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Implementation of a Motion Planning Framework for the daVinci Surgical System Research Kit

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INTRODUCTION

Our goal is to extend the capabilities of robots used for laparoscopic surgeries, in particular the daVinci Surgical System (Intuitive Surgical). Primarily, we have integrated Robot Operating System (ROS) [1] as a middleware for the teleoperation control mode of the daVinci Research Kit (dVRK) [2]. This integration of ROS significantly enhances the ability to leverage the vast number of tools commonly used for robotics, to be employed to the dVRK.

In the traditional teleoperation mode, the Master Tool Manipulators (MTMs) interface with the Patient Side Manipulators (PSMs). Corresponding changes in the position and orientation of the MTM's grippers translate into corresponding actuation of the PSM's joints and correspondingly its end effector's pose. Integration of ROS as a middleware for data flow significantly enhances the ability to add computer intelligence to the surgical procedures. Within the described framework, kinematic and dynamic simulation models of the MTMs and PSMs have been developed. The framework is tightly integrated with *RViz*, a 3D visualization tool that is native to ROS and allows for tasks such as planning, manipulation and trajectory control.

For planning and manipulation tasks, it is necessary to have a 3D representation of the environment and obstacles. In order to generate 3D point clouds of the environment, we utilize a pair of compact stereo cameras. However, 3D volumes and point clouds from both live and registered preoperative imaging from various sources may be readily incorporated into the system. *In this paper, a system architecture and a method for a collision free motion planning is proposed from 3D streaming point clouds. The goal is to provide assistance to the surgeon by guiding a tool to follow an optimal path while avoiding sensitive anatomical features or other obstacles.*

ROBOT SIMULATION & CONTROL

The daVinci Surgical System consists of three primary components: MTMs (master manipulators), PSMs (slave arms) and High Resolution Stereo Viewer (HRSV). A developed ROS-based framework between MTMs and PSMs includes the following components:

Simulation: CAD models for the actual PSMs and MTMs have been developed (Fig. 2). These models have been used to define Unified Robot Description Format (URDF) files, which are compatible for simulation in ROS. These simulations may be run concurrently with actual teleoperation of the daVinci by mimicing the joint states and velocities of actual MTMs and PSMs in a live 3D rendering of the environment.

Teleoperation Interface: The teleoperation program provides a communication bridge over which ROS operates. This bridge is capable of reporting all joint positions, end-effectors cartesian pose, joint torques and current feedbacks of every MTM and PSM. Spontaneously the joint positions, end effector cartesian pose and joint torques can be set for any arm using standard ROS topics.

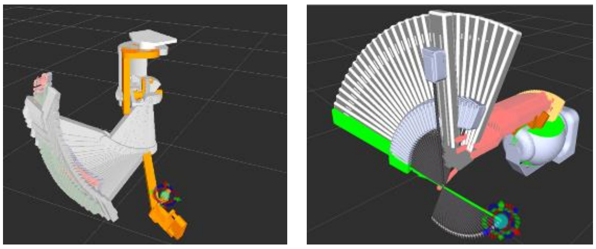

Fig. 1: Planned trajectory execution on both MTM and PSM.

Control: Controlling PSMs or MTMs directly from simulation is achieved by clicking the simulated PSMs or MTMs tip and dragging it in the dextrous workspace (Fig. 1). This simplification in control is possible only by efficient merging of low level libraries to the higher level graphical applications.

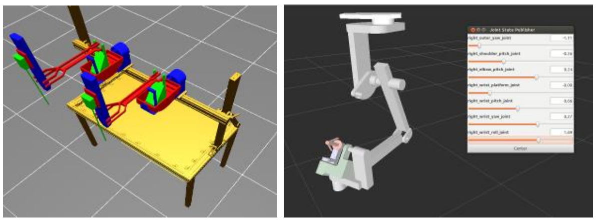

Fig. 2: Kinematic simulation coupled to hardware through ROS. PSMs (left) and MTM with slider control (right).

MOTION PLANING

In an effort to incorporate computer intelligence beyond the traditional teleoperation modality, the framework is configured to collect discrete points (6-DOF poses) in the operating space (OS) of the MTMs and generate a collision free path connecting those points for the PSMs in their OS. The points are selected using the MTMs pinch events as a trigger, which causes the current position and orientation of the corresponding MTM to be queued (Fig. 3). A proposed use case is where the surgeon's only visual access to the patient is via a stereoscopic viewer that is interfaced with stereo cameras near the PSMs. In cases where it is difficult to visualize the entire area that the surgeon is operating on, computer-guided path planning would allow specifying a set of guided points for a general surgical motion plan. The desired path may be analyzed and improved by the planning and selection algorithms to generate an obstacle free path if one exists, or report failure otherwise.

