Endoscopic Robots

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Abstract. Endoscopy is an important procedure for the diagnostic and therapy of various pathologies. We develop extensive and automated systems for this field. Due to application of these new systems, a patient is subject to considerably less strains, as opposed to prevailing commercial systems. The capability of such instruments, unlike the presently used systems, to independently follow anatomical peculiarities of the body means also a reduced risk of complications for a patient. A further advantage is that difficult to access regions deep inside the body, like the small intestine or peripheral parts of the bronchial tubes, can thus be reached.
The control is made automatic with a 6D-localisation system, a CCD camera, contact sensors, curvature sensors, and pressure sensors. This makes it possible for the doctor to control the endoscope via a human-machine interface without using his own force, and to avoid many problems of today, e.g., looping in the large intestine. The endoscope is driven in accordance with a new driving concept on the basis of fluid actuators or a magnetic probe.
By fusion of all the sensor data in a relational data model, a model of the body inside by means of supplementary image processing. Amongst other things, it make possible to do a quick postoperative checkup. The relational model has been developed specially for endoscopy. In addition, the doctor can intraoperatively see with this model what parts inside the body have already been examined. In this way, a complete examination of, e.g., bronchi can easily be proved.

1 Introduction

A new application for robotic systems is to automate the endoscopy. In our laboratory we develop a new endoscopic system which bases on a motion system for the endoscopic tip and the supply-tube of the tip. Classical the endoscope is being pushed by the physician. The insertion of endoscopes are often combined with sharp pain for the patient and danger to perforate the wall of the tube. Our systems will be used for the colon, rectum, bronchial tree, fallopian tube, etc. To build a new automated endoscopic system we use our years of experience and competence in the field of robot supported surgery and microrobotics [1] [2].

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2 A New Motion System

Our new endoscopic system is designed to work with fluidic elements and strong electromagnetic fields [3] or only with fluidic elements for the motion actuators. The endoscopic tip needs an extern power supply because an endoscopic capsule, which is not connected directly with the external world, cannot be used for taking up pictures. This is for the simple reason that the power requirement for complex sensors and the light source nowadays and in the near future is still too high. Not sufficient energy can be stored e.g. in-coupled (i.e. with electromagnetic induction) in the capsule. For therapy there is the need to remove several biopsies out of the body. Another approach is the improvement of classical endoscopes with steerable distal ends [4] [5]. The incoupled force for the movement of the distal end had to be redirected to the tip by the tube's wall and initiate strong pain.

The endoscope is divided into two parts: the tip and the supply-tube. The architecture of the endoscopic tip is presented in Fig. 1. The tip includes a CCD-camera, fibre optics for the light-source, a working channel and an air-/ water channel. Additionally, the tip includes a position sensor for 6D-localisation and several touch-sensors for the navigation system. The 6D-localisation system is used to get the absolute position and orientation of the tip in the tube. The function of the 6D-localisation system will be presented below.

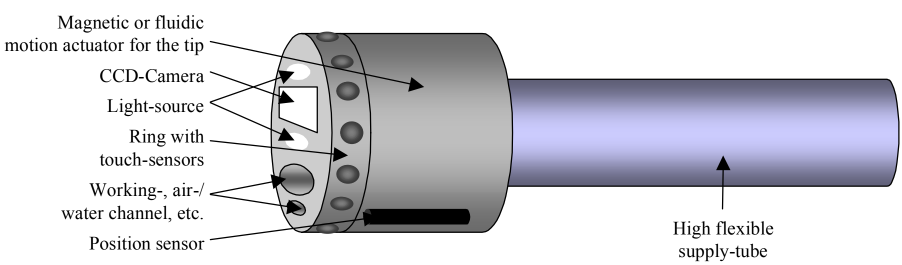

Fig. 1. Tip of the new endoscopic system

To pull a standard colonoscope out of the colon a physician applies a force between 3 - 5 N. A new motion system has to produce about the same force to pull the high flexible supply-tube in the colon. Our aim is to examine not only the colon [6] [7] but also the small intestine and other tubes. The diagnostic of the small intestine is a new challenge for the endoscopy. It is not possible to examine the complete small intestine with standard endoscopes. With our flexible approach it is possible to examine the whole small intestine. The length of the required supply-tube for the endoscopic system is between 6 - 8 m. For the intestinoscopy the required force to pull a supply-tube in the small intestine driven by the tip is higher than for colonoscopy.

