Multi-modal imaging, model-based tracking, and mixed reality visualization for orthopaedic surgery

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Conventional Method for Orthopaedic Surgery

- Clinical problem: Bone fracture
- From open surgery to nowadays minimally invasive surgery (MIS)
- MIS resolution: Insert K-wire and screw to fixate the fracture ***relying on X-Ray***
  - ✔ Faster and better recovery
  - ✔ Less blood loss
  - ✔ Avoidance of damages to surrounding tissues
  - ✗ More difficult surgical task
  - ✗ Less intuitive targeting with 2D projections
  - ✗ Often undergo multiple failure attempts
  - ✗ High X-Ray usages
  - ✗ Surgical team frustration

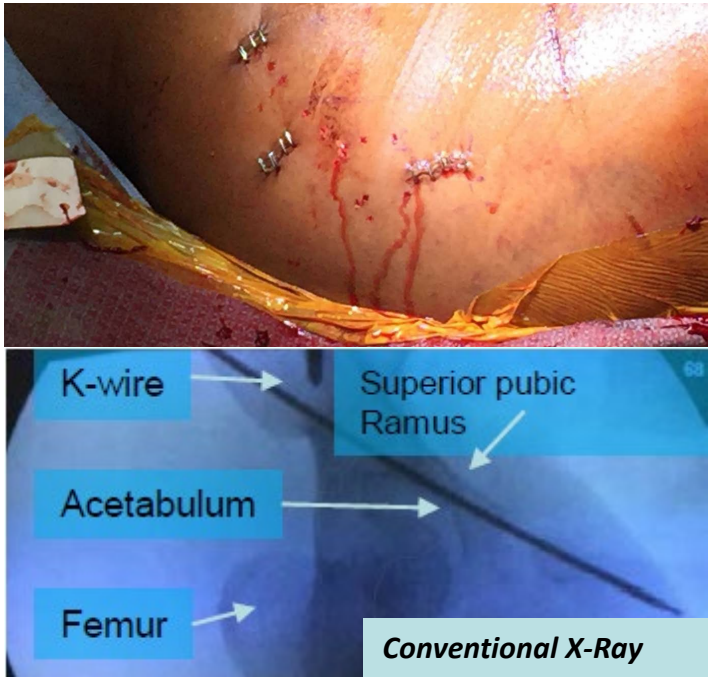
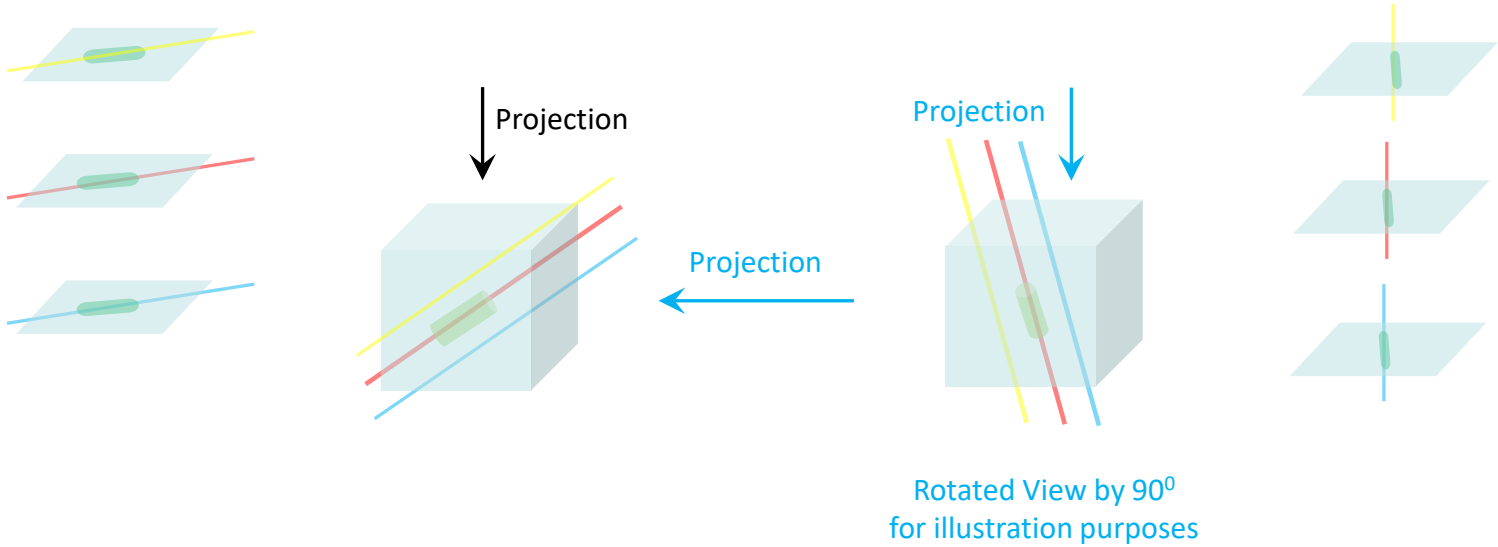


