Integration of CBCT and a Skull Base Drilling Robot

Team member: Hao Dang, Zihan Chen

Mentors: Jeff Siewerdsen, Peter Kazanzides

Course mentor: Russ Taylor

JOHNS HOPKINS UNIVERSITY

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Outline

- Background & Motivation
- Project Goals
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Background

Neurosurgery has many challenges:

- Complex anatomy
- Complex bone removal for tumor resection
- Critical nature of adjacent neural and vascular structures

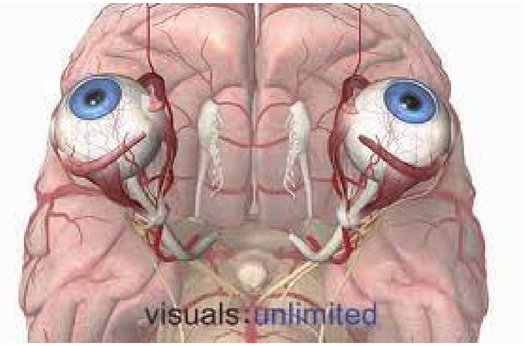


Fig1

- For example, acoustic neuroma surgery
  - drill the posterior wall of the internal auditory canal (ICA)
  - critical structures
    - semicircular canals
    - the cochlea
    - facial nerve

  are within millimeters.

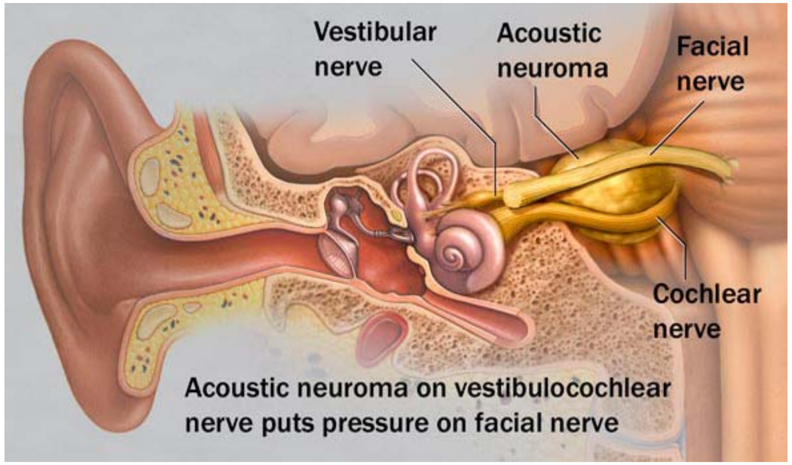


Fig2

Fig1: http://fotosa.ru/ru/stock/search.asp?ID=2113807&anchor=2, Fig2: http://www.gammaknifeonline.in/gamma_knife_for_acoustic_neuroma

Image guided robots
—well suited to neurosurgery

Basis:

- Static nature of human skull
- Locally fixed segments of the spine

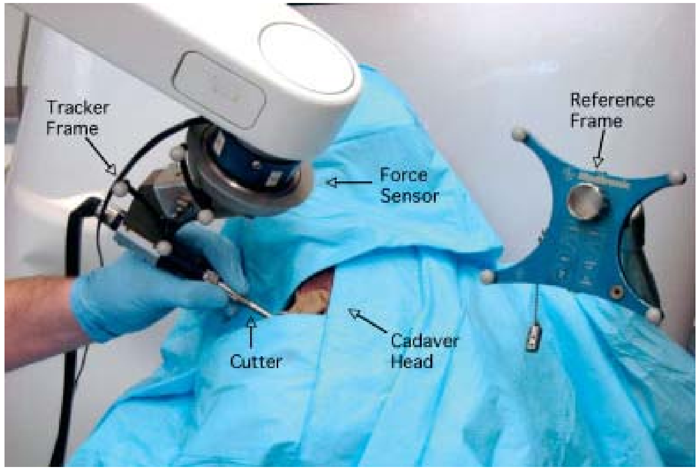
Advantages:

