Robot Learns Skills from Surgeon for Subretinal Injection

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Abstract— **Subretinal injection is known to be a challenge operation in ophthalmic microsurgery domain, which requires delicate motion and sensitive perception. Image guided robot-assisted surgery (RAS) is a promising solution that brings significant improvements in outcomes and reduces the physical limitations of human surgeons. In this paper, we first propose the basic framework of tracking and learning, which allows the robot to learn subretinal injection surgical skills from the surgeon. These surgical skills can potentially give a certain degree of autonomy and reduce the robotic console training time for the surgeons. The framework contains a data collection hardware and a deep learning software. The data collection hardware is based on the microscopic-stereo vision tracking system, which tracks the movement of the instrument for subretinal injection. The deep learning part targets to summarize the features of injection trajectories and thus it conclude a pattern inside varies of trails. We prove and demonstrate the feasibility of our framework on the phantom eye experiments.**

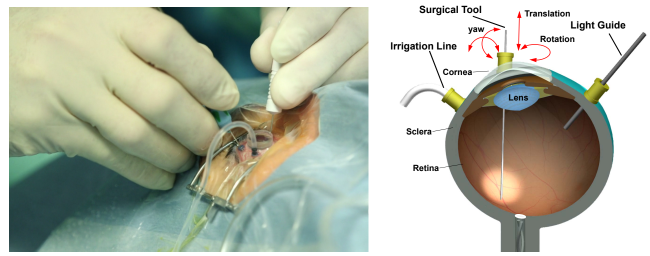

Fig. 1. A conventional subretinal injection setup. The incision ports are made by trocars at the sclera in a circle 3.5mm away from the limbus to provide entrance for surgical tools: light source, instrument, and irrigation line [3]. The light source is used to illuminate the intended area on the retina, allowing its planar view to be analyzed by surgeon through the ophthalmic microscope. The irrigation line is used for liquid injection to maintain appropriate intraocular pressure.

I. Introduction

Subretinal injection has been successfully used in clinical trials to deliver therapeutic interventions of proteins, viral agents, and cells to the interphotoreceptor/subretinal compartment that has direct exposure to photoreceptors and the Retinal Pigment Epithelium (RPE) [1]. It presents the potential to create effective outcomes for well-known retinal diseases including Age-related Macular Degeneration (AMD) which is the leading cause of blindness in developed countries [2]. For this operation, conventionally, the surgeon is required to inject a microcannula into a specific area of the translucent retina to a certain depth, this is a target which is normally defined pre-operatively (See Fig. 1). The precise control of the depth of the needle tip is critical for subretinal injection, as a shallow injection will not release sufficient drug and an overly deep injection may result in irreparable damage to the retinal pigment epithelium (RPE) and causing vessel rupture. On the other hand, this critical depth control will be affected by hand tremor of the surgeon and visual artifacts caused by the microscopic view of the target area. Therefore, subretinal injection is known to be a delicate and complex procedure, which needs enhanced skills and considerations.

To overcome surgeon's hand tremor, many researchers in the recent years have introduced high precision robotic setups in different scales and design mechanisms [4]–[8]. Over years, these ophthalmic robots are becoming mature to enter the clinical trial, for instance Robotic Retinal Dissection Device (R2D2) performed the world first robotic Internal Limiting Membrane (ILM) peeling surgery [9]. During the surgery, the surgeon needs to handle a console to tele-operate the slave robot. The surgical outcome heavily relies on the human factors, such as a surgeon's hand-eye coordination and experience. This working mechanism requires the surgeon to spend extra time to be familiar with the system, which may extend the training period even longer which typically is around 10 years of intensive training to be a qualified ophthalmologist.

During this training progress, the surgeon will obtain the theoretical and practical knowledge which is hard to use metrics to measure and describe. In 2016, Shademan et al. proposed the application of supervisory functions for autonomous robotic soft tissue surgery, which shows a superior to surgery performed by expert surgeons and RAS techniques in ex vivo porcine tissues and in living pigs. Different from the suture surgery, there are some patterns and metrics to follow for example spaced sutures with small gaps between consecutive sutures to prevent leaks; yet, gaps should be large enough to allow blood flow for healing. However, for subretinal injection in ophthalmologic operation, the surgeon mostly inject the needle into the retina up tp a certain depth by experience without extra visual and tactile perception and feedback. Due to the fact that the retina is transparent and the interaction force between the retina and the surgical instrument is normally less than 7.5 mN [10].

