Proposal for Robot Assistance for Neurosurgery

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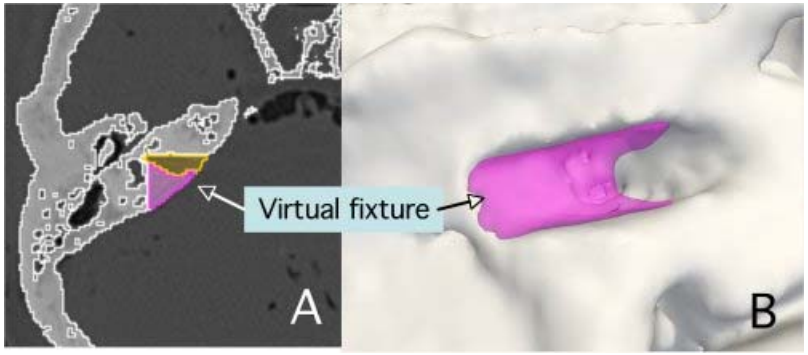
Funding History

- 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”



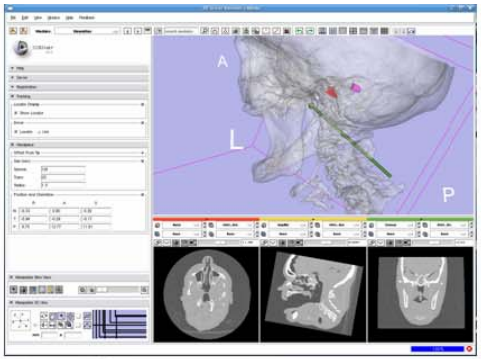
Prior Work

- 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

