NOVEL HAPTIC TOOL AND INPUT DEVICE FOR BILATERAL BIOMANIPULATION ADDRESSING ENDOSCOPIC SURGERY

K. Houston, O. Tonet, C. Eder, A. Menciassi, P. Dario
CRIM Laboratory, Scuola Superiore Sant'Anna, Pisa, Italy

A. Sieber
Profactor Research & Solutions GmbH, Austria

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Abstract: In this paper a teleoperation system is presented which consists of a sensorised polymer microgripper as a suitable end effector on an endoscopic microinstrument which is controlled by a novel tweezer-like haptic input device. This tweezer device gives the operator the ability to remotely feel these forces generated by grasping operations with the microgripper. This feedback is used to control the amount of force applied in manipulation of tissues during the procedure. The mechanical and electronic design of the microgripper, microinstrument and haptic tweezers is also presented and preliminary results detailed.

1 INTRODUCTION

Thanks to technological advances, an increasing number of precision operations are nowadays possible through key hole surgery interventions. However, during key hole surgery sensory feedback information is reduced, distorted or even absent, which is the case of visual, force and tactile information, respectively. These sensorimotor limitations also reduce dexterity in manipulation tasks. In this context, microengineering and microrobotics can help providing the surgeons with a new generation of smart instruments. Research efforts have been devoted to restoration of haptic (force and tactile) feedback (Kazi, A. et al, 2001). Forces exerted during surgery and the role of haptic perception have been investigated in many papers (Sheridan, T.B. et al, 1992, Kitagawa, M et al).. In traditional key hole surgery procedures, the attenuated haptic sensation still plays an important role (Bholat, O. S. et al, 1999), but it cannot be further restored or enhanced. In the case of mechatronic or robotic instruments, however, the interaction forces and torques between instrument and tissue can be measured and fed back to the surgeons hand by means of actuators and dedicated interfaces. Recent surgical instruments (Rosen, J. et al, 1999, Tavakoli, M. et al, 2005) and telerobotic systems used for research (Cavusoglu, M. C. et al, 2001, Mayer, H. et al, 2005) incorporating haptic interfaces have been developed (Menciassi, A. et al, 2001, Menciassi, A., 2003). The telesurgery concept has been enhanced and brought to a commercial stage, e.g. da Vinci Surgical System by Intuitive Surgical, Inc. (Guthart, G. S. et al, 2000), which however does not yet incorporate force feedback.

There are also several authors which have produced working prototype manipulation system with force feedback tools (Howe, R.D. et al, 2006, Pillarisetti, A. et al, 2006, Mitsuishi, M. et al, 2005) Howe, R.D. et al, 2006, Pillarisetti, A. et al, 2006, Mitsuishi, M. et al, 2005). This paper aims to present an entire teleoperation system which consists of an endoscopic tool with a microgripper end-effector and a novel haptic force sensing tweezers which can together give a remote force sensing ability during key hole surgery procedures, for example in laparoscopy or endoscopy . All of these new tools are connected to a user interface with micro-controller communication to dynamically display microscopic video, gripper force values and also modes to change the haptic behaviour of the tools in real-time.

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2 METHODS

2.1 Microgripper

The sensorised microgripper used as end-effector for the endoscopic microinstrument is an SMA (shape memory alloy) wire actuated polymer type and has been detailed in previous work (Houston, K. et al, 2007). The SMA actuation principle is based on a simple SMA wire applying a tensile force through the centre of the symmetrical microgripper structure, thus causing the tips of the device to move inward (Figure 1). The advantages of this microgripper are that it is robust, has a large gripper tip span, is made primarily of polymer, and is low cost, as it can be mass-fabricated by SDM (shaped deposition manufacturing. The first polyurethane microgripper prototype measures 22 mm length in total, with a width of 6 mm. Figure 2 showing a FEMLAB 3.0 structural strain displacement simulation to verify the design.

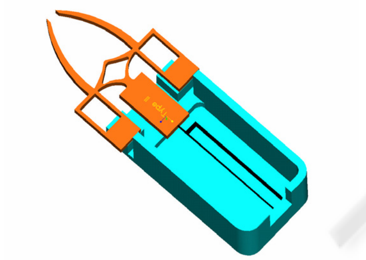

Figure1: SMA actuated microgripper.

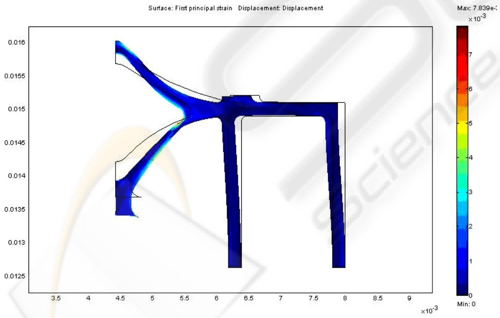

Figure 2: FEMLAB strain due to SMA wire force.

