Extensible Real-time MRI Platform for Intraoperative Targeting and Monitoring

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INTRODUCTION

Procedures in interventional neurosurgery include a number of different imaging tasks, including trajectory planning, device aiming, insertion monitoring, treatment monitoring, and post-operative treatment confirmation. Other groups have demonstrated successful approaches to many of these tasks [1-2], yet these solutions were built on platforms that were vendor or task specific and sometimes discontinued or otherwise not publicly available. There is a great need within the MR community for extensible software platforms that can allow rapid development of tools for MR-guided procedures [3-5]. One such platform is based upon the RTHawk system for real-time acquisition and reconstruction and the Vurtigo system for interactive visualization.

We have developed a system on this platform for performing MR-guided and monitored Convection Enhanced Delivery [6] intracerebral infusions. Real-time MR aids in rapid aiming of an MR-visible trajectory guide, then monitoring of the insertion of a rigid catheter and infusion of MR-visible agents. Initial testing of our extensible software application platform in phantoms and *ex vivo* brain tissue has shown targeting accuracy on the order of 1-2 mm.

MATERIALS AND METHODS

This targeted drug infusion system was developed as a set of plugins for the RTHawk and Vurtigo development environment. RTHawk (HeartVista; Palo Alto, CA) is an extensible software platform that permits pulse sequences, acquisition trajectories, and reconstruction techniques to be easily developed, interleaved, and modified in real-time [7], with nearly all scanner-specific programming abstracted away. Reconstruction, user interface, and visualization are written as a customizable pipeline of processing blocks. Vurtigo (Sunnybrook Health Sciences Centre; Toronto, Canada) is an open-source system that simplifies simultaneous display and interaction with multiple 2D and 3D datasets [8]. It is also designed as an extensible platform, with support for user-developed plugins implementing a variety of behaviors. Together, they compose an extensible architecture that simplifies the development of real-time applications (Fig. 1).

The interventional apparatus was a rigid catheter aimed and inserted through the Navigus pivot-point-based aiming system (Medtronics; Minneapolis, MN), which includes a skull-mounted ball-joint pivot base and an MR-visible external trajectory guide. Tests were conducted using a GE Healthcare 1.5 T Signa HDx MRI scanner. Images from a conventional high-resolution 3D baseline scan were loaded into Vurtigo and target and pivot points identified by the user (Fig. 2). Our system then automatically calculated physical scan location for four real-time imaging planes: an "aiming plane" perpendicular to the desired trajectory guide orientation and 35-50 mm above the pivot point; two trajectory-aligned planes parallel to and including the desired needle trajectory; and a "monitoring plane" perpendicular to the trajectory and centered at or slightly above the target point. One or more of these planes can be imaged in real-time using a T_1-weighted GRE sequence that acquires a 20 cm FOV with 0.8 mm resolution in a scan time of 1.4 s per slice.

While receiving real-time feedback on the position of the external trajectory guide on an in-room monitor, the interventionalist moves the guide until it is centered on a colored "aiming point" marker (Fig. 3). The interventionalist then tightens the locking ring and replaces the trajectory guide with the remote introducer assembly. A fused silica catheter is then inserted into the remote introducer and advanced to the indicated depth, while being monitored with real-time MR. Device tip position was assessed using a final conventional high-resolution 3D scan (Fig. 4).

Three phantom tests were conducted, each targeting a 1 mm radius "dimple" on the tip of a nylon machine screw in a water-filled container, with target depths of 80-100 mm, similar to what would be seen in human studies. Two *ex vivo* insertion experiments were performed, targeting selected anatomical structures in an excised non-human primate brain, with target depths of 40-60 mm from the pivot point (20-30 mm into the brain).

RESULTS AND DISCUSSION

Phantom experiments showed radial error of 1.6±0.3 mm, and *ex vivo* experiments showed radial error of 1.6±0.9 mm. As neurosurgeons expect accuracy on the order of 1 mm as offered by conventional stereotactic systems, this must be improved. Significant sources of error are table motion, mechanical play in the joint between the external trajectory guide and the ball socket base, slight curvature of the trajectory guide, and accidental changes in device position due to bumping it while installing the remote introducer assembly. Although scanner-controlled table motion was very consistent, with typical variation on the order of 0.1 mm, the table can be displaced manually up to 0.9 mm without triggering a scan-interrupting fault. The ball socket to trajectory guide joint allows ±0.2 mm of play and the trajectory guides all showed some degree of curvature, with maximum displacements ranging up to ±0.5 mm (measured at a point 60 mm above from the pivot). Displacements at the aiming point are amplified through the "lever" of the insertion mechanism and can lead to radial errors 2-3 times larger at the target point. Based on these findings, we are working on developing improved hardware to eliminate these sources of targeting error.

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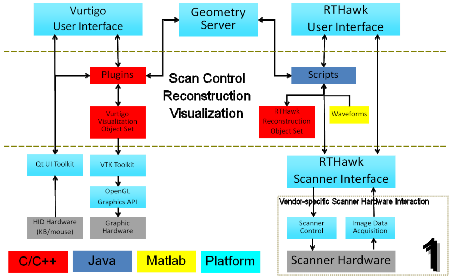

Fig. 1: The platform accelerates development by allowing a focus on scan control, reconstruction, and visualization, while abstracting away hardware interaction and user interface programming.

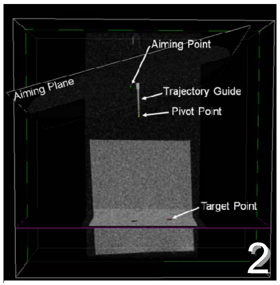

Fig. 2: Target and pivot points are defined for trajectory planning.

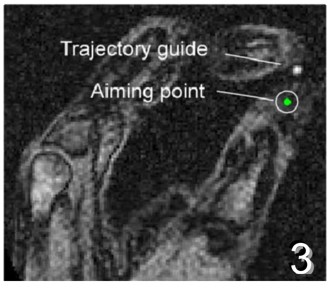

Fig. 3: An aiming point is calculated, then the user moves the trajectory guide to overlay the aiming point.

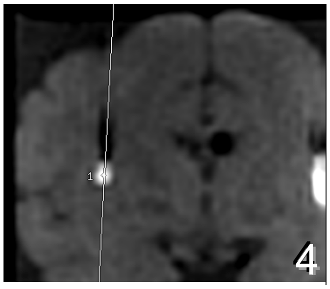

Fig. 4: Catheter placement and infusate delivery is assessed in this high-resolution 3D scan.