Challenges in navigational strategies for flexible endoscopy

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Purpose

Flexible endoscopy is the technology of choice for endoluminal interventions. Additionally, screening programs for colorectal cancer are started in several countries. The increased demand of flexible endoscopies requires technological solutions to increase safety and efficiency of endoscopy procedures. Currently, the non-intuitive and non-ergonomic steering mechanism form a barrier in the extension of flexible endoscope applications. Automating the *navigation* of endoscopes could be a solution for this problem.

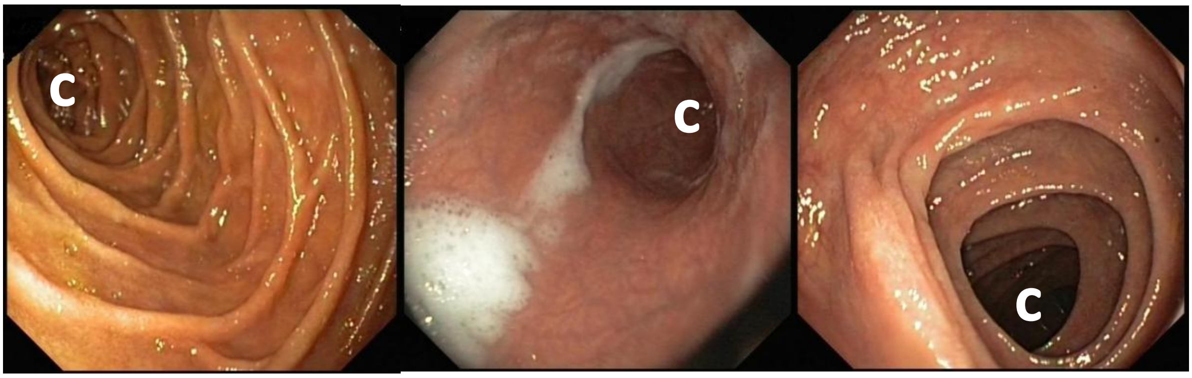

Figure 1: Images, produced by flexible endoscopes, depicting a variety of lumen views.

Several research groups have tried to automate flexible endoscope steering. In this earlier research the technique of *dark region detection* or *lumen centralization* was explored. As can be seen in Figure 1, the center of the lumen (**C**) is the deepest area of the environment, and mostly appears as a darker area in the images. Depth and image intensity for instance, can be discriminated on images to identify the deepest or darkest part of the image. This makes both techniques suitable for finding the center of the lumen. Steering is subsequently based on keeping the lumen center in the center of the image. It is assumed that by doing so, the endoscope will travel towards the center when the endoscope is inserted. This technique thus influences *tip direction*. However, this approach implies the assumption that the endoscope always travels in the viewing direction of the camera. As the endoscope is flexible, this is not always the case (Figure 2).

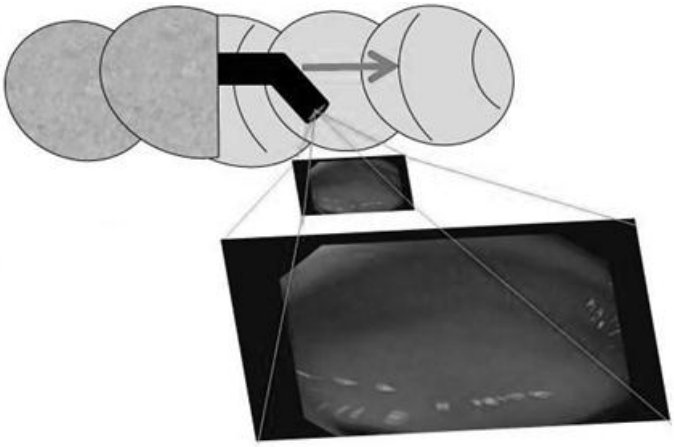

Figure 2: Situation in the flexible endoscopy procedure. The tip of the flexible endoscope is bent and the camera produces a wall view. Lumen centralization will lead to the conclusion that the tip direction has to be corrected. However, the endoscope is already traveling towards the lumen center and does not have to be corrected.

We have demonstrated the feasibility of a new approach earlier: optical-flow based endoscope steering. 'Optical flow' is the technique that calculates the displacement of image features between two images. From this displacement, the traveled path and camera motion can be derived (except for a scale factor). If this camera motion is known, and the target position is known, a more accurate and robust navigation strategy for flexible endoscopes is within reach.

However, in flexible endoscopy both the endoscope and the environment are flexible. This makes calculating camera motion from optical flow challenging. There is an unknown relation to what motion is present in the real world (3D) and what displacements this motion causes in the optical flow field (2D). It is known however, that when the camera makes a translational motion, the optical flow field produces a radially outward pattern. The center of this pattern, the Focus of Expansion (FOE), then corresponds to the current heading direction of the camera.

This still does not explain what happens when the camera rotates. Therefore, the image sequences, produced during a colonoscopic procedure, are recorded together with EM tracking data. From the EM data, the relation between 3D (translational and rotational) motion and the corresponding optical flow field can be obtained. The goal is to find the optimal optical flow algorithm to derive camera motion from the endoscopic images.

Methods

Different optical flow algorithms were used to analyze image displacement on five test sequences of varying difficulty. This was done to establish the best preprocessing steps and settings of each algorithm. Pixels of human colonoscopy test images were displaced over a known distance. The settings that led to the most equivalent optical flow results, were accepted as the standard settings of the algorithm. Accuracy of the algorithm with the corresponding preprocessing steps was determined from the FOE outcome. The automatic results were compared to the results of human observers, who manually indicated the FOE. The algorithms were ultimately compared on computational speed, number of failed frames and accuracy.

Next to a heading direction we need a target direction. This direction is obtained using a lumen detection algorithm. Manual indication of the lumen by medical doctors was used as the golden standard in this case, and the automated results were compared to this using a correlation analysis.

After this is established, the algorithms are applied to the image sequences of colonoscopy exams. Orientation data of these exams are obtained in vivo using the Olympus Evis Exera I, or in vitro using the NDI Aurora magnetic detection system. The orientation outcome is used as the golden standard and compared to the optical flow results.

Results

Optical flow algorithms are most sensitive to motion blur artifacts. In movies where this was the main artifact, the poorest accuracies were obtained. Bubbles, for instance from rinsing activities of the endoscopist, had less influence on accuracy. Lumen detection could be performed satisfactory in the test image sequences. The search algorithms will be combined and applied to the EM-tracked colonoscopic image data. We expect the results obtained from the EM data to correspond satisfactorily to the automated data, especially during translational motion at normal speed. However, rotational motion is more difficult to obtain from optical flow data. Moreover, the EM tracking is less accurate for rotational motion, which makes the golden standard less reliable.

Conclusion

Automating flexible endoscope navigation could lead to an increase in patient safety for endoluminal therapeutic procedures. Additionally, it may decrease the costs of diagnostic flexible endoscope procedures by shortening the learning curve and increasing the efficiency of insertion. Earlier attempts at automating the navigation have, to our knowledge, not succeeded yet. We think this is mainly due to false premises about the dynamic interaction between the endoscope and the environment. In the current research, we show that an alternative approach can be used to establish camera motion with respect to the environment. Combining the knowledge of the traveled path with the knowledge of the target location shows potential of solving the navigational problems in automating flexible endoscopy.