As an added part of this work, a further miniaturised SMA actuated microgripper shown in Figure 3 (right) was designed and fabricated using the same techniques, Figure 3 (left) shows the first sensorised prototype.

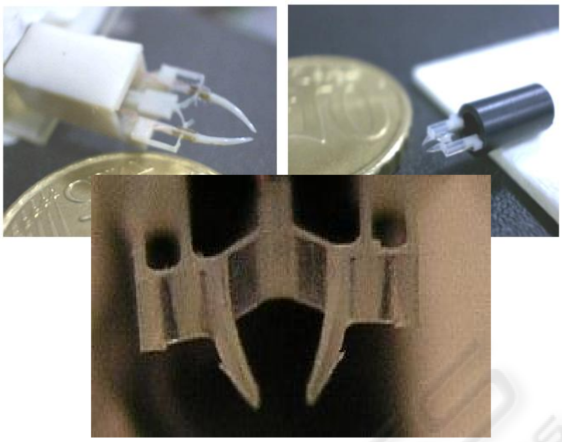

Figure 3: First gripper prototype (top left) and miniaturized version (top right, bottom).

To name a few advantages of the smaller microgripper, this device is less than half the total length of the first prototype (11 mm), half the width (3 mm), has a gripper tip maximum span of 500 µm and requires a lower operating power. Figure 8 shows a design of the device attached to the endoscopic tool. The microgripper itself is fabricated by the SDM process which has been implemented and detailed in many previous works with success (Eisinberg, A. et al, 2005). The four micro strain gauges are embedded in the microgripper at the points of maximum structural strain. In one version, all eight micro strain gauge wires and two SMA power supply wires are embedded in the polymer microgripper housing for robustness and a silicone membrane covers the opening of the actuator housing where the SMA wire connects with the moving microgripper structure. This allows the device to be used in fluid environments. Figure 4 shows another version where the moulded gripper structure is mounted on a glass substrate with a copper/polyamide flexible electrical connector. This allows all 8 strain gauge connections to be accessible inside the housing- in practical terms this means that there are no fragile wires coming from the microgripper, and makes the gripper assembly more modular and robust. There is then also the possibility of integrating electronics onto the substrate.

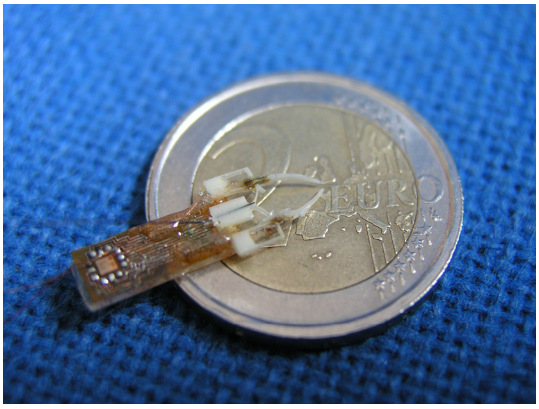

Figure 4: Modular design of the gripper structure on glass substrate with flexible circuit.

The microgripper requires a current of 70 mA for total tip closure. A step current input applied to the SMA actuator demonstrates the dynamic behaviour of the device (step response plotted for six current steps from 40 to 90 mA) in Figure 5. The calculated time constant is 8 seconds, while although quite high is normal for SMA mechanisms. In order to decrease the time constant and thus the speed of grasping, a preheating control strategy was used which maintained the SMA wire heated with a current of 40 mA; this was below the actuation current of the wire. In order to actuate the gripper, the current was then increased above 40 mA, and this makes the actuator more responsive. Using this strategy, the time constant was reduces to 2 s, a substantial improvement in the dynamic response of the microgripper. Figure 6 shows the improvement in tip displacement of the microgripper against time.

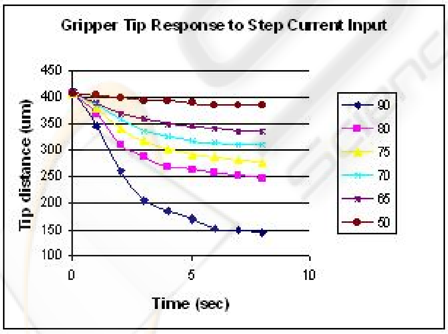

Figure 5: Response of SMA microgripper to step current input.

The signal of the strain gages in the microgripper is sampled with an Analog Devices AD 7730 analog to digital converter as shown in Figure 7. Offering a programmable input stage (±80 mV to ± 10 mV) and 24 bit resolution this device is suitable for bridge/transducer applications.

