위장 내시경법 : 자율미니로봇의 전망

(Endoscopy in the Gastrointestinal Tract: Perspectives of Autonomous Mini Robots)

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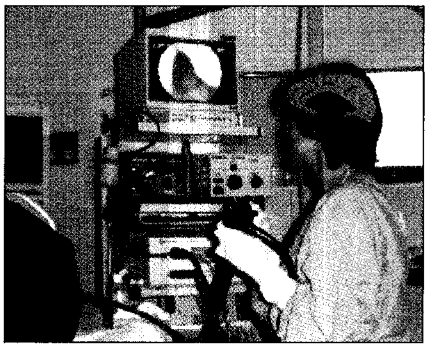
Introduction: from traditional colonoscopy to semi-autonomous robots for colonoscopy

Presently, many diagnoses of important pathologies are performed by exploiting minimally invasive techniques which allow medical doctors to introduce advanced endoscopes in the human body through natural orifices or small incisions. The diagnosis of colon cancer (Figure 1), which is one of the main causes of death in industrialized countries, is carried out using a colonoscope which has onboard a CCD camera, bundles of optical fiber for illumination, several working channels for air, water and miniature wire-actuated instruments for local treatment and biopsy. The introduction and advancement of a conventional colonoscope into the patient' s colon is a difficult and tedious procedure for medical doctors and is generally uncomfortable for patients. Pain could even result when the colon is over-insufflated with air or over-stretched by the rather rigid colonoscope which has a diameter ranging between 13 mm and 19 mm.



The recent development of CMOS cameras, which do not require high illumination intensity, would allow the reduction in size and weight of the "tail" of the colonoscope. Flexibility of the scope would even be enhanced with a smaller "tail". Given this situation, conventional colonoscopes could be replaced by semi-autonomous self-propelling robots which navigate the colon by pulling a very thin and flexible "service tail": the tail should only be used for trans-portation of air, water and electrical energy from an external source while the robot propels itself into the colon. Several semi-autonomous robots for colonoscopy were developed and extensively tested in the authors' laboratory.

In the following paragraphs, two typologies of robots able to navigate autonomously in the gastrointestinal tract and, specifically, in the colon are presented.

The first generation includes flexible robots based on the "inchworm" locomotion principle. The robots of the second generation are rigid and they include a system of sliding clampers for adhering the gastrointestinal tissue and advancing onto it.

Inchworm locomotion in the gastrointestinal tract

Several locomotion mechanisms for semi-autonomous endoscopes, often inspired by

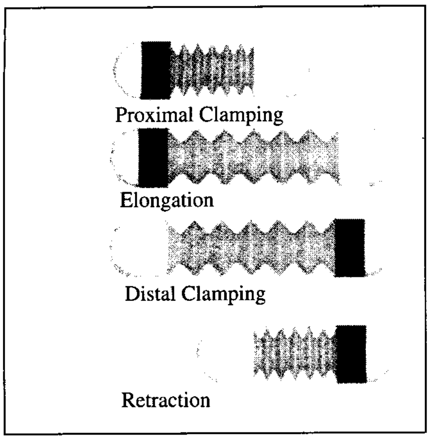


Figure 2 – a. Schematic diagram illustrating the sequence of the inchworm locomotion principle. The shaded area on the distal and proximal clamping actuators indicates the active clamping states.

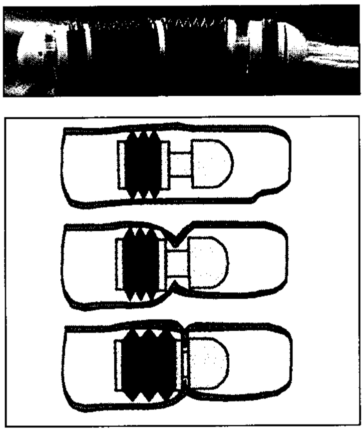


Figure 2 – b. Prototype of an inchworm colonoscope. Scheme of the grasping mechanism: suction of the tissue into the gap, closing of the jaws.

of actuators: clamper and extensor. The clamper is used to adhere or clamp the device securely onto the locomotion environment while the extensor produces a positive displacement (known as the stroke, i.e. the difference in length of the extensor in its elongated and retracted phases). The simplest inchworm device consists of two clampers at its ends and one extensor in the middle. Figure 2 shows the gait sequence of forward propulsion and an inchworm prototype.

minirobots for industrial inspection, have been developed by various researchers in the world. The authors first approached the problem of locomotion by exploiting an inchworm device which is particularly suited to unstructured or even hostile environments where wheels and tracks fail. An inchworm device is made up of basically two types

Locomotion principle based on "sliding clampers"

The inchworm device has a good efficiency in straight paths, but it has got some difficulties in negotiating the intestinal bends. In fact, the intestinal tissue is collapsed and poorly supported and the

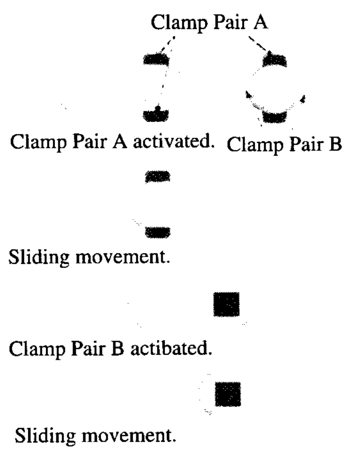


Figure 3 – a. Schematic diagram illustrating the sequence of the "sliding clampers" locomotion principle. The shaded area indicates the active clamping states.

