An open-source testbed for developing image-guided robotic tumor-bed inspection

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INTRODUCTION: Delineating tumor margins intraoperatively is a challenging task in many soft tissue cancer surgeries because of tissue deformation and mobility. We hypothesize that a combined approach of imaging, machine learning and cooperative robotics can help mitigate this challenge by enabling intraoperative tissue scanning of the tumor bed to identify and localize residual cancer cells. To realize this system, we develop an open-source testbed and demonstrate its viability with a combined optical and acoustic imaging approach for tissue scanning. Combining optical and acoustic imaging is beneficial in this application because it can help characterize the tissue at the surface layer while providing depth information about the anatomy being imaged [1]. For tumor bed inspection, this is necessary and make it possible to identify potentially residual cancer cells, and how far they penetrate the surrounding anatomy. In this study, we focus on the implementation of the imaging and analysis portion of the testbed and discuss its extension to a complete system.

METHODS: The goal of this testbed is to enable parallel flow of multiple imaging inputs that are spatially registered using robotics and temporally synched. To deploy this system, we make use of 3D Slicer for visualization as well as SlicerIGT (http://www.slicerigt.org/wp/) to stream imaging inputs (Figure 1). These tools also offer the flexibility to swap out the imaging modality in the system easily. Signal processing and data fusion can then be done with artificial intelligence (AI) tools in SlicerAIGT (https://github.com/SlicerIGT/aigt) which enables direct communication between AI models and imaging inputs in 3D Slicer. To demonstrate the technical viability and function of this testbed, we investigate the use of a combined temporally enhanced ultrasound (TeUS) imaging [2] and broadband spectroscopy to detect tissue heterogeneity in animal models. Tissue phantoms, made up of heterogeneous tissue (beef, turkey, beef on top of turkey and turkey on top of beef) are imaged with throughput broadband spectroscopy and ultrasound. Following this acquisition, the absorption of broadband light is computed to characterize the surface tissue optically. Additionally, the TeUS signals from the tissue are used to classify pixels in the US images according to their tissue type with a simple support vector machine (SVM).

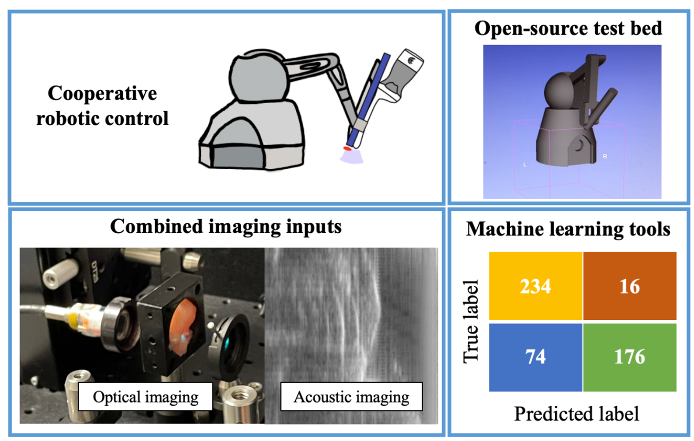

Figure 1: Concept for open-source testbed using combined optical and acoustic imaging as a sample use-case.

RESULTS: Using this test bed, we were able to successfully demonstrate a tumor bed inspection system that deploys combined optical and acoustic imaging with machine learning. More specifically, the absorption curve for each broadband acquisition showed distinct separability for every tissue phantom and our trained SVM could successfully classify 82% of the ultrasound pixels in the TeUS images according to their tissue type (Figure 1 – bottom right).

CONCLUSIONS: These preliminary results demonstrate the viability of this testbed for robotic tissue scanning in addition to the potential usage of combined optical and acoustic imaging for tissue recognition. To achieve this, we are currently working on using this imaging system as the input for the cooperative robotic control scheme.

ACKNOWLEDGEMENTS: L. Connolly is supported by an NSERC CGS-M award. G. Fichtinger is supported as a Canada Research Chair. This work was funded, in part, by CANARIE's Research Software Program.

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