EYE REFLECTION ANALYSIS AND APPLICATIONS

Nitschke C., Nakazawa A., Takemura H. – Osaka University, Japan – {christian.nitschke, nakazawa, takemura}@cmc.osaka-u.ac.jp

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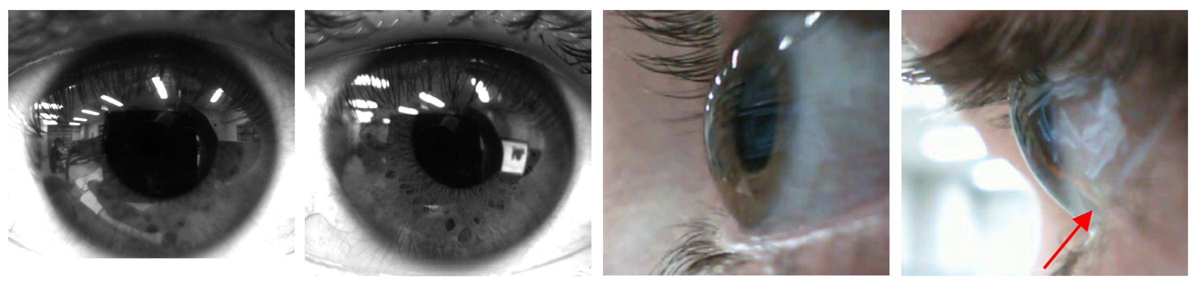
Registration and Video Analysis

Abstract Recently, the geometric relation between a human eye and its image has been formalized to analyze corneal reflections [NN06]. Proceeding with these efforts, we aim in strategies exploring the relation of camera, eyes, and scene in arbitrary environments to enable insights for human-scene interaction. We study the light transport under multiple eyes, including calibration, feature matching, back and forward projection. The findings enable a novel method for display-camera calibration.

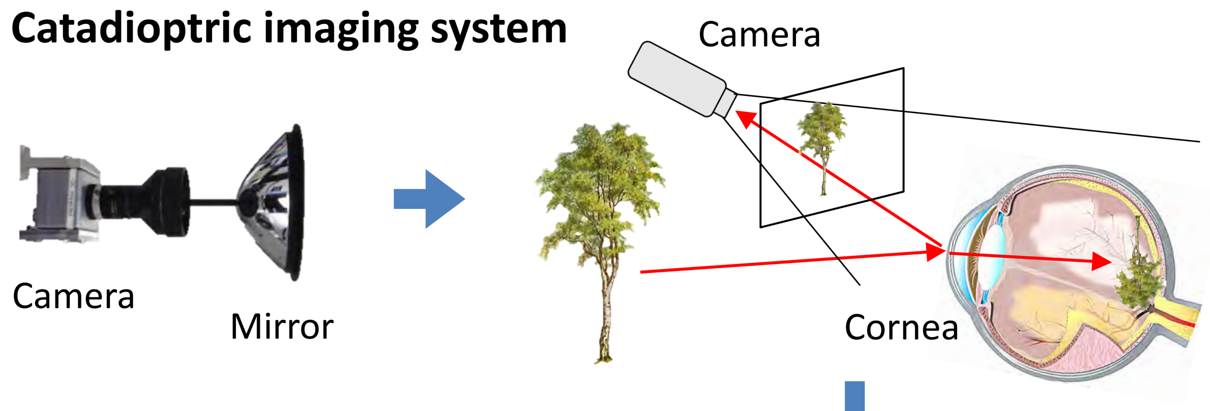
MOTIVATION

1. **Eyes as sense organ:**
   - Eyes provide rich information about physical world
2. **Eye image analysis:**
   - Eye provides visual cues for person-related information
   - Cornea captures wide-angle view of environment