PLANNING SETUP

A primary contribution of this work is the ability to leverage the vast array of existing tools into this framework for use with the dVRK. In particular, several popular motion planners are used including RRT, KPIECE, and SBL with their variants. All these planners are Random Time Planners and almost always produce a non-optimal path [3]. For this reason, one unique random time planner of particular interest for this paper is the RRT* planner, which guarantees an optimal path, if one exists. The planner searches for a path using traditional RRT algorithm and then improves upon the path produced incrementally as time progresses [3].

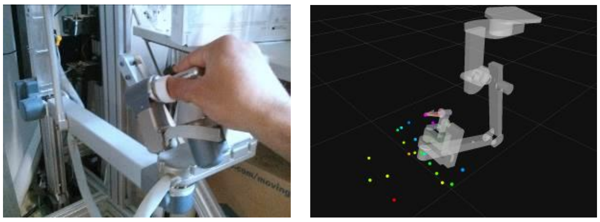

Fig. 3: Registering points from MTM by gripper pinch (left) and corresponding, registered points in simulation (right).

POINT CLOUD GENERATION & STREAMING

Visual feedback is essential for surgical teleoperation, especially under circumstances near sensitive or delicate structures. In order to render a 3D reconstruction of these structures and objects, we generate point clouds of the environment. To mimic a surgical system with stereo vision, two identical cameras are used (Microsoft LifeCam Cinema) are used to create the point clouds. The baseline between left and right camera is minimized to give a close range of depth information, maintaining a ratio of the focal distance to baseline depth that closely mimics that of the clinical daVinci stereo endoscope. The following ROS packages are used: *uvc_camera*, *camera_calibration*, and *stereo_image_proc* to provide camera drivers, camera calibration, stereo vision processing, disparity map generation and 3D point cloud generation. By tuning parameters for generating a disparity map in the range that needs to be detected, a high-quality point cloud is obtained [4]. An example of point cloud streaming is shown in Fig. 4.

POINT CLOUD BASED MOTION PLANNING

Prior to motion planning with the physical robot, accurate positioning of the point cloud with respect to the PSMs is essential. The 3D point cloud is first registered to the robot frame. *ar_pose*, a ROS wrapper for ARToolkit [5], is used to calculate the transformation between the camera frame and the PSMs. Markers are attached to camera, left PSM and right PSM respectively to provide their relative positions and orientation using *ar_tool*. The *Tf* ROS package provides a convenient way to manage all the frame transformations in the system. The transformation between any two frames can be obtained at any time by building a transformation tree. Utilizing the point cloud registration, motion planning and trajectory planning can be implemented in the real world corresponding to the simulation. The point cloud could be further registered to previously acquired anatomical or functional imaging, or a previously generated plan.

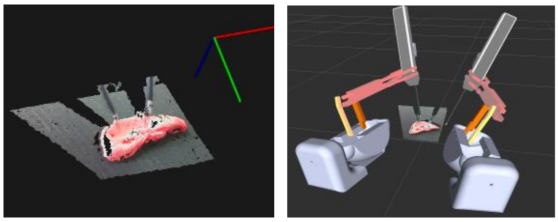

Fig. 4: An example frame from point cloud streaming of a liver phantom (left). Integration of the registered environment point cloud and the PSM robot model (right).

DISCUSSION

The paper describes a framework that enables simulation and motion planning with the dVRK utilizing ROS-based tools, and a demonstration of example tasks that have been successfully implemented. Fig. 5 shows the outcome of a motion-planning problem for an anatomical target (a heart model in this case) that was identified as an obstacle. The PSM's start and goal pose are show in orange and green respectively, and the PSM follows a collision free path around the obstacle. The path is optimized using the RRT*, as can be seen, the path is smooth and tight around the anatomy.

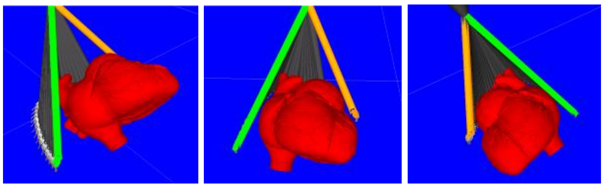

Fig. 5: Exampled planned path from start pose (orange) to goal pose (green) around a model of an anatomical obstacle.

We are currently working on more complex simulations based on registration of actual anatomical data to acquired point clouds. Further, we are working towards integration of force feedback on the MTMs based upon the virtual interactions with the 3D model so as to develop a sense of the forces being encountered at the PSMs. This requires the estimation/calculation of an accurate dynamical model of the MTM, another research area we are currently investigating as well.

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