Camera Augmented Mobile C-Arm (CAMC): Calibration, Accuracy Study, and Clinical Applications

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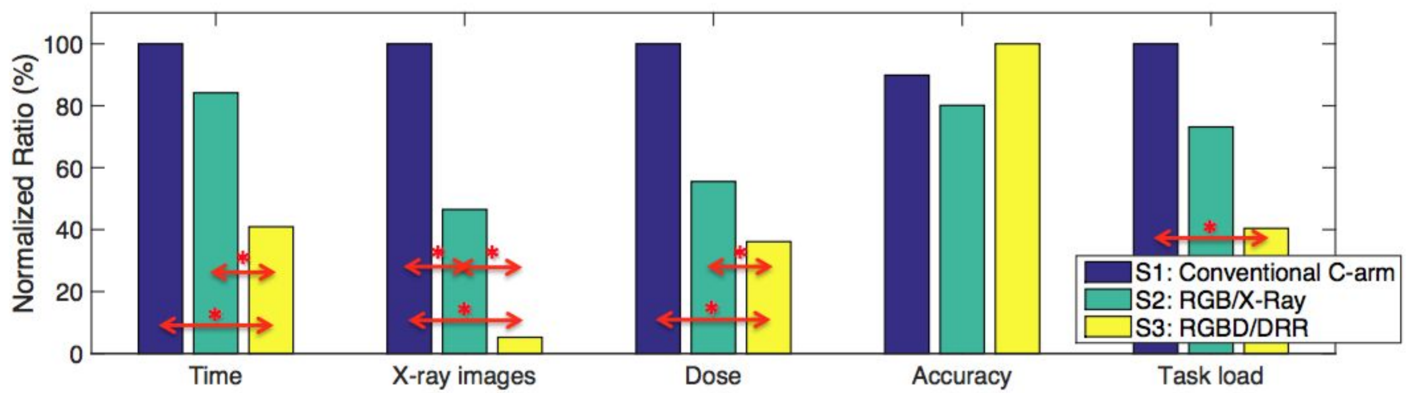
Project 6

Project Background and Objective

Orthopaedic surgeries are time intensive and require multiple images to ensure correct placement and direction of tools.

Research has been done to create a manual calibration algorithm, that creates an intra-operative mixed-reality visualization.

Goal is to automate the existing manual calibration process between CBCT scanner and RGBD camera.



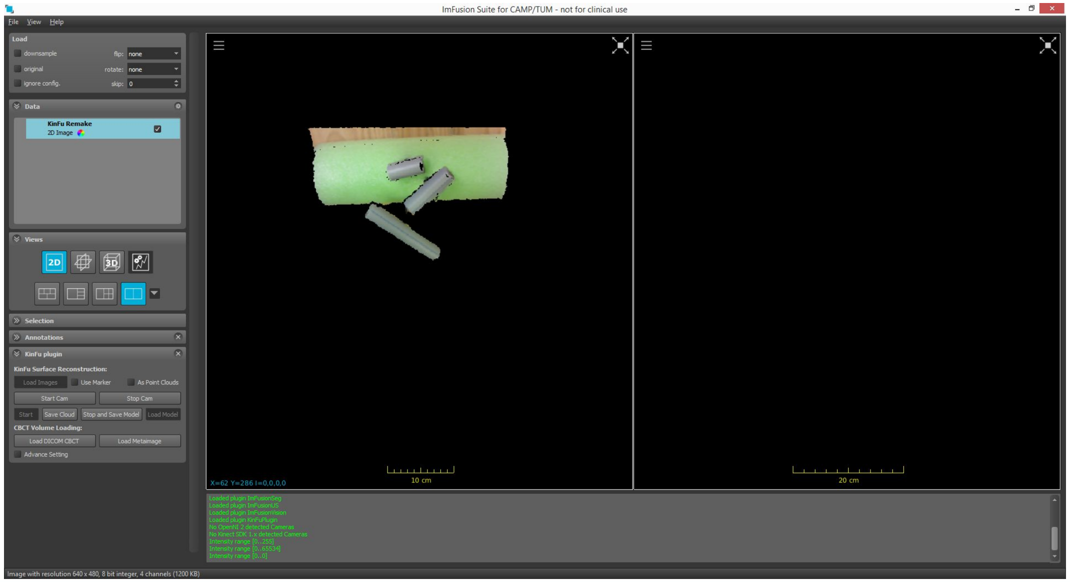
Paper Selection

N. Navab, S. Heining and J. Traub, "Camera Augmented Mobile C-Arm (CAMC): Calibration, Accuracy Study, and Clinical Applications", IEEE Transactions on Medical Imaging, vol. 29, no. 7, pp. 1412-1423, 2010.

