Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Semi-Automated Intra-Operative Fluoroscopy Guidance For Osteotomy And External-Fixator

Hong Lin, Mikhail L. Samchukov, John G. Birch, Alexander Cherkashin
Texas Scottish Rite Hospital for Children, Dallas, TX, U.S.A

Abstract --- **This paper outlines a semi-automated intra-operative fluoroscopy guidance and monitoring approach for osteotomy and external-fixator application in orthopedic surgery. Intra-operative Guidance module is one component of the "LegPerfect Suite" developed for assisting the surgical correction of lower extremity angular deformity. The Intra-operative Guidance module utilizes information from the preoperative surgical planning module as a guideline to overlay (register) its bone outline semi-automatically with the bone edge from the real-time fluoroscopic C-Arm X-Ray image in the operating room. In the registration process, scaling factor is obtained automatically through matching a fiducial template in the fluoroscopic image and a marker in the module. A triangle metal plate, placed on the operating table is used as fiducial template. The area of template image within the viewing area of the fluoroscopy machine is obtained by the image processing techniques such as edge detection and Hough transformation to extract the template from other objects in the fluoroscopy image. The area of fiducial template from fluoroscopic image is then compared with the area of the marker from the planning so as to obtain the scaling factor. After the scaling factor is obtained, the user can use simple operations by mouse to shift and rotate the preoperative planning to overlay the bone outline from planning with the bone edge from fluoroscopy image. In this way osteotomy levels and external fixator positioning on the limb can guided by the computerized preoperative plan.**

Keywords --- **Preoperative planning, intra-operative guidance, fluoroscopic image, LegPerfect Suite, osteotomy, external-fixator, image registration, Hough transformation.**

I. Introduction

Intra-operative deviations from a pre-operative computerized planning (such as osteotomy level, hinge location relative to the osteotomy, and the orientation of the frame to the limb) often occur for a variety of reasons. These deviations prevent the surgeon from correctly executing the preoperative planning, i.e. they influence the actual outcome of deformity correction compared to the desired outcome as predicted by the preoperative planning program [1]-[3], Fig. 1. To minimize intra-operative deviations and to make the actual operation as close as possible to the preoperative planning are the goals for the intra-operative guidance module. Intra-operative osteotomy and apparatus guidance module works in such way that it combines the surgery planning information provided by our Computerized Preoperative planning module with real-time intra-operative fluoroscopic imaging in such as manner as to overlay (register) the preoperative planning on the fluoroscopic image in real-time. In the registration process, at least three operations must be performed on the preoperative planning. They are rotation, translation and uniformed scaling, and in some circumstances, the projective transformation [4]-[5]. The Intra-operative Guidance module can perform the semi-automated image registration, among which the scaling factor between the preoperative planning and intra-operative fluoroscopic image is obtained automatically by mean of image processing procedure. This image processing procedure includes edge detection and Hough transformation [6]-[10]. The operator of this program will determine the remaining registration parameters such as rotation and translation interactively by matching the bone edge from the C-Arm fluoroscopic image and the bone outline in the preoperative planning with a pointing device such as a mouse. However, the operator of this program could override the scaling factor at manual registration operation [3]. Once the registration operation is accomplished, the surgeon can confirm proper the osteotomy level and external fixator orientation using wires placed over the limb while using the C-Arm the real time C-arm fluoroscopic image on the monitor. The capability of intra-operative guidance module may allow the surgeon to confirm the appropriate osteotomy level, hinge location as well as frame orientation, which will in turn facilitate accurate intra-operative execution of the preoperative deformity correction planning.

II. Methods

A. System Design

Hardware Needed: Intra-Operative Image Guidance module operates on a workstation with a personal computer, a monitor, a keyboard and a mouse. A special hardware attached to the computer is an image capturing board. This Image Capture board will occupy one PCI slot of computer's motherboard. Interfacing through a coaxial cable, the real-time video image signal from the fluoroscopic C-Arm X-Ray machine in OR can be transmitted to the image capturing board in computer. In this way, the real-time fluoroscopic X-Ray image displaying on the computer screen can be obtained. Placed on the operating table, a metal plate of fiducial template in the shape of right triangle with 50mm measurement of both right angle sides within the fluoroscopic X-Ray viewing area is used for scaling factor calibration. A conventional

