Prototyping clinical applications with PLUS and SlicerIGT

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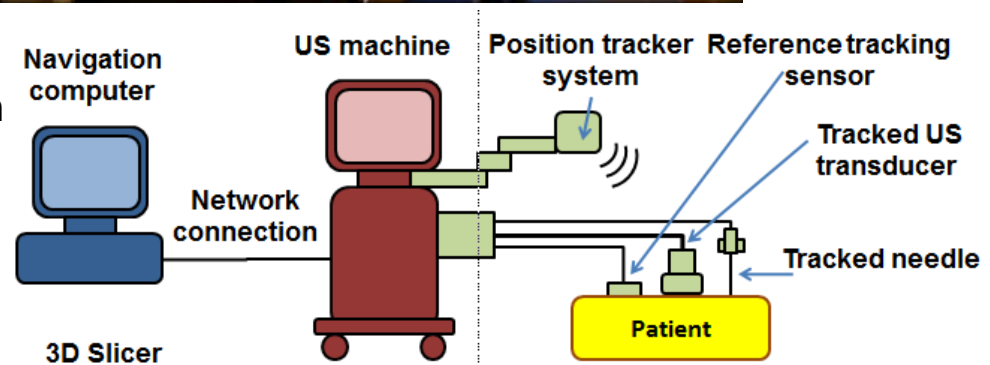|	
PLUS	http://www.plustoolkit.org
SlicerIGT	http://www.slicerigt.org
Perk Lab	http://perk.cs.queensu.ca

Tracked ultrasound navigation

Problem:
- Increasingly popular, but difficult to learn
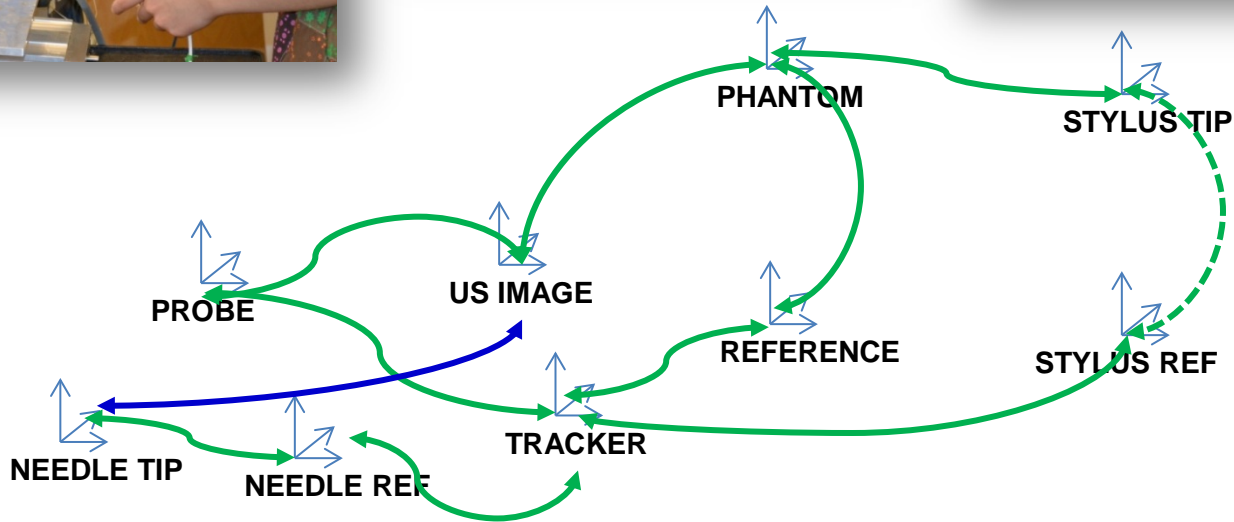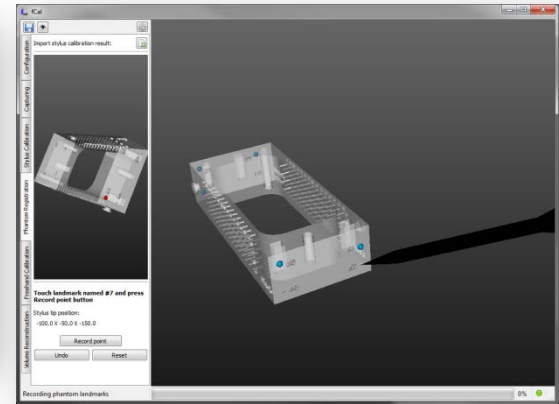- Demands substantial engineering effort

Our Approach:
- Platform for prototyping applications
- Predictable performance
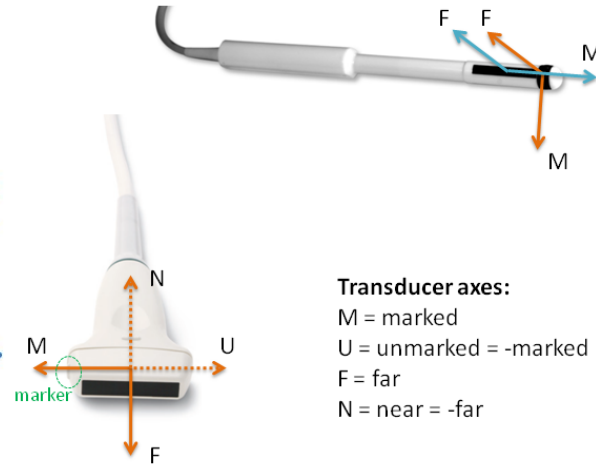- Invariant to the clinical application

