

# An Automation Concept to Enhance Colonoscope Maneuverability

Chih-Nan Ni, Dian-Ru Li, Cheng-Han Lin,  
Chia-Wei Lin, Po-Chun Hsu and Hao-Ming Hsiao\*

Department of Mechanical Engineering, National Taiwan University  
No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan, 10617

(Received July 2, 2014; accepted February 9, 2015)

**Key words:** colon cancer, colonoscope, medical device automation, fiber optic sensor, servomotor

Colonoscopy is the current gold standard for the visual diagnosis and treatment of colon-related health problems. However, the size of the colonoscope, combined with the nonautomatic nature of the device, can cause discomfort to patients during examination. To reduce the burden for patients and allow physicians to work more efficiently, an automated colonoscope concept is proposed. Fiber optic sensors mounted at the tip of the colonoscope measure the distance from the intestinal wall in two directions. The signals from these sensors are then fed into a control module to drive a motor-dial assembly that controls the movement of the tip of the colonoscope. Two DC motors connected to two rollers spinning in opposite directions automatically advance the colonoscope inside the colon. Results show that our automated colonoscope prototype is able to repeatedly advance inside a 100-cm-long *in vitro* simulation model in less than a minute without contacting the model wall.

## 1. Introduction

Colon cancer is a common disease worldwide. Currently, colonoscopy is the gold standard for manual colon examination. During colonoscopy, the physician holds the colonoscope in one hand to advance it inside the colon while using the other hand to rotate dials that control the movement of the tip of the colonoscope. However, during examination, the colonoscope often touches the intestinal wall, which may cause discomfort to the patient.

Phee *et al.* was one of the first researchers to present the locomotion and steering concepts of an automated colonoscope.<sup>(1,2)</sup> Over the years, Chen *et al.*, Litten *et al.*, Khessal *et al.*, and Ott *et al.* developed various types of robotic colonoscope with automated functions in attempts to reduce both physician workload and patient discomfort.<sup>(3–8)</sup> Recently, Valdastrì *et al.* have attempted to achieve painless colonoscopy in trials with modifications on existing colonoscopes with magnetic air capsules.<sup>(9)</sup> We envision

---

\*Corresponding author: e-mail: hmhsiao@ntu.edu.tw

that, in the future, physicians may not need to manually operate the colonoscope, which would allow them to focus on finding lesion sites and treating them accordingly. Therefore, in this study, an automated colonoscope concept is proposed and developed. A servomotor assembly controls the movement of the tip of the colonoscope on the basis of signals from two fiber optic sensors. For locomotion, two DC motors connected to two rollers spinning in opposite directions automatically advance the colonoscope inside the colon. Our colonoscope is able to steer close to the center of the intestinal wall, thereby reducing patient discomfort during examination. These automated functions can be added directly to existing colonoscopes without significant modifications, making this automation concept feasible for actual clinical practice. A similar concept could be extended to other medical applications, such as catheter automation to help facilitate the implantation of intravascular stents for the treatment of vascular diseases.<sup>(10–12)</sup>

## 2. Design Concept of Automated Colonoscope

### 2.1 Fiber optic sensors

In this work, 2-mm-diameter fiber optic sensors (FS-N11MN, KEYENCE) were used to achieve the automated concept. The sensors [Fig. 1(a)] use optical intensity, polarization, frequency, or phase changes to detect the distance from an object. The output voltage from the sensor can be measured to determine the distance of the object from the sensor. Two fiber optic sensors were mounted on an add-on fixture at the tip of the colonoscope for detection [Fig. 1(b)]. The entire tip profile, after adding sensors and their housing fixture, became 12 mm in diameter.

### 2.2 Servomotor and DC motor

The dials of the colonoscope, typically controlled manually by physicians during examination, were integrated with a servomotor (GWS S03T 2BBMG, Grand Wing Servo Tech) to automate control of the colonoscope tip. When the detected distance between the colonoscope and the intestine wall is too small, on the basis of the signals from the sensors, the servomotor adjusts the dials automatically to prevent direct contact. To use the servomotor for such control, the pulse width modulation (PWM) technique was implemented. By adjusting the PWM duty cycle, the on-or-off durations related to different signal outputs can be determined.