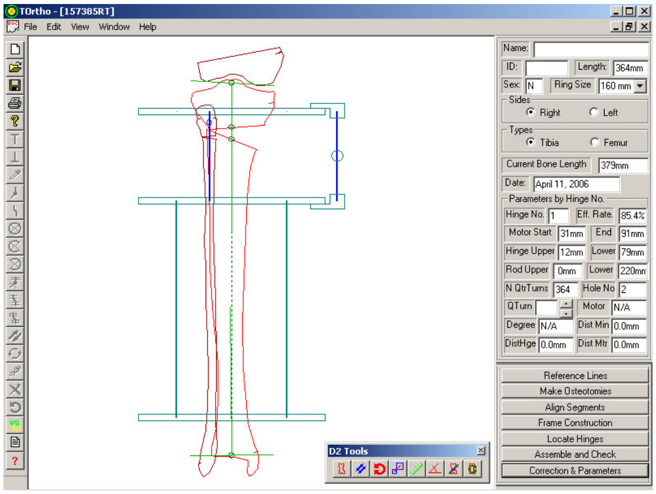

Fig. 1. The preoperative planning of angular deformity correction is made in the ideal condition.

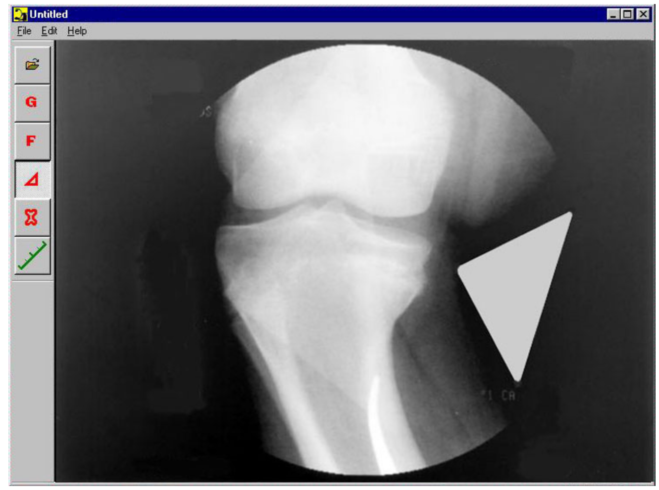

Fig. 2. Intra-operative C-Arm image with triangular fiducial template.

mouse or special type of Joystick could be used by the surgeon or operator to run the system in OR.

Software Module: Running on Microsoft windows operating system, intra-operative guidance module will open up a screen with real-time fluoroscopic image exactly the same as the image displayed on the monitor of the C-Arm X-Ray machine. When the preoperative planning file is opened, the screen will display and overlay the drawings of the preoperative planning over the fluoroscopic image [11]-[14], Fig. 2. Together with the preoperative planning, a marker of right triangular shape with both right sides measured 50mm length relative to bone length in planning will also be drawn next to the drawings of preoperative planning. The module can automatically scale the planning by comparing the area of triangular metal plate in fluoroscopic image and the triangle marker. The area of triangular metal plate in fluoroscopic image is obtained by two-step image processing operations: the edge detection and the Hough transformation on the fluoroscopic image.

User Interface Design: This module has four operating modes (toolbar button) vertically displayed on left side of screen, they are "Capture", "Freeze", "Bones" and "Marker". The "Capture" and "Freeze" are exclusive and the "Bones" and "Marker" are exclusive, like two sets of radio button. Starting with the "OpenFile", the module will be opening up and loading the output of preoperative planning file. By clicking the "Capture", the real-time fluoroscopic C-Arm X-Ray image will be displayed on computer screen, together with the right triangle metal plate.

B. Semi-Automated Planning to Fluoroscopy Registration

In order to guide the osteotomy and apparatus intra-operatively, the bone outline of the preoperative planning and bone edge in C-Arm x-ray image need to be registered. This registration process requires at least three operations. They are scaling, rotating and translation on the bone outline from the preoperative planning. For this purpose, a triangular marker proportionally to the measurement of bone outline is created in the intra-operative guidance module. Placing on the operating table, a non x-ray transparent triangle metal plate served as a fiducial template. The calibration is made such that once the triangular marker is overlaid (registered) with the triangle metal plate in the C-Arm x-ray image, the measurement of bone outline and the apparatus from the preoperative planning would be the same as those in the C-Arm x-ray image.