- Precise intra-operative guidance ➔ limits of human vision
- Mechanical assistance ➔ limits of fatigue and dexterity
- Virtual fixture ➔ outcut, damage critical structure

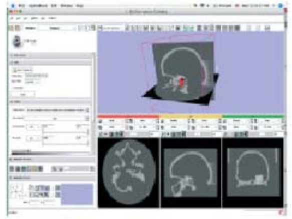
Skull base drilling robot system

System overview

StealthStation navigation system

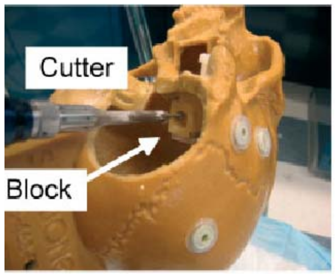


NeuroMate Robot

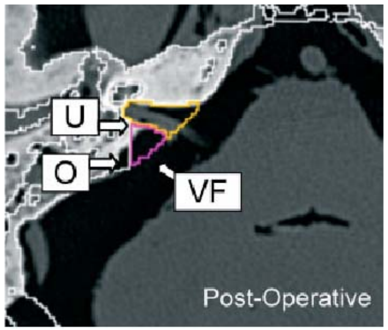


3D Slicer
Virtual fixture

Performance



Foam Skull:
Average placement error—0.6 mm
Average dimensional error—0.6 mm



Cadaver head:
Outcut—1–2 mm, with maximum about 3 mm.
Uncut—not critical

Images are from An integrated system for planning, navigation and robotic assistance for skull base surgery.Tian Xia, Peter Kazanzides, etc*. The International Journal of Medical Robotics and Computer Assisted Surgery, Volume 4, Issue 4, pages 321–330, December 2008

Motivation

- Note that the pre-opera registration residual error
  - Stealth reference frame to the Stealth CT frame <1 mm
  - reference frame to the Robot world frame <0.5 mm

- Why starts with good registration but ends with larger outcut?
  - Virtual fixture is not updated intraoperatively
    - Defined on pre-CT
    - Deformation exists
      - head pose(in pre-CT and surgery)
      - bone drill out
      - soft tissue
    - Solution: intra-opera images
    - Navigation system also prefers
  - Other reasons
    - robot kinematic error
    - skull motion…

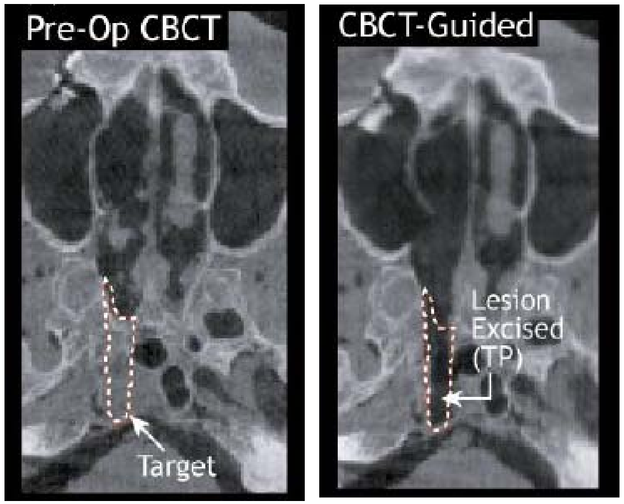


Fig1

Fig1: Siewerdsen JH, Moseley DJ, Burch S., Bisland S, Bogaards A, Wilson BA, and Jaffray DA, "Volume CT with a flat-panel detector on a mobile, isocentric C-arm: Pre-clinical investigation in guidance of minimally invasive surgery," Med. Phys. 32(1): 241-254 (2005).

