Multi-modal Imaging, Model-based Tracking, and Mixed Reality Visualization for Orthopaedic Surgery

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Introduction

Conventional System (Intra-operative X-Rays)

- Challenge of navigating the instrument in 3D, and depth understanding
- ➔ A lots of X-Rays from different perspective for navigation
- ➔ Multiple attempts for one single placement
- ➔ Long operating time, and surgical team frustration

Proposed System (Mixed Reality Visualization + Tool Tracking)

- Transformation of the challenge to a simplified task that is more intuitive and easier to master.
- Therefore, it helps *speeding up* the procedure, *reducing radiation* usage, and *less frustration*.

Fig 1a: Conventional system often requires multiple attempts. (Source: [1])

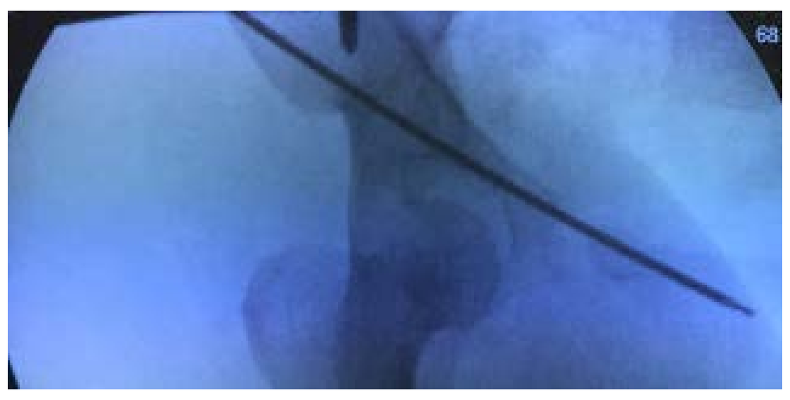


Fig 1b: An example of navigating instrument in 3D using X-Ray. (Source: [1])

Steps:

1. An intra-operative Cone-Beam CT is acquired; meanwhile the surface of the subject is reconstructed. The system is able to visualize them together with live-point-clouds feedback as shown in Fig 2a.
2. User can plan their desired screw placement path based on the intra-operative medical data. This planning (the yellow line) will be displayed on top of the mixed reality visualization as shown in Fig 2b.
3. User then can select the drill CAD model, and align the live-point-clouds with the model to initialize the tracking. A virtual drill model as well as projected path (the purple line) is shown (Fig 2c).
4. At last, user can simply align the purple line and the yellow line to reach a better starting point that is closer to their expected drill path, in a short period of time (Fig 2d).

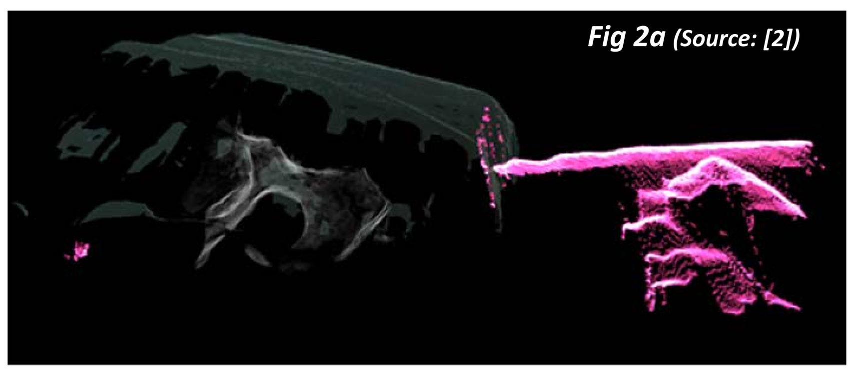


Fig 2a (Source: [2])

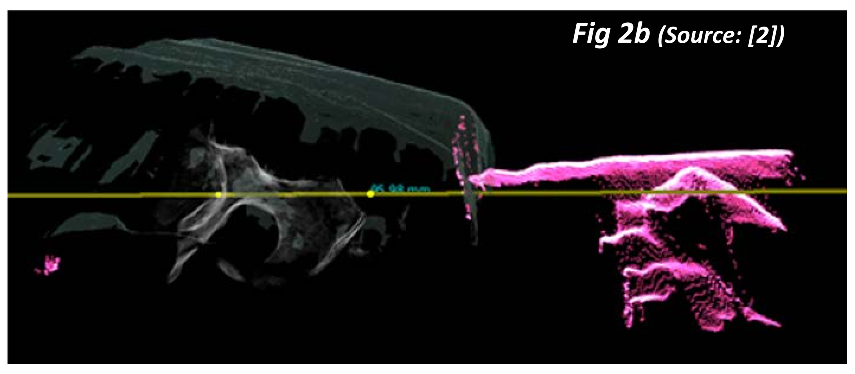


Fig 2b (Source: [2])