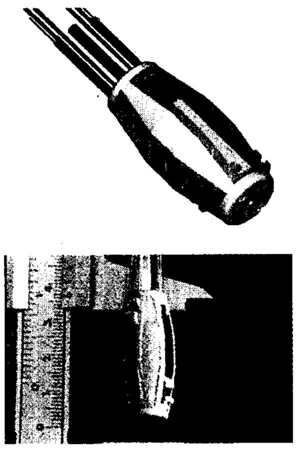


Figure 3 – b. 3D model and photo of a sli-ding clampers prototype.

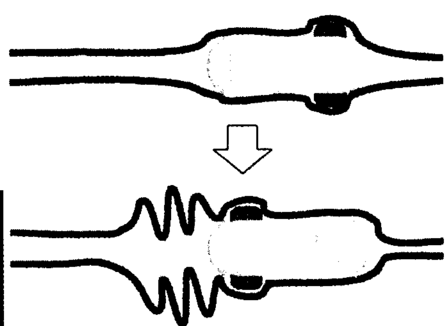


Figure 3 – c. Formation of folds proximal to the device during advancement.

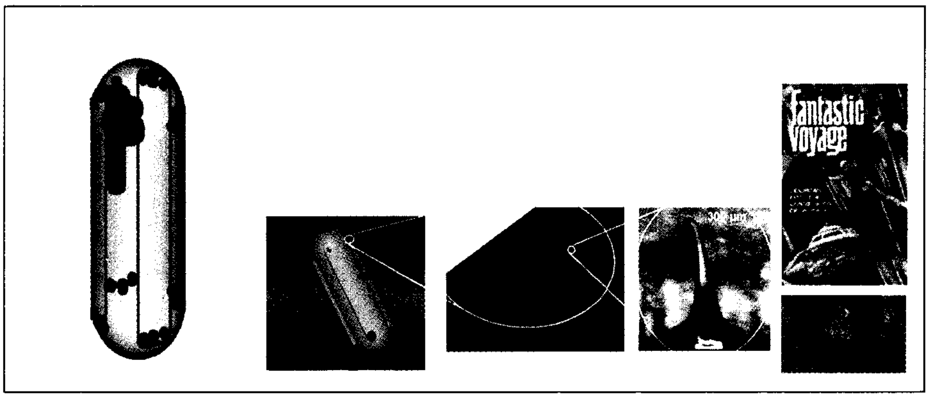


Figure 4 - a. Schematic capsule which exploiting sliding clampers. The mechanism is actuated by using an internal micro-motor and battery.

Figure 4 - b. The sliding mec... capsule must be joined with an effe... clamping. The picture shows a ... clamping system based on a micro-... array of micro-hooks which grasp ... biomimetic manner (many parasitic ... hooks for adhering onto the skin).

Figure 4 - c. The capsule could realize in the future the dream of navigating in the human body.

robot, during locomotion, develops a sort of "accordion effect". In order to reduce this effect, a device was configured with two pairs of clampers working antagonistically such that one of which always grasp onto the intestinal tissue that is distal with respect to the other clamping mechanism. Figure 3 shows the working principle of this "sliding clampers" device advancing forward, the design and the photograph of a prototype, and the behavior of the poorly supported tissue during the advancement.

Conclusions and future works : toward autonomous endo-scopic pills

The robotic solutions for locomotion in the colon illustrated in the previous paragraph are intermediate results and study platforms for the achievement of a more challenging future result: the smooth and natural loco-motion in the human body for diagnostic and therapeutic purposes. Some autonomous endoscopic capsules to be swallowed already exist on the market (the M2ATM pill produced by the Given Imaging Ltd in Israel, NORIKA V3 produced by RF Lab in Japan), but the problem of autonomous and active locomotion is still open. Current capsules often rely just on normal peristalsis for locomotion and this fact is a huge limit for accurate diagnoses, which would require the ability to stop, to go forward, backward, to slow, etc in order to better observe the surrounding tissue.

The main future activity for the authors will consist in developing an "all inside" locomotion system for a microcapsule with an adequate size to be swallowed and completely wireless. The authors will try to exploit the good attributes of both locomotion concepts presented in the previous paragraphs and they will also investigate more "biomimetic and smooth" locomotion solutions. High speed, effectiveness in bends and uncons-trained intestine, low rigidity and small dimension will be the principle requirements for trans-forming a technological jewel in a medical effective tool.

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