A Master-µslave Robot for Vitreo-retinal Eye Surgery

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Introduction

Vitreo-retinal eye surgery relates to surgery at the inner side at the back of the eye, e.g. the vitreous humor and the retina. Nowadays it is performed manually via a trocar, like minimally invasive surgery (MIS). Vitreo-retinal instruments are typically 0.6 mm in diameter with a length of 30 mm. Eye surgery demands special operating skills. Steady hand movements are desired to operate delicate tissue e.g. the retina, with high accuracy [1]. During eye surgery forces are below the detection limit (60 mN). Robotic assisted surgery with force feedback is a solution, for which a master-µslave system is being designed and realized. The µslave robot, performing the actual surgery, is controlled by the surgeon via a master. Advantages of a master-slave system are: a comfortable body posture, intuitive instrument handling, downscaled instrument movements, upscaled force feedback and filtering of hand tremor.

Figure 1: Concept design of a master-µslave system.

1. Master-µslave

Both master and µslave parts are supported by a frame, which is mounted to the surgical table (figure 1). This layout makes a direct view on and a physical contact
with the patient possible. The µslave is equipped with multiple instrument manipulators (IMs) and is adjustable to position the IMs over either the left or the right eye. The master part consists of a 3D monitor for visual feedback and two haptic interfaces by which the surgeon controls the instrument manipulators. The supporting frame allows ergonomic adjustments for the haptic interfaces. Key properties of the master-µslave system are: easy to place, compact and light weight design, direct view on the patient, intuitive operation and suitable for a complete intervention by an integrated instrument changing system.

1.1. Master device

Today’s manual surgery arrangements are maintained by the chosen master layout. Three main components can be distinguished in the design of the master (figure 1): the frame, a 3D display and two 5 DoF interfaces with force feedback to manipulate the instruments.

The basic idea is that by virtually placing the hands of the surgeon inside the eye of the patient an intuitive working environment is created. This means that the haptic interface must have the same geometry and degrees of freedom as the instrument inside the eye (figure 2).

A preliminary design [2] has been made for the haptic interface (figure 3).
In figure 3 the geometry of the 5 DoFs; $\Phi$, $\Psi$, $\Theta$, $Z$ and the button to operate the instrument e.g. a gripper (tweezers), are indicated. All DoFs are backdrivable. Per DoF it is equipped with a position encoder and a force feedback motor. Flat flexible conductors are implemented to minimize the disturbance forces of the wires. Currently this master device is tested with a similar project on MIS [3].

1.2. Instrument manipulator of the $\mu$slave system

The design of the IM is such that the point where the instrument enters the eye (trocar point) is kinematically defined creating an intrinsically safe design. Four DoFs about the trocar point are desired (figure 2), a fifth DoF is used to actuate the instrument e.g. tweezers.

Key properties of the IM are:

- $\varphi, \psi = \pm 45^\circ$
- $Z \geq 30 \text{ mm}$
- $\theta = 360^\circ$
- Force measurement with a resolution of 1 mN at the tip of the instrument
- Accuracy of $<10 \mu\text{m}$

The IM is designed for high stiffness, is backlash-free and offers high accuracy. Common instruments can be used with only minor modifications to fit the IM. The IM has four modules (figure 4):

- Parallelogram mechanism, to manipulate $\varphi-\psi$.
- $Z$-stage
- $\Theta$-module
- Instrument changing system, which is integrated within the $Z$-stage.

The $\mu$slave will be equipped to perform a complete intervention. Different instruments are used during surgery, therefore the IMs are equipped with an onboard instrument changing system. It consists of a storage including instruments and an actuator to select the desired instrument. The $Z$-DoF and a bistable instrument clamp are used to change. Instruments are changed automatically in a fast and secured way. During surgery the instrument is held in the bistable clamp. The clamp is actuated in $\Theta$. Within the theta module a force/torque sensor is placed. The $\Theta$-module is mounted
to the $Z$-stage via micro linear ways and actuated in $Z$ via a backlash-free low friction leadscrew. $\Psi$ is manipulated by leaning the parallelogram mechanism forward- and backwards. It is driven by a statically determined spindle drive, creating an actuator with high stiffness. By rotating the complete parallelogram mechanism sideways $\Phi$ motion is realized.

Currently the modules of the IM are realized and tests will be performed in the near future.

Figure 4: Instrument manipulator

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**References:**

