

OCT-GUIDED POSE ESTIMATION AND CONTROL FOR MAGNETIC SURGICAL ROBOTS

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Abstract

Minimally invasive surgical procedures require precise control and localization of surgical instruments within complex biological tissues. Articulated magnetic surgical tools, capable of navigating through constrained anatomical spaces, provide enhanced dexterity and reduced patient trauma. However, accurate pose estimation and real-time feedback control remain significant challenges due to limited visibility, soft tissue deformation, and instrument flexibility. This project proposes a novel framework that leverages **Optical Coherence Tomography (OCT) imaging** combined with deep learning techniques for the real-time **pose estimation** and feedback-controlled manipulation of an articulated magnetic surgical tool. In this work, a synthetic OCT imaging pipeline is developed to emulate B-scan cross-sectional images of the surgical tool within tissue-mimicking environments. The images incorporate depth-dependent attenuation, speckle noise, and structural representation of the articulated tool, enabling realistic training data for machine learning models. Using these synthetic images, a **convolutional neural network (CNN)** regressor is trained to estimate the tool's pose, including its 2D position, orientation, and joint articulation angle. The network demonstrates robust generalization in predicting both the tool's spatial location and articulation state, even under noisy imaging conditions. The predicted pose is then integrated into a **feedback control loop** that continuously adjusts the tool's motion toward predefined target positions and orientations. A proportional control strategy is employed to compute velocity commands based on the estimated pose, enabling accurate trajectory tracking and precise joint manipulation. The system's performance is evaluated in terms of positional accuracy, angular error, and convergence speed, demonstrating reliable control and minimal deviation from desired targets. This framework provides a foundation for OCT-based **sensor-guided robotic interventions**, offering a non-invasive, high-resolution imaging modality for real-time pose estimation and control. By combining synthetic OCT datasets with deep learning and control strategies, the proposed approach addresses critical challenges in minimally invasive surgery, including instrument localization, articulated joint management, and reliable feedback-driven manipulation.