Image Source: [1]

[1] M. Fischer, B. Fuerst, S.C. Lee, J. Fotouhi, S. Habert, S. Weidert, E. Euler, G. Osgood, N. Navab, "Preclinical usability study of multiple augmented reality concepts for K-wire placement". In: International Journal of Computer Assisted Radiology and Surgery, June 2016, Volume 11, Issue 6, pp 1007-1014

Main Challenge in Orthopaedic Surgery

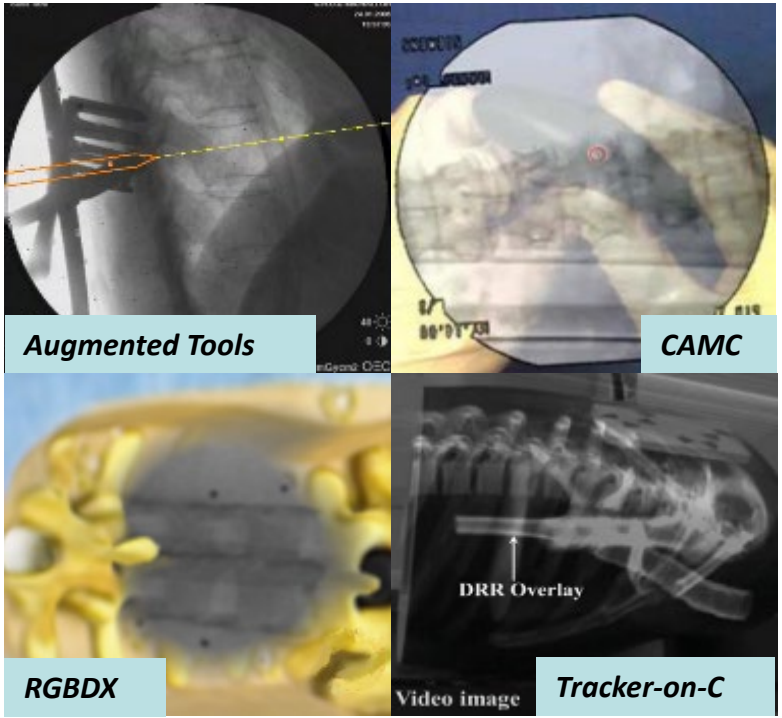
- Not enough information in a single ***2D X-Ray for the targeting in 3D***
- Need to back and forth to verify in two orthogonal views