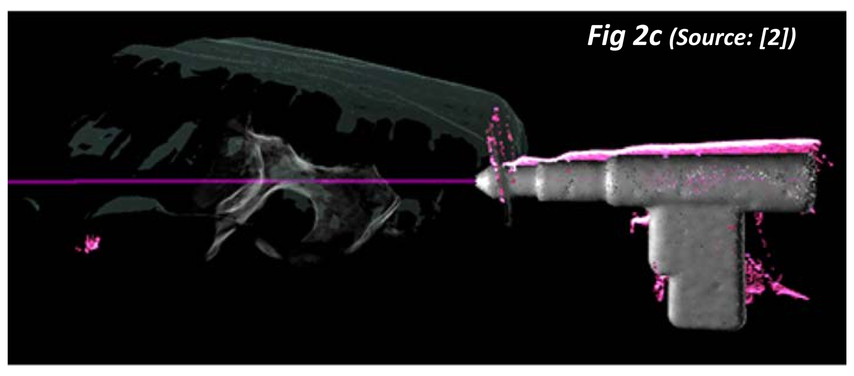


Fig 2c (Source: [2])

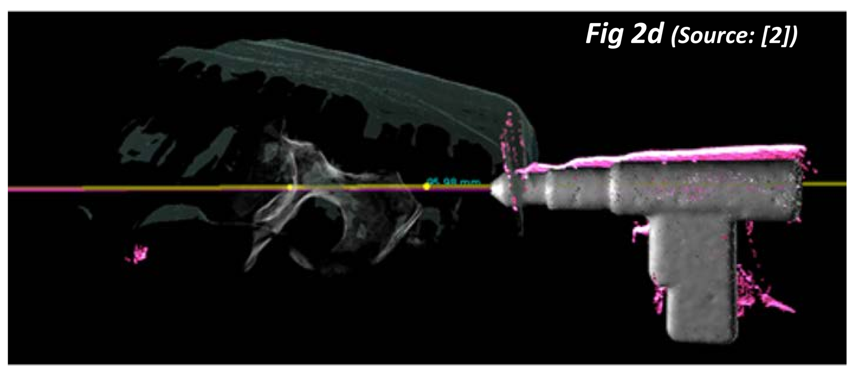


Fig 2d (Source: [2])

Method

Camera-to-C-arm Calibration[3]

- An RGBD camera is rigidly mounted on a C-arm machine
- A calibration phantom is scanned by C-arm to produce a CBCT volume; meanwhile, the depth camera reconstructs the phantom surface
- Point clouds features on the CBCT volume and on the surfaces are extracted as shown in Fig 3a
- Fast point feature histogram is used to match two feature point clouds
- Finally, iterative closest points algorithm is used to refine the calibration result as in Fig 3b
- The calibration result allows overlaid likes in Fig 3c

Realtime Model-based Tool Tracking[4]

- The depth camera is also used in model-based tool tracking after a semi-auto initialization
- Every frame acquired provides the surface normal (Fig 4a)
- It can then be segmented based on the geometric features as in Fig 4c
- The visible part of the model in previous frame (Fig 4d) is used to retrieve the segmented label, which results in Fig 4e
- At last, the labeled point clouds feature can be compared with the model feature (Fig 4f), using iterative closest point algorithm, which then provides the tracking result that can be used to visualize the virtual mode as in Fig 4g

Mixed Reality Visualization + Tool Tracking

- Provided the tracking and the calibration results, an example of mixed reality support visualization is shown in Fig 5
- Key features:
  - Tracked virtual model and projected drill path (purple line)
  - User planned ideal drilling trajectory (yellow line)
  - Overlaid of anatomic structure and surface
  - Multiple perspective for quick alignment
  - Radiation-free interactive alignment interface