Project Goals

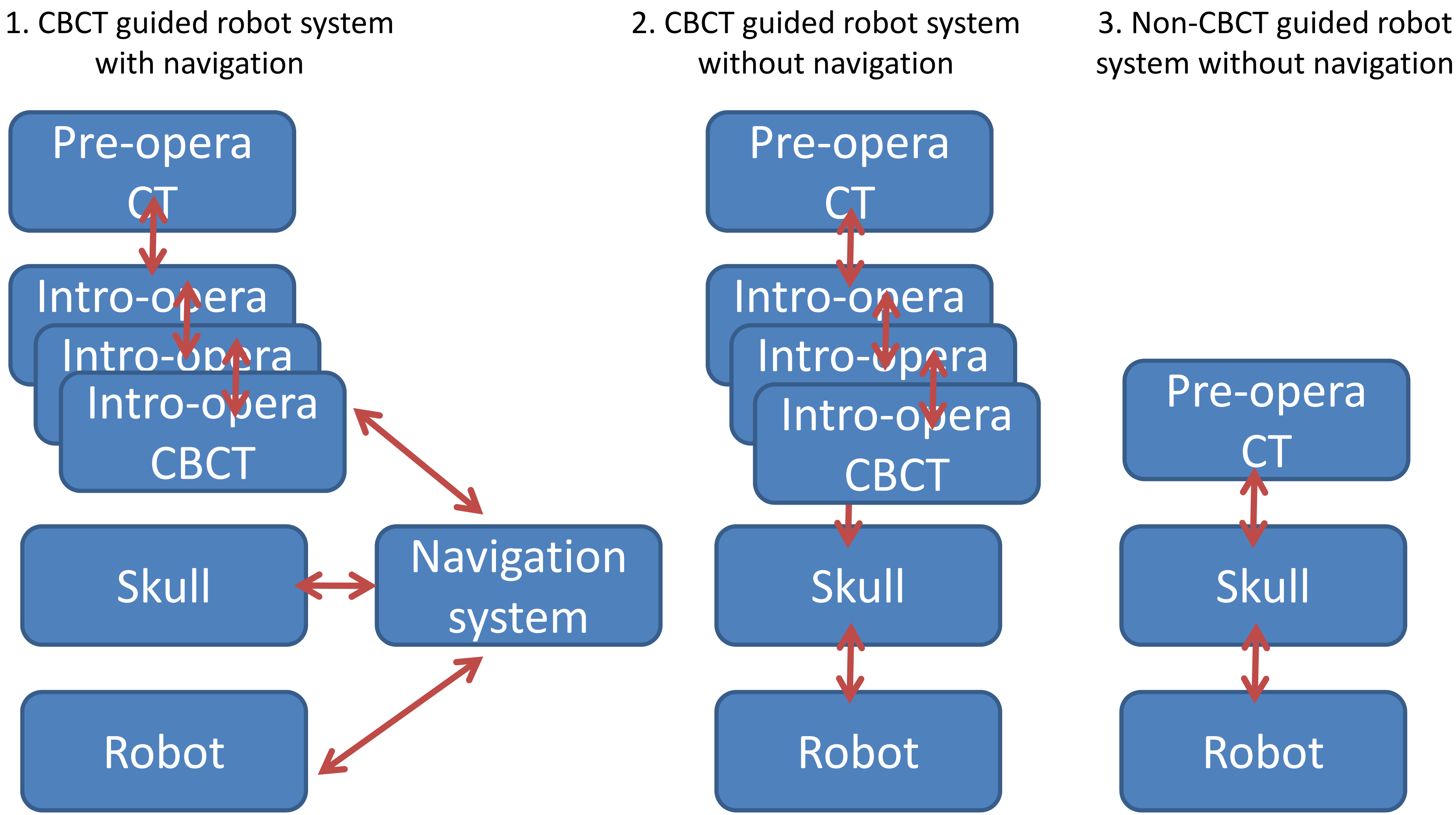
Integrate C-arm CBCT into robotic system

- Transform pre-defined and updated virtual fixture to robot world frame via
  - Pre-CT to CBCT images registration
  - CBCT images to the NeuroMate robot registration
- Examine performance of the integrated system
  - Two forms of phantom experiments (Target-pointing and Foam drilling) and hopefully cadaver experiments
  - Compare two versions of integrated systems (with and without navigation) with previous non-CBCT system