calibration
registration



3D Slicer

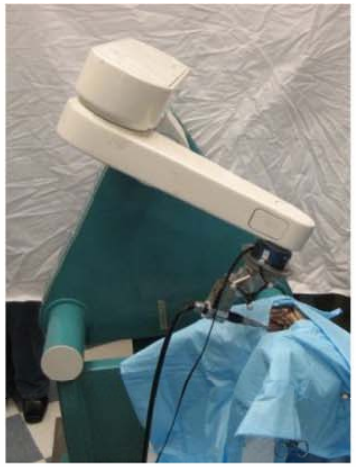
VF definition

navigation
data

Application &
Robot Control

motion
control

input
force



NeuroMate

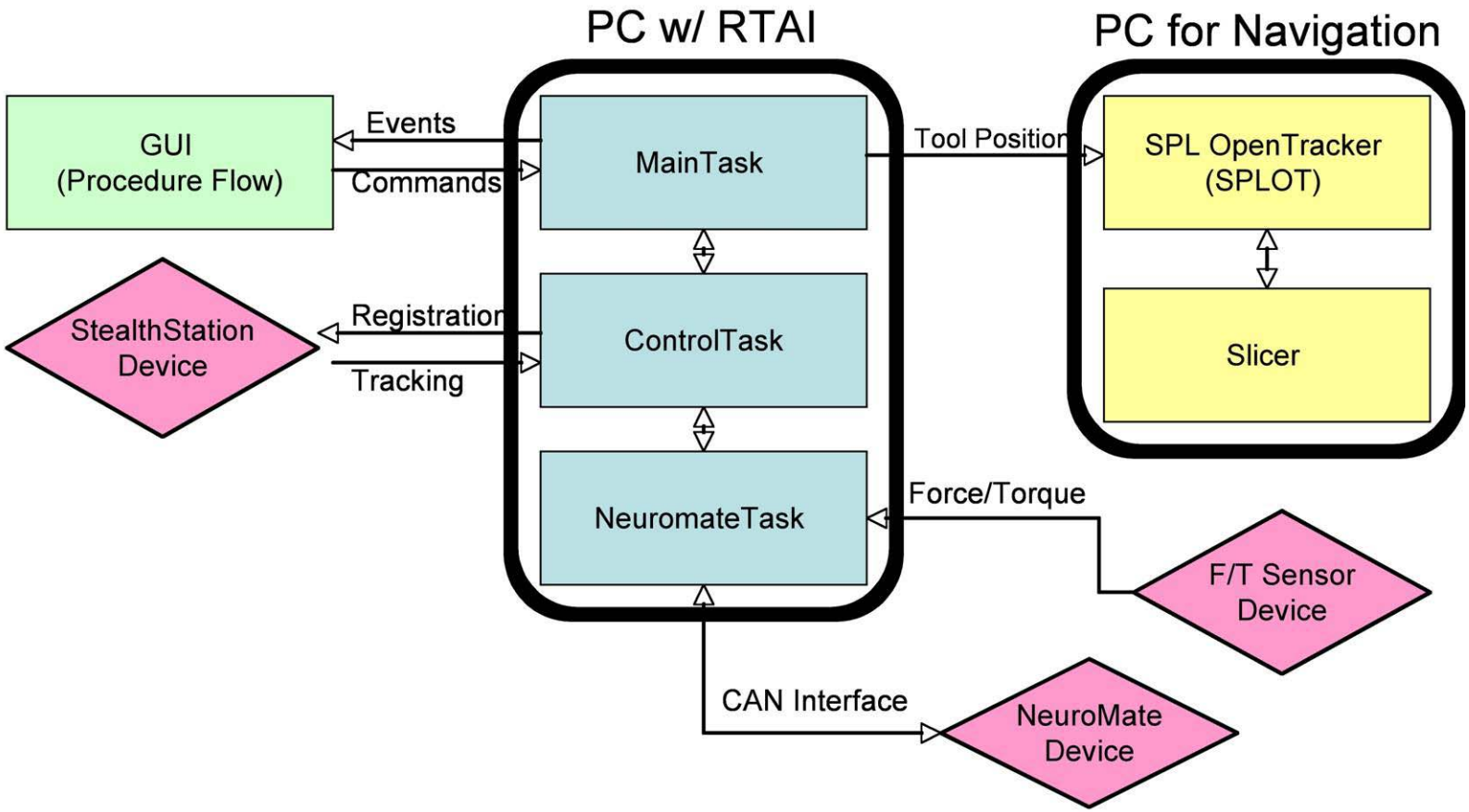
cooperative
control w/
virtual fixture

surgeon

patient

Real Time OS
(RTAI)

