EyeRhas: A master-µslave system for vitreо-retinal eye surgery

Introduction

Vitreо-retinal eye surgery relates to surgery at the inner side at the back of the eye, e.g. the vitreous humor or the retina. Nowadays it is performed manually via a trocar, like minimally invasive surgery (MIS). Vitreо-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. 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 will be designed (figure 1). The µslave robot, performing the actual surgery, is controlled by the surgeon via a master. 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.

Figure 1. Concept design of the master-µslave system.

µSlave

The slave will be provided with multiple instrument manipulators (IMs, figure 3) and is adjustable to position the IMs over either the left or right eye. The design of the IM is such that the point where the instrument enters the eye is kinematically defined. This point is called the Remote Center of Motion (RCM), defining a RCM results in an intrinsically safe design. Four DoF about the RCM are desired (figure 2).

Key properties of the IM are:
• Rotation around the RCM
  • \( \psi, \psi = \pm 45^\circ \)
  • \( Z = 30 \text{ mm} \)
• \( \phi = 360^\circ \)
• Force measurement with a resolution of 1 mN at the tip of the instrument
• Accuracy of <10 \( \mu \text{m} \)

The µslave is 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 is used to change. Instruments are changed automatically in a fast and secured way. Currently the first parts of the IM are realized at the TU/e GTD and tests will be performed in the near future.

Figure 3. The instrument manipulator

Master device

The main components of the master device are: a frame, two 5 DoF haptic interfaces and a 3D-display (see figure 1). A preliminary design has been made for the haptic interface (figure 4). 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).

Figure 4. Two 5 DoF haptic interfaces

Three parts can be distinguished in the design of the interface:
• \( \phi; \psi \): Chosen is for direct drive to minimize friction. The \( \phi \) housing is mounted on top of the \( \psi \) shaft
• \( \theta-z \): A parallel layout is used. This part is mounted on top of the \( \phi \) shaft
• button; The button part is mounted at the bottom of the pen, it has force feedback (scaled) and can operate a gripper (tweezers)

All degrees of freedom are backdrivable. Position is measured by encoders. Flat flexible conductors are used to minimize the disturbance forces of the wires.

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