

## A Novel System for Colonoscopy

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**Abstract.** *There are good reasons for inspecting the walls of the bowel. Cancer of the colon is on the increase, and if it is allowed to develop untreated, the outlook for the patient is poor. However, if it can be detected at an early stage the prospects for successful treatment are good. The usual method of bowel inspection is by a colonoscope, a manually inserted and manoeuvred flexible instrument. Colonoscopy has a number of disadvantages; it is difficult to manoeuvre the colonoscope around the various bends in the colon, it is slow and it can be dangerous and painful. Recently there have been attempts to automate the process of colonoscopy by designing small mobile "robots" able to climb the bowel. These robots are designed to carry inspection equipment in the form of miniature cameras. It is suggested that they would overcome some of the objections to manual colonoscopy. Although these may have certain advantages, they also have disadvantages; they may find it difficult to obtain the necessary purchase on the bowel walls, they may find corner turning difficult and they are intrinsically slow. We describe a totally new concept applied to colonoscopy. Instead of relying on insights gained from industrial robots to guide the design process, we start by examining the design constraints imposed by the nature of the task. These constraints are completely different to those relevant to industrial robotics. As a consequence of the unusual constraint set, the "mobile robot" which emerges from the design process is completely different from conventional industrial mobile robots. The overall concept is described, together with the results of preliminary tests. Instead of conventional locomotion, the system uses an inflatable tube to gain access to, and to climb, the bowel. This tube, by virtue of its method of deployment, affords protection to the bowel wall as well as providing the means of climbing. The system is not yet fully developed and considerable future work is needed before clinical trailing can begin.*

*Keywords.* Colonoscopy, robot, everting, balloon

## 1. Introduction - colonoscopy

Robots are finding increasing application as assistants to surgeons during operations. Early applications were in orthopaedic and minimal access surgery (Bouazza-Marouf, 1999; Cuschieri, 1997 e Cuschieri, 1998) which required very little intervention by the robots. Now, more invasive applications are opening up. Many patients require some form of diagnosis within the gastro-intestinal tract. A large and increasing amount of this diagnosis is performed today by colonoscopy. Colonoscopy has assumed ever-increasing importance since colorectal cancer has become the second most common form of malignant tumour in the developed world (Cancer Research Campaign, 1993). The vast majority of cases of colon cancer develop from initially benign internal polyps. If these can be detected at an early stage the chances of successful treatment are good.

To enable diagnosis further and further up the colon, use can be made of a flexible endoscope such as the fibre-optic type in which an image of the inspection site is transmitted to the surgeon via a coherent bundle of optical fibres. Unfortunately, flexible endoscopes are controllable only at the tip and are positionally uncontrollable over most of their length Fig. (1). This makes it extremely difficult to manipulate a flexible colonoscope from its transanal insertion up the colon to the inspection site. This difficulty is exacerbated by the labyrinthine nature of the colon, by the complexity of folding of its walls and by its relative fragility. In addition, some parts of the colon are affected by the breathing of the patient and by other movements of the intestine such as peristaltic actions, which attempt to expel the intruding instrument.

Successful operation and manipulation of a flexible endoscope requires great skill and the inspection process may take a considerable time. At present even the most skilled colonoscopist can only achieve inspection of the first metre of colon. This leaves over half of the colon unable to be inspected.

## 2. Colonoscopy assist devices

Because of the importance of colonoscopy and the difficulties and dangers of manually deploying flexible endoscopes, research has been done on methods to assist the insertion and manipulation of these instruments. A comprehensive study



Figure 1: A typical colonoscope.

has been reported (Mosse, 1999). Here four different ways of assisting a colonoscope to traverse the bowel are described. These are:

- a water-jet propulsion system for driving the colonoscope tip,
- a suction crawling system, similar to an inchworm robot but with suckers to help adhesion to the bowel wall,
- a concept for stimulating the gut muscle to propel a cigar-shaped module along by peristaltic action,
- a specially lubricated sleeve to house the colonoscope tip and ease its passage through the bowel.

If nothing else, this study shows the extreme difficulties involved in designing semi-autonomous machines for colonoscopy. The author admits, of the four methods, that “...no one approach (is) particularly promising.”

Other researchers have proposed climbing robotic devices to carry miniature cameras through the bowel to the colon. One particular embodiment of this concept is the microrobot of Pisa University (Carrozza, 1996) and the related MUSYC system (BIOMED 2). Here, an extensible body is mounted between two cylindrical pistons. These pistons have variable diameter, which may be changed by internal actuation. The robot “climbs” inside the bowel using an inching movement in the following manner;

- The rear piston is extended to full diameter and engages the bowel wall
- The front piston is retracted and disengages from the wall
- The body extends, driving the front piston forward
- The front piston now extends and engages the wall
- The rear piston retracts
- The body shrinks and pulls the rear piston forward
- This inchworm movement is repeated.

