Electromagnetic Anchor Tracking for Soft Tissue Navigation

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Abstract

The compensation of intraoperative (rigid) movements and the detection and compensation of deformations is still a big challenge for navigation systems in soft tissue and in particular liver surgery. Although most clinical navigation systems are based on optical tracking systems recent improvements enable navigation systems based on electromagnetic tracking systems. With electromagnetic tracking systems it is possible to measure continuously locations of sensor coils inside the body. We present an algorithm to compensate (rigid) movements and detect deformations of soft tissue like liver parenchyma based on locations inside the tissue. We performed an ex vivo experiment with a turkey breast. The position of a target point was predicted by the algorithm and this prediction compared to the direct measurement of the target point by the electromagnetic tracking system.

Schlüsselworte: Electromagnetic navigation, liver surgery, deformation, registration

1 Problem

The exact intraoperative location of the tumor and adjacent vessels is an important information for the surgeon in oncological liver surgery, which can be provided by navigation systems. In contrary to conventional navigation in neurosurgery or orthopaedic surgery the liver like other soft tissues changes its shape significantly between preoperative image acquisition and the intraoperative intervention. Therefore optical navigation systems based on intraoperative 2D [1] and 3D [2] ultrasound have been developed to capture the current liver position and shape. To detect movements or deformations during the actual resection new ultrasound acquisitions have to be performed, which disturb the surgical procedure. A continuous monitoring of movements and deformations at relevant locations would improve the efficiency and accuracy of the navigation. One possibility for such a monitoring are optical fiducial needles introduced by Meier-Hein et al. [3] for percutaneous radiofrequency ablation of liver lesions. The optical trackers have to be placed outside the liver due to line-of-sight restrictions of optical tracking systems. However with electromagnetic tracking systems it is in principle possible to measure locations of sensor coils *inside* the liver [4]. Recently sensor coils with ever smaller diameters below one mm have been developed enabling their insertion directly into the liver. Besides the position of the sensor coils also their orientation is measured. The question is how these orientation information can be used in addition to the position information to compensate rigid movements and detect deformations of the liver in order to indicate the necessity to acquire new ultrasound data for an electromagnetic navigation system.

2 Methods

2.1 Electromagnetic Navigation System with Anchor Sensor Coils

The basis of the navigation system is the electromagnetic tracking system Aurora from Northern Digital Inc. (NDI). The position and orientation of 5 and 6 degrees of freedom (DOF) sensor coils are measured by the system. This means a 5 DOF sensor coil measures translations in three directions and rotations about two axes. The rotation around the sensor axis can not be determined, in contrast to a 6 DOF sensor coil. A 3D ultrasound machine (GE Voluson 730 Expert) is used for intraoperative imaging. The position and orientation of the ultrasound transducer is measured by a 6 DOF sensor coil and the position and orientation of a pointer instrument by two 5 DOF sensor coils. We developed anchor sensor coils which are inserted and fixed in the liver and which can be sterilized and are biocompatible. A 5D sensor coil with a diameter of 0.8 mm and a length 11.0 mm has been integrated into a shrinkable tubing together with a marker wire usually used for the preoperative marking of breast lesions (see Fig 1). This marker wire has two wire tips which are anchored in the tissue. The anchor sensor coil is inserted by a cannula and can also easily be pulled back into the cannula to reposition or remove the anchor. At least two of the 5 DOF anchor sensor coils have to be inserted into the liver to measure a translation (three directions) and rotation (around three axes) of the tissue. We assume that in clinical practice not more than four sensor coils will be inserted into the liver.

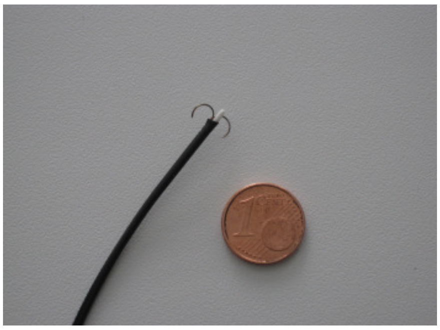

Fig. 1: Small anchor sensor coil with a one cent coin for size comparison.

