Mapping Tactile Information of a Soft Manipulator to a Haptic Sleeve in RMIS

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I. Introduction

In Robot-assisted Minimally Invasive Surgery (RMIS), robotic tools enter the body through narrow openings and manipulate soft organs that can move, deform, or change in stiffness. The traditional robotic manipulation concepts that rely on fixed stiffness distributions, such as the da Vinci Robotic System, have limitations on these laparoscopic and robot-assisted surgical procedures due to restricted access through Trocar ports, lack of haptic feedback [1], and difficulties with rigid robot tools operating inside a confined space filled with organs [2]; the use of such systems can, in extreme cases, lead to harmful tissue tears [3-4]. Along the way, the solid structure of the laparoscopic instrument attached to the robotic arms and their external articulation make it problematic to change surgical targets inside the abdomen.

In this paper, we will present a novel approach to overcome the disadvantage of lack of haptic feedback in RMIS. Current work at King's also addresses the problem of rigid robot systems, and, with this in mind, we have developed a soft and stiffness-controllable MIS robot device allowing for more complex operations to be conducted inside a patient [5]. The work described here focuses on acquiring haptics information from tactile sensors attached to the MIS robot arm. Whilst our approach is generic and also applicable to rigid manipulators, here, we describe how tactile information from a stretchable tactile sensor sleeve of a soft manipulator is mapped to a haptic sleeve worn by a surgeon while operating with the manipulator. This paper will focus on the complete system (Section II): the stretchable tactile sensor sleeve (Section III), the wearable pneumatic haptic sleeve (Section IV) and the communication architecture between the two devices (Section V).

The presented system will be developed using the soft modular manipulator inspired by the octopus morphology for RMIS by Cianchetti et al. [5]. This research is part of the EU FP7 project STIFF-FLOP (STIFFness controllable Flexible and Learnable manipulator for surgical OPerations). The manipulator is a novel cylinder-shaped device which is manufactured from EcoFlex 00-50 silicone and covered by an off-the-shelf flexible braided sheath. This structural design allows omnidirectional bending, elongation capability and selective stiffness changing when pneumatically actuated via integrated chambers within the cylinder. The device has an overall length of 50 mm and an outer diameter of 35 mm with an elongation capability of up to 85%.

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II. System Overview and Objective

The conceptual system is shown in Figure 1. The tactile sensor sleeve and wearable haptic device are connected to a data acquisition module. Via a bridge, both components are linked to a ROS PC. An implemented system map processes data from the tactile sensors and actuate elements of a pneumatic haptic sleeve.

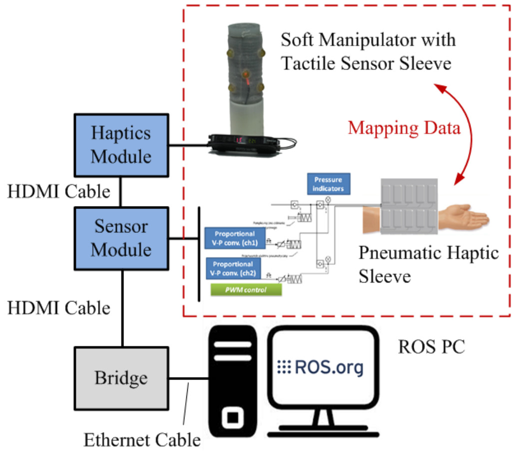

Fig. 1. ROS Interface of the Tactile Sensor and the Pneumatic Haptic Sleeve

The objective is to investigate how to best map the transferred information so that the surgeon obtains the most beneficial feedback. Hence, the received feedback should be useful for the surgeon and not distract or even obstruct him or her during an operation. An overview about the sensor and haptic sleeve is given in the next sections.

III. TACTILE SENSOR SLEEVE DESIGN

To develop a novel design and structure, the following two functional requirements are considered for the proposed tactile sensor sleeve:

1. The STIFF-FLOP robotic soft manipulator enters the body through narrow openings. This RMIS tool is able to squeeze, stiffen and elongate. Sensory data of a single sensor should not be affected by these features.
2. For RMIS, the tactile sensor array will need to be designed so that it can be miniaturized.

