Development of a teleoperated robotic system for retinal surgery

A. Gijbels[1], E.B. Vander Poorten[1], P. Stalmans[2], D. Reynaerts[1]
[1]*Department of Mechanical Engineering, University of Leuven, Belgium*
[2]*Department of Ophthalmology, University Hospital of Leuven, Leuven, Belgium*
andy.gijbels@kuleuven.be

Keywords: robotics, telemanipulation, retinal surgery

Introduction

Retinal surgery is a type of Minimally Invasive Surgery. The surgeon manually guides instruments through trocars in the sclera to operate at the retina (Fig. 1(a)). A microscope is placed above the patient's eye to have visual feedback on the surgical scene (Fig. 1(b)). The surgeon manipulates the instruments while placing his/her hands on the patient's forehead in order to achieve the highest precision (Fig. 1(c)).

(a) (b) (c)

Figure 1: The practice of conventional retinal surgery.

Still retinal surgery is extremely difficult to perform because of the scale and the fragility of the retinal anatomy. For some procedures, the required precision is in order of 10µm. Surgeons suffer from hand tremor with an rms amplitude of 180µm [1]. Further, 75% of the interaction forces between the instrument and the retina are smaller than 7.5mN and are only felt by the surgeon in 19% of the cases [2]. These limitations negatively affect the outcome of conventional retinal surgery and even hinder the clinical use of effective but risky surgical procedures. To tackle these issues, the authors developed a teleoperated robotic system to assist surgeons during delicate retinal procedures.

1. Telemanipulation system

The developed system consists of a haptic joystick and a surgical manipulator (Fig. 2). The manipulator holds the instrument and interacts with the retinal tissue. The surgeon controls the movements of the surgical manipulator by using the control handle of the haptic joystick. The system offers multiple features that enhance the surgeon's skills beyond human limitations. First, the surgeon's control actions are scaled down before being sent as a position command to the surgical manipulator. This results in an achievable positioning accuracy of 10µm. Second, the surgeon's tremor is filtered out of these position commands resulting in a positioning precision smaller than 10µm. Third, the interaction forces between the instrument and the retina can be measured with a force sensor that is integrated in the instrument and fed back to the haptic joystick after being amplified up to 10N. This allows the surgeon to feel how much force he/she exerts on the delicate retinal tissue and to react appropriately.

The surgical manipulator and the haptic joystick are carefully designed to achieve these characteristics. Both systems consist of four degrees of freedom (DOFs) to enable the following instrument motions: two rotations about the incision (θ, ϕ), a rotation about the instrument axis (ψ) and a translation through the incision (R) (Fig 1(a)). These are the minimal required DOFs to perform retinal surgery. Both systems consist of a novel bar mechanism to implement these abovementioned DOFs.

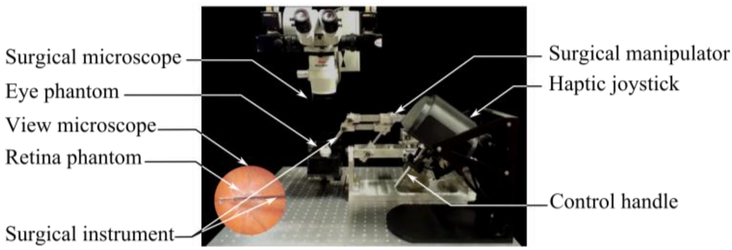

Figure 2: Overview on the components of the developed telemanipulation system.

1.1 Surgical Manipulator

The surgical manipulator consists of a novel bar mechanism that implements the four DOFs at the incision without any physical joint being present at this location (Fig. 3). This is necessary because of spatial and sterilization constraints that exist at the incision. DOFs ϕ and ψ are driven by joints q_1 and q_4 respectively. DOFs R and θ are driven simultaneously by joints q_2 and q_3. The system is nearly symmetric with respect to a plane through the ϕ-axis and perpendicular to the base. Counterweights are used such that the gravitational effects on the system are negligible w.r.t. the torque characteristics of the drive mechanisms. Joints q_1, q_2 and q_3 are actuated with combinations of a Maxon RE30 DC-motor and a capstan drive mechanism to avoid backlash and limit friction (gear ratio q_1: 12:1; q_2, q_3: 10:1). Gurley encoders are used for angle measurement (q1: 65536 CPT; q2, q3: 144000 CPT). The ψ-module consists of collet clamping mechanism to fix the instrument to a hollow tube. The hollow tube is equipped with a zero-backlash gear which is actuated with a Maxon RE8 DC-motor with a Maxon MR 100 CPT encoder and a pinion (gear ratio 6:1). Table 1 summarizes the key properties of the surgical manipulator calculated by using the motor and encoder specifications and the robot's worst-case kinematic equations.