The original paper for this augmented visualization concept using a double mirror system was by Dr. Nassir Navab's Computer Aided Medical Procedures (CAMP) group at Johns Hopkins University and Technische Universitat Munchen.

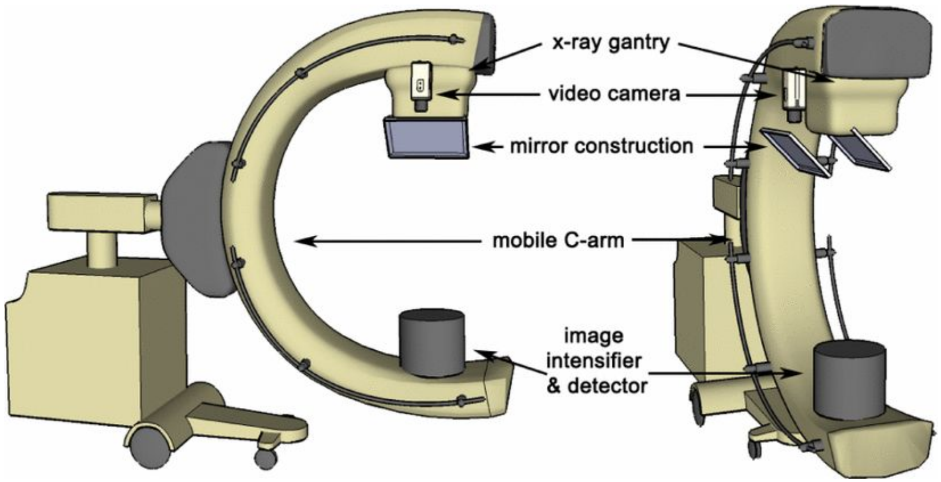
Problem

As explained in the project overview, the large number of x-ray images taken during orthopaedic surgeries result in high radiation dosage for the physicians and patient. However, they are necessary in guiding and confirming the surgeon's placement of tools and fixtures. Improved live visualization of the patient in orthopaedic surgery without the use of external markers would greatly reduce the number of x-rays and thus radiation dosage, also improving the overall surgical workflow.



Key Result and Significance

After successful calibration of the CBCT and RGBD using a double mirror construction, pre-clinical applications of this visualization in simulations and cadavers show promising results. The number of x-ray images required was dramatically reduced, and radiation time and dose was also considered to be less compared to the original procedure.



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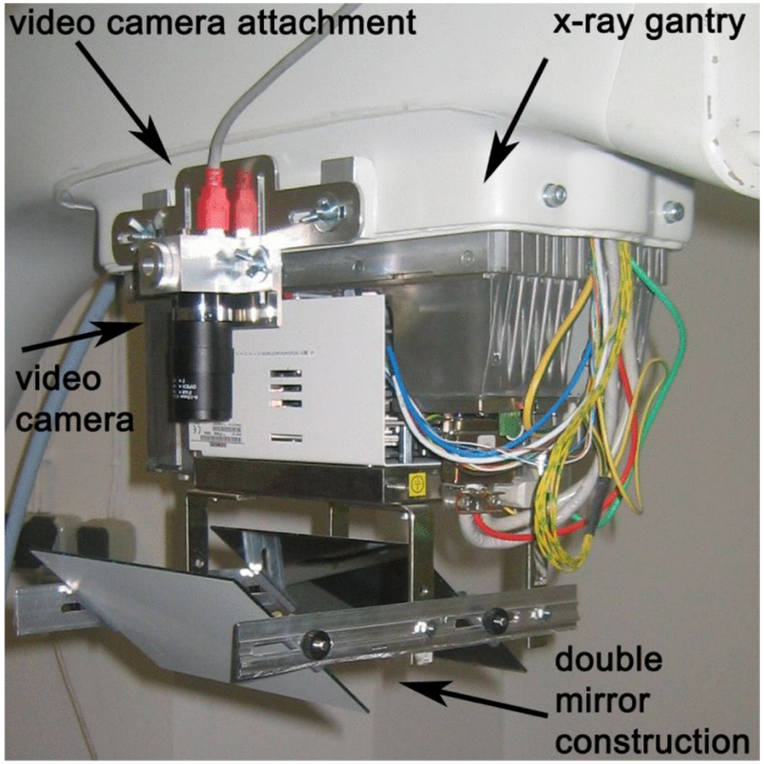
System Overview

