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COLON INSPECTION SYSTEM WITH AN INTERNAL SUPPORT STRUCTURE

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Abstract. *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 long flexible instrument controlled manually. Colonoscopy has a number of disadvantages however; it is difficult to manoeuver 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. The overall concept of a totally new concept in colonoscopy 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, robotics, eversion, inflatable tube*

1. Introduction

Many patients require some form of diagnosis within the gastrointestinal 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 (CRC, 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 fiberoptic 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 (Figure 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.

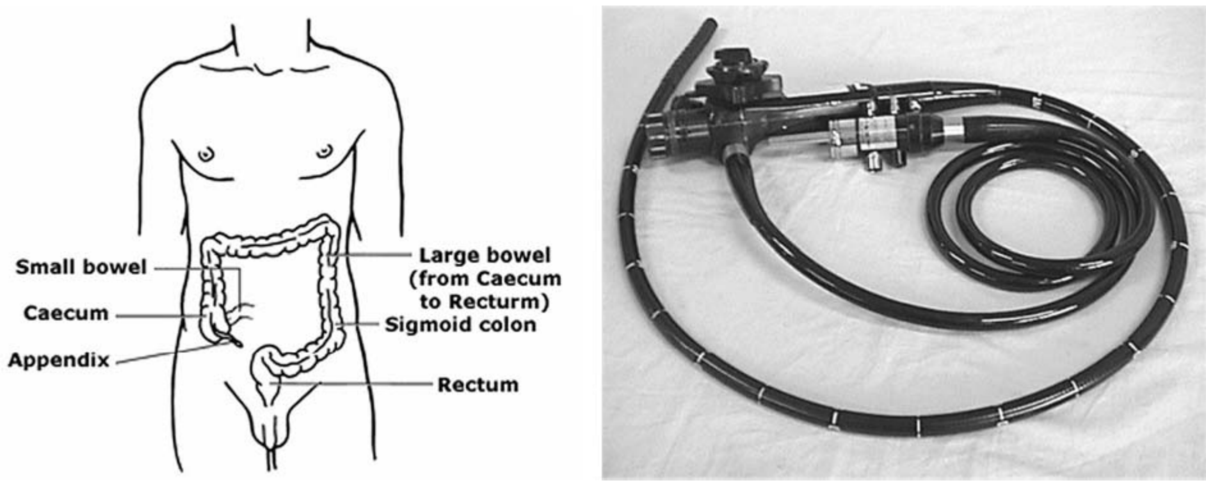

Figure 1. The position of the colon and a typical colonoscope.

2. Colonoscopy-assist devices

Because of the importance of colonoscopy and the difficulties and dangers of manually deploying flexible endoscopes, much research has been undertaken on methods to assist the insertion and manipulation of these instruments. A comprehensive study has been reported (Mosse, 1999) in which four different ways of assisting a colonoscope to traverse the bowel are described. These are:

1) a water-jet propulsion system for driving the colonoscope tip,
2) a suction crawling system, similar to an inchworm robot but with suckers to help adhesion to the bowel wall,
3) a concept for stimulating the gut muscle to propel a cigar-shaped module along by peristaltic action,
4) 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.”

Many researchers have proposed climbing robotic devices based on the inchworm principle (Carrozza, 1996). 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-initic 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.

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 ceasum, 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, Fig. 2.

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.

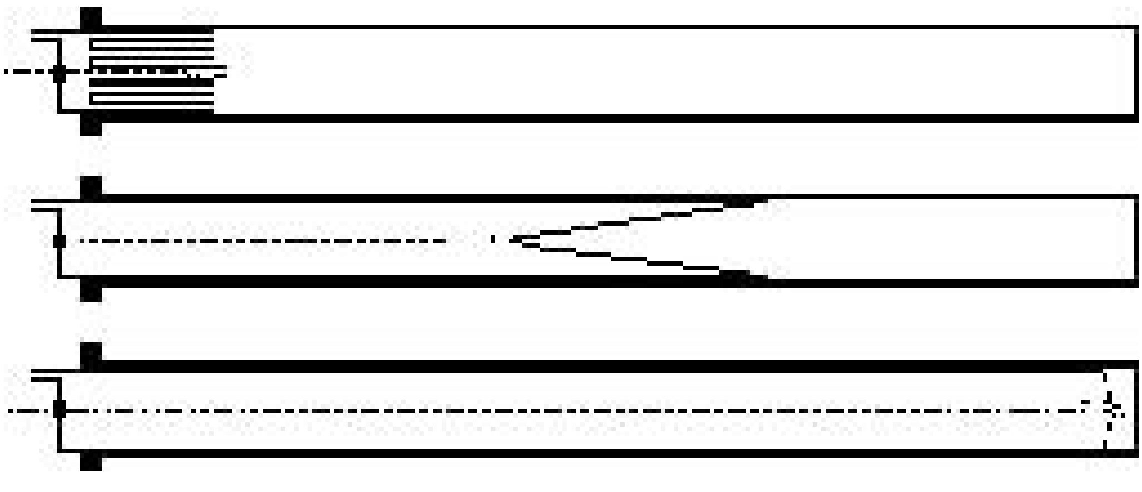

Figure 2: Schematic of the eversion process.

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 ladder module with it. It should be noted that damage to the bowel wall is avoided in ways. First the balloon itself always lies between the ladder 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.

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 lm 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.

3.1 Experiment 1

The first experiment involved 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 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.

3.2 Experiment 2

The second experiment involved deployment along a tube made of latex rubber and of the same dimensions as the balloon. This more accurately simulates human bowel. Figure 3 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.

Figure 3: A balloon deployed in a latex ‘colon’.

3.3. Experiment 3

The third experiment involves 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. Inspection / intervention system

The difference between this design and any other is the use of track, or ladder, which is deployed by the balloon for the robot to climb along. An inspection/intervention system can now be attached to the proximal end of the ladder protruding from the anus and climb up the ladder along the whole length of the colon with very little risk to the integrity of the colon walls. Figure 4 shows a CAD model of a ‘robot’ on the ladder. The inspection/intervention system is not shown as this is still subject to patenting. Depending on the driving mechanism, pneumatic or electrical, would define the requirements for any umbilical to take power to the module. Biopsies can be taken and stored in the module for analysis.

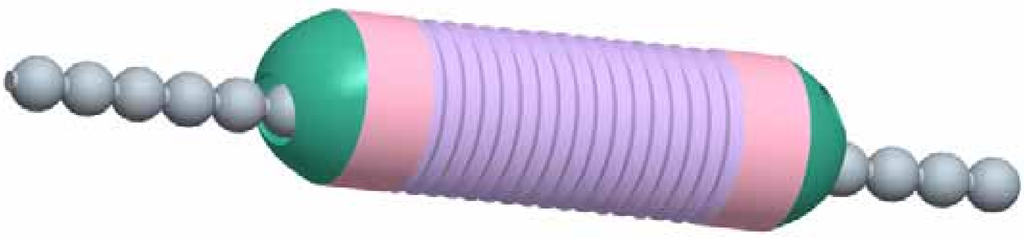

Figure 4. Cad model of the 'Robot' on the ladder

5. 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.

6. Acknowledgements

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