Prototype CBCT imaging system in Prof. Siewerdsen's lab (with Siemens)
✓Based on a mobile isocentric C-arm
✓sub-mm 3D spatial resolution
✓soft tissue visibility
✓Typical acquisition and reconstruction time are ~60s and ~20s respectively

The image above is from *Focus Group Meeting High-Performance 3D C-Arm Imaging* Poster

Technical Approach



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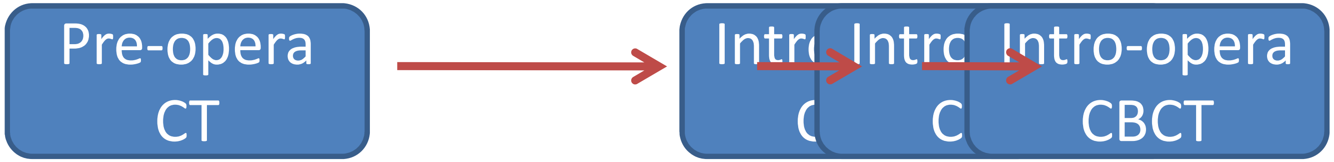


- Take the first CBCT Images after patient’s head is fixed
- Segment fiducial locations in CBCT and CT images
- Paired-point registration(Min)

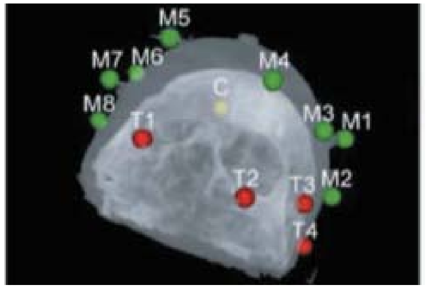


Fig1 fiducials in CBCT

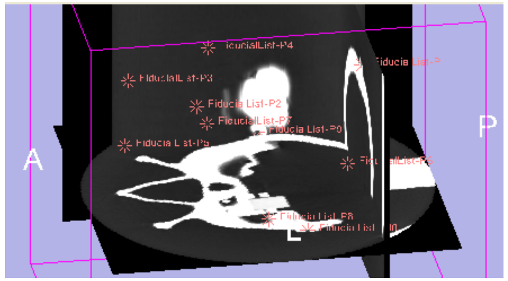
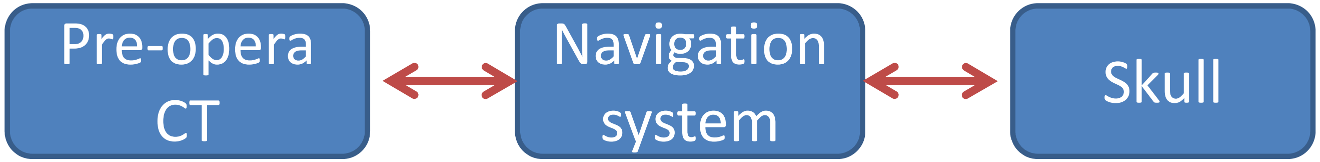


Fig2 fiducials in CT

- Register following CBCT images with former ones
- Image-based deformable registration (max)
  - Difference between images is usually deformable
  - e.g. Demons deformable registration with intensity matching

Fig1: Automatic image-to-world registration based on x-ray projections in cone-beam CT-guided interventions. Hamming NM, Daly MJ, Irish JC, Siewerdsen JH. Med Phys. 2009 May;36(5):1800-12.