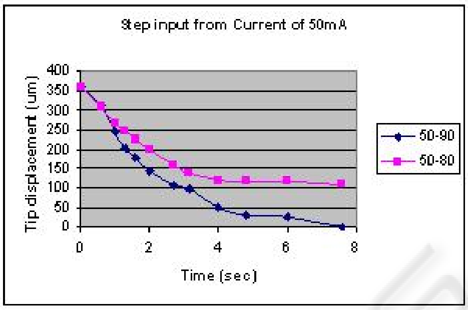

Figure 6: Improved response of SMA microgripper due to preheating.

Further signal processing is then done by a separate Atmel microcontroller (ATMEGA8) connected via USB to PC. The software for the microcontroller is programmed in C++, while the visualisation of the data is performed under National Instruments LabView.

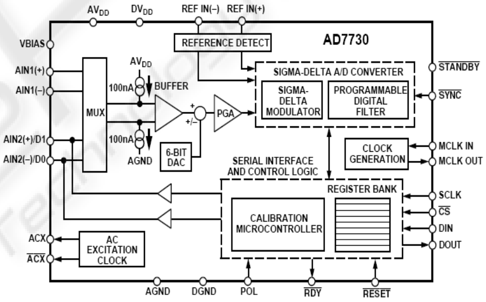

Figure 7: AD7730 strain gauge signal processing circuit.

2.2 Endoscopic Device

The microgripper is mounted on the tip of the endoscopic device (Figure 8), which can be bent in two degrees of freedom up to ±90˚. Bending of the tip is performed by pulling on steering wires. The principle of the mechanism is described in detail in (Harada, K. et al, 2005). For precise actuation of the 4 steering wires two high precision servo drives with a theoretical resolution of 13 bit are used. The tube is made of hard *Delrin* plastic, machined using traditional turning techniques, while the rolling spheres are of polyurethane, procured from off-the-shelf stock. The smaller micro parts for passage of wires and location of the spheres were machining using a precision CNC milling machine. The all-plastic assembly is finished with the controlling wires which can be any type of strong wire-for the prototype, a fishing line wire was used .

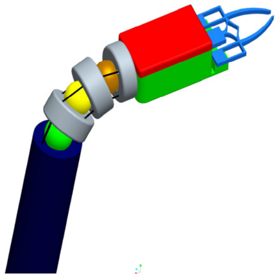

Figure 8: CAD drawing of the endoscopic instrument with the gripper as end-effector.

2.3 Interfacing the Heptic Input Device

In the lower arm of the tweezers like input device two strain gauges are integrated to allow a force measurement, as shown in Figure 9. The signal of these two strain gauges is processed in a half Wheatstone bridge configuration and then amplified by a factor of 100. To digitize the signal the first channel AD0 of the Atmel ATMEGA8 microcontroller is used. Analogue channel 1 is used to acquire the signal of the potentiometer integrated in the Servo (Graupner 381) giving real feedback of the position of the servo. One digital output is used to drive the Servo with pulses in the length of 1 to 2 ms with a resolution of 0,5 µs. Figure 12 shows the haptic tweezers being used in a micromanipulation task with force feedback. Figure 10 shows the actual haptic tweezers prototype in the users hand.

Figure 11 show the flow diagram for the haptic tweezers in active mode. The AD7730 ADC is continuously updating the microgripper tip force. As this is happening, the ATMEL ADC is updating the strain gauge voltage which relates to the actual haptic tweezer force that the user perceives. The microcontroller then compares the perceived and actual forces and updates the new haptic tweezer servo value to reflect the force changes, if any.

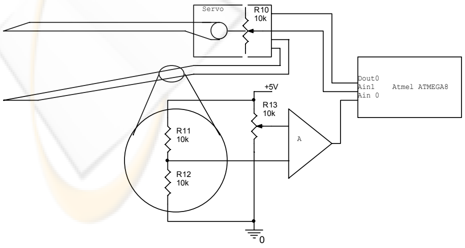

Figure 9: Haptic tweezers circuit.

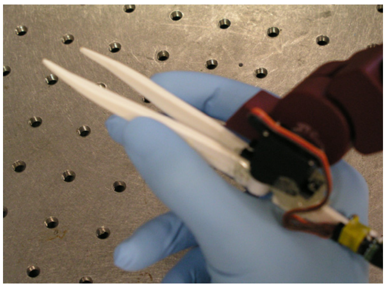

Figure 10: Hepatic tweezers in users hand.

Thus in real life, when one grasps a pair of tweezers, as the tips close, the force perceives on the finger tips increases linearly. This is exactly how the haptic tweezers behaves, in that when the user picks up the tweezers, there is initially no movement.

