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A Soft Inductive Tactile Sensor for Slip Detection Within a Surgical Grasper Jaw

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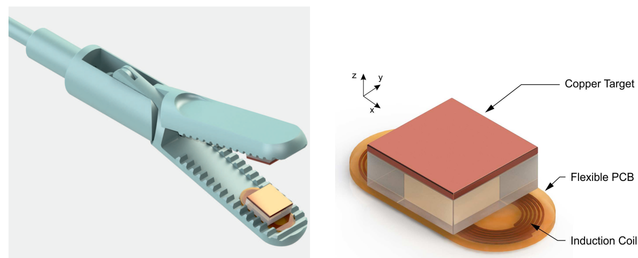
***Abstract*—This paper presents a two-axis Soft Inductive Tactile Sensor (SITS) designed for use on the face of a surgical grasper to detect the slip of tissue. A scaled version of the proposed sensor is manufactured and experimentally characterized, showing high repeatability and low hysteresis. The sensor was then used to detect slip while holding a tissue simulant in laboratory conditions. Slip was initiated in 72 cases with different load conditions and the coefficient of friction was recorded. Results showed the sensor capable of detecting slip on a surface comparable to biological soft tissue and has promise for future surgical use. To show the capabilities of the sensor within a grasping environment, the sensor was then configured into a 3.5mm x 8mm footprint to fit into a representative grasper jaw. The grasper was then used to assess the grasping pressure and shear when used by a consultant urologist, yielding similar applied pressure to previous studies showing its capability to measure force within the size constraints of current laparoscopic instruments.**

I. Introduction

Minimally Invasive Surgery (MIS) brings advantages over traditional open surgery methods, including a lower degree of blood loss, improved cosmesis and faster recovery [1]. Graspers are a key instrument used to manipulate and hold tissue in MIS procedures, in essence replacing the surgeons fingertips. However, the mechanical nature of these tools inhibits haptic feedback to the user and increases the likelihood of incorrect force application [2]. Studies have shown that increased haptic sensing and feedback can reduce tissue damage caused by excessive pressures, and that sensing on the face of the grasper is crucial [3], [4].

Our approach in this paper differs, instead of focusing on imposing an upper "safe" threshold force, we seek to identify the level at which insufficient force and therefore insufficient traction causing slip, is also measured. This established a "safe zone" for grasping with a lower chance of causing trauma. While this gives a general view for the grasping forces, the thresholds are not universal and will vary based on grasped tissue type. Our aim here is to employ a real-time measure of the friction coefficient between the tissue and jaw and use this as a means by which to identify the risk of slip events occurring.

The Soft Inductive Tactile Sensor (SITS) (Fig. 1) was selected for the purpose owing to its multi-axis load-sensing capability [5]. The eddy-current effect is utilised to detect the changing position of a conductive target above a number of sensing coils. The target is separated from the coils by an elastomer, allowing customisation of the sensor geometry and load sensing range appropriate to the application.



(a) (b)

Fig. 1. (a) Render of the SITS integrated into a grasper face; and (b) A two-axis SITS. Two coils are positioned below a copper target and silicone elastomer to detect forces in the z and x axes.

II. Sensor Characteristics

The SITS consists of three main components (Figure 1b): a conductive target, spiral coils, and a layer of silicone elastomer. The eddy current effect is used to deduce the changing position of the conductive target above the coils, while the silicone elastomer allows this movement to be calibrated to a specific force. A multi-coil arrangement can allow the SITS to be configured to measure forces between 1 and 3 DoF.

The SITS used consisted of two 7 mm planar spiral coils totalling 24 turns per coil on a Kapton flexible printed circuit-board (FPC). An 8 mm square copper target was affixed to a square of 2 mm thick 50A silicone elastomer (DragonSkin 50, Smooth-On), and affixed between coil centres.

To characterize and evaluate the SITS, the multi-axis load regime used in Wang's work [5] was applied to the sensor using a custom test apparatus. Characterization of the sensor revealed the maximum hysteresis to be 8.77 & 9.71% (0.09, 1.55 N) of the maximum applied shear and normal force (0.03, 16 N) (Figure 2).