The design of the tactile sensor sleeve is described in the following subsections.

A. *Individual Sensing Elements*

The single tactile sensors use light intensity modulated fibre optics based on a prismatic tip [6]. The tip is cut at 45° angle in order to provide an internal reflection of 90° [7]. The sensor base has a 10 mm diameter and 1 mm thickness and is manufactured using a rapid prototyping machine (Project HD-3000 Plus, 3D Systems). The base embeds a 1 mm optical fibre. A flexible hemi-spherical dome of 8 mm diameter and 4 mm height (thickness: 1 mm) is mounted on the base. The emitted light is reflected on a 2 mm diameter mirror inside the dome which is manufactured of EcoFlex 00-50 silicone.

B. *Tactile Sensing Integration into Stretchable Sleeve*

In order to distribute the sensor elements along the manipulator, a sleeve has been designed (see Figure 2).

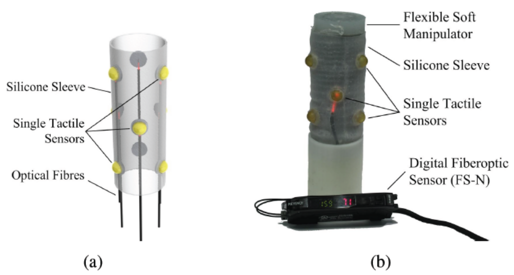

Fig. 2. (a) CAD Drawing and (b) Prototype of the Sensor Sleeve with Multiple Tactile Sensor Elements

The single sensors are placed into equally allocated holes along a silicon sleeve. In order to fit the stretchable sleeve to this manipulator, the silicone mould has a 30 mm diameter and 45 mm length. The optical fibres are winded along the braided sheath to feed forward necessary fibre length in case of elongation.

IV. WEARABLE PNEUMATIC HAPTIC SLEEVES

A pneumatic actuated haptic sleeve is conceived around the end-user's forearm. It is based on a set of small chambers that are filled with air causing local pressure.

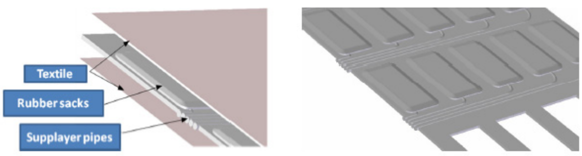

Fig. 3. Concept of the Proposed Haptic Sleeve

FigureFig. 3 shows the matrix of 4×5 pneumatic selectors having a dimension of 55×30 mm each, where applied pressure and sensitivity of human forearm affect the technical capability of sleeve to transfer the feeling of a force feedback to the end-user.

V. INTUITIVE HAPTIC FEEDBACK MAPPING

When the surgeon operates and navigates the soft and flexible tool inside the human body, interactions between the manipulator and tissue/organs occur. In general, continuous minor physical contact which is unavoidable appears. This kind of sensing information is not relevant to the surgeon as it is classified as not harmful to any surrounding tissue. Feeding back this data might result in a distraction and cause complications because the clinician is unable to concentrate on the surgical procedure.

Thus, possible scenarios and interrelated sensing information will be categorised and classified in order to support the surgeon while he/she is performing the procedure with the aim of preventing possible inappropriate movements. This data will then be translated into actuation modes of the pneumatic haptic sleeve. Rather using a linear transformation, the aim is to convert tactile sensor signals into substantial haptic feedback which make the surgeon intuitively reacting in the appropriate way to reconfigure the manipulator.

VI. CONCLUSIONS AND FUTURE WORK

This paper introduces a new approach to feed back tactile information in RMIS to the surgeon's forearm. A tactile sensor sleeve for flexible and soft snake-like manipulators is presented. A control strategy will interpret the signals and feed useful and intuitive feedback by using a haptic device which is a wearable pneumatic actuated sleeve.

The implementation of this system will allow us to study how much feedback is beneficial for surgeons and when haptic feedback becomes more distractive than beneficial.

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