Surgical Robotic Platform for Endoscopic Dissection
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INTRODUCTION
Endoscopic Submucosal Dissection (ESD) is an effective and less invasive treatment for colorectal cancer [1]. This clinical technique allows for an en-bloc removal of lesions of the gastrointestinal (GI) tract. ESD is performed using a traditional flexible endoscope, through which surgical tools can be introduced. These procedures are typically time consuming due to the difficult control of the tools, and they often require around 95 min for removing lesions, that can reach 3-4 cm in diameter. The probability of intestinal perforation exceeds 18% and the hemorrhage risk ranges from 3.5% to 15.5% [2]. A procedure supported by a flexible robotic endoscope may offer a solution to overcome these limitations, thus improving the degrees of freedom (DoFs) and the overall operational efficiency [3].

Within this clinical panorama, the aim of this paper is presenting the development of a novel miniaturized robotic device to be coupled to the tip of a traditional endoscope for the surgical dissection of GI neoplasms (Figure 1).

Figure 1. Concept of the miniaturized robotic device for the surgical dissection of the GI neoplasms.

MATERIALS AND METHODS
The robotic platform consists of the miniaturized robot, the actuator housing (hereafter called external platform), the control unit and the master console to allow the user driving and control (Figure 2). During the operation, one surgeon (Surgeon A in Figure 2) stands close to the patient to maneuver the endoscope for exploring the GI tract and reaching the target area. Another surgeon (Surgeon B in Figure 2) operates the miniaturized robot through the master console, carrying out the surgical procedure.

The key feature of the proposed robot is that traditional endoscope and instruments can be utilized: the device can be easily attached to and detached from the endoscope. Indeed, the miniaturized robot has been designed to be coupled to the tip of traditional flexible endoscopes in the range of 11.5 - 14.5 mm in diameter.

The robot exploits the flexibility of the endoscope for navigation through the intestine and integrates two-active robotic arms (i.e., cautery and gripper) extending the DoFs, and thus enhancing the efficiency during complex tasks such as manipulation and surgical tissue dissection. Furthermore, the endoscope provides the optical system for visual feedback and one working channels for conventional instruments.

The proposed technology is a two-armed robot with a total of six DoFs. The left arm is in the form of a gripper able to grasp and lift the tissue of the patient. This arm is featured by 3 DoFs (i.e., slide, pitch and open/close of the gripper). The right arm is a mono-polar cautery with 3 DoFs (i.e., slide, roll and pitch) employed to cut the lesion. The workspace generated from the DoFs of the two-activated robotic arms (i.e., cautery and gripper) is shown in Figure 3. The green and blue shells are formed by the motion range of the tip of the right and left arm, respectively. The workspace covers a large part of the endoscope field of view thus allowing to reach the target area for performing a proper tissue dissection. The orientation of the gripper arm is driven by external cables (i.e., one cable for the open/close, two cables for the slide and two cables for the pitch) managed by three external motors located into the external platform. Differently, three miniaturized motors have been integrated in the cautery arm to provide motion.

Figure 2. An overview of the endosurgery scenario.
Figure 3. Workspace of the two-activated robotic arms.
The motors are controlled through 2 haptic interface devices, which are interfaced using LabVIEW. One of the devices is used for controlling the cautery system. The other one is fitted with a custom adaptor designed as a handle for the endoscopic surgical gripper.

While navigating through the intestine, the two-active robotic arms are retracted inside the body of the miniaturized robot; when the target area is reached, the arms are outside of the body and they can start to operate. The external shape of the cap body is 26 mm in diameter (including the endoscope tip) and has a total length of 50 mm; these sizes have been defined considering anatomical constraints (i.e., dimension and shape of the anus and intestine). The internal endoscope is like any other traditional endoscope and can be pushed or controlled as usual. As users interface, the miniaturized robot supports two Geomagic Touch phantoms (3D System, Inc.).

To verify the feasibility of the design solution, a mock-up that faithfully reproduces the miniaturized robot has been realized using a 3D printer machine (ProJet MJP 3600, 3D System, Inc.). Moreover, the mock-up has been fixed on the tip of a traditional endoscope (Evis Exera III ColonovideoScope, Olympus) and inserted in a Transanal Endoscopic Microsurgery (TEM) simulator to verify the field of view of the endoscope once integrated.

Finally, the authors have prepared the mechanical drawing and assembled all fabricated components. Each part is made in metal materials (i.e., stainless steel) with numerical control machine tools.

RESULTS

Figure 4a shows the mock-up of the miniaturized robot lodged on the tip of the endoscope. After dexterity tests performed by an expert surgeon, we could confirm that the motion capability of the endoscope was unchanged after integration and the workspace of the two arms seemed suitable for carrying out a surgical operation. The surgeon carried out in-vitro tests on colon simulator (Figure 4b) and confirmed that the field of view of the endoscope was not affected by the robot encumbrance.

After verifying the potentiality of the 3D printed prototype, a final device, with the same features (i.e., DoF and geometry) of the 3D printed prototype, has been designed, fabricated and assembled (Figure 5). The miniaturized robot is made up of 87 steel components. The gripper arm is expected to generate around 3 N of lifting force and 10 -14 N of gripping force. Around 1.5 N is available at the cautery tip, based on preliminary modelling.

CONCLUSION AND DISCUSSION

A robotic platform including a miniaturized robot for the dissection of gastrointestinal neoplasms has been developed thanks to a deep collaboration between engineers and medical doctors.

Considering the weak points of the current medical techniques, the proposed robot guarantees instrument triangulation and tissue manipulation as in TEM procedure, and it should be also able to remove the lesions in all colon tract. As in the ESD technique, it is compatible with traditional endoscopes and the general anaesthesia is not mandatory, thus a traditional endoscopic room is enough for carrying out a complete surgical operation. Consequently, the hospitalization times, and hence the general hospital costs, could be significantly reduced.

For the future, the functionality of the robot will be validated with bench tests and in-vivo experiments will be conducted to prove the clinical advantages of the proposed system.

REFERENCES