Navigation computer

US machine

Position tracker system

Reference tracking sensor

Tracked US transducer
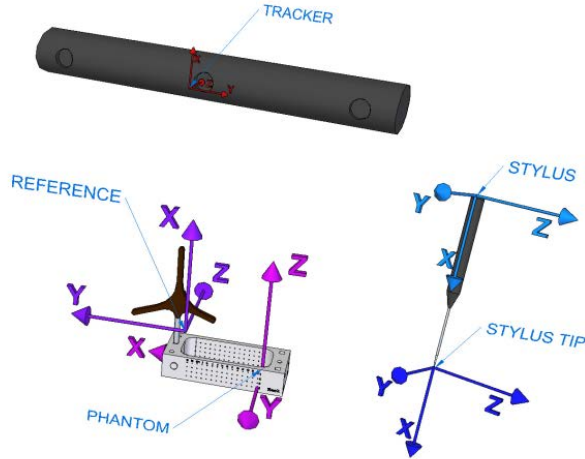
Network connection
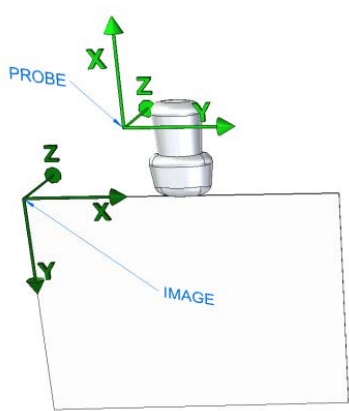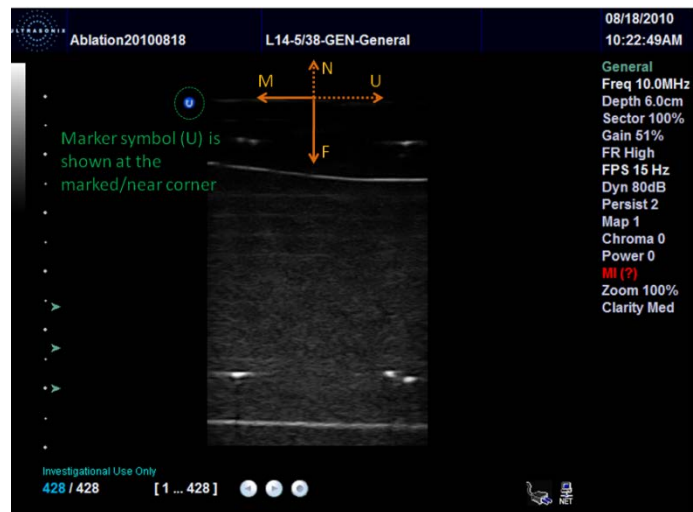
Tracked needle

3D Slicer
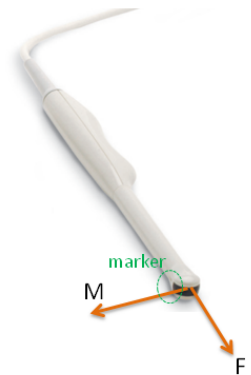
Patient

Calibration

Compute the US IMAGE to NEEDLE TIP transform

Explosion of chances for error

Transducer axes:
M = marked
U = unmarked = -marked
F = far
N = near = -far

Marker symbol (U) is shown at the marked/near corner

Data acquisition - tracking

- **Ascension EM tracker**

- **NDI Aurora, Polaris, and Certus optical and electromagnetic trackers**

- **Claron MicronTracker optical tracker**

- **Brachy steppers (CMS Accuseed, Burdette Medical systems, CIVCO)**

- **PhidgetSpatial inertial measurement device**

- **CHRobotics inertial measurement device**

- **3dConnexion SpaceNavigator 3D mouse**

- **OpenIGTLink (for BrainLab, Siemens MRI scanners, and other compatible devices)**

- **Software devices: file source, US simulator**
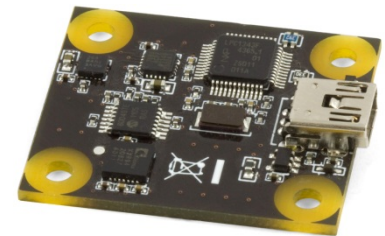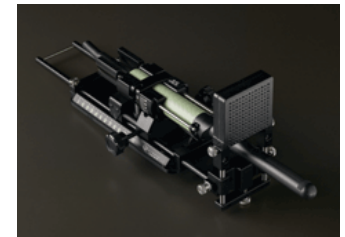
Data acquisition - imaging

- **Ultrasonix: B-mode & RF (through research interface)**

- **BK ProFocus: B-mode & RF (through research interface)**

- **ImagingControl framegrabbers**

- **Epiphan framegrabbers**

- **Video for Windows devices**

- **OpenIGTLink (for MUSiiC, Siemens MRI scanners, and other compatible devices)**

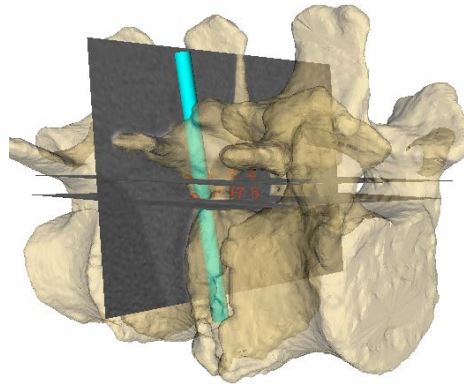- **Other software devices: file source, US simulator**

