Fast Procedure for Identifying the Current and Desired C-arm Views of an Intramedullary Nail

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Introduction: Intramedullary nail (IM nail) fixation is a popular technique in orthopaedic trauma surgeries. The rod is placed into the canal of the patient’s fractured bone and fixed using metal screws. The action of fixing the IM nail is challenging since the surgeon cannot see the distal holes in the rod after insertion. Although several different methods have been introduced to provide less or no radiation for distal locking of IM nails, each has limitations and disadvantages, resulting in most surgeons still choosing to use the freehand technique. Multiple drillings are often needed, but subsequent drillings can follow the first drill hole and repeated drilling can damage the cortex and cause weak fixation. Freehand techniques for finding the distal holes are mainly based on fluoroscopic imaging (C-arms), in a trial-and-error manner. Longterm use of C-arms can lead to cancer or cataracts in the surgical staff. The ideal view of the IM nail is when the distal holes appear as circles. For any C-arm pose that is different than the ideal view, the distal holes will appear as ellipses; the specific shape depends on the viewpoint. Once the ideal view is acquired, the remaining steps associated with screw fixation are straightforward. The overall goal of our research is to design and develop an IM-nail distal locking navigation technique that leads to more accurate and faster screw placement with less radiation dose, with a minimum number of added steps to the operation, to make it more accepted within the orthopaedic community. The specific purpose of this study was to develop and validate an automated technique for identifying the current pose of the IM nail relative to the C-arm.

Methods: The proposed method requires a biplanar set of X-ray images of the IM-nail’s distal portion (Fig. 1). An accelerometer-based C-arm tracking system has already been developed by our research group (modified from the optical tracking system reported in Amiri 2011 [1]), providing the location of the C-arm’s X-ray source and imaging plane at any arbitrary orientation. After capturing two bi-planar X-rays, the corresponding calibration files describing each image’s intrinsic and extrinsic parameters are interpolated from a previous overall calibration of the imaging space. Accordingly, each of the X-ray images (i.e. intensifier-detector set) can be computationally positioned into the equivalent position as at the time of exposure (relative to a global coordinate system which is located in the operating room). Although each acquired IM-nail image does not have enough texture for the purpose of positioning, thanks to its specific geometric design, we can extract pseudo-features that are conjugate in both of the X-ray shots. The image-processing algorithm is entirely automated, saving a significant amount of time and producing more accurate results for the pseudo-feature extraction. The custom user interface provides a double-check option to the user (surgeon/radiation technologist); if the user does not accept the result, then an enhanced, processed image will be displayed on the monitor so that the pseudo-features can be manually selected by clicking on them (Fig. 1). After feature extraction, the 3D, global position of each feature of interest is computed. Based on the fact that each IM-nail has simple and measurable geometrical properties, a local coordinate system can be located on the centreline of the distal hole. Since each extracted pseudo-feature in the acquired image corresponds to a real geometric component of the IM-nail’s distal part, and since the global positions of each of the described features is computed at this stage, transformation parameters between the local (IM-nail coordinate system) and global coordinate systems can be solved by having more than three corresponding points (because of the number of extracted features, we always have more than three conjugate points) using Horn’s Method (Horn, 1987 [2]). The computed translation and orientation parameters are displayed on the user interface. The radiation technologist can then reposition the C-arm by these amounts to capture the ideal shot. Validation was performed by capturing biplanar images of the IM nail, and comparing the calculated 6 degree of freedom data to that derived by fitting a 3D model of the IM nail to JointTrack bipline open-source software. The CAD model of the IM-nail was created by measuring its dimensions using a vernier caliper (this was sufficient for the relatively simple geometry), and imported to JointTrack software. The validation experiments were performed on an Arcadic Orbic Iso-C C-arm (Siemens AG, Munich, Germany). A metal IM nail was inserted into a plastic foam cube having an arbitrary orientation in space, and then several bi-plane X-ray shots were acquired from the IM-nail’s distal part using the tracked C-arm. For the purpose of accuracy assessment and reliability testing, the 3D global coordinates of the IM nail were also computed using the JointTrack bipline software.

Results: Translations accuracies were less than 0.6 mm in all three directions; rotational accuracies for roll and pitch were less than 2º; rotational accuracy for yaw was less than 3º (Table 1). Computation time was less than 8 seconds (Table 1).

Discussion: In terms of reconstruction accuracy, the described method seems very promising and can fully satisfy the expectations of orthopaedic trauma surgeries. Due to the fact that only two images are required to perform the navigation computations, this method can be simply adapted into current orthopaedic trauma surgeries to have better and more accurate
outcomes of IM-nail fixation. The X-ray images do not need to be calibrated for each IM-nail image (only one time for each C-arm that is used for IM-nail navigation purposes), which is an important advantage over another IM-nail navigation technique (e.g. Leloup 2008 [3]). As described earlier, each additional minute added to the time of surgery will notably increase the operation expenses. Such a system could reduce operating time and radiation dose by reducing the amount of trial and error that currently takes place. The computation time involved in IM-nail navigation using our method and software is remarkably lower than the time needed for finding the distal holes in current methods of orthopaedic trauma surgery. The main limitation of this validation study is that it was only performed for a single IM nail geometry; other geometries will be tested in the future. The next phase of the project is to create a complete system suitable for the operating room, and test it with surgeons and radi-techs.

**Significance:** Distal locking of intramedullary nails for fracture fixation is challenging and typically done by a trial-and-error technique using C-arm imaging. Our automated technique of identifying the current pose of the C-arm compared to that required to achieve the ideal view should improve accuracy, reduce operating time and radiation dose, and improve patient outcome.

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**References:**

![Image: User Interface]

**Table 1: Validation results of navigation method for a specific IM nail**

<table>
<thead>
<tr>
<th>Separation Angle (°)</th>
<th>Computed Translations (mm)</th>
<th>Computed Orientations (°)</th>
<th>Computation Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tx</td>
<td>Ty</td>
<td>Tz</td>
</tr>
<tr>
<td>40</td>
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<td>-37.43</td>
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<tr>
<td>True Values**</td>
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<tr>
<td>Difference at 45°</td>
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<td>0.55</td>
<td>0.08</td>
</tr>
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* Separate angle = the b-planar angle between the two positions of source-detector sets for two X-ray shots
** True values based on JointTrack biplane fitting of a 3D model of the IM nail to the 2D images

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