STUDY OF A NEW INTELLIGENT TOOL FOR THE COLONOSCOPY

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ABSTRACT

In the last few years, we have observed a fast development of modern science and technology but especially in the field of medical engineering. The Minimally Invasive Surgery (MIS) has became one of the most important research area and medical endoscope (***Figure 1***) is one typical medical instrument that complies with the requirement of MIS.

This paper deals with the design of a new type of micro-robot for intestinal inspection. Because of the injuries caused by the colonoscope during the operation, and the long time spent at the hospital by the patient, we focus on a new type of intelligent colonoscope. The main purpose of this medical tool is to minimize the contact between the colonoscope and the interior boundary of the colon, and to make the progression of the colonoscope easier for the surgeon.

Our current prototype is electro-pneumatically driven. It is constituted by three metal bellows, and its position in the intestine is driven by three sensors positioned on the superior plate. Some experimental results are presented.

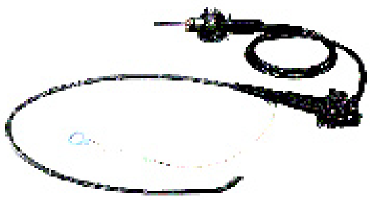

Figure 1 *Photography of a typical medical endoscope*

1. INTRODUCTION

The evolution of human beings and the fast development of the modern sciences and technology show us that the scientific world is fast moving. In the medical domain, MIS progress rapidly and becomes dominant in the field. In the last few years, the medical endoscope system, one of the typical medical instruments, progress rapidly. With the gradual development and the link between the traditional endoscope system technology and some modern technics, it become possible for people to realize the diagnosis and therapy of miniature injury and even more injury surgery.

This paper deals with the development of a robotic colonoscope, which uses pneumatic actuators in its bendable portion. This colonoscope is controlled to allow the minimization of the contact between the patient's intestine and the colonoscope. There are different possibilities to create a flexible movement. We chose the Flexible Micro-Actuator (FMA) which allows movements of great amplitude along 3 directions in inflection and extension.

Metal bellows afford to work with pneumatic energy. In [1], experiences were performed with metal bellows. It is proposed to use this kind of electro-pneumatic actuators which have the advantage of an inherent compliance due to bellows flexibility and air compressibility. The robot described in [2] uses this metal bellows technology to move inside a 17 mm diameter vertical rectilinear pipe. Pistons and micro-motor actuate their blocking systems, and the robot is able to carry masses heavier than 1 kg.

A silicon bellows is used for miming the *"inchworm"* movement [3]. This miniature robotic manipulator is a kind of shuttle equipped with two micro-arms. It is a self-propelling 18-mm diameter endoscope, 50 mm long in the contracted state, and 80 mm in the extended state, as is showed in ***figure 2***. This endoscope is aimed to inspect and intervene in the human colon.

Figure 2 *A micro robot prototype for intestinal inspection [3]*

Another micro robot prototype for intestinal inspection based on the same principle of *"inchworm"* locomotion as proposed by [4] uses three grippers and two extensors. The three grippers inflate and grasped the inside surface of the intestine and the two bellows elongate and contract. Using also the *"inchworm"* locomotion , a study of a new endoscope system is proposed in [5]. It uses four articulations, which move with the action of a current in a magnetic field.

In the same idea of flexible micro-actuator, the shape of a finger, which is composed of three rooms independently controlled, is developed [6,7]. With this technics of three independent pressure chambers radially distributed, the conception of a colonoscope with a bendable portion at its end has been considered [8]. This portion is a 3D pneumatic actuator with three degrees of freedom. It is flexible and bendable to any angle.

Another approach in gastrointestinal diagnosis, is given by [9]. Without direct contact with the human intestine, and only for the purpose of taking images of the digestive tract, a new device in form of a small capsule was developed.

After discussions with some surgeons, we have decided to direct our research not to help the surgeons during the progression of the colonoscope, but to design a tool which help them in MIS, i.e. to limit the contact between the colonoscope and the intestine.

Thus, we have chosen to use pneumatic actuators, which have the advantage of being naturally compliant [10]. Our approach to allow our prototype to bend has been to chose three metal bellows, thus we may control the three degrees of freedom.

2. GENERAL STRUCTURE

2.1 Basic Idea

The final prototype will be designed to move easily in the human intestine by positioning itself in the center of it. Three sensors return the distances between the center of the head of the colonoscope and the internal surface of the intestine, and the position may be computed.

Currently, our prototype is built of three plates interconnected with bellows. The top plate is oriented perpendicular to the desired direction with the aid of the pressure input to the bellows. The diameter of our prototype is about 25 mm and its length about 88 mm.