The CAMC system mounts a RGBD video camera onto a common intraoperative mobile C-arm with a double mirror system “such that the X-ray source and the camera optical center virtually coincide. To enable an image overlay of the video and X-ray image in real time a homography has to be estimated that maps the X-ray image onto the video image taking the relative position of the X-ray detector implicitly into account.”



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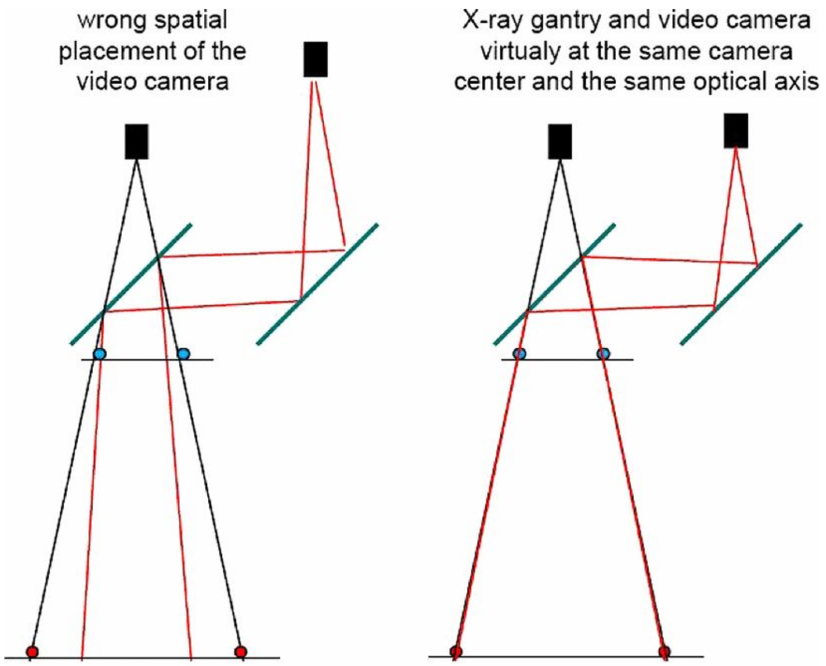
System Calibration

A one-time initial calibration is required to register the optical camera and x-ray. The three step calibration procedure first corrects distortion in each imaging, then aligns the two images, and finally estimates the homography for the image overlay.



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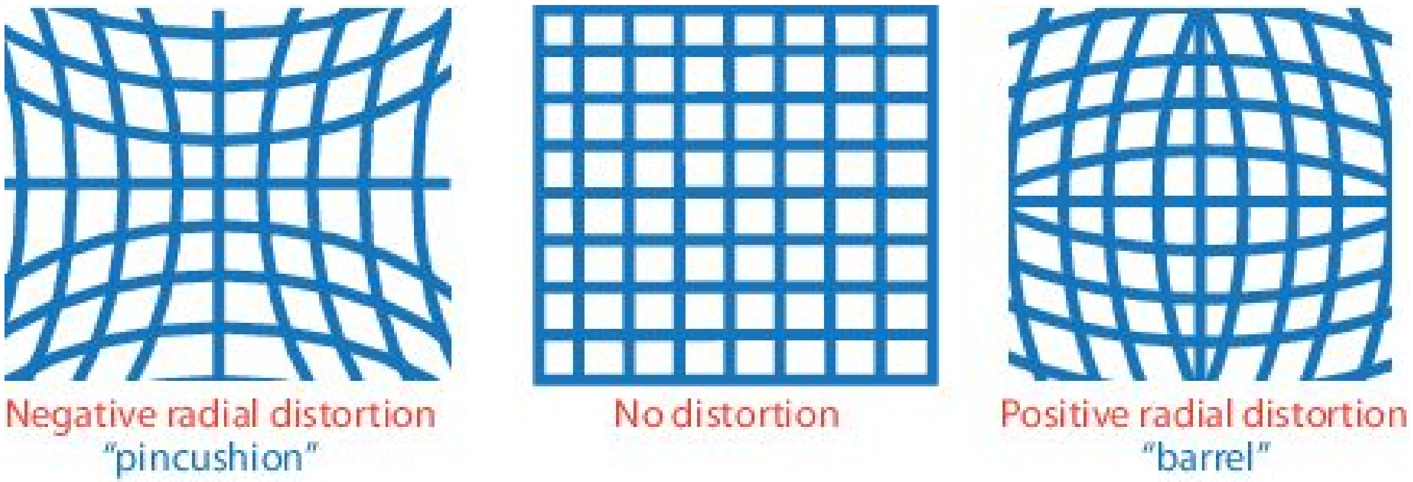
System Calibration - Step 1

