Endoscopic Reconstruction with Robust Feature Matching

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Abstract

Feature matching based 3D reconstruction is a standard technique in 3D Computer Vision. An natural extension is to reconstruct dynamic surfaces from videos, such as reconstructing sinus from endoscopic videos. However, since the camera is moving and the surfaces are more or less deformable, the feature matching is not always satisfactory. We will employ a state-of-the-art feature description and matching strategy called Hierarchical Multi-Affine (HMA) for endoscopic feature representation. The main goal of this project is to develop methods for surface reconstruction from endoscopic videos. Specific tasks includes:

1. to build up the 3D endoscopic reconstruction pipeline;
2. to validate the pipeline's performance under a baseline design;
3. to test the pipeline's performance with improved components such as **more robust feature matching**.

Background, Specific Aims, and Significance

[*Descriptions in the following are cited from a NIH-funded project proposal with permission.*]

1. **Background of endoscopic reconstruction**. It is estimated that there are more than 200,000 functional endoscopic sinus surgeries (FESS) procedures performed annually in the United States at a cost of several billion dollars annually. As the name implies, all of these procedures are performed under endoscopic guidance, and a large fraction employ **surgical navigation systems to visualize critical structures that must not be disturbed during the surgery**. Although navigation is widely employed for FESS, its capabilities are far from optimal. In particular, **the sinuses contain structures that are smaller than a millimeter in size**, and yet delineate critical anatomy such as the optic nerve or the carotid artery. However, the accuracy of navigation is 2 mm under near ideal conditions. As a result, **navigation can provide a qualitative sense of location**, but final confirmation of anatomic structures ultimately relies on the surgeon's ability to interpret and relate the CT image to the endoscopic view. This process, which is further complicated when the anatomy is distorted or otherwise altered by surgery, requires time, skill and experience and can lead to errors in judgement that adversely affect outcome.

2. **Aims of this course project**: To develop methods for surface reconstruction and optionally further shape estimation from endoscopic videos. In detail, we propose to develop algorithms that are able to compute a surface reconstruction from video to an accuracy of 0:5 mm so that anatomic changes and surgical progress can be measured at any point of a procedure.
3. **Significance of endoscopic reconstruction**. The significance of our work is the introduction of a paradigm shift in surgical navigation by using a device present in every endoscopic surgery, namely the endoscope, to **improve registration and visualization of anatomy**. This will have numerous positive impacts. Most importantly, our work will provide an inexpensive, non-invasive, radiation-free method to enhance registration accuracy at any point of the procedure. Enhancements in registration will reduce ambiguity for the surgeon during surgery, enhancing confidence, and improve workflow by reducing the need to re-register or re-image the patient. The endoscope will also be used as a measurement device to update anatomic models during a procedure. This not only will improve the ability of the surgeon to visualize the progress of the surgery, but it will accrue additional benefits to the patient and hospital, as it may reduce the level of radiation exposure and cost by eliminating the need for intraoperative CT imaging.

