A Miniature Wirelessly Actuated Magnetic Surgical Tool for Minimally Invasive Grasping

A. Lim[1], S. Salmanipour[2], O. Onaizah[2], C. Forbrigger[2], T. Looi[1],
J. M. Drake[1], E. Diller[2]

[1]*Centre for Image Guided Innovation and Therapeutic Intervention (CIGITI),*
The Hospital for Sick Children, Toronto, Canada

[2]*Department of Mechanical and Industrial Engineering, University of Toronto*
andrewwilliam.lim@mail.utoronto.ca

INTRODUCTION

The implementation of robotically-assisted surgery has led to improved surgical outcomes in urology, gynecology and general surgery by offering benefits such as reduced surgeon tremor and increased tool precision and dexterity. However, surgical disciplines with narrower workspaces, such as neurosurgery or pediatrics, have yet to see many of these benefits largely due to the lack of small yet dexterous tools. With existing tools, robotically-assisted surgery is ineffective, and adoption into these disciplines is resisted [1-2].

Existing tools typically rely on cable driven actuation. Although reliable and able to generate substantial tool tip forces at large scales, miniaturization remains a challenge. Frictional inconsistencies between moving parts at the tool's tip in cable driven systems become amplified and component fabrication for these intricate mechanisms is difficult at smaller scales. Wireless magnetic actuation avoids these limitations and is an effective actuation method for complex mechanical mechanisms used in various microrobotic applications [3]. Therefore, in this work we present a magnetically-actuated, cable-less strategy for a three-degree-of-freedom (3-DOF) gripper-wrist tool tip with a diameter of 4 mm.

MATERIALS AND METHODS

Gripper-Wrist Design: The gripper-wrist is composed of nitinol and nickel-coated N52 NdFeB permanent magnets (Fig. 1). In the presented design, a single flexural joint is used for the 2-DOF (yaw, pitch) wrist to avoid friction while simultaneously providing axial rigidity. The gripper is composed of two parallel gripping digits connected by a semicircular restoring spring. Permanent magnets are fixed to the proximal ends of the gripping digits and the distal end of the wrist, creating local and global magnetization vectors. The 3x1x1 mm magnets on the gripping digits are responsible for gripper closure and have magnetization vectors oriented inwards. The three 1x1x1 mm magnets located at the distal end of the wrist are responsible for actuating wrist orientation and have proximally-oriented magnetization vectors. The gripper-wrist's orientation and digit tip separation are actuated using an 8-coil electromagnetic system [4] capable of delivering a controlled magnetic field up to 40 mT.

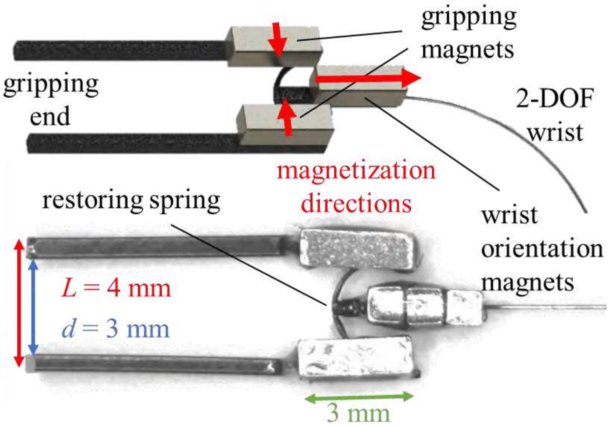

Fig. 1 (Top) 3D render of design with wrist bent. (Bottom) overhead image of the 4mm gripper-wrist prototype.

Gripper-Wrist Fabrication: The gripper-wrist was fabricated in-house. Curved nitinol components were shape set in a high-temperature oven at 550°C for 5 minutes. The gripping digits, restoring spring and 2-DOF wrist were joined using a LaserStar 990 series laser welding system. Permanent magnets were fixed to the gripper using epoxy and left to cure for 24 hours.

Gripper Closure Response: The gripper's digit tip separation, *d*, was measured without wrist deflection using several external magnetic field magnitudes in the direction of the undeflected wrist. Field magnitudes up to 130 mT were generated using two 2.5 cm cube N52 permanent magnets with varying separation distances. A Lake Shore Model 425 gaussmeter was used to measure the applied magnetic field at the proximal tip of the gripping digits.

Wrist Range of Motion Characterization: The wrist's range of motion was characterized using a 75 mT magnetic field, created by two 2.5 cm cube N52 permanent magnets separated by 4.5 cm. The orientation of the wrist's base with respect to the direction of the field was varied, and the gripper's tip orientation was measured.

"Pick and Place" Demonstration: Using the coil system, a time-varying external magnetic field was applied to the gripper-wrist to perform a "pick and place" demonstration on a tissue-mimicking polydimethylsiloxane (PDMS) cargo fabricated such that its density was similar to brain tissue. Kinematic control of the gripper was implemented with a proportional controller and real-time image-tracking

feedback from an overhead camera. The magnitude of the field parallel to the gripper's local orientation controls tip separation while the magnitude and direction of the field vector in the orthogonal plane orients the wrist. The goal of the task was to move the gripper to a position above the cargo, lower its height, grasp the cargo, move to its target position, release the cargo, and finally move back to its initial position.

