Stereo Eye Tracking with a Single Camera for Ocular Tumor Therapy

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Introduction

Ocular tumors are a severe disease that may lead to blindness or even death if left untreated.
Nowadays, specialists successfully treat the disease by radiating the patient's primary tumor with charged particles [1]. There is, however, a severe drawback: Although the tumor radiation itself is noninvasive, an invasive patient preparation is required. A surgeon thereby sutures radio-opaque clips on the outer scleral surface of the diseased eye. These clips are used to target the tumor during radiation therapy.
By introducing an eye tracker into the current treatment workflow, clip surgery could be avoided. The whole tumor therapy can potentially be made noninvasive [3].

Eye tracker

Eye trackers are devices able to estimate where a person is looking, i.e. the point of gaze. Certain eye trackers are based on a 3D model and therefore even have the ability to estimate the location of the eye in 3D space. **This property enables us to use an eye tracker as a navigation system**, namely to localize the eye and target the tumor during radiation therapy [3].
We present a new type of eye tracking system, extending an existing solution [3], where we are able to drastically increase accuracy and stability without having a significantly bigger device. **The proposed stereo eye tracker** (Fig. 1) **consists of one physical camera and we complement it with two planar mirrors** [2].

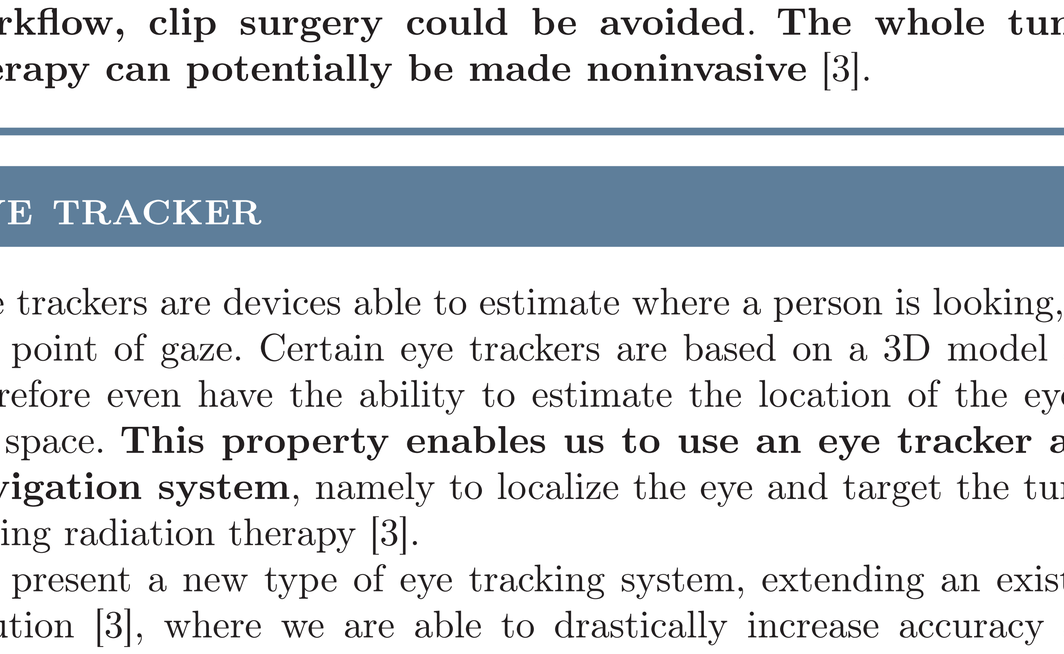

Figure 1: Eye tracker with camera ($\mathbf{o}_j$) and hot-mirrors (m_A,m_B).
By using a setup with two mirrors, we combine the benefits of a single camera system (only one camera to calibrate, no camera synchronization needed) with the advantages of a stereo camera system (simplified eye tracking model, fewer patient specific parameters, simplified calibration algorithm, better accuracy and precision).

References

[1] Goitein, M., Miller, T.: Planning proton therapy of the eye. Medical Physics 10(3), 275–283 (May 1983)

[2] Wyder, S., Cattin, P.C.: Stereo eye tracking with a single camera for ocular tumor therapy. In: 3rd MICCAI Workshop on Ophthalmic Medical Image Analysis (OMIA3). Athens, Greece (2016), (in press)

[3] Wyder, S., Hennings, F., Pezold, S., Hrbacek, J., Cattin, P.C.: With Gaze Tracking Toward Noninvasive Eye Cancer Treatment. Biomedical Engineering, IEEE Transactions on 63(9), 1914–1924 (2016)

Catadioptric stereo

By observing a scene (eye) over two mirrors, stereo images can be captured with a single camera (catadioptric stereo).
This construction (Fig. 2) enables us to make the device compact and accurate at the same time. This is because we can optimally deflect different optical paths between the eye and the camera with the introduced mirrors. Furthermore, our point of gaze estimation is very accurate and the eye position estimation is very precise due to the virtual stereo camera frame (triangulation).