Distortion Correction

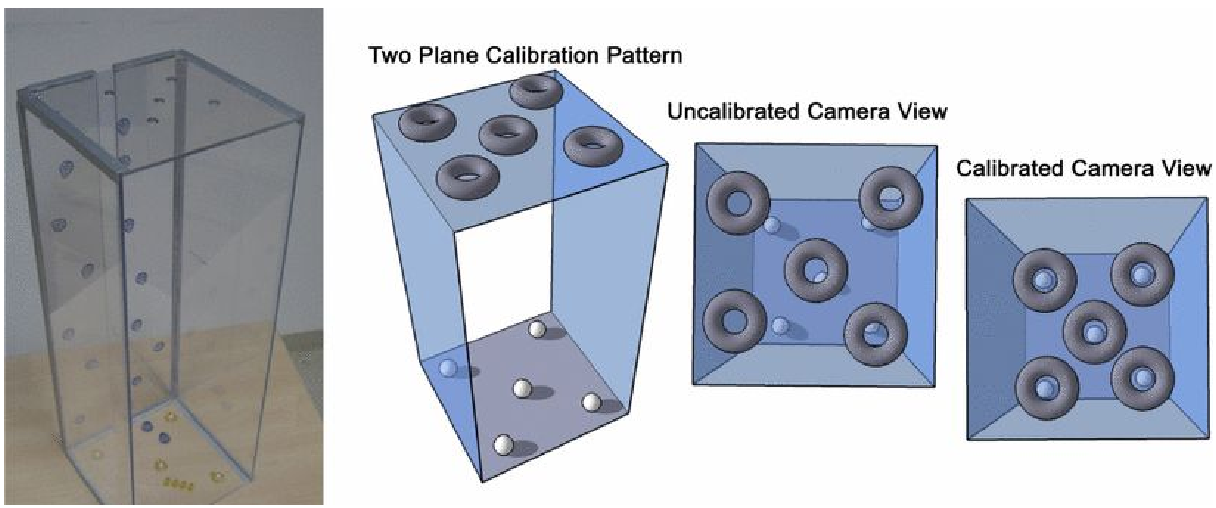
Both the optical video camera and the X-ray imaging have distortions. The optical camera distortion is estimated and corrected using a nonlinear radial distortion model. The vendor provides look-up tables for geometrical X-ray distortion for most common poses of the C-arm.



System Calibration - Step 2

Alignment of X-Ray Source and Camera Optical Center

To align the x-ray source and camera optical center with the double mirror construction, markers are viewed in each modality then the video camera is adjusted until the pairs of markers align. A two-plane calibration pattern of rings and spherical markers such that upon perfect alignment, the spherical markers will be centered in the ring markers.