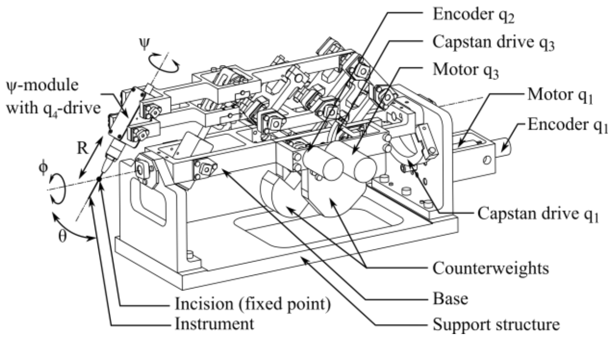

Figure 3: Design of the surgical manipulator.

Table 1: Key properties of the different DOFs of the surgical manipulator.

	R	Θ	ϕ	ψ
Range	>30mm	>50°	>90°	∞°
Resolution	<1µm	<200µ°	<700µ°	<0,24°
Cont. Force/Torque	>10N	>1Nm	>1Nm	>3,5mNm

1.2 Haptic joystick

The joystick consists of a novel mechanism to give the handle four DOFs (Fig. 4). DOFs θ and ψ are driven by joints q_1 and q_4 respectively. DOFs R and ϕ are driven simultaneously by joints q_2 and q_3. Joints q_1, q_2 and q_3 are actuated with combinations of a Maxon RE30 DC-motor and a capstan drive mechanism to avoid backlash and limit friction (gear ratio q_1: 26:1; q_2, q_3: 13:1). Scancon 30000 CPT encoders are used for angle measurement. Note that at q_1 the motor is stationary, while the capstan is moving and that at q_2 and q_3 the capstans are stationary and the motors are moving. For clarity the q_4 drive mechanism is made invisible. It drives the ball spline using a Maxon EC20 flat with a Baumer 1025 CPT encoder and a capstan drive mechanism (gear ratio: 5.4:1). Table 2 summarizes the key properties of the haptic joystick, which are calculated in a same manner as those of the surgical manipulator.

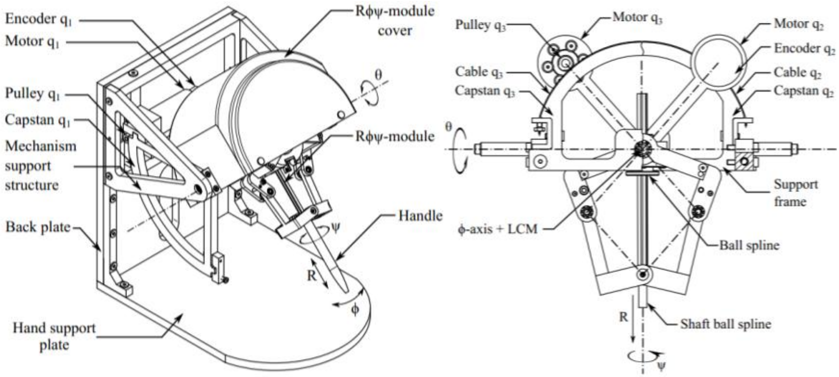

Figure 4: Design of the haptic joystick (left: total system; right: Rϕψ-module).

Table 2: Key properties of the different DOFs of the haptic joystick.

	R	θ	ϕ	ψ
Range	>30mm	>90°	>60°	>210°
Resolution	<1.5µm	<9µ°	<16µ°	<0,24°
Cont. Force/Torque	>22N	>11N	>11N	>44mNm

Conclusion

Nowadays, retinal surgery is still performed in a manual fashion. This paper reported on the development of a 10µm precise telemanipulation system that could vastly shift the boundaries of conventional retinal surgery on the mid-term. Results of an in-vitro experimental campaign have already demonstrated a ten-folded improvement of the surgeon’s positioning precision.

References:

[1] C.N. Riviere and P.S. Jensen, “A study of instrument motion in retinal microsurgery”, *Proc. Of the 22nd Annual EMBS Int. Conf.*, 2000.

[2] R. Gupta, P. Jensen, and E. Juan, “Surgical forces and tactile perception during retinal microsurgery”, MICCAI, 1999.