

# Corneal-Imaging Calibration for Optical See-Through Head-Mounted Displays

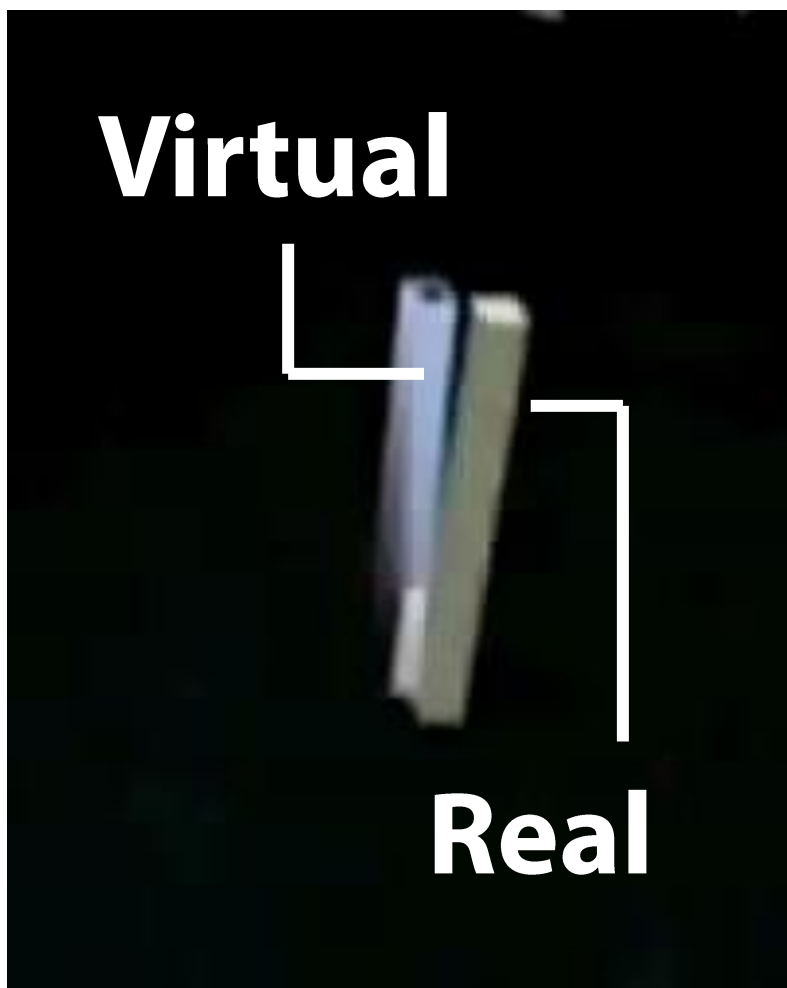
Alexander Plopski  
Kiyoshi Kiyokawa  
Haruo Takemura

Yuta Itoh  
Gudrun Klinker

Christian Nitschke

# Spatial Consistency of OST-HMDs

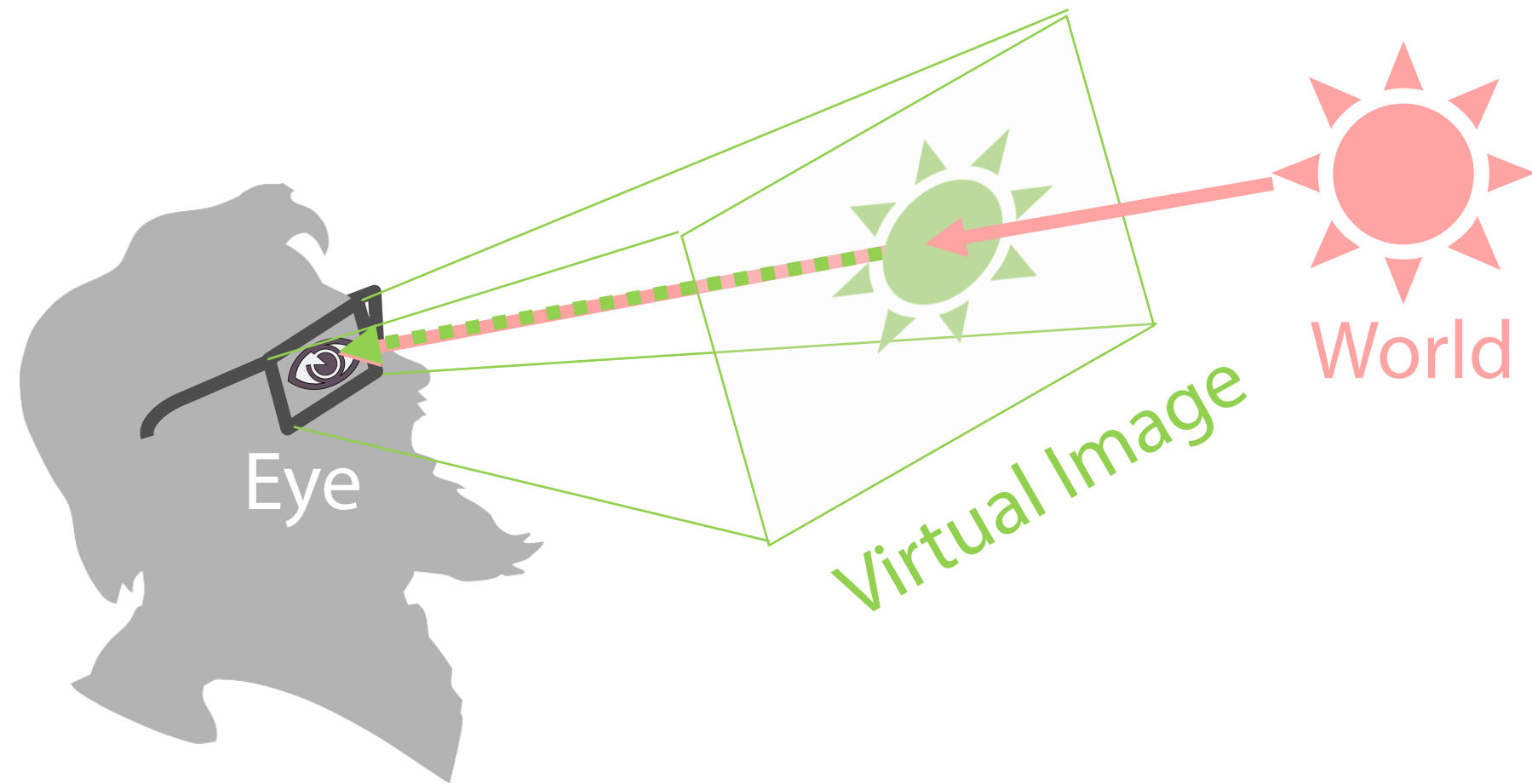
Not consistent



Consistent

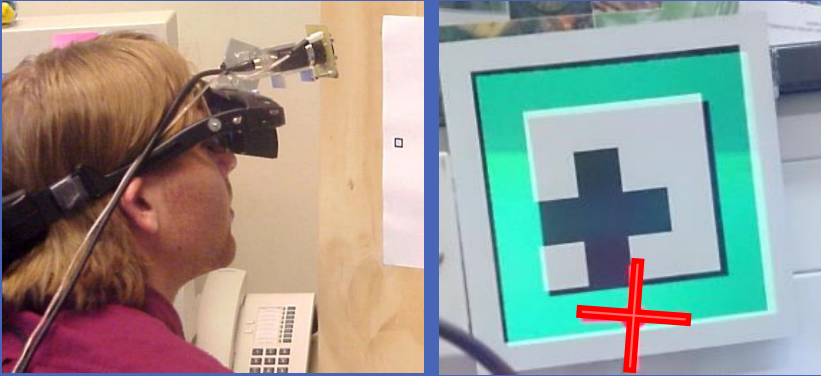


# Eye and HMD Calibration



# Manual Method

user interaction required<sup>6</sup>

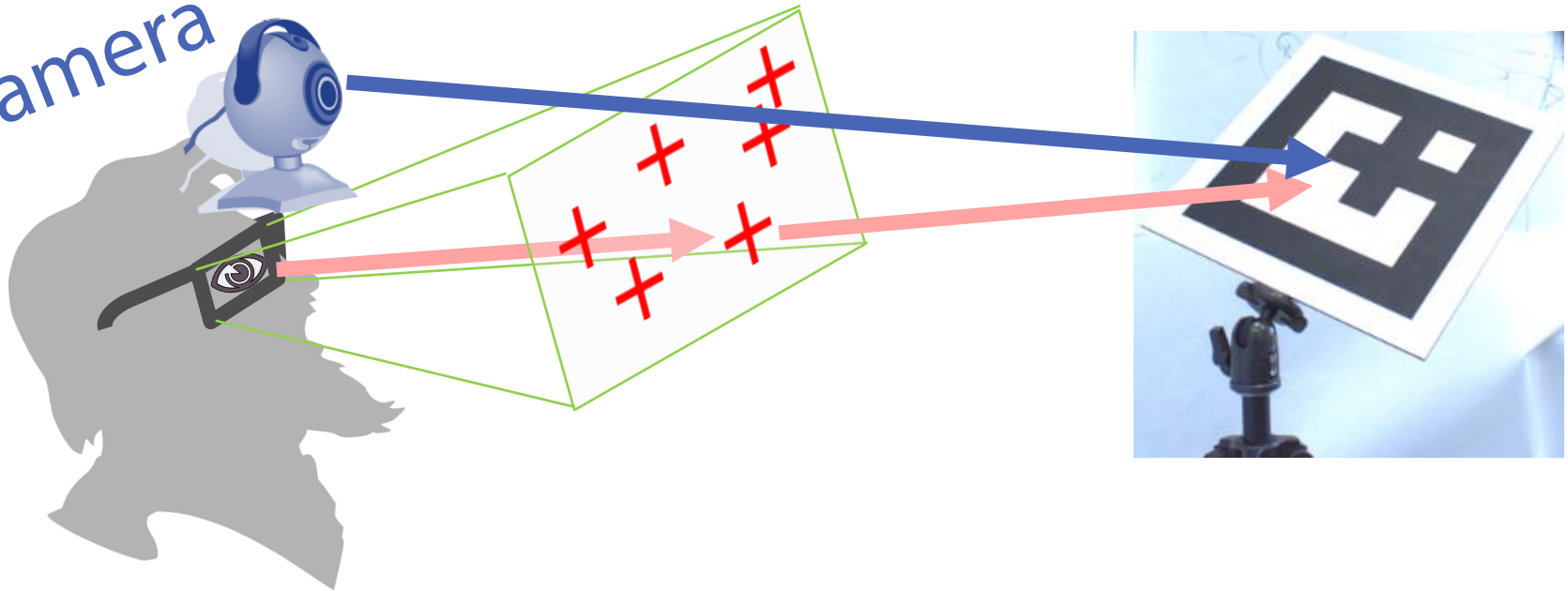


SPAAM

Single Point Active  
Alignment Method

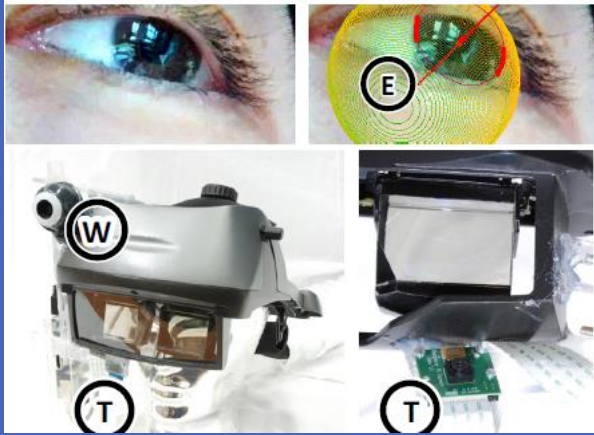
[Tuceryan '00] [Genc '02]

