Software and Robotic Integration Final Report

Please provide a full-length report on 3D Slicer / ROS path planning software by June 2, 2023 at 5pm. This system should comprise the following components:

1. System Description

Path Planning: A 3D Slicer implementation to select a straight trajectory from a set of inputs. This algorithm should take in a set of possible entry and target points (represented as a `vtkMRMLMarkupsFiducialNode`), and two binary image volumes representing the critical structures and target or structure (represented as either a `vtkMRMLLabelMapVolumeNode` or `vtkMRMLLabelVolumeNode`). It should return two points representing a selected final trajectory (represented as either a user defined type or a `vtkMRMLMarkupsFiducialNode`). The final trajectory should be selected with the constraints (a) avoidance of a critical structure, (b) placement of the tool into a target structure, (c) trajectory is below a certain length, (d) maximizing distance from critical structures (as in Coursework 1). Note this algorithm will be tested on the BrainPlanning dataset provided.

OpenIGTLink Communication: Use OpenIGTLink to translate the selected trajectory into ROS using an appropriate data format (for example a `vtkMRMLMarkupsFiducialNode` or `vtkMRMLLinearTransformNode`). It is highly recommended to transfer structures to ROS for validation, but not a requirement. Care should be taken here to apply the appropriate transformation to ensure data is in the correct coordinate frame. This transform can either be performed prior to transmission in 3D Slicer or after transmission in ROS.

ROS Robot Model: define a `RobotModel` and appropriate helper classes so that its end effector can be moved to a given position (as in Coursework 2), determined from the data read from OpenIGTLink. The `RobotModel` class should following the Unified Robot Description Format and a robot with at least two joints (6DOF are recommended for achieving the correct position). There should be a class that listens to data transmitted on an appropriate OpenIGLink channel and identifies the point/pose requested and then tries to move the end effector of the `RobotModel` to the requested point/pose and prints an message if the robot cannot achieve the position.

Validation should be performed to demonstrate the selected point in 3D Slicer and the robot end effector are co-located. This evaluation should be performed in 3D Slicer and ROS.

2. Report Format

- Introduction (1-2 pages, 16.6% of grade). Describe why integration between imaging processing and robotic simulation is useful in the context of medical applications. Why is using: (a) image processing, (b) robot simulation useful for medical applications. Finally describe the advantages to developing an end-to-end pipeline for a clinical setting. Consider both advantages in implementation (designing the system) and validation (assessing accuracy and robustness).

- Methodology (3-5 pages, 33.3% of grade). Describe in detail the components of the system (3D Slicer path planning, OpenIGTLink for data transfer from 3D Slicer to ROS, ROS implementation to move robot, OpenIGTLink for data transfer from ROS to 3D Slicer), and a detailed description of how information is transferred between components. Care should be taken to clearly explain where coordinate transformations and changes in data representation are necessary for data transfer between software components.
- Validation (3-5 pages, 16.6% of grade). Describe in detail how each component was tested to validate output was correct. Finally, end to end testing to validate the entire workflow should be described. Screenshots and data visualization can be used to demonstrate results.
- Discussion/Conclusion (1 page, 16.6% of grade). Briefly summarize the key conclusion for your end to end pipeline. What, if any, components would you change to improve performance and why?
- Code (16.6% of grade): all python scripts used should be provide. A brief readme to explain each component and how to run the end-to-end pipeline should be provided.

3. Grading Rubric

<table>
<tr>
<td rowspan="2">Introduction (15)</td>
<td rowspan="2">In 1-2 pages describe integration of imaging software and robotics, including key features for software, robot, and system integration</td>
<td>Overview & Rationale (6)
• 6/6 Describe how robotic simulation and image processing are designed for different purposes and how to develop an end-to-end prototype via integration to use advantages of both systems.
• 5/6 Missing description of advantages to software integration.
• 4/6 Missing description of why end-to-end prototype is useful.
• 3/6 Missing discussion of either robotic simulation or image processing.
• 2/6 Missing description of both robotic simulation and image processing.
• 1/6 Only provides discussion of end-to-end pipeline but not the component pieces
• 0/10 No rationale given.</td>
</tr>
<tr>
<td>Imaging System (3)
• 3/3 Describe medical image processing guidance for path planning and scene reconstruction.
• 2/3 Describe medical image processing guidance but either scene reconstruction or path planning is missing.
• 1/5 Image processing is mentioned but no rationale for why this is important.
• 0/5 No discussion of image processing.</td>
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		Robotic System (3) • 3/3 Describe robotic simulation to provide an environment to test robot design and kinematics before hardware implementation • 2/5 Robotic simulation mentioned but either design or kinematics is missing • 1/5 Robotic simulation is mentioned but no rationale given for why this is important • 0/5 No discussion of robotic simulation
		System Integration (3) • 3/3 Describes system integration and a method to achieve it, and corresponding limitations • 2/3 Describes system integration and a method to achieve it but not limitations • 1/3 Mention system integration but does not describe method to achieve it • 0/3 No mention of system integration
Methodology (40)	In 3-5 pages describe how each component works: (a) path planning in 3D slicer, (b) trajectory communication to ROS, (c) robot movement in ROS. Clearly describe how each component is linked together and the flow of information. Diagrams and flow charts are highly recommended	For each component (10 pts per component x3) • 2 pts data inputs • 2 pts data outputs • 6pts data flow within method. • 6 pts for describing how data is transformed between each connection (3 pts for Slicer to IGTLink; 3 pts IGTLINk to ROS) • 4 pts for describing inputs and outputs for the end-to-end pipeline.
Validation (15)	In 3-5 pages describe how each component was tested to validate the results. Appropriate screen shots and visualisations are highly recommended. Please ensure all figures have captions including the component shown and what in the image demonstrates the software is working appropriately	For each component (5 pts per component x 3): • 5/5 validation tests are appropriate, assess edge cases, and all pass as expected. • 4/5 validation tests are appropriate, all pass, but not all edge cases are assessed • 3/5 validation test are appropriate and cover edge cases, but some fail • 2/5 validation tests are appropriate but over half fail • 1/5 validation tests are present but not appropriate for the method • 0/5 no validation is provided
Discussion (25)	In 1 page summarize the key conclusions including algorithm performance, any	• 2 pts describe the algorithm performance • 2 pts linking performance to validation test • 2 pts identifying key weaknesses

	weaknesses, and possible future improvements.	• 2 pts weaknesses linked to validation results • 2 pts identified future improvements.
Code (20)	Components: • 3D Slicer Path Planning • 3D Slicer to ROS communication • ROS Robot Move	**For each component (5 pts per component x 3):** • 5/5 The code runs without error. There is a clear link between the report and code • 4/5 The code runs without error. The link between the report and code is not clear. • 3/5 The code runs with error but all components have been implemented. • 2/5 The code is missing key components. • 1/5 The code is unable to run. • 0/5 No code is provided. System Integration (5) • 2 pts output from path planning transformed to IGTLink correctly • 2 pts IGTLink to ROS data listener correct. • 1 pts for data loading correct.