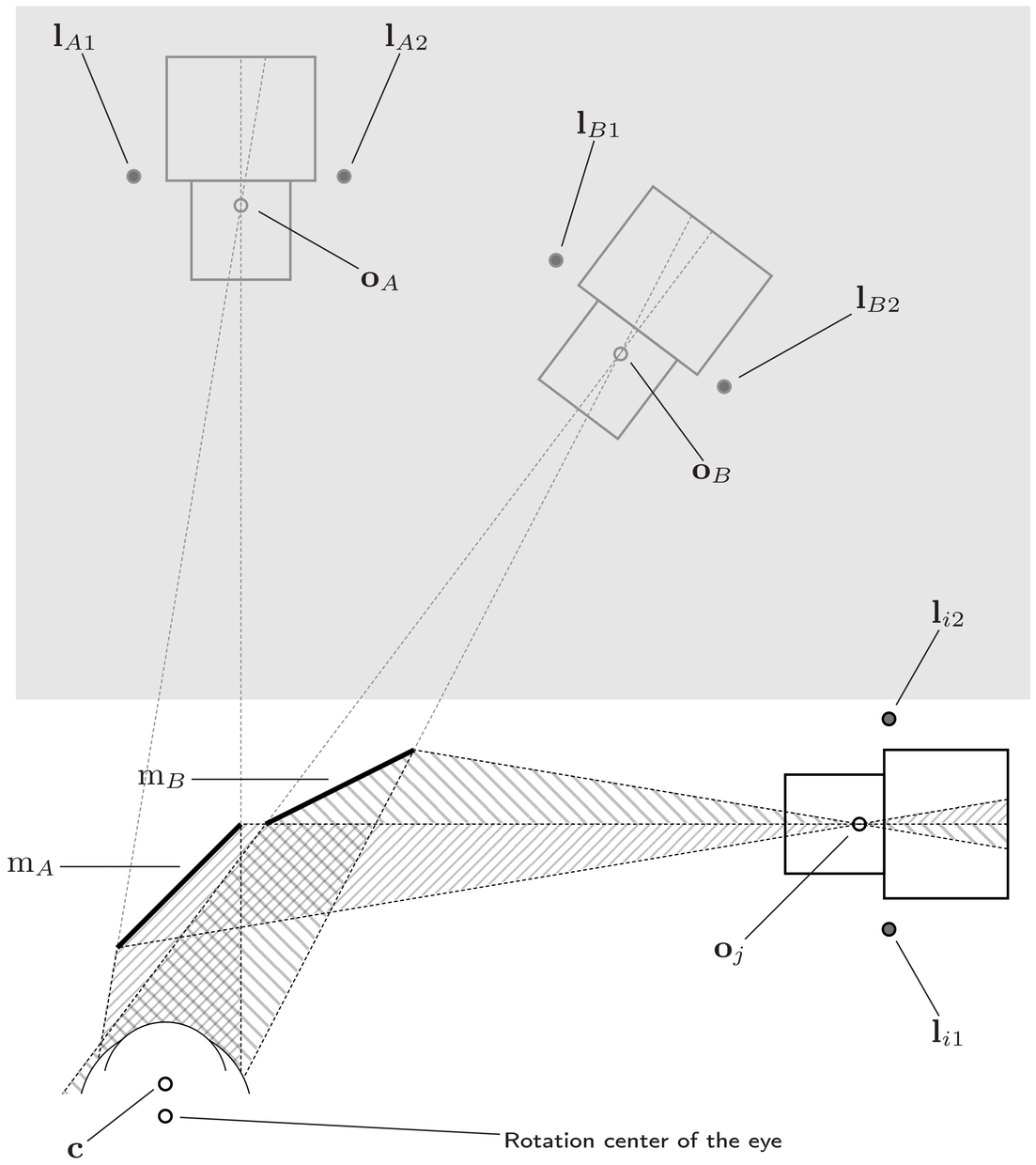

Figure 2: Optical arrangement: Eye nodal point ($\mathbf{c}$), camera ($\mathbf{o}_j$), LEDs ($\mathbf{l}_{i1}$,$\mathbf{l}_{i2}$), hot-mirrors (m_A,m_B), virtual cameras ($\mathbf{o}_A$,$\mathbf{o}_B$), and virtual LEDs ($\mathbf{l}_{A1}$,$\mathbf{l}_{A2}$,$\mathbf{l}_{B1}$,$\mathbf{l}_{B2}$). The gray shaded box corresponds to physical space occupied by the treatment device.

Setup comparison

The following list summarizes the main properties of the proposed system [2] and compares them to the state of the art [3].

- ⊕ Average point of gaze error over ten volunteers measured at point $\mathbf{c}$ (eye nodal point): $< 0.96°$ ($< 2.10°$ in [3]).
- ⊕ Precision of eye position estimation is higher in [2], due to the bigger triangulation angle.
- ⊕ The algorithm is more robust, because it does not require optimizations in uncertain solution spaces, as is the case in [3].
- ⊕ No subject specific parameters are required to estimate the patient's eye position (three are used in [3]).
- ⊕ No eye tracker calibration points are required to estimate the patient's eye position (at least four are used in [3]).
- ⊖ Slightly higher effort required to calibrate the hardware (optical adjustments and determination of virtual camera positions).