Camera



# Automated Method interaction-free

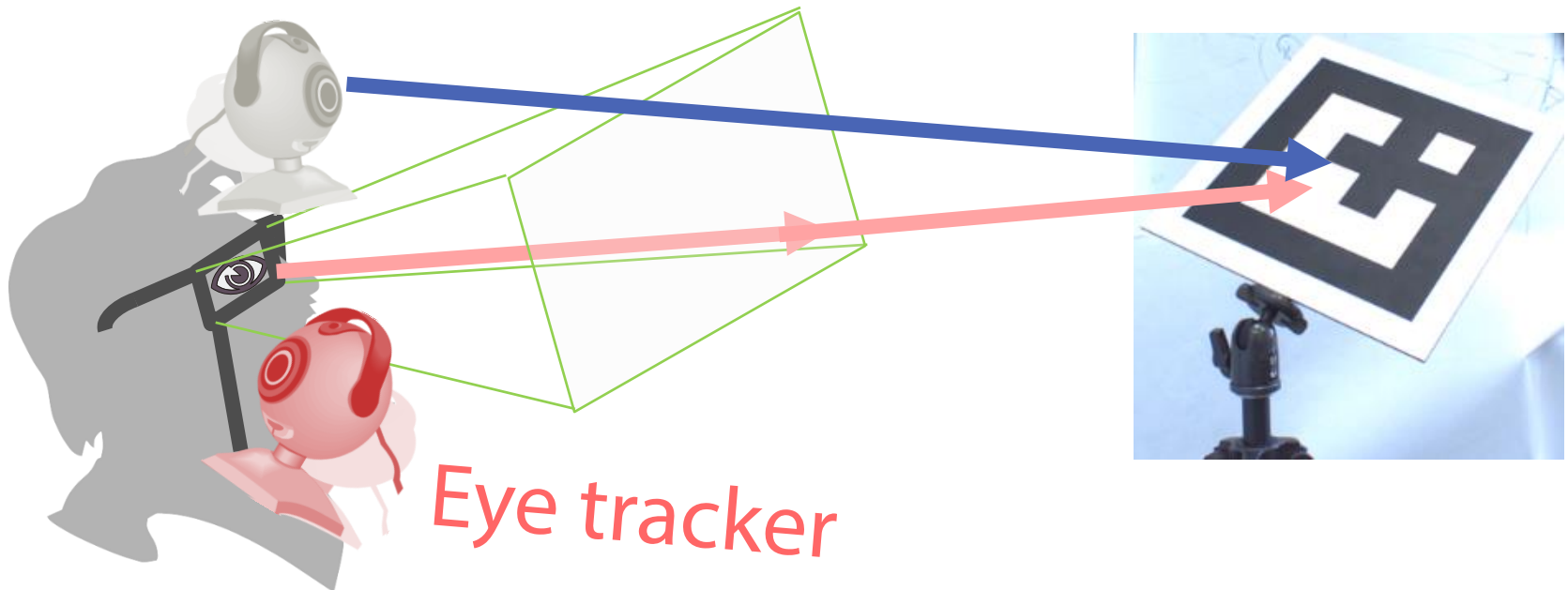
7



~~INDICA~~

INteraction-free

DI splay CA libration [Itoh '14]



World point (3D)