In this paper, we proposed a framework which allows the robot to learn subretinal injection surgical skills from the

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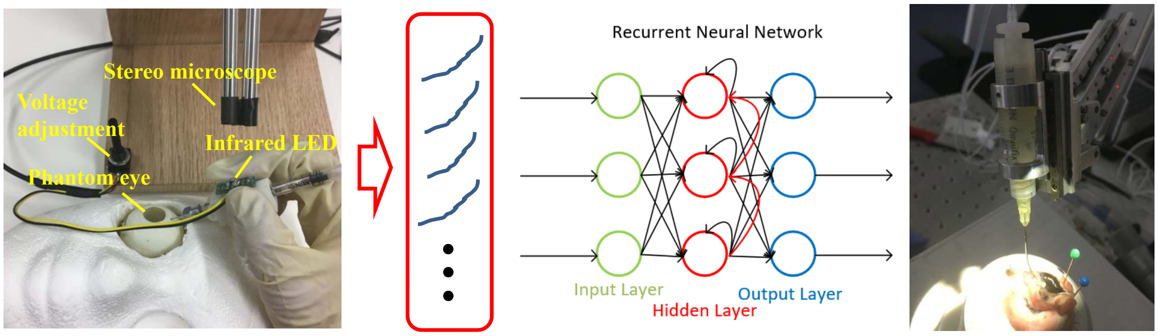

(a) (b) (c) (d)

Fig. 2. (a) The stereo microscope setup to record the instrument's trajectory for injection in the phantom eye. The light with brand of 800-1100 nm can go through the light filter which is attached in front of each microscope. The intensity of infrared led can be adjusted by the voltage adjustment. (b) The data set of the recorded trajectory path. (c) The RNN network with LSTM units. (d) The robot is controlled to follow the trajectory with the control of the network when the surgeon have send the injection command

surgeon directly. The tracking system can record the micron level movement of surgeon's hand to obtain the injection's 3D trajectory points with time stamp. Afterwards, a recurrent neural network (RNN) with long short-term memory (LSTM) units for layers is used to summarize the common pattern and features of the injection samples. Last but not least, this network with trajectory prediction ability is used to control the robot to perform the autonomous injection.

II. Method

The overall framework is depicted as in Fig. 2. The stereo microscope setup is built up to record the instrument's motion. The infrared LED (950 nm) is selected as the detection marker and the filter is used to block the light except 800-1100 nm. With this method, the led marker can be robustly detected with 15.1 Hz in C++ environment. The stereo microscope trajectory system is calibrated by the classical black-white chess board and the accuracy performance is further checked by the piezo motor (1 μm accuracy, SmarAct GmbH) with ± 30 μm accuracy which is qualified for trajectory recording. The recorded data is firstly processed by a bandpass filter which the hand tremor normally with 8-12 Hz. The re-sampled data with 15 Hz is feed to the RNN network with the input of (x, y, z, t), where x, y, z is the position of point in 3D space and t is the time stamp. The benefit of RNN network with LSTM units is that it has the capable of learning long-term dependencies which makes it suitable for the speech processing and trajectory prediction [11]. We trained the network with 70 preprocessed trajectories, and 30 trajectories are used to test the network. The network is used to control the virtual robot first in V-rep which primary demonstrate the feasibility of the proposed the framework.

III. Conclusion

This paper demonstrate a feasible framework for the robot to learn skills from the surgeon directly from the perception of subretinal injection trajectory. A stereo microscope vision system is built up to track the trajectory of instrument's motion with error of 30 μm. Afterward, a RNN network is trained for the trajectory dataset and this network is test in the V-rep virtual environment. We will perform the real robot test for phantom tissue as well as the ex-vivo and pig eye in further work.

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