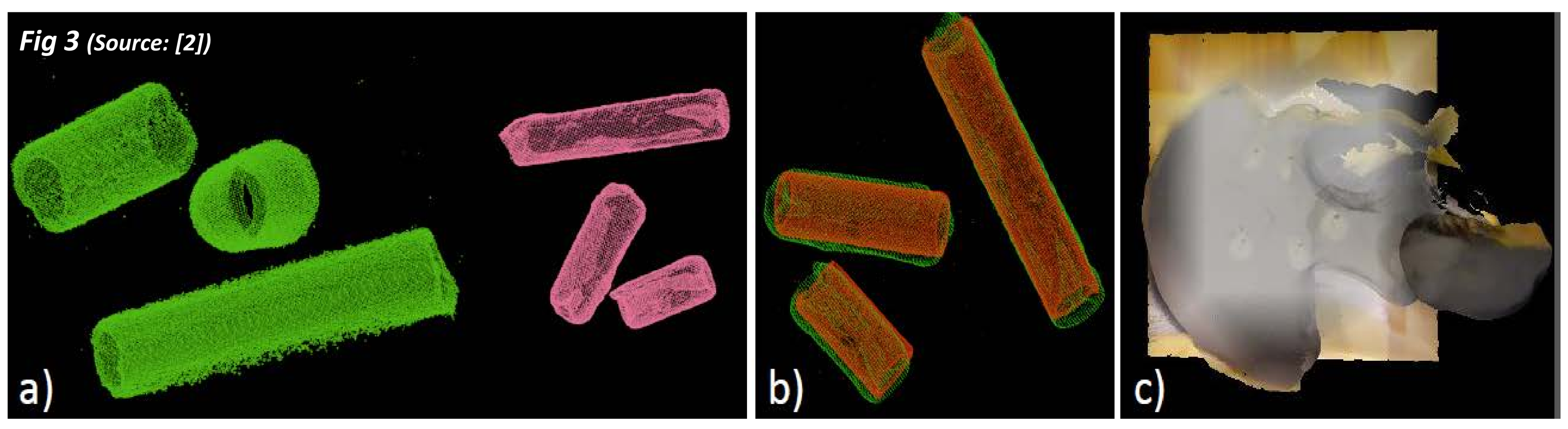


Fig 3 (Source: [2])

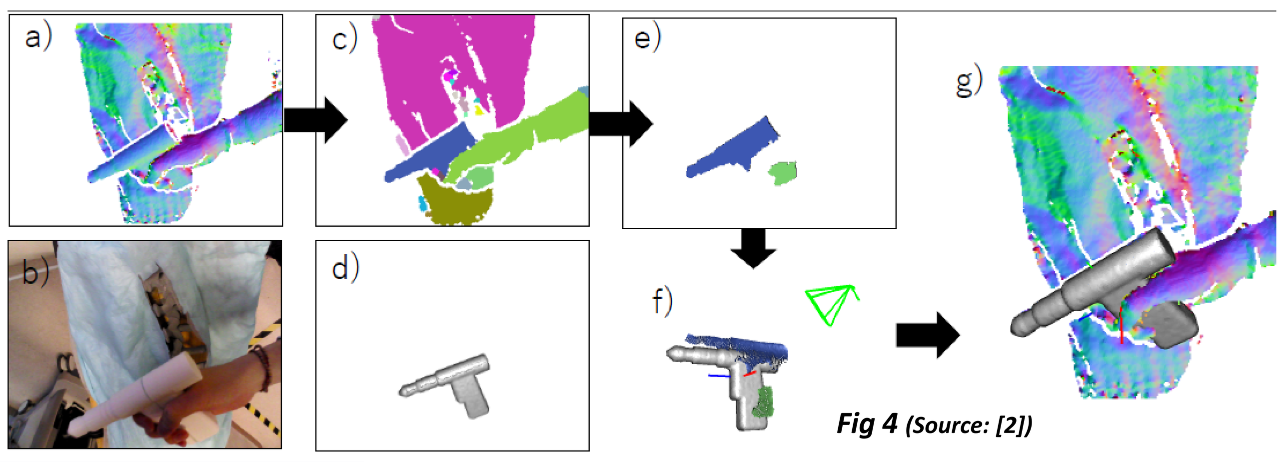


Fig 4 (Source: [2])