Fig. 1. (Color online) (a) Fiber optic sensor and (b) sensor locations at the tip of the colonoscope.

The PWM technique was similarly applied to the DC motors for controlling forward motion. Two DC motors (Maxon Motor) were fixed at an acrylic base and connected to two rubber rollers (5.2 cm in diameter). The colonoscope was placed at the center of the two rollers to achieve advancement in the colon by spinning in opposite directions at a speed that could be constant (1.67 cm/s) or variable. The collected data, such as the advancement speed, are fed into the control module via the encoder to ensure appropriate colonoscope behavior.

### 2.3 Control module and data acquisition

The widely used proportional-integral-derivative (PID) algorithm is implemented for the colonoscope control. The Compact Rio control module (National Instruments, Austin, TX, USA) and LabView software are used to achieve the aforementioned functions. Through data acquisition cards, the Compact Rio control module is able to read the signal outputs from the fiber optic sensors and then control the motor movements accordingly.

The collected data from the sensors are fed into the control algorithm in LabView for data processing. On the basis of the sensor values, the control algorithm is able to drive the servomotor for the tip movement while advancing the colonoscope via DC motors at the same time. Figure 2 shows the block diagram of the entire control process.

## 3. Results and Discussion

### 3.1 Colonoscope prototype

A colonoscope prototype was constructed. Two fiber optic sensors were mounted on an add-on fixture located at the tip of the colonoscope for detection. One servomotor was installed on the dials of the colonoscope to control tip movement [Fig. 3(a)]. An acrylic fixture was made to host the motor-dial assembly to prevent it from flipping during operation. During operation, two DC motors [Fig. 3(b)], connected to two rollers (5.2 cm in diameter) spinning in the opposite directions, help advance the colonoscope forward inside the colon at the constant speed of 1.67 cm/s. The spinning speed can be adjusted on the basis of the signal feedback from the sensors. For example, if the sensors are too close to the intestinal wall (less than 5 mm), the spinning speed is reduced by a

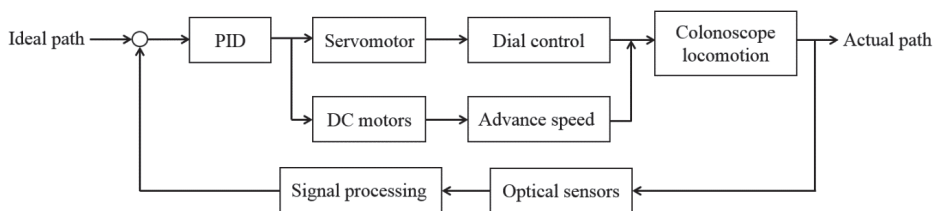


Fig. 2. Block diagram of the control process.

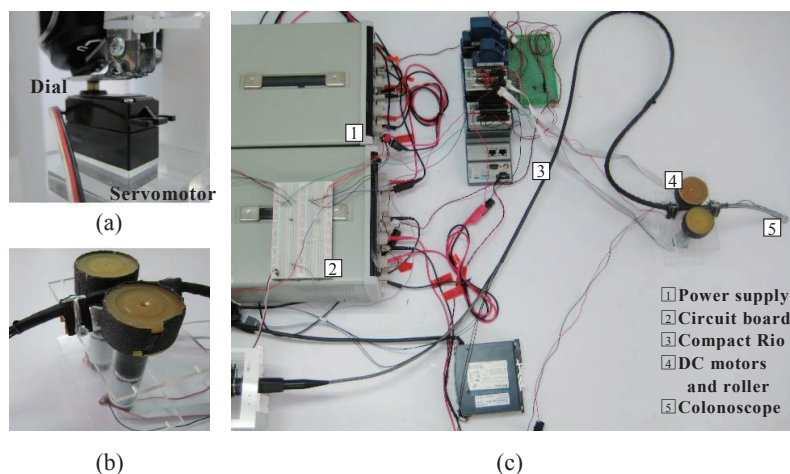


Fig. 3. (Color online) Integrated colonoscope prototype: (a) servomotor-dial assembly, (b) DC motors with two spinning rollers, and (c) top view of the colonoscope prototype and its accessories.

