Automatic Instrument Tracking Endo-illuminator for Intraocular Surgeries

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1 Background

Vitreoretinal surgery encompasses intraocular surgical procedures performed in the posterior segment of the eye where instruments are inserted into the vitreous cavity to treat vision threatening diseases [1]. This surgery requires highly skilled surgeons to visually inspect and differentiate normal anatomy of the retina from pathology and manipulate retinal tissue with microsurgical instruments (Fig.1). Because the retina is on average 250 μm in thickness and retinal anatomical detail is microscopic, adequate illumination for a clear view of the retina during surgery is extremely crucial [1]. However, the current illumination solutions available require surgeons to devote one working hand to achieving suitable illumination.

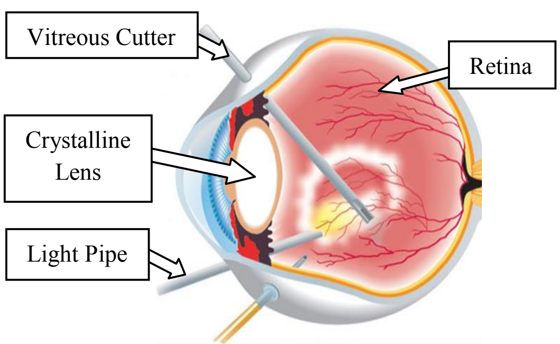

Fig.1 Vitreoretinal Surgery

The traditional illumination option is a needle-like optic fiber enclosed by a rigid conduit, and is known as an endo-iluminator (Fig.1) [1]. The surgeon views the surgery through a microscope with an optical path that passes through the lens of the patient's eye, while the light pipe is inserted via a small incision through the sclera. The light pipe provides a cone of illumination, where the angle of orientation and the proximity to the viewing surface can be controlled manually by the surgeon to achieve the desired lighting condition. Although this provides adequate lighting at all times, the surgeon has to devote one hand entirely for illumination, while performing surgery solely an end effector in the other hand (uni-manual surgery) [1]. Instances exist when manual control of two end effectors would we preferred (bimanual surgery). Alternative strategies of illumination such as diffuse illumination or illuminated instruments have thus far proved inadequate as they often creates shadows or limited field of view, undermining the visibility and clarity of tasks performed during the operation [1, 2].

The superiority of bi-manual surgery is evident in virtually all surgical fields and is ideal for implementation in vitreoretinal surgery [3]. Benefits include reduced surgery times, lower risks of complications, and faster learning curves for training surgeons. Additionally, bi-manual techniques in vitreoretinal surgery allow the surgeon to externally depress the eye without the need of a trained assistant. Lastly, uni-manual surgery is sometimes simply not an option. In highly complex cases commonly associated with diabetic patients, the procedure is far more challenging and habitually requires bi-manual surgery in spite of currently available diminished lighting conditions [1].

In this paper, we present a novel technology that makes an endo-illuminator "automatically" track the surgical instrument during operation to maintain the lighting quality (Fig.2) [4]. This eliminates the need for the surgeon to hold and maneuver the endo-illuminator. As opposed to other extra-ocular robotic solutions that take up valuable space around the patient [5], we present an intraocular actuation approach that results in a novel, compact, and low cost system.

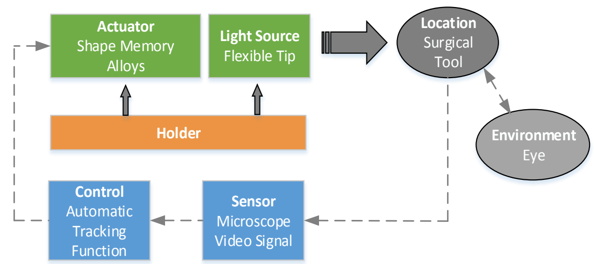

Fig.2 Technology Solution Overview

2 Methods

Our approach, illustrated in Fig.2, comprises: an image recognition and processing module that uses a live video feed of the surgical feed from a microscope to locate and track the tip of the surgical instrument that is actively manipulated by the surgeon's primary hand; an intra-ocular actuation system that bends the flexible end of our proposed endo-illuminator such that it is always points at the instrument tip, based on the instrument tip location feedback received from the image processing module; and a holder that secures the rigid end of our proposed endo-illuminator in a fixed orientation during the surgery. These three modules are described in further detail below.

2.1 Flexible SMA Actuated Endo-Illuminator

Our proposed endo-illuminator closely resembles a regular endo-illuminator in size and shape (Fig.3). However, a flexible portion, enclosing the optical fiber, is introduced at the distal end, which is actuated via three shape memory alloy (SMA) wire loops that are symmetrically arranged around the flexible end. When current is applied to heat the SMA wire loops, this flexible portion bends to direct a focused light.

Because of the high force-to-weight ratio, fast reaction time, large deformation range, scalability to meet desired gauge sizes, ease of manufacture, and low cost, SMA wires prove to be an effective actuation solution [1]. Most importantly, the use of SMA wires allows the entire actuation mechanism to be housed inside the eye. This provides a compact solution, minimizing the footprint in an already crowded surgical space.

