Group 13: An Improved GUI and Visual Navigation of the Robo-ELF
600.446 Computer Integrated Surgery II, Spring 2012
Paper Review

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Paper: "Robotic Assistance to Flexible Endoscopy by Physiological Motion Tracking", *Laurent Ott, Florent Nageotte, Member, IEEE, Philippe Zanne, and Michel de Mathelin, Senior Member, IEEE*

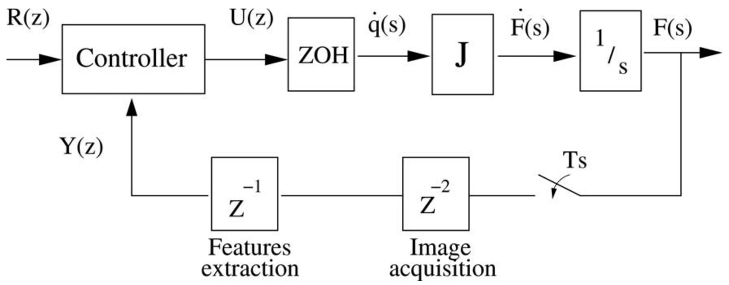
Overview:

This paper presents the work of a group from the University of Strasbourg, developing a robotically assisted flexible endoscope for minimally invasive surgery. They develop methods to automatically compensate for patient breathing motion and for motor backlash. They present an in-lab experiment using an artificial phantom and an *in vivo* experiment with an anesthetized pig. In the paper, the group describes the design of their system, their basic control scheme using visual servoing, derivation and validation of a kinematic model for the endoscope, methods for compensating for periodic breathing motion and motor backlash, and experimental results of their system.

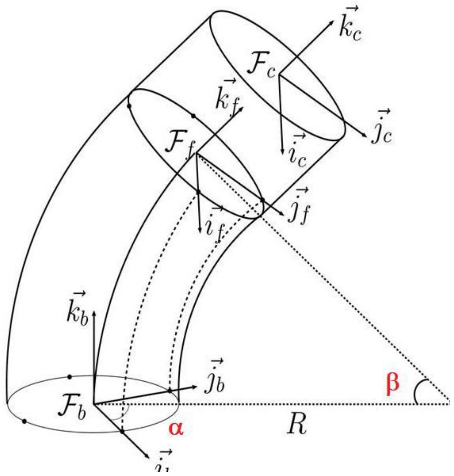
This paper was selected because the goals and methods of the work are very similar to our own. We are also developing a system to robotically control a flexible endoscope, and there are, to our knowledge, few projects similar to ours anywhere. We have had to find a kinematic model for our flexible endoscope, just as the Strasbourg group does. Part of our future work includes developing the methods described in this paper to compensate for breathing motion and motor backlash. If we decide to adapt our current system for a bronchoscope, both of these techniques will be necessary additions, and the work presented in this paper will be invaluable to our efforts.

Methods:

The robotically controlled endoscope system consists of a modified endoscope, motor controllers, a video processing unit, and a computer running compensation and control algorithms. The group modified an existing endoscope by replacing hand control wheels with two hollow shaft motors that directly drive the two axes of motion in the scope, rotation about the scope axis and flexing of the tip. They used a standard PID controller to drive the motors. The desktop computer ran code to implement a visual servoing control loop:

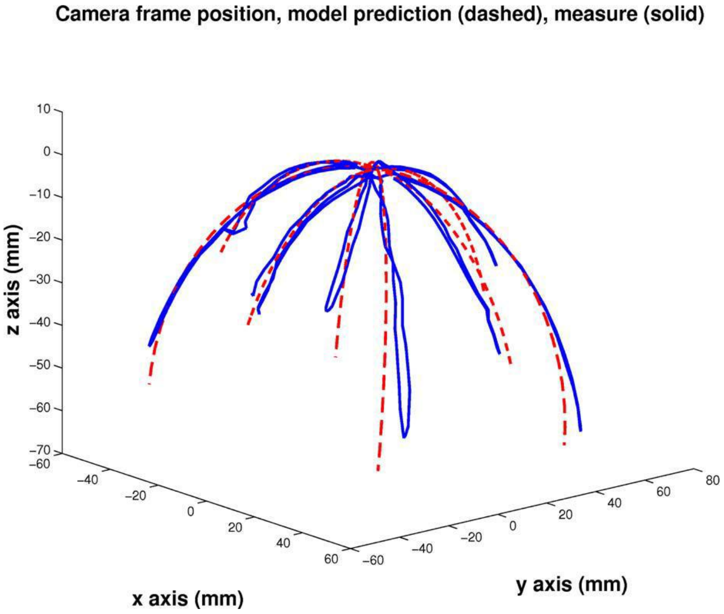


A kinematic model for the endoscope is required to perform the control methods. The flexible scope tip was modeled geometrically as a continuum robot with the camera affixed to the end. Using this model it is possible to calculate two critical angles, labeled α and β in the diagram below, and a transformation between the camera frame, Fc, at the tip of the flexible end and the non-flexible body of the scope, Fb. Both angles can be directly related to the motor positions, which are connected to the flexible tip via cables. Using this information to build a kinematic model, the velocity of the camera frame can be related to the velocity of the motors.