given value or formula in the control algorithm. Four data acquisition boards (National Instruments 9474, 9215, 9505) inserted in the Compact Rio read the sensor signals and control the motors. Figure 3(c) shows the top view of the integrated colonoscope prototype and its accessories.

### 3.2 In vitro simulation model

An *in vitro* simulation model (Fig. 4) mimicking the curvatures and angles of a human intestine was used to validate our colonoscope prototype. This simulation model was a plastic folded pipe (35 mm in diameter, 100 cm long) and consisted of two sharp turns greater than  $85^\circ$ , which divided the model into three sections shown in Fig. 4(b). When the angle gradually increased from  $85$  to  $125^\circ$ , our colonoscope was able to complete the simulation test repeatedly and consistently within 60 s in all trials.

It is necessary to first calibrate the relationship between the output voltage of the fiber optic sensor (FOS) and its distance from the target. Figure 5 shows the sensor voltage as a function of the colonoscope tip distance to the simulation model wall. With this relationship in place, the colonoscope is able to deduce its distance to the wall on the basis of real-time feedback signals from sensors.

Figure 6 shows the detected distance to the simulation model wall from the center of the right and left sensors located at the tip of the colonoscope (sampling rate of 10.2 Hz). As shown, when making the first turn [Section 1 in Fig. 4(b)], the left sensor detected the fast-approaching model wall and the servomotor made necessary adjustments accordingly to drive the sensor back to the center line. After passing the first turn, it was the right sensor's turn to come near to the model wall. It continued to do so for the remainder of the test until completion. This was due to the fact that the colonoscope had

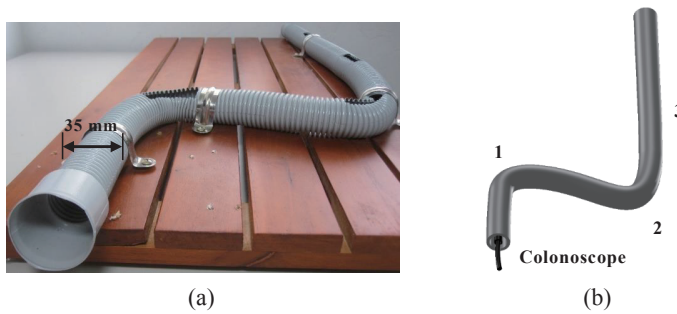


Fig. 4. (Color online) (a) *In vitro* simulation model and (b) model consisting of three sections for demonstrating colonoscope maneuverability.

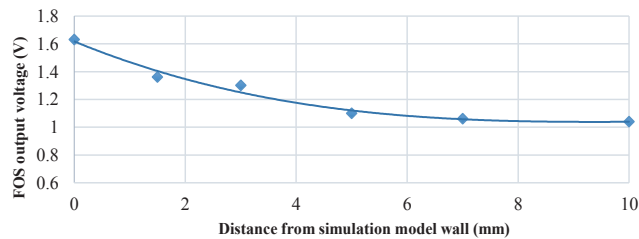


Fig. 5. (Color online) Output voltage of the fiber optic sensor as a function of the colonoscope tip distance to the simulation model wall.