Corneal reflections | Iris texture | Corneal shape | Corneal limbus

Catadioptric imaging system



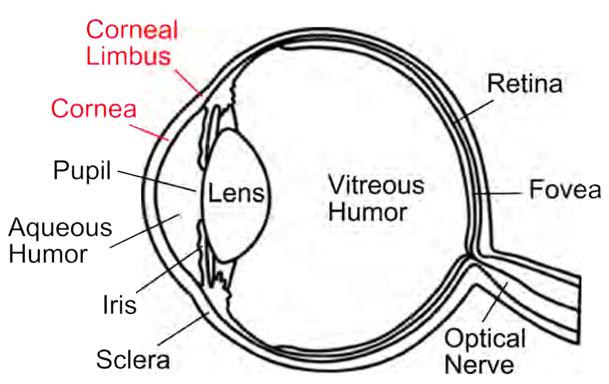
[JF07] | [TDM+03] | [NN06]

IMPLICATIONS

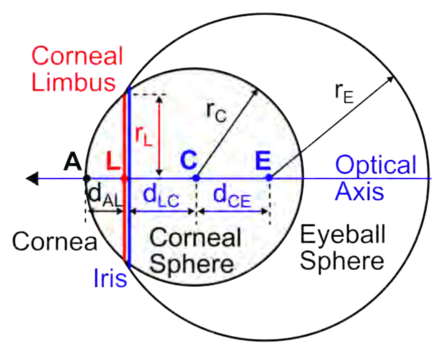
1. **Novel scenarios, system configurations**
   - Calibration-free (without awareness, interaction)
   - Dynamic setups (scene, cameras)
   - Natural environments
2. **Applications of relation between camera, eyes, and scene**
   - Primary:
     - Modeling (face/body, environment reconstruction)
     - HCI (POG/FOV tracking, 3D perception)
   - Secondary:
     - Surveillance, medicine, psychology, marketing etc.

CORNEAL REFLECTION ANALYSIS

(A) Geometric eye modeling

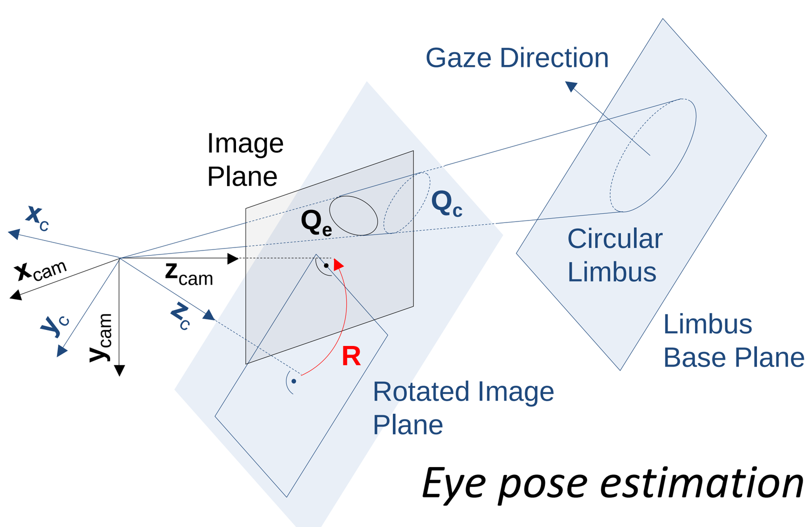


Cross section of eyeball



Spherical eye model

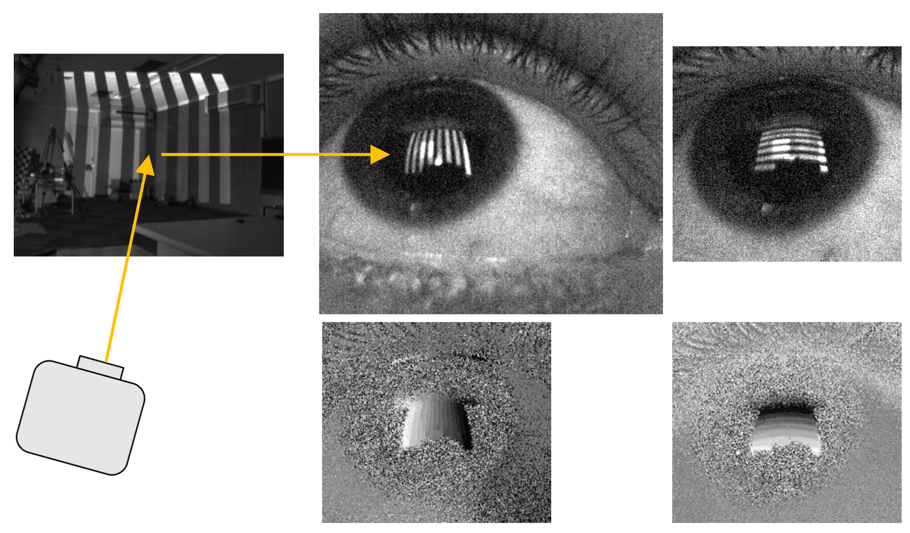
(B) Calibration of corneal imaging system



