Proposal for
Robot Assistance for
Neurosurgery

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Funding History

• Active funding for development of open source software for (medical) robotics:
  – NSF CISST ERC infrastructure
  – ERC Supplement for Surgical Assistant Workstation (with Intuitive Surgical)
  – NSF Major Research Instrumentation (MRI) for sensing, modeling, and manipulation

• ERC provided seed funding for preliminary work in neurosurgery. SPL contributed resources.

• Targeting PAR-07-249 (Collaborations with NCBC): due Jan 17, 2008
Preliminary Work

• Use robot assistance to improve safety of skull base drilling:
  – Define “safe zone” (virtual fixture) in CT
  – Register CT, patient, and robot
  – Robot holds cutting tool
    • Cooperative control: responds to surgeon’s forces
    • Virtual fixtures: prevent excursion outside “safe zone”
Prior Work

• Acrobot Robot for knee surgery
  – Brian Davies, Imperial College, London
• Virtual fixtures for sinus surgery
  – Li & Taylor, JHU
• Other robots for skull base surgery
  – Bumm et al., Germany
  – Federspil et al., Germany
  – NeuRobot (Sim et al.), Singapore
System Architecture

StealthStation

3D Slicer

VF definition

navigation data

calibration registration

Application & Robot Control

Real Time OS (RTAI)

NeuroMate

input force

motion control

surgeon

cooperative control w/ virtual fixture

patient
Cadaver Experiment
Results

- Phantom experiments with foam blocks to measure accuracy
- Cadaver experiments to assess clinical feasibility and accuracy

Table 1: Results of phantom experiments (errors in mm): Dimensional error is positive for overcut (more bone removed).

<table>
<thead>
<tr>
<th>Num</th>
<th>Placement</th>
<th>Dimensional</th>
<th>Depth</th>
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<tr>
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<td>Y</td>
<td>X</td>
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<td>-0.96</td>
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<tr>
<td>Mean</td>
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<td>-0.56</td>
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<tr>
<td>StDev</td>
<td>0.76</td>
<td>0.80</td>
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Issues Encountered

• Stability of Slicer 3.0 IGT code

• Slicer CT coords ≠ Stealthstation CT coords
  – Need rasToIjk matrix from xml file

• Interface between robot and Slicer (SPLOT) negatively affected PC performance

• 2D view does not show tool or VF model
  – Stealthstation showed tool
Issues Encountered

- Created standalone VTK program to simplify VF and remove section to allow cutter access
- Too many screens to look at:
  - Robot, Slicer, Stealthstation, endoscope (sometimes)
- Accuracy could be better (about 1.5 mm)
Proposal Goals (1)

• Preoperative planning
  – Multimodal image fusion (CT, MRI)
    • MRI useful when tool must avoid nerves/vessels that are tethered to skull base
  – Create 3D model of virtual fixture
    • Accounts for cutter radius
    • Simplified for better real-time performance
    • Maybe offset for registration uncertainty?
Proposal Goals (2)

• Intraoperative control
  – Integrate Robot GUI within Slicer
  – Use middleware between Slicer and robot controller (RTOS)
  – Maybe update registration?

• Intraoperative visualization
  – Dynamically construct and display model of area that has been cut
  – Automatically show surgeon “best” view
  – Integrate endoscope video
  – Simple interface via pendant (or foot pedal)
Proposal Goals (3)

• Postoperative validation
  – Perform cadaver experiments
  – Align postoperative and preoperative CT
  – Quantify performance of system
    • Key metric is bone overcut
    • Can use DSC (Dice Similarity Coeff), etc. to compare dynamically constructed cut model to postop CT
Where are we going?

• This technology (constrained control with virtual fixtures) is good for bone.

• Would like to extend to soft tissue (e.g., endoscopic removal of deep brain tumors)
  – Preop virtual fixtures lose relevance
  – Local sensor feedback (OCT, US) can show critical structures around tumor
  – Dynamically construct VF from local sensor feedback?
  – Deform preop VF based on local sensor feedback (including video)?
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