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Smart actuators for active micro-endoscope

Key words: Nanotechnology, electronic conducting polymers, micro gripper, endoscope, modelling and simulation.

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1) Context:

Endoscope is a medical or industrial instrument allowing End users to view various areas that are difficult to access like in intrusive surgical operations, microsurgery or in mechanical structures. It works by inserting thin flexible tubes, which exploit a lens or a miniature camera. Among the different applications, it can be used either in the industry for the non-destructive testing of pipes to analyse defects and to ensure maintenance, or in medical field, to inspect the interior of a body cavity or interior surfaces of an organ and also for treatment of various pathologies. More precisely, it may be inserted for the human body through the mouth when exploring the stomach or bronchi, through the nostrils for the nasal cavity, vocal cords, or sinuses, and through the anus to study the colon, whereas other examinations may sometimes require to make small incisions.

During the surgical procedure, the orientation must be changed when another direction of view is needed, but these endoscopes have a fixed angle. Consequently, the surgeon can lose orientation and target locations. In the case where surgeons cannot easily move the endoscope shaft through a narrow passage because of constraints imposed by other surgical instruments or by anatomical constraints, an adjustable micro camera is needed to control its orientation while having a small diameter for miniaturization efficiency. The main advantage of this alternative solution is saving time while offering a better visibility and an inspection in all directions. Nevertheless, current commercial thin endoscopes do not contain any adjustable micro-camera, which limits seriously their possible operation for medical applications.

In order to expand the view-field that is usually not visible when using the 0-degree scope [1], some solutions already exist based either on a flexible material rod, or on a 30-degree scope. However, these technics are complicated to apply, especially in the human body. In fact, endoscopes able to change their view without moving are too rigid for procedures like gastroscopy [2]. To address this issue, this thesis propose to integrate a smart microsystem in the endoscope dedicated to the micro-camera orientation. The chosen scientific solution exploits the advantages of microfabrication technologies on flex with soft micro-actuators based on electronic conducting polymers (ECPs). Such kind of materials able to imitate natural muscles by converting electrical energy into mechanical energy (Fig. 1), have severable advantages compared to dielectric and ferroelectric polymers. These advantages include low driving voltage (<2V) opening their use to digital electronics (5V) and even to portable IoT applications (3.3V), low cost, lightweight and noise-free operation. Therefore, this make ECPs actuators a promising technology for specific integrations [3]. As the biocompatibility material is fundamental in the medical field, their sensitivity to the environment in which they operate will be considered.

2) Objective:

By developing ECPs microsystems for the control of micro-camera orientation attached to the endoscope, this thesis aims to help surgeons to increase their diagnostic capabilities during surgery. The main objective is to allow surgeons to change the view angle without modifying the position of the endoscope itself. For the minimization of medical tools, and less invasive clinical procedures, the proposed microsystem will addresses difficulties associated to the miniaturization with high integration flexibility. The high challenge that will be reported in this thesis is to develop an extremely thin active endoscope with a controlled tilting angle. Therefore, the smallest commercially available image sensor (575x575µm2) as well as micro-actuators thicknesses of 40-80µm will be carefully investigated. Finally, the actuators interaction within the target environment will be considered in order to ensure the biocompatibility.

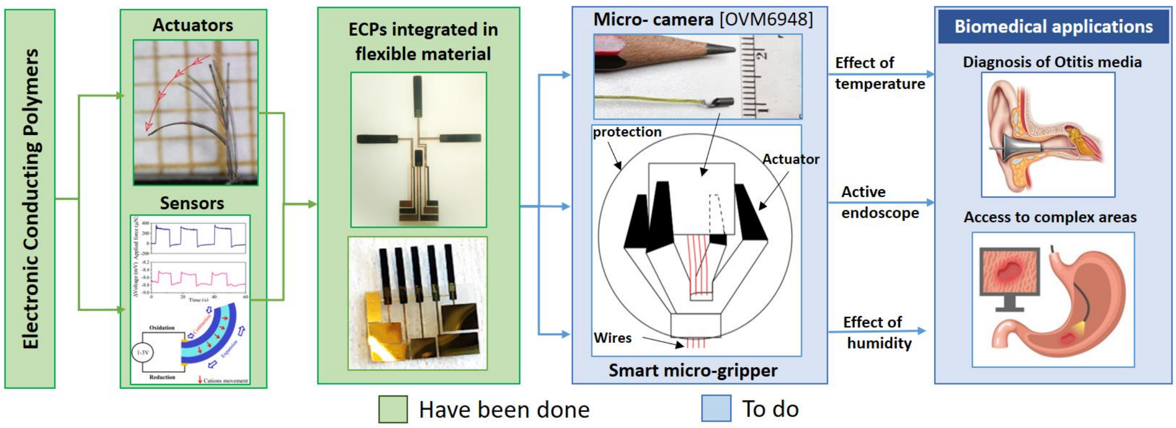

Figure 1: Microsystem for micro-camera orientation and effects of medical environment on ECPs transducers