Eye pose estimation

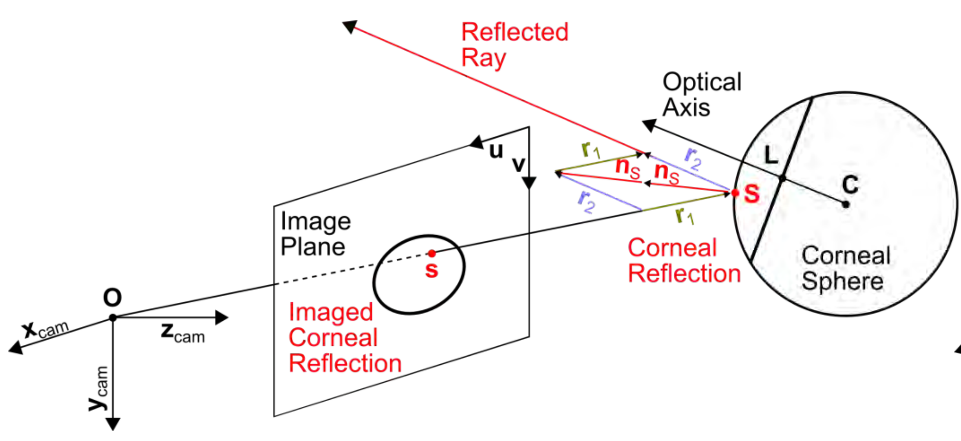
(C) Eye and scene image feature matching

Passive (natural light)

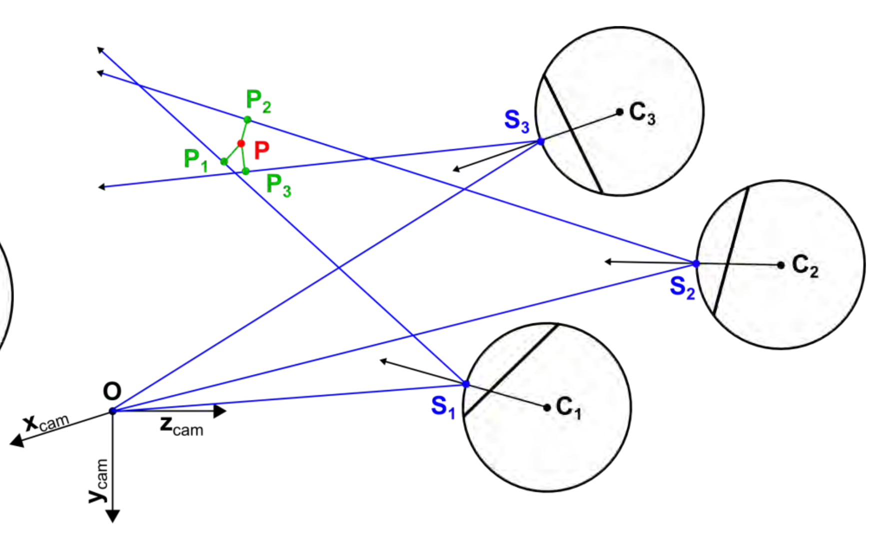


Active (controlled light)