Guidance, visualization and planning
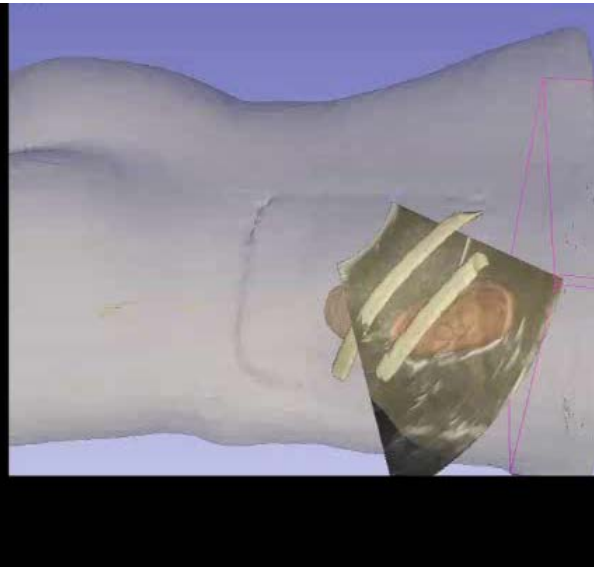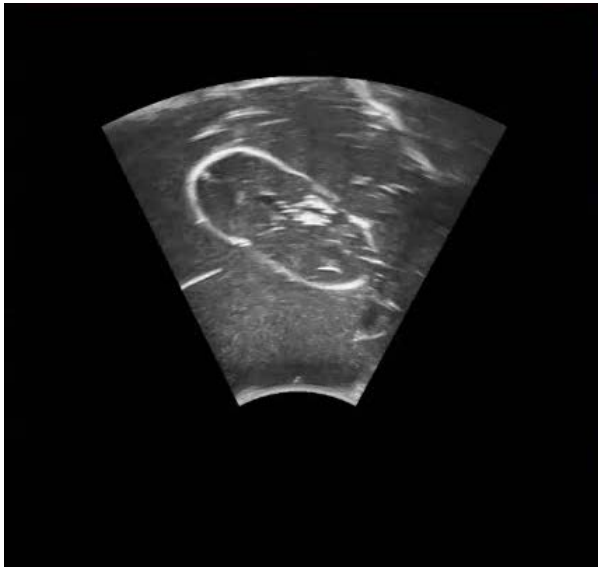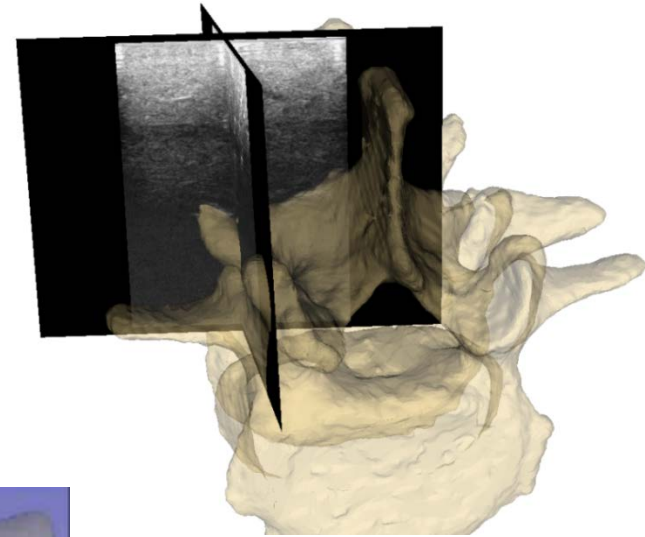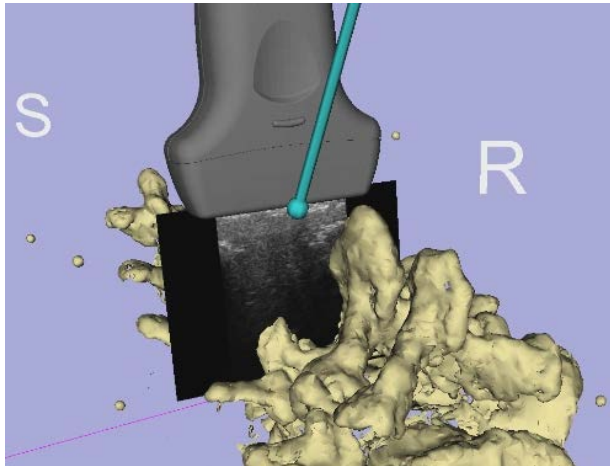
3D Slicer
www.slicer.org

Images and video by Tamas Ungi, MD, PhD

Laboratory for Percutaneous Surgery (The Perk Lab) – Copyright © Queen's University, 2013

SlicerIGT layout

www.slicerigt.org

Navigation computer

US machine

Position tracker system

Reference tracking sensor

Tracked US transducer

Network connection

Tracked needle

Patient

3D Slicer

| SlicerIGT |
| Visualization |
| Registration |
| OpenIGTLink |

PLUS software layer

Synchronization	Tracker SDK
Calibration	
OpenIGTLink	Imaging SDK

Tracking hardware

Imaging hardware

Detailed architecture

SlicerIGT

Perk Tutor

| Live ultrasound | ... | Transform recorder |

ProstateNav

SlicerRT

| DICOM-RT import | ... | Dose comparison |

3D Slicer

3D Slicer extension manager

| Registration | Segmentation | ... | Visualization |

OpenIGTLink

VTK, ITK, CTK, QT, DCMTK, ...

PLUS

Calibration, volume reconstruction, ...

OpenIGTLink

| Video interface | Tracker interface |

software

hardware

| Ultrasound / video | Tracker system | MRI scanner | Robots, needle guides |

Custom phantoms

www.slicerigt.org
www.plustoolkit.org

PLUS feature summary

Main concepts

- Hardware abstraction: use exactly the same software w/ any hardware device
- Documentation: document and share everything, specifications, user guides, tutorials, tips & tricks, file formats, CAD models, etc.
- User & developer support: forum, email, remote desktop, house calls
- Quality assurance: testing, issue tracking, releases

Software functions

- Data acquisition from imaging and tracking devices (real, simulated, playback from recording) from any number of devices, synchronized
- Automatic spatial and temporal calibration methods
- Recording to memory / file
- Live streaming to 3D Slicer (or other compatible app, via OpenIGTLink)
- Remote control of streaming, recording, volume reconstruction functions from 3D Slicer (or other compatible app, via OpenIGTLink)
- RF data processing: brightness conversion, scan conversion
- Real-time Ultrasound simulation from segmented CT, MRI, etc. images
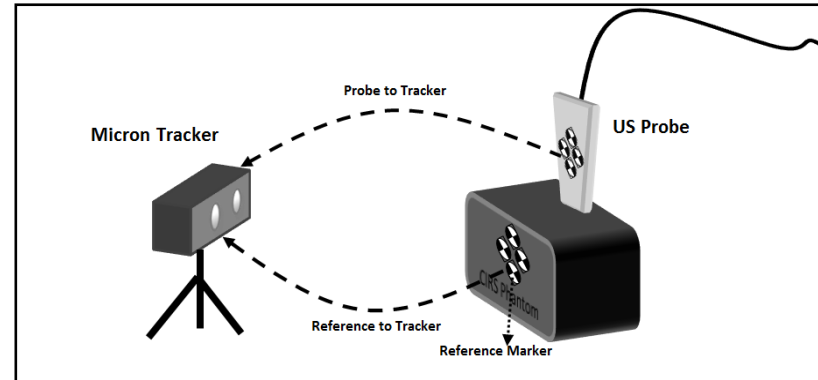- Volume reconstruction: real-time, with optional hole-filling