State-of-the-art

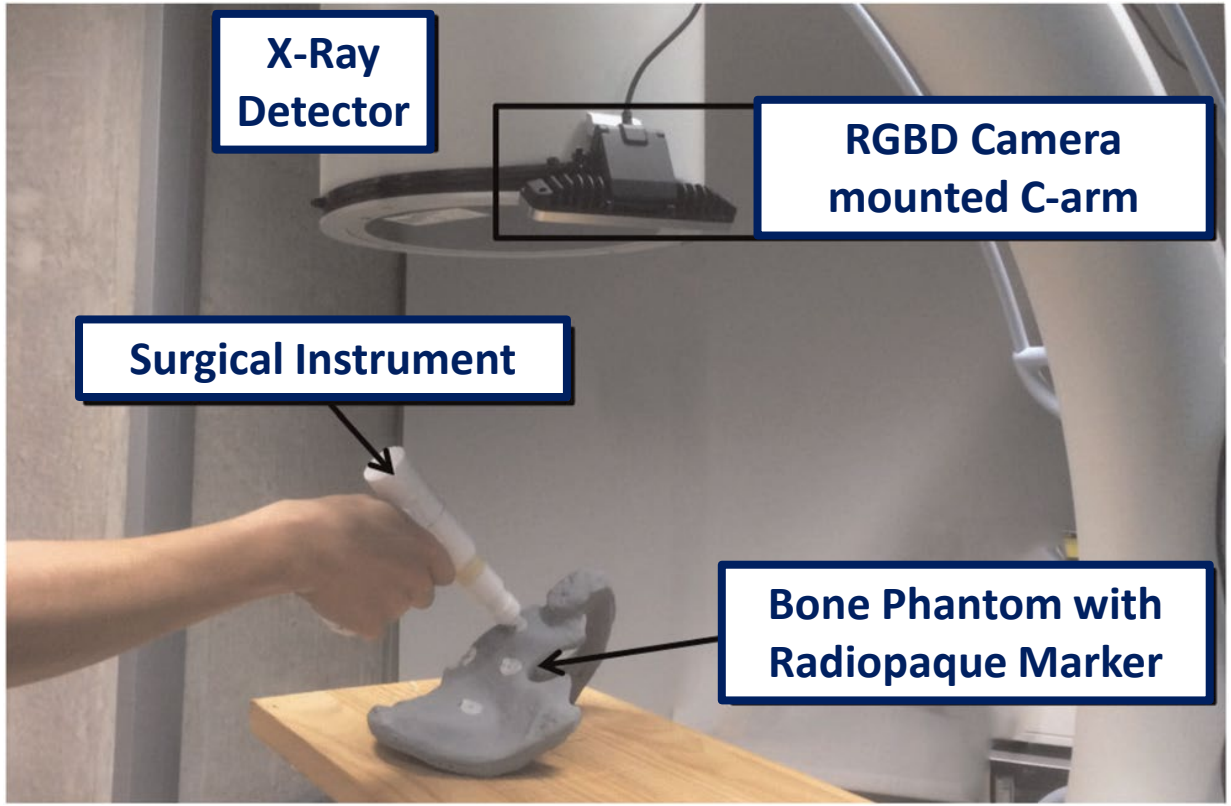
- Augmented Tools using Navigation System[2]
- Camera Augmented Mobile C-arm (CAMC)[3]
- RGBDX[4]
- Tracker-on-C[5]

➔ Towards Mixed Reality for Data Visualization



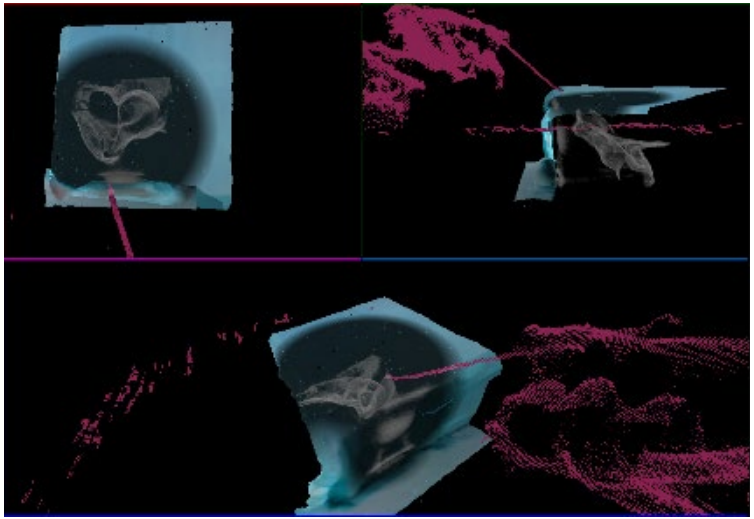
[2] van de Kraats EB, van Walsum T, Kendrick L, Noordhoek NJ, Niessen WJ (2006) Accuracy evaluation of direct navigation with an isocentric 3d rotational X-ray system. Med Image Anal 10(2):113–124
[3] Navab N, Heining SM, Traub J (2010) Camera augmented mobile c-arm (camc): calibration, accuracy study, and clinical applications. Med Imaging IEEE Trans 29(7):1412–1423
[4] S. Habert, J. Gardiazabal, P. Fallavollita, N. Navab. RGBDX: first design and experimental validation of a mirror-based RGBD Xray imaging system International Symposium on Mixed and Augmented Reality (ISMAR), 2015
[5] Reaungamornrat, S.; Otake, Y.; Uneri, A.; Schafer, S.; Mirota, D.J.; Nithiananthan, S.; Stayman, J.W.; Kleinszig, G.; Khanna, A.J.; Taylor, R.H.; Siewerdsen, J.H., "An on-board surgical tracking and video augmentation system for C-arm image guidance," in *International Journal of Computer Assisted Radiology and Surgery (IJCAR), 2012*