- Point passive probe to fiducials on skull within navigation system FOV

Fig1

- Paired-point registration with fiducial locations in CT frame

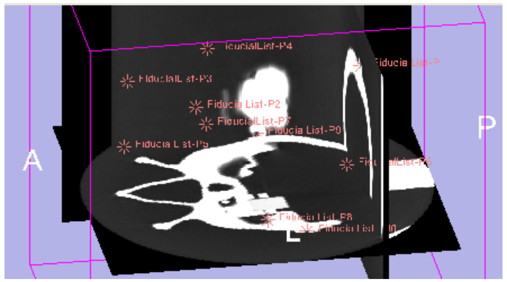
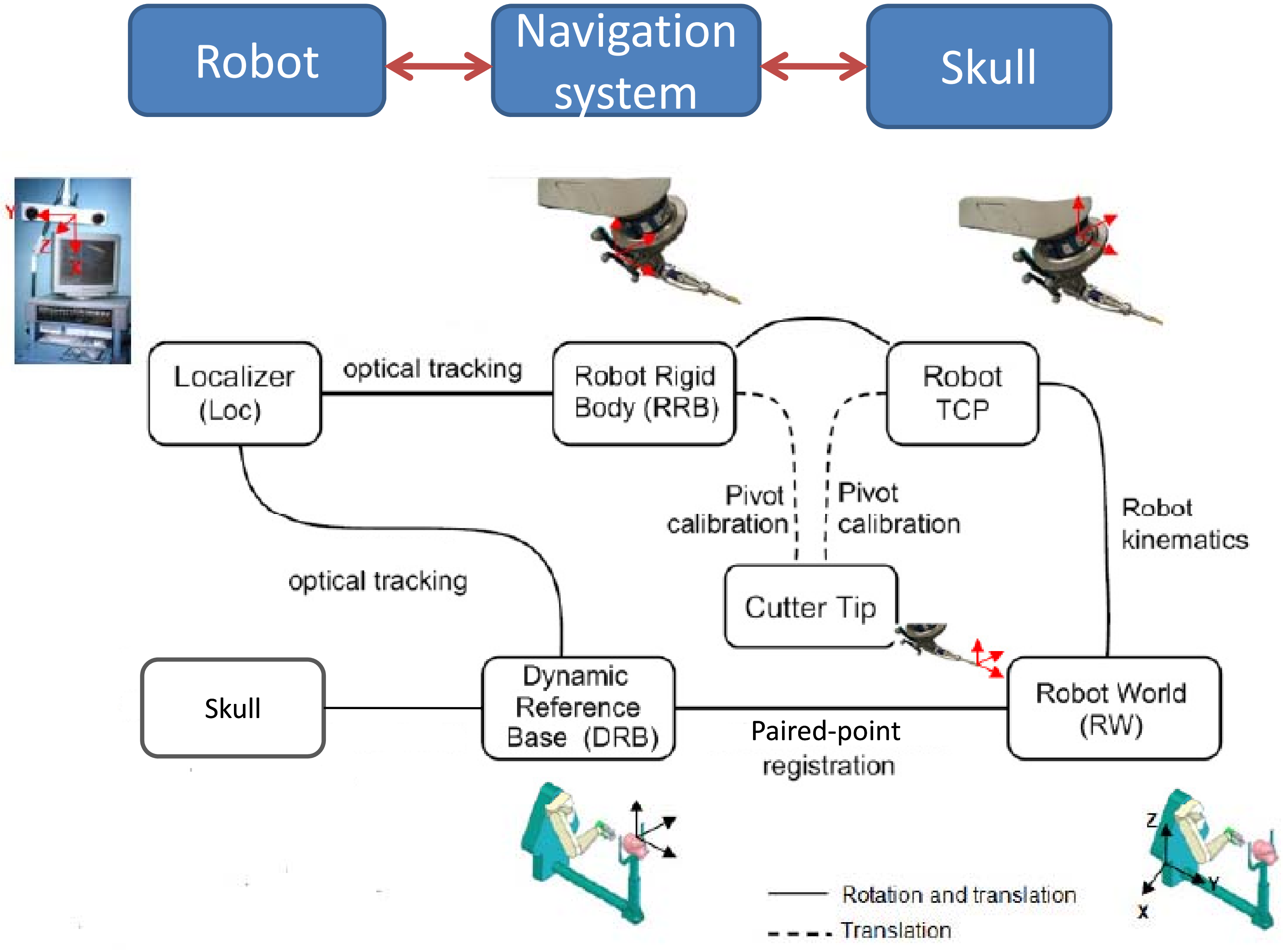