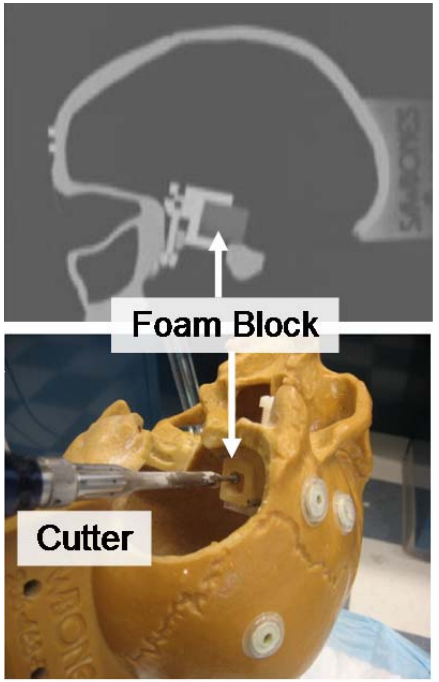
Software Architecture



Cadaver Experiment

Results

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



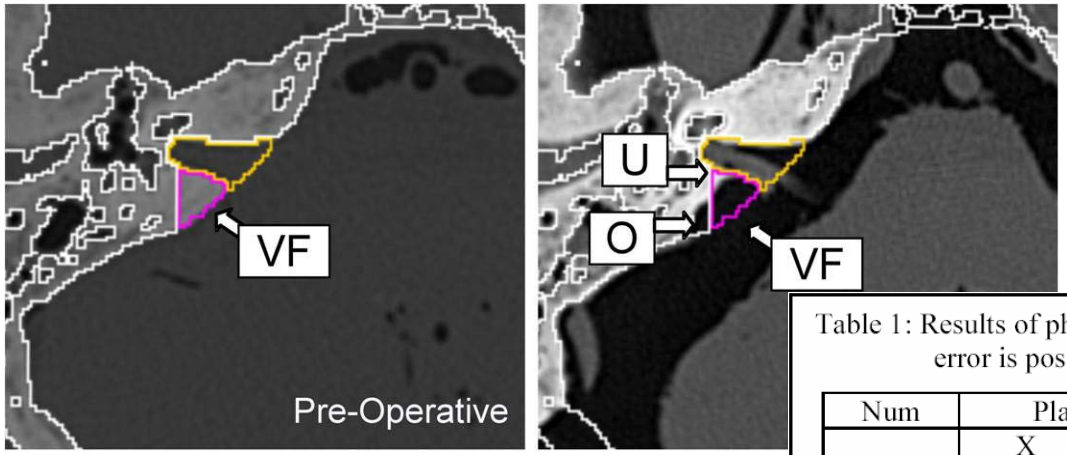


Table 1: Results of phantom experiments (errors in mm); Dimensional error is positive for overcut (more bone removed).

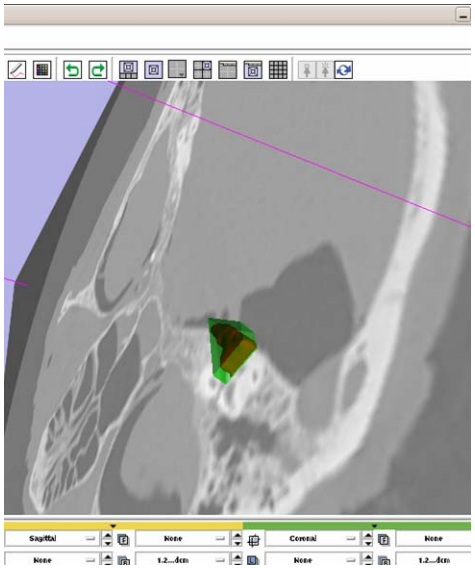
Num	Placement		Dimensional		Depth
	X	Y	X	Y	Z
1	-0.49	-0.96	0.25	0.05	1.19
2	-1.28	-1.11	0.70	0.33	0.51
3	0.44	-0.79	0.99	0.35	1.39
4	-1.04	0.62	0.54	0.10	1.85
Mean	-0.59	-0.56	0.62	0.21	1.23
StDev	0.76	0.80	0.31	0.15	0.56

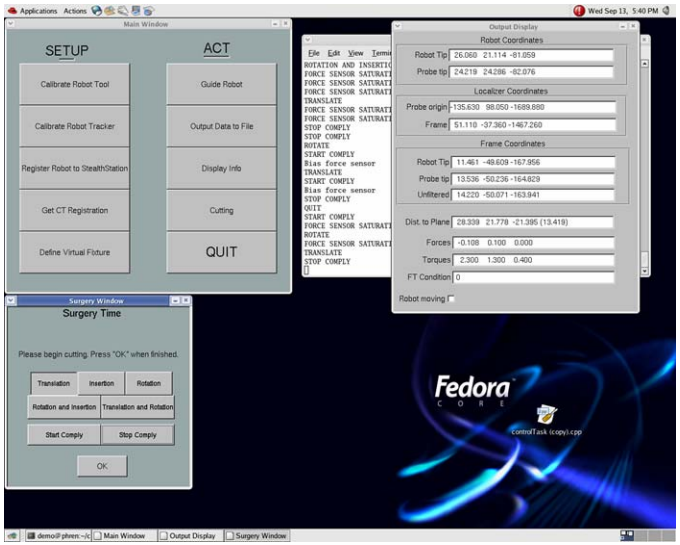
Issues Encountered

- 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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