PLUS visitor stats

	Today	Estimate	Yesterday	7 Days	Week avg	30 Days	12 Months
Page views	0	0	0	31	5	369	5882
IP hosts	0	0	0	23	3	255	1428
Unique visitors	0	0	0	25	4	259	1572
Unique sessions	0	0	0	26	4	305	4136
Return visitors	0	0	0	3	0	106	718
Bounce	0	0	0	20	3	149	710
Bounce Rate	0.0%	0.0%	0.0%	87.0%	60.2%	58.4%	49.7%
Page views per visitor	0.0	0.0	0.0	1.2	0.8	1.4	3.7
Sessions per visitor	0.0	0.0	0.0	1.0	0.7	1.2	2.6
Visitors per IP host	0.0	0.0	0.0	1.1	0.7	1.0	1.1

Public interventional US database

- Public database US images of an abdominal Phantom acquired at different image acquisition parameters.

- The database contains tracking information of the transducer in addition to the 2D ultrasound image slices.

- PLUS gathers temporal and spatial calibration of the US and tracker, and captures the metaIO images in a format that records both the US image and the transducer position and orientation data.


Kitware: Vikas Revanna Shivaprabhu, Andinet Enquobahrie, Zach Mullen, Stephen Aylward

Prostate cancer interventions

BWH, UBC, and Queen's

- Integration of multi-parametric MRI with interventional TRUS for augmented display, tissue characterization and guidance.

- PLUS: acquisition of rotation-tracked RF TRUS and ultrasound volume reconstruction

- Distance transform applied to gland contours; distance maps were registered non-rigidly using BRAINS module of 3D Slicer.

- Volume image acquisition in n>10 MR/US registration & fusion display in n=1 prostate brachytherapy.
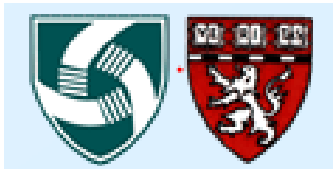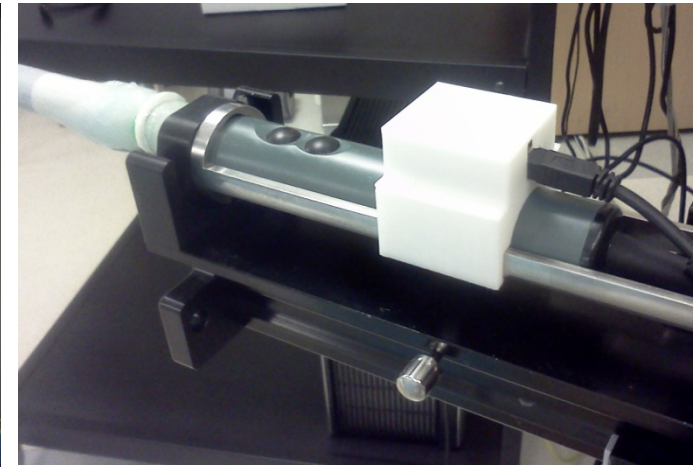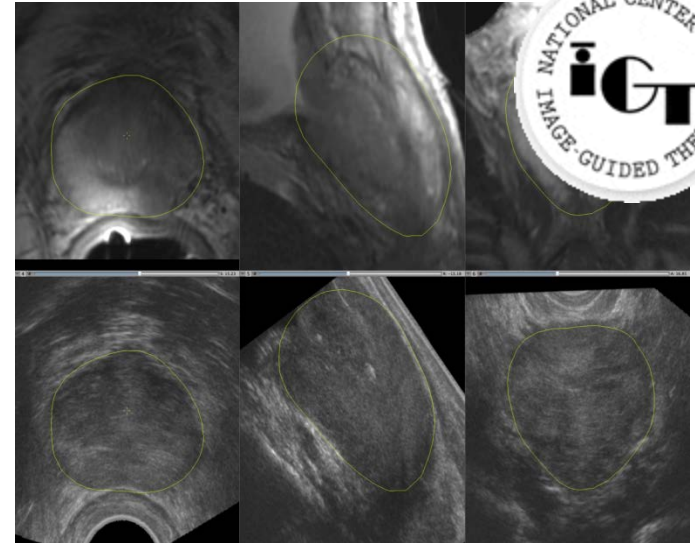
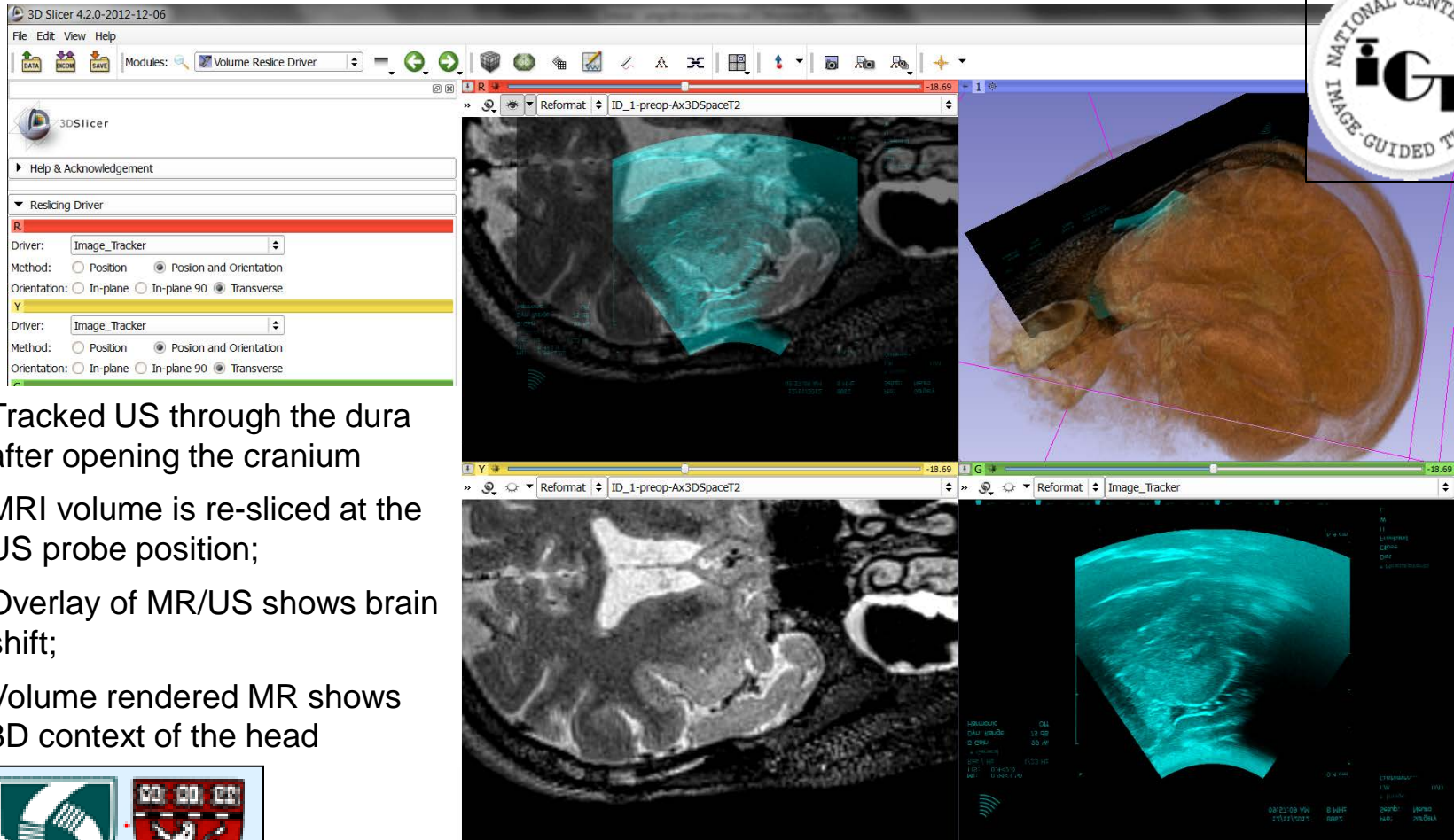**BWH Rad: Fedorov, Kapur, Song Wells, Tempany; BWH Radonc: Neubauer Sugar, Nguyen; BK Medical: Robert Owen (R01 CA111288, PI Tempany).**
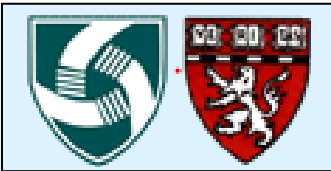
Brain surgery

