Admittance control of a handheld microsurgical instrument

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INTRODUCTION

The current state of the art in neurosurgery for deep-seated brain tumors and cerebrovascular lesions still yields high postoperative rates of cerebral infarction and cranial nerve deficits. In particular, petroclival meningioma resection is one of the most challenging and risky procedures: reported rates of permanent cranial nerve deficits range from 20% to 76%, while the rate of gross total resection ranges from 20% to 85% [1]. Robotics has potential to reduce morbidity and mortality by performing assistive functions such as reduction of unwanted motion and minimization of force applied to nerves and vascular structures.

Handheld robotic instruments for neurosurgery may offer advantages in terms of cost and ease of use compared to other approaches such as teleoperated or shared-control robots [2]. This paper describes a method for minimization of force applied by an active handheld robotic micromanipulator known as Micron [3]. Wells et al. [4] previously presented a method for parallel position/force control of Micron. As an alternative approach with a clearer physical interpretation, this paper presents an admittance control approach [5] that modifies the setpoint of the position control to minimize applied force, and demonstrates the approach in an artificial simulation of neurosurgical blunt dissection.

MATERIALS AND METHODS

Robotic Instrument

Micron is an actively handheld surgical tool composed by a miniature Gough-Stewart platform attached between the end-effector and a cylindrical handle (Fig. 1). The position control, which considers the human presence in the loop, actuates the end effector to provide functions such as physiological tremor compensation, virtual fixtures, or force control.

A Fiber Bragg Grating force sensor with two degrees of freedom [6] was embedded in the end-effector of Micron. To emulate a force sensor with three degrees of freedom, the sensor was augmented with a load cell mounted underneath the workpiece; load cell data were fused with the onboard sensing to obtain the force parallel to the long axis of the instrument.

Fig. 1 Micron, an active handheld microsurgical instrument.

Admittance Control

The inputs to the admittance control are the set-point of the position loop and the force measurements. Then the control provides an updated set-point for the position loop (Fig. 2). The main goal is to modify the set-point of the position control with the aim of reducing the applied force: when no force is acting on the manipulator, there is no force feedback and the position control should fit the desired trajectory. When an external force is present, the controller changes the position in accord with the selected mass-damper-spring dynamics.

Since microneurosurgical tasks generally involve small velocities and very small accelerations, the virtual mass coefficient is set to zero. The environment has low stiffness, so contact stability can be easily achieved [5]. Hence, decoupling the admittance control for each direction, we get the following dynamics (Figs. 2, 3):

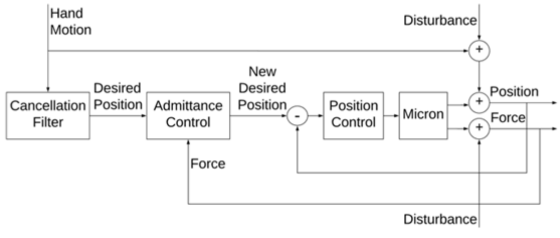

Fig. 2 Complete position and admittance control block diagram of Micron.

$$d\,(\dot{x}_d - \dot{x}_a) + k\,(x_d - x_a) = f \qquad (1)$$

where d and k are the virtual damping and virtual stiffness coefficients, f is the external applied force and $(x_d - x_a)$ is the desired position change. The parameter values, selected by manual tuning, are:

$$m = 0 \quad mN/(m/s^2)$$
$$d = 10 \quad mN/(m/s)$$
$$k = 0.02 \quad mN/m$$

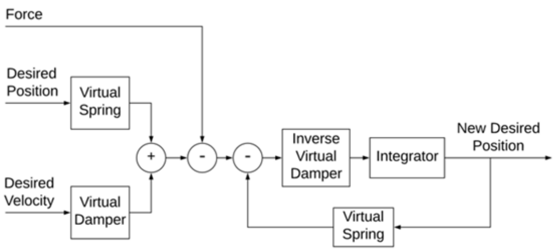

Fig. 3 Admittance control block diagram with one degree of freedom.

Experiment

The method has been tested under a board-approved protocol in a blunt dissection experiment with a human in the loop. Sorbothane® rubber was chosen as an underlying substrate due to its tissue-like properties [7]. On each rubber workpiece, to enable a simulation of blunt dissection, 10 circles of polyethylene film (12.7 μm thick, 3.6 mm in diameter) were placed (Fig. 4).

The task involved peeling of the polyethylene from the Sorbothane. The experimental subject, not a surgeon, had considerable experience with Micron. The procedure was performed under 16x magnification using a Zeiss OPMI® 1 stereo operating microscope. The subject was instructed to apply the least possible force during the task. The subject peeled 32 circles under each of two test conditions: with tremor compensation only, and with tremor compensation plus admittance control. Force was measured in three dimensions throughout each task.

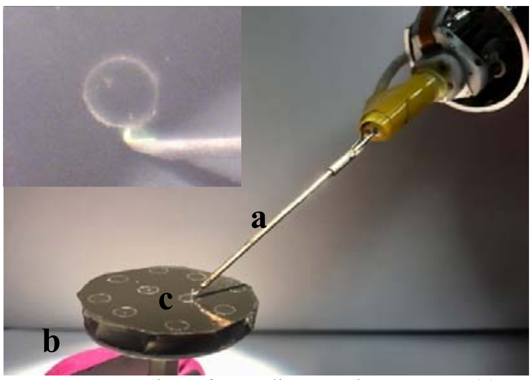

Fig. 4 Representation of a peeling test in progress. (a) FBG sensor embedded in Micron end effector; (b) Sorbothane® as artificial tissue model; (c) circular layers of polyethylene film. Inset: view through microscope.

RESULTS

Averages of the maximum applied force in the three directions are reported in Fig. 5, together with the standard deviation. Forces are reported in body coordinates (where z is the long axis of the instrument).

Table 1 Comparison between applied forces [mN] under position control and applied forces under admittance/position control.

		Maximum applied force (confidence interval 90%)	Average applied force (confidence interval 90%)
Position Control	X	18.30 ± 0.92	3.38 ± 0.16
	Y	8.90 ± 0.71	2.48 ± 0.44
	Z	12.53 ± 0.96	4.84 ± 0.01
Position Control and Admittance Control	X	13.26 ± 0.81	2.62 ± 0.14
	Y	6.17 ± 0.49	1.65 ± 0.15
	Z	8.09 ± 0.38	3.38 ± 0.01

DISCUSSION

This paper reported on the implementation of admittance control to minimize force applied during blunt dissection with an active handheld microsurgical instrument. Preliminary results showed a decrease in the exerted force by 27% and 30% in the transverse coordinates, and 35% along the long axis of the instrument. Future work will deal with optimization of the control system tuning, and testing under more realistic conditions.

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