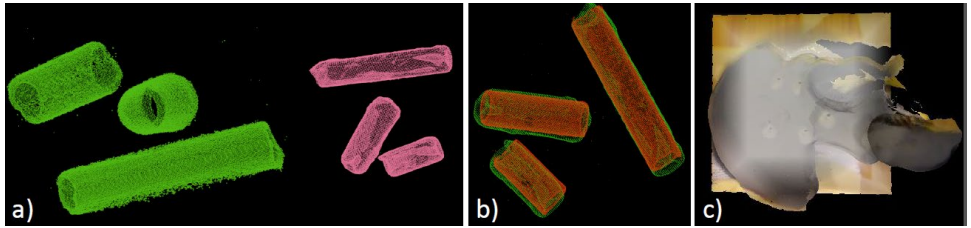
Mixed Reality Visualization System Setup



Mixed Reality Visualization

1. Phantom scan in both cone-beam computed tomography (CBCT) and depth camera spaces
2. Using Fast Point Feature Histogram (FPFH) and Iterative Closest Points (ICP) algorithm to recover the spatial relationship
3. Enable the mixed reality visualization[6]
   - Multiple arbitrary views for navigation
   - Live point clouds feedback in all views
   - Directly working on intra-operative medical data
   - More intuitive to understand tools and anatomy relationship

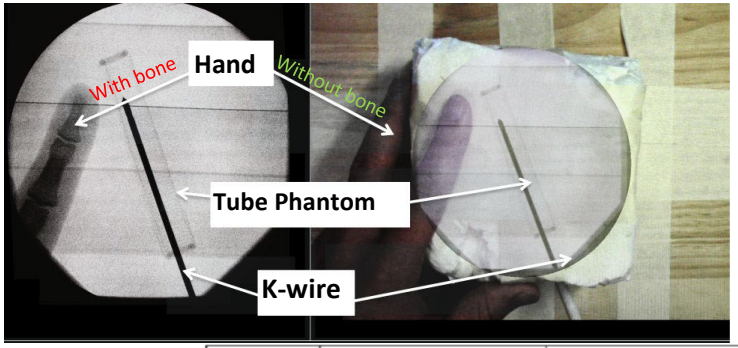


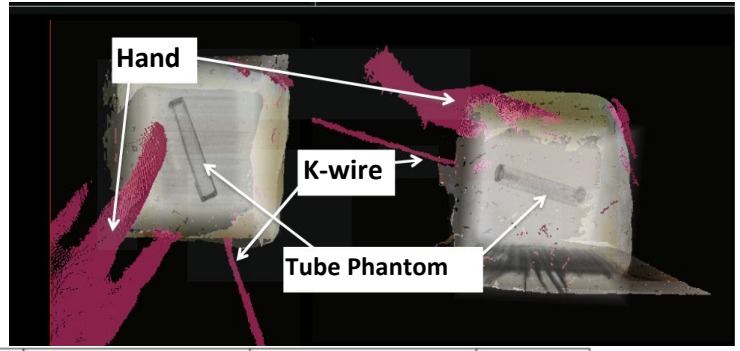


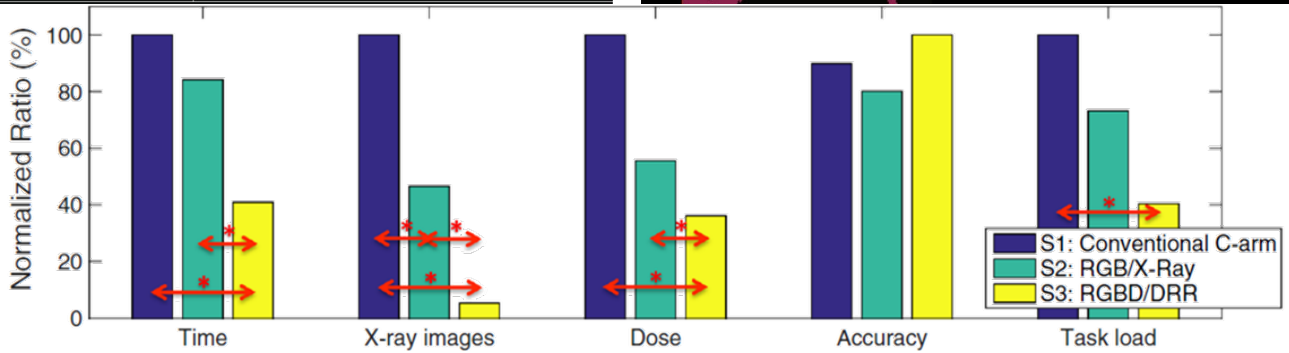
[6] S.C. Lee, B. Fuerst, J. Fotouhi, M. Fischer, G. Osgood, N. Navab, "Calibration of RGBD camera and cone-beam CT for 3D intra-operative mixed reality visualization". In: International Journal of Computed Assisted Radiology and Surgery, June 2016, Volume 11, Issue 6, pp 967-975