- Tracked US through the dura after opening the cranium

- MRI volume is re-sliced at the US probe position;

- Overlay of MR/US shows brain shift;

- Volume rendered MR shows 3D context of the head

Brigham and Women's Hospital: PI Wells and Aylward, Neurosurgeon Alexandra Golby, NIH Grant R01CA138419 on Image registration for ultrasound-based neurosurgical navigation
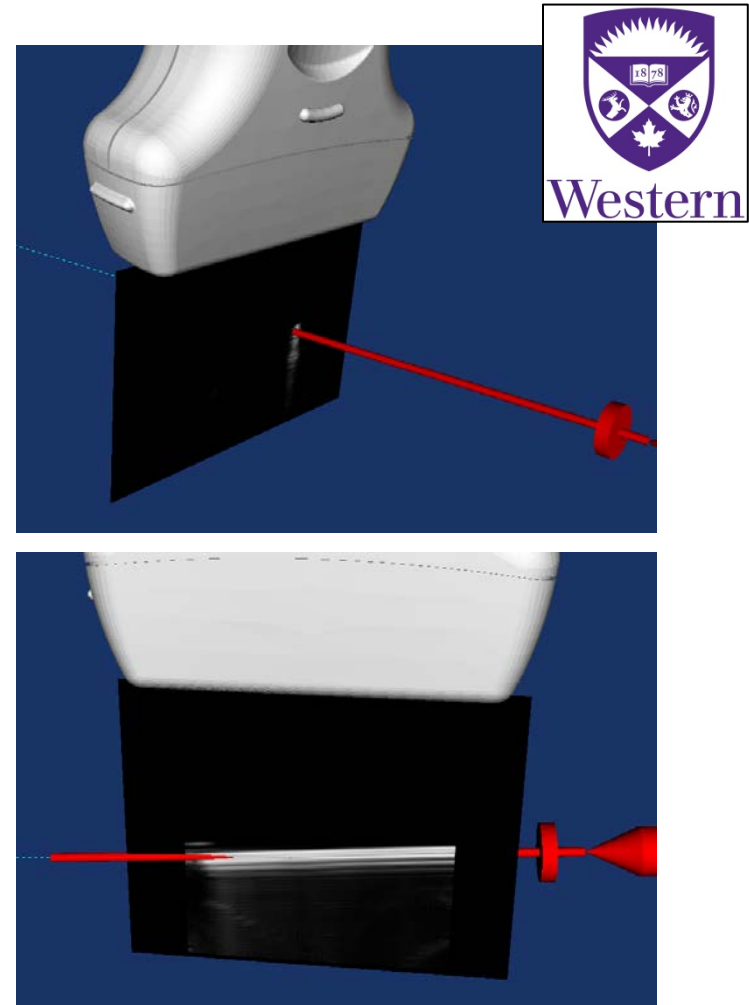
Laboratory for Percutaneous Surgery (The Perk Lab) – Copyright © Queen's University, 2013

Central-line needle guidance

- US-guided, elecromagnetically eagnetic-tracked central venous needle insertion system

