Tracking of Orthopaedic Instruments in 3D Camera Views

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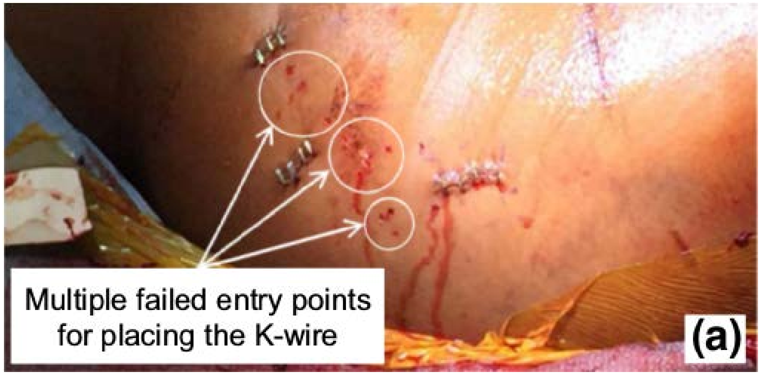
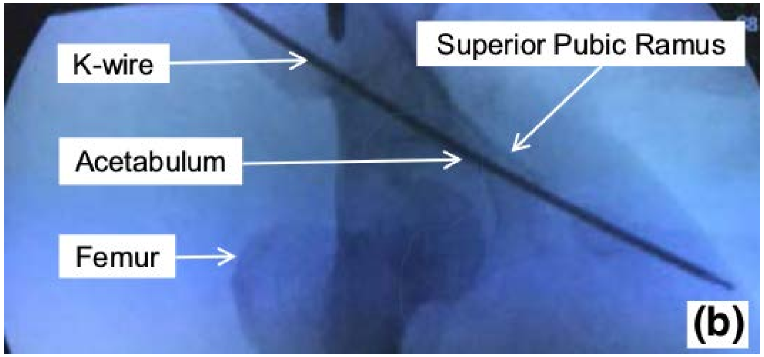
Clinical Motivation

- K-wire tracking is an important part of computer assisted orthopedics surgery
- Multiple intra-operative X-ray images during K-wire insertion[1]
- Severe damage to important structures [2]
  - External iliac artery
  - External iliac vein
  - Obturator nerve
- Correction could cause multiple entry wounds



Multiple entry wounds

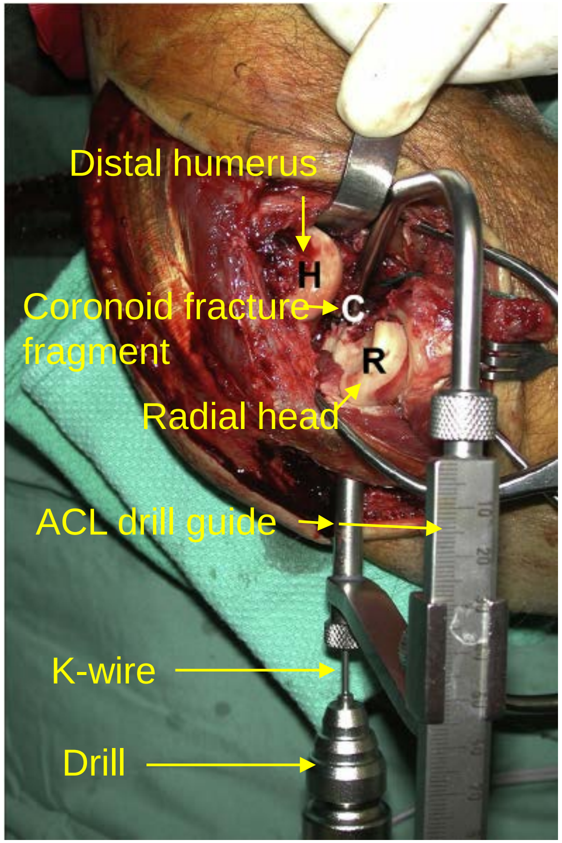


X-ray image of hip region in pelvic surgery [3]

[1] Starr, Adam J., Charles M. Reinert, and Alan L. Jones. "Percutaneous fixation of the columns of the acetabulum: a new technique." Journal of orthopaedic trauma 12.1 (1998): 51-58.
[2] Starr, A. J., et al. "Preliminary results and complications following limited open reduction and percutaneous screw fixation of displaced fractures of the acetabulum." Injury 32 (2001): 45-50.
[3] Fischer, Marius, et al. "Preclinical usability study of multiple augmented reality concepts for K-wire placement." International Journal of Computer Assisted Radiology and Surgery 11.6 (2016): 1007-1014.