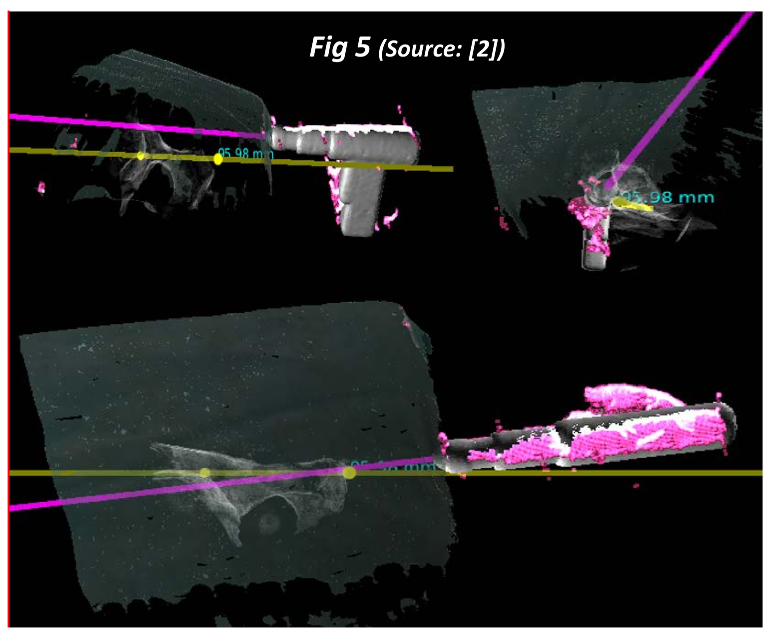


Fig 5 (Source: [2])

Results

Evaluation of the tracking accuracy, tracking quality, and guidance quality

- Tracking Accuracy: Measured by TRE (Fig 6a-c). Average accuracy of 3.4mm.
- Tracking Quality: Measured by different poses (Fig 6d-f). Larger error when the observed shape is more symmetric ambiguous.
- Guidance Quality: Measured by point to line distance (Fig 7a-c). ~3 mm off from the plan. Able to bring user closer to their desired entry point.

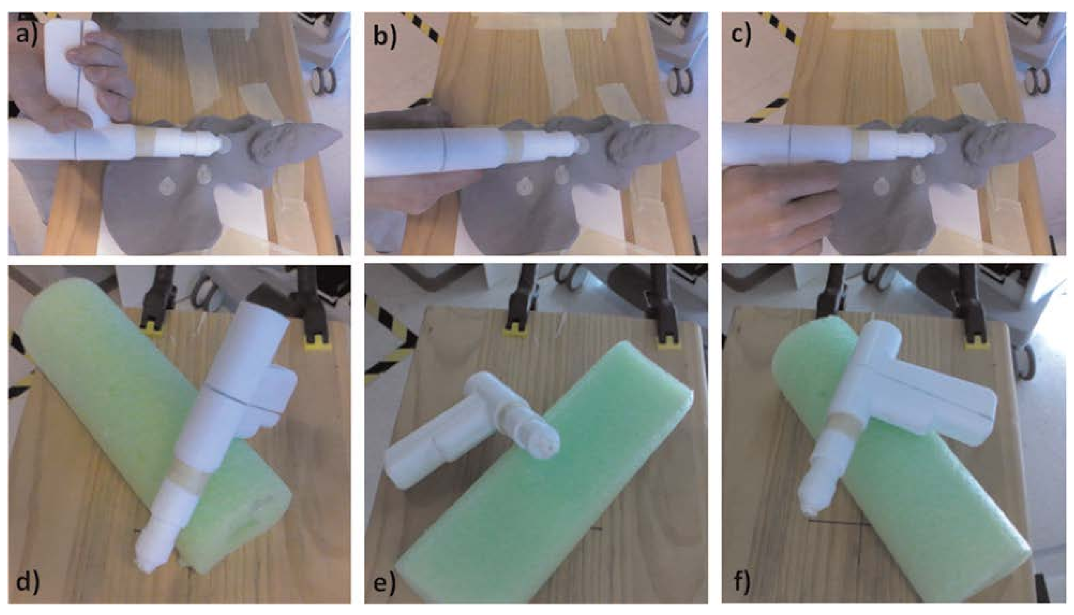


Fig 6: Illustrations of TRE and tracking quality measurement (Source: [2])

Tab 1: TRE measurement in mean ± std [mm] (Source: [2])

	δx	δy	δz	$\lVert d \rVert_2$
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

Tab 2: Tracking quality measured in [mm] (Source: [2])

	δx	δy	δz	$\lVert d \rVert_2$
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