Fig2

- Repeat until reaching acceptable registration error

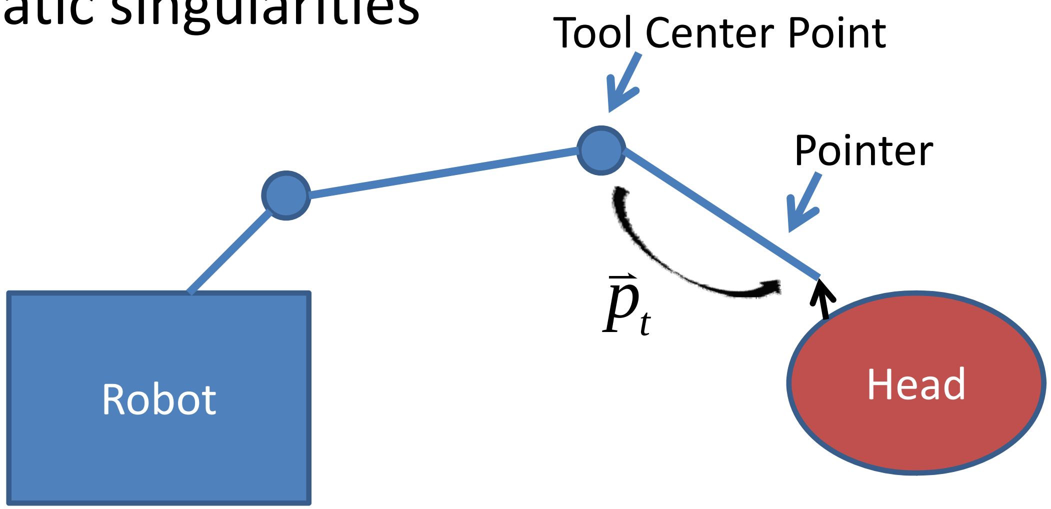
Fig1: http://www.ndigital.com/medical/polarisfamily-4markerprobe.php



The image above is modified Fig2 in Accuracy Improvement of a Neurosurgical Robot System.HaideggerT., Tian Xia, Kazanzides, P.Biomedical Robotics and Biomechatronics, 2008. 2nd IEEE RAS & EMBS International Conference on, pages 836 – 841, 27 January 2009

2

- Do pivot calibration, $\vec{p}_t$
- Guide robot pointer directly to fiducials on skull in cooperative mode
- Register fiducial locations in robot world frame to locations in CBCT frame
- Carefully position the robot with respect to the head to avoid the kinematic singularities



