Intraoperative Fiducial Tracking in TORS

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Introduction

The base of tongue tumors has become a significant health care concern nowadays. When doing the transoral surgery, expert surgeons always rely on experience to remain correctly oriented with respect to critical anatomy. Such practice leaves considerable room for improvement and has brought TORS-TransOral Robotic Surgery, which is a minimally invasive surgical intervention for resection of base of tongue tumors.

Image guidance with stereoscopic video augmentation is a critical process in some TORS systems. Intraoperative fiducial tracking is a basic and essential step towards the video augmentation.

We have developed and implemented a method to do intraoperative fiducial detection and tracking, which mainly consists of three steps:

- Use color and edge characteristics to detect the frame which encompasses the three fiducials
- Use color and position characteristics to detect the fiducials
- Apply Kalman filter to track the fiducials in videos

The Problem

Identify and segment critical oropharyngeal structures from preoperative images → Deformably register these data to the intraoperative endoscopic view on CBCT → Register the intraoperative CBCT with planning data to the endoscopic video

It can be interpreted as ${}^{video}T_{CT} = ({}^{video}T_{CBCT})({}^{CBCT}T_{CT})$, and $Data_{video} = ({}^{video}T_{CT})\ Data_{CT}$. Calculation of the former, ${}^{video}T_{CBCT}$, is based on the 3D position of rigid fiducials in both coordinates.

Current existing method to find ${}^{video}T_{CBCT}$ is a manual process which is based on user input, either by the operator using 3DUI virtual cursors of MTMs, or by placing tool tips of PSMs directly onto the sphere, which would require robot-to-tooltip calibration. A method doesn't depend on user input could let the user focus more on the surgery and enhance the consistency.

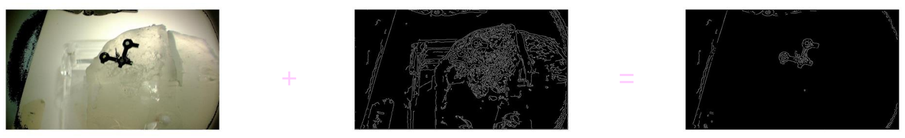
The binocular vision system of the da Vinci robot uses the fiducial position in each camera to get its 3D position in the video coordinate. The automatic fiducial tracking method should detect the fiducials based only on the 2D camera image.

The Solution

The method we've developed is based only on the 2D intraoperative image to track the fiducials. User input during the surgery is not necessary.

- Fiducial Frame Detection

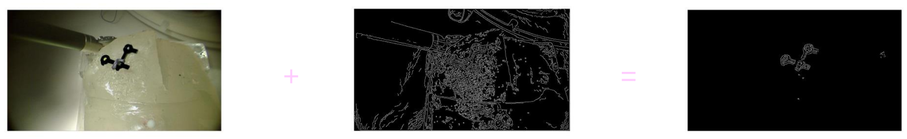
Case 1:



RGB color information (much noise) + Gray image Edge information (much noise) = Fiducial frame with noise (much less noise)