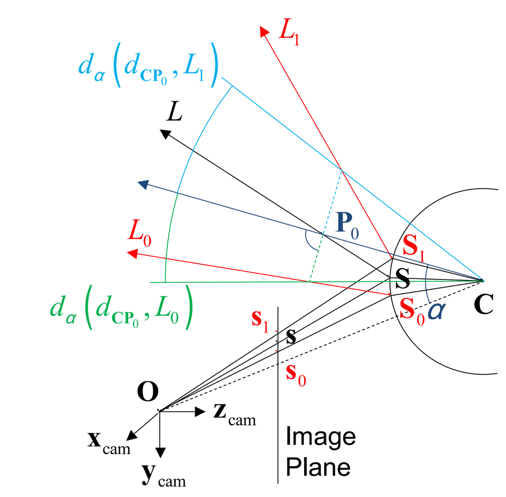
(D) Light field and scene geometry modeling



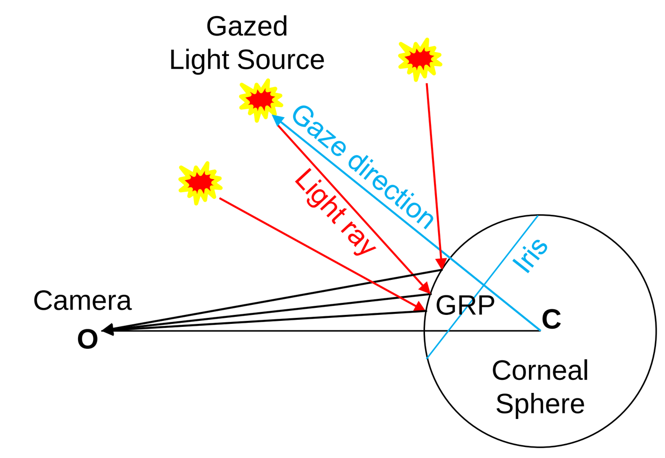
Corneal reflection model



Light path triangulation



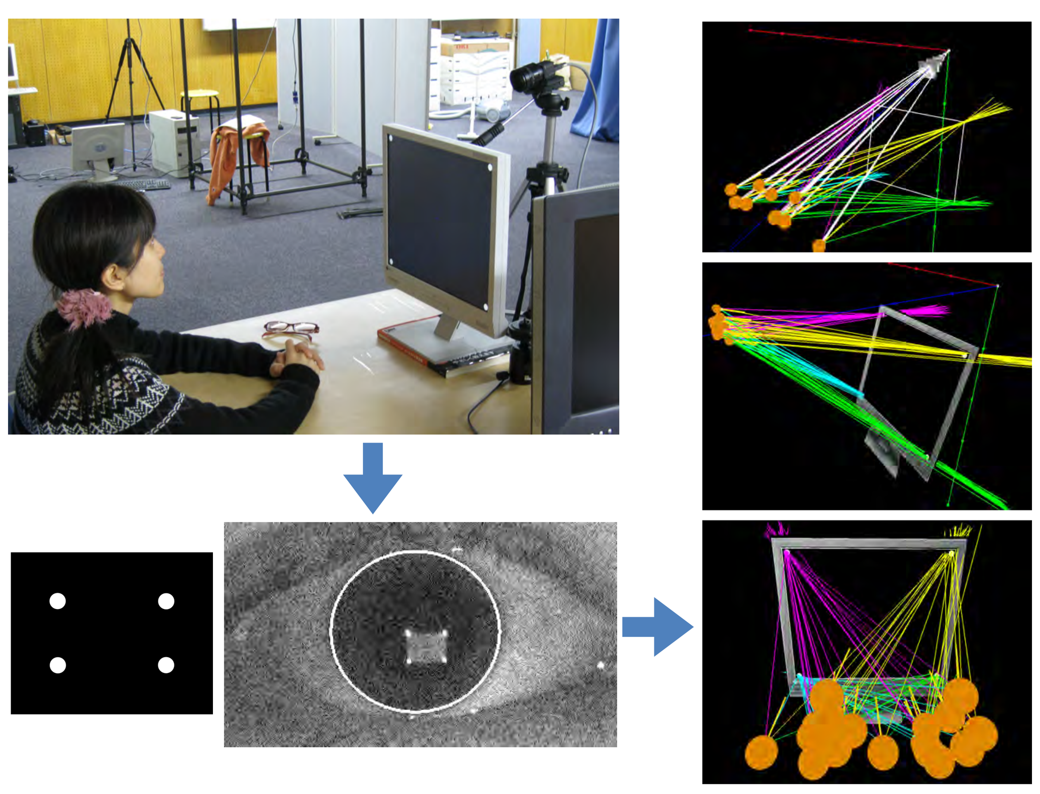
Light path distance metric



Gaze reflection point (GRP)

APPLICATION: DISPLAY-CAMERA CALIBRATION FROM EYE REFLECTIONS [NNT11]