Clinical Motivation

- Main challenge: mental alignment of patient, medical instruments and intra-operative X-rays[4]
- Aid visualization with camera augmented solutions[5]
- But require K-wire tracking
- Optical trackers are available[6] but not applicable to K-wire



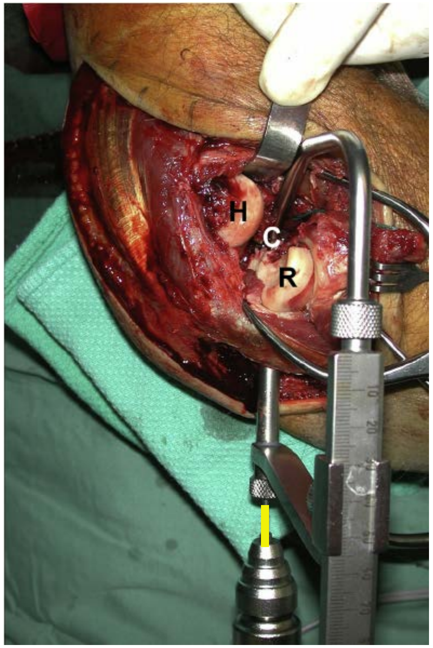
K-wire insertion with drill guide[7]

[4] Starr, A. J., et al. "Preliminary results and complications following limited open reduction and percutaneous screw fixation of displaced fractures of the acetabulum." Injury 32 (2001): 45-50.
[5] Navab, Nassir, Sandro-Michael Heining, and Joerg Traub. "Camera augmented mobile C-arm (CAMC): calibration, accuracy study, and clinical applications." *IEEE transactions on medical imaging* 29.7 (2010): 1412-1423
[6] Synowitz, Michael, and Juergen Kiwit. "Surgeon's radiation exposure during percutaneous vertebroplasty." *Journal of Neurosurgery: Spine* 4.2 (2006): 106-109
[7] Kovacevic, D., Vogel, L. A., & Levine, W. N. (2015, November). Complex Elbow Instability: Radial Head and Coronoid. Hand Clinics.

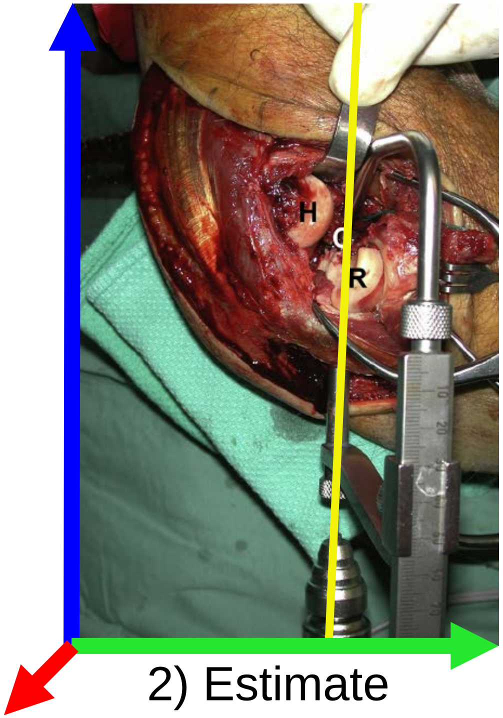
Solution

Deep learning based K-wire tracking algorithm using RGB images

- Eliminates the need for multiple X-ray images
- Can be easily integrated into augmented reality solutions to orthopedics surgery



