Use Case for European Robotics in Ophthalmologic Micro-Surgery

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***Abstract*—Vitreo-retinal surgery is used as a denominator of a set of particularly demanding micro-surgical interventions that take place on the retina at the far side of the eye. The associated interventions require extreme precise instrument manipulation in order to be able to safely work on fragile membranes or vessels in charge of blood circulation. Motions lie close to or even go beyond the limits of human motion capability. Referral of patients to the limited number of expert centers is frequent. Some eye problems require such high levels of precision that they cannot be treated adequately at present. Affected patients have no effective treatment options and endure a significantly reduced quality of life. EurEyeCase is a new research project funded under the Horizon 2020 framework that aims at overcoming the present status quo through progressing robot-assisted ophthalmologic micro-surgery. This extended abstract introduces the EurEyeCase objectives and the technology that is being developed.**

I. Robot-assisted vitreo-retinal eye surgery

EurEyeCase focuses on intra-ocular vitreo-retinal eye surgery, in short VR surgery. VR surgery is characterised by a wide range of surgical interventions that are close to and beyond the limits of human capabilities. A significant number of eye problems can not be treated safely or adequately due to limitations in achievable dexterity and precision of 'manual' instrument positioning. The affected patients experience a significant reduction of quality of life. The argument for using robotic technology, namely that it offers new levels of precision and would be valuable for this particular type of interventions, has been made already back down in the late eighties by Charles *et al.* [1]. Since then several research systems have made their appearance and this at different research labs all over the world [2]–[15]. However, up till now, there is not a single commercial robotic solution on the market that meets the precision and dexterity needed for vitreo-retinal surgery. Bourla *et al.* investigated the feasibility of using the da Vinci® surgical system for this procedure, but concluded the system was not adequate for this purpose. Difficulties with visualisation were reported. It was also found difficult to keep the stress at the incision site below acceptable levels [16]. Recently, a US-based company, is reported to have raised substantial funding to develop a commercial eye-surgical robot. However, at this point it is not clear whether the focus will lie on VR procedures rather than on cataract-removal.

II. VR basics and clinical use cases

VR surgery is currently performed manually. At the beginning of the procedure the surgeon carefully puts a selection of up to four trocars into place at 3 to 4 mm from the corneal limbus, the border between the cornea and the sclera (Fig.1). Through these trocars thin instruments are inserted to operate on the interior part of the eye. The vitreous humour, a gel-like substance that occupies most of the interior volume of the eyeball, can be removed during a so-called *vitrectomy* [17]. This can be done to clear out bleeding, to release traction on the retina or to simplify work in other interventions. The vitreous humour is replaced by a physiologic fluid which allows smooth instrument motion and lowers the risk of development of retinal tears. Due to adhesion between the retina and the vitreous humour, such tear could develop by simply moving (slicing) through the vitreous humour.

In some cases membranes have grown over the retina. Such membranes could deform the retina itself and affect the vision.

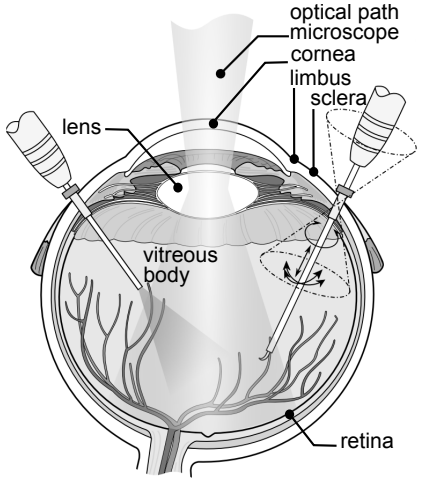

Fig. 1. Anatomy of the eye, focus on structures relevant for VR

By using a dedicated pick and forceps the microsurgeon can choose to peel these membranes. For *epiretinal membrane peeling* (ERM-peeling) a membrane up to about 60μm is to be peeled off from the retina [18]. In the case of ILM peeling the *internal limiting membrane*, up to about 4μm thick, is to be removed without damaging the below retina. Application of excessive forces can give rise to serious complications such as retinal tears and hemorrhages [19], [20].

The retina can itself be detached from the back of the eye, which poses a critical situation possibly leading to complete loss of vision if not treated adequately. By carefully positioning the retina back to its place and fixing parts by photocoagulating with a high-intensity laser, thus creating fibrosis for permanent reattachment, *retinal detachment repair* can be conducted [21].