- PLUS is used for calibrating the ultrasound probe at various depths

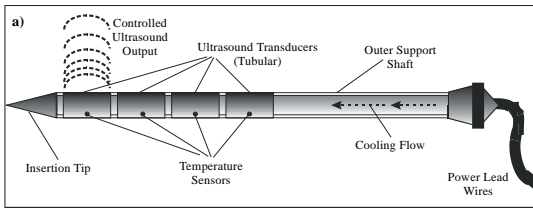- **Obtained Health Canada Approval**, human trial is scheduled to begin shortly

Robarts Research Institute: Elvis Chen, Terry Peters, *et al.*

Interstitial HIFU liver ablation

- PLUS is used for tracked ultrasound data collection
- Prototyping of a commercial guidance system
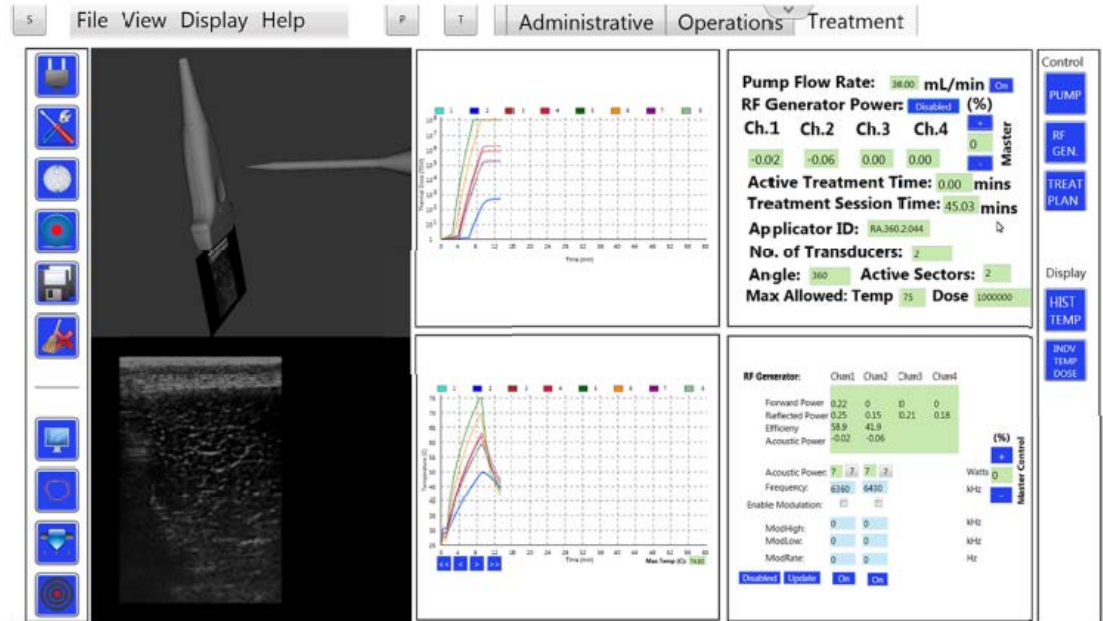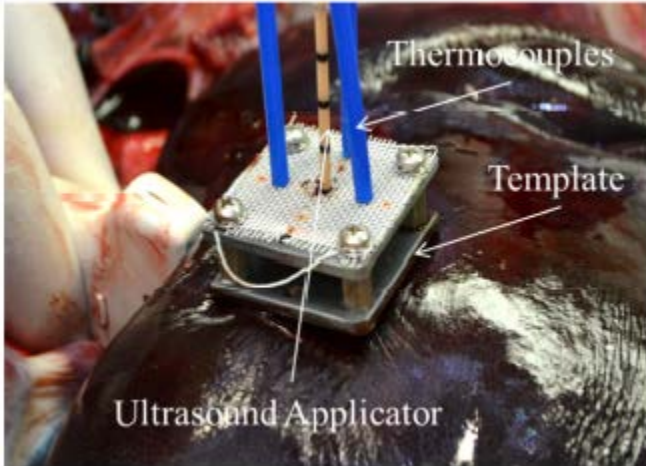
Ghoshal *et al.*, SPIE Medical Imaging, 2013

Acoustic MedSystems, Inc. (Savoy, IL, USA);
Dept. of Animal Sciences, University of Illinois (Urbana, IL, USA);
Dept. of Radiation Oncology, University of California (San Francisco, CA, USA)