Deliverables 1

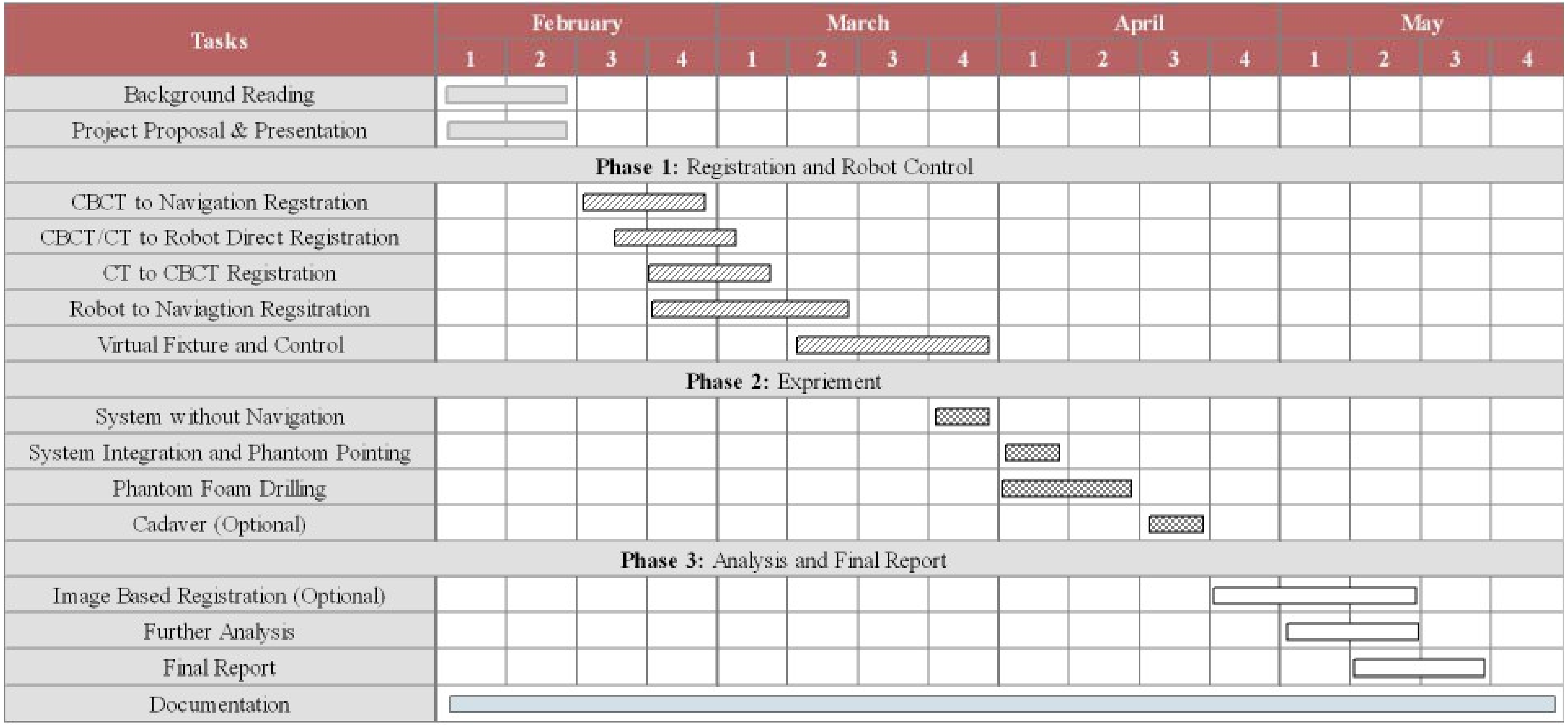
- Minimum
  - Fusion of intro-opera CBCT and pre-opera CT images by fiducial-based rigid registration
  - Complete transformation flow including robot, skull, CBCT images along with navigation system
  - Target-pointing experiment on phantom using CBCT-Guided skull base drilling robot system(CBR system) with navigation

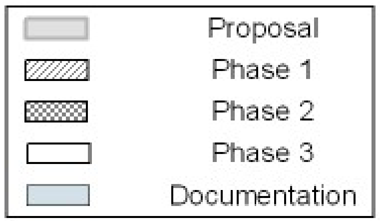
Deliverables 2

- Expected
  - Foam-drilling experiment on phantom using CGR system with navigation
  - Transformation flow including robot, skull, CBCT images without navigation
  - Parallel phantom experiments using two CGR systems and previous non-CBCT system. Compare results.
- Maximum
  - Imaged-based CBCT to CT registration framework
  - Cadaver experiment using CGR system and comparison of results with Phantom studies

Timeline

Project Timeline: Integration of CBCT and a Skull Base Drilling Robot Hao Dang, Zihan Chen





Key Dates	
02/22/2011	Presentation
03/27/2011	Finish Phase 1
04/15/2011	Phantom Foam Drilling
05/19/2011	Final Poster

Dependencies

No.	Dependencies	State	Date	
1	Access to NeuroMate® Robot	100%	N/A	Got access to mock room
2	Move robot to Med Sch	20%	03/20/2011	Further discussion needed
3	Access to CBCT and MISTC	100%	N/A	N/A
4	Radiation traingin & badge	50%	02/24/2011	Hao OK, Zihan working on it
5	Phantom	100%	N/A	Red Skull in Jeff's lab
6	Cadaver & Neurosurgeo	20%	TBD	Need assess after phase 2. Got support from Jeff
7	Bio hazard training	20%	03/20	Online training

Budget: Rental fee of a truck to move robot to medical school. ~$50.Prof. Peter will support.