Mixed Reality Visualization for Better Orthopaedic Surgery

- Evaluation study on simple tube phantom







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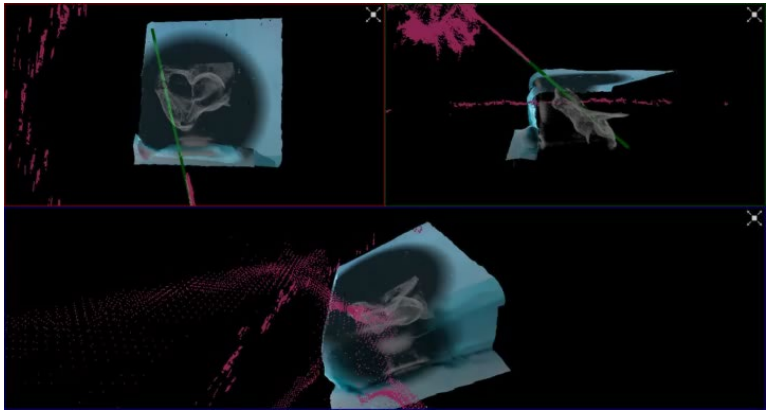
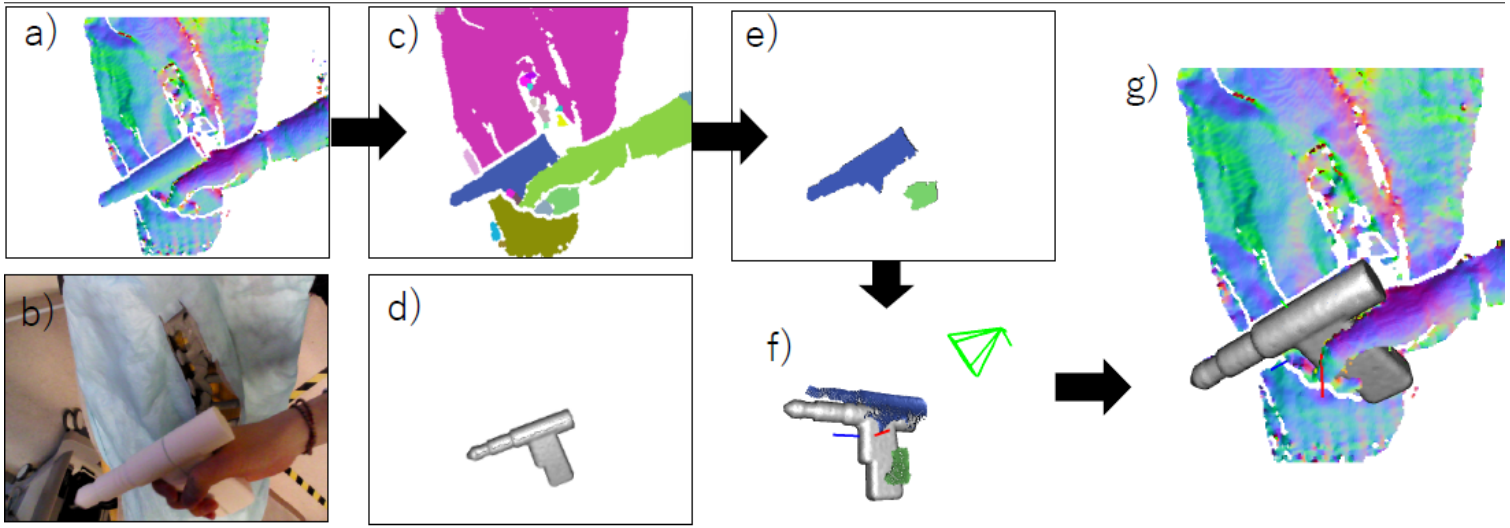
Towards to Synthetic Model – What is Missing?

