Precise and automatic alignment of a diagnostic device using image processing

Degree programme: BSc in Micro- and Medical Technology
Specialisation: Control Technology
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Ziemer Ophthalmic Systems is specialized in diagnostics and treatment for corneal sicknesses. Their diagnostic device, the Galilei, is using advanced camera systems to determine the topography of the cornea, which requires precise alignment relative to the patient‘s eye. To this day, the alignment is done manually by the operator. The goal of this thesis is to align the camera system in front of the patient‘s eye using computer vision.

Introduction

The measurement head of the Galilei device (shown in figure below) aligns the x- and y-axes using the topview camera, whose center, indicated by the red lines in the Topview image below, must align with four projected Purkinje-dots. The z-axis is aligned with two 45°-angled Scheimpflug cameras, offering a transverse plane view of the anterior segment of the eye. Aligning the corneal apex with the red reference line maximizes Topview image sharpness. This thesis aims to automate the process with a prototype measurement head using stepper motors.

Goals

- Optimize the image processing algorithms by Ziemer, to detect the Purkinje-dots and corneal apex
- Implementation of a tracking controller for the motor position on a microcontroller.
- Testing of the final product, to verify application on the human eye.

Methods

Image processing - The existing edge detection algorithms are optimized to allow faster processing and higher sampling frequencies. The computer vision software calculates the momentary error on all three axes, being the input of the motor controller.
Control Systems - The tracking controller is using an adaptive velocity trajectory based on the error signal. The velocity trajectory is prototyped in Matlab and the tracking controller is implemented in Simulink for configuration and testing purposes.

Results

Image processing - Camera images are stored on the main disk, then loaded into memory for edge detection processing. The Purkinje-dots detection was already fast (~10 ms) and required no optimization. The corneal edge detection algorithms were simplified by removing filters and reducing the search zone, cutting processing time from 140 ms to 15 ms. Loading images as raw bitstreams takes ~20 ms each, compared to 250 ms for other formats such as bmp.
Control Systems - Motor controlling functions, containing steps to millimeter conversion and range checks, are implemented. According to the momentary error, a velocity trajectory is computed based to the integration of a sinusoidal acceleration profile, which yields smooth movement of the measurement head.

Discussion

The refined computer vision algorithms allow precise tracking of the current position of the measurement head. Furthermore, the motor controller provides agile movement of the measurement head. In conclusion, this thesis provides a suitable proof-of-concept for further development.

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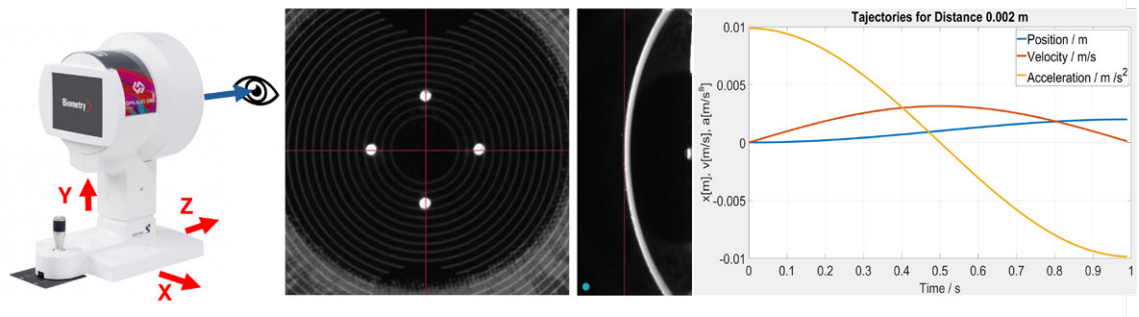

From left to right: Measurement head with the three axes of movement, Topview image, Scheimpflug image, Movement profile with sinusoidal acceleration and its integration for velocity and distance.