For the reason that the small intestine is flexible, long and winded, the motion system is not allowed to generate the whole force to pull the 8 m long supply-tube in the small intestine. The required force has to be reduced to prevent closed loops in the intestine. Tip driven endoscopic systems require an automated intelligent supply-tube to prevent loops during pulling the endoscope in or out of the tube. Our approach bases on a distributed automated intelligent motion system with several motion actuators (see Fig. 2).

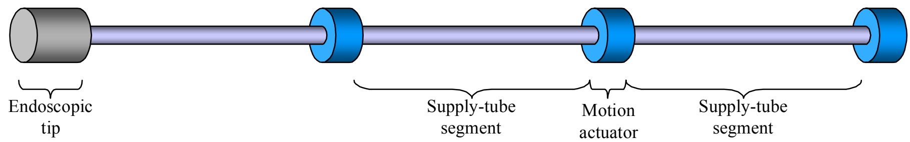

Fig. 2. Automated intelligent supply-tube

A design for a motion actuator bases on fluidic inch-worm locomotion principle (Fig. 3a). Every motion actuator includes min. three inner fluidic elements and a front end- and back end fluidic element. Every supply-tube's motion actuator has its own controller and the motion mechanism bases on fluidic elements for all our systems. The magnetic mechanism of a endoscopic tip cannot be used for these motion actuators because only one strong permanent magnet can be controlled individually. This magnet is placed in the tip. The endoscopic tip is controlled separately. With an ergonomic human-machine-interface (HMI) the tip and intelligent supply-tube are controlled individually.

With both force sensors connected between motion actuator and supply-tube segments the controller regulates the flow of the fluid and so the pressure in the inner fluidic elements. The reaction of a motion action is presented in Fig. 3b.

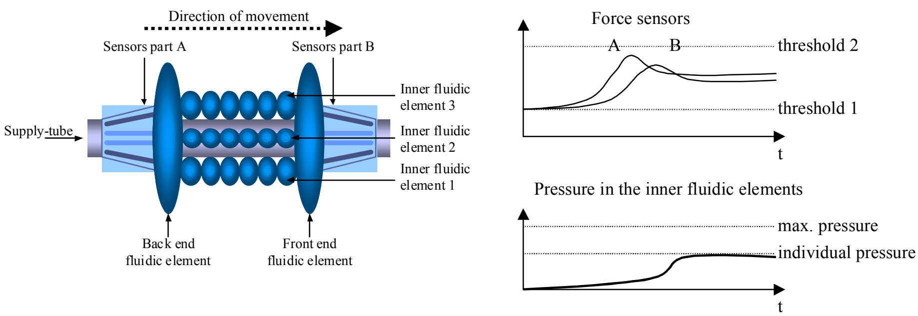

Fig. 3. a) A motion actuator and b) its force reaction

The resulting controller for every motion actuator is presented in Fig. 4. The size of the controller and the supply-tube is limited. The required fluidic pressure for all motion actuators is too high and the cycle time is too short. A triggering of every fluidic element with an own microvalve is not possible, because the fluidic elements cannot be regulated independent from outside because of the limited size of the supply tube. The solution for this problem is to trigger synchronously the corresponding fluidic elements in every motion actuator. The cycle is generated outside of the endoscope. About three fluidic pipes supply all supply-tube's motion actuators. The motion actuator's controller regulates independently the fluidic pressure resp. flow individually to control the force of every motion actuator. This mechanism is required when an actuator e.g. sticks to the wall. The following motion actuator has to decrease the force to reduce the speed to avoid a supply-tube's loop. The previous motion actuator has also to decrease the force to reduce tension between these two elements. The cycle time and the variation of the pressure for the individual control is about ten time slower than the cycle time of the fluidic elements.

Another approach is the use of shape memory alloy (SMA) for microvalves, which is used for other endoscopic robots [6]. The SMA springs open and close the shuttle of the valves. The cycle time of the valve is limited by the slow speed of the SMA spring.