Automated Metal Plate Registration:
The triangle metal plate is used for the automatic obtaining the scaling factor of planning. Two-step processing of fluoroscopic image is conducted. i) Edge Detection: The edge detection step extracts edges of all objects from fluoroscopic image. Since the fiducial template is in the regular shape of right triangle, three straight lines of its edge in the fluoroscopic image should be extracted [6]-[7], Fig. 3. ii) Hough Transformation: The Hough transformation step finds the straight lines of the edges extracted from fluoroscopic image [8]-[10], Fig. 4. In order to secure that the all three sides of triangle template from fluoroscopy are obtained, the number of straight lines N to be extracted is predefined to be N<=6. This is for the consideration that other objects in the fluoroscopic image may be extracted as straight lines as well. After those straight lines are found, the angle differences of each line are calculated. Since the right triangle template has three vertexes with 90, 45, 45 degrees, three lines passing three sides of triangle can be determined and the lines which do not meet the conditions are eliminated. iii) Triangle Area Calculation: Upon obtaining its three sides, the area of triangle template can be obtained as well. By comparing the areas of triangle

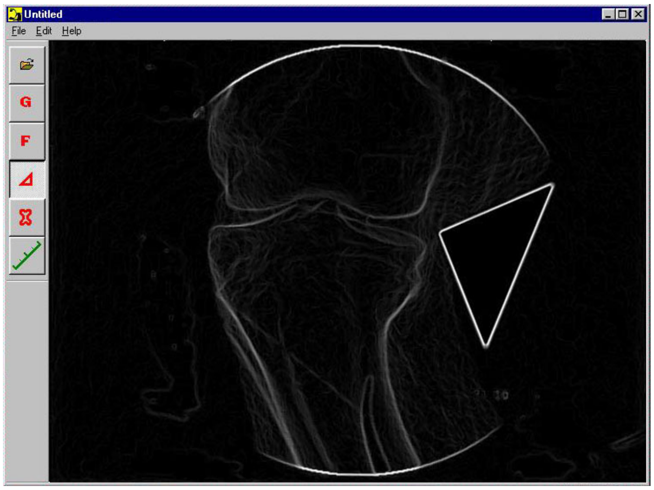

Fig. 3. C-Arm image was edge detected and enhanced

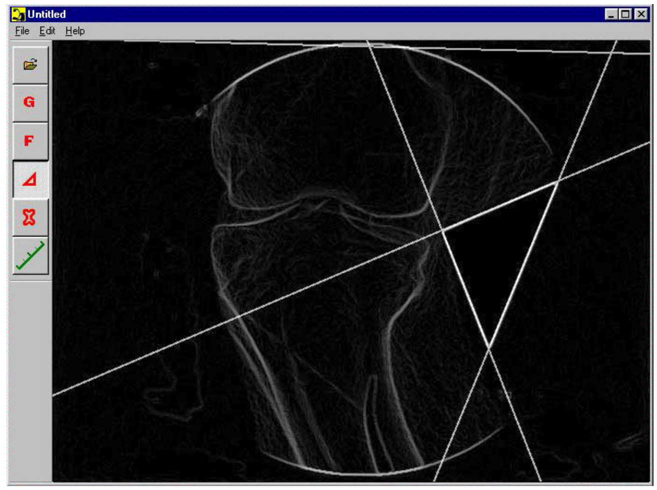

Fig. 4. Four straight lines were detected by Hough Transformation, including three sides of triangle template.

template from fluoroscopy and triangle marker from planning, the scaling factor for the preoperative planning can be determined.

