Int J CARS (2012) 7 (Suppl 1):S169–S176
DOI 10.1007/s11548-012-0716-3

Remote active magnetic actuation for a single-access surgical robotic manipulator

C. Di Natali[1], P. Valdastri[1]
[1]STORM Lab, Mechanical Engineering Department, Vanderbilt University, Nashville, TN, USA

Keywords Robotic surgery · Magnetic control · Single access robotic surgery · LESS surgery

Purpose

Magnetic coupling is one of the few strategies to transmit motion through physical obstacles. This approach can be applied to remotely control and manipulate medical devices/robots inside the human body preventing the need for dedicated incisions [1, 2]. The most straightforward approach to take advantage of magnetic coupling to control a medical device inside the human body consists in simply using a couple of permanent magnets, one embedded in the device and the other operated by the user [3, 4]. A magnetic camera for laparoscopy developed by Ethicon Endo-Surgery, Inc., will soon hit the market, promising to reduce the access trauma of minimally invasive surgery [5]. However, due to the exponential decay of magnetic field strength with distance and to the friction occurring at the interface between the controlled object and biological tissues, reliable and precise motion control is hardy achievable. As represented in Fig. 1 and preliminary described in [6], the approach we propose consists in first coupling the driven and the driving object across the obstacle (i.e. the abdominal wall), and then achieving controlled motion of the driven unit on different planes by physically rearranging in space the external source of magnetic field by robotic control (e.g. in Fig. 2 the rotation of external "driving" magnets about their own axis induces the rotation of the internal "driven" magnets, which can be connected by cable transmission to a mechanism or a joint to provide actuation). This novel actuation concept can be used to achieve multiple-degree-of-freedom high-resolution motion in an ultra-compact size, ultimately allowing the deployment of a complete bimanual modular surgical robotic platform through a single 12-mm incision.

Methods

The robotic arm we designed, represented without the external cover in Fig. 3, is composed by the following parts: the magnetic linkage, providing anchoring, actuation and a first roll degree of freedom (DoF), a double 4-bar mechanism that provides 2 DoF planar robot (which 3 DoF constitute a robotic anthropomorphic arm), and a distal 3 DoF spherical wrist. Its external diameter is 12 mm, while its total length is 25 cm. It is designed to be introduced through a standard 12-mm trocar and coupled with an external magnetic system trough the abdominal skin of the patient. The external magnetic system provides anchoring, the rotational DoF for the manipulator and transmit actuation for the double 4-bar mechanism. In particular, 2 external DC brushless motors rotate 2 external permanent magnets. These are coupled with two internal permanent magnets, embedded on board the manipulator and free to rotate. These two internal magnets actuate the double 4-bar mechanism by cable transmission. A three DoF wrist, actuated by on board miniaturized motors, completes the 6 DoF manipulator. In the present work we emphasize the magnetic actuation concept and the design and characterization of the double 4-bar mechanism. Considering a 3-cm average abdominal tissue thickness upon insufflation, maximum anchoring and magnetic actuation forces were estimated by finite element analysis. Internal magnets (NdFeB) were selected bearing in mind the 12-mm access port constraint. Then, experimental test benches replicating the modelled configurations were developed in order to assess model predictions. Starting from the magnetic actuation force available, we designed, fabricated and tested the double 4-bar mechanism optimizing workspace, speed of motion, and force and torque at the end effector.