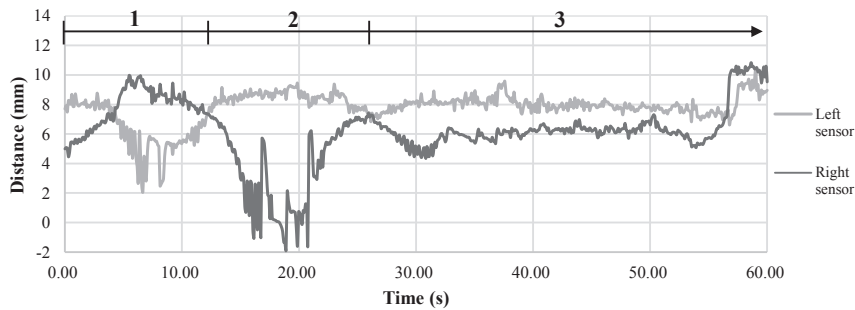


Fig. 6. Detected distance to the model wall from sensors at sections 1, 2, and 3.

relatively high bending rigidity, so it was challenging to mold it into a perfect S-shape once completely inside the simulation model. However, the colonoscope tip made necessary adjustments to prevent the colonoscope from coming into serious contact with the model wall. Simulation results show that our automated colonoscope concept is feasible, and it demonstrates a great potential for future clinical applications.

#### 4. Conclusions

In this study, an automated colonoscope concept is proposed to provide a new approach to colon examination. In the proposed design, fiber optic sensors mounted at the tip of the colonoscope measure the distance from the intestinal wall. The signals from these sensors are fed into a control module to drive a motor-dial assembly that controls the movement of the tip of the colonoscope. Two DC motors automatically advance the colonoscope inside the colon. These automated accessories can be directly installed onto existing colonoscopes without significant modification of the structure of the colonoscope.

We envision that in the future, the entire colonoscopy procedure will be completed automatically, allowing physicians to focus more intently on finding lesion sites and treating them efficiently. In addition, the automated colonoscope will help to prevent patient discomfort during examinations. Our integrated colonoscope prototype successfully completed simulation trials repeatedly and consistently, meeting the original design goals. Therefore, this automation is feasible for applications in actual clinical practice and thus has great potential for full commercialization in the future.

#### Acknowledgements

This research was supported by the Ministry of Science and Technology in Taiwan through Grants MOST-103-2622-E-002-010-CC1 and NSC-102-2221-E-002-130-MY3. The authors are grateful for the support and help.

#### References

- 1 S. J. Phee, W. S. Ng, I. M. Chen, F. Seow-Choen and B. L. Davies: *IEEE Eng. Med. Biol. Mag.* **16** (1997) 85.
- 2 S. J. Phee, W. S. Ng, I. M. Chen, F. Seow-Choen and B. L. Davies: *IEEE Eng. Med. Biol. Mag.* **17** (1998) 81.
- 3 G. Chen, M. T. Pham and T. Redarce: 2008 IEEE International Conference on Robotics and Biomimetics (IEEE, Bangkok, 2009) pp. 703–708.
- 4 G. Chen, M. T. Pham and T. Redarce: *Robot. Auton. Syst.* **57** (2009) 712.
- 5 J. D. Litten, J. H. Choi and D. Drozek: *J. Med. Devices* **5** (2011) 044502.
- 6 J. D. Litten, J. H. Choi and D. Drozek: *Med. Devices (Auckl.)* **4** (2011) 197.
- 7 N. O. Khessal, M. H. Teng, D. Tan and L. C. Teng: *TENCON 2000. Proceedings (IEEE, Kuala Lumpur, 2000)* pp. 71–76.
- 8 L. Ott, F. Nageotte, P. Zanne and M. de Mathelin: *IEEE Trans. Robot.* **27** (2011) 346.
- 9 P. Valdastri, G. Ciuti, A. Verbeni, A. Menciassi, P. Dario, A. Arezzo and M. Morino: *Surg. Endosc.* **26** (2012) 1238.
- 10 H. M. Hsiao, Y. H. Chiu, K. H. Lee and C. H. Lin: *Comput. Aided Des.* **44** (2012) 757.
- 11 H. M. Hsiao and M. T. Yin: *Biomed. Microdevices.* **16** (2014) 133.
- 12 H. M. Hsiao, A. Nikanorov, S. Prabhu and M. K. Razavi: *J. Biomed. Mater. Res. B Appl. Biomater.* **91** (2009) 508.