Due to venous thrombosis in the lamina cribrosa, the blood circulation and oxygen supply of the retina gets seriously disturbed in the case of *Retinal Vein Occlusion* (RVO) [22], [23]. Current therapies, such as grid laser and panretinal laser photocoagulation, have not been found to be effective in improving visual acuity [24], or are associated with serious complications [25]. Retinal vein cannulation, i.e. reopening a thrombotic retinal vein by injecting a thrombolytic agent in the lumen of the vessel has been proposed in the past [26]–[28], but 'manual' execution has been found problematic [29]. The difficulty lies in the small size of these brittle vessels in combination with physiological involuntary movements (tremor) from the surgeon (amplitude is in the order of the targeted vessel diameter [30], [31]) and the need for prolonged infusion up to 40 minutes. Piercing of the vessel and injection of agent in/under the retina could lead to retinoschisis, retinal detachment, pronounced hemorrhage or toxic damage.

III. EurEyeCase objectives

In view of the small size internal and epiretinal membrane 4-60μm and of the retinal veins (40-120μm), compared to the large amplitude of human tremor (well over 100μm), it was decided in close collaboration with the clinicians to put the **EurEyeCase** focus on membrane peeling (ERM and ILM) at one side and on retinal vein cannulation at the other side. In particular following scientific objectives will be targeted.

The following four scientific objectives have been identified: *1)* Development of robot-assistance control schemes for μm positioning and mN manipulation surgical tasks; *2)* design of a set of innovative miniature sensorised instruments for vitreoretinal surgery (VR surgery) that help improve peeling and cannulation tasks; *3)* development of a robust online 3D reconstruction of retina (10Hz); reconstruction based on stereoscopic images incorporating information from OCT, pose, contact and force-sensing; *4)* conduct clinically relevant research. The developed robot technology and instruments can be used to actually conduct clinically relevant research on complex vitreoretinal surgical techniques such as epiretinal membrane peeling and vessel cannulation. E.g. research that shines a light on optimal peeling strategies, or provides insight in the effect of injection of anticoagulant in the vicinity of occlusions in retinal veins.

One aspect that will be investigated with additional care is the question on what kind of operation modus is superior. The main operation modi in this domain have been so far:

- hand-held operation [5], [13];
- co-ordinated manipulation [6], [10], [12];
- teleoperation [2]–[4], [7]–[9], [11], [14], [15].

Pro's and cons of all approaches have been claimed on several occassions in the past. However, so far a detailed analysis and comparision of these operation modi has not been conducted yet. **EurEyeCase** will set up a detailed experimental plan to allow fair and objective comparison of 2 of the 3 operation modi, namely comparison of teleoperation [14] and co-ordinated manipulation, departing from work by Meenink *et al.* and from Caers, Gijbels *et al.*, respectively [14] and [12].

IV. EurEyeCase Consortium

EurEyeCase gathers a consortium of researchers, industrials and clinicians that are joining forces to advance the current state-of-the-art in robotic VR surgery. Fig.2 summarizes the partners involved in this collaborative project. The consortium constitutes of 3 academic partners, the University of Leuven (co-ordinator), the Technical University of Eindhoven and ETH Zürich, 1 knowledge center bridging scientific knowledge with medical technology, ACMIT GmbH, 3 medical device manufacturers of which 1 is set to commercialise robotic eye surgery (Preceyes, Medical Robotics Technology BV), and 2 companies offering OCT-technology (OptoMedical Technologies GmbH, Medical Laser Center Lübeck). Finally, 3 clinical expert centra (University Hospital Leuven, Luigi Sacco, University of Milan and Rotterdam Eye Hospital), where directions for further development and feedback on conducted experiments are given.

V. Conclusion

EurEyeCase aims to step up the speed of development and validation of existing and novel VR technology. It does so by targeting two relevant (and urgent) clinical indications namely retinal membrane peeling (ERM and ILM) and retinal vein occlusion.

Fig. 2. EurEyeCase Consortium

By approaching the problem in a structured and multi-faceted, cross-disciplinary fashion, in tight collaboration with the clinical partners, **EurEyeCase** aims to lift current systems and algorithms to higher Technology Readiness Levels (TRLs).

Furthermore, by departing form existing hardware, belonging to two different operation categories, namely: teleoperation and co-ordinated manipulation, it becomes possible to compare the value of both operation categories, and this on a fairly short term. It is expected that this information will be of greater and more general use to the surgical robotics research community.

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