Planning Drawings to Bone Image Registration: After marker registration, the preoperative planning drawings should have scaled proportionally to the bone image in the fluoroscopic x-ray image. Remaining tasks are the shifting and rotating the planning manually until the bone outline of planning drawing is aligned (registered) with the bone edge in fluoroscopic image on screen, Fig. 5. Selecting the "Bone" button on the toolbar, the pointing device operation will switch to the controlling of the preoperative planning. By clicking and holding the left mouse button and moving the cursor pointing on the center of reference line, the whole planning drawing will follow the shifting movement. After aligning the center of reference line with the corresponded center of bone joint, the preoperative planning can be rotated until the bone outline of preoperative planning is fully overlaid (registered) with the bone image from the fluoroscopic C-Arm X-Ray image [3]. In this way, the level of osteotomies, location of hinges as well as frames orientation could be guided by the preoperative planning through the real-time fluoroscopic X-Ray image in the surgical operation.

C. Osteotomy and Apparatus Guidance Procedure

Intra-operative Guidance Operations: The solutions to the intra-operative guidance operations could be classified as the manual guidance solution and automated guidance solution. For the manual guidance operation solution the operating surgeon manually locates the level of osteotomies, position of frames and hinges by watching the real-time fluoroscopic image on the computer screen. The following is the detailed description for the manual guidance solution.

Manual Guidance Solution: After the preoperative planning with real-time fluoroscopic X-Ray bone image registration is accomplished, the surgeon by the patient in the operating room would hold a guiding wire under the C-Arm X-Ray camera to align with the osteotomy by watching on the screen for its movement overlaid with the bone image in the real-time fluoroscopic X-Ray. Once it reaches the satisfied position, i.e. it is aligned or overlaid with the osteotomy drawings from preoperative planning, the marker could be drawn on patient's body, as it is drawn prior to the operation as one of the routine procedures now. The alignment of hinges and frames are starting with the upper or lower most ones, which is the closest to the joints. As same as that of the osteotomy, the markers could be drawn on patient's body for the expected location of the frames implementation as well. After all the markers are in place, the C-Arm machine would be removed from the working area and the osteotomies and frames can be performed and implemented. Since the shifting and rotating operations of the preoperative planning on screen are simple, if the movement of patient occurs, the preoperative planning drawing could be easily re-aligned (re-registered) with bone image from C-Arm image.

There are two other options in displaying the C-Arm image and drawings of preoperative planning. Instead of using conventional computer monitor, a projector or miniaturized head mount screen could be used. The projector operation option needs to add a projector next to the camera of the fluoroscopic X-Ray machine [15]. Instead of watching the computer monitor on a workstation, the surgeons could watch the plannings and image from a screen which is placed anywhere in OR. The miniaturized head mount screen works as a foldable sunglass [16]. The operating surgeons could watch everything on this miniaturized screen without turning his head to the workstation monitor.

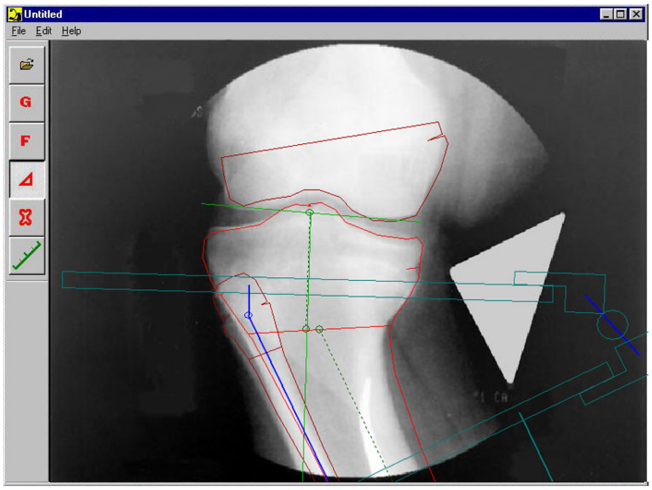

Fig. 5. The planning was properly scaled and aligned with bone edge in C-Arm image.

IV. Discussion

Since the orientation of C-Arm fluoroscopy is often not perpendicular to the operating table, the image of triangle metal plate may be distorted. The projective transformation for registration of metal plate template and triangle marker may be necessary. In the meantime, the angles of triangle vertexes could be away from 90, 45 and 45 degrees as well. However, the distortion of the triangle metal plate could be used for obtaining the direction angle of C-Arm camera, which in turn to be used to determine the projection direction of the bone image from the fluoroscopic C-Arm X-Ray.