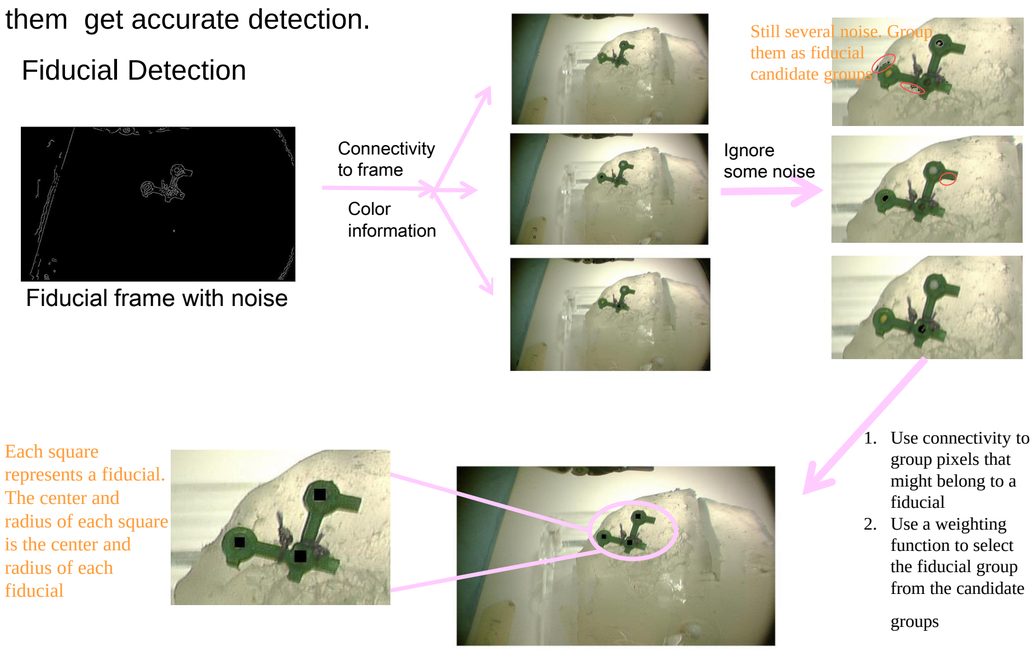
Case 2:

(Video)



Case 1 and Case 2 are of different illumination condition, so the noise differs, but both of them get accurate detection.

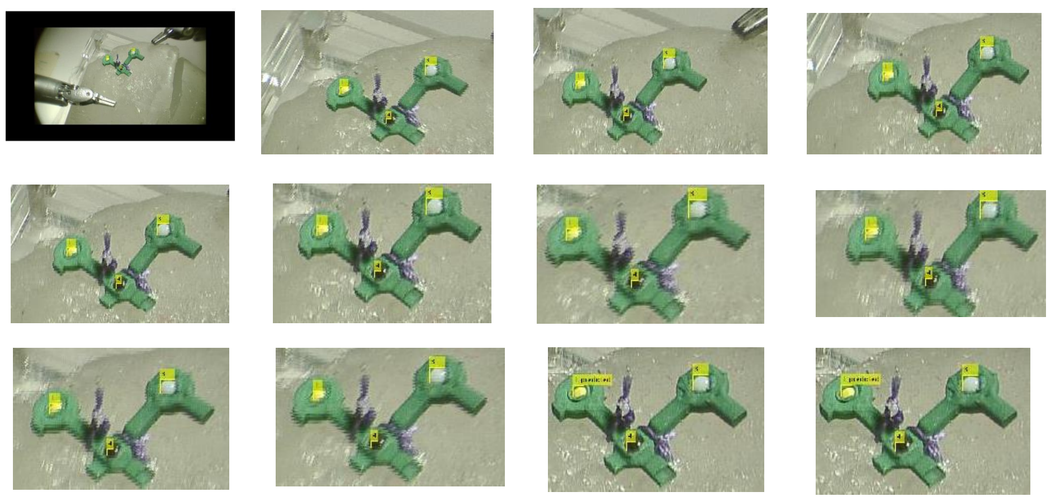
- Fiducial Detection



- Apply Kalman filter for tracking
  - Detect fiducial for each frame of video
  - Apply Kalman filter to find fiducials, of which the detections in the previous step are missing
  - Use the Matlab "multiObjectTracking" and associated functions for implementation
  - The tracking is based on motion with the assumption that all objects move in a straight line with constant speed