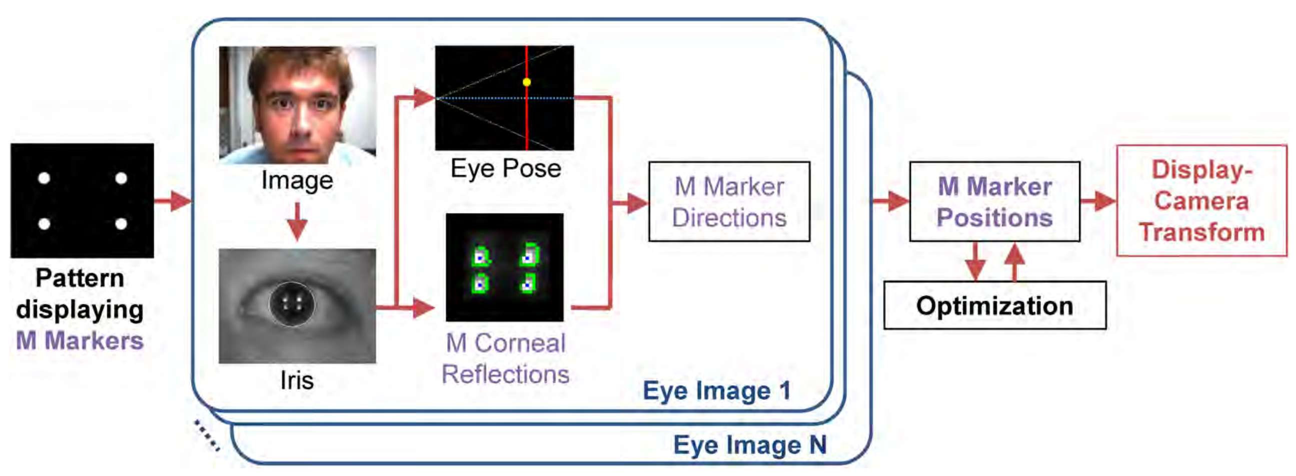
(A) Idea to analyze corneal reflections for monitor/projection screen pose estimation



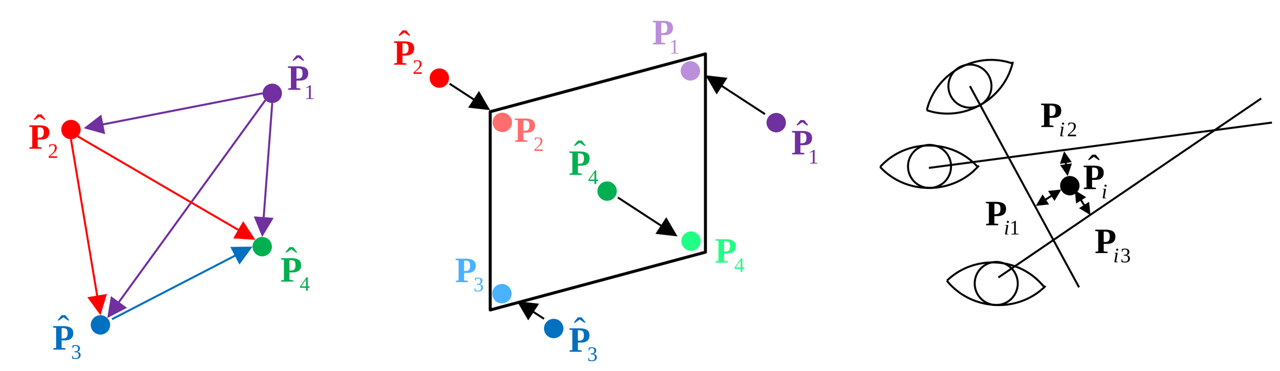
Typical setup with data | Result

(B) Novel calibration method without special hardware and user interaction/awareness