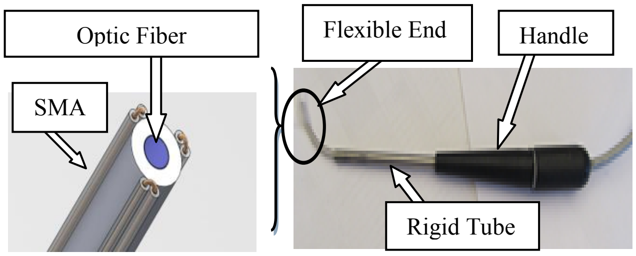

Fig.3 Flexible SMA Actuated End

2.2 Instrument Tracking System

A video feed from the optical microscope is used to determine the location of the tip of the surgical instrument, such as a vitreous cutter (Fig.4a), via image processing. Pixels from the RGB (Red, Green, and Blue) color space are mapped to the HSV (Hue, Saturation, and Value) color space (Fig.4b), where the instrument tip is identified as being either brighter or darker than the background. After applying several filters, the instrument tip location is confirmed in real-time. A feedback control program uses this information to sends a corrective command to the SMA actuator, which in turn bends the flexible end of the endo-illuminator to direct a cone of light such that the instrument tip is centered in the area of illumination.

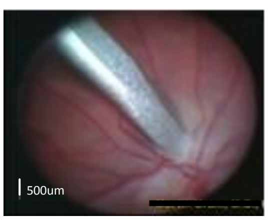

Fig.4a Vitreous Cutter Tip: Original RGB

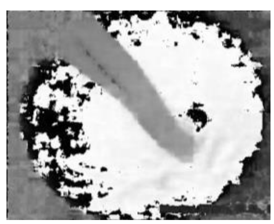

Fig.4b Hue-Value Image

2.3 Instrument Holder

A holder was designed to provide mechanical support for the rigid tube of the endo-illuminator outside the eye (Fig.5). When the endo-illuminator is introduced in the operative eye, the surgeon can pre-bend the holder such that the rigid tube of the endo-illuminator is securely positioned in an initial desired direction. Since the actuation of the flexible end inside the eye is completely automatic, the surgeon no longer has to hold the endo-illuminator and is thus able to perform bi-manual surgery.

The holder consists of a magnetic base that mounts on the eye-shield that covers the non-operative eye, held in place by a complementary magnet positioned underneath the eye-shield. The holder's base connects to an adjustable interlocking metallic conduit that can be pre-bent into any desired shape and forms the "neck" of the holder. This neck culminates in a ball and socket joint where the rigid tube of the endo-illuminator is ultimately attached. The simplicity of the attachment and anchoring of the holder via the use of magnets minimizes both the set up and cleaning time before and after the operation.

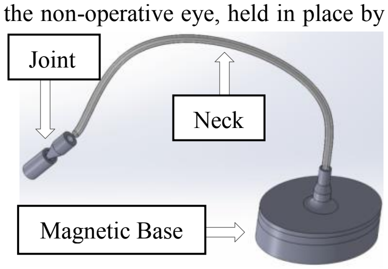

Fig. 7 - Instrument Holder

The proposed holder is compact in size, thus placing minimal burden on the surgical space. Furthermore, since the holder is referenced with respect to the patient's head via the eye-shield on the non-operative eye, if the patient where to inadvertently shift during the surgery, the endo-illuminator rigid and flexible ends retain their relative position with respect to the operative eye. This ensures patient safety.

3 Results and On-going Work

A 10x scale-up model of the endo-illuminator was fabricated and successfully tested in saline solution to simulate intra-ocular conditions. When current was applied to the SMA wires, the maximum end deflection reached 80° (Fig.6). The response time to reach this maximum bending angle from the neutral position was less than one second.

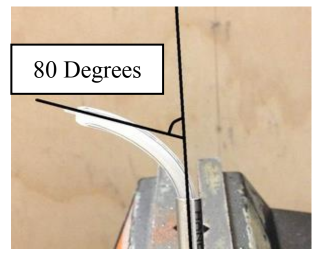

Fig.6 Maximum End Bending

An image recognition and processing algorithm was developed and tested using existing video files of vitreoretinal surgeries to successfully demonstrate the tracking of an instrument tip. A to-scale holder was fabricated and tested by attaching it to an eye-shield placed on a dummy head. From physical inspection and evaluation, the magnetic force was found sufficient to support the holder base securely. With this arrangement, all possible endo-illuminator insertion points on the sclera were accessible. The total set-up of the holder took less than 1 min.

On-going work is primarily focused on the miniaturization of the endo-illuminator to the ultimate functional size of 25 gauge and an overall system level testing of the automatic tracking system in real-time, including image processing speed, accuracy of tracking, and time-delay of SMA wire actuation. Once a fully functional prototype has been developed, our team will conduct testing to validate the efficacy of the proposed approach in ex-vivo and in-vivo models.. The authors would like to acknowledge Alex Chang, Eeshan Khanpara, Sheena Koushik, Kai-li Yu, Mike Ober, and Flavio Rezende for their contributions to this project.

5 References

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