- Evaluation study on synthetic bone phantom
  - Difficulty to orientate with the live point clouds
  - Noise in the point clouds introduce confusion of the understanding
  - Some views only contains partial point clouds due to difficult perspective to the camera
- Requires better data representation
  - Complete model
  - Clear projected drill path for easier alignment
  - Better guidance for orientating in multiple views



Depth Camera Model Based Instrument Tracking

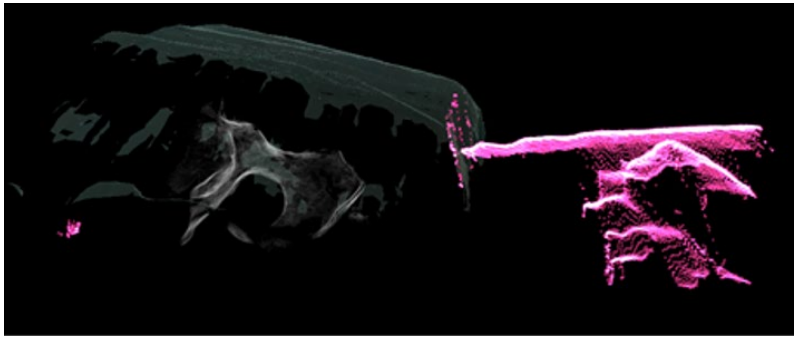
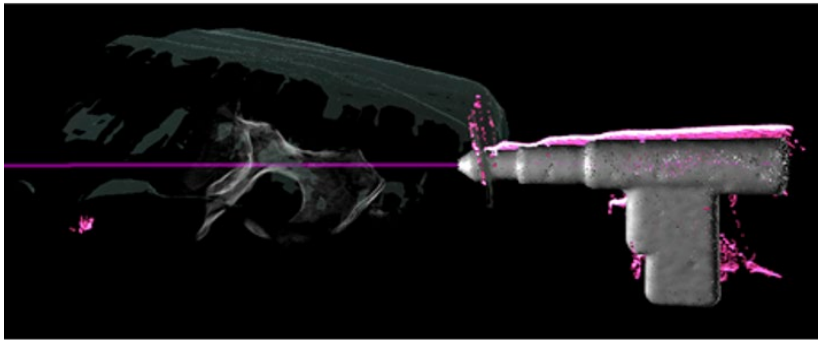
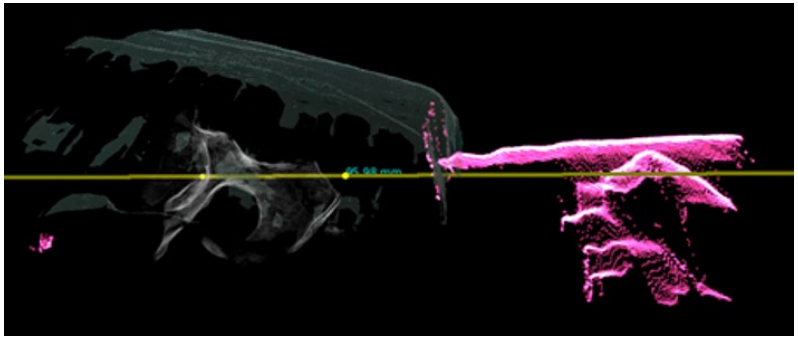
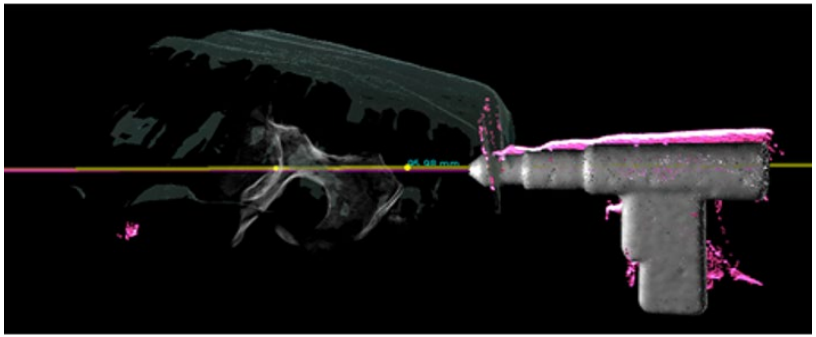
- Customized model based dense simultaneous localization and mapping (SLAM) using a single depth camera