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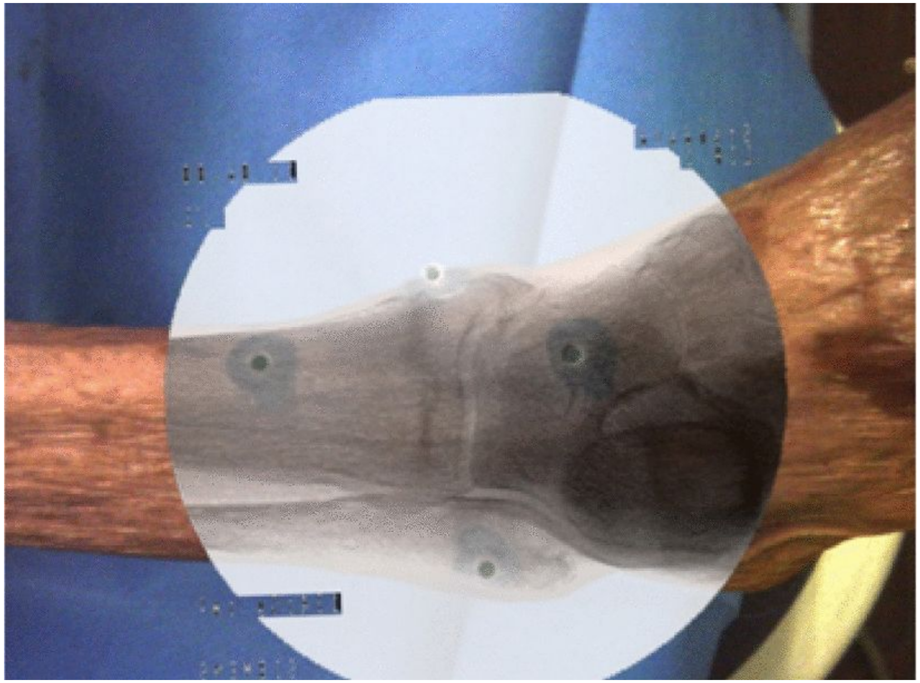
System Calibration - Step 3

Homography Estimation for Image Overlay

The homography H from the image of the video camera to the X-ray image allows visualization by superimposing the X-ray image onto the video image. H is computed by four to 16 corresponding points simultaneously detected by solving the linear equations system and QR Decomposition.



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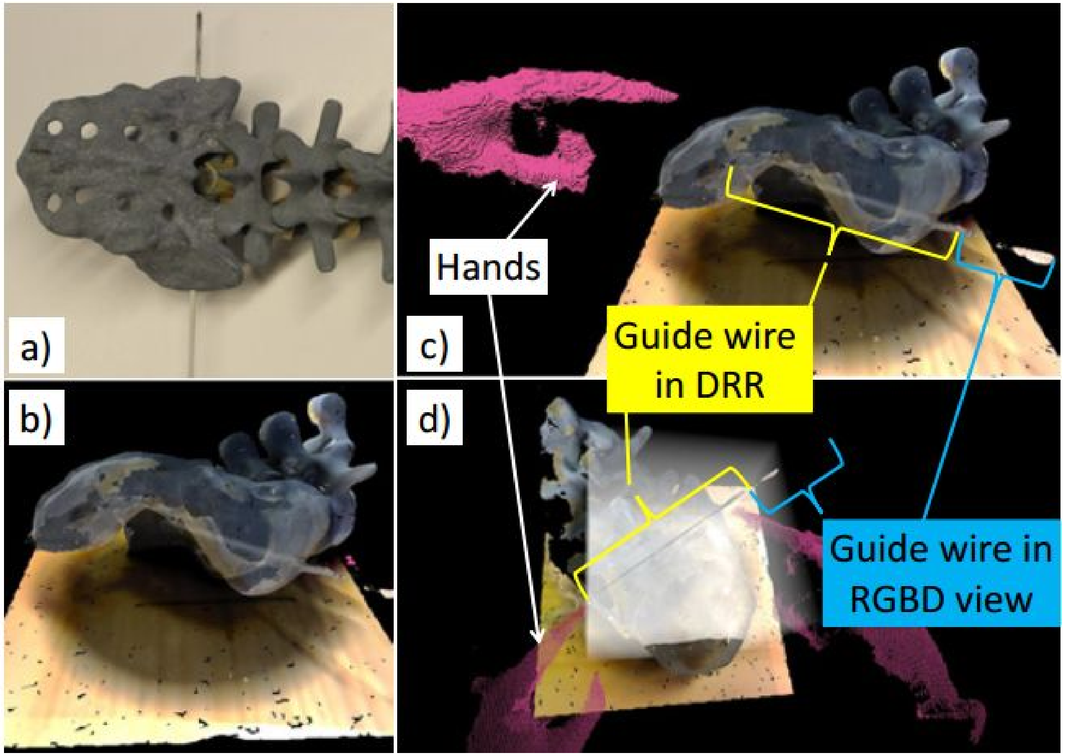
Pre-Clinical Applications