2.2 The Servovalves and The Bellows Actuator

We use pneumatic energy with metal bellows for the conception of our prototype. Due to its fabrication, the bellows can have different kinds of movement.

The principal properties of the bellows are their resistance against the pressure, the temperature and the corrosion; they have a good sealing, a natural elasticity, and a long life cycle without maintenance.

By taking the classical hypothesis, we can consider that each bellows is characterized by a second order transfer function $H_1(s)$ [11].

$$\frac{X(s)}{P(s)} = H_1(s) = \frac{\omega_{01}^2}{s^2 + 2\xi_1\omega_{01}s + \omega_{01}^2} \quad (1)$$

with:

$\omega_{01} = \sqrt{\frac{k}{M}}$: M is the mass supported by each bellows and k is the stiffness of the bellows.

We use $\xi_1 = 0.3$ a good compromise between response time and oscillations [11].

We require to control the pressures that we send to the bellows in order to bend the prototype in the desired orientation.

To be able to control the various pressures in the bellows, we use servovalves. Thus, the servovalves and the bellows (submitted to the weight of the device) will generate the dynamics of our system.

For the transfer function of a servovalve, we have chosen a second order. Let call it $H_2(s)$:

$$H_2(s) = \frac{\omega_{02}^2}{s^2 + 2\xi_2\omega_{02}s + \omega_{02}^2} \quad (2)$$

with:

$\omega_{02} = 2\pi f_2$

$f_2 = 200Hz$ for phase $-90°$, and $\xi_2 = 0.3$

Finally, ***Figure 3*** shows the block diagram for the dynamic of the servovalves-bellows system:

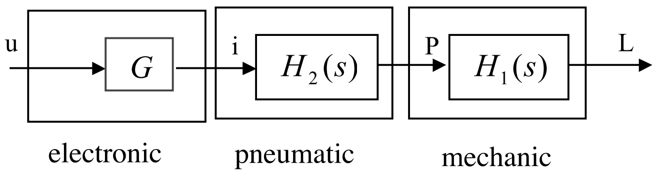

Figure 3: *Block diagram of the dynamics of the servovalve and one bellows together*

where:

u is the alimentation of the electronic card (0 to 10V),

i is the control current of the servovalves (-20 mA to 20 mA),

P_i is the pressure command of the bellows i,

L_i is the length of the bellows i.

2.3 Mathematical modeling

The bellows we use are named A, B and C, and their length are respectively L_A, L_B and L_C.

Figure 4 shows that we consider only two plates to model our prototype in our experiment.

All these mechanical modeling is developed in [12]. By expressing the forces of each bellows and from basic mechanics, we find at the end of the calculations, the expression of the angles and the height h as a function of the internal pressure :

$$\theta_I = \arctan\left(\frac{\sqrt{3}(P_B - P_C)}{2P_A - P_B - P_C}\right) \quad (3)$$

$$\theta_{II} = -\frac{2S_e}{3kr}\frac{P_A - \frac{1}{2}P_B - \frac{1}{2}P_C}{\cos\theta_I} \quad (4)$$

$$h = l_0 + \frac{S_e}{3k}\sum_i P_i + \frac{mg}{3k}\cos\theta_{II} \quad (5)$$

where :

θ_I : first rotation angle,
θ_{II} : second rotation angle,
h : length of an arc between the centers of the plates ($h = R\theta_{II}$),
l_0 : length of the at rest bellows,
P_i : pressure in the bellows i,
m : masse of the superior plate,
S : effective surface of the bellows,
k : stiffness of the bellows,
r : radius of the circle on which are placed the bellows.
g : acceleration of the gravity.

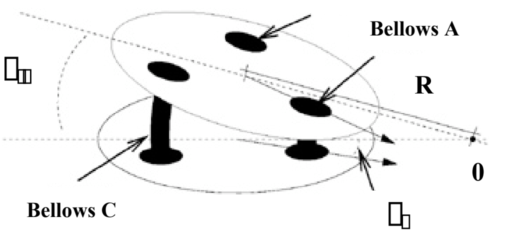

Figure 4 *Model of our prototype with the superior plate, the inferior plate and the three bellows.*

We presented the equations above connecting the position of the higher plate (angle θ_I , angle θ_{II} and height h) than the pressures acting over each bellows (equations 3, 4 and 5). These are the equations which describe our system. Thus, we can move on to the computation of the position of the colonoscope in the intestine, the three inputs to the system being the pressures in each bellows.

