Design of the MUSHA Hand II for Robotic-Assisted Laparoscopic Surgery

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INTRODUCTION

Robot-assisted laparoscopic surgery has been widely preferred since its introduction, as it reduces blood loss, hospital stay and mortality of patients. Various Multi-Port Laparoscopy (MPL) robotic system, Single-Port Laparoscopy (SPL) systems and Natural Orifice Transluminal Endoscopic Surgery (NOTES) systems[1-3] were developed.

Although those surgical systems demonstrated impressive dexterity, the end-effectors (graspers, retractors, etc.) installed to the distal of the systems remain similar to the tools used in manual laparoscopic surgery. For example, most of the EndoWrist graspers and retractors for the da Vinci surgical system share similar two-jaw design. Limited dimension of access port might be the major reason that restrained surgical end-effector to simple and compact design.

Since human organ/tissues are generally slippery and existing graspers could not provide prehensile grasp, a high gripping force need to be applied on the tissue to secure reliable pinch grasp. Inappropriate grasp force may cause tissue injury, especially for handling larger organs like the bowel, liver and spleen. Moreover, the missing of tactile sensation of current grasper may worsen the situation, as the surgeon could not know the contact force he/she is applying on the organ via the robotic system.

Aimed at a miniature hand with human-like functionality for robot-assisted laparoscopic surgery, the three-fingered MUSHA Hand (MUltifunctional Smart HAnd) have been developed as our first effort [4]. Based on the obtained result, the MUSHA Hand II was developed, as shown in Fig. 1, with significant improvement on dimension, integrity and compatibility with the da Vinci Research Kit (dVRK) surgical system. This paper presents the design, development and preliminary experimentation of the new hand.

MATERIALS AND METHODS

The MUSHA Hand II, was designed and developed, as shown in Fig. 1(a)~(d). The hand is composed of an actuation unit, a ϕ12mm tube and three identical snake-like fingers. The fingers are remotely actuated by the actuation unit through multiple tendons inside the tube.

Driven by the actuation unit, the hand can be folded to a ϕ12mm cylinder shape, as shown in Fig. 1(a). Then, the hand can be inserted into an abdominal cavity through a ϕ13mm trocar. After the insertion, it can be configured to the grasper or the retractor mode, as shown in Fig. 1(b) and (c), respectively. In addition, three-dimension force sensor was integrated to each fingertip. Thus the hand can also perform palpation, as shown in Fig. 1(d).

The hand is designed to be installed to one of the Patient Side Manipulators (PSMs) of the dVRK, as shown in Fig. 1(e). Therefore, the original dVRK interface was adopted and the four channels of actuation from the dVRK were utilized. In addition, two DC motors (Maxon DCX12S) were used to augment the dexterity and functionality of the hand.

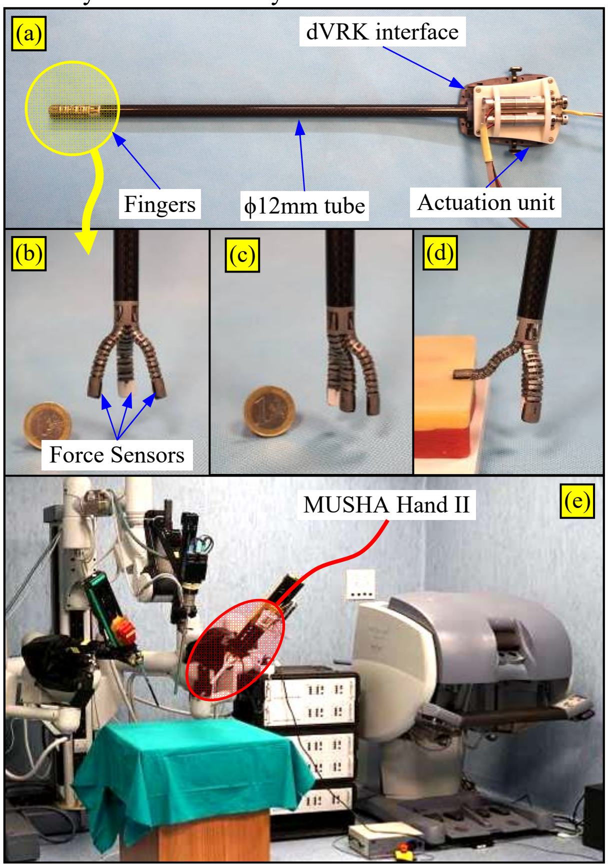

Fig. 1 The Developed MUSHA Hand II. (a) The hand folded to a ϕ12mm cylinder shape. (b) The hand in grasper mode and (c) retractor mode. (d) Fingertip sensor can be utilized for palpation. (e) The Hand install in the dVRK system.

The MUSHA Hand II has three identical underactuated fingers. Design details of the finger is shown in Fig. 2. The finger is consisted of a proximal segment and a distal segment, which connected by a passive abduction/adduction joint.

The distal segment consists of four vertebrae and one sensorized fingertip, connected by four revolute joints. The segment is driven by two antagonistic tendons (red ones) made from ϕ0.4mm steel cable, as shown in Fig. 2.

The proximal segment has six vertebrae, which can be further divided to the P1 sub-segment and the P2 sub-segment. Two tendons (blue ones) are used to drive the P1 subsegment. Another two tendons (green ones) are used to couple the motion of the two sub-segments, as two ends of each tendon were anchored on the hand base and the most distal vertebra of the P2 sub-segment. Therefore, as the P1 sub-segment is driven to bend outward or outward, the P2 sub-segment is bent to the opposite direct.