Interlocking of Intramedullary Nails

Pedicle Screw Placement

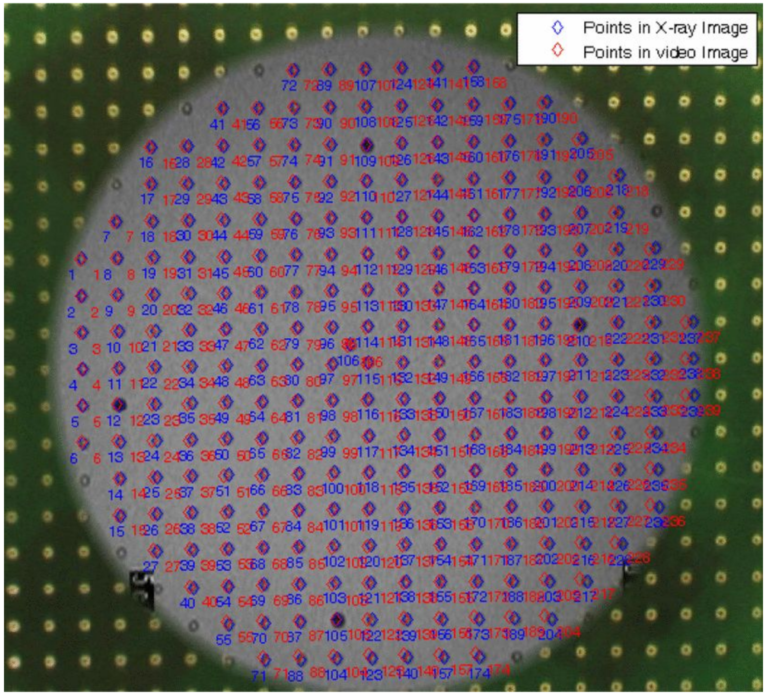
Simulated Vertebroplasty



Sing Chun Lee et al. “Calibration of RGBD camera and cone-beam CT for 3D intra-operative mixed reality visualization”. In: Int J CARS (2016). doi: 10.1007/s11548-016-1396-1.

Results - Accuracy Evaluation

A pattern used for geometrical X-ray calibration and distortion measurement is attached to the image intensifier to detect the accuracy of the image overlay. The markers of the pattern are visible in both X-ray and video images, and the distances between the corresponding points were calculated. The mean error was calculated to be approximately 0.5mm on the plane of the calibration pattern. An accurate image overlay required per-pose re-estimation of the homography.



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Results - Marker Tracking Evaluation

A mechanical device was rigidly attached to the detector plane and moved in 0.5 mm steps to detect the accuracy of marker detection. The results indicated that movement of 1mm or more could be detected. The threshold for non-valid overlay was set to 1.5 pixels to alert the surgeon of misalignment.

	#1	#2	#3	#4	#5
overall duration	15:00	20:10	17:00	9:15	14:46
overall radiation	0.4	0.2	0.4	0.1	0.5
setup time	2:31	0.38	0:20	0:45	2:33
insertion time	8:05	14:32	13:00	5:30	5:11
filling time	4:24	5:00	3:40	3:00	7:02
setup radiation	0.3	0.0	0.0	0.0	0.1
insertion radiation	0.1	0.2	0.4	0.1	0.2
filling radiation	0.1	0.0	0.0	0.0	0.2
placement cat.	A	A	A	B	C

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Results - Radiation Dose Evaluation

It is important to note the CAMC configuration, the source is oriented above the table. The table absorbs 30% of the radiation in standard configurations but the upside-down configuration provides a slightly increased distance between the patient and X-ray source. The radiation dose was evaluated to be 31 microGrays, within acceptable values of local standards.

Conclusions

Pros:

- Thorough explanations of motivation, medical procedures, and system setup
- Clear and helpful diagrams
- Beneficial explanation of the three step calibration

Cons:

- Lacked robust testing of the calibration accuracy
- No comparison to similar methods, or clinical standard for margin of error
- Results of the pre-clinical applications was not quantitative
- Could have used explicit surgeon feedback and suggestions for improvement

Next Steps

This proof of concept has since been improved and expanded to the current project, which now does not require the double mirror construction, nor the markers. It was very helpful to understand the origin of the current project, and many of the other papers mentioned in the background have provided a starting ground for ways to improve the current calibration. The accuracy evaluation process discussed can be used for the current project as well.

Questions?

Reading List

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