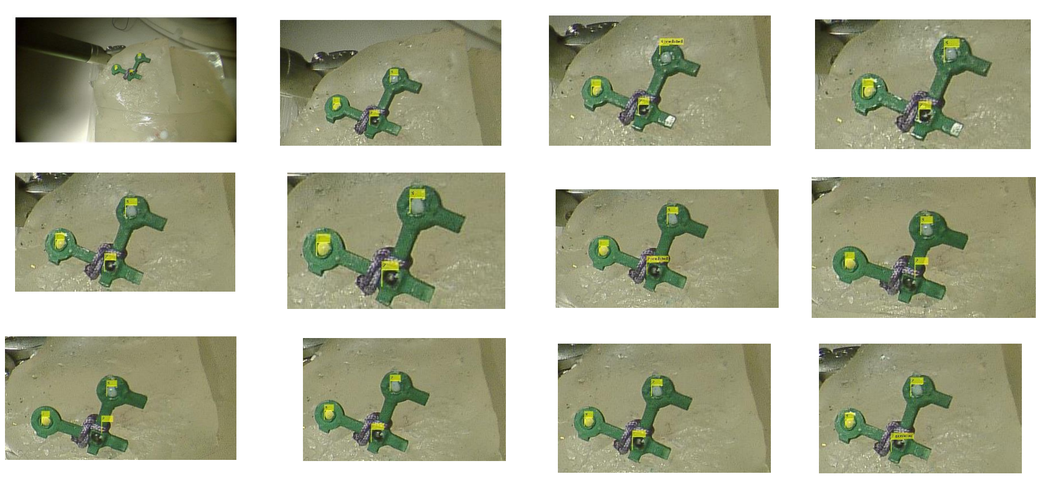
Outcomes and Results

- When the rigid fiducial is flatwise placed and yawing :

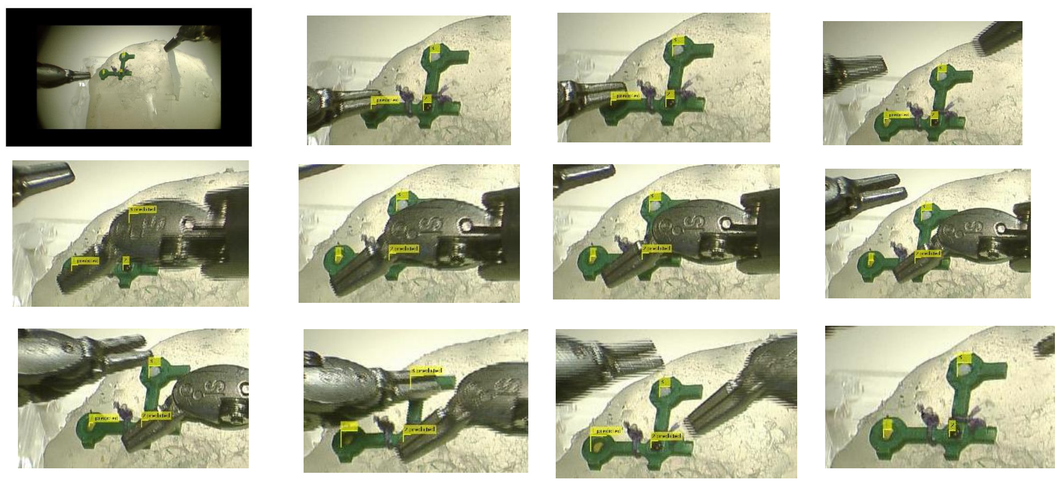


(selected frames between 10 to 70, mostly consecutive)

- When the rigid fiducial is pitching:



- When the fiducial is occluded for some video frames:



- Summary:

The outcome of my project can be evaluated by looking at the fiducial bounding box, showed in each of the images above. The algorithm is robust for yawing and occlusion, but for large angles of pitching, the black fiducial is always detected wrong. It is because the RGB value of the black fiducial changes largely according to shading and reflection, while at the same time, shading can make the RGB value of other pixels quite similar to that of the black fiducial.

For example:

A solution for this is to redesign the color of the black fiducial, to make it more unique.

Future Work

Given the opportunaty to continue this project, I plan to

- Redesign the fiducial
- Check the tracking result of the intraoperative videos
- Rewrite the code using cisst

Lessons Learned

- Color image segmentation
- Active Contour without edges algorithm
- Libraries of Cisst
- And don't underestimate the difficulty of a project before getting the desired outcome

Acknowledgements

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