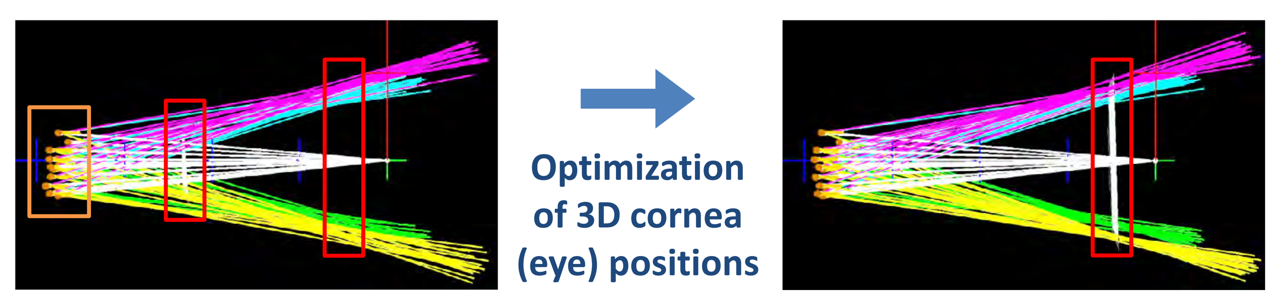
1. Capture face images with display pattern reflections
2. Estimate eye poses using imaged iris contour
3. Calculate reflected marker back-projection rays
4. Estimate marker positions as intersection of multiple rays
5. Estimate display pose (display-camera transform)
6. Optimize eye poses and back-projection rays



(C) Optimization of eye poses and reflection rays subject to geometry constraints