2.2 Compensation of Rigid Movements by Landmark Registration with Orientations

Each 5 DOF anchor sensor coil provides the position of a point inside the liver and a direction (rotation about two axes). When the intraoperative ultrasound image is acquired also the reference positions and directions of the anchor sensor coils are measured. To compensate rigid movements after the image acquisition the current positions and directions are rigidly registered by a landmark-based registration method. A simple approach to integrate the directions into the landmark-based registration procedure is to transfer the directions into artificial point landmarks. Therefore to the position of a sensor coil the direction vector is added to get the additional artificial point landmark. The length of the direction vector is a weighting factor between point positions and directions. We used a length of 1 cm.

2.3 Detection of Deformations

To detect deformations the fiducial registration error (FRE) that means the average of the residual differences after rigid registration is computed. If the FRE is above a given threshold the surgeon gets a warning that deformations have been detected and a new ultrasound image should be acquired.

3 Results

We evaluated the presented algorithm on an ex vivo turkey breast phantom. Four anchor sensor coils were placed into the turkey breast with the help of injection needles (Fig. 2, left). Three different series with 300 measurements each were performed. At first the phantom was not moved or deformed at all and only the random scatter of the location measurements was determined. In the second series the phantom was moved rigidly (translated and rotated) by hand on a plastic plate while measuring the position and orientation of the sensor coils. In the last series the turkey breast is manually deformed and again the position and orientation of the sensor coils measured (Fig. 2, right).
We used the three measurement series for the evaluation of the presented algorithm in two different scenarios. In the first scenario the rigid movement is compensated and the deformations detected by three sensor coils and the forth sensor coil defines and measures the position of a target point. The difference between the measured and computed target points position is called the target registration error (TRE). In the second scenario only the position and orientation of two sensor coils are used to determine the position of a target point defined by one of the other two sensor coils.

For the first scenario we got the following results. If the phantom is not moved the average TRE over all 300 measurements is 0.2 mm. For rigid movements an average TRE of 2.3 mm was measured. If the phantom is deformed the average TRE increases to 10.9 mm. For the second scenario also 0.2 mm average TRE was measured, if the phantom is not moved, 3.0 mm, if the phantom was moved rigidly, and the average TRE increases to 8.6 mm if deformations were induced.

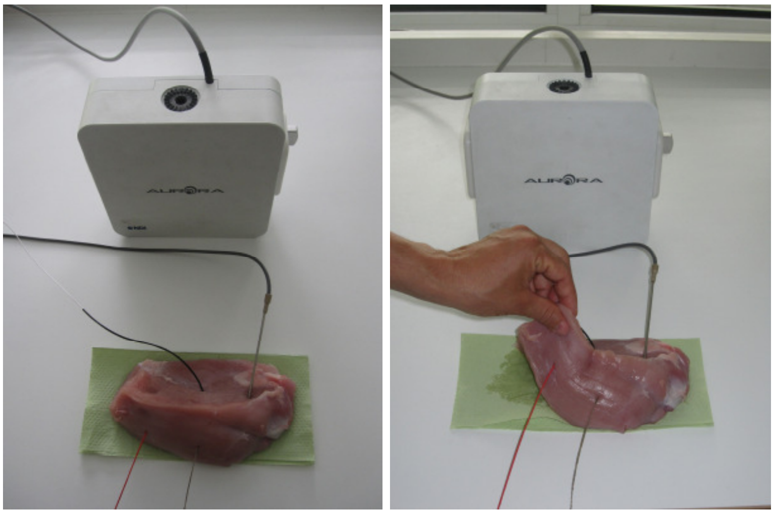

Fig. 2: A turkey breast phantom with four sensor coils inserted which locations are measured by the Aurora tracking system (left). The phantom is moved rigidly and deformed manually (right).

4 Discussion

We presented an algorithm for compensation of rigid movements and deformation detection of soft tissue based on anchor needles inserted into the liver. In an ex vivo experiment it has been shown that rigid movements can be compensated with three anchor sensor coils and even with two. Before clinical application we will investigate other variants of the algorithm for example presented by Liu et al. [5]. Clinical measurements will show if it is necessary to implement also a compensation strategy for deformations by non-rigid registration.

5 References

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