2022 Hamlyn Symposium on Medical Robotics
June 26-29, 2022, Imperial College London and the Royal Geographical Society, London, UK

A Haptic Feedback Glove for Minimally Invasive Surgery

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INTRODUCTION

Robot-assisted minimally invasive surgery (MIS) has countless benefits over open surgery, from shorter recovery times and lower risk procedures for the patient to higher accuracy and broader capabilities for the surgeon [1]. However, a significant detriment to these procedures is that current systems lack haptic feedback. The lack of haptic feedback in MIS forces the surgeon to depend merely on visual cues, such as the deformation of tissue under load, to estimate the forces [1]. The likely outcome of misreading these cues is torn tissue, patient discomfort or broken sutures [2]. Moreover, haptic feedback is specifically vital for robot-assisted endoscopy procedures. A recent study evaluating an Endoscopic Operation Robot (EOR) concluded that haptic feedback is beneficial in remote manipulation of flexible endoscopes. When haptic feedback was absent there were more incidences of overstretching of sigmoid colon in a colonoscopy training model [3]. This work presents a soft robotic glove that provides haptic feedback for endoscopic procedures (Fig. 1, A). In our previous work, we introduced a soft robotic sleeve [4] that can detect forces between a colonoscope and colon walls during navigation. The glove receives force input from the soft robotic sleeve wrapped around the colonoscope (Fig. 1, B). Any incident force on the sleeve, during endoscopic navigation, is relayed to the surgeon as haptic feedback through proportional inflation of the glove's pneumatic actuators.

MATERIALS AND METHODS

The glove design consists of three finger actuators. The actuators are attached to the main glove piece in a modular fashion using adjustable straps. The finger actuators are designed to be wrapped around the proximal phalanges on the dorsal side of the hand. This allows the surgeon to operate the endoscope without the actuators hindering their finger dexterity. Loss of finger dexterity could hamper handling and manipulation of the endoscope during the surgery. Current commercial haptic feedback gloves use vibrotactile or linear resonant

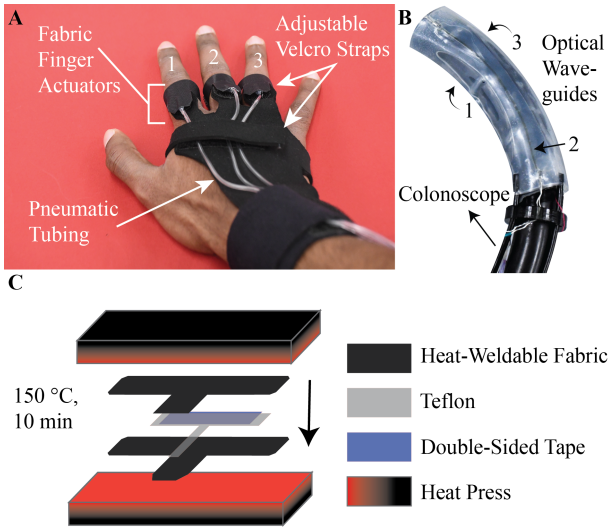

Fig. 1 A) Haptic feedback glove showing soft actuators (numbered) and tubing. B) Soft robotic sleeve showing three optical waveguides [4]. C) Fabrication diagram of finger actuators.

actuators (LRAs) mounted onto the palm and fingertips [5]. This can affect palm and fingertip dexterity, rendering such gloves unsuitable for haptic feedback in endoscopies. The number of finger actuators in the proposed glove can be varied depending on the number of sensors attached to the endoscope. The finger actuators are made from a combination of materials. First, heat weldable fabric (Seattle Fabrics, Inc.) and Teflon (McMaster-Carr Supply Company) are laser-cut into a T shaped pattern. Then, the Teflon is sandwiched between two pieces of the heat weldable fabric (Fig. 1, C) and sealed together using a heat press at 150° C for 10 min. This forms a completed actuator with the Teflon creating space for an air pocket. Tubing and Velcro® straps are then attached to the actuator. The main glove serves as a connection between the finger actuators and the wrist, providing a secure fit. It is made from Neoprene and has Velcro® straps to adjust to the user's hand size. The soft robotic sleeve used in this study has three

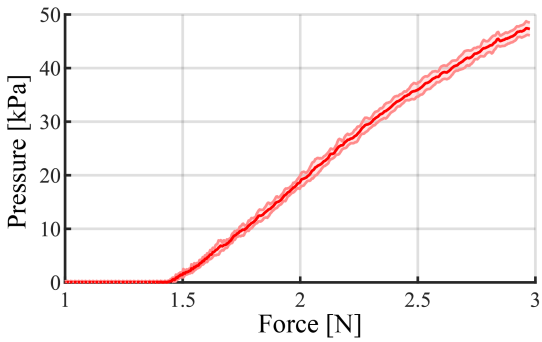

Fig. 2 Test results displaying actuator inflation pressure in response to incident force on soft robotic sleeve.

