System design of adaptive image-guided percutaneous needle intervention software using open source components

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Motivation: Adaptive therapies have the potential of improving the quality of intervention by dynamically optimizing the treatment plan during the procedure. The goal of our work was to evaluate how existing open source toolkits, components, architectures, and applications can facilitate research software development for adaptive image guided interventions. We focus on percutaneous needle insertion interventions for biopsy, but the same system can be applied for deployment of therapy.

Workflow for adaptive image-guided interventions: A typical static image-guided intervention workflow consists of pre-operative imaging and planning and intra-operative planning, calibration, planning, targeting (needle insertion), and verification steps. The workflow is almost linear, sometimes the targeting and verification steps are performed multiple times. In adaptive image-guided interventions, the calibration and planning steps are revisited (and adjustments are done if tool or patient motion is detected) before each targeting step. This forms a control loop consisting of the calibration, planning, targeting, and verification steps. *Representation of dynamic data:* We propose to store the dynamically changing data in a hierarchical structure. Each acquired image, model, and the planned target positions are represented as a data node. Spatial relationships between these data nodes are represented by transform nodes. The advantage of this representation is that performing the calibration-planning-targeting-verification cycle requires minimal modifications of the data structure: addition of two new transformation nodes (representing patient and tool motion), the image node of the latest verification image, and update of the planned targets. *Implementation using 3D Slicer:* We evaluated usability of 3D Slicer with a custom MRI-guided robot-assisted prostate biopsy software module (ProstateNav) for implementing adaptive planning on previously acquired clinical data. The goal of the testing was to evaluate if adaptive planning could be used to compensate the effect of unintended patient motion and achieve better targeting accuracy. The data model of 3D Slicer is based on MRML, which made it possible to directly apply the hierarchical data structure described above to represent dynamically changing information. We assumed independent and rigid motions of both the patient and robot. The rigid transformation did not represent accurately all the soft tissue motions that appeared in the image volumes, but gave a reasonable approximation for the prostate motion (the organ of interest, which contained all the targets). During adaptive image-guided interventions, the same objects may appear at varying positions at specific times, and objects can have different expected and actual positions. To present all these information in a comprehendible manner to the clinicians, we implemented the following two simple rules: 1. Display only the relevant data. 2. Display all data in the reference frame of the latest acquired image. Sample screenshot of the planning and verification steps are shown on *Figure 1*.

Conclusion: 3D Slicer architecture allows implementation of adaptive percutaneous intervention software. If patient motion can be assumed to be rigid, then only custom module development is needed. Enhancement of 3D Slicer core is needed for straightforward implementation of non-rigid deformation compensation.

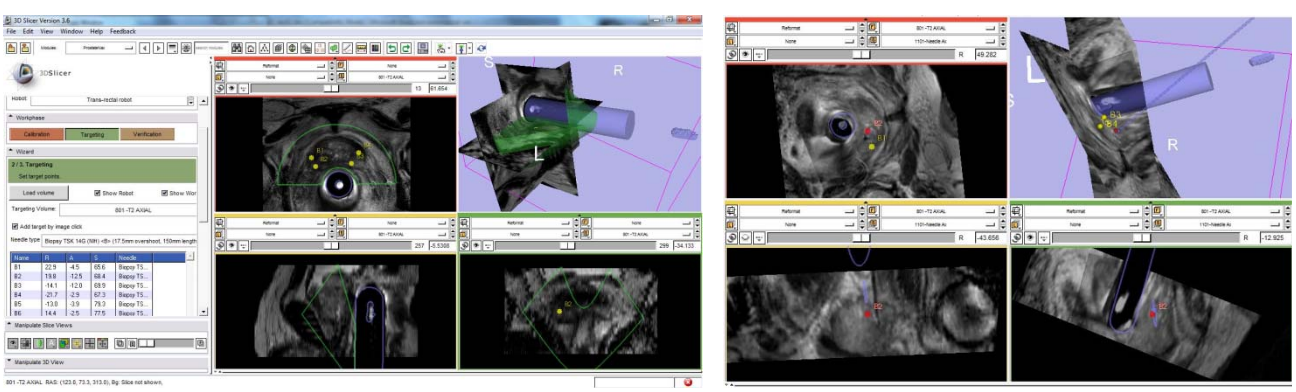

Figure 1. Screenshots of planning and verification steps of the MRI-guided prostate biopsy module in 3D Slicer.