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Martina Finocchiaro, Alberto Arezzo, Arianna Menciassi, Alicia Casals, Albert Hernansanz and Gastone Ciuti

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M. Finocchiaro[1,2,3], A. Arezzo[4], A. Menciassi[2,3], A. Casals[1], A. Hernansanz[1*], G. Ciuti[2,3*]

[1] *Center of Research in Biomedical Engineering, Universitat Politècnica de Catalunya,*

[2]*The BioRobotics Institute and* [3]*Department of Excellence in Robotics & AI, Scuola Superiore Sant'Anna,*

[4]*Department of Surgical Sciences, University of Torino*

** These senior authors equally contributed to this work.*

martina.finocchiaro@upc.edu

INTRODUCTION

Over the years, the continuous development of intraluminal procedures resulted in strong benefits for the patients, *i.e.*, reduced blood loss, lower risks of infections, diminished scaring impact and quicker recovery time [1]. However, these improvements imposed high mental and physical stress to the clinicians [2], [3]. In this context, the introduction of robotic technologies has resulted in notable improvements in terms of endoscopes flexibility and control stability, by designing multi-steerable snake-like robots and endoscopic capsules. Nevertheless, it also introduces additional degrees of freedom (DOF) to control and sensing information to process, posing the basis for a new framework of human-robot interaction and high-level telemanipulation control [4]. Besides the mechanical design of the surgical device, the Human Machine Interface (HMI, *i.e.*, the interface used to maneuver the endoscope, together with the adopted control strategy and the quality of the feedback received during the interventions) has an important impact over the outcomes of the procedure. Accordingly, all these factors can vary the difficulty of the tasks and are strictly connected to the users' physical and mental stress, influencing their final performances [5]. Focusing on one intraluminal intervention, *i.e.*, robot-assisted colonoscopy, a variety of HMI have been designed in the last decades, including different input devices, assistive tools and feedback [6]. However, few studies aiming at assessing the best features of the HMI have been performed so far [7]–[9], leading to a lack of knowledge about the optimal HMI able to minimize the cognitive and physical load of the operators and maximize their performace. Herein, we present the results of a survey administered to more than 70 endoscopists across different European countries, to get insights about the clinicians' desires on the next generation HMI for robot assisted colonoscopy.

MATERIALS AND METHODS

A group of 71 endoscopists, both gastroenterologist (80%) and colorectal surgeons (20%), with different levels of experience (15% with less than 2 years, 58% with more than 10 years, and 27% in the middle), filled an anonymous online survey (available at [10])

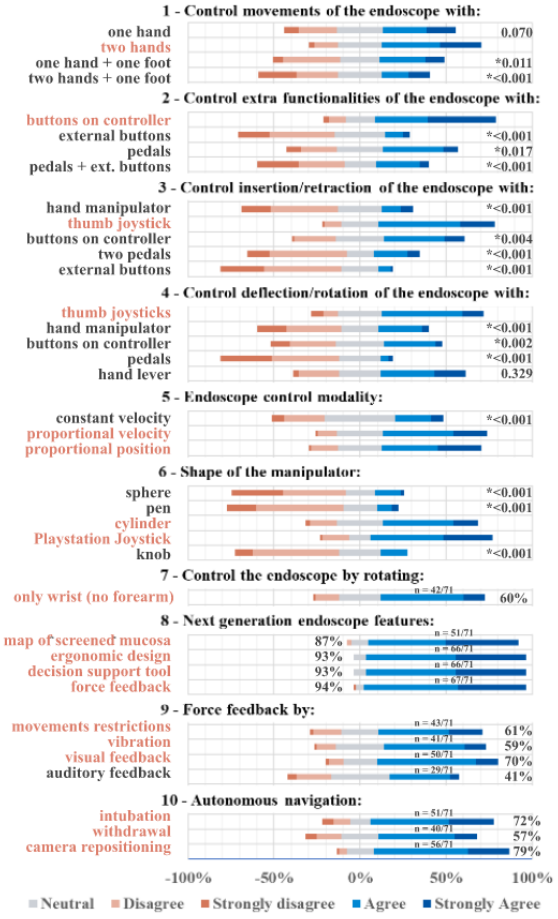

Fig. 1 Summary of the questions and answers provided by 71 endoscopists using a 5-point Likert scale. From questions 1-6, the clinicians' preferred option is highlighted in pink, and the respective *p-values* (preferred option vs other option) of the Wilcoxon signed rank test are reported. For questions 7-10 the answers collecting a percentage of agreement (*agree* + *strongly agree*) > 50% are highlighted in pink. The number of subjects agreeing (n) and their percentage with respect to the total number of subjects interviewed is reported.

comprising 38 questions. The questionnaire (Fig. 1) asked to rate with a Likert scale (1 to 5) the level of agreement regarding the inclusion of several features on the next generation HMI for robot-assisted colonoscopy. Explanatory graphics were provided to help understanding the questions, which were conceived jointly by both clinicians and engineers. Consensus measure [11] was used to assess the dispersion of the clinicians' answers, whereas subjects' preferences were estimated comparing the distributions of the medians through the Wilcoxon signed rank test. The percentage of subjects agreeing with each statement was computed by summing all the *agree* and *strongly agree* answers.

RESULTS

The average consensus computed was 0.78 ± 0.04, indicating a high degree of agreement among the clinicians for each question. Accordingly, the subjects expressed their preference in controlling the endoscope with two hands without using pedals and activating the extra functionalities with buttons integrated in the controller (Fig. 1). The clinicians prefer to control the insertion and retraction of the endoscope by moving a joystick placed on top of the controller with a thumb (up/down), instead of pushing/pulling a manipulator towards the monitor, pressing pedals, or using buttons. Same preferences were expressed for controlling the deflection and rotation of the endoscope (*i.e.*, moving thumbs joystick up-down/right-left). Regarding the control strategy, similarly high rates were given to the proportional velocity control (*i.e.*, the velocity of the tip is proportional to the joystick displacement from its rest-position) and the proportional position control (*i.e.*, the whole deflection of the tip is proportionally mapped on the joystick range of motion), both $p\ value < 0.001$. The manipulator shape is preferred to be cylindrical or Playstation® joystick style, and allowing manipulation by moving only the wrist, without involving the forearm. Force feedback (*e.g.*, to assist the navigation, provide contact forces, attract the camera towards important spots *etc.)* is highly requested (94%) either with haptic constrains (movement restriction and vibration) or with visual information. In addition, all the clinicians highly recommend the insertion of (1) optional autonomous navigation for intubation, withdrawal and tip repositioning, (2) an intelligent tool for decision support during the examination and diagnosis, and (3) a virtual map showing the parts of the mucosa not visualized during the screening. Finally, up to 93% of the clinicians interviewed agree on the need of a more ergonomic design with respect to the conventional colonoscope to reduce the physical load.

DISCUSSION

Results show clear preferences of the clinicians for most of the questions, pointing the high consensus and the outcome of the statistical tests. Considering the inquiries related to the physical aspects of the HMI, the platform commercially available best fitting all the clinicians' desires are the PlayStation® style joystick and the 6-DOF Haptic device (Touch Haptic device, 3D System), which might increase the easiness of use of the controls and reduce the physical load. However, the information collected could drive the design of new custom interfaces, best fitting all the requests. On the software side, clear interest has been shown in the adoption of intelligent tools assisting both navigation and decision-making.

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