Soft Robotics in Gastrointestinal Endoscopy: Engineering a Hydraulic AI-Assisted Colonoscope to Minimize Patient Risks and Enhance Usability

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Over 4 million colonoscopies result in severe adverse reactions (SAEs) such as perforations, internal bleeding, and other side effects by the external pressure placed by a gastroenterologist due to a conventional colonoscope's (CC) rigidity. Compounding the issue, only 18,756 active gastroenterologists in 2025 can provide treatment, rendering 10,000,000 patients underserved, stemming from the CC's complexity. To minimize patient risks and enhance usability, this project introduces a soft robotic colonoscope paired with a hydraulic control unit (HCU) to create a semi-autonomous, self-propelling, and adaptive tool for gastroenterologists. The silicone design features 3 sections with a central stiffening mechanism, optimized via FEA simulations and kinematics. The HCU, powered by 4 reverse polarity peristaltic pumps, includes 8 individually activated solenoids and water pressure sensors which are managed by an Arduino Mega for precise actuation and a pre-programmed joystick. This cost-effective approach enhances maneuverability with greater degrees of freedom and bend angles compared to CC systems, supported by video and motion tracking. Additionally, this soft robotic colonoscope has navigated through a number of colon structures, proving its compatibility with a diverse patient population. To create a more operator friendly colonoscope, conductive ink pressure sensors are integrated within the soft colonoscope to supply an input colon pressure, and output a proportional pressure to the haptic glove for real-time tactile feedback. This feature is coupled with a Faster RCNN model for higher adenoma detection by classifying and localizing polyps. This innovative system improves accessibility and efficiency, addressing critical challenges in colorectal cancer detection.

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