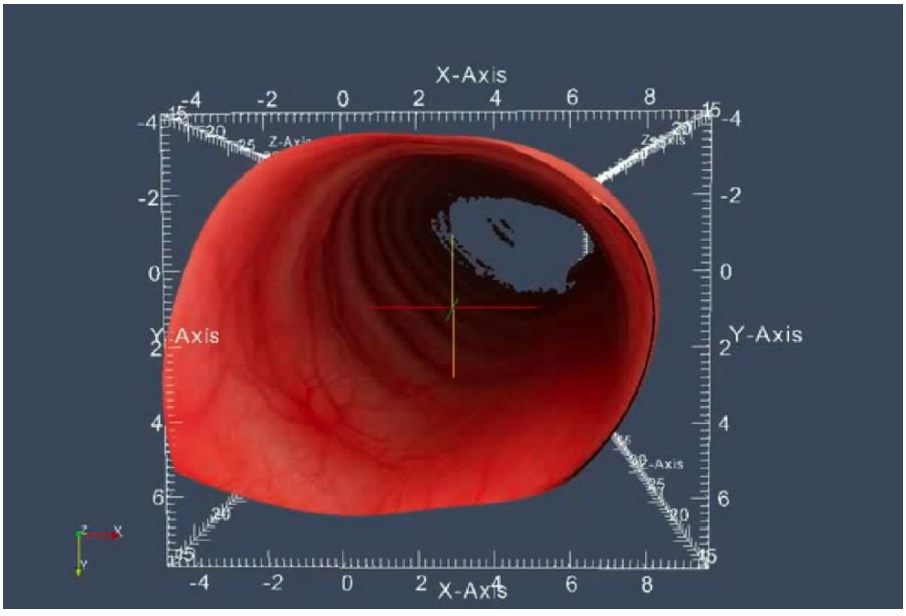


Figure 1. The visualization of reconstruction result, which this project aims to produce.

Technical Approach

The Hierarchical Multi-Af ne (HMA) algorithm for fast and accurate feature matching is illustrated in the figure below. Its basic idea is to represent a plane or surface using multiple affine-transformation components.

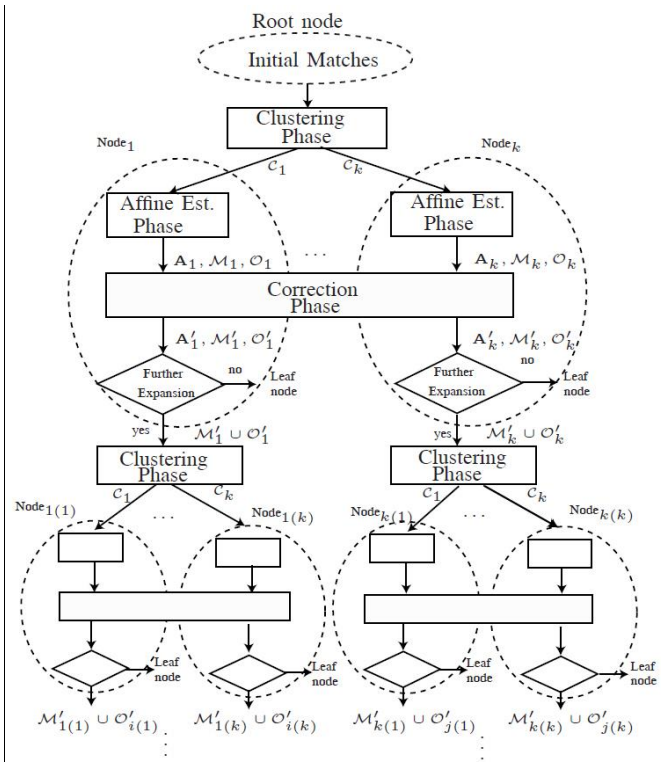
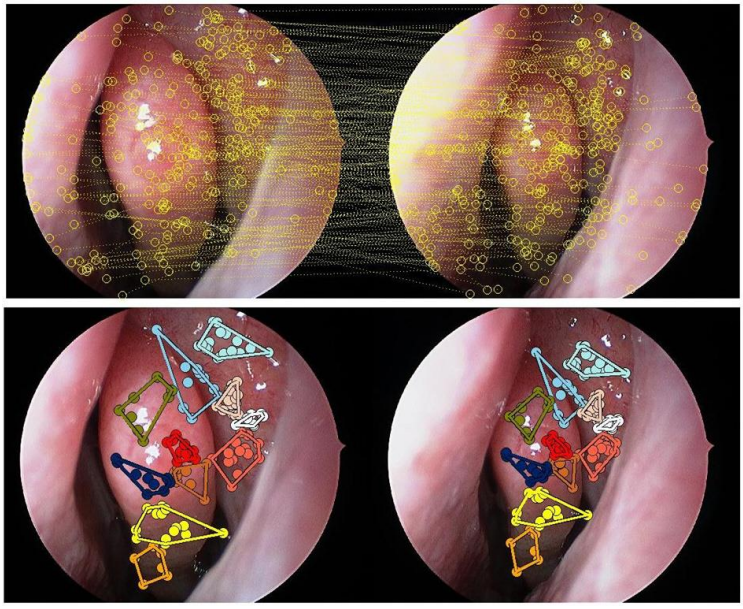


Figure 2. Figure from G. A. Puerto-Souza and G. L. Mariottini. Hierarchical Multi-Affine (HMA) Algorithm for Fast and Accurate Feature Matching in Minimally-Invasive Surgical Images. 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems October 7-12, 2012. Vilamoura, Portugal.