III. Slip Detection

Tests were conducted to evaluate the sensitivity of the sensor for the identification and quantification of slip. The system was used to probe a tissue simulant (Adult Skin, SynDaver Labs, FL, USA) placed under a slip regime. The simulant was selected as a controlled medium with which to simulate

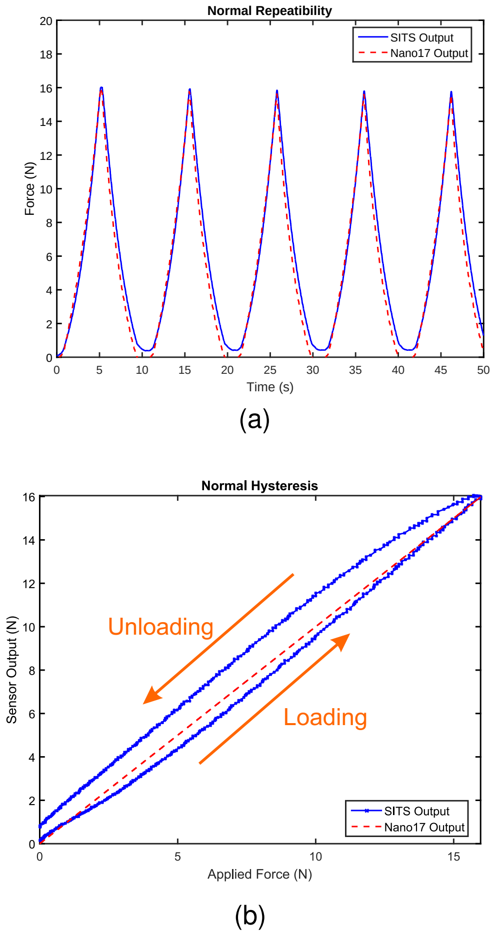


Fig. 2. (a) Five cycles of the Normal loading repeatability test; and (b) Normal force hysteresis of the sensor

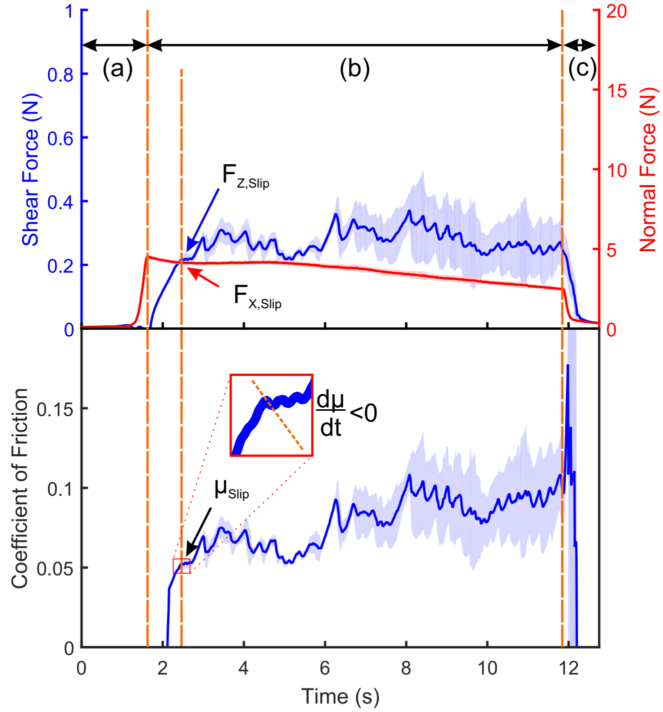


Fig. 3. Example plots of the force and Coefficient of Friction (Mean ± SD) (a) Loading Phase, (b) Shear Phase, (c) Unloading Phase. The slip point ($d\mu/dt < 0$), Forces at Slip ($F_{XZ,slip}$) and Friction at Slip (μ_{slip}) are indicated.

