National Center for Image Guided Therapy | Brigham and Women's Hospital | Harvard Medical School | Philipps Universität Marburg | Surgical Planning Laboratory

A Method for Solving the Correspondence Problem for an n-Camera Navigation System for Image Guided Therapy

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Purpose

Precise navigation or tracking is a key component of image-guided procedures including biopsy, surgery, and radiation therapy. Users of optical navigation systems (that typically comprise of a pair of stereoscopic cameras) are well aware that having multiple cameras covering the field of view significantly facilitates workflow by minimizing the disruption of line of sight between the cameras and the tracked instruments. An algorithmic challenge in the use of an n-camera system for triangulation is the correspondence problem between the $n \cdot (n-1)/2$ resulting different binocular camera systems, and we describe a method for solving it.

Methods

We setup a tetra-optical camera system [1] and used five fiducial markers to localize an object (Fig. 1) or a patient in 3-space. If all fiducial markers are visible to all cameras, and correspondences between them are not known, up to 25 solutions are possible for a camera pair, and 125 for 6 camera pairs (or 4 cameras). Narrowing these to a single solution or knowledge of correspondences between the points leads to a unique solution and is the focus of this work.

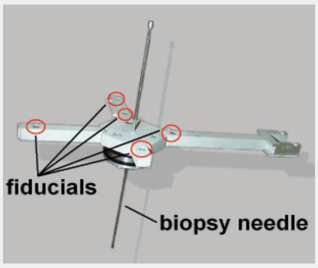

Figure 1.

In a pin-hole camera geometry all image points on one epipolar line correspond to points on a single epipolar line in the second image [2]. If a point in 3-space is visible in *m* images, then the intersection of the *m* resulting epipolar lines is used to reconstruct its 3D coordinates. Because of measurement errors, the lines often do not intersect in a point, and in our algorithm, we develop an efficient method for determining the approximate intersection points of these line clusters. In the case when $m=2$, we compute center point of the minimal distance between the lines. When $m > 3$, we compute the pairwise center points, and average the point cloud of centers thus obtained. The resulting points are matched with the (known) tracker or patient model via translation and rotation [3]. Therefore, we calculate the gravity center of a point cloud (Figure 2). The next images demonstrate step-by-step how a camera-detected model is matched with the tracker model. First the gravity center points for the patient (or instrument) model (Figure 3) and the detected model (Figure 4) are calculated and moved to the origin.

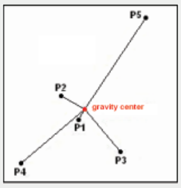

Figure 2.

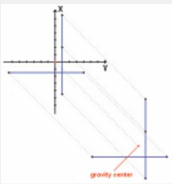

Figure 3.

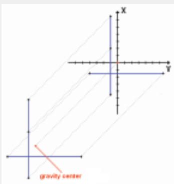

Figure 4.

Next, the point of the patient model with the largest distance to the gravity center is calculated (P_1^{ct}, Fig. 5). Equivalent, the point of the patient model with the largest distance to the gravity center is calculated (P_1^{vk}, Fig. 5). If such a point does not exists for the detected model (within tolerance), we can already skip this model and test the next point cloud. Otherwise the rotation axis and angle (Fig. 6) are determined to rotate P_1^{vk} on P_1^{ct} via the center of gravity (Fig. 7).

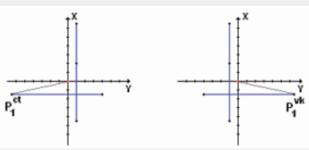

Figure 5.

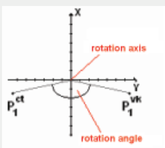

Figure 6.

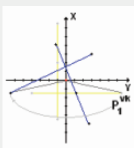

Figure 7.

Then, a second point is calculated for the patient model (P_2^{ct}, Fig. 8) and the detected model (P_2^{vk}, Fig. 8) and the rotation axis (Fig. 9) and angle (Fig. 10 and 11) are determined to rotate P_2^{vk} on P_2^{ct} (Fig. 12).

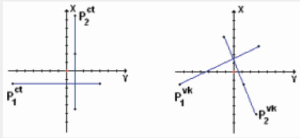

Figure 8.

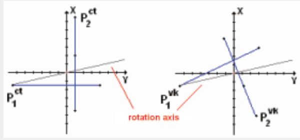

Figure 9.

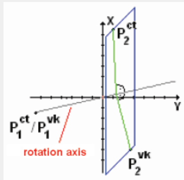

Figure 10.

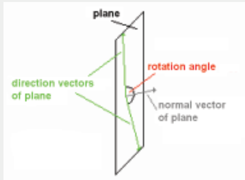

Figure 11.

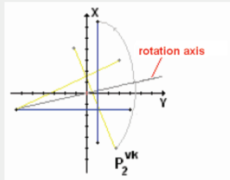

Figure 12.

After the second rotation, both models overlap on three points: the gravity center, P_1 and P_2. In 3-space the remaining three model points should also overlap if the detected model fits to the patient model. Otherwise this detected model can be skiped and the next point cloud is analyzed via translation and rotation.

Results

For evaluation we performed navigation in several scenarios using a tetra-optical camera system. We used standard CCD video cameras (Teli CS8320BC) and LEDs with wavelength of 890±45 nm. The correspondence algorithm was able to recover 3-space coordinates in all experiments, and repeated position measurements of the same position and orientation of the models could be reproduced within 0.5 mm. To accomplish the repeatability evaluation, we fixed the models to a robot (Mitsubishi RV-E2) with a positioning accuracy of ca. 0.4 mm [4]. Figure 13 shows an example for a two camera system where a patient could not be detected, because the patients body covered a fiducial F. Figure 14 presents an example for a four camera system where all fiducials are seen at leats with two of the four cameras. Therefore, the detection of the patient is possible when the correspondence problem is solved with our algorithm. We also measured the absolute deviation for our four camera system. Therefore, we fixed a LED to the Mitsubishi robot and drove the LED to the corners of a cube. Then, we detected the LED in every corner with every camera pair and plotted the resulting cubes into one diagram (Figure 15).

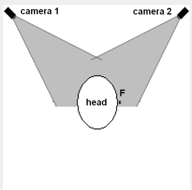

Figure 13.

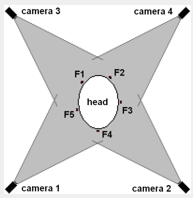

Figure 14.

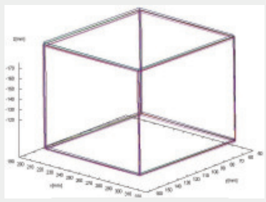

Figure 15.

Conclusions

We have introduced an algorithm for solving the correspondence problem for a multi-camera navigation system that can be used to track patient or instrument position in an operating or interventional suite. Compared to using a single stereo pair, a multi-camera navigation system allows a significantly larger field of view and is more robust to occlusions caused by breach of line of sight. Such a system is being planned for the ***A**dvanced **M**ultimodality **I**mage **G**uided **O**perating (AMIGO)* Suite of the ***N**ational **C**enter for **I**mage **G**uided **T**herapy (NCIGT)* funded in part by the NIH Grant P41RR019703 [5].

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[5] National Center for Image Guided Therapy (NCIGT), *Advanced Multimodality Image Guided Operating (AMIGO) Suite* funded by NIH Grant P41RR019703 (http://www.ncigt.org/pages/AMIGO)

4th NCIGT and NIH Image Guided Therapy Workshop, October 12-13, 2011, Crown Plaza Hotel, Arlington, Virginia.