Haptic feedback and ultrasound guidance for lumpectomy with SlicerROS2 *

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There is no standard development platform for image-guided robotics research. As a result, researchers often spend time creating custom programs to solve common problems. Though there have been several attempts made to build a common platform, none have succeeded in providing developers with a full suite of tools necessary to build interventional, image-guided robotic systems. Moreover, researchers are often split between different operating systems, communication protocols and preferred programs. SlicerROS2 is a software module that was designed to fill this gap (`https://github.com/rosmed/slicer_ros2_module`). The module combines the open-source medical imaging platform 3D Slicer (`slicer.org`) with the expansive robotics libraries in robot operating system (ROS - `ros.org`). As both programs (3D Slicer and ROS) have highly active support communities and widespread adoption in the world of medical imaging and robotics respectively, we believe this research module will greatly help facilitate future research. In this demo, we will show how SlicerROS2 can be used in this capacity using a relevant clinical application as an example.

Example application: Lumpectomy is a common treatment option for breast cancer patients where a tumor is removed from the breast while preserving overall breast cosmesis. One of the biggest challenges a surgeon faces during lumpectomy is achieving complete tumor resection and sufficient resection margins. These challenges arise because breast tumors are often non-palpable and have non-linear and indistinct borders.

The NaviKnife system was designed at Queen's University to address this challenge using electromagnetic (EM) navigation and intraoperative ultrasound. First, a tracked localization needle is inserted into the tumor to help monitor the position of the tumor while the patient moves and breathes. After this, intraop-

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erative ultrasound is used to identify the extent and shape of the tumor for the navigation display. The surgeon's electrocautery is also tracked so that they can see where their tool is relative to the tumor, as they operate. This entire platform is deployed using open-source software including: 3D Slicer, OpenIGTLink (`openigtlink.org`) and the PLUS toolkit (`plustoolkit.github.io`).

Recently, we have extended this system by incorporating haptic feedback in the form of a virtual fixture to better enforce sufficient tumor margins. A virtual fixture is a computer-generated constraint that is communicated to the user via cooperative robotic control of the surgeon's tool. In this new system, the surgeon's electrocautery is cooperatively guided by the Omni Bundle robot (Figure 1). The surgeon is then provided with a visual display of where their tool is relative to the tumor, and we also apply a small force to the handle of the Omni if they breach the tumor boundary.

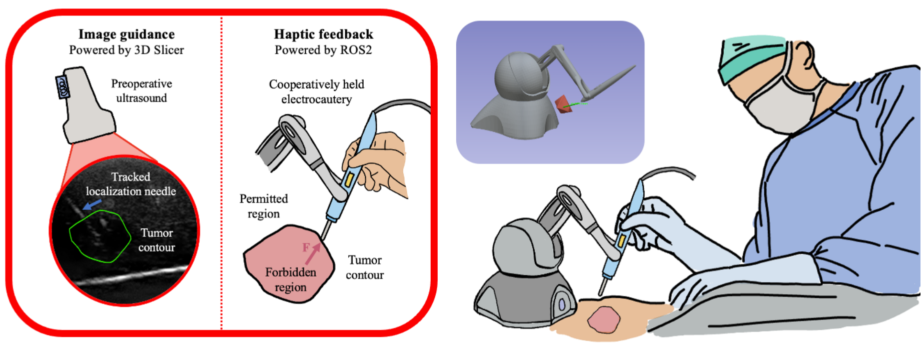

Fig. 1. Overview of the proposed approach for robot-assisted breast conserving surgery.

This new system is built on top of the existing NaviKnife infrastructure using SlicerROS2. In the NaviKnife system, the ultrasound images and positional data from the EM tracker are streamed into Slicer using PLUS and the OpenIGTLink interface. Collision between the surgeon's tool and tumor is computed using the "BreachWarning" module which is part of the SlicerIGT extension (`https://github.com/SlicerIGT`). To incorporate haptic feedback, we first load the robot into the Slicer scene using the universal robot description file (URDF) and ROS robot state publisher. From there we use a simple conditional statement to publish a position signal to the motors in the handle of the Omni bundle if the surgeon's tool breaches the tumor. This signal is sent using ROS messages and commands.

This scenario is just one use-case where SlicerROS2 can be used to deploy image-guided robotics. For more information, we have provided extensive documentation on the module and how it can be used here: `https://slicer-ros2.readthedocs.io/en/latest/`.