AN IMAGED-BASED TECHNIQUE FOR TRACKING C-ARM FLUOROSCOPESWITH AN EXAMPLE USE IN HIGH TIBIAL OSTEOTOMY

Mohammad Amini BSc[1]*, Tiffany Ngo BSc[1], Robert McCormack MD[2], Shahram Amiri PhD[12]

[1]*University of British Columbia, Department of Mechanical Engineering, Vancouver, BC, Canada, mohammad.amini@hiphealth.ca

[2]University of British Columbia, Department of Orthopaedic Surgery, Vancouver, BC, Canada

INTRODUCTION

C-Arm fluoroscopy is extensively used as a qualitative visual feedback tool in orthopaedic surgery. Even though it is very broadly used, C-arm's 2D imaging modality is incapable of providing an accurate 3D quantitative assessment of the operative anatomy. Particularly for large bones, evaluating landmarks outside of the limited fluoroscopic view size can be very challenging, if not impossible. For instance, in High Tibial Osteotomy (HTO) it is challenging to assess the critically important distance between the mechanical axis of the leg (a line passing through the centres of the hip and the ankle) and the centre of the knee joint. The techniques suggested in literature for overcoming these limitation are either limited to providing only two-dimensional anterior/posterior (AP) views (Messmer 2006), or they do not cover a large enough three-dimensional imaging volume for assessment of long operative anatomies (Grzeda 2010). Our research group has previously developed a sensor-based tracking system (TC-Arm) which adds on to C-arm equipment to provide additional quantitative capabilities (Amiri 2014) without the limitations mentioned above. In the previously introduced configuration, external instrumentation was used for kinematic tracking of image locations in three-dimensions. In this study, as an additional module to the sensor-based tracking, an image-based registration technique is introduced that enables tracking along the length of the surgical table with minimally added instrumentation. The system was tested on a composite model of the leg, to include the femur and tibia, to measure the varus/valgus and the mechanical axis deviation (MAD) as typically assessed in a HTO. The accuracy of these measurements was measured in comparison to optically-digitized references.

MATERIALS AND METHODS

In this study, a new image-based tracking module was developed for the previous TC-Arm platform. This module consists of a reference panel with an array of fiducial markers, locations of which are uniquely identifiable in an automated image segmentation process. The 'panel' is designed to cover the length of long operative anatomies (i.e. the entire lower limb) and can be mounted under any conventional radiolucent surgical table. The corresponding image analysis software was developed in MATLAB (2013a) which segments the marker positions in each image and identifies the image coordinates with respect to the panel. Each image's intrinsic and extrinsic parameters are then identified by 2D-3D matching of the panel's 3D model to the marker's epipolar geometries using optimization algorithms. Finally, the defined linear transformation matrices are applied for positioning all fluoroscopic images with respect to the same global reference.

A Sawbone model of the leg was used as a phantom and marked with radio-dense fiducial markers at the centres of the hip, knee, and ankle joints. An Optotrak optoelectronic tracking system was used to digitize marker coordinates (Figure 1A). The phantom was imaged by taking orthogonal bi-planar radiographic views of the three joints and the corresponding marker positions were reconstructed by the TC-arm. To validate the functions of the new module, first the tracking accuracy was determined by taking orthogonal-stereo views from eight equally spaced points along the table retrofitted with the panel and compared to the reconstructed positions of the panel design. Secondly, the TC-Arm results were compared to the corresponding digitized references on the Sawbone model to calculate errors in the varus/valgus angle and the MAD measurements.

RESULTS

The system was able to reconstruct the reference panel's location with 3.6 ± 2.2 mm error in the direction perpendicular to the table (Tx), 1.1 ± 0.7 mm in the direction along the table (Ty), 1.0 ± 0.3 mm in the direction across the table (Tz); rotational errors for reference panel reconstruction for various axes was 0.3 ± 0.2º (Rx), 4.1 ± 3.0º (Ry), and 3.0 ± 2.4º (Rz) (Table 1). Additionally, the measurement accuracies on the Sawbone model was 1.3 ± 0.8 mm for the mechanical axis deviation and 1.4 ± 1.1º for the varus/valgus angle.