This kind of robot, like any that uses the bowel wall for traction, is intrinsically difficult to make safe. There is a conflict between gaining enough purchase on the wall and protecting the wall from high forces. It may also be rather slow, may find corner-turning a problem and may be difficult to extricate in the event of power failure.

This kind of design problem is often found where robots are proposed for use in a surgical-assist role but where there is an *ab-initio* assumption of what a robot is. A commonly held view of a robot is that of the well-known industrial version found doing tasks such as welding or automatic assembly. However, the industrial robot is not a good template for the surgical robot where the task constraints are entirely different. The previously mentioned bowel-climbing robot has taken as its template the pipe-traversing “pig” familiar in the oil and gas industries.

The main constraints imposed on the design of the surgical-assist robot are:

- patient safety
- surgeon ease-of-use
- unobtrusiveness within the theatre
- sterilisability or disposability.

In the following sections we describe the concept of a bowel-climbing robot system able to carry inspection, and possibly intervention, equipment along the bowel. Unlike other extant bowel climbing robots, the proposed device poses very little hazard to the patient as it does not use the bowel wall for traction and therefore does not apply large forces to the wall. Its design also allows it to progress along the bowel at a far higher rate than other robots so that the duration of inspection sessions is minimised.

A number of preliminary trials are described whose results give confidence that the method is entirely feasible.

### 3. The balloon eversion instrument

The basic aim of designing a system for colonoscopy is to allow the transport of an inspection module from the point of insertion (the anus) to ideally the caecum, but in practice as far as possible along the bowel. In the manually operated flexible endoscope described above, the module is the optical head that captures the images. The means of transport is the semi-rigid tube that also carries the optical fibres. In the bowel-climbing robot device, the module is a miniature camera and the means of transport is the inchworm vehicle. In each of these two cases, the major constraint of patient safety is violated. The flexible endoscope applies high forces to the bowel wall to push its way around corners; the robot applies high forces to obtain traction. What is needed is a means of load transport that does not threaten damage to the bowel wall. This can be achieved by using balloon eversion.

If a long cylindrical balloon is lightly inflated, it may be turned inside out by pushing the closed end back down inside the balloon body. If, at any stage during this process the pushing on the closed end is released, the balloon will roll itself back out, under the inflationary pressure, to its original configuration. This can be used as a simple and effective method for the transport of an inspection module along the bowel to the colon.

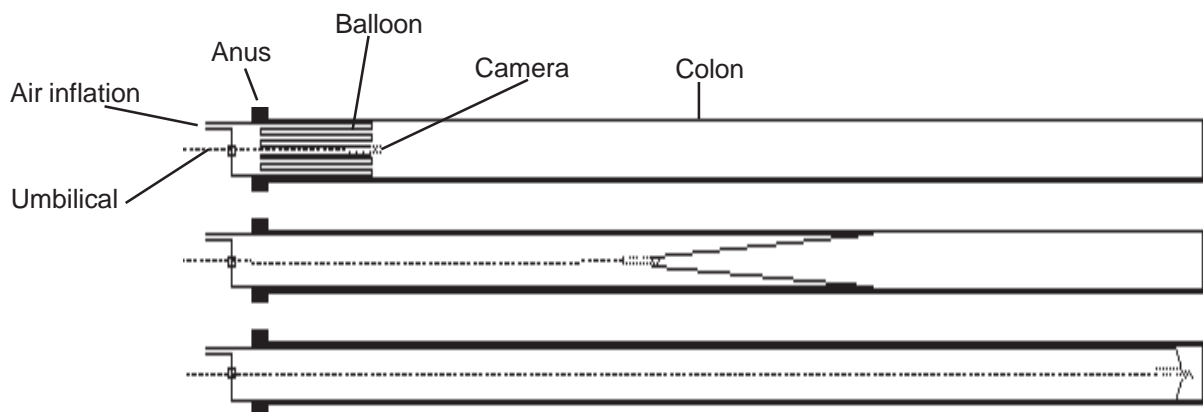


Figure 2: Schematic of the eversion process.