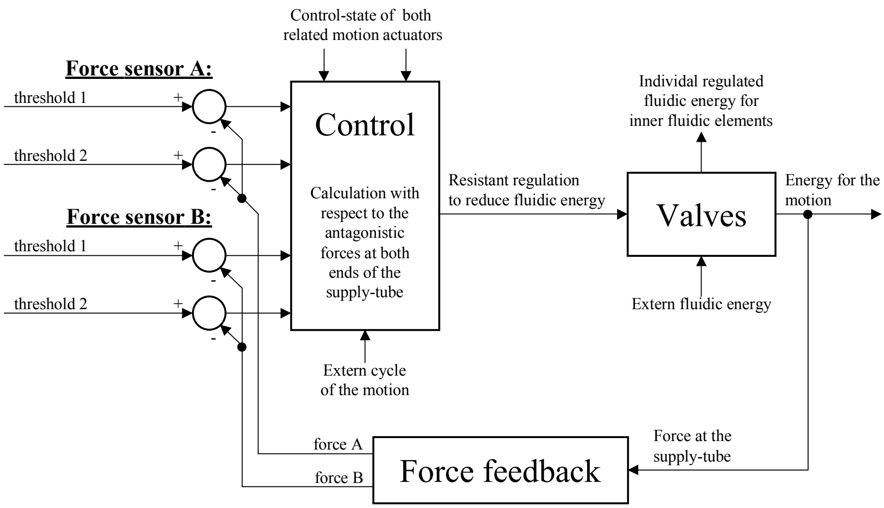

Fig. 4. Motion control

The main stages of the inch-worm locomotion is presented Fig. 5. The actual movement control of Fig. 4 inflates regular all inner fluidic elements. A bending of the motion actuator is generated with an extension of the motion actuator's controller. With miniaturised valves an individual bending is generated (Fig. 5b) to increase the stability and speed of the whole motion system.

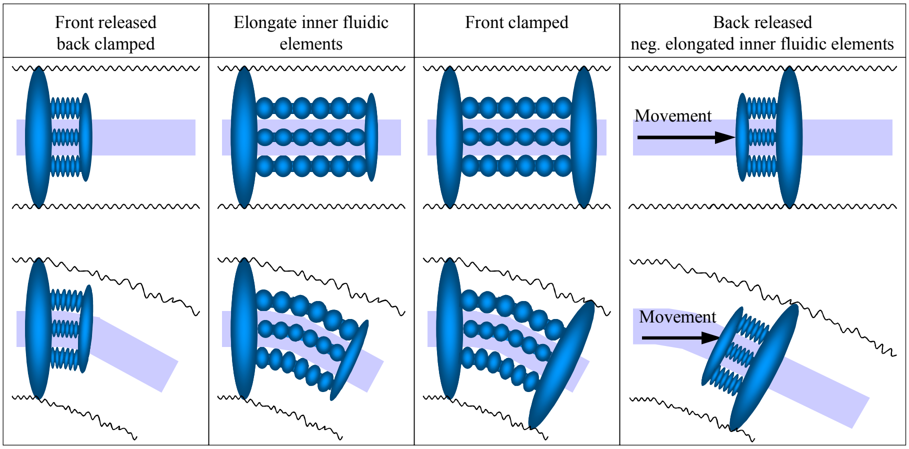

Fig. 5. Locomotion stages a) without bending extension b) with bending extension

Our approach to design new microvalves, which individually throttle down the pressure in the element (Fig. 6) is to miniaturise this valves to a size, that all fluidic elements of the motion actuator have their own microvalve.