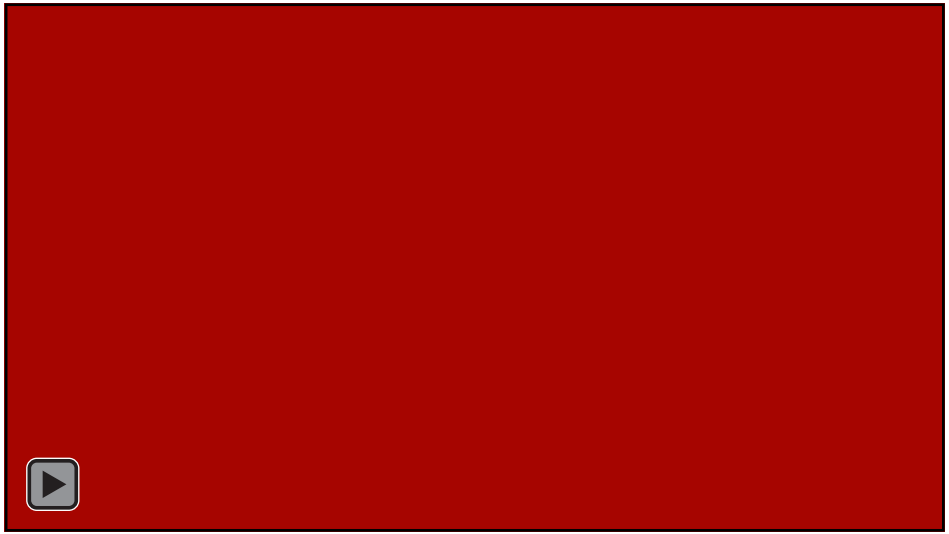
[3] K Tateno, F Tombari, N Navab, “Real-time and scalable incremental segmentation on dense slam”. In: IEEE International Conference of Intelligent Robots and Systems, September 2015, pp 4465-4472

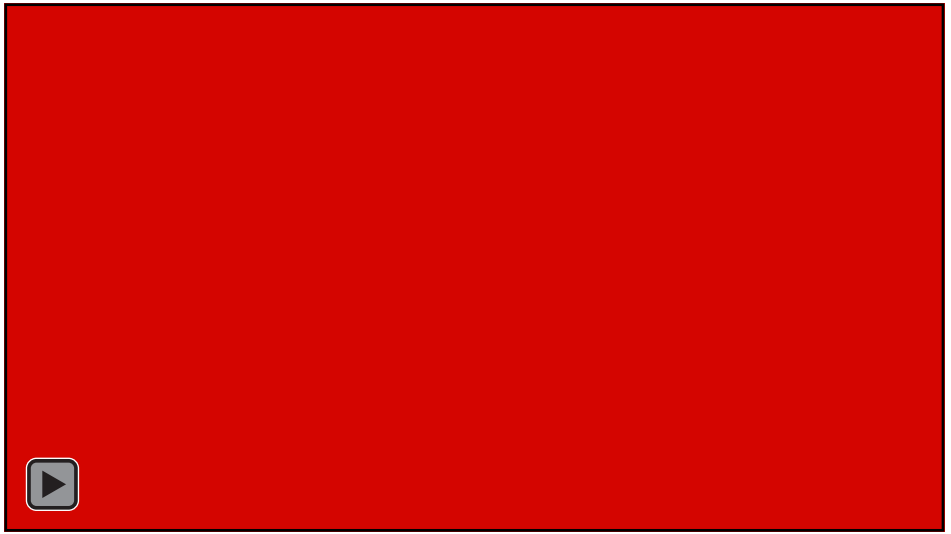
Suggested Workflow with Our Mixed Reality System

- Transformed the surgical task to a simple line alignment in multiple views

Demo





Tracking Accuracy

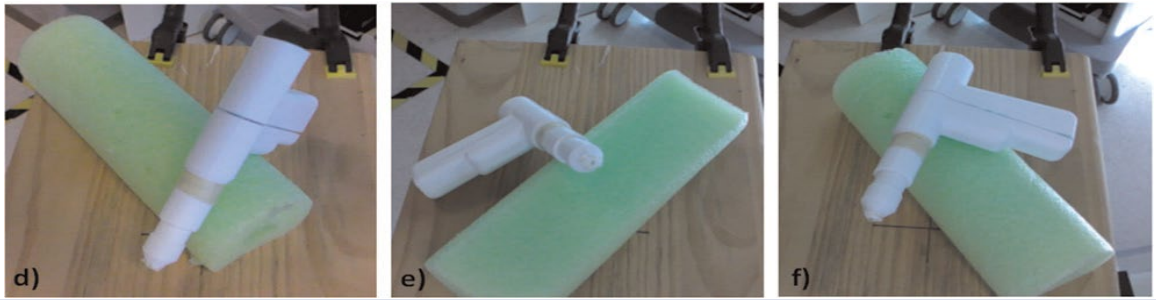
- TRE measurement of the markers by pointing: average accuracy of 3.4mm.
- Accuracy depends on level of occlusions

mm	δx	δy	δz	$\|\|\boldsymbol{d}\|\|_2$
Partial occlusion	6.02 ± 1.80	1.35 ± 0.85	5.78 ± 0.41	6.40 ± 1.85
Low occlusion	1.28 ± 0.12	0.30 ± 0.19	1.68 ± 0.64	1.36 ± 1.12
High occlusion	17.5 ± 4.70	7.50 ± 2.18	8.91 ± 4.47	20.68 ± 4.54