1) Identify K-wire



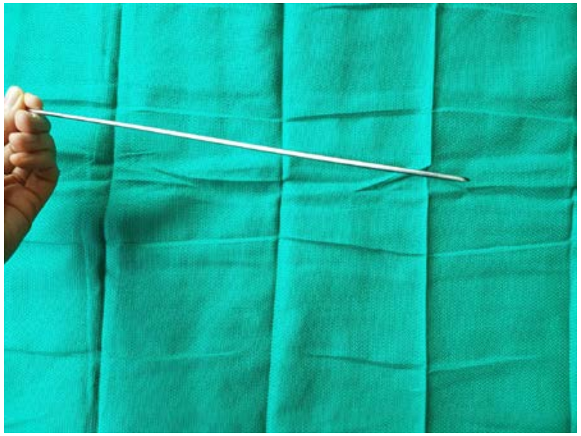
2) Estimate orientation/pose

3) Show K-wire orientation/pose

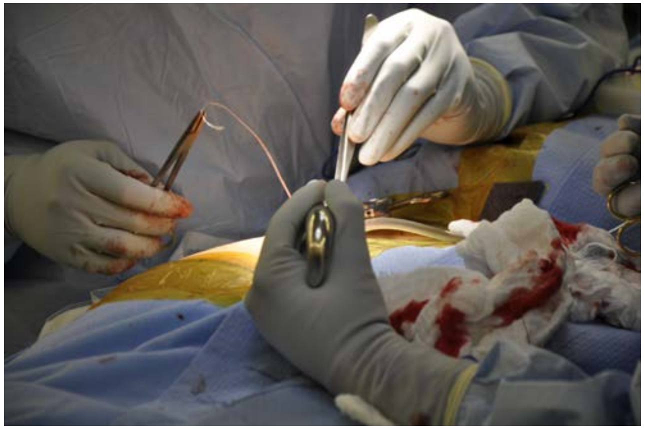
All images from Kovacevic, D., Vogel, L. A., & Levine, W. N. (2015, November). Complex Elbow Instability: Radial Head and Coronoid. Hand Clinics.

Technical Approach

- Create data
  - Create a modular data set by capturing foreground and background separately
- Design network
  - Design and train a CNN based neural net to segment K-wire in RGBD images
  - HED for tool tracking[8] , U-Net[9]...
- Pose estimation from segmented stereo image pairs