A) Panel Reconstruction Accuracies	Translation ± SD (mm)			Rotation ± SD (º)		
	Tx	Ty	Tz	Rx	Ry	Rz
	3.6 ± 2.2	1.1 ± 0.7	1.0 ± 0.3	0.3 ± 0.2	4.1 ± 3.0	3.0 ± 2.4
B) HTO Accuracies	Mechanical axis deviation ± SD (mm)			Varus/Valgus Angle± SD (º)		
	1.3 ± 0.8			1.4 ± 1.1		

Table 1: A) Reconstruction accuracy found by comparing eight equally spaced points along the table retrofitted with the panel and compared to reconstructed positions of panel design. B) Measurement accuracy of the mechanical axis deviation and varus/valgus angle for HTO by comparing digitized references of fiducial markers on Sawbone model with TC-Arm results.

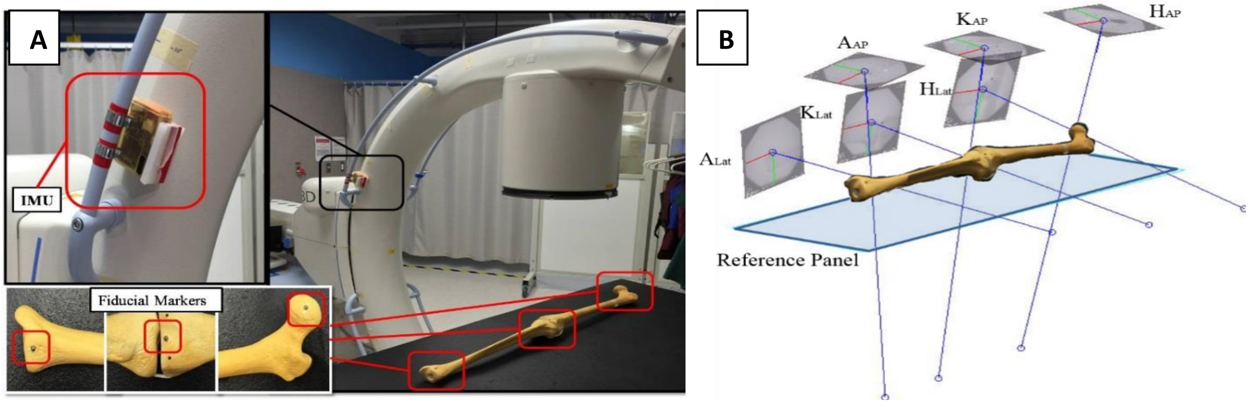

Figure 1: A) Sawbone model of the leg used as phantom with fiducial markers at hip, knee and ankle joint locations set up under TC-Arm with an Inertial Measurement Unit (IMU) location indicated. Reference panel is hidden under the surgical table. B) TC-Arm's 3Dreconstruction of AP and lateral image locations at hip, knee, and ankle joint. The blue box indicates the reference panel location and blue lines indicate x-ray source direction to the corresponding image centres.

DISCUSSION

The new addition to the TC-Arm (Amiri 2014) had a reasonable tracking accuracy (<3.6mm, <4°). Considering the application in HTO surgery, the system measured the mechanical axis deviation for the high tibial osteotomy application with an accuracy of 1.3 mm and 1.4°.Comparing this result with the acceptable tolerance of less than 10 mm for MAD reported in the literature (Paley 2002), our demonstrated results are considered to be within an acceptable range. With the introduced method, the capability for three-dimensional quantitative assessments of operative anatomies for any size can be added to any C-arm equipment in the OR. This can have great potential for many complex orthopaedic trauma, reconstruction, or preservation surgeries (Wang 2010) including high tibial osteotomy. The pilot study results are promising and show great potential for better utilization of a widely accessible OR equipment.

REFERENCES

- Messmer Peter, Matthews Fellix, Image fusion for intraoperative control of axis in long bone fracture treatment, European Journal of Trauma, 32(6), pp: 555-561
- Amiri Shahram, Wilson David R., A low-cost tracked C-arm (TC-arm) upgrade system for versatile quantitative intraoperative imaging, International Journal of Computer Assisted Radiology and Surgery, 9(4), pp: 695 –711, 2014.
- Grzeda Victor, Fichtinger Gabor, C-arm rotation encoding with accelerometer, International Journal of Computer Assisted Radiology and Surgery, 5(4), pp: 385-391
- Paley Dror. Principles of deformity correction. Berlin: Springer, 2002.
- Wang Lejing, Weidert Simon, Parallax-free intra-operative X-ray image stitching, Journal of Medical Image Analysis, 14, pp: 674-686, 2010

DISCLOSURES

The authors listed on this paper do not have industry sponsorships related to the presented research.