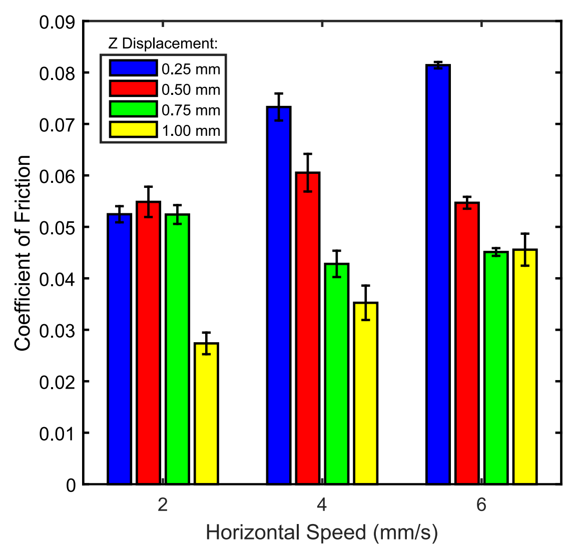


Fig. 4. Mean values of measured friction coefficient at slip, $\mu_{slip} \pm 95\%CI$

soft biological tissues, owing to its similar frictional properties on the untextured side when wet [6]. Compressive loads were applied by lowering the sensor to varying displacements from 2.5 to 10 N. Twelve conditions (three speeds four displacements) were repeated six times, totalling 72 tests.

Results data were post-processed to generate the coefficient of friction (μ) at all points along each test (Figure 3). The point at which slip occurred was defined as the first peak, or the point at which the differential ($d\mu/dt$) first became negative. At this point, coefficient of friction (μ_{slip}) was recorded. This method could be employed in real-time within surgical robotic systems to identify and potentially prevent undesirable slip events from occurring.

Figure 4 presents the change in coefficient of friction with varied load and speed. An increase in vertical displacement and normal load causes a decrease in μ_{slip} whereas an increase in horizontal speed causes a decrease. This is consistent with previous studies on the frictional properties of hydrogels, which is generally lower than that of soft tissue [7]. This shows the SITS can both monitor the coefficient of friction between grasper and tissue and detect the point at which slip occurs. This shows potential for avoiding trauma through control of graspers in surgical robotics.

IV. Grasping Prototype

To assess the effectiveness of the sensor when implemented on a grasper face, the coils were miniaturised to fit upon the face of a typical 5 mm surgical grasping face. Two-layer coils of 3.5 mm diameter were produced with 6.5 turns per layer and 100 μm trace width and spacing, totalling 13 turns. A 4 mm square, 0.2 mm thick target was suspended above a 4 x 4 x 2 mm section of EcoFlex 00-30 silicone, and arranged between the coil centres. The sensor was calibrated up to a maximum of 4.8 N (300 kPa) normal and 1.0 N shear.

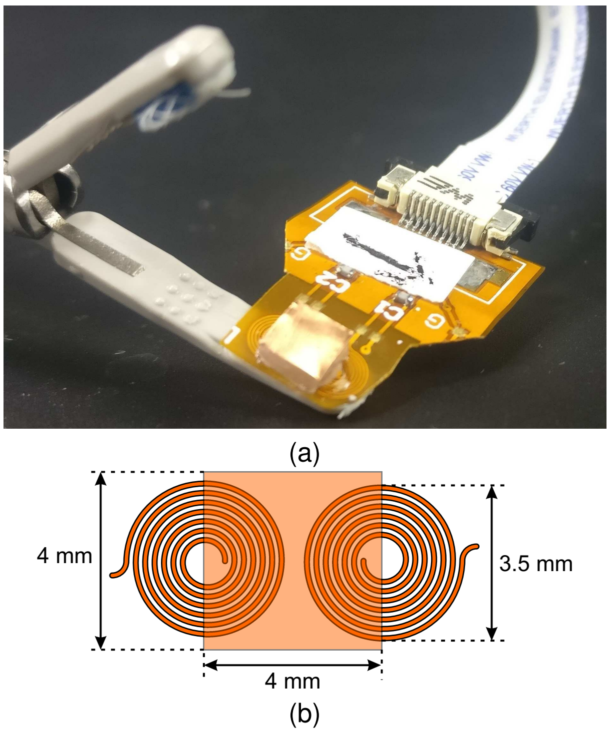


Fig. 5. (a) The manufactured prototype, with the sensor mounted on a toothless 5 mm laparoscopic grasper (Epix, Applied Medical; and (b) Schematic of the miniaturised coil, indicating coil and target sizes

The sensor was affixed to the face of a pair of representative 5mm atraumatic surgical graspers (Epix, Applied Medical, CA, USA) with cyanoacrylate glue (Loctite 401, Henkel, Germany). In this prototype the sensor interface was not placed within the grasper jaw but this would be accommodated in future versions. The sensor replaced one of the two silicone pads on the face of the Epix graspers, allowing direct contact between the sensor grasped sample to directly measure the tissue tool interface.