Two ϕ0.4mm nitinol rods are inserted in the holes of each vertebra, from the fingertip to the hand base, to bring all the joints compliance, including the passive abduction/adduction joint.

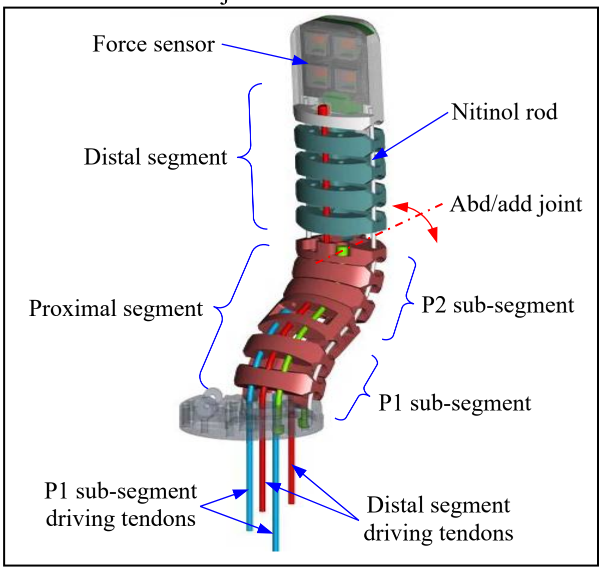

Fig. 2 Design of the underactuated finger

RESULTS

Preliminary teleoperated grasping experiment were conducted.

The hand was mounted on one of the PSM of the dVRK system, as shown in Fig. 1(e). After been inserted through a trocar, the hand was switched to the grasper mode shown in Fig. 1(b).

Control of the hand is also integrated with the dVRK system through ROS (Robot Operating System). Motion of the master tool manipulator (MTM) was mapped to the MUSHA Hand II. Specifically, the rotation of the most distal joint of the MTM was mapped to the rotation of the whole hand along the tube. The open/close of the MTM gripper was mapped to the flexion/extension of the distal segments of the three fingers.

A ϕ15mm ball made from plasticine was placed within the view of the dVRK endoscope, as shown in Fig. 3(a). Then hand was teleoperated by a subject operating the MTM of the dVRK (see Fig. 3(b)). Fig. 3(c)~(e) show the sequence of the MUSHA hand reaching, grasping and lifting the object, respectively. Fig. 3(f) shows a clos-up of the fingers pinching the object by its fingertips.

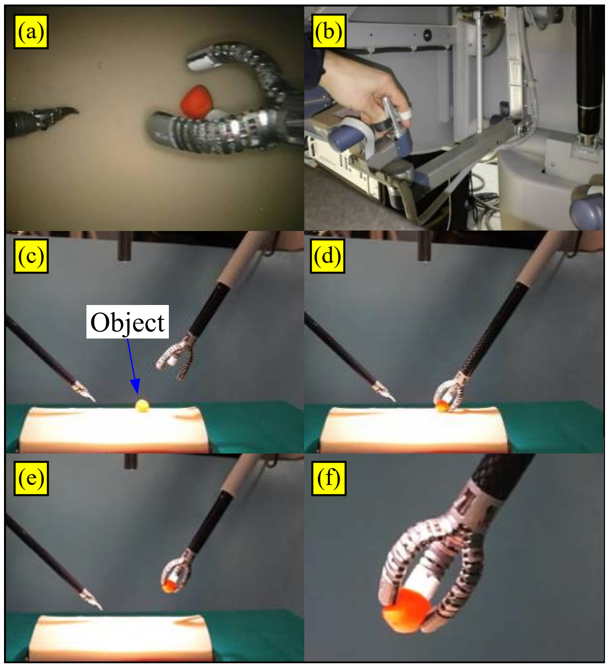

Fig. 3 Preliminary teleoperated grasping experiment. (a) The view from the dVRK endoscope. (b)The MTM of the dVRK. (c)~(e) Sequence of the hand grasping an object. (f) Close-up view of the hand grasping the object.

DISCUSSION

This paper presents the design and preliminary experiment of the MUSHA Hand II, which is a miniature three-fingered hand with fingertip force sensor for robot-assisted laparoscopic surgery. After been inserted through a ϕ13mm trocar, the hand can be switched to different configuration to perform various tasks. The hand was integrated with the dVRK system and preliminary teleoperated grasping was successfully performed. Further experimentation, including quantitative organ manipulation and palpation, will be performed to verify the dexterity and functionality of the hand.

REFERENCES

[1] S. Thielmann, U. Seibold, R. Haslinger, G. Passig, T. Bahls, S. Jörg, et al., "MICA - A new generation of versatile instruments in robotic surgery," in 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2010, pp. 871-878.

[2] K. Xu, J. Zhao, and M. Fu, "Development of the SJTU Unfoldable Robotic System (SURS) for Single Port Laparoscopy," IEEE/ASME Transactions on Mechatronics, vol. 20, pp. 2133-2145, Oct 2015.

[3] J. Zhao, X. Zheng, M. Zheng, A. J. Shih, and K. Xu, "An endoscopic continuum testbed for finalizing system characteristics of a surgical robot for NOTES procedures," in 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2013, pp. 63-70.

[4] M. Selvaggio, G. A. Fontanelli, V. R. Marrazzo, U. Bracale, A. Irace, G. Bregio, et al., "The MUSHA underactuated hand for robot-aided minimally invasive surgery," The International Journal of Medical Robotics and Computer Assisted Surgery, p. e1981, 2018.