RESULTS

To determine the potential of this design for use as a surgical grasping mechanism, its ability to close and its total angular range of motion at a constant field magnitude were characterized. Fig. 2 exhibits the gripper's tip separation response to various parallel field magnitudes. Full gripper closure was observed at 75 mT. Fig. 3 shows a maximum wrist yaw deflection of 88° counter-clockwise and 84° clockwise using 75 mT. Our experimental setup was physically limited to maximum wrist deflections of these values and we postulate that further deflection is possible. A similar range of motion is expected for the wrist's pitch DOF. Finally, Fig. 4 shows frames from a "pick and place" video demonstration on a PDMS cargo.

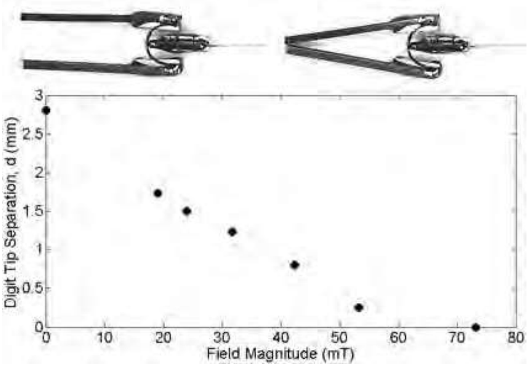

Fig. 2 (Top-left) no field applied; (top-right) gripper under 75 mT of external field pointing left; (bottom) digit tip separation under various magnetic field strengths.

Fig. 3 (Left and right) maximum flexural wrist response to a 75 mT field oriented +/-115° away from the wrist's undeflected position. (Middle) undeflected gripper-wrist under no external magnetic field.

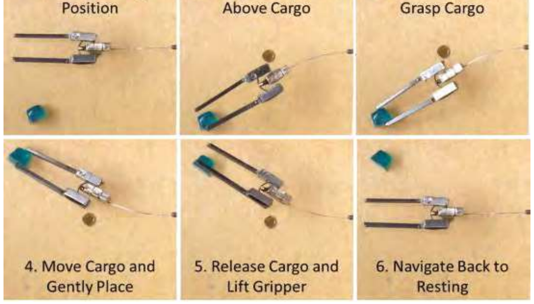

Fig. 4 Frames from the "pick and place" demonstration using the 4mm magnetically actuated gripper-wrist.

DISCUSSION

This work presents a 4 mm magnetically-actuated gripper-wrist tool tip. Early experiments are promising, demonstrating that the wrist has a range of motion of at least 172° and full gripper closure can be achieved using a 75 mT external field. Furthermore, a "pick and place" demonstration was performed on a PDMS cargo using a 40 mT 8-coil electromagnetic system.

The simple design of the proposed mechanism lends itself well to further miniaturization to accommodate more confined surgical workspaces. A more efficient use of space in the mechanism would likely enable miniaturization in future designs while maintaining functionality.

Although this study provides evidence for feasibly grasping and transporting tissue-mimicking cargo, tool tip forces were not characterized. Marcus *et al.* suggested a force exertion of 0.02-0.09 N per digit tip for effective brain tissue retraction on cadavers [5]. Future work will involve characterizing the presented gripper's tip forces.

While this study was limited to a system capable of delivering a maximum of 40 mT, Rahmer *et al.* have developed a clinically scaled coil system that can generate field strengths up to 400 mT and accommodate workspaces over 20 cm [6]. A system with these capabilities would likely be able to actuate our presented gripper-wrist in small surgical workspaces such as the head for neurosurgical applications. It is also probable that fields of this magnitude would increase the range of motion of our flexural wrist and allow for much higher gripping forces to be exerted.

Finally, this magnetically actuated mechanism is not limited exclusively to grasping. Several other tool-tip functions would benefit from this design including magnetically actuated cutting and bipolar electrocautery tips for robotically-assisted surgeries. These functionalities, in addition to grasping, have the potential to feasibly extend the use of surgical robotic systems to neurosurgery and pediatrics, aiming to improve their surgical outcomes.

REFERENCES

[1] Marcus HJ, *et al.* da Vinci robot-assisted keyhole neurosurgery: a cadaver study on feasibility and safety. Neurosurg. Rev. 2015 Apr;38(2):367-71

[2] van Haasteren G, *et al.* Pediatric robotic surgery: early assessment. Pediatrics. 2009 Dec;124(6):1642-9.

[3] Kummer MP, *et al.* OctoMag: An Electromagnetic System for 5-DOF Wireless Micromanipulation. IEEE Trans. on Robot. 2010 Dec;26(6):1006-17.

[4] Salmanipour S, Diller E. Eight-Degrees-of-Freedom Remote Actuation of Small Magnetic Mechanisms. IEEE Int. Conf. Robot. & Autom. Accepted for publication, 2018.

[5] Marcus HJ, *et al.* Forces exerted during microneurosurgery: a cadaver study. Int J Med Robot. 2014 Jun;10(2):251-6.

[6] Rahmer J, Stehning C, Gleich B. Remote magnetic actuation using a clinical scale system. PLoS One. 2018 Mar;13(3):e0193546.