Software Framework for a Surgical Guidance System using Magnetic Markers

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Use of active, optical tracking Surgical Guidance systems provides line of sight problems to the surgeon. We plan to use a new magnetic system, 'Aurora' from Northern Digital Inc. (Canada) and Mednetix AG (Switzerland), in intra-operative fluoroscopy to develop an integrated system for surgical guidance. Here we outline the modules developed for use with this system, including a novel registration method.

1. Summary

Intra-operative fluoroscopy is useful in many percutaneous procedures and spinal surgeries, such as bone biopsy and vertebroplasty. Drawbacks, however, include exposing the surgeon to repeated doses of radiation, obstructing access with the C-arm in the operating area, and the limited number of views available.

A possible solution to these problems is 'virtual fluoroscopy', where an initial fluoroscopic image is captured and a representation of a (tracked) instrument is projected onto the image. This reduces the amount of exposure to radiation during the procedure, allows multiple views and reduces the amount of obstruction from the C-arm during surgery.

2. Previous work

Existing 2D-3D point registration algorithms rely on the availability of a large number of data points; Iterative Closest Point (ICP) and other statistical approaches do not work well with small data sets owing to local minima. Our system is intended to be used with 4 to 6 markers. A recent, and similar, alternative to ICP is 3PLFLS[1] - we will discuss the differences in our approach later.

3. Workflow

The markers will be in view of the C-arm whenever calibration/registration is performed or updated, they could be on the instrument to be artificially rendered itself, or a separate calibration object.

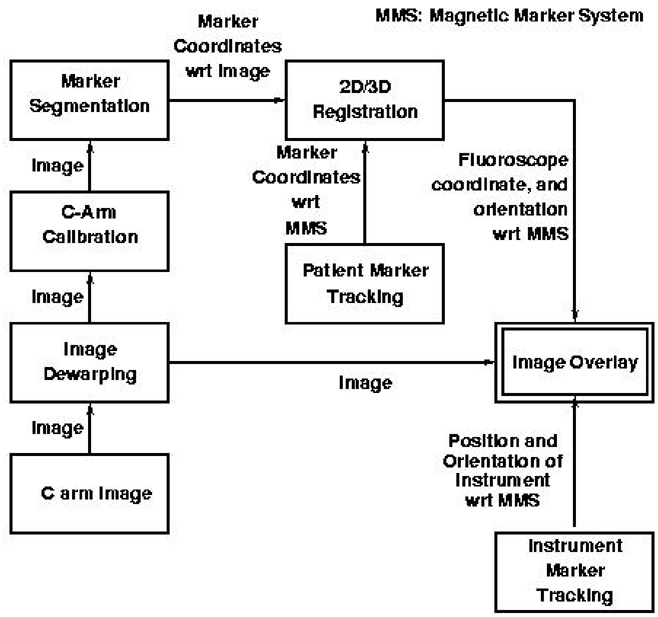

Figure 1. System Diagram of envisioned Virtual Fluoroscopy System

- C-arm image acquisition - A C-arm image is acquired with a frame grabber card.
- Image Dewarping - A patterned aluminum plate is imaged by the C-Arm and the two-pass scan line strategy as shown in [2] is used for building an LUT for dewarping.
- C-arm Calibration - A helix of beads is imaged in the C-Arm and calibration methods shown by Schreiner in [3] are used to determine the intrinsic parameters of the C-Arm.
- Segmentation of markers - Magnetic markers are segmented from the C-Arm images using a generalized Hough Transform and interpolation. The segmented markers are used to compute their 2D coordinates on the image (geometric centers).
- 2D/3D registration - The set of 3D marker coordinates and their corresponding set of 2D image coordinates are used to compute the orientation and position of the camera (C-arm) with respect to the marker coordinate system. The algorithm assumes knowledge of the focal length and image scale. It selects three points out of the set segmented in the image, then cycles through all possible permutations of triangles in

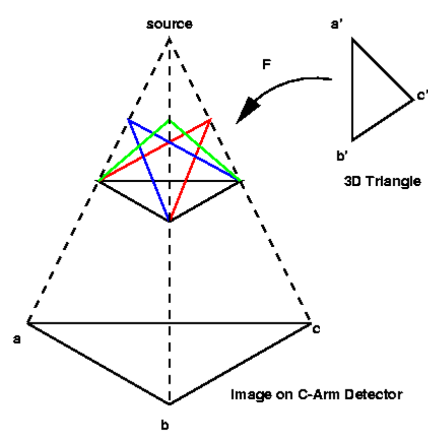

Figure 2. Four poses of a triangle

3D, each of which give 4 different poses (Figure 2), using constraints[4] for a closed-form solution to select the pose with least error. A gradient descent approach is used to refine this pose. Our approach here avoids the use of optimization methods to find point-to-point correspondence[1].

- Marker tracking - As the magnetic marker system is not yet available, we have used the Polaris optical tracking system from Northern Digital Inc. (NDI). The tracking device supplies the 3D coordinates of the markers in its coordinate system.
- Image Overlay - Slicer[5] was extended to take fluoroscope input and project a 3D representation of an instrument onto the image using the previously obtained transformation from tracking system to C-arm space. This stage provides the real-time surgical guidance.

4. Results

The software framework has been tested on real and simulated data sets. Preliminary registration results with artificial data sets (4 and 6 points) and white noise (magnitude 1 mm): average time 7.9s, residual RMS error of 0.5, 4 degree maximum error in the rotation matrix, L2 error in translation of 1.1 mm.

5. Conclusions

The Registration algorithm as developed so far provides quick and accurate solutions. Further degrees of information from the markers should provide us with more opportunities than the existing point-to-point correspondence. We hope to extend this using the orientation and length(in image space) of identified markers.

The final system is envisioned to be a part of a larger surgical aid which can present a surgeon with visualizations of different data sets (fluoroscope, CT data, MRI data) embedded with rendered surgical tools in real time. Further work is required: integration of the system, experimentation in more realistic conditions (animal, cadaver experiments); testing the segmentation algorithm in more cluttered images, and the monitoring of deformations that occur during surgery. Effects on surgical efficiency and operative time will also be examined.

Acknowledgements

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