3) Originality of the thesis and Missions:

In comparison with rigid endoscopes, flexible endoscopes can typically adapt to anatomy better and therefore are less invasive and less traumatic to the patient. However, although some flexible active endoscopes are existing, their shaft diameters are higher than 4mm, and thus require higher surgical incisions. In this thesis, the first objective is to develop extremely thin active endoscopes in order to create less soft tissue damage. As a result, there will be significantly less discomfort and pain for the patient as well as a decrease in recovery time. Our second objective is to introduce a new feature for the current endoscopes by offering the possibility of a variable vision field. In fact, active endoscope compared to passive endoscope can minimize conflicts with other tools and can simplify surgical planning by their ability to achieve variable viewing angles from fixed positions. In terms of means, this thesis is targeting to move the smallest micro camera in the world. Its orientation will be controlled by using a micro-system based on ECPs actuator with thicknesses around 40-80µm. In addition, the use of ECPs which is a non-magnetic material as actuator instead of DC motors extends the application field to patients who hold devices sensitive to magnetic fields, i.e. patient carrying cardiac pacemaker, neurostimulators, cochlear implant and derivation valves. Lastly, it is worth noting that the integration of these “intelligent” materials in medical applications has not yet been exploited and in which it is tricky to obtain reliable measurements. Hence, the thesis ambitiousness is to increase the technology readiness level of soft material microsystems in the medical field, by offering proofs of concept in the form of prototypes for targeted applications.

The thesis main tasks can be divided into three axis detailed hereafter.

3.1) Simulation and optimal design of a flexible actuation system:

According to the specification of developing an active endoscope with a small diameter and an actuation with polymers, two design solutions will be explored. The first one deals with ECP actuators design to move the smallest commercially available image sensor [OVM6948]. This implies a low risk since the ability to use one micro-actuator to support and move the weight of micro camera during its bending has already been successfully demonstrated [9]. The second solution is to design, simulate and optimise an innovative smart micro grippers using the association of several micro-actuators to grasp and move the micro-camera.

3.2) Smart micro gripper prototype:

Design results of WP1 will be exploited in order to micro-fabricate the ECP smart micro gripper in IEMN clean room. As prior experiences of micro actuator integration in soft microtransudcers performed at IEMN Lab, are quite conclusive, this implies also low risk. In addition, WP2 includes a characterization of the actuation system in air environment as well as an experiment validation of WP1 simulation results. This task is also devoted to studying and investigating the evolution of the micro actuator characteristics (strain, force, impedance, electronic conductivity, cyclic voltammetry, sensing, etc.) as a function of temperature and relative humidity over the range of values that can be found in the human body. This goal will be achieved through close collaboration with Univ. of Tartu. At IEMN Lab, the necessary set up to carry out these measurements is already available.

3.3) Fabrication and test of micro-camera orientation:

Once the micro-gripper will be associated with the micro-camera, a transparent encapsulation will be made in order to protect this system and to avoid its interactions with the human body fluids. Two prototypes with different configurations will be manufactured. The design and the efficiency of the first prototype is evaluated and used as a feedback for the second one. An open-loop controller will be implemented to adjust the micro-camera orientation. The connection between the micro-gripper and the external control system have to be ensured. Therefore, an insertion will be preliminary performed in an artificial ear, nose, or mouth to evaluate the motion accuracy and device control. This experimental validation will be done with the assistance of Pr Y. Nguyen. This thesis does not address endoscope pipe or shaft but rather the actuation technology for micro-camera orientation.

4) Environment:

The IEMN is spread over sites of Valenciennes and Villeneuve d'Ascq in France.

The candidate will integrate the MEMS Bioinspired Team. Over the last ten years, this team has been working intensively on the electronic conducting polymers (ECPs) integration in flexible microsystems. Working in close collaboration with Univ. of Tartu, this team has already proposed a numerical and experimental analysis of mass loading effect (micro-camera) on ECPs based actuators [9]. The proof of concept will include the smallest micro-camera in the world [OVM6948]. The scientific support of LPPI - EA2528, Cergy Pontoise (Dr C.Plesse) will be required to optimize the right ECP biomaterials for the micro-actuator that will be manufactured in our Micro and Nano Fabrication Center of IEMN Lab. In the medical field, Dr Y. Nguyen (Ear-Nose-Throat surgeon, Pitié Salpêtrière Hospital, professor at Sorbonne University) has been identified as a partner of choice to determine the best changes to be made to the active endoscope with respect to the end user.

5) Candidate profile:

The PhD candidate will be in charge of the three tasks described above. Experience in micro/nano fabrication in a cleanroom environment is mandatory. Skills among the following research fields would be an advantage: micro-nanofabrication processes, mechanical engineering (flexible substrate), and electrical engineering. In addition, experience and strong interest in biocompatible materials, especially conductive electroactive polymers will be a plus.

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