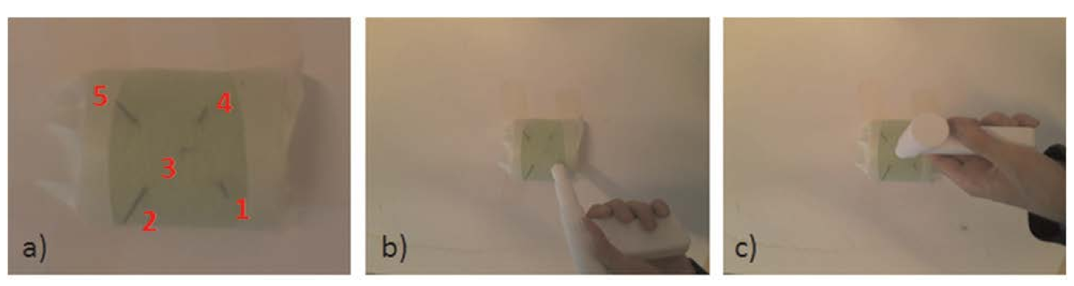


Fig 7: Illustrations of guidance quality measurement (Source: [2])

Tab 3: Guidance quality measured in [mm] (Source: [2])

	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5
$\lVert d \rVert_2$	3.0563	3.4618	6.3178	3.0304	2.5764

[1] M Fischer, B Fuerst, SC 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

[2] SC Lee, B Fuerst, K Tateno, A Johnson, J Fotouhi, G Osgood, F Tombari, N Navab, "Multi-modal imaging, model-based tracking and mixed reality visualisation for orthopaedic surgery". In: Healthcare Technology Letters, August 2017, in press.

[3] SC 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

[4] 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

Conclusions

A novel approach for skew/k-wire placement in Orthopaedic Surgery

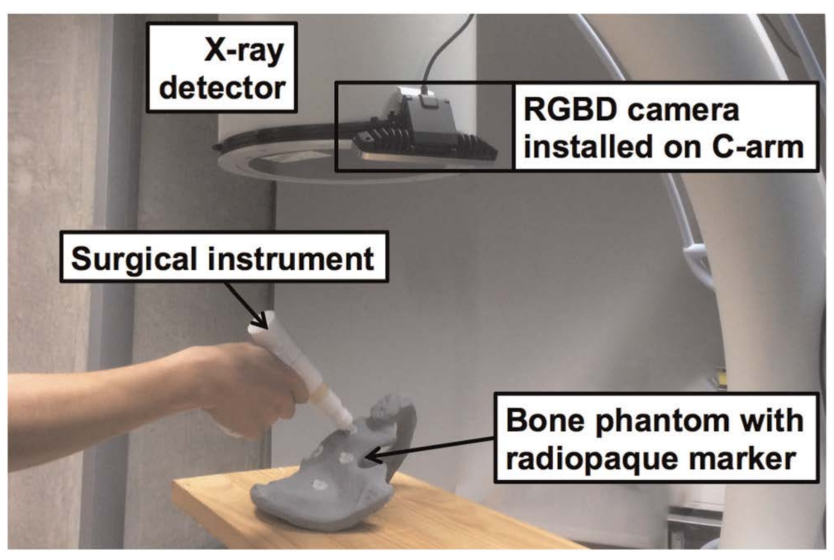
- Simple setup comparing to external tracking devices
- Provides quick guidance support by transforming the 2D-3D navigation task into line alignments in multiple views
- Evaluation results show it could help brining user closer to their desired entry point as close as around 3mm

✗ Rooms for Improvements

- Not accurate enough for exact placement or robotic automated placement
- Could have better perceptual visualization

✓ Advantages

- Simple and one-time setup calibration
- Simplified the task as a simple alignment
- Better depth understanding
- Reduced X-rays usage
- Shortened operating time
- Intuitive and quick tool guidance support



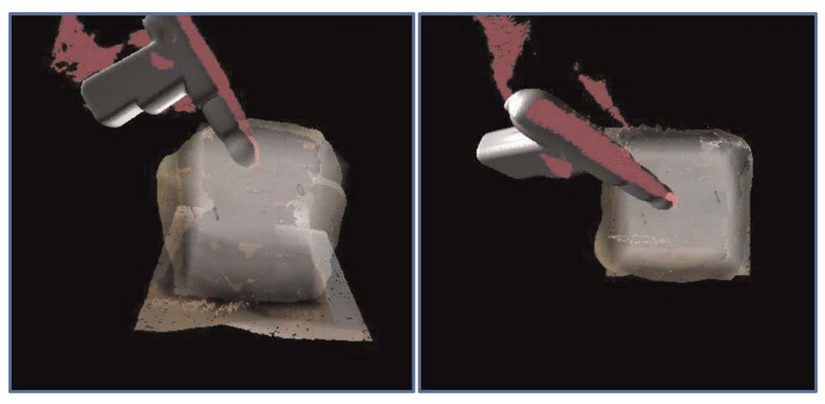


Image Source: [2]

Acknowledgement

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