AN ACCURATE TECHNIQUE FOR REGISTRATION OF THE ANTERIOR PELVIC PLANE USING MULTIPLE FLUOROSCOPIC VIEWS

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INTRODUCTION

Accurate assessment of the orientation of the pelvis on the operating table is a crucial step for a number of surgical procedures in orthopaedics. The anterior pelvic plane (APP) has been traditionally used as a reference in various pelvic surgeries including a number of trauma, reconstruction and arthroplasty applications. The APP is either manually traced by over the skin palpation in conventional methods, or is identified by digitization or image-based registration techniques in a computer-assisted approach. Manual palpation has limitations because of the presence of a thick layer of soft tissues covering the landmarks and difficulties in accessing these landmarks in a lateral patient pose. Image-based navigation techniques require access to a three-dimensional model produced from a pre-operative image of the patient, and can increase the time of surgery significantly for registration. A quick and accurate method for registering the position and orientation of the pelvis without the need for a three-dimensional image can be a critically important component of a surgical navigation or an image-guided device, with significant impact on efficiency and quality of the surgery.

Recently, we have introduced a sensor-based Tracked C-arm (TC-arm) system that can be added on to conventional C-arm fluoroscopy (a C-shape X-ray imaging system commonly used in surgery) (Amiri 2014a) for producing spatially calibrated imaging views. This system has been suggested previously for registration of the APP in positioning the acetabular cup in a total hip arthroplasty application (Amiri 2012). In this approach, the registration technique takes input from 4 oblique projection views to capture the APP landmarks: the Left and Right Anterior Superior Iliac Spine (LASIS and RASIS) segmented as two points along the length of the iliac crest, and 2 Left and Right Pubic Tubercles (LPT and RPT) segmented as circular arcs. The registration algorithm fits a parametric model of the APP to the radiographic inputs using optimization [Amiri 2014b] (Fig 1-A). Although preliminary tests showed promising results, considerable variability was observed in further tests in link to uncertainties in identifying the ASIS landmarks as singular points on the projections: By definition, the ASIS is the most anterior point on the iliac spine. However, a lack of reference for what direction is the true anterior on an oblique projection makes identifying the ASIS landmarks subjected to uncertainties and subsequently to errors in estimating the true orientation of the APP.

The purpose of the current work is to improve the previous algorithm for a robust registration of the APP, and to evaluate its accuracy and repeatability. The new technique can add to the capability of the available OR equipment for improvements in accuracy and efficiency of pelvic surgery.

MATERIALS AND METHODS

A Tracked C-arm system (TC-arm) (Amiri 2014a) was mounted on a Siemens Arcadic Orbic C-arm. A replica model of the pelvis (Sawbones) were used for validation. To mark the true APP, the model was placed anteriorly on a flat surface laminated with fresh paint; the marked spots on the bone determined the PT and ASIS. Radio-dense ball-bearings of 1.6mm were

press-fitted into the marked spots on the bone. These served as references for the true orientation of the APP in the imaging space. A rig was designed to hold the pelvis simulating a lateral-approach hip arthroplasty, and four oblique views were obtained using the TC-arm system. The system's software interface was used to reconstruct the APP: The PT landmarks were segmented by fitting circular arcs to the anterior ridge of their projections. In the new addition, the software allowed marking the ASIS in the interactive user-interface using the tangential reference to the ipsilateral PT as a guide (Figure 1-B). The user could see the tangential reference moving with the selected ASIS point along the length of the projection of the iliac-crest to maintain the tangency between the PT and ASIS. The imaging was repeated 10 times and the orientation of the APP was reconstructed for each case.

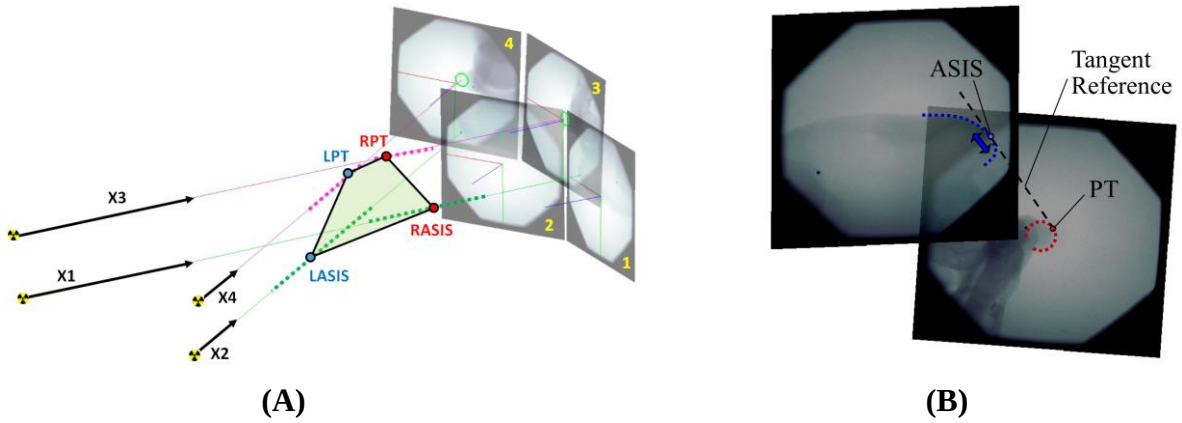

Figure 1: A) To reconstruct the APP, a parametric model of the pelvis was fitted to the landmark epipolars (LPT, RPT, LASIS, and RASIS). B) In the new algorithm the ASIS is segmented using a Tangent Reference as a guide.

To generate a ground-truth reference, keeping the bone in its original position each of the landmarks (Left and right ASIS and PT) were captured in orthogonal (AP and lateral) radiographic views, their coordinates were reconstructed from their epipolars. The orientation of the APP was determined from the reconstructed coordinates of the individual landmarks. Comparison between this reference and result of the APP reconstruction algorithm determined the bias (mean of error) and precision (standard deviation of error).

RESULTS

Results showed accuracy of 1.4° for registering the pelvic tilt and 4.4° for registering the pelvic rotation (Table 1). The overall accuracy of registration of the APP was 4.7°, and the overall precision was 0.82°, showing high repeatability.

	Pelvic Tilt	**Pelvic Rotation**	**Combined (Rot & Tilt)**
Accuracy (°)	1.40	-4.40	4.70
Precision (°)	0.39	0.98	0.82

Table 1: Accuracy and precision of APP orientation calculated against the ground-truth

DISCUSSION

The technique introduced in this study provides a robust image-based method for accurate registration of the pelvic pose based on fluoroscopic imaging. The levels of errors found in this study (<5°) is in accordance with previous studies that recommended a 5° cut-off threshold of error for acceptable acetabular anteversion (Lewinnek 1978). High repeatability observed (SD<1°) suggest a systematic bias, which is expected to be generated because of the

width the iliac crest. If the bias is proved to be consistent, it can be subtracted from the measurements.

Previously a hybrid of digitization and radiographic assessment has been suggested for registering the orientation of the pelvic bone (Grutzner 2004) with precision (SD) of up to 3°. The current method shows 7.5 times improvement in the repeatability of the registration of the pelvic tilt (SD<0.4°). This technique addresses an important challenge in accurate estimation of the pelvic bone which is crucial for reliable placement of the surgical instruments and producing standard radiographic views.

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DISCLOSURES

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