Sample foreground shot before segmentation

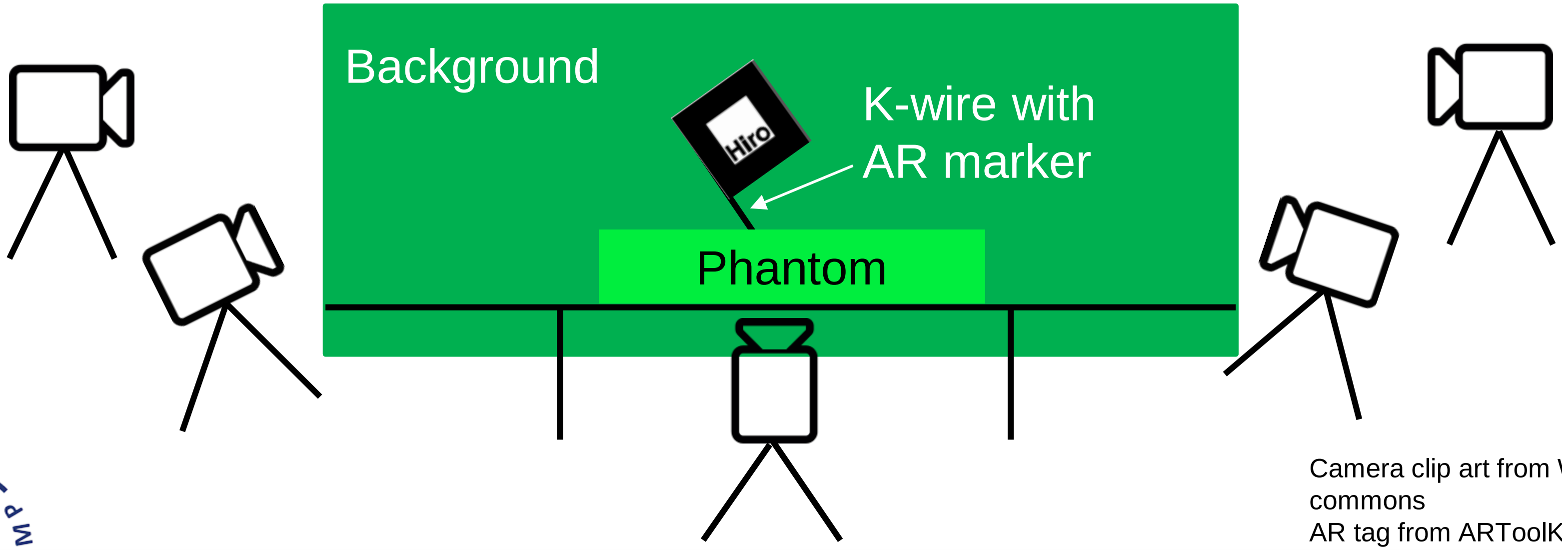


Sample background shots

[8] Pakhmov et. al, Semantic-boundary-driven approach to Instrument Segmentation for Robotic Surgery
[9] Ronneberger, O., Fischer, P., & Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation. In MICCAI 2015 (Vol. 9351, pp. 234–241)

Technical Approach

- Create data
  - Use multiple, calibrated cameras to reconstruct 3D scene
  - Pivot calibration with marker on K-wire
  - Modular approach: Capture foreground (K-wire) and background separately
  - Background: Drapes, hands, instruments, blood etc.
  - Compose training/testing dataset of varying complexity by combining foreground and background

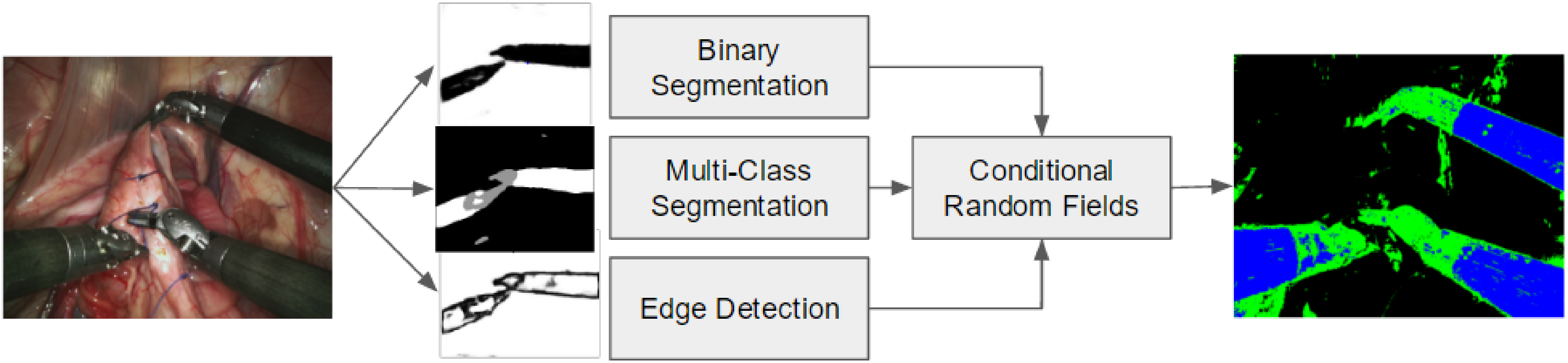


Camera clip art from Wikimedia commons
AR tag from ARToolKit

Technical Approach

Design network

– HED (Holistically-nested Edge Detection) for tool segmentation [8]



– U-Net: Fully convolutional network for biomedical images[9]

[8] Pakhmov et. al, Semantic-boundary-driven approach to Instrument Segmentation for Robotic Surgery
[9] Ronneberger, O., Fischer, P., & Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation

Deliverables

Minimum

- Phantom to create training data
- Modular data set
  - Foreground videos with K-wire against green drape
  - Segmentations of the K-wire position
- CNN trained on K-wire video with plain background to segment position