Management Plan

- Weekly meet with Prof. Peter in Hackerman Hall and Prof. Jeff in Traylor Research Building separately.
- Monthly meet with Prof. Peter and Prof. Jeff together. Place TBD.
- Present plan, checkpoint and final results, receive feedback from Prof. Taylor and the class.
- 15 hours per person for programming/experiments/ discussion every week.
- Access the viability of Phase 2 when Phase 1 is finished.

Responsibilities

Phase I	
CBCT to Navigation Registration	Hao Dang
CBCT/CT to Robot Direct Registration	Zihan Chen
CT to CBCT Registration	Hao Dang
Robot to Navigation Registration	Hao Dang, Zihan Chen
Virtual Fixture and Control	Zihan Chen
Phase II	
System without Navigation	Zihan Chen
System Integration and Phantom Pointing	Hao Dang, Zihan Chen
Phantom Foam Drilling	Hao Dang, Zihan Chen
Cadaver (Optional)	Hao Dang
Phase III	
Image based Registration (Optional)	Hao Dang, Zihan Chen
Further Analysis	Hao Dang, Zihan Chen
Final Report	Hao Dang, Zihan Chen
Documentation	Hao Dang, Zihan Chen

Reading List

Robotic system

1. Accuracy Improvement of a Neurosurgical Robot System.HaideggerT., Tian Xia, Kazanzides, P.Biomedical Robotics and Biomechatronics, 2008. 2nd IEEE RAS & EMBS International Conference on, pages 836 – 841, 27 January 2009
2. An integrated system for planning, navigation and robotic assistance for skull base surgery.Tian Xia, Clint Baird, George Jallo, Kathryn Hayes, Nobuyuki Nakajima, Nobuhiko Hata, Peter Kazanzides*. The International Journal of Medical Robotics and Computer Assisted Surgery, Volume 4, Issue 4, pages 321–330, December 2008

C-Arm Cone Bean CT

1. Siewerdsen JH, Daly MJ, Chan H, Nithiananthan S, Hamming N, Brock KK, and Irish JC, "High-performance intraoperative cone-beam CT on a mobile C-arm: An integrated system for guidance of head and neck surgery," Proc. SPIE Visualization and Image-Guided Procedures Vol. 7261: 72610J-1 – 72610J-8 (2009).
2. Nithiananthan S, Brock KK, Daly MJ, Chan H, Irish JC, and Siewerdsen JH, "Demons deformable registration for cone-beam CT guidance: Registration or pre- and intra-operative images," Proc. SPIE Visualization and Image-Guided Procedures, Vol. 7265: 72650L-1:7 (2010).
3. Bachar G, Barker E, Chan H, Daly MJ, Nithiananthan S, Vescan A, Irish JC, and Siewerdsen JH, "Visualization of anterior skull base defects with intraoperative cone-beam CT," Head and Neck 32(4): 504-512 (2010).
4. Daly MJ, Siewerdsen JH, Cho YB, Jaffray DA, and Irish JC, "Geometric calibration of a cone-beam CT-capable mobile C-arm," Med. Phys. 35(5): 2124-2136 (2008).
5. Daly MJ, Siewerdsen JH, Moseley DJ, Jaffray DA, and Irish JC, "Cone-beam CT for image-guided head and neck surgery: Assessment of dose and image quality using a C-arm prototype," Med. Phys. 33(10): 3767-3780 (2006).

Q & A