Top; folded balloon unit with camera system is inserted into the anus

Middle; low pressure air is admitted to the balloon and it unfurls along the colon, taking the camera and umbilical with it

bottom; fully inflated balloon reaches the end of the colon, as it is pulled back the camera can be used to inspect the colon for cancerous lesions

The inspection module is assumed to be in the form of a cylinder whose diameter is less than that of the bowel. It carries a camera at one end. A hole is made in the closed end of the balloon, the module is passed through the hole and is sealed in place with its camera pointing outwards. Any wires or cables for servicing the module (with electrical power, cleaning water, etc.) pass back down the inside of the balloon and through a port at the open end.

The balloon is deployed as follows. First the closed end carrying the module is pushed along the inside of the balloon to turn it inside out. The body of the balloon is offered up to the anus of the patient. The balloon is gradually turned the right way out by the application of low pressure compressed air. In the process the balloon passes through the anus and unrolls along the bowel wall taking the inspection module with it. The inspection module eventually appears out of the end of the colon in a position to begin the inspection process. Finally, the balloon is deflated and pulled out of the bowel via the anus bringing the inspection module with it. During this retraction process the camera can capture images of the bowel wall.

It should be noted that damage to the bowel wall is avoided by four mechanisms. First the balloon itself always lies between the module and the bowel wall and so protects the wall. Second, there is no relative movement between the balloon wall and the bowel wall as the unrolling takes place. Thirdly, pressure on the wall due to the inflation process is smoothly distributed and there are no points of high loading. Last, the module itself is designed to have a smooth cigar-shaped body with no sharp edges to protect the wall during retraction.

### 4. Experimental trials

A limited series of experiments have been carried out to investigate the feasibility of the proposed system. A tube has been constructed out of thin latex rubber. It is around 1m long and 40mm in diameter. One end is closed around a short cylindrical plug to simulate the inspection module. KY jelly is used to lubricate the system and to simulate the natural moistness of the human bowel. The balloon is attached to a short length of plastic tube that acts as a store for the balloon at the beginning of deployment. The balloon has been deployed in three different experimental trials.

#### 4.1. Experiment 1

The first experiment involves deployment of the balloon system along a rigid perspex tube. Although the rigidity of the tube makes it unrepresentative of the human bowel, it has acute corners so that the ability of the balloon to negotiate bends

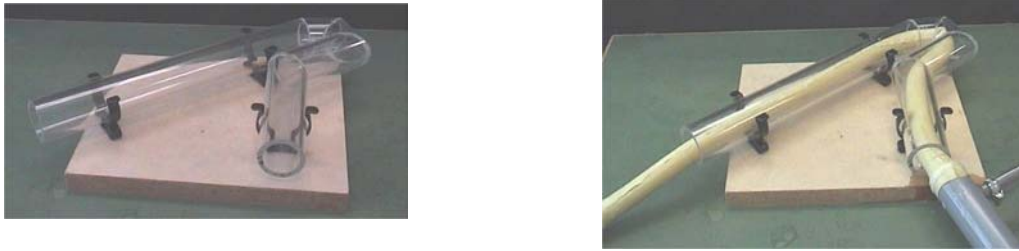


Figure 3: Full deployment within a rigid plastic tube.

can be assessed. The transparent nature of the perspex allows the progress of the deployment to be observed. In all tests the system has been able to transport the module from one end of the tube to the other without difficulty. The time taken varies with the applied air pressure but is typically a few seconds. Fig. (3) shows the rigid perspex tube and the tube with the balloon fully deployed within it.

#### 4.2. Experiment 2



Figure 4. Simulated bowel on the left, simulated bowel with balloon deployed in it on the right..

The second experiment involves deployment along a tube made of latex rubber and of the same dimensions as the balloon. This more accurately simulates human bowel. Fig. (4) shows the parts used in this experiment. In all experiments of this type the balloon has been deployable along the whole length of the simulated bowel in a few seconds using human lung-power to drive the system.

#### 4.3. Experiment 3

The third experiment involved deployment along a length of porcine intestine. The balloon system is inserted into the attached anus of the pig carcass and inflated along its length. Again, the tests have been entirely successful with the balloon negotiating the bends in the intestine without difficulty and within a few seconds.

### 4. Conclusion

A novel concept for the design of a colonoscopy instrument has been described. It may be regarded as a mobile robot, but its mobility is by unconventional means. Unlike other extant systems it does not make use of the bowel wall to achieve its mobility. Instead, the eversion of a balloon under air pressure is used to drive an inspection module along the bowel. The system is inherently safe because the balloon skin protects the bowel wall during the insertion process and because there is no relative motion between the balloon and the bowel wall.

A number of experiments have been described to test the feasibility of the system. All have been successful. A considerable amount of engineering design remains to be done before clinical trials can begin.

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