Spinal interventions

US-guided Spinal Interventions

- Uses PLUS applications *fCal* and *PlusServer*

- Records tracked US images, reconstructs US volumes

- Needle guidance using the built 3D model and live US

- Serves registration of CT-atlas to tracked US
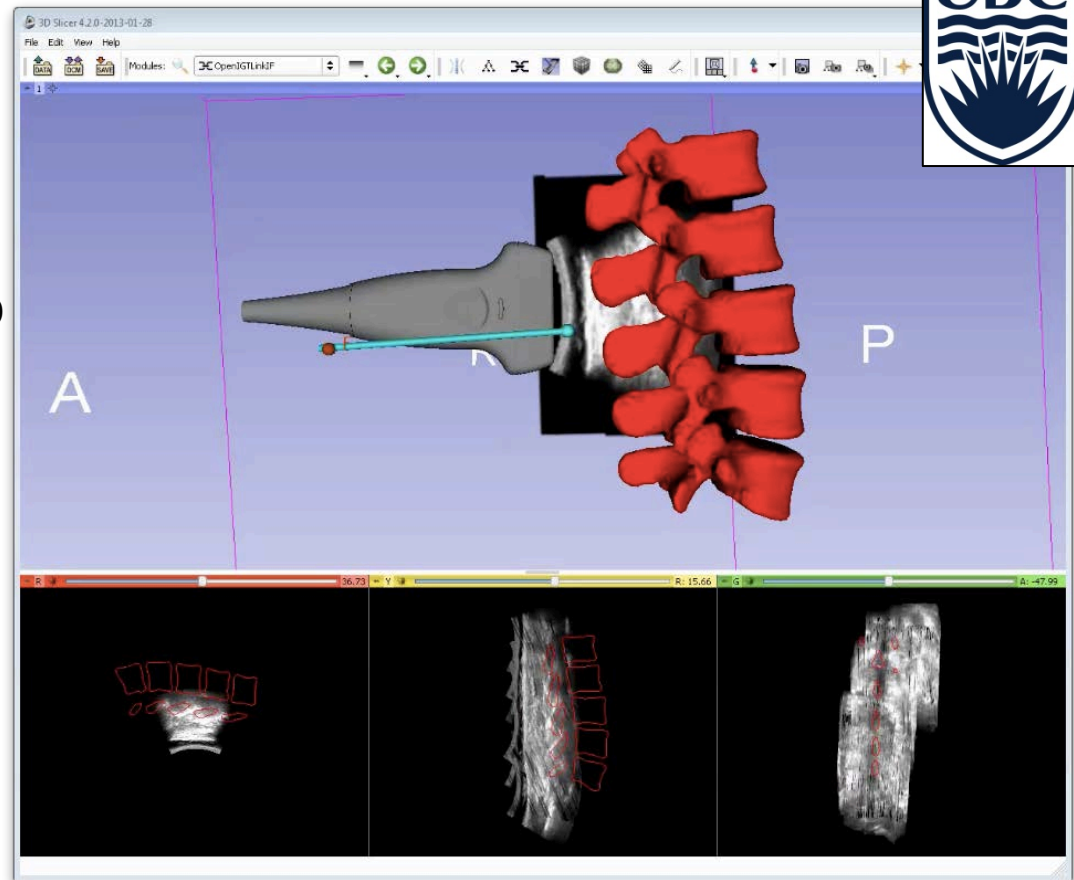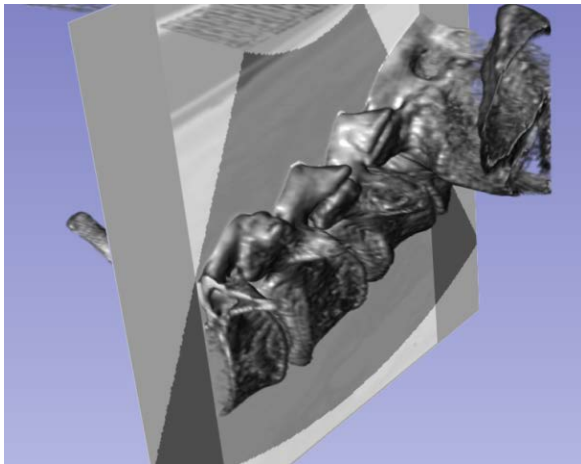
UBC: P. Abolmaesumi, R. Rohling, A. Rasoulian, S. Sojoudi, I. Hacihaloglu; Queen's: P. Mousavi, S. Nagpal , T. Ungi.

Perk Tutor training platform

- Simulated training on phantoms
- Quantitate skill acquisition and retention
- Performance metrics
- Open source software and hardware platform

Ungi *et al.*, IEEE Trans Biomed Eng, 2012
Moult *et al.*, IJCARS, 2013

Typical delivery times
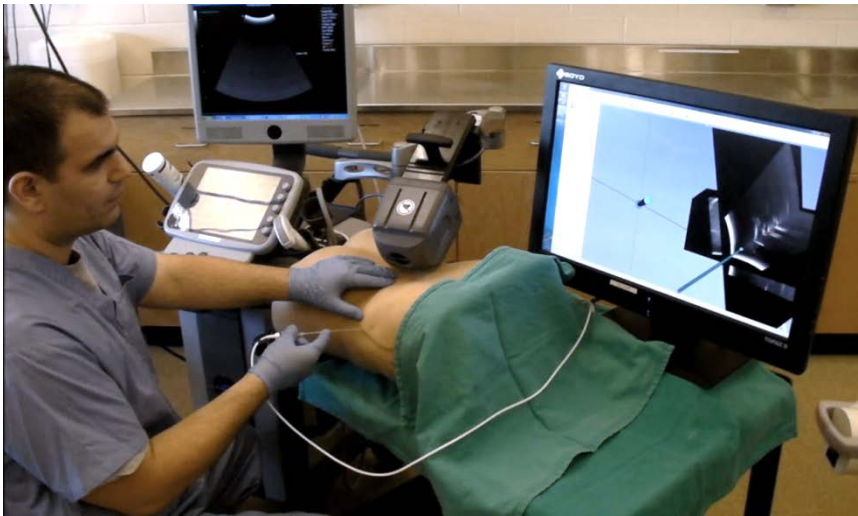

Idea / first contact   2 weeks   4 weeks   6 weeks   8 weeks   10 weeks   12 weeks
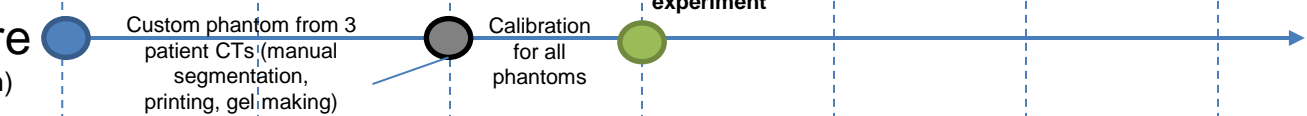
Generic tracked US
(no new devices, SlicerIGT expert team)

First phantom experiment

Hardware setup (1 day)
Calibration (1 day)
Slicer scene setup (1 day)

Queen's spine puncture
(custom phantom, SlicerIGT expert team)

Custom phantom from 3 patient CTs (manual segmentation, printing, gel making)

Calibration for all phantoms

First phantom experiment

Queen's nephrostomy
(new phantom, SlicerIGT expert team)

Ordering phantom

First phantom experiment

Phantom imaging, hardware setup, scene setup (1 day)

BWH prostate biopsy
(new imaging device, first project with PLUS)

adding BK ultrasound as an imaging device

testing, optimization

First patient case

2012 June   2012 July   2012 September
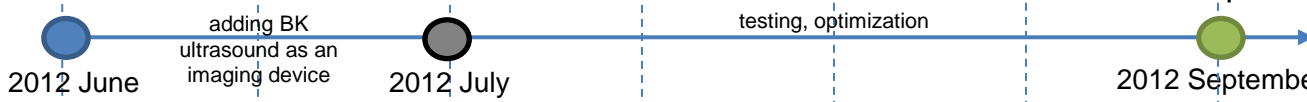
BWH brain surgery
(new tracking device, some experience with PLUS)

adding BrainLab as a tracker device, system setup, calibration

First patient case

2012 Nov   2012 Dec

Start   Intermediate step   First patient/phantom case

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Take-home message

No platform

- Each application is developed from scratch for each problem/procedure/device
- Major work to implement new features
- Huge waste of time/money/effort overall.