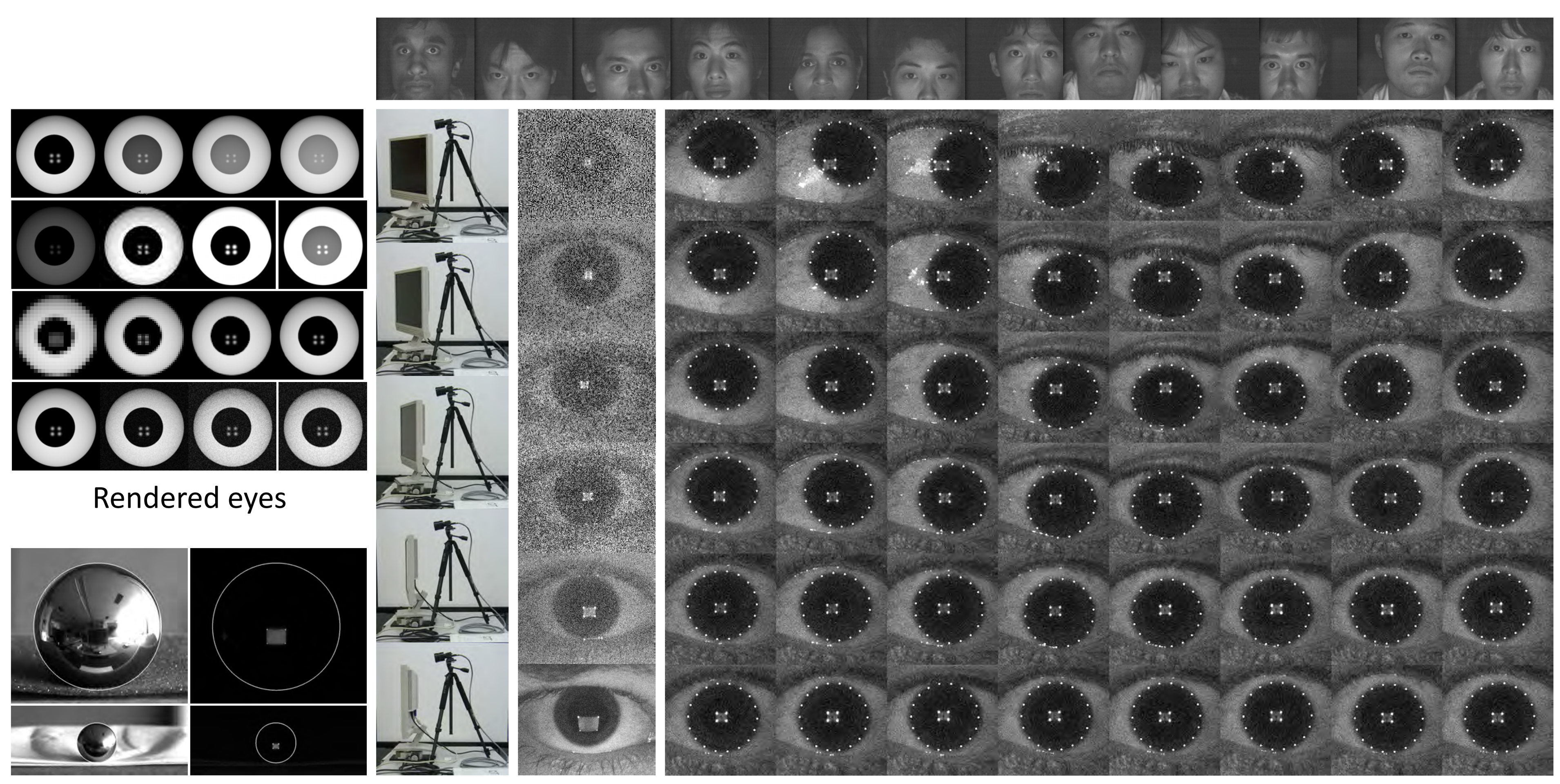
Display size | *Display planarity* | *Triangulation*



Result | Optimized result

(D) Comprehensive performance evaluation

1. Combination of eye pose estimation and display-camera calibration [FHB07] leads to large error
   - Influence of individual eye geometry (iris contour, corneal asphericity)
   - No influence of marker size, iris reflectivity, (standard) image resolution, noise (after blur)
2. Optimization enables large improvement
   - Error decreases considerably and converges
   - Error increases with distance and gaze angle, but is still acceptable
   - No statistical significance of eye condition (normal, near-sighted)
   - Ambiguity in circle pose estimation can be resolved
   - Improvements also achieved with spherical mirror calibration



Rendered eyes

Ground truth | Pose | Distance | Gaze angle

(E) Future Work

- Limitations (camera calibration, eye detection, environmental light, glasses)
- Display pattern (edges [SFW10], coded corners/edges, application content)
- Configuration (transparent screen with background camera, occluded mobile screen)

FUTURE DIRECTIONS

- More complex hardware (stereo camera, active IR LED illumination)
- Aspheric, individual eye model
- Eye pose estimation (active light)
- Feature matching (robust passive, fast active)

[FHB07] Francken et al. *Screen-camera calibration using a spherical mirror*. Proc. CRV 2007.
[JF07] Johnson & Fahrid. *Exposing digital forgeries through specular highlights on the eye.* Proc. IH 2007.
[NN06] Nishino & Nayar. *Corneal imaging system: Environment from eyes.* IJCV 70(1), 2006.
[NNT11] Nitschke et al. *Display-camera calibration using eye reflections and geometry constraints.* CVIU 115(6), 2011.
[SFW10] Schnieders et al. *Reconstruction of display and eyes from a single image.* Proc. CVPR 2010.
[TDM+03] Tsumura et al. *Estimating the directions to light sources using images of eye for reconstructing 3D human face.* Proc. IS&T/SID CIC 2003.