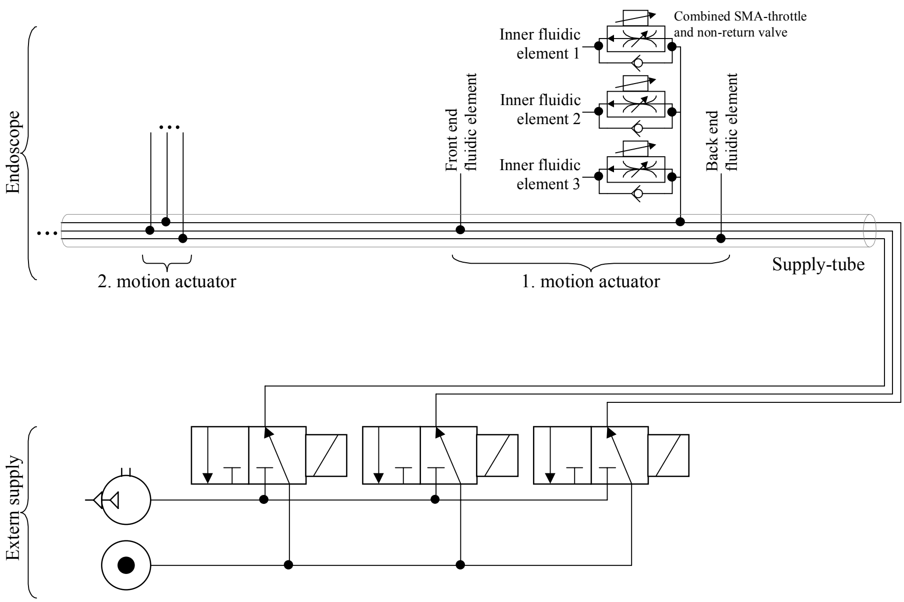

Fig. 6. Control of the motion actuators

We additionally plan to develop new mechatronic elements for the tip of the endoscope to assist the surgeon during diagnostic or therapy. One of these elements is a controllable telescope camera to support the diagnostic of small tubes. This is our first approach to examine i.e. the fallopoian tube or the peripheral bronchial tree. One or two tools have to be added to the endoscopic tip for cutting and catching biopsies. The new endoscope is a modern microrobotic system for medicine. Mainly, we want to support the diagnostic and therapy of tubes with an inner diameter between 2 and 16 mm. An extremely small inner diameter has the fallopian tube with about 1 mm.

3 An Introduction in the Complex Navigation System

The tip of the endoscope contains a position sensor (see Fig. 1). We use a less expensive 6D-localisation system with failure detection, which is developed from our project partners. A comparable, but more expensive 6D-localisation system is produced from Biosense [8]. We used for our first tests a 6D-localisation system from Polhemus. The precision of the Polhemus system is to inaccurate.

The 6D-localisation system is necessary for the navigation system. The navigation system merges the position and orientation with the taken images (see Fig. 7) to simplify matching of successing images. The 6D-localisation system is a very important sensor for the navigationsystem. A simple rigid matching of endoscopic images and a preoperative acquired 3D-scan was presented in [9]. We try to generate a flexible 3D-model of the tube to improve the endoscopy. Special colour is used to spray small synthetic landmarks on the tube's wall which is examined. These landmarks simplifies the matching, too. The preoperative acquired data e.g. 3D-CT-scans and other intraoperative acquired data e.g. US-images, sensor information are added to this flexible model. The construction of this model is complex. The analysis of important characteristics in the model is a major task of our work.

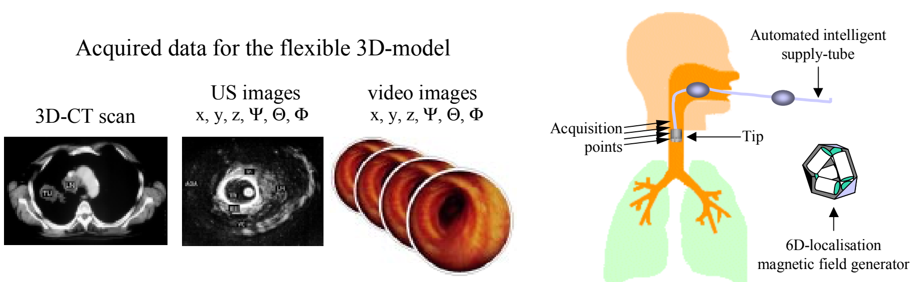

Fig. 7. Part of the data acquisition for the navigation system

4 Conclusion

A miniaturisation within the area of the endoscopy is desirable. Miniaturisation of automatic handling modules for integration into an endoscopic system is a strong demand for future development. An intelligent navigation system extends the possibilities for the physician. New endoscopic systems reduces the strains on a patient.

Acknowledgement

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