Anatomy-specific tissue scanning with robotically-controlled imaging instruments

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Introduction

In Minimally Invasive Surgery (MIS), tissue scanning with imaging probes is required for subsurface visualisation to characterise the state of the tissue. However, scanning of large tissue surfaces in the presence of motion is a challenging task for the surgeon. Hence a robot-assisted local tissue scanning was designed in our work. We designed a new cylindrical marker for pose estimation, which performs well in all directions. Vision information from marker and kinematics information from surgical robotics is used to implement the calibration from PSM (Patient Side Manipulator) base to ECM (Endoscopic Camera Manipulator) base before tissue scanning. A Kalman Filter is applied to fuse vision information and kinematics information, which can improve the accuracy of pose estimation during automatic tissue scanning. We also plan to employ previous calibration result and images generated during the movement for re-calibration after moving the ECM for a better field of view.

Method

1. Pose estimation

Automatic tissue scanning requires the pose of ultrasound probe w.r.t ECM. The transformation can be described by using PSM end effector pose w.r.t ECM and a rigid transformation ${}^{P}T_{E}$, which can be calculated before tissue scanning. The core of work is to estimate the end effector pose w.r.t ECM using exist information.

1.1 Cylindrical marker

Cylindrical marker we designed can provide vision information for pose estimation (${}^{M}T_{C}$). It uses the lines which are composed of feature center and geometry to calculate pose except rotation along x axis and use combination of horizontal and vertical blobs to orient x axis.

Compared with planner marker, our marker works well in all directions.

Compared with chessboard, the lines composed of feature center can provide more robust pose estimation.

1.2 Fusion with kinematics (Kalman Filter)

Sometimes, cylindrical marker may be invisible because of occlusion. The kinematics (${}^{B}T_{E}$), which is controlled by dVRK controller, can provide additional information to filter the noisy vision-based pose[1]. This is the first methods combine the marker-based method and kinematics information.

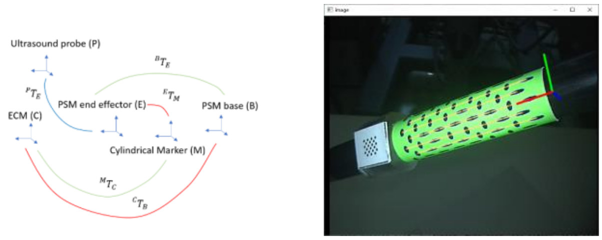
A Extend Kalman filter is used to fuse both kinematics and vision information. State vector of Kalman filter contains position, direction in quaternion format, linear velocity and angle velocity. The update process is a nonlinear system, which can be described as follow formulas.

$$x^{t} = x^{t-1} + v * \Delta t$$

$$q^{t} \approx q^{t-1}(1 + \frac{1}{2}\omega * \Delta t)$$

2. Continuous calibration

To use ${}^{B}T_{E}$ and ${}^{M}T_{C}$ estimate end effector pose w.r.t ECM , the transformation of ${}^{E}T_{M}$ and ${}^{C}T_{B}$ should be calibrated as an AX=YB problem[2]. Previous work have not considered the movement of ECM during surgery. If the cylindrical marker is out of FoV (Field of View), the ECM requires movement to make the marker is always in FoV. By using the images captured during movement, continuous calibration can calculate the new transformation of ${}^{E}T_{M}$ and ${}^{C}T_{B}$.



(a) (b)

Figure 1 - (a) A description of coordinate systems and related transformations. Blue lines – rigid transformation requiring calibration before tissue scanning. Green lines – flexible transformation. Red lines – rigid transformation requiring calibration during tissue scanning (b) Cylindrical marker and pose estimation result. RGB coordinate system – the pose of marker. Orange lines - lines that are composed of feature center.

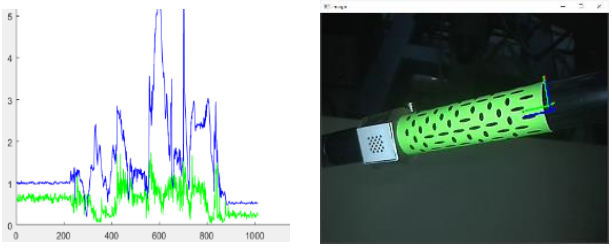
Evaluation

1. Pose estimation accuracy test

The motion control requires that the PSM end effector pose w.r.t ECM. ${}^{E}T_{M}$ is rigid transformation. Therefore, our evaluation focuses on comparing marker pose w.r.t ECM from different routes and ground truth. Ground truth is provided by KeyDot marker [1]. KeyDot marker is precise enough. We captured 10 images which is close to ECM to calculate the transformation from KeyDot to cylindrical marker. After initial calibration, we can estimate the marker pose w.r.t ECM using the kinematics and vision information. The comparison is shown in Fig. 2. According to the result, cylindrical marker has better performance than kinematics information. An adaptive weight method [4] will be applied to fit the different accuracy.

2. Automatically tissue scanning accuracy test

We plan to use the same methods as Zhan et al. [3] used in their work.



(a) (b)

Figure 2 - (a) Pose estimation error of marker-based method (Green) and kinematics-based method (Blue). (b) Pose estimation result. Red – ground truth. Green – marker-based method. Blue – kinematics-based method

Current and further work

1. Current work

Marker design: We designed a cylindrical marker, which has higher robust and better performance in all direction.

Initial calibration: Before the surgery, an initial calibration is applied to calculated the transformation between PSM base and ECM.

Fusion: We applied an Extend Kalman Filter to fuse the vision and kinematics information.

2. Further work

Motion control: To implement autonomous tissue scanning, we need to control the PSM along expected trajectory. A motion control by using pose estimation result will be applied to realized the function.

Continuous calibration: By using the images captured during movement, continuous calibration can be realized.

Improvement in fusion method: We plan to use Unsent Kalman Filter to improve the performance of pose estimation.

References

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