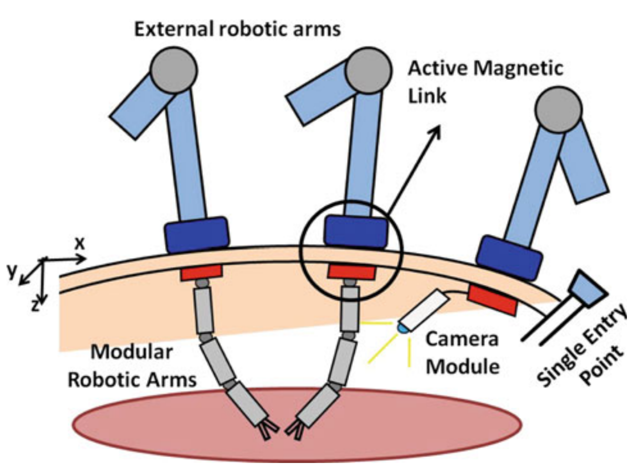

Fig. 1 Concept of the magnetically actuated surgical platform

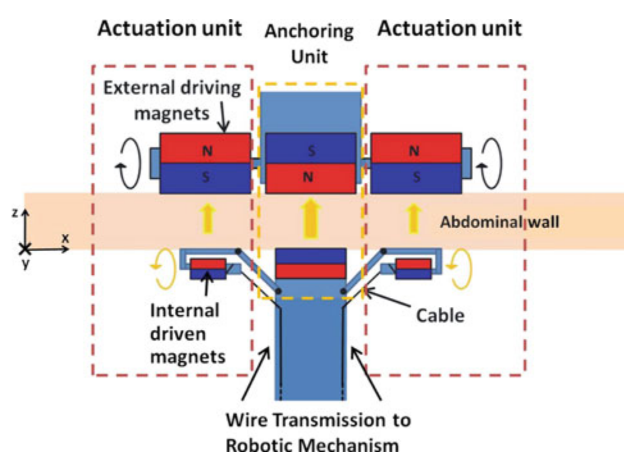

Fig. 2 Schematic design of remote active magnetic actuation. An anchoring unit and two rotational actuation units are combined to provide multiple DoF

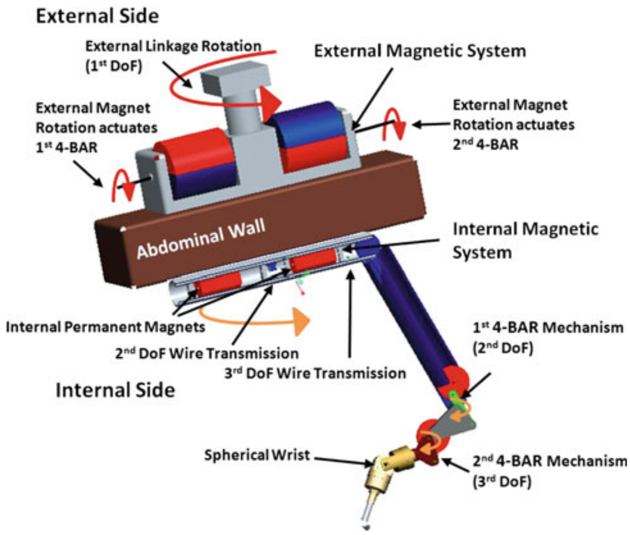

Fig. 3 Schematic design of a surgical manipulator implementing 2 DoF by remote active magnetic actuation

Results

The 3 proximal DoF of the proposed magnetically actuated manipulator can provide 5 N at the end effector in the three Cartesian directions, with a motion resolution of 0.5° for the second DoF and 3.5° for the third DoF. A full range motion will take 3 s for the second DoF and 0.56 s for the third DoF. The available torque is 0.9 Nm at the second DoF and 0.36 Nm at the third DoF. The total workspace that can be reached is about a 15-cm-side cube, which is comparable with standard surgical robotic systems [7].

Conclusion

A double 4-bar mechanism can be used in conjunction with trans-abdominal active magnetic actuation to provide 2 DoF for a surgical robotic manipulator to be introduced through a 12-mm trocar.

References

[1] Park S, Bergs R, Eberhart R, Baker L, Fernandez R, Cadeddu J, (2007) “Trocar-less instrumentation for laparoscopy magnetic positioning of intra-abdominal camera and retractor”. Annals of Surgery 245(3):379–384.

[2] Nelson B, Kaliakatsos K, Abbott J, (2010) “Microrobots for Minimally Invasive Medicine”. Annual Review of Biomedical Engineering 12(1):55–85.

[3] Cadeddu J, Fernandez R, Desai M, Bergs R, Tracy C, Tang S, Rao P, Desai M, Scott D, (2009) “Novel magnetically guided intra-abdominal camera to facilitate laparoendoscopic single-site surgery: initial human experience”, Surgical Endoscopy 23(8):1894–1899.