Expected

- Realistic data set of surgical workspace by composing foreground and background videos of surgical workspace with instruments (ie. scalpel)
- CNN trained with realistic data that can segment K-wire
- Algorithm to extract K-wire orientation from segmented position

Maximum

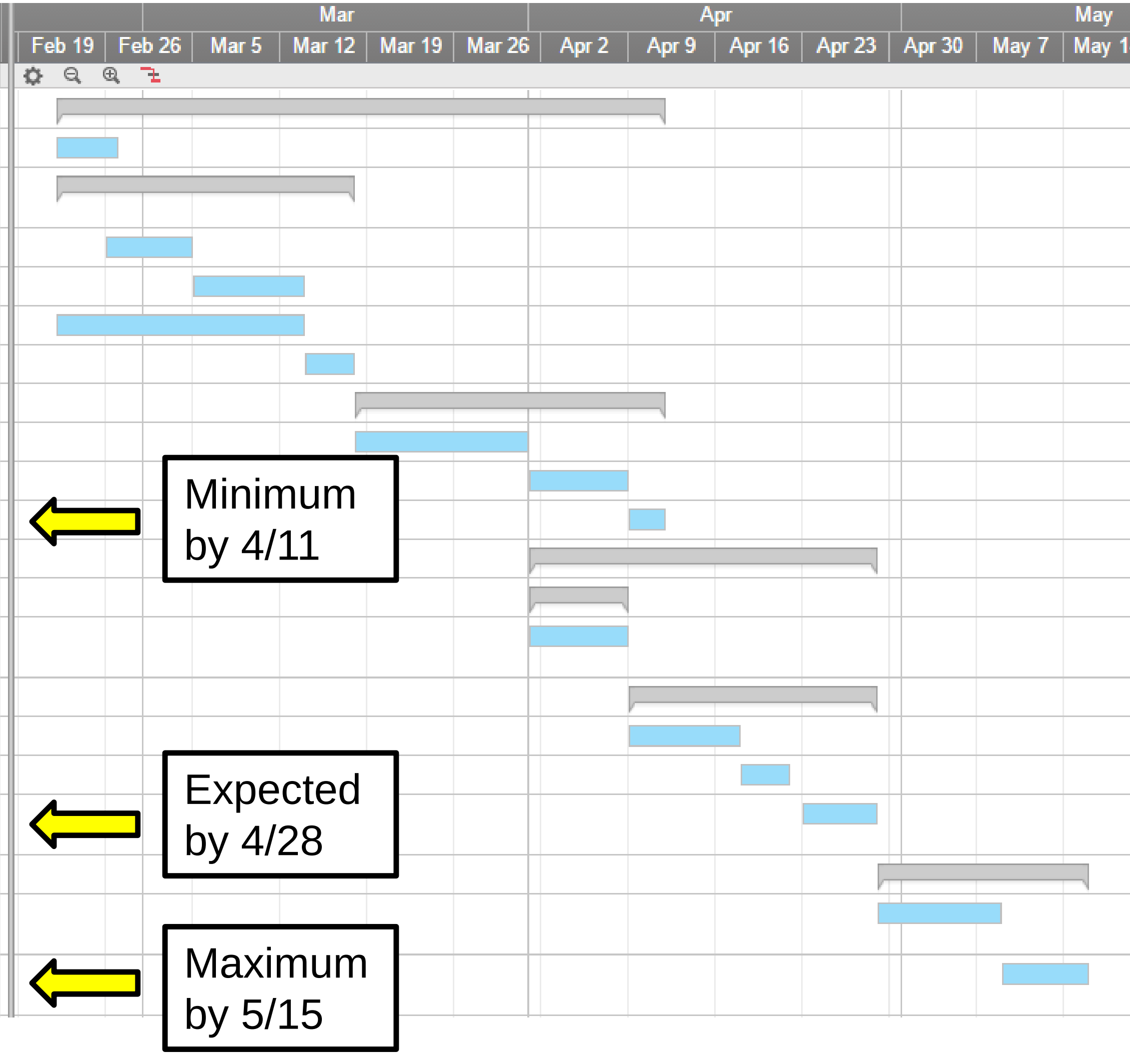
- Algorithm to estimate position of K-wire tip inside the patient