**P**

World Camera

**W**

Screen **S**

$R_{WS}, t_{WS}$

$R_{WT}, t_{WT}$

$R_{SE}, t_{SE}$

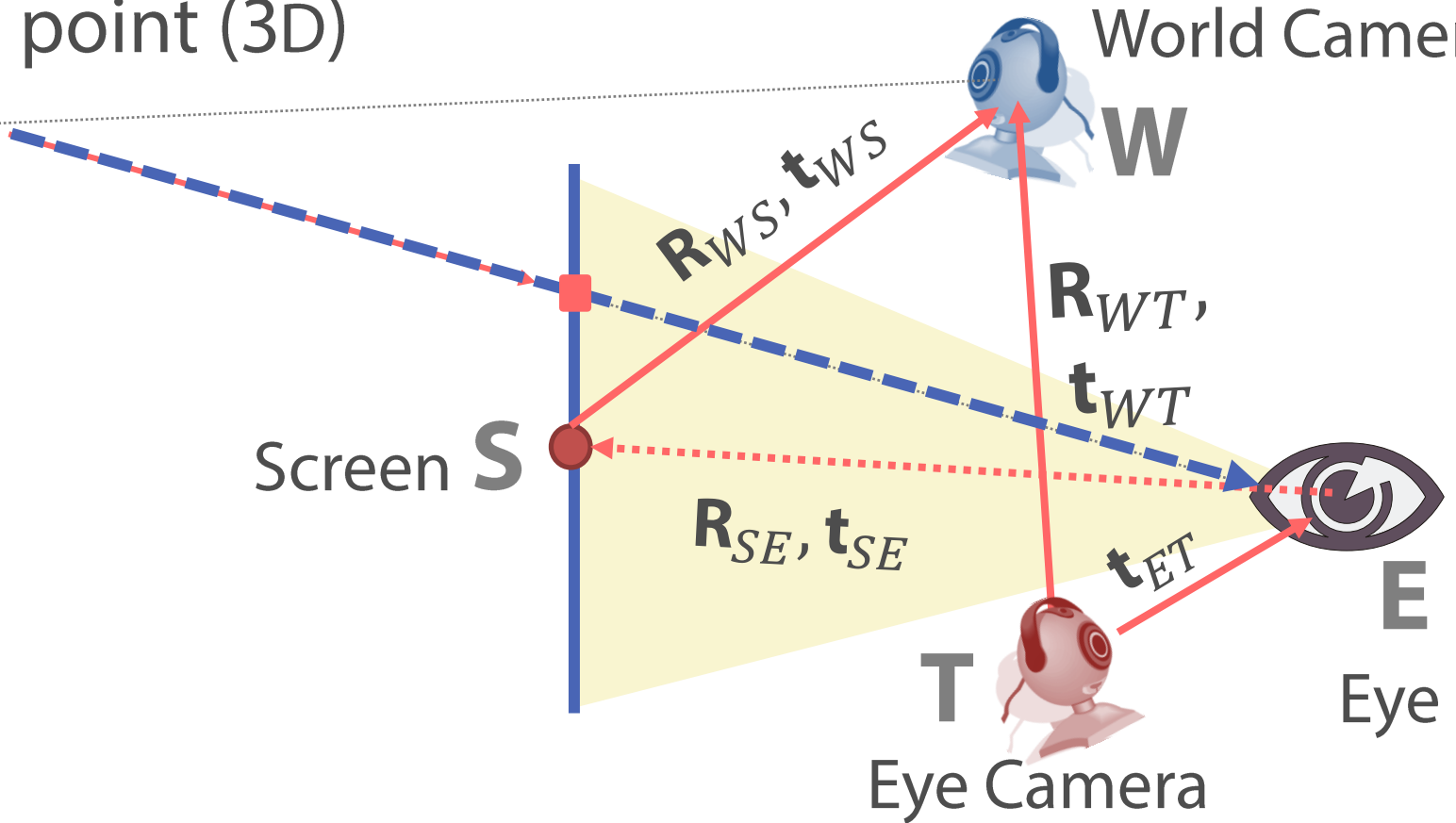
$t_{ET}$

**T**

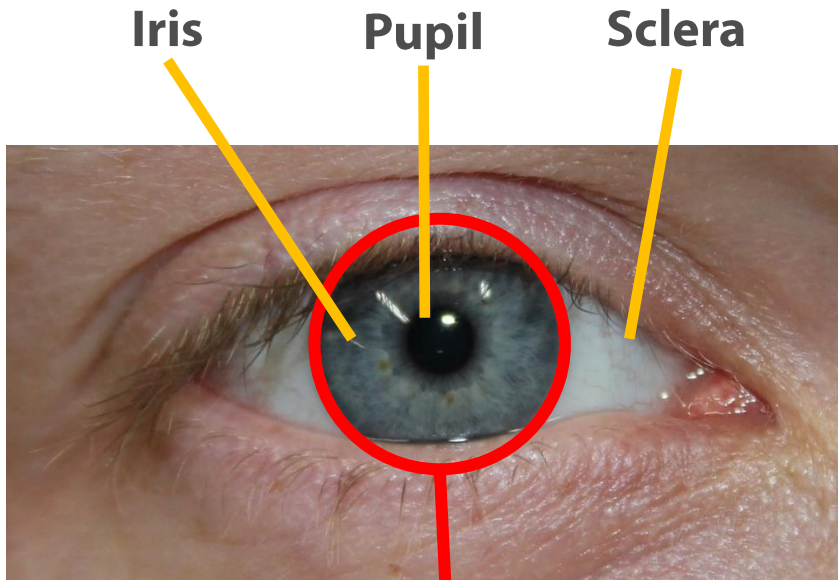
Eye Camera

**E**

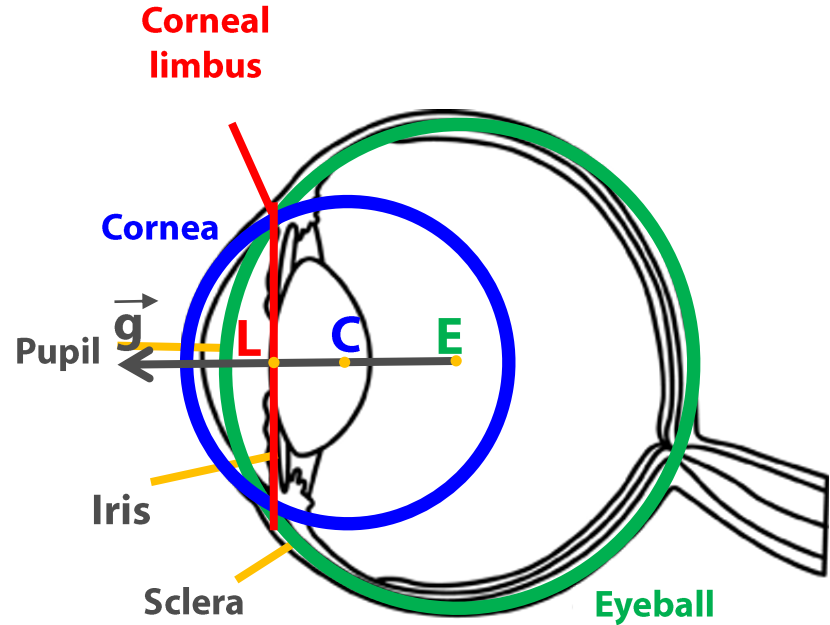
Eye



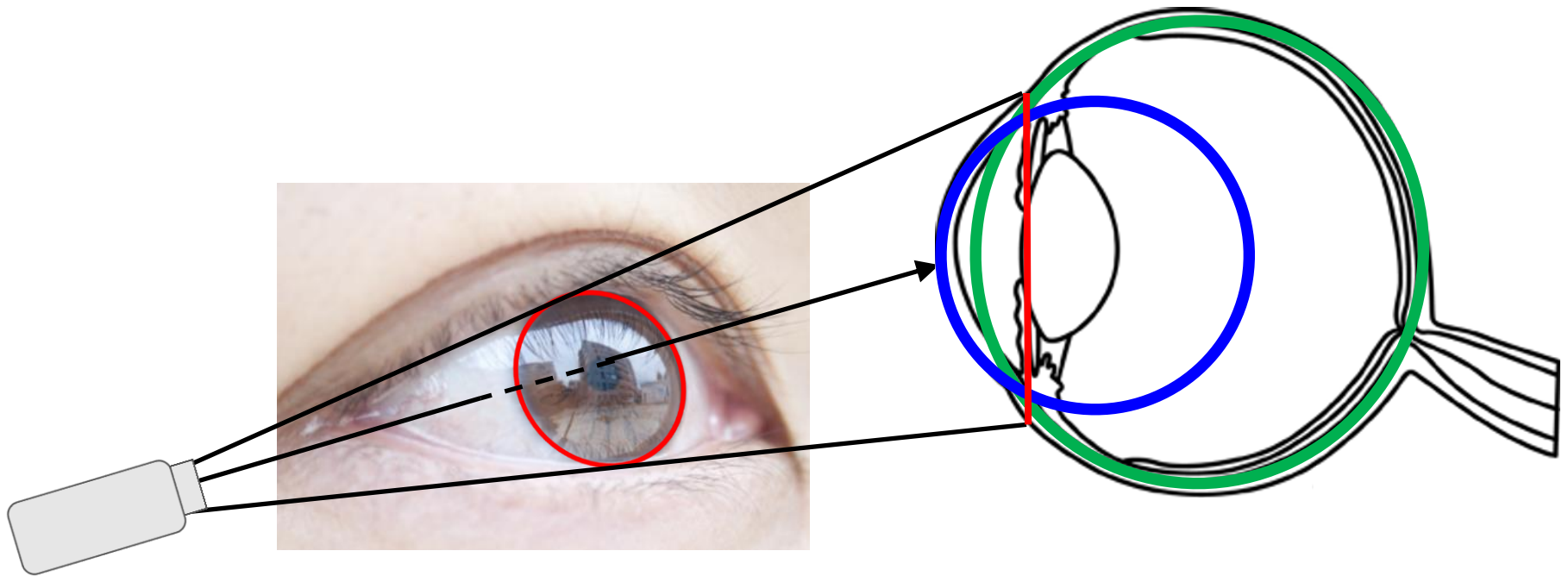
# Eye Model



**Corneal  
limbus**



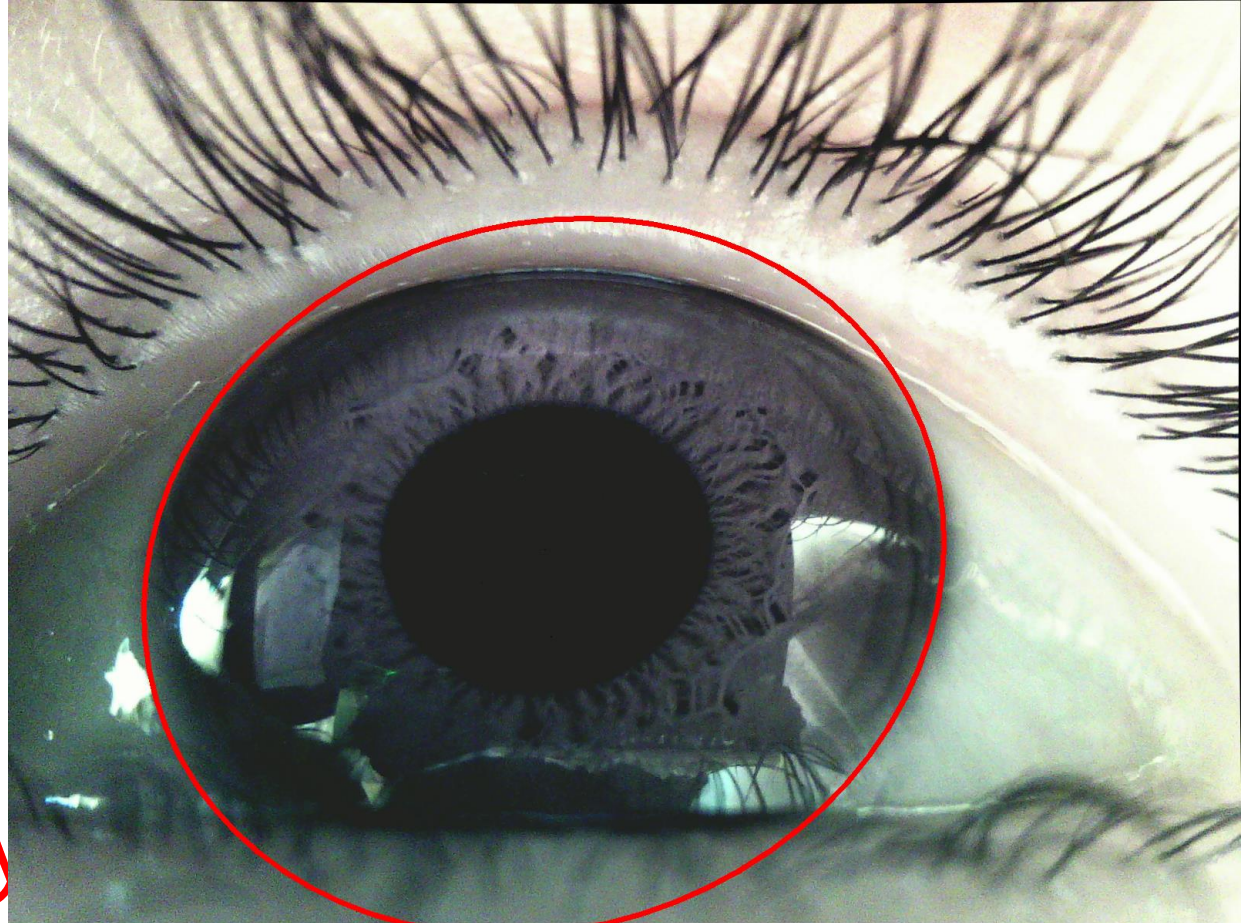
# Limbus-based Estimation



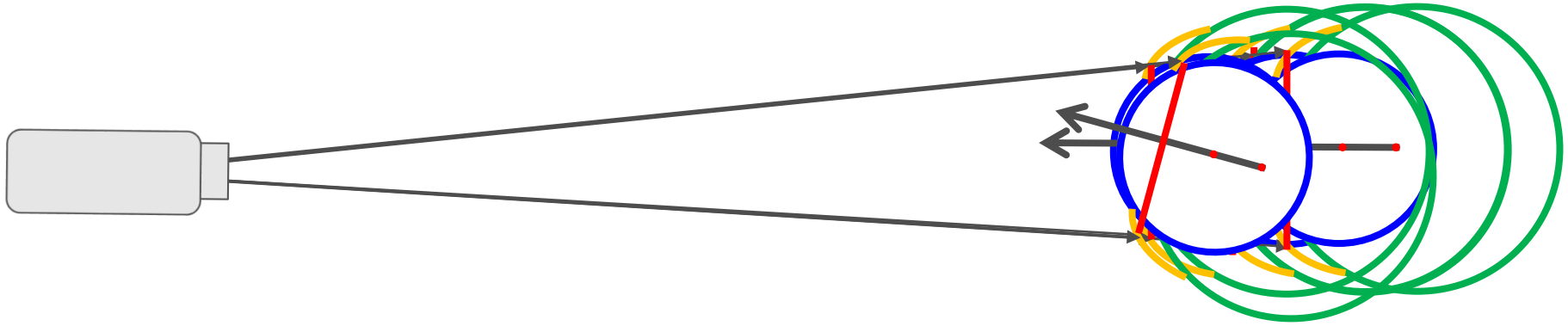


# Problems

- Occlusion
- Transition
- Highlights
- Contrast
- Do we really



# Eye Pose from Limbus Detection



Incorrect Eye Pose results in misalignment of virtual content

# Can we do better?

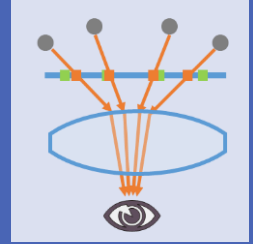
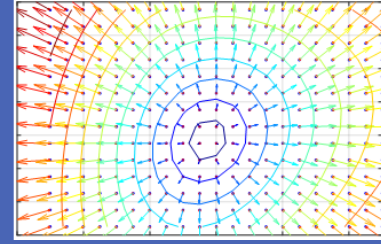
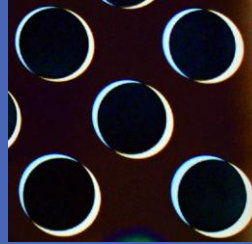
# Why no Infra-Red Light?

- Complicated calibration
- Additional hardware
- Problems in environments with strong illumination
- Long-term impact is unknown

# Summary of our 3 talks



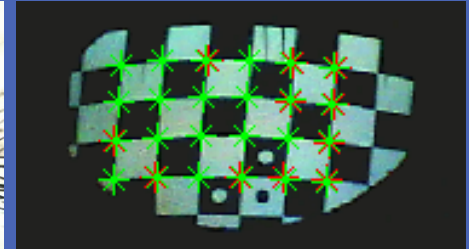
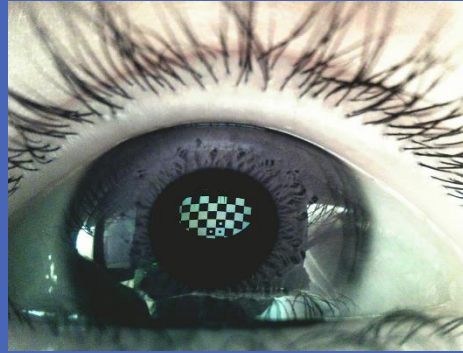
## 1. Better *HMD* model



By Yuta



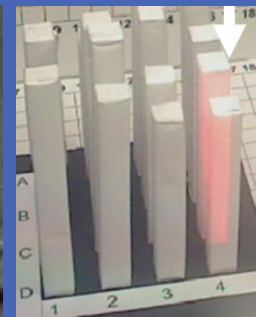
## 2. Better *Eye* position



By Alex



## 3. Formal *User* study

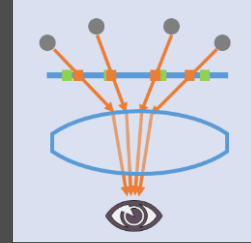
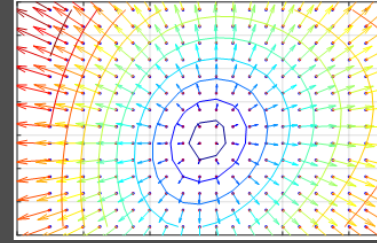
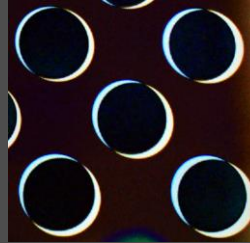


By Kenny

# Summary of our 3 talks



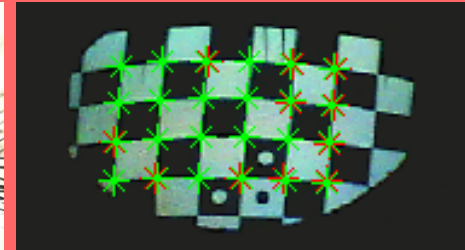
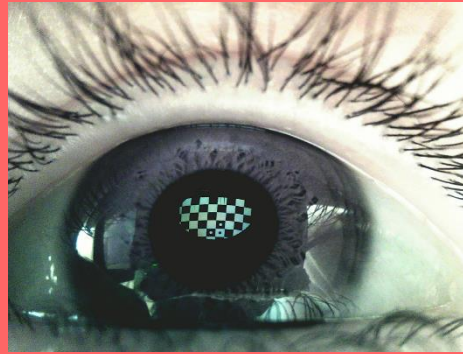
## 1. Better *HMD* model



By Yuta



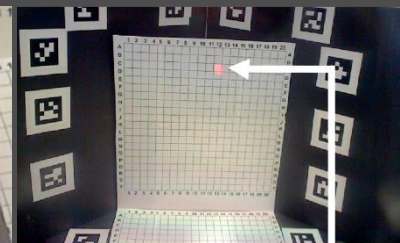
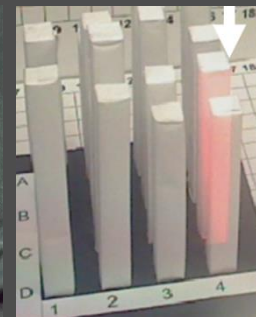
## 2. Better *Eye* position



By Alex

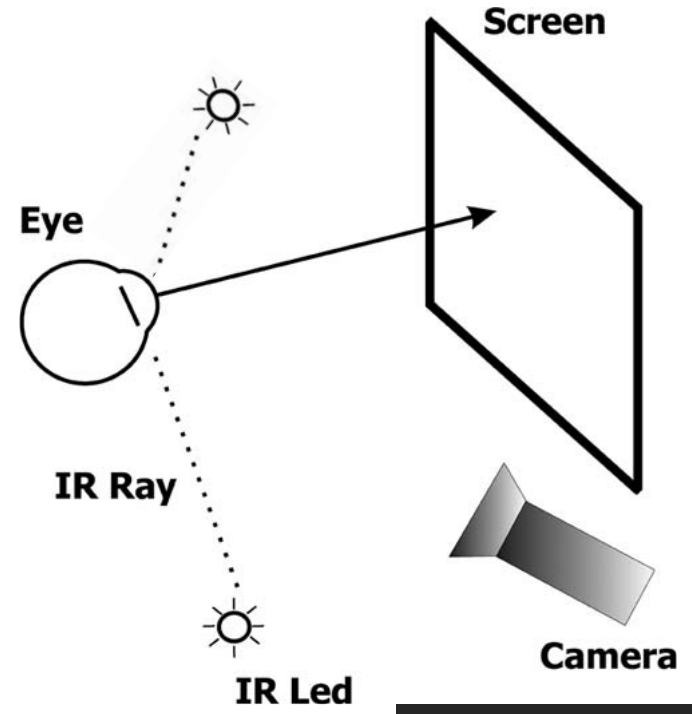


## 3. Formal *User* study



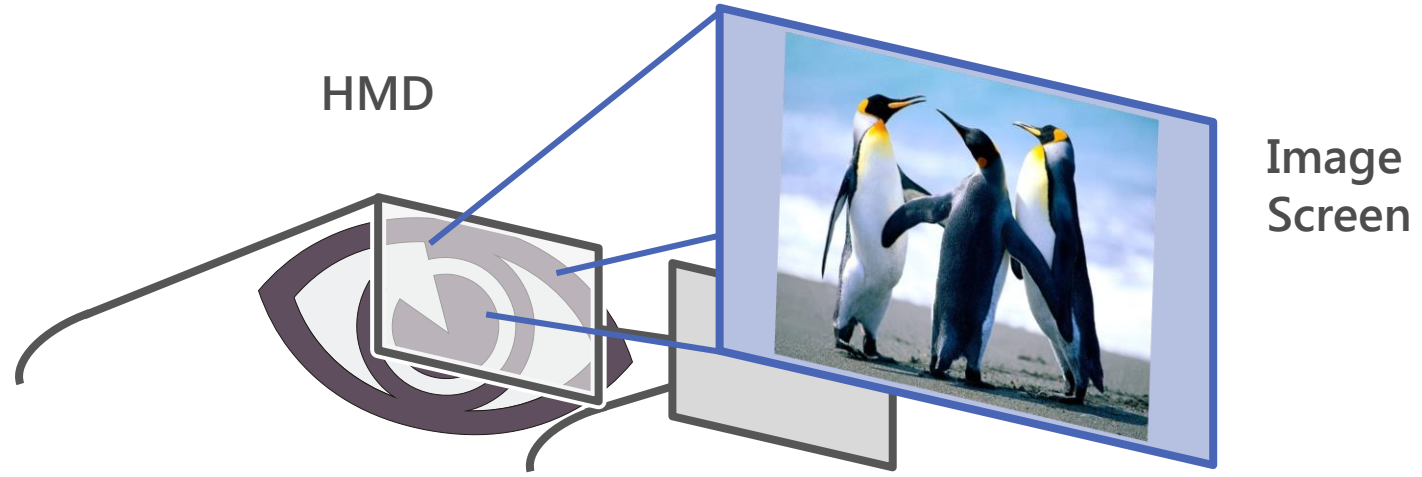
By Kenny

# Pupil-Center-Cornea-Reflection (PCCR)

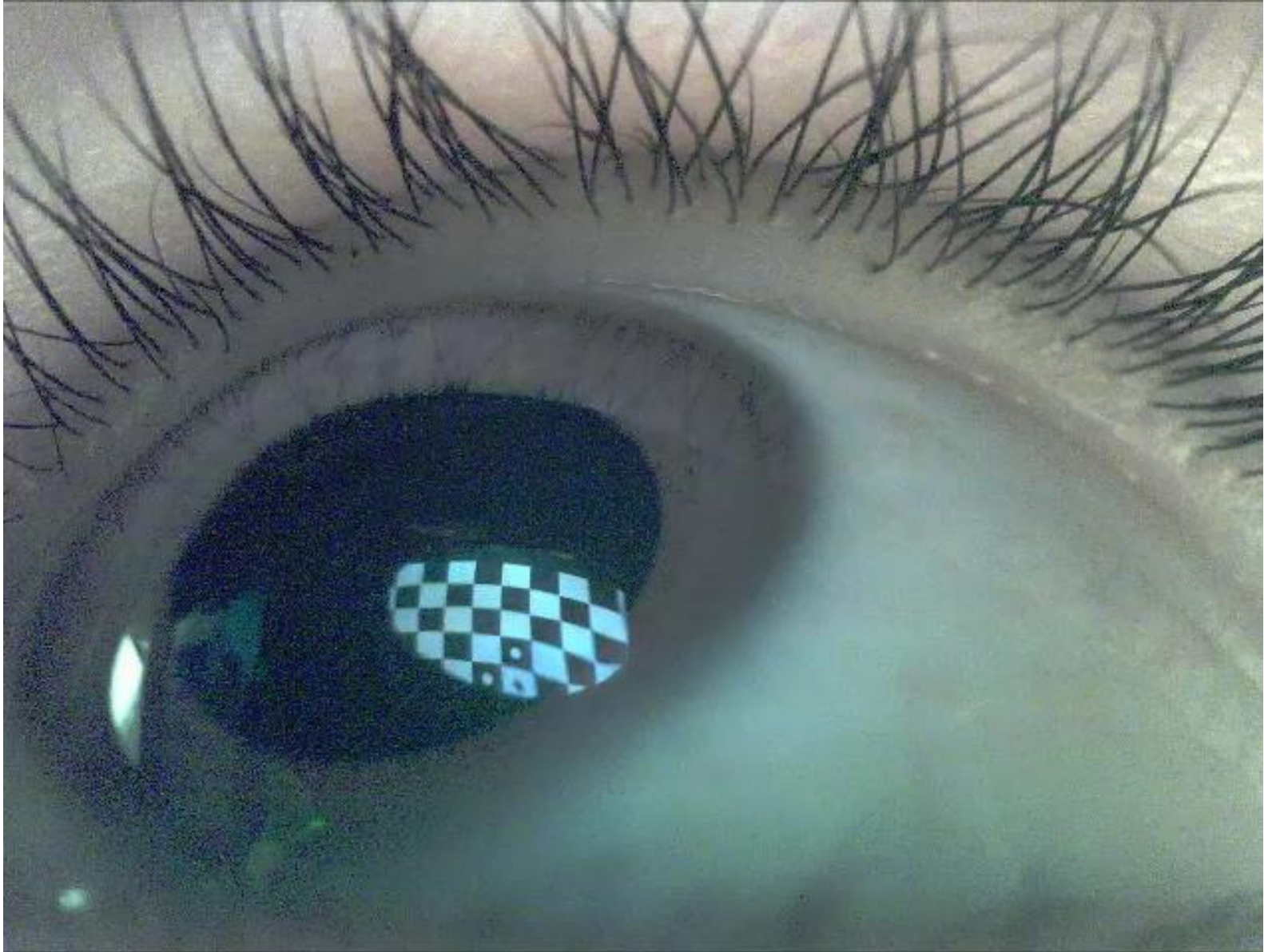


Villanueva '08

# HMD Screen resembles a plane



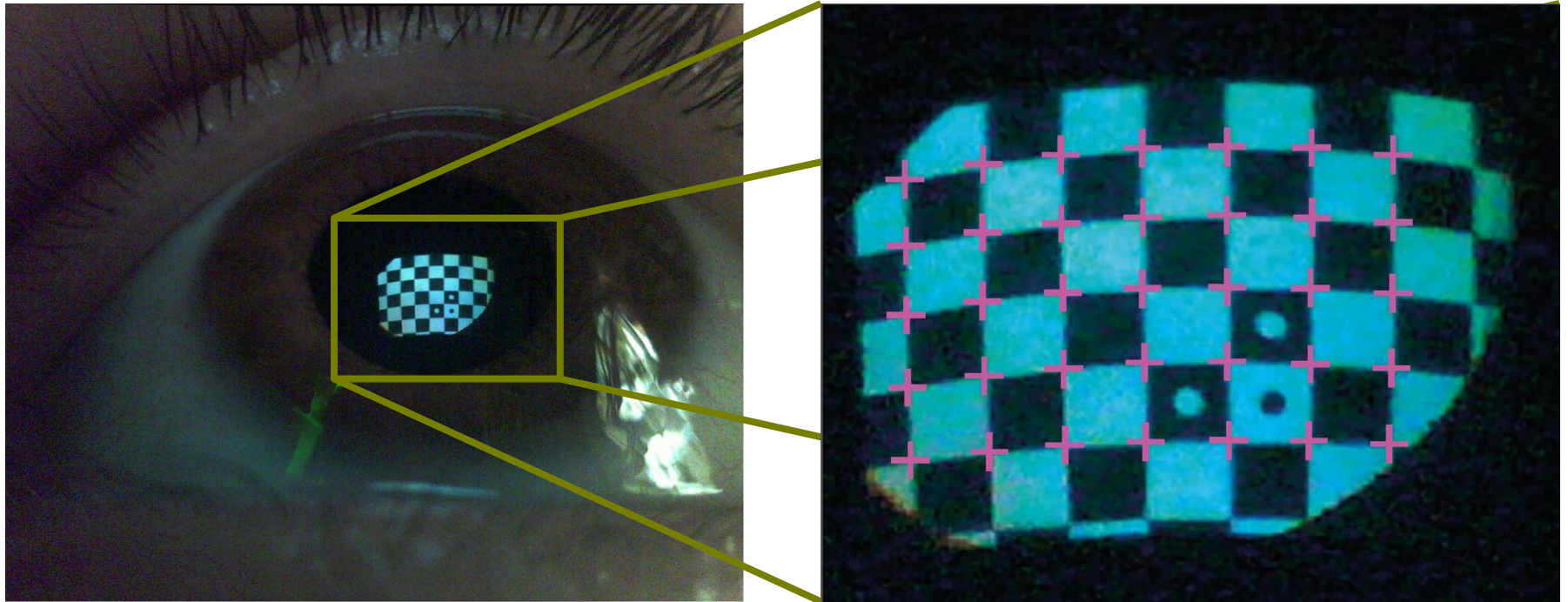
# Corneal Reflection



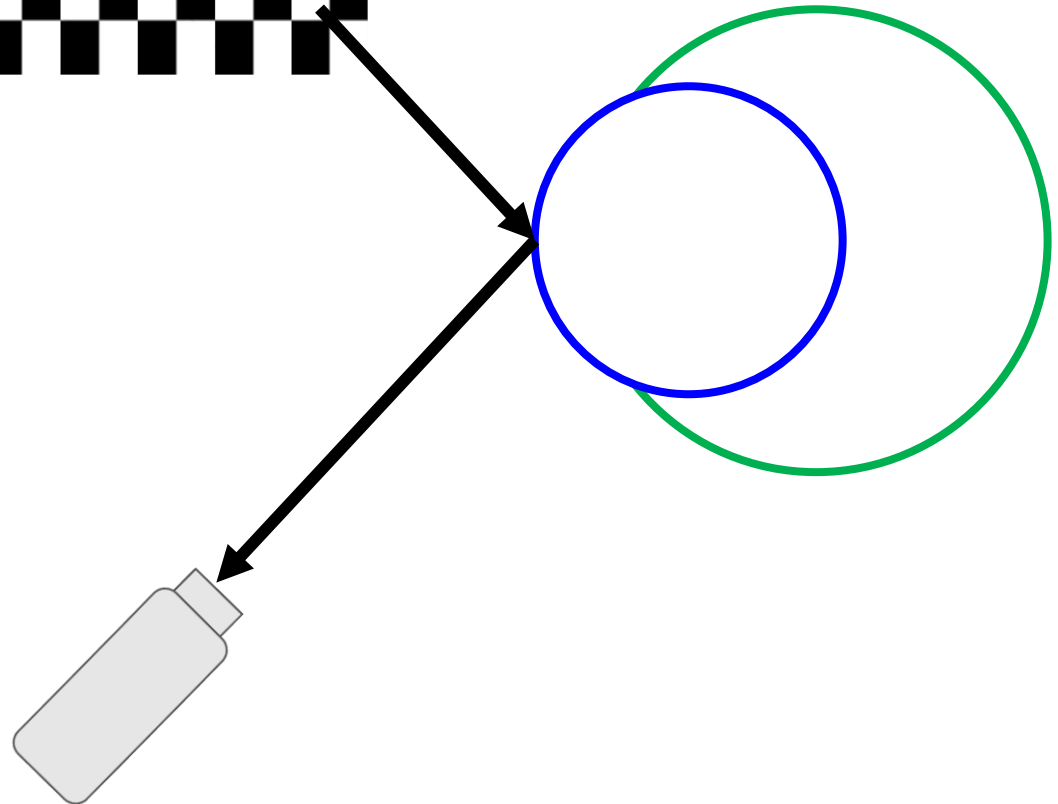
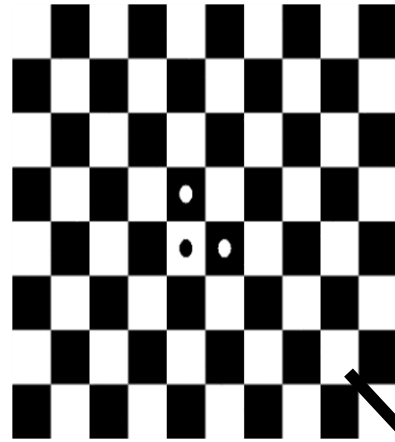


# Detected Checkerboard in 2D

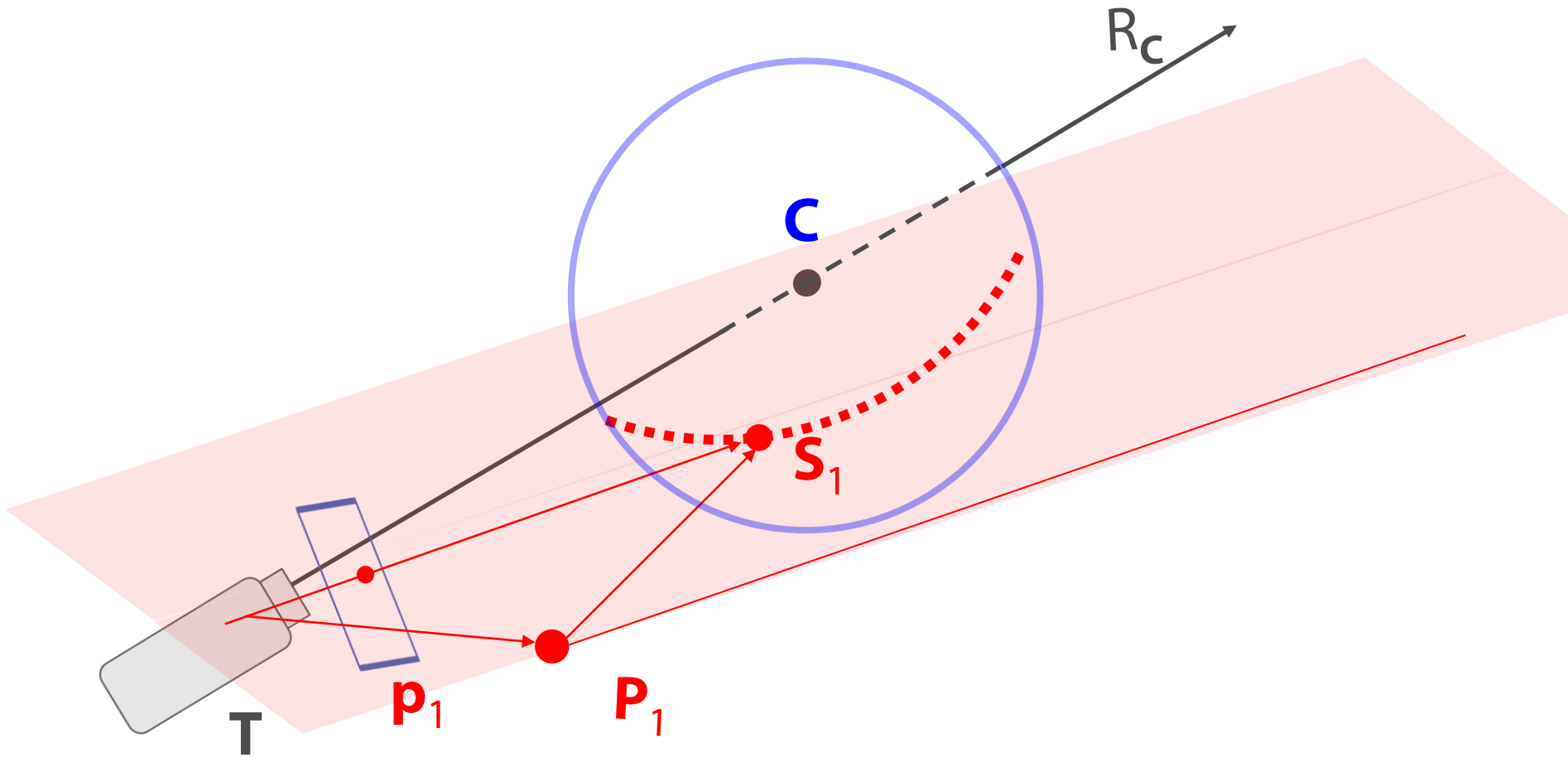
Detected grid corners



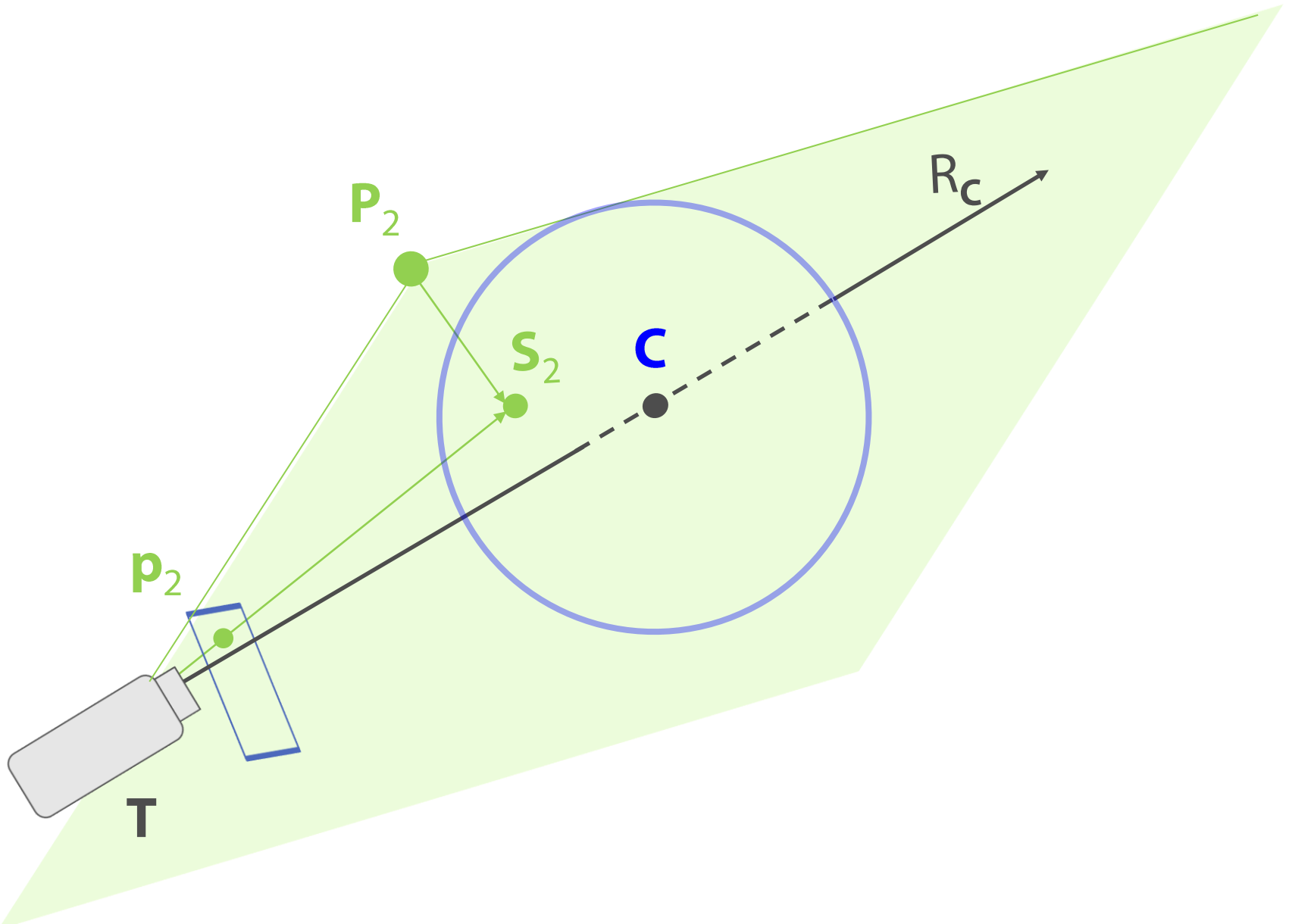
# Scene Reflection in the Eye



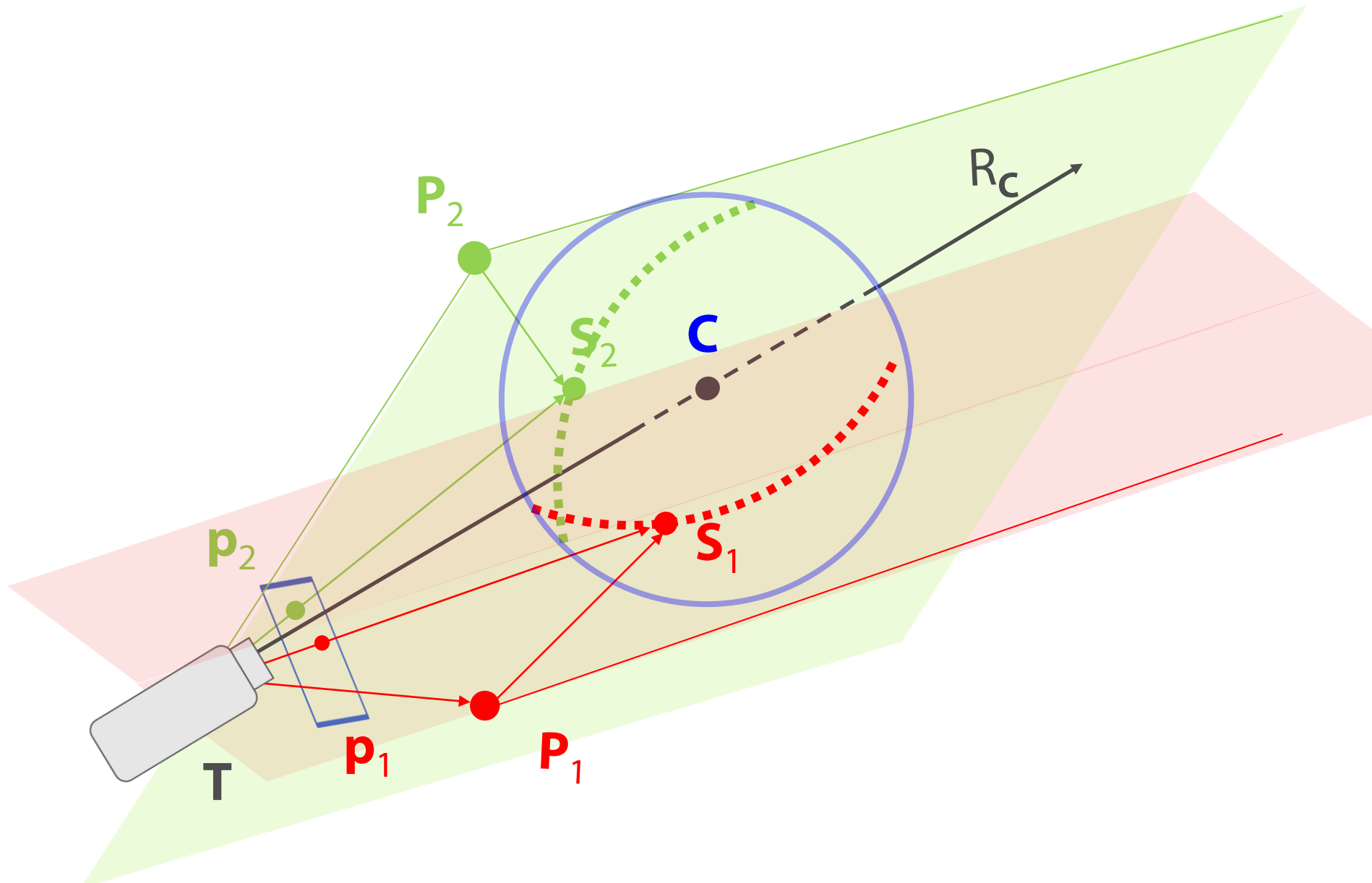
# Cornea Position Estimation



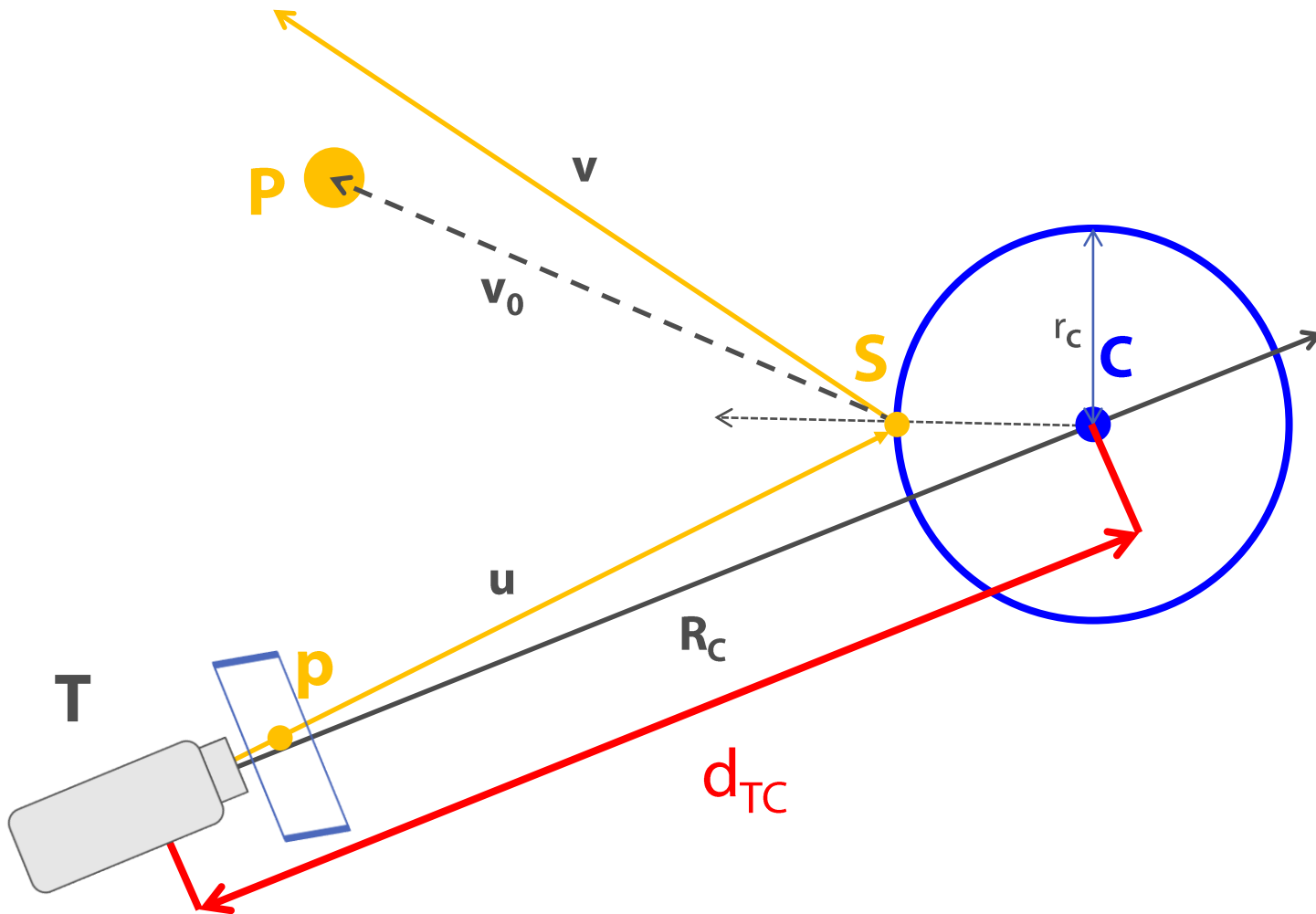
# Cornea Position Estimation



# Cornea Position Estimation



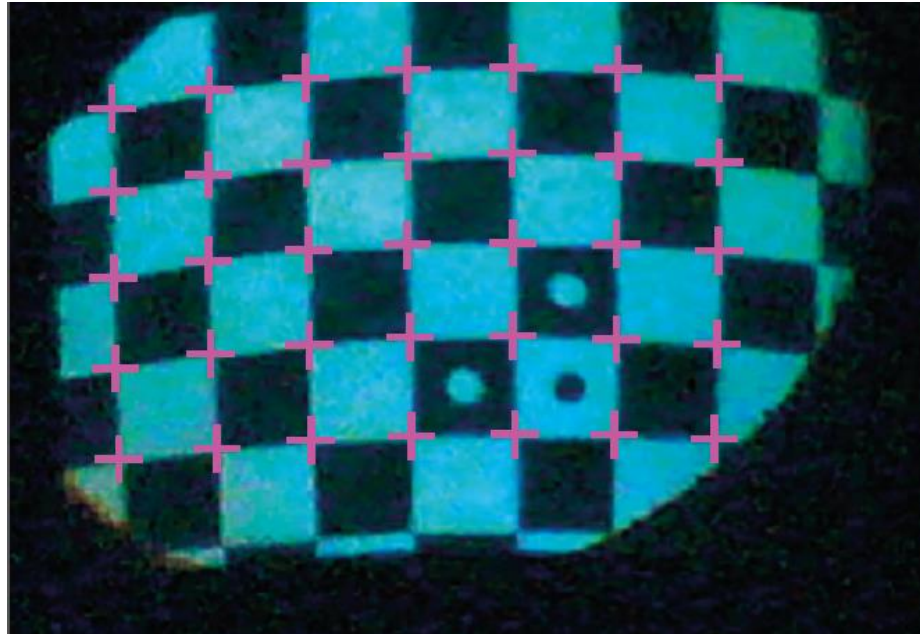
# Cornea Position Estimation



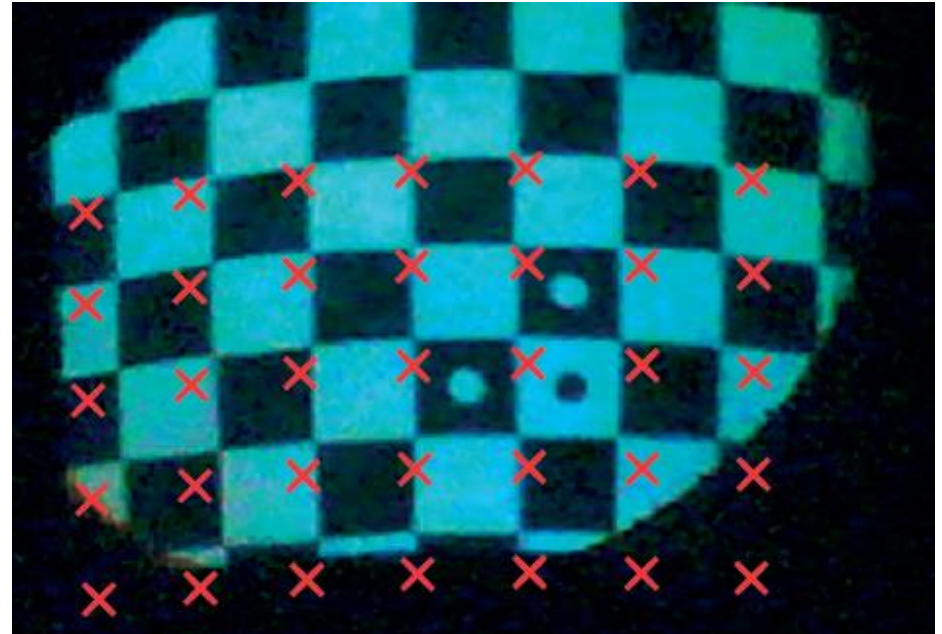
$v \times v_0 = 0$  is 6th degree polynomial in  $d_{TC}$

# Reprojected Points (3D $\rightarrow$ 2D)

Detected grid corners

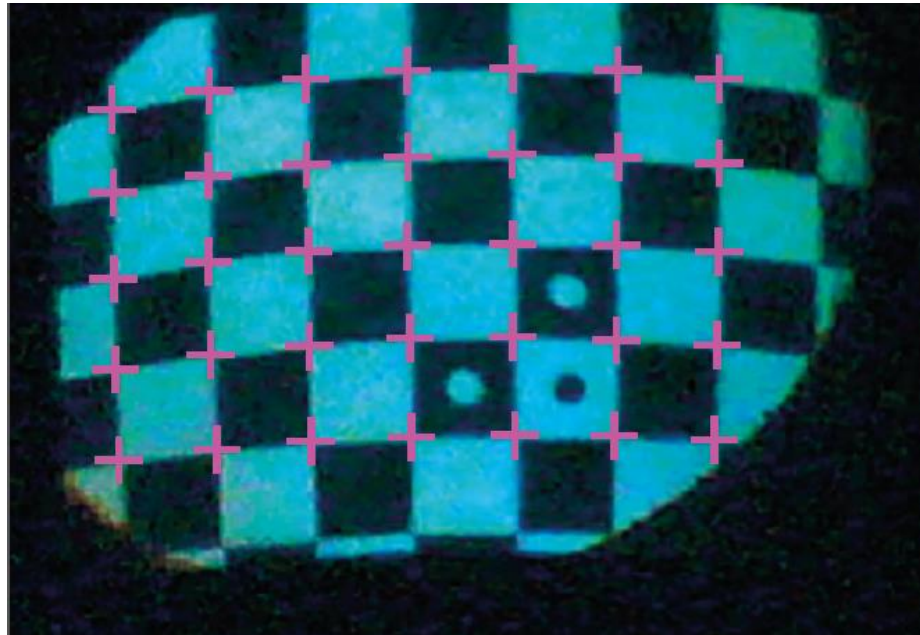


Limbus-based reprojection

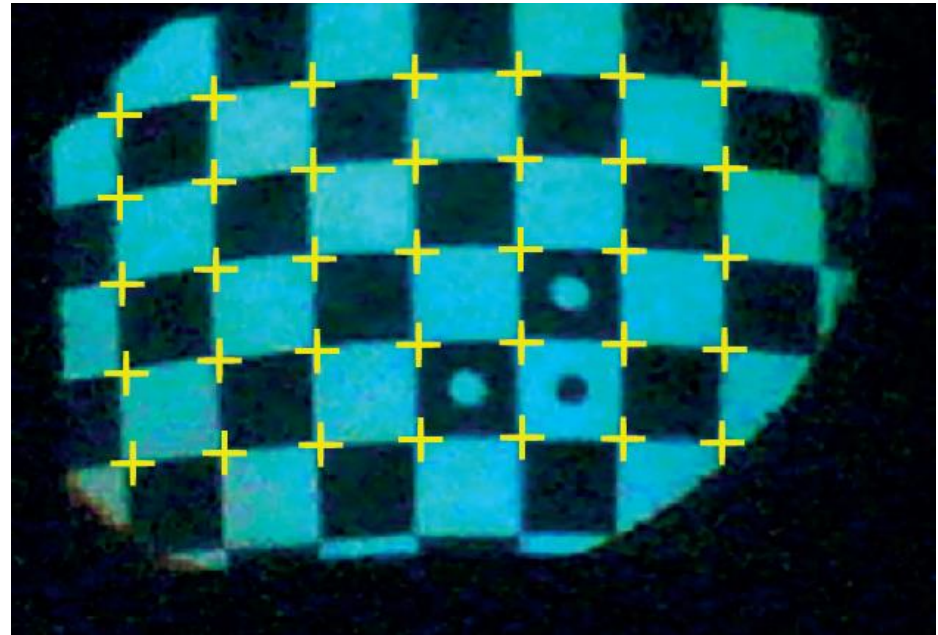


# Reprojected Points (3D $\rightarrow$ 2D)

Detected grid corners



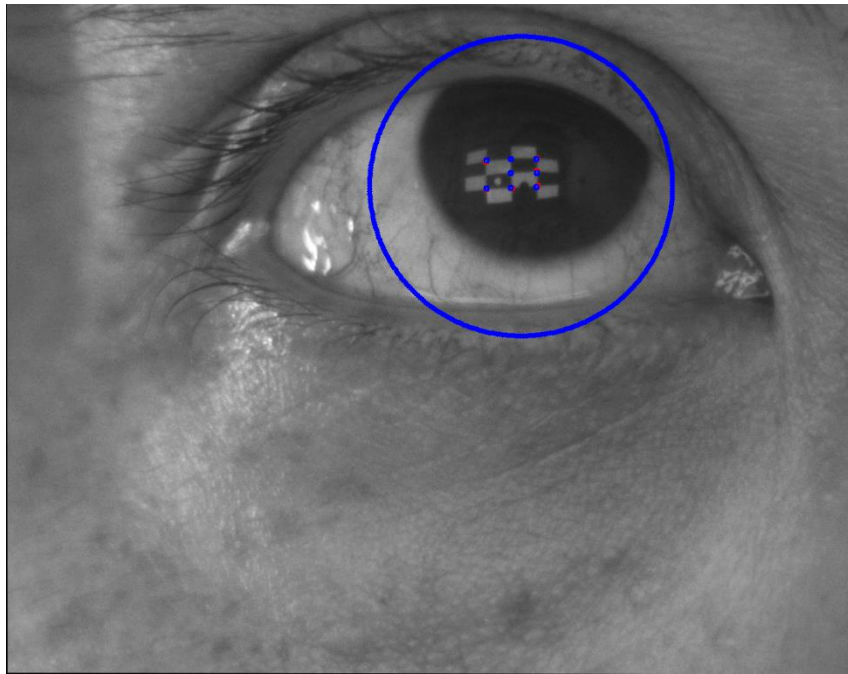
CIC-based reprojection



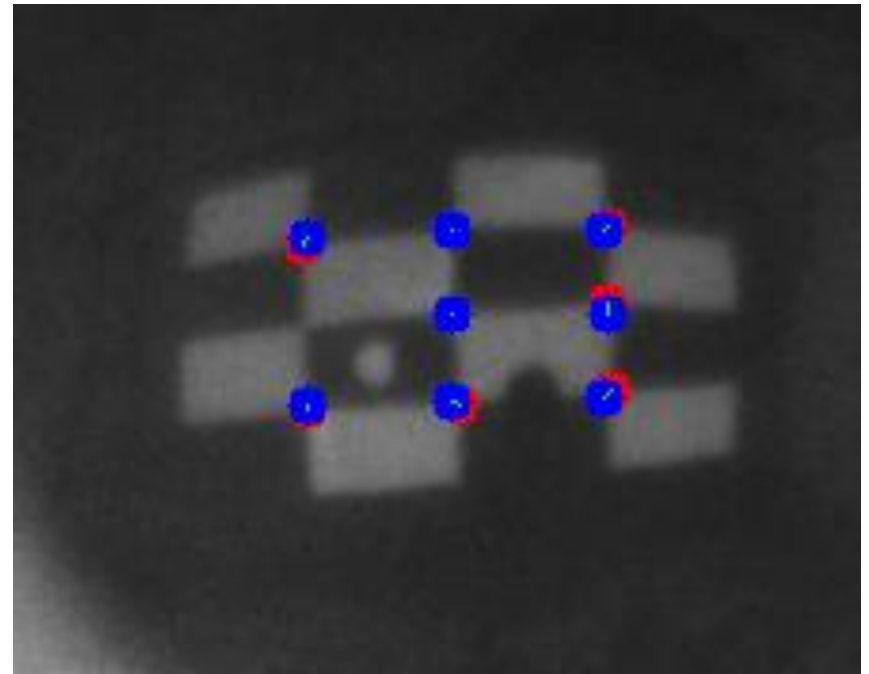


# Reprojected Points (3D $\rightarrow$ 2D)

Original Image

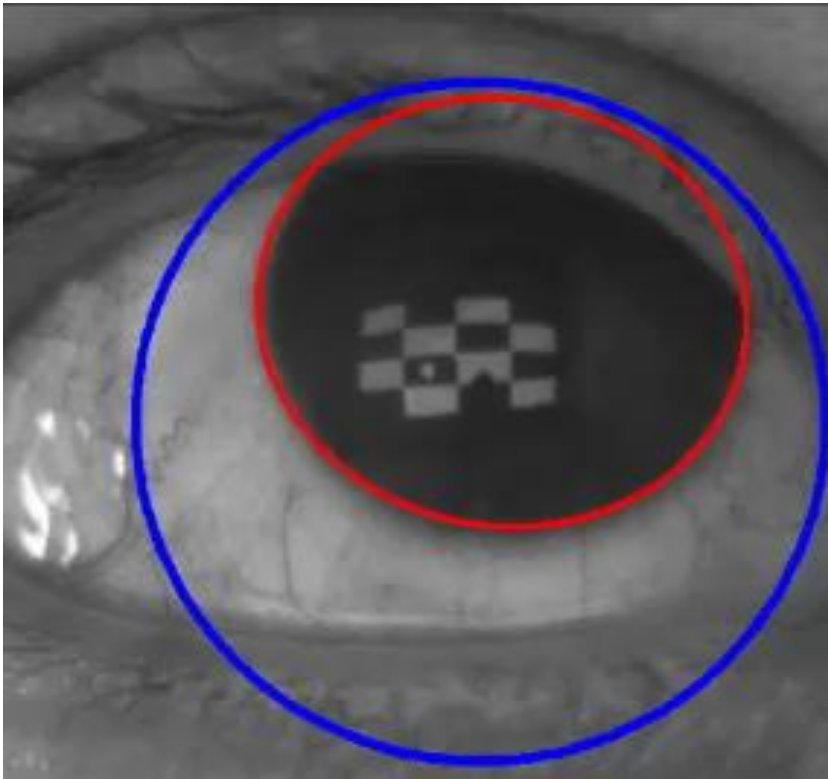


Detected and Projected  
Corners

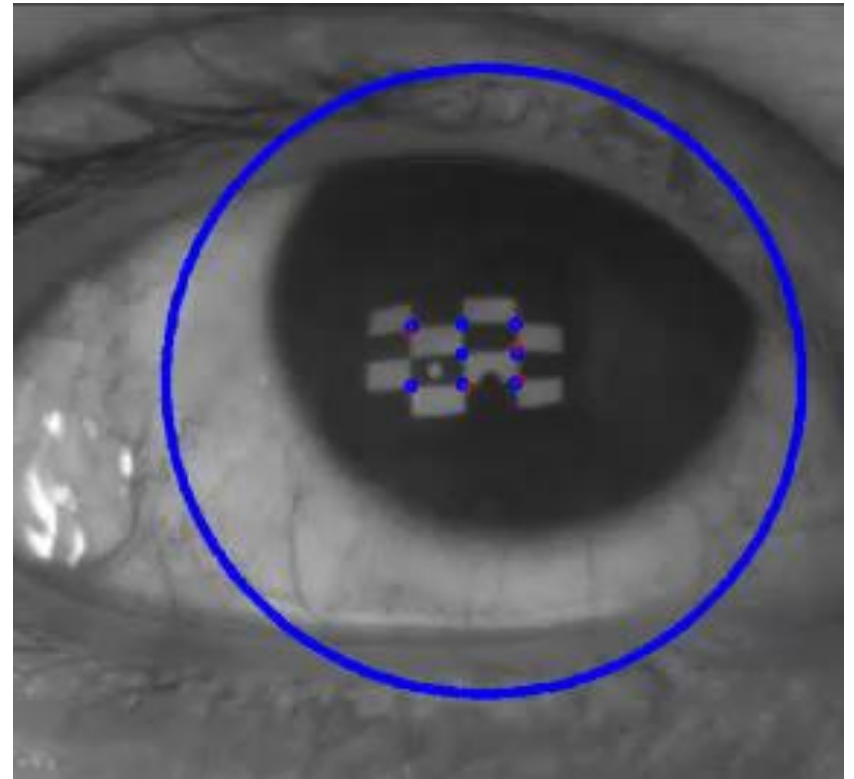


# Estimated Cornea Position

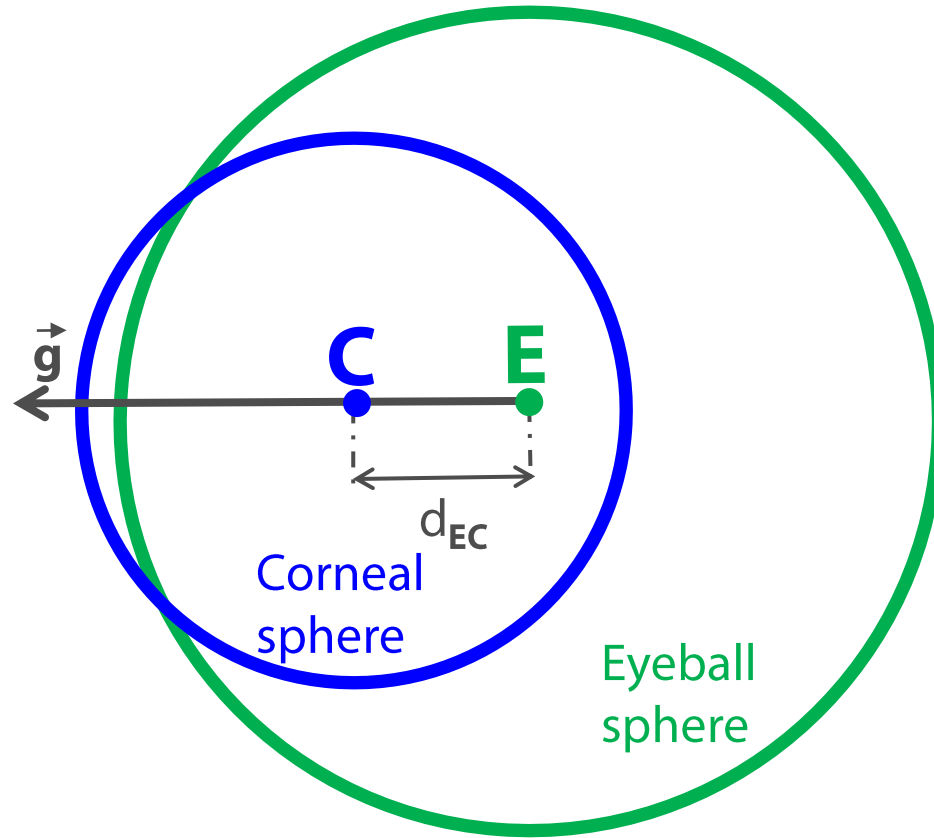
Limbus



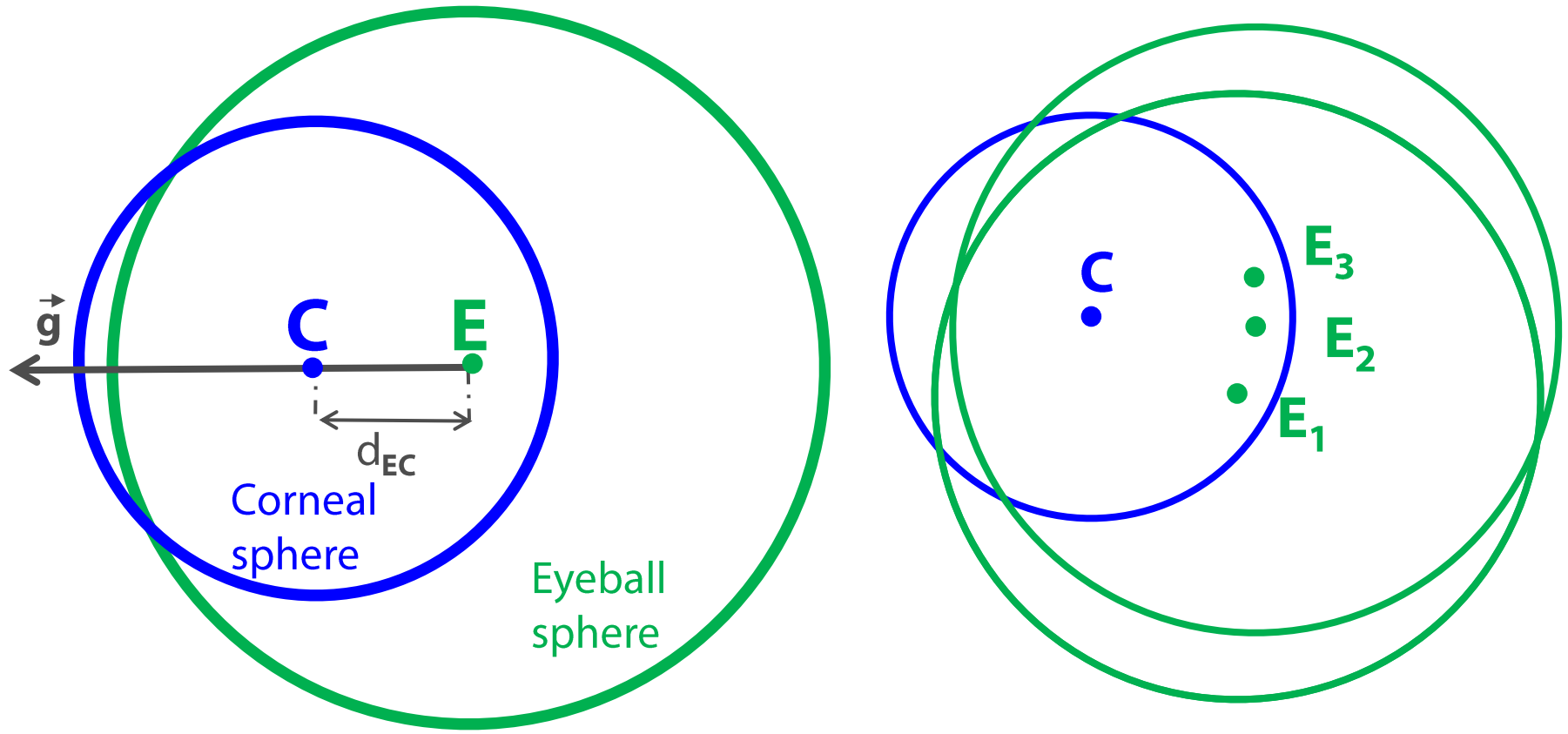
CIC



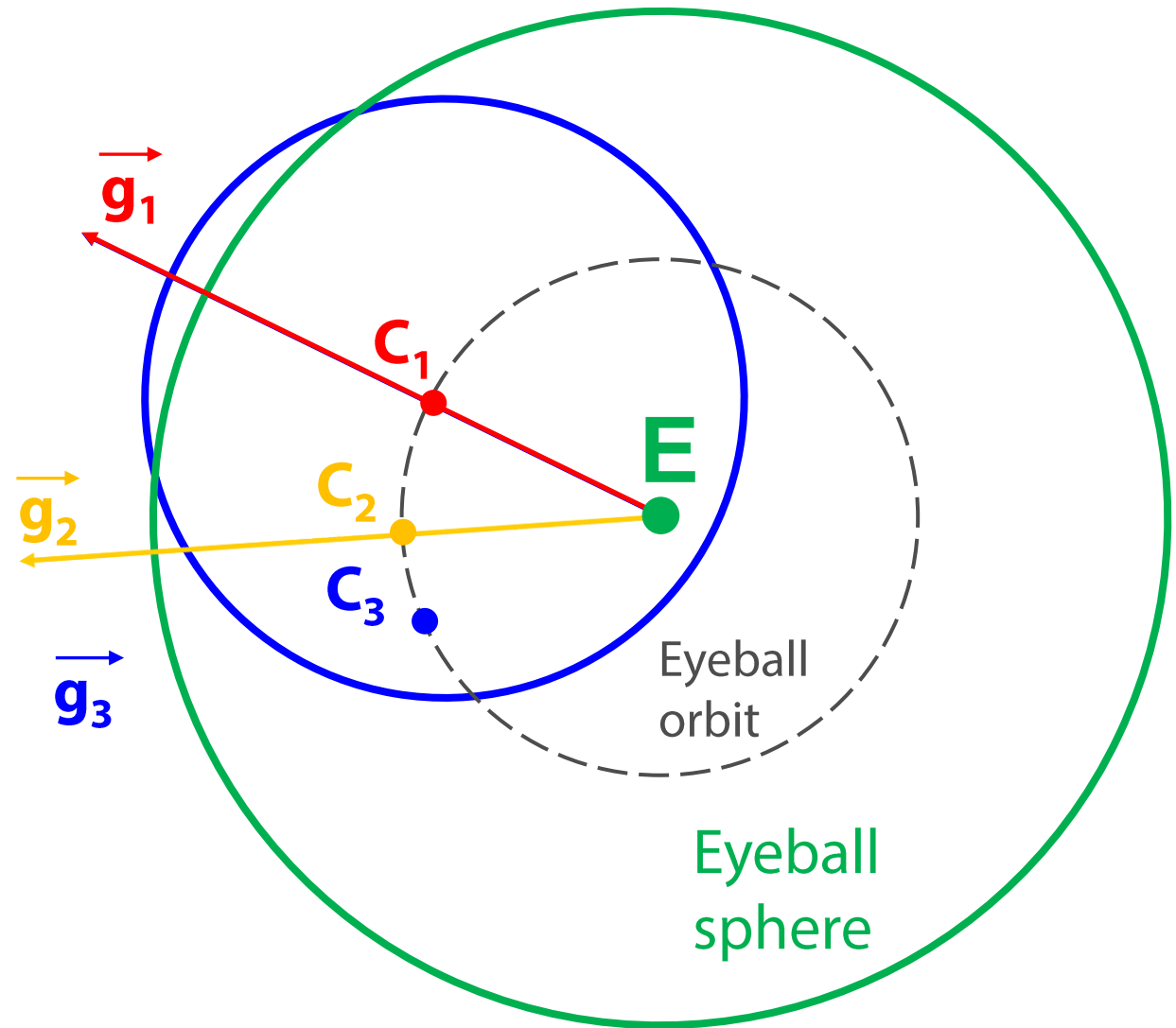
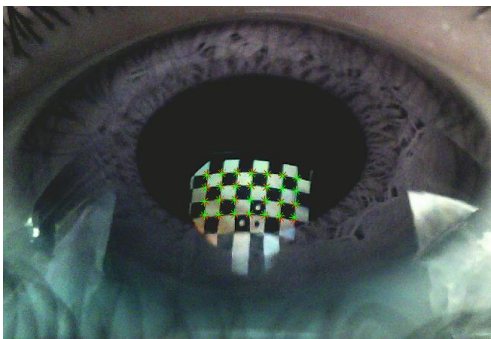
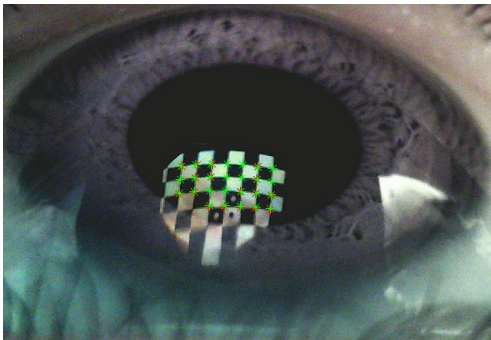
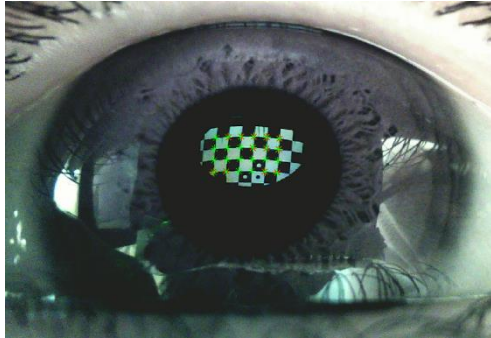
# Eye Model



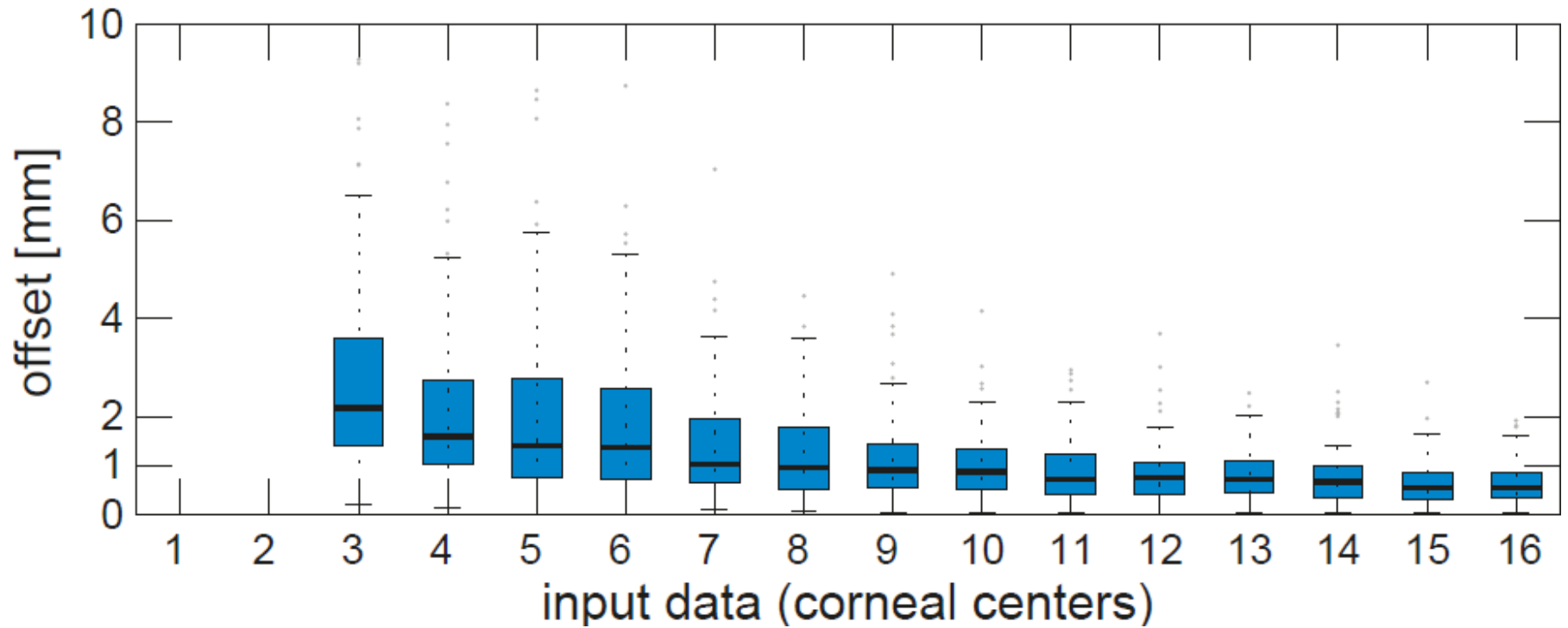
# Eye Position Estimation



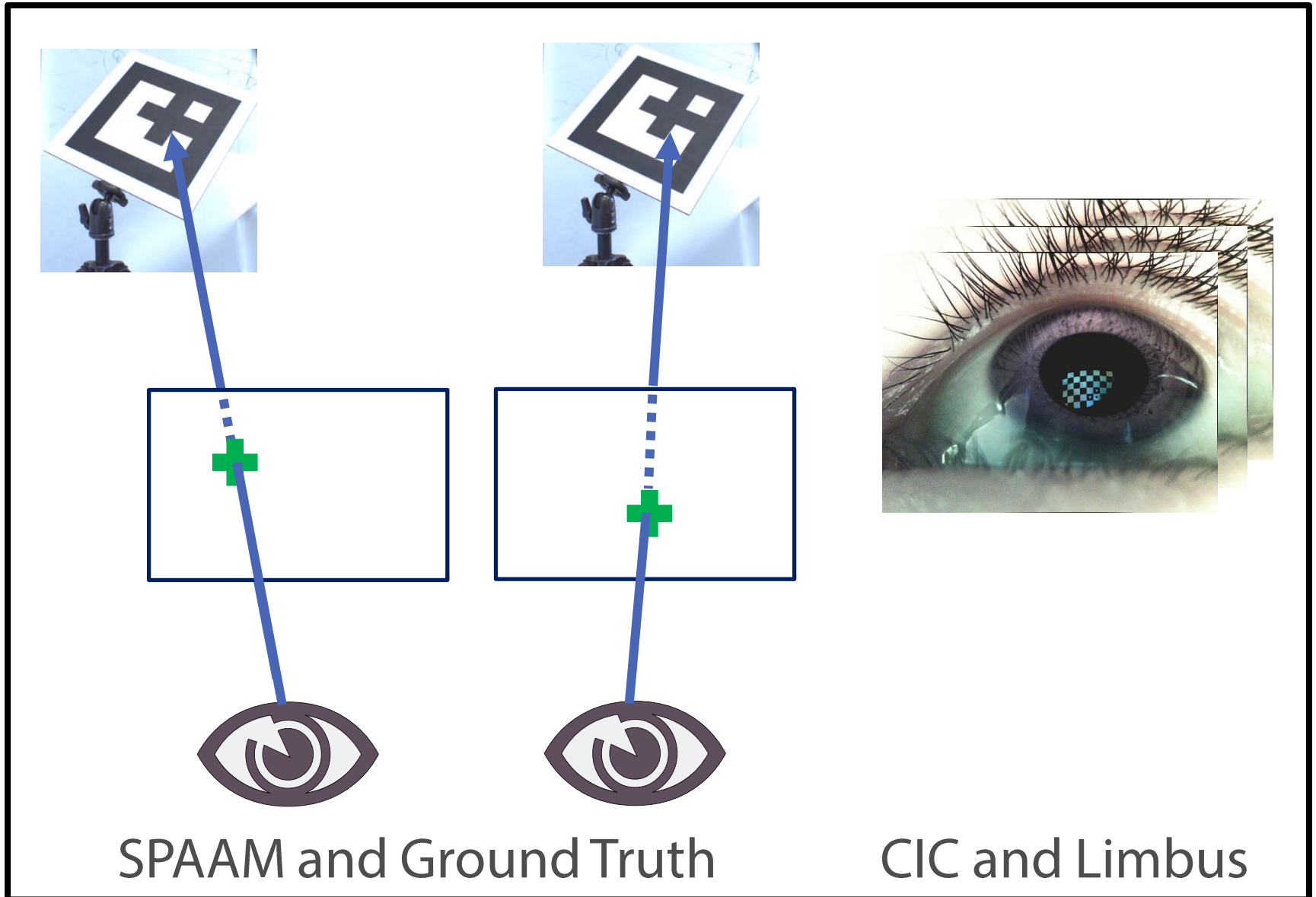
# Eye Position Estimation



# Eye Position Stability



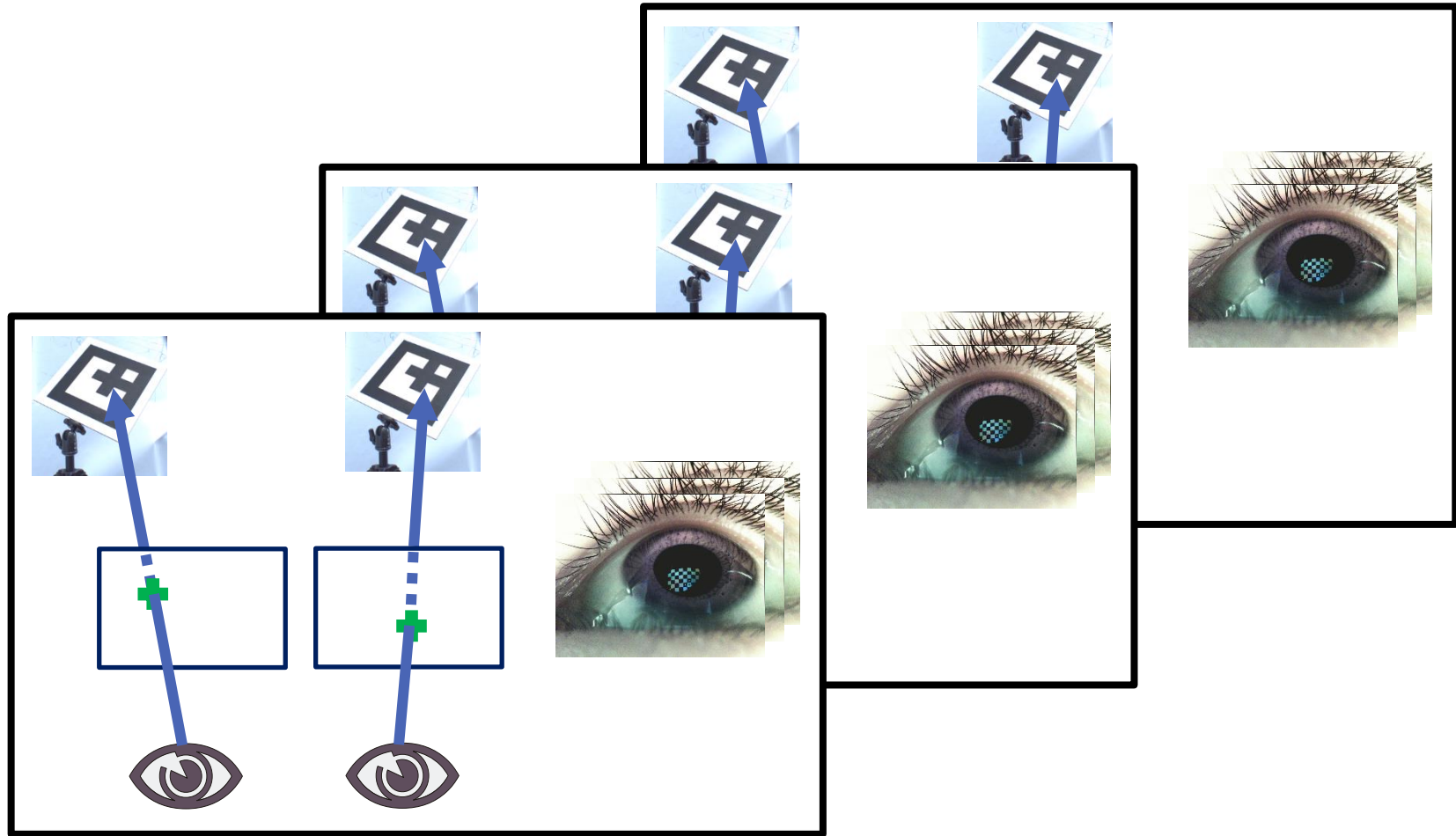
# Experiment



SPAAM and Ground Truth