The comparison between SIFT raw matching and HMA matching is shown below.



(Patient data, distributed with permission.)

The 3D reconstruction pipeline is shown in the figure followed.

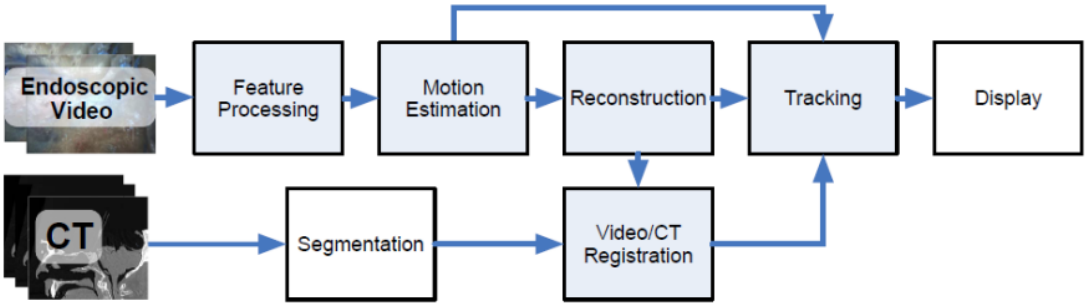


Figure 3. Figure from [*Mirota etal 2012*]: D. Mirota, H. Wang, R. H. Taylor, M. Ishii, G. L. Gallia, and G. D. Hager. A System for Video-Based Navigation for Endoscopic Endonasal Skull Base Surgery. IEEE Trans. Med. Imaging, 31(4), 963-976 (2012).

Deliverables

- **Minimum:** (Expected by 7th April - 14th April)
    1. Matlab program for robust feature matching by HMA algorithm.
    2. Feature matching validation experiments, analysis and documentation.
    3. C++ Program for motion estimation by RANSAC and 5 point algorithm.
    4. Motion estimation validation experiments, analysis and documentation.
    5. C++ program for video-CT registration by Trimmed ICP algorithm.
    6. Video-CT registration validation experiments, analysis and documentation.
- **Expected:** (Expected by 21st April - 28th April)
    1. Program for 3D reconstruction.
    2. 3D reconstruction validation experiments, analysis and documentation
- **Maximum:** (Expected by 9th May)
    1. Experiments for the holistic pipeline and documentation.

Reference

1. D. Mirota, H. Wang, R. H. Taylor, M. Ishii, G. L. Gallia and G. D. Hager. A System for Video-Based Navigation for Endoscopic Endonasal Skull Base Surgery. IEEE Trans. Med. Imaging, 31(4), 963-976, 2012.
2. G. Puerto, M. Adibi, J. Cadeddu1 and G. L. Mariottini, Adaptive Multi-Affine (AMA) Feature-Matching Algorithm and its Application to Minimally-Invasive Surgery Images. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 2371 - 2376, Sept. 25-30, San Francisco, California, 2011.

3. G. A. Puerto-Souza, and G. L. Mariottini. Hierarchical Multi-Affine (HMA) algorithm for fast and accurate feature matching in minimally-invasive surgical images. 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems October 7-12, 2012. Vilamoura, Algarve, Portugal.
4. G. Puerto and G. L. Mariottini. A comparative study of correspondence-search algorithms in MIS images. Medical Image Computing and Computer Assisted Interventions (MICCAI12), Nice, France, 2012.
5. G. A. Puerto and G.L. Mariottini. A Fast and Accurate Feature-Matching Algorithm for Minimally Invasive Endoscopic Images". IEEE Transactions on Medical Imaging, 2013.
6. R. I. Hartley and A. Zisserman. Multiple View Geometry in Computer Vision. Cambridge University Press, ISBN: 0521540518, second edition, 2004.
7. R. Szeliski. Computer Vision: Algorithms and Applications. Springer, 2010.