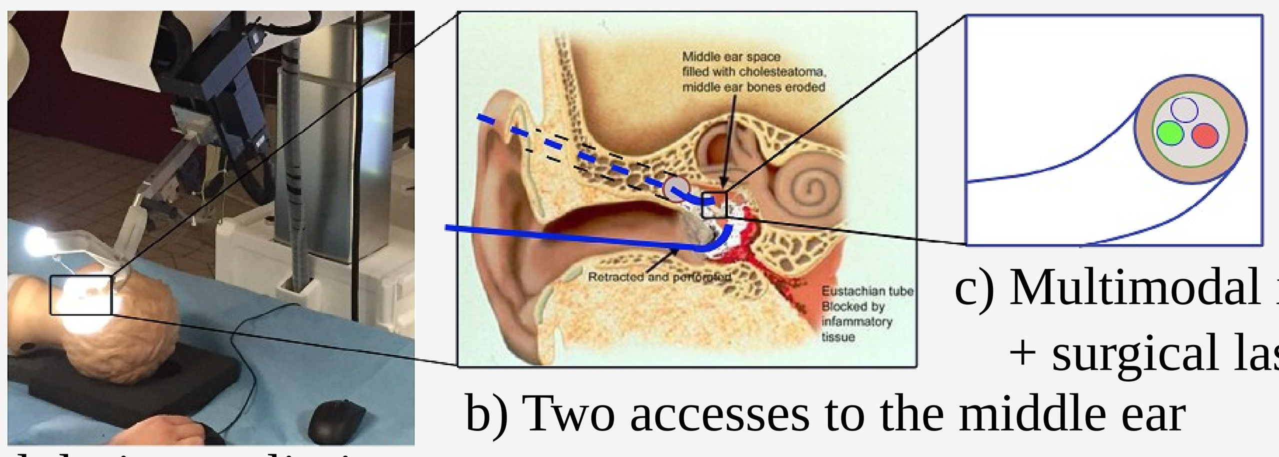
Motivations



c) Multimodal imaging + surgical laser

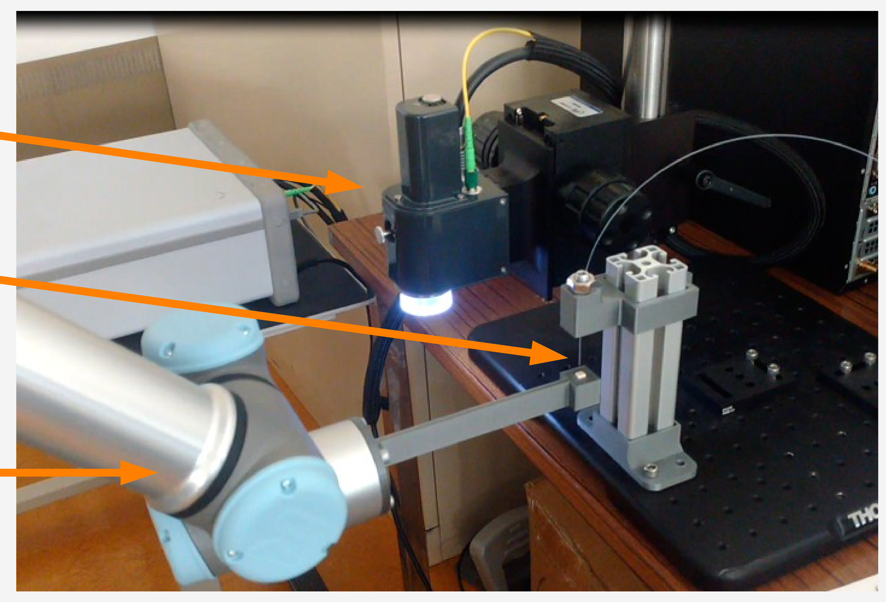
b) Two accesses to the middle ear

a) RobOtol during preliminary tests

Cholesteatoma is a disease characterized by an abnormal growth of skin cells in the middle ear. Conventionnal cholesteatoma surgery is challenging with reccurence rate up to 25 %. An advanced treatment for this disease is laser surgery that has been proven to remove efficiently the residual cholesteatoma [1]. In the µRoCS project, we propose a dexterous continuum robot with embedded laser instrument for exhaustive cholesteatoma removal (Figure 1). As part of this project, this study focuses on measuring the vaporized volume of cholesteatoma during the laser ablation process depending on the laser parameters. This volume will be obtained using OCT scanning and the proposed image processing.

