Automatic intraocular lens segmentation and detection in optical coherence tomography images

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Abstract

We present a new algorithm for automatic segmentation and detection of an accommodative intraocular lens implanted in a biomechanical eye model. We extracted lens curvature and position. The algorithm contains denoising and fan correction by a multi-level calibration routine. The segmentation is realized by an adapted canny edge detection algorithm followed by a detection of lens surface with an automatic region of interest search to suppress non-optical surfaces like the lens haptic. The optical distortion of lens back surface is corrected by inverse raytracing. Lens geometry was extracted by a spherical fit. We implemented and demonstrated a powerful algorithm for automatic segmentation, detection and surface analysis of intraocular lenses in vitro. The achieved accuracy is within the expected range determined by previous studies. Future improvements will include the transfer to clinical anterior segment OCT devices.

Automatische Segmentierung und Detektion von Intraokularlinsen in optischen Kohärenztomographie-Aufnahmen

Zusammenfassung

Wir stellen die Entwicklung eines neuen Algorithmus zur automatischen Segmentierung und Detektion von in einem biomechanischen Augenmodell implantierten, akkommodativen Intraokularlinsen vor, bei welchem Linsenkrümmung und -position bestimmt wurden. Der Algorithmus enthält ein Entrauschen und eine Korrektur der durch das Messsystem eingeführten Verzerrung, welche durch eine mehrstufige Kalibrierung umgesetzt wurde. Die Segmentierung wird durch ein modifiziertes Verfahren zur Kantendetektion nach Canny realisiert, welchem eine Detektion der Linsenoberfläche mittels automatischer "Region of Interest"-Suche folgt. Letztere

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blendet beispielsweise Haptikreste der Linse aus. Die optische Verzerrung der Linsenrückfläche wird durch inverse Strahldurchrechnung korrigiert und die Linsengeometrie über sphärische Approximation ermittelt. Wir konnten einen leistungsfähigen Algorithmus zur automatischen Segmentierung, Detektion und Oberflächenanalyse von Intraokularlinsen in vitro implementieren und demonstrieren. Die erreichte Genauigkeit liegt in einem Bereich, der aufgrund von vorausgehenden Studien erwartet wurde. Zukünftig soll der Algorithmus auch auf Daten von klinischen Vorderkammer-OCTs angewendet werden.

Keywords: Cataract surgery, accommodation, intraocular lens, accommodative IOL, OCT, image processing

Schlüsselwörter: Kataraktoperation, Akkommodation, Intraokularlinse, Akkommodative IOL, OCT, Bildverarbeitung

Introduction

The refractive power of human eyes changes dynamically to image objects at different distances. This capability is called accommodation and is maintained by variation in lens geometry and position [1]. The ciliary muscle is connected to the lens capsule by zonula fibers and slackens the fibers by contraction effectuating a steepening of lens curvature. This ability slowly decreases and finally disappears with age as the lens loses elasticity [2] while the ciliary muscle's functionality is largely preserved [3]. This condition is called presbyopia.

Lens flexibility and consequently the ability to change refractive power of the human eye is lost at the latest, when the natural lens is replaced by an artificial intraocular lens (IOL) due to cataract or clear lens extraction. Nevertheless, patients often have remaining pseudoaccommodation (ability to accommodate without any geometrical lens changes). This ability is a consequence of small pupil size, myopic astigmatism, corneal aberrations, corneal multifocality and good visual perception [4]. The range of pseudoaccommodation is often adequate for elderly people but especially younger patients who had proper accommodative response prior to IOL implantation (e.g. after traumatic cataract) subjectively feel a loss of quality of life [5]. One possibility of preserving near and far vision is the implantation of a multifocal intraocular lens [6]. The implantation of such lenses often causes glare or halos around bright spots and a reduction of contrast sensitivity combined with good visual performance at the same time. Several approaches have been presented to overcome this drawback of IOL implantation by implementation of a so-called accommodative intraocular lens (AIOL) [7–12]. It has to be considered that pseudoaccommodation is also present after implantation of an AIOL and that it is difficult to differentiate between both conditions [13]. Most implants use a focus-shift principle which translates ciliary muscle contraction (e.g. HumanOptics 1CU) or support from the vitreous (e.g. Bausch & Lomb Crystalens^{TM}) into forward movement of the IOL optics [12]. Other approaches try to implement a deformable lens based on a liquid or gel [8] or a dual-lens concept similar to a photographic zoom-lens. However, current AIOLs still lack of a sufficient accommodative range [14]. Patients need a range of 3 to 4 dpt in order to regain reading ability in a comfortable reading distance of approx. 33 cm. New designs of AIOLs might also change geometry additionally to the lens position to increase the range of accommodation. To improve the design of an AIOL, simultaneous and dynamical measurement of geometrical and positional changes of current and future lenses is important. Actual measurement devices such as automatically rotating slit projection cameras (e.g. Pentacam, Oculus Optikgeräte GmbH, Wetzlar, Germany) analyze the anterior segment of the eye but those devices often do not correct optical distortion for intraocular optical surfaces resulting in inaccurate lens parameters [15]. In addition, a complimentary device such as the ACMaster (Carl Zeiss GmbH, Jena, Germany) might be necessary to determine axial lens position when the anterior chamber is too deep. The anterior eye segment can also be imaged noninvasively by optical coherence tomography (OCT)[16–18]. This method allows to capture a 3D dataset of the lens and the adjacent components. However, the collected data is superimposed by noise and additionally distorted by the refractive surfaces which the OCT beam passes during measurement. Moreover the lens has to be extracted out of the dataset using image processing.

The purpose of this work was to implement an automatic image processing that extracts the geometrically correct lens with its front and back surface from a OCT raw image during accommodation.