

Within the doctoral topic “Autonomous Robotic Surgical System”, I worked on the development of an endoscopic plug-in capsule able to diagnose and treat early digestive tumor. To achieve the result, the support of Professor Alberto Arezzo and the engineering team of the Sant'Anna University in Pisa was crucial.

Introduction: digestive tract tumors represent a challenge for the national healthcare system. They are burdened by high mortality and morbidity rates and lead to increased healthcare cost. In Italy, we registered over 60,000 new cases per year of colon, rectal, stomach and esophagus cancers. Screening programs allow early diagnosis of the tumor and consequently a less invasive treatment compared to more advanced one. Investments in prevention improve patients' quality of life and reduces healthcare cost. Endoscopic Submucosal Dissection (ESD) is a procedure that allows *en bloc* endoluminal excision of early lesions of the gastrointestinal tract but is burdened by a high rate of complications. The most feared, perforation, which is reported with a rate of up to 10%, and bleeding, rate about 9%. Furthermore, the procedure is described by the operators as complex, uncomfortable, with high average time, approximately 95 minutes for lesions between 3-4 cm. It is due by the inability to manipulate, to perform traction and suturing with available endoscopic instruments. Transanal Endoscopic Microsurgery (TEM) compared to ESD is a surgical technique. However, it could be performed only on the distal 15-20 cm of the rectum due to the size and rigidity of the platform.

Methods: the aim of this PhD work is to overcome the limits of both TEM and ESD by developing a new master-slave system, miniaturized, and flexible platform that allows endoluminal resections in all sections that can be explored with common endoscopes. The experimental phase began with the settlement of a multidisciplinary team involving surgeons and engineer. Then the team studied the relevant literature to establish the foundations from which to start in terms of geometry and the required forces.

Our research work addresses several key challenges in the development of a robotic surgical system, focusing on communication, miniaturization, hardware/software integration, and design optimization.

The main non-technical issue was facilitating collaboration between surgeons and engineers. We initially faced difficulties due to different problem-solving approaches and terminologies. However, through multiple meetings and open discussions, the team learned to adopt and share each other's perspectives, leading to effective teamwork. The first technical challenge was miniaturizing the robotic arms while maintaining sufficient force for surgical tasks. The soft pneumatic arms were the best we were able to test in terms of optimized force interaction with tissue.

Results: the prototype capsule is 30mm in length, an external diameter of 23mm, the soft arms could reach a bending angle of 90° with a pressure inside the arm of 1,5 bar, able to develop a pulling force of 1N and a lifting force of 1,4N. The platform is composed by the plug-in capsule, the processor unit and the double controller, one for each arm, Geomagic.

This research highlights the interdisciplinary collaboration and technical innovation needed to meet the challenges of robotic surgical system development.

Conclusions: at the conclusion of the study, a functional prototype was created and tested on phantom and ex-vivo models, successfully performing basic tasks such as reaching a target, pulling/pushing, and collecting tissue samples, demonstrating the platform's potential for future clinical applications.