Experimental setup

- OCT 1325 nm TELESTO-II Thorlabs
- Optical fiber connected to LBO surgical laser 532 nm, 8 W, Velas-8G
- UR3 robot arm

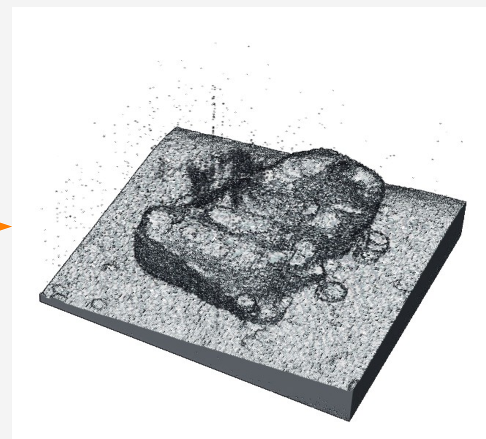


A fibered laser is employed to vaporize the cholesteatoma samples. The studied parameters are the laser power and the exposure time. The sample is manually positioned in contact with the fiber tip before each laser pulse. The distance is therefore considered constant throughout the study. After each laser pulse, a 3D image of the sample is taken using an OCT to estimate the small vaporized volume. A UR3 robot arm is used to position the sample under the fiber tip and the OCT probe alternately.