To evaluate the performance of the prototype graspers, a consultant urologist performed a grasping task to assess the performance in the angular face of the grasper. The task was performed in an EOSim portable laparoscopic training platform (eoSurgical Ltd., Edinburgh, UK). The tissue simulant used for slip analysis (Adult Skin, SynDaver Labs, FL, USA) was used to replace ex-vivo tissue for the grasping task. The task involved ten compressions on the tissue simulant. Two typical grasps are presented in Figure 6. For both grasps, the normal (compressive) force rises to just over 1N, before quickly reducing after pressure is released. This equated to just over 50 kPa, reflecting the average pressure for a consultant grasp deduced in previous work [3].

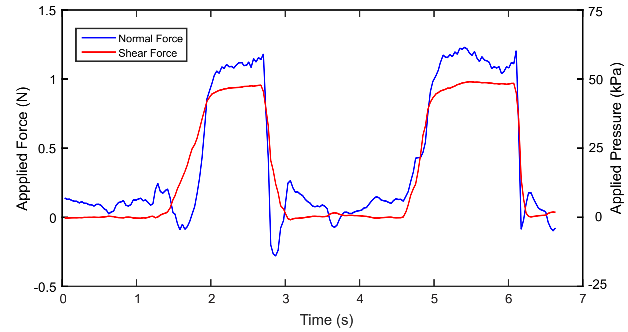


Fig. 6. Force data from two typical grasps from the Pull tests, indicating an increase in both normal and shear as the grasper face closes

V. Conclusion

This paper presents an two axis SITS as a demonstrator of the technology's capabilities in the detection of slip of grasped objects. A SITS was developed to measure the coefficient of friction with a tissue simulant, where the point of slip was defined as the first friction "peak". The sensor was capable of determining the frictional properties of the sample to be consistent with previous studies.

Next, the sensor was miniaturised and integrated onto a grasping face. Through testing with a consultant, this prototype was able to measure compression and shear on the grasper face up to 1 N. This fits within the range of the average pressure applied by consultants, and so shows promise as a sensor for surgical grasping.

Overall, this work demonstrates the potential of using real time measures of slip based on measurements from the tissue-tool interface to inform the surgical grasping process and potentially avoid the application of both excessive and insufficient forces during minimally invasive surgery.

References

[1] T. W. Kong, K. M. Lee, J. Y. Cheong, W. Y. Kim, S.-J. Chang, S.-C. Yoo, J.-H. Yoon, K.-H. Chang, and H.-S. Ryu, "Comparison of laparoscopic versus conventional open surgical staging procedure for endometrial cancer," *Journal of gynecologic oncology*, vol. 21, no. 2, pp. 106–111, 2010.

[2] O. A. Van der Meijden and M. P. Schijven, "The value of haptic feedback in conventional and robot-assisted minimal invasive surgery and virtual reality training: a current review," *Surgical endoscopy*, vol. 23, no. 6, pp. 1180–1190, 2009.

[3] D. Jones, A. Jaffer, A. A. Nodeh, C. S. Biyani, and P. Culmer, "Analysis of mechanical forces used during laparoscopic training procedures," *Journal of endourology*, vol. 32, no. 6, pp. 529–533, 2018.

[4] H. Visser, E. Heijnsdijk, J. Herder, and P. Pistecky, "Forces and displacements in colon surgery," *Surgical Endoscopy And Other Interventional Techniques*, vol. 16, no. 10, pp. 14 263–1430, 2002.

[5] H. Wang, J. W. Kow, G. Boer, D. Jones, A. Alazmani, and P. Culmer, "A low-cost, high-performance, soft tri-axis tactile sensor based on eddy-current effect," in *IEEE Sensors*, 2017.

[6] L. Bostan, Z. Taylor, M. Carré, S. MacNeil, S. Franklin, and R. Lewis, "A comparison of friction behaviour for ex vivo human, tissue engineered and synthetic skin," *Tribology International*, vol. 103, pp. 487–495, 2016.

[7] E. R. Reale and A. C. Dunn, "Poroelasticity-driven lubrication in hydrogel interfaces," *Soft matter*, vol. 13, no. 2, pp. 428–435, 2017.