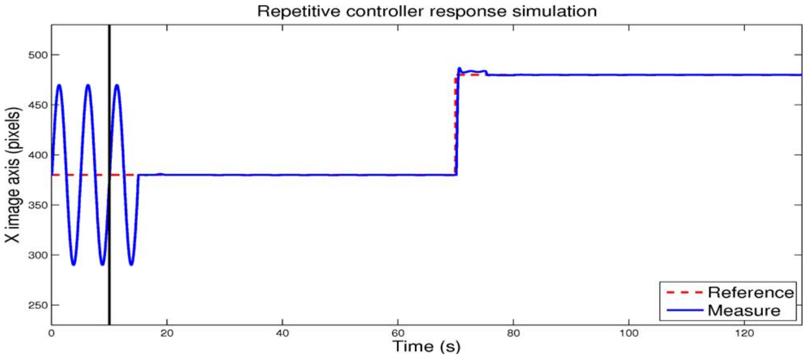
Ott, et al. 2011. Geometric model of flexible endoscope tip.

The group verified their model by performing an experiment to compare the position values predicted by the model with values measured using the camera. They moved the scope through its full range of motion with a black and white checker pattern in view of the camera so that the position could be calculated from the camera image. Below are the results of this test. They observed a translation error of 7.36mm and a rotation error of 11.93°. They defined a workspace error as the average difference in total size of the scope workspace. This error was 2.78mm and 8.98°. They blamed this error on motor backlash and approximations in the kinematic model.



Ott, et al. 2011. Model validation results.

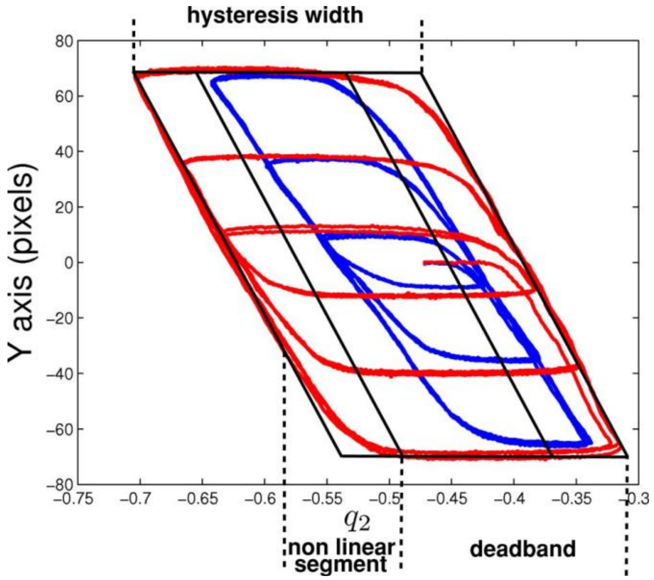
The group asserted that breathing motion is too fast to compensate for using only standard PID control methods and a repetitive control function is required. They implemented a repetitive controller with feedforward to compensate for periodic breathing motion. They tested their control method in simulation and obtained very good results.



To compensate for breathing motion, they used feature extraction and tracking in the endoscope image. A feature was selected by the user and automatically tracked by their control algorithm.

Ott, et al. 2011. Periodic motion compensation simulation results.

They also added backlash compensation to eliminate more of the errors. They measured the backlash behavior of the motors and observed that there is a “deadband” in the motion response of the motors when changing direction. There is also a non-linear segment of motion contained in the total hysteresis section of the motion.



The simulation results of their algorithm showed that setting the amount of compensation motion equal to the deadband width yielded by far the best results.

Ott, et al. 2011. Backlash behavior.

The group performed two experiments with their completed system. One with a phantom artificially moved at a constant period, another *in vivo* with an anesthetized pig. The phantom results showed an 80-90% reduction in image motion corresponding to a reduction from 25mm to 2mm of movement. The *in vivo* results showed about an 80% reduction in motion corresponding to a reduction from 12.7mm to 1.7mm of movement.

Based on their experimental and in-lab results, the group concluded that their system successfully compensated for breathing motion and motor backlash. They showed that their methods are effective and require nothing more than the standard endoscope video image to perform well. They posited that these methods could be extended to compensate for motion along the camera axis by motorizing tools in the working channel of the scope, but this would require stereo vision instead of a single camera.

Analysis:

I thought this was a very good and applicable paper. There are few papers discussing roboticizing flexible endoscopes, and this one provides in depth discussion of modeling and control methods for doing so. Their explanation of modeling and control methods is thorough and informative. They confirmed their system with an *in vivo* experiment and achieved excellent results. Unfortunately they did not give a very extensive description of the experimental and simulation design and execution. It would have been useful to see information about the number of trials in the model validation and other in-lab experiments. They also did not provide any discussion of their feature tracking and extraction techniques, which in my opinion, are very important to the proper functioning of the system. It is often difficult to properly identify and track features in a surgical setting. There are often occlusions, changing lighting conditions, and changing environment conditions. Based on the success of their *in vivo* experiment, these did not seem to be a problem. However, some discussion and acknowledgement of these issues would be appreciated.