2.4 <u>Determining of the position of the endoscope in the intestine</u>

After discussions with surgeons who carry out this type of interventions, we noted that their knowledge and experience allowed the easy progression of the endoscope. Indeed, to locate himself and to anticipate the curvatures of intestine, the surgeon has only the image returned by the mini camera placed at the end of endoscope, and the both levers to fold the end of the tool.

It is essential to know the position of the endoscope in the intestine to be able to act automatically on the pressures of the bellows and to readjust the higher plate of the endoscope.

To be able to locate the endoscope, it is necessary to place distance sensors without contact on the higher plate of the endoscope. Three sensors placed at 120° apart from each other, give us the distances to the walls of the intestine. Let these distances be respectively d_A, d_B and d_C (***figure 5***). With these three distances, it becomes possible to know the position of the center of the higher plate (point P_n on ***figure 5***) compared to the walls of the intestine. Once this position is known, we can automatically reposition the colonoscope by exploiting the pressures of the three bellows. It is simple, with the theory of the medians, to find a best position of the colonoscope in the intestine, approaching towards the centerline of the intestine [13].

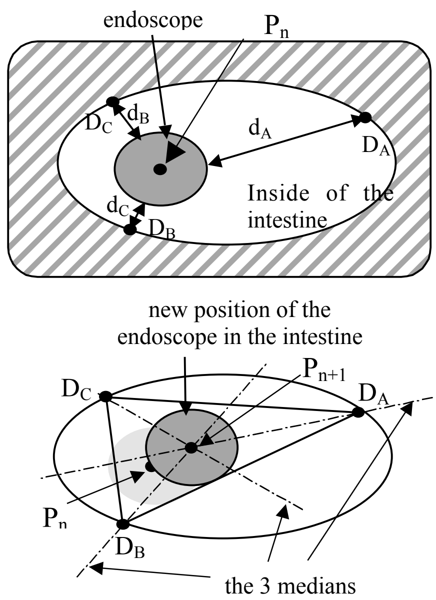

Figure 5 *Calculation of the change of the endoscope position in the intestine.*

3. EXPERIMENTED RESULTS

During our experiments, we control the different pressures we want in the bellows of the robot, and we can recover the distance d_A, d_B and d_C returned by the three distance sensors.

A very significant factor for the performance analysis of our prototype is its capacity to be bent: we compare the angle of inclination θ_{II} in experiments, with the computed with equation 4 as a function of the pressure sent in the bellows (***figure 6***). We can obtain an inclination angle with a pressure in only one bellows. But we use the angle θ_I to be able to control the direction of the curve, so we can curve our endoscope in each direction ($\theta_I \in [-\pi, \pi]$).

For example *figure 7* shows a bending angle $\square_{II}$ = 20° with an angle $\square_{I}$ =-60° . We showed that we are completely in agreement with our ideal model, and totally able to control the prototype.

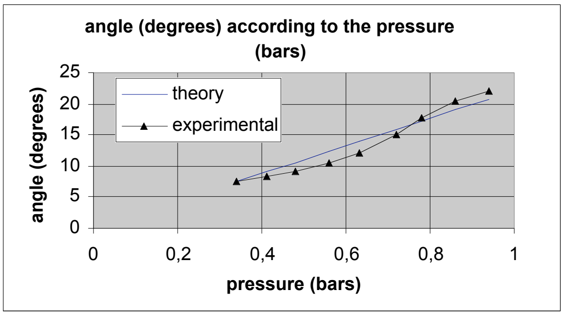

figure 6 *Comparative curve of the inclination angle of the prototype: theoretical (equations 5) and experimental result*

Figure 7 *Curved prototype following the angle $\square_{I}$ = - 60°, $\square_{II}$ = 20°*

4. CONCLUSION AND PERSPECTIVES

Currently, we find a important demand in the medical field to improve the techniques of endoscopy. As we described along this paper, we centered our efforts on the design of an endoscope compatible with Minimaly Invasive Surgery.

For now, we are able to control the prototype, and we intend to minimize the contacts between the endoscope and the internal walls of the intestine. Once this goal is reached, it will be easier for the surgeon to perform his operation, and less painful for the patient who undergoes it.

In this paper, we described the design, the modeling and the experimental results of our prototype of an endoscope based on the use of metal bellows. It currently has a diameter of approximately 25 mm and a 88 mm length. Our experiments show that the bellows are a good solution to perform a movement of elongation and curvature, and placing them at 120° gives very good results to obtain a displacement in inflection.

Now our work consists of implementing the control laws and to test them with the endoscope. Currently, the simulations give results in accords with our prototype.

Thus, our next tests will validate the totality of our model. We will finally seek to reduce the size of the robot as much as possible to approach the real needs of the surgeons, while seeking to preserve the performances acquired during the tests.

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