On platform

- Core functions are already implemented
- Many advanced algorithms are available
- New modules developed for specific needs
- Larger initial learning investment, but minimal wasted effort overall.

O Me! O Life!

"…

The question, O me! so sad, recurring—What good amid these, O me, O life?

Answer.

That you are here—that life exists, and identity;

That the powerful play goes on, and you will contribute a verse."

Walt Whitman (1819 – 1892)

The PLUS team

Andras Lasso, PhD – lead software architect

Tamas Ungi, MD, PhD – systems developer

Csaba Pinter, Msc – systems developer

Tomi Heffter, MSc – systems developer

Adam Rankin, MSc – systems developer

PLUS   http://www.plustoolkit.org

SlicerIGT   http://www.slicerigt.org

Perk Lab   http://perk.cs.queensu.ca

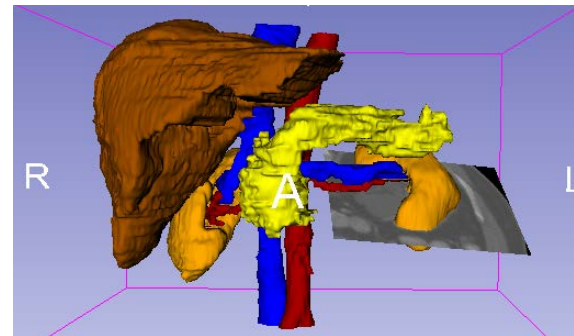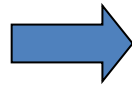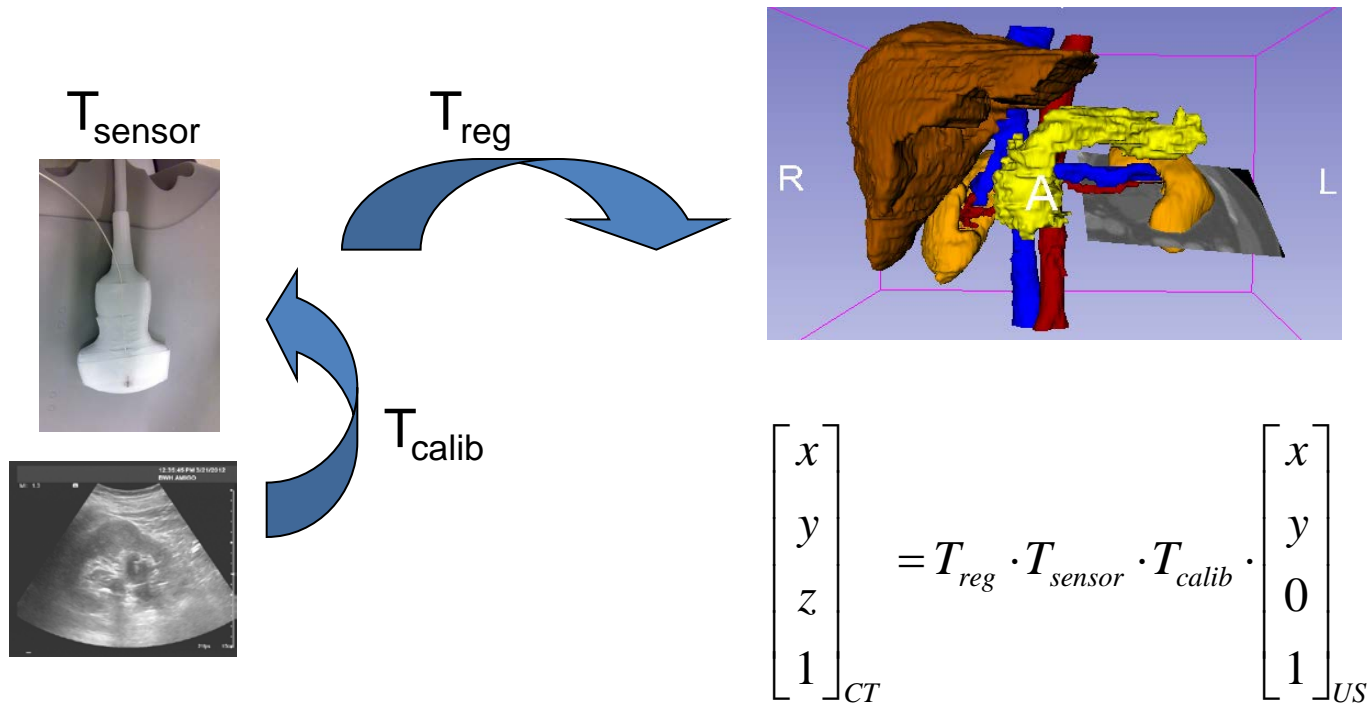# Appendix

Navigation in abdominal surgery

- *Navigation in abdominal surgery*
  - Unidad de Medicina y Cirugía Experimental, Hospital General Universitario Gregorio Marañón, Madrid, Spain
  - Surgical Planning Laboratory, Brigham and Women's Hospital, Boston, USA

- Navigation using 3D models (3D Slicer, http://www.slicer.org)
  - Actual scenario provided by Transcutaneus Ultrasound imaging

- 3D models obtained from a pre-operative CT image

Navigation in abdominal surgery

T_{sensor}

T_{reg}

T_{calib}

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{CT} = T_{reg} \cdot T_{sensor} \cdot T_{calib} \cdot \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{US}$$

Registration (Treg)?

Navigation in abdominal surgery

- **Transcutaneus US-CT Registration:**
  - Image US (3D) – Image CT (3D) registration
  - Create 3D US with *Plus software* (Queen's University)
    - Volume Reconstructor
      https://www.assembla.com/spaces/plus/wiki/Volume_Reconstruction
    - MHA file with US images and US probe position (EM tracking)