Dependencies

Dependency	Status	Plan	
Access to servers for training CNN	Resolved		
Get Keras installed in server	In progress	Resolve by Feb 28th	Contacted Anton
Access to camera and surgical instruments	Resolved		
Access to segmentation library	Resolved		
Learn to create a phantom	Unresolved	Resolve by Feb 28th	Discuss with Javad
Observe K-wire use in clinic	In progress	First visit, no K-wire used	Planned future visits to the OR

Timeline

Task Name	Start	Finish	Duration
⊟ **Minimum Deliverables**	02/22/17	04/11/17	49d
Create phantom	02/22/17	02/26/17	5d
⊟ **Make data set of modular video components**	02/22/17	03/17/17	24d
K-wire on plain background	02/26/17	03/04/17	7d
Segment k-wire positions	03/05/17	03/13/17	9d
Take videos of surgical workspace	02/22/17	03/13/17	20d
Extract 3D pose	03/14/17	03/17/17	4d
⊟ **Create CNN**	03/18/17	04/11/17	25d
Implement a network	03/18/17	03/31/17	14d
Train CNN on k-wire video	04/01/17	04/08/17	8d
Validate segmentation results	04/09/17	04/11/17	3d
⊟ **Expected Deliverable**	04/01/17	04/28/17	28d
⊟ **Augment data set**	04/01/17	04/08/17	8d
Compose segmented K-wire videos with surgical workspace	04/01/17	04/08/17	8d
⊟ **Refine CNN**	04/09/17	04/28/17	20d
Train CNN on composed video	04/09/17	04/17/17	9d
Validate segmentation results	04/18/17	04/21/17	4d
Validate 3D pose estimation from stereo pairs	04/23/17	04/28/17	6d
⊟ **Maximum Deliverables**	04/29/17	05/15/17	17d
Create algorithm to estimate K-wire tip position	04/29/17	05/08/17	10d
Evaluate K-wire tip position estimation in phantom	05/09/17	05/15/17	7d



Management Plan

- Weekly CAMP meetings at 3pm Tuesday
- Group meeting: 2h on Tuesday and Friday
- Meeting with different mentors for each part as needed
- Code management by Git

Jie Ying	Athira
Set up phantom and scene	Do camera calibration
Collect data	
Preprocess data	
Implement one network	Implement one network
Analyze and compare results of each net	
Compose videos	Extract 3D pose information
Create algorithm to estimate tip position	

Reading List

1. Fischer, Marius, et al. "Preclinical usability study of multiple augmented reality concepts for K-wire placement." International Journal of Computer Assisted Radiology and Surgery 11.6 (2016): 1007-1014.
2. Jégou, S., Drozdzal, M., Vazquez, D., Romero, A., & Bengio, Y. (2016). The One Hundred Layers Tiramisu: Fully Convolutional DenseNets for Semantic Segmentation. *arVix Preprint*. Retrieved from http://arxiv.org/abs/1611.09326
3. Long, Jonathan, Evan Shelhamer, and Trevor Darrell. "Fully convolutional networks for semantic segmentation." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. 2015.
4. Pakhmov et. al, Semantic-boundary-driven approach to Instrument Segmentation for Robotic Surgery
5. Lee et. al, Simultaneous Segmentation, Reconstruction and Tracking of Surgical Tools in Computer Assisted Orthopedics Surgery
6. Ronneberger, O., Fischer, P., & Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation. In Medical Image Computing and Computer Assisted Intervention - MICCAI 2015 (Vol. 9351, pp. 234–241). Springer, Cham. https://doi.org/10.1007/978-3-319-24574-4_28
7. Szegedy, C., Reed, S., Erhan, D., Anguelov, D., & Ioffe, S. (2014). Scalable, High-Quality Object Detection. arXiv. Retrieved from http://arxiv.org/abs/1412.1441