Image processing

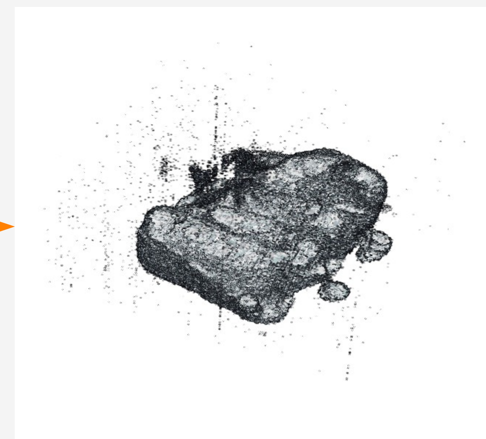
Initial image

Manual thresholding



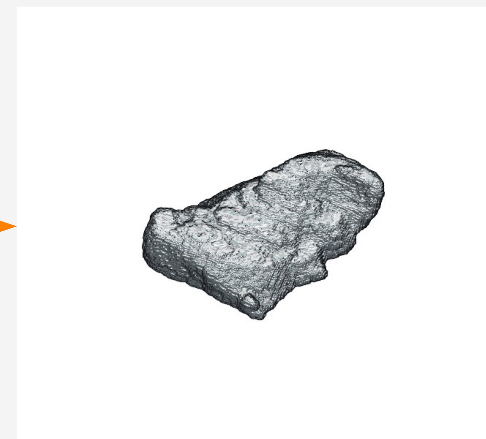
Binarized image

Support removal



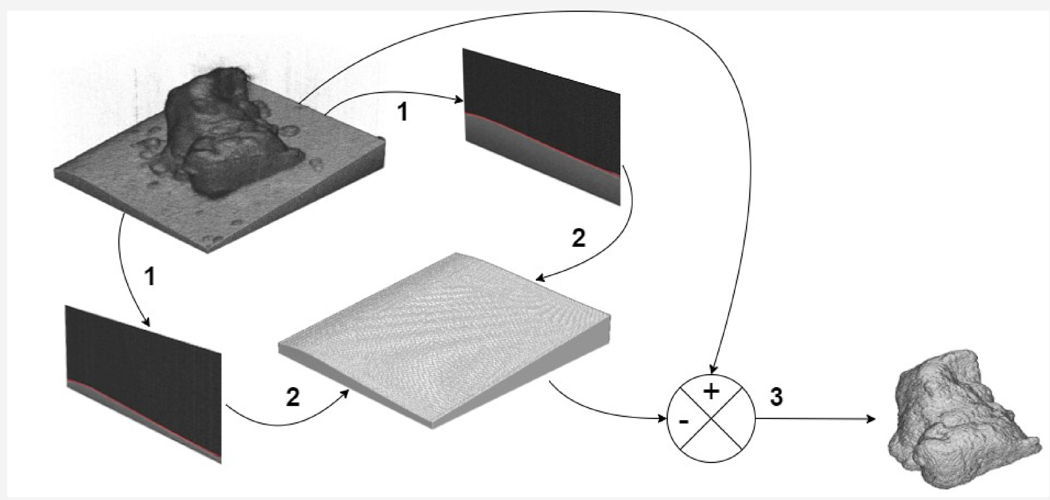
After support removal

Filtering



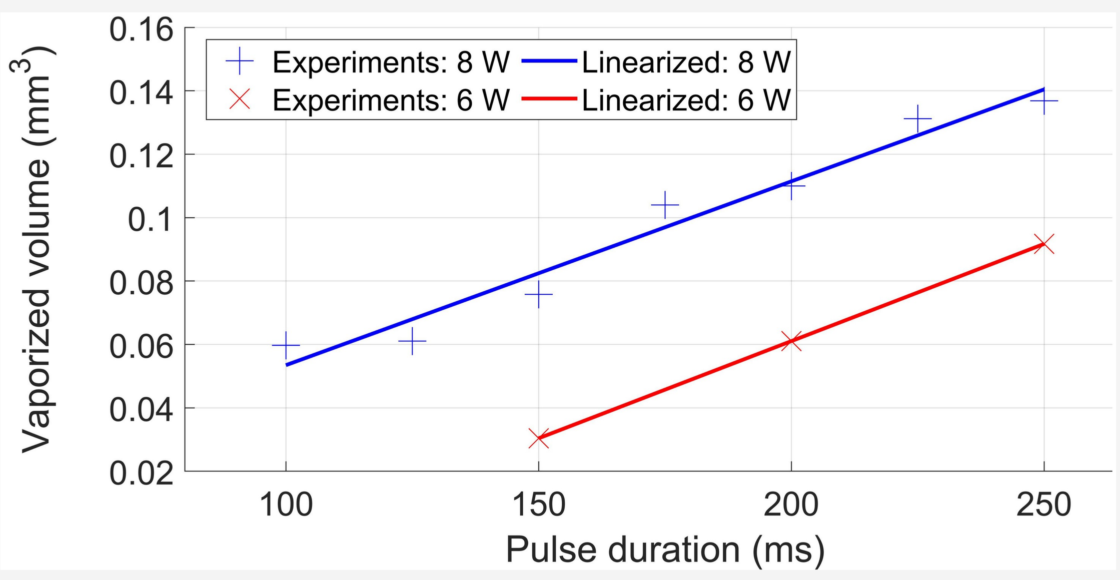
Final image for volume estimation

First, a threshold is applied to roughly separate the volumes of matter (cholesteatoma and support) from the background.
Then, in order to remove the support, two arbitrary cross-sections containing only the support and not the tissue (e.g., at the boundaries of the image) are extracted (step 1 on the right figure). The surface of the support in these cross-sections are obtained using the Canny edge detector. As the support has a prismatic shape, its surface can be approximated by performing a linear interpolation between the outlines detected in the previous step (step 2). The estimated support is then removed from the binary image obtained after thresholding (step 3).
The false negatives (holes in the middle of the matter) or false positives (matter in the background) are finally removed using morphological operations.



Details of support removal

Results



The experimental results of the vaporized volumes with respect to the duration of the laser pulse for two different laser powers, 6 W and 8 W, are presented above. The results are consistent with the litterature [2]. The vaporized volume increases linearly with the exposure time. Moreover, the steady-state ablation rate increases when the laser power increases.

Conclusion & Perspectives

This study provide an effective method for cholesteatoma laser ablation monitoring using OCT and the proposed image processing. Based on the obtained quantitative results, the surgeon can select the proper laser parameters (power and time exposure) as well as the required number of pulses for any specific volume of residual cholesteatoma during the laser ablation process.
Future work will focus on the integration of the OCT probe into our hybrid concentric tube robot [3] to perform cholesteatoma detection and laser ablation monitoring.
The integrated OCT probe will also be used to control the distance between the fiber tip and the cholesteatoma during the ablation and study its impact on the ablation process.

References

[1] G. le Nobel and A. James, “Recommendations for Potassium-Titanyl-Phosphate Laser in the Treatment of Cholesteatoma,” The Journal of International Advanced Otology, vol. 12, 2016
[2] H. El-khalil, A. Alshare et al. “A three-dimensional transient computational study of 532-nm laser thermal ablation in a geometrical model representing prostate tissue,” International Journal of Hyperthermia, vol. 35, pp. 1–10, 2018.
[3] D.-V.-A. Nguyen, C. Girerd et al. “A hybrid concentric tube robot for cholesteatoma laser surgery,” IEEE Robotics and Automation Letters, pp. 1–1, 2021