Because the distances from C-Arm camera to triangle template and to the bone are different, the magnifications between the two would be different too. In this regard, consideration needs to be taken in order for scaling calibration.

The error of accuracy has not been fully evaluated at this development stage. The maximum on screen measurement error is evaluated and to be found less than 2.0 mm. However, it is expected that the overall accuracy should be within the acceptable range for lower extremity orthopedic surgery. Further study is needed for the error of accuracy evaluation.

Preoperative planning, intra-operative guidance as well as post-operative modification/validation played an important role in assisting the surgical correction of the lower extremity angular deformity in pediatric orthopedic surgery. All these modules in LegPerfect Suite are equally important. The designing concept for the LegPerfect Suite is that each module is providing the suggestions and references. However, the operating surgeons make the final decision.

III. Conclusion

The C-Arm fluoroscopic video signal can be used as a source for intra-operative monitoring and guidance module. This module may assist the surgeon in the operating room to minimize deviations from the preoperative surgical deformity correction plan. Also, deviations from the preoperative plan occurring intra-operatively can be simulated and the outcome predicted to allow intra-operative adjustments in correction strategies.

V. References

[1] R.E. Ellis, "From Scan to Sutures: Computer-Assisted Orthopedic Surgery in the Twenty-First Century", Proc. of 27th Annual Int'l Conf. IEEE/EMBS, 2005.

[2] D. Paley, J. E. Herzenberg, "Principles of Deformity Correction". Springer-Verlag, 2002. pp 175-193.

[3] H. Lin, J.G. Birch, M.L. Samchukov, "Post-operative Adaptation of Pre-operative Planning for Angular Deformity Correction by Radiographic Assessment", Proc. of 25th Annual Int'l Conf. IEEE/EMBS, 2003.

[4] D.L. Hill, P.B. Batchlor, M. Holden et al., "Image Registration", Physics in Medicine and Biology, v46, ppR1-R45, 2001

[5] J.B. Maintz, M.A. Viergever, "A Survey of Medical Image Registration", Medical Image Analysis, v2, n1, pp1-37, 1998.

[6] T. Pavlidis, "Algorithms for Graphics and Image Processing" Computer Science Press, 1982.

[7] J. Canny, "A Computation Approach to Edge Detection", IEEE Transaction On Pattern Analysis and Machine Intelligence, V8, N6, Nov 1986

[8] R.O. Duda, P.E. Hart, "Use of the Hough Transformation to Detect Lines and Curves in Pictures", Comm. ACM 15(1), 1972.

[9] J. Bao, J Gao, "Digital Image Self-Adaptive Acquisition in Medical X-Ray Image", World Computer Congress Beijing, China, 2000.

[10] A. Queisser, "Computing the Hough Transform", C/C++ User Journal, pp24-29, Dec. 2003.

[11] H. Lin, J.G. Birch, M.L. Samchukov, R.B. Ashman, "Computer-aided Preoperative Planning of Lower Extremity Deformity Correction", Proceedings of 14th Annual Int'l Conf. IEEE/EMBS 1992;3:1278.

[12] H. Lin, J.G. Birch, M.L. Samchukov, R.B. Ashman, "Computer assisted surgery planning for lower extremity deformity correction by the Ilizarov method", Proceedings of 1st Int'l Symposium on Medical Robotics and Computer Assisted Surgery, 1994;2;126.

[13] H. Lin, J.G. Birch, M.L. Samchukov, R.B. Ashman, "Computer-Assisted Surgery Planning for Lower Extremities Deformity Correction by the Ilizarov Method", J Image Guided Surgery. 1995;1:103-108

[14] J.G. Wright, N Treble, A.R. Feinstein, "Measurement of Lower Limb Alignment Using Long Radiographs", J. Bone Joint Surg. Br. 1991, 73:721-723.

[15] J.P. Tardif, S. Roy, J. Meunier, "Projector-Based Augmented Reality in Surgery without Calibration", Proc. of 25th Annual Int'l Conf. IEEE/EMBS, 2003.

[16] H. Fuchs, A. State, E.D. Pisano, et al. "Performing Ultrasound-Guided Needle Biopsies from within a Head-Mounted Display", Proc. of Visualization in Biomedical Computing, pp591-600, 1996.