optical waveguides [4] to serve as force sensors, and each of them is connected to a finger actuator. The actuators are arranged on the glove to match the spatial orientation of waveguides of the sleeve, i.e, the actuator on the index finger maps force input from the leftmost waveguide. (Fig. 1, A-B). The glove is connected to a fluidic control board, with solenoid valves (GVP-321C-24D, Nitra® Pneumatics) and an Arduino® Mega 2560 micro-controller. The control algorithm uses pulse width modulation (PWM) to vary the duty cycle controlling the solenoid valve, based on the input from the soft robotic sleeve. Thus, the magnitude of incident force on the soft sensors determines the value of the duty cycle, triggering a proportional inflation of the actuators.

RESULTS

A. Force Calibration

The soft robotic sleeve was subject to a force compression calibration test using an indenter fixed to an Instron testing machine. As the indenter presses down on the optical waveguide sensors, light transmission decreases and this causes a change in signal voltage. The control algorithm then triggers inflation of the actuators in the glove. The test was performed over a range of 0-3 N. The PWM duty cycle is adjusted so that forces greater than 1.5 N trigger actuator inflation [4]. This is to ensure that the surgeon is notified of potentially dangerous forces to the colon wall while ignoring smaller, inconsequential forces. This threshold can be changed as necessary. As seen in Fig. 2, as the force increases beyond 1.5 N, the actuators inflate and the internal pressure rises linearly to about 50 kPa. This demonstrates the ability of the actuators to apply haptic feedback in a manner proportional to the incident force on the sensor. The actuators inflate to max pressure in 103 ms.

B. In-Vitro Validation

An *in-vitro* test was performed by imitating a colonoscopy procedure. The soft robotic sleeve was wrapped around a colonoscope model. An artificial colon model was created from thermoplastic elastomer (TPE) (Stretchlon® 200, FibreGlast, USA) and the colonoscope was inserted into it (Fig. 3, A). During navigation, when the colonoscope pushes on the colon wall, the light transmission in the optical waveguides decreases and the voltage values drop. This increases the value of the duty cycle and triggers the inflation of the

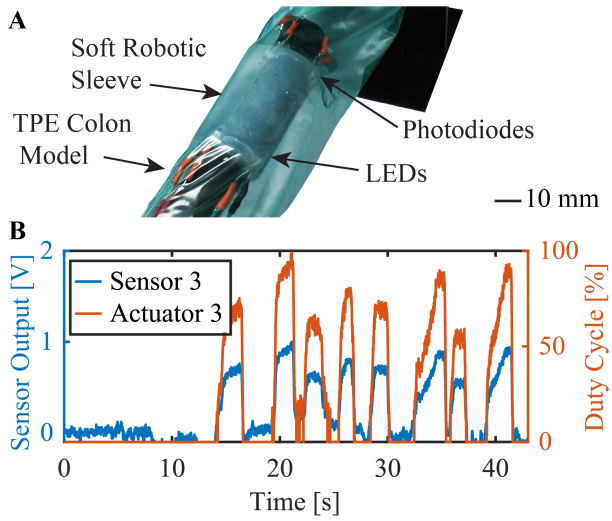

Fig. 3 *In-vitro* validation test. A) Setup. B) Results.

actuators on the haptic glove. As seen in Fig. 3, B, when a sensor (i.e., optical waveguide) on the colonoscope pushes against the colon wall, the voltage difference and duty cycle increase and results in inflation of the glove's actuator. This demonstrates the preliminary viability of the haptic glove in endoscopic procedures.

DISCUSSION

The goal of this study was to evaluate the feasibility of a soft glove to provide haptic feedback to a surgeon during an endoscopic procedure. We concluded that the glove successfully pressurizes the fingers of the wearer proportional to the force exerted on a colon wall during a colonoscopy procedure, and thus provides continuous haptic feedback. The next steps for this study would be to determine the adaptability of the haptic glove to various users (i.e., expert and novice endoscopists) and validate its usability in a clinical colonoscopy setting. Future work will also incorporate a gyroscopic sensor to ensure that the actuators spatially map force even when the colonoscope is rotated.

ACKNOWLEDGMENTS

This work was supported by the National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health under award number R21EB029154 and by the the National Center for Advancing Translational Sciences, National Institutes of Health, through BU-CTSI Grant Number 1UL1TR001430. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH.

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