Automated Device for Intravitreal Injections

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Abstract:

An automated system that injects medication into the vitreous humor of the eye (intravitreally) is proposed in this work. By providing a robotic injection system with an integrated local sterile environment, we can increase safety for patients, decrease procedure times, allow for integrated data storage and documentation, and reduce costs for medical staff and expensive operating rooms. The intended system allows for an assisted injection that is initiated via a computer and monitored by a remote ophthalmic surgeon via a visual-auditory communication system. As the injection needle is guided through software, including eye-tracking and iris recognition, the only component that touches the eye is the injection needle. Precision and safety are fundamental to the system design and do not depend on the manual dexterity of medical staff using a hand-held system.

Keywords: Ophthalmic assistive device, intravitreal injection, teleophthalmology

1 Intravitreal Injections

Neovascular age-related macular degeneration (AMD) is the primary cause of legal blindness in industrialised countries \[1\]. This disease is characterised by uncontrolled vascularisation and degenerative lesions in the retina and causes loss of central vision. Since the approval of the first intravitreally applied drugs for the treatment of AMD \[2, 3\], the intravitreal injection has become one of the most frequently performed surgical procedures in ophthalmology with more than 4 million injections worldwide in 2014. The demand for intravitreal therapy (IVT) of various drugs including mostly vascular-endothelial-growth-factor (VEGF) inhibitors evolved dramatically over the past decade. Especially the demand for IVT to treat the chronic diseases AMD and diabetic maculopathy/retinopathy is severe and is going to increase in the foreseeable future \[4\]. This work proposes an assistive device for intravitreal injections to render IVTs more time and cost efficient, while increasing safety for the patient. The system allows for precise and safe injections into the eye, but is remotely controlled and surveilled by the treating physician \[5\].

2 Robot-Assisted Injection Procedure

The assistive system for the efficient treatment of AMD and other ocular diseases intravitreal injections was designed according to several requirements, which ensure safety for the patient and the physician, increase cost and time efficiency of the injection procedure, and allow for usability. The system is illustrated in Fig. 1(a). The proposed device consists of two modules, the positioning module used for the positioning of the device over

End-effector with injection needle
Porcine cadaver eye
Injection
Retraction

Figure 1: (a) The assistive injection system is positioned over the patient’s head. (b) It consists of a positioning and an injection module. (c) Automated intravitreal injection into \textit{ex vivo} porcine eyes during experiments.
the eye, and the injection module inside a sterilisable dome for the injection process, as illustrated in Fig. 1(b). It allows for a fully automated intravitreal injection that is remotely started via a computer and monitored by an ophthalmic surgeon via an intuitive user interface and a visual-auditory communication system. The wall or ceiling mounted system offers a local sterile environment above the patient’s face to decrease infections and account for patient safety. As the injection needle is guided through software, that includes eye tracking and iris recognition, the only component that can touch the eye is the injection needle. Precision and safety are inbuilt measures and do not depend on the state of mind of medical staff using a hand-held system. After intravitreal injection, the intravitreal injection is automatically documented by the system. The key advantages of an automated intravitreal injection procedure have been identified as 1) increased patient safety through patient and eye identification, 2) high-precision of the injection procedure with a predictable surgical outcome, 3) the procedure is independent of a physician’s surgical skills, 4) cost and time efficiency as the physician can remotely control the system, and 5) parallel procedures are possible. Prior to the injection procedure, a nurse prepares the patient and the system is coarsely positioned over the patient’s head. This is followed by fine positioning the system by the positioning module, such that the eye is centred in the system workspace. The vision system allows for several functionalities, such as tracking of the pupil, scanning the iris, locating the desired injection point, and monitoring of the patient. The camera images are displayed to the user interface at all times, allowing the physician to monitor the patient. The injection process includes the positioning of the needle over the eye, followed by injection and needle removal. The process is completed by automated data documentation and storage.

3 Results

To analyse the iris recognition performance, 100 images of 20 different eyes, i.e. five images per eye, were taken followed by iris segmentation. The Hamming distance was derived for all possible intraclass (same eyes) and interclass (different eyes) combinations. The two distributions were completely separated, such that a Hamming distance threshold of 0.4 would result in 100% correct recognition rate. To demonstrate the functionality of the automated system for injections into the eye, experiments were conducted in ex vivo porcine eyes. Cadaver eyes were obtained from the abattoir and intravitreal injection experiments took place less than 10 hours post mortem. Resulting, it was found that all injections were within the safe region for injection on the cadaver eye. The visually measured accuracy of positioning was found to be 0.8±0.6 mm for four separate injection experiments. Figure 1(c) shows the successful injection into a porcine eye conducted with the proposed automated injection system.

4 Conclusion

A first robotic prototype for intravitreal injections has been developed in close cooperation with ophthalmic surgeons, taking into account the standard of care, patient safety, patient acceptance, clinician acceptance, cost and time efficiency, as well as technological constraints. Injection studies have been performed on cadaver pig eyes, which prove the functionality of the system. During experimentation with the current system, possible changes have been identified, that, upon implementation in a clinical prototype, will extent and improve the current design.

5 References