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Colon Lumen exploration with Robotized Optical Coherence Tomography Catheter

Guiqiu Liao, Zhongkai Zhang, Oscar Caravaca Mora, Philippe Zanne, Benoit Rosa, Diego Dall'Alba, Paolo Fiorini, Michel de Mathelin, Florent Nageotte, Michalina J. Gora

Strasbourg University, Strasbourg, France
Verona University, Verona, Italy

Abstract: Optical Coherence Tomography (OCT) shows the ability of real-time diagnosis for the external environment or internal small lumen. OCT has not been applied to larger internal lumen like the colon or stomach due to the difficulty of scanning. In this work, we use a robotized helical scanning probe to explore large lumen. Based on the segmentation of the stabilized OCT image, high accurate distance and quantitative contact feedback are obtained for the robotic scanning. The proposed method for distance/contact feedback shows robustness on both phantom and real deformable colon tissue. The robotic scanning is conducted on the soft phantom.

Key words: Robotic scanning, Optical Coherence Tomography, Deep learning, Side-viewing catheter, Real-time Image Processing

Technical abstract

The integration of a robotic surgical endoscope and the Optical Coherence Tomography (OCT) catheter shows potential for real-time large lumen diagnosis. Due to the limited field of view (FoV) of catheter-based OCT, robotic scanning is required to actively navigate the OCT probe along the target tissue. The endoscopic camera can be used to globally guide the OCT probe. However, the accuracy is not sufficient for maintaining the tissue in the imaging FoV of the OCT probe or preventing the probe from being over-pressed on the tissue.

The scanning can be effectuated either with or without contact. We extract information from the OCT images to provide quantitative distance and contact information with a self-designed deep neural network (DNN) architecture. By estimating the contour position of the probe sheath and tissue, we can calculate the closest distance between the probe and the tissue. For the contact situation, we estimate the contact region size. The estimated distance serves as positive feedback for the robot, while the contact region size serves as negative feedback.

A previously developed learning-based online OCT stabilization algorithm is also integrated with the feedback estimation. With OCT stabilization, the relative orientation between tissue and probe is corrected, that allows the robotized catheter to quickly explore lumen with complex geometry.

The image processing for feedback was tested on both phantom and real tissue. Robotic scanning experiments are conducted with a steerable robotized OCT instrument and a soft and deformable optical phantom. We compare the variation of distance and applied forces obtained for manual teleoperation, open-loop scanning with only a pre-programmed movement, and closed-loop scanning.

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