Tracking Quality

- Placed the tool at different locations without moving it
- When the shape appears more symmetric, it appears bigger errors

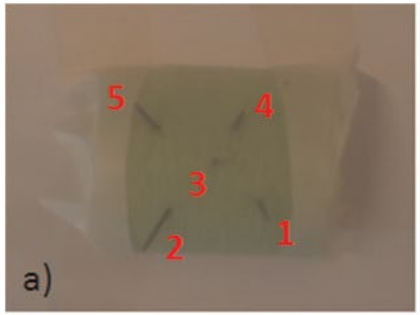
mm	δx	δy	δz	$\|\|\boldsymbol{d}\|\|_2$
Pose 1	1.09	0.83	4.03	4.26
Pose 2	2.45	4.50	0.65	5.16
Pose 3	0.67	1.14	0.18	1.33
Average	1.40	2.16	1.62	3.04

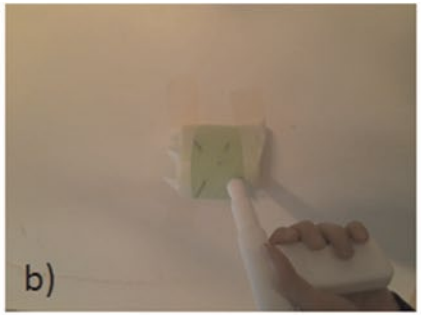


Guidance Quality

- Accuracy depends on occlusion levels
- Measured the distance to line distance, which indicates potential guidance quality
- Around 3mm on average

	Pin 1	*Pin 2*	*Pin 3*	*Pin 4*	*Pin 5*
$\|\|\boldsymbol{d}\|\|_2$	3.0563	3.4618	6.3178	3.0304	2.5764





Conclusion & Discussion

- Simple setup compared to external tracking devices
- Provides quick guidance support by transforming the 2D-3D navigation task to line alignments in multiple views
- Evaluation shows that it supports user quickly find a better entry point and orientation (accuracy up to 3mm on average)

✓ Transformed the core surgical task to line alignment tasks in multiple views

✓ Reduced X-rays dose

✓ Shortened operating time

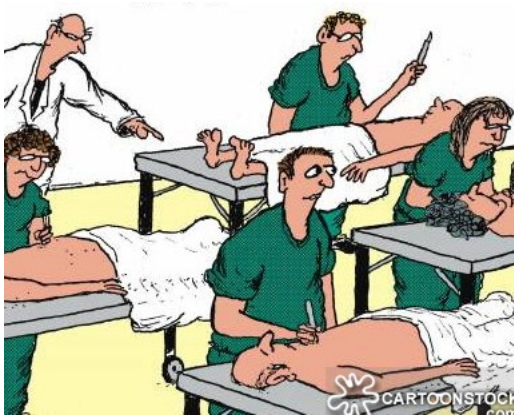
✓ Intuitive and quick tool guidance support

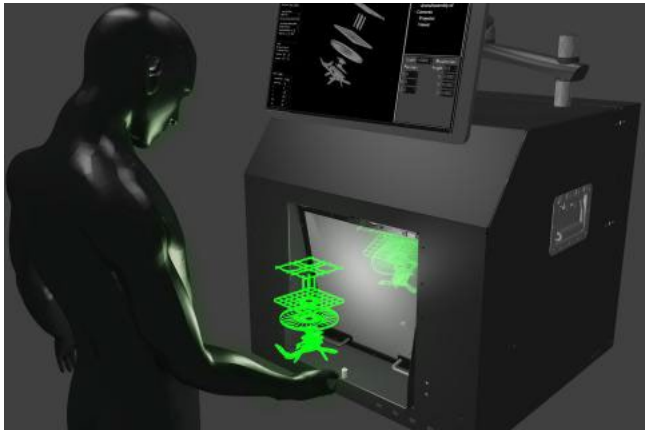
✗ Not accurate enough for exact placement or robotic automated placement

✗ Perceptual visualization should be further improved

Future Work

- Improve the system's accuracy
- Evaluate the system with cadaver study
- Incorporate the concept into HMD (e.g. Hololens)
- Consideration of mid-air visualization technique





Thank you!
Q & A

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