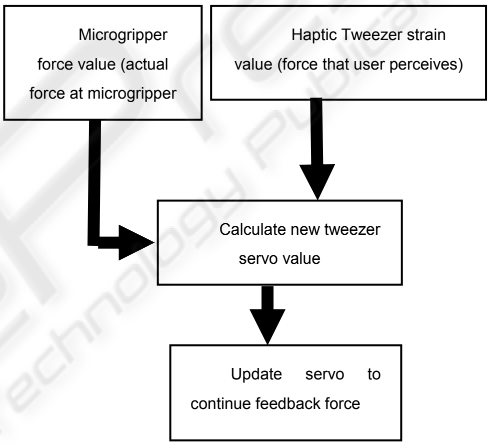

Figure 11: Force feedback flow diagram.

When the user then applies a force with the finger tips to close the tweezer tips, the strain gauge on the device detects this force and activates the servo motor-the position of the servo is always such as to follow the finger tips of the user, while all the time giving the sensation of a natural spring.

In the active mode (when there is an actual force on the tips of the microgripper tool), the scheme in Figure 11 is followed: the difference between the force on the microgripper tips and the force perceived by the user is used to update the haptic tweezer servo value-this is done continuously.

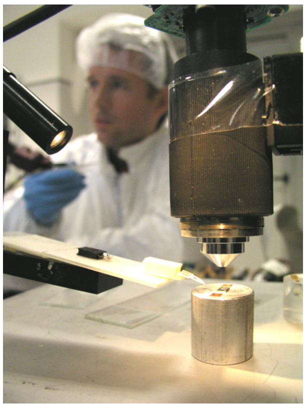

Figure 12: Haptic tweezers being used for micromanipulation task with force feedback under microscope.

2.4 Software

The current, and thus the actual position of the microgripper, is set according to the actual position of the control device. The feedback parameter is the force sensed by the microgripper. This parameter together with the position of the actuator and the signal of the strain gauges integrated in the lower arm of the device are used to drive the input devices actuator (PID control). Figure 13 shows the software flow scheme for the system.

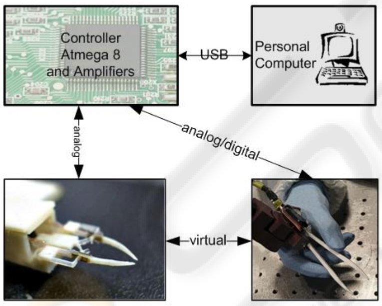

Figure 13: Software scheme.

be used for surgical or biomanipulation task in a haptic environment. At 3 mm in diameter, the tool is suitable for keyhole surgery and can achieve ±90 degrees rotations around both axes.

The prototype sensorised microgripper has a tip distance of 500-800 µm, and can be set to any distance in the assembly process. The maximum tip force is approximately 1 mN. The tip of the sensorised microgripper is a flat edge of 100 µm, however this geometry can be tailored in the design of the mould according to the task. The tool length is 22 mm and is 6 mm wide.

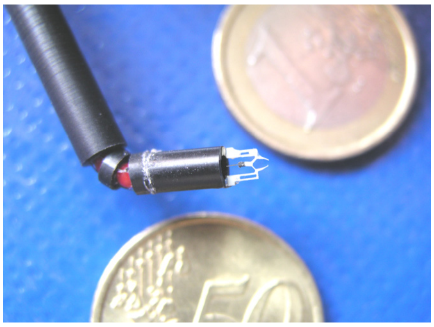

Figure 14: Prototype haptic biomanipulation tool.

The smaller microgripper has a smaller tip distance of 400 µm and again can be set during assembly. The diameter is 3 mm, the tip has a right angled point edge which is useful for precision grasping of small particle without minimisation of adhesive forces.

The prototype haptic tweezers has the dimensions of a normal off-the-shelf pair of plastic tweezers used in a medical lab (length of approx. 150 mm, width can be set by software, but as with a normal pair of tweezers, a maximum tip distance of approx. 40 mm is optimum). This prototype has a working tweezer angle of 90 degrees, however only about 20 degrees of movement is necessary to simulate a pair of tweezers-a larger angle is not very comfortable for the fingers when used for long periods. Because the servo is a 13 bit model of high resolution, the 20 degree angle sweep of opening and closing the tweezers has a resolution of over 40 increments per degree, giving a very smooth movement with no vibrations. The position of the tweezer tips is updated at a frequency of 50 Hz. The maximum torque of the input device is approx. 190 g/cm and the device is designed so that one arm of the tweezers will snap off easily before the maximum torque is reached.

3 CONCLUSIONS

Nowadays robot aided key hole surgery and teleoperated surgical techniques lack devices able to provide haptic feedback to the surgeon, particularly in the small scale. This paper presented a new teleoperation system with a novel endoscopic tool, force sensing microgripper and haptic tweezers which allows the surgeon to feel the gripping force at the tip of a microgripper instrument, even if as in the case of teleoperated surgery, they are miles away.

The authors are convinced that these first promising results are one step closer to a new era of surgical instruments giving "reality-like feelings" in endoscopic and teleoperated surgery.

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