[4] Swain P, Austin R, Bally K, Trusty R, (2010) “Development and testing of a tethered, independent camera for NOTES and single-site laparoscopic procedures”, Surgical Endoscopy 24(8):2013–2021.

[5] Best S, Olweny E, Park S, Smith P, Fernandez R, Scott D, Bergs R, Cadeddu J, (2011) “New Generation Magnetic Camera Facilitates Porcine LESS Nephrectomy”, Journal of Urology 185(4):413–413.

[6] Ranzani T, Di Natali C, Simi M, Menciassi A, Dario P, Valdastri P, (2011) “A Novel Surgical Robotic Platform Minimizing Access Trauma”, in Proc. of 4th Hamlyn Symposium on Medical Robotics, London, UK, 15–16.

[7] Madhani A, (1998) “Design of teleoperated surgical instruments for minimally invasive surgery”, Ph.D. dissertation, Dept. Mech. Eng., Massachusetts Inst. Technol., Cambridge.

Preliminary experience with a new robotic platform for single-incision laparoscopic surgery

G. Basili[1], G. Petroni[2], A. Menciassi[2], D. Pietrasanta[1], M. Niccolini[2], P. Dario[2], O. Goletti[1]
[1]General Surgery Unit, Pontedera Hospital, Pisa, Italy
[2]The BioRobotic Institute, Scuola Superiore S’Anna, Pisa, Italy

Keywords Single port laparoscopy · Minimally invasive surgery · Robotic surgery

Purpose

The concept of single access procedures has gained a greater attention of general surgeons over the last 4 years [1, 2]. Single incision laparoscopic surgery (LESS) represents a good compromise between standard laparoscopy and totally scarless procedures. Despite such a wide momentum currently surrounding “single access” procedures, LESS surgery is considered to be a more complex procedure because it involves manipulating the operating instruments through one access port. Impaired eye-hand coordination, restricted manipulation and frequent clashing of the instruments are the main disadvantages of this procedure [3]. In this context, robotic-assisted surgery represents a growing discipline designed to enhance the dexterity of the laparoscopic surgeons.

A representative example of these benefits is offered by the daVinci Single-Site Surgical System, which allows the surgeon to perform complex tasks avoiding the frequent clashing of the standard single-access instruments. However, enhanced dexterity in terms of instrumentations tip maneuverability remains unresolved and, moreover, the large size and the high cost of the system itself will limit its uptake amongst surgeons.

We have developed a novel teleoperated robotic system for minimally invasive surgery called SPRINT (Single-Port lapaRoscopy bimaNual roboT) [4]. The main goal of our experiments was to demonstrate the feasibility of performing complex abdominal procedures by using the proposed system.

Methods

SPRINT is a master–slave teleoperated robotic platform designed for bimanual interventions by means of a single access port. The system is composed by two main arms having a maximum diameter of 18 mm, a stereoscopic-camera (Karl-Storz, Tuttlingen, Germany), and additional devices, e.g. retractor or other assistive instruments that can be inserted through a central lumen left free in the access port after the introduction. The arms are inserted in a cylindrical introducer which has a diameter of 30 mm. As the arms reach the bottom of the introducer, the base link of each one has to be rotated by 90°. The proximal joints comprise the shoulder and the elbow mechanisms, which are operated by external and on-board motors respectively. As for the elbow, the actuation of the distal joints is operated by embedded motors, while the actuation of the gripper is performed by another external motor. The surgeon console is composed of two master manipulators, a foot-switch and a 3D full-HD display. The experiment was carried out in an authorized laboratory. Small bowel resection with a latero-lateral anastomosis was performed.

Results

As it is a preliminary experience, the system was placed within the peritoneal cavity through an incision of about 8–10 cm. The robot was suspended in an open fashion (Fig. 1). The 3D display and the image stability allowed the surgeon to perform the reported procedures similarly as the standard minimally invasive counterpart. The system allowed a gentle manipulation of the viscera and, in particular, of small bowel loops. Although there isn’t at the moment a dedicated needle holder, movements and maneuvers for needle placement were performed properly.

A latero-lateral intestinal anastomosis was performed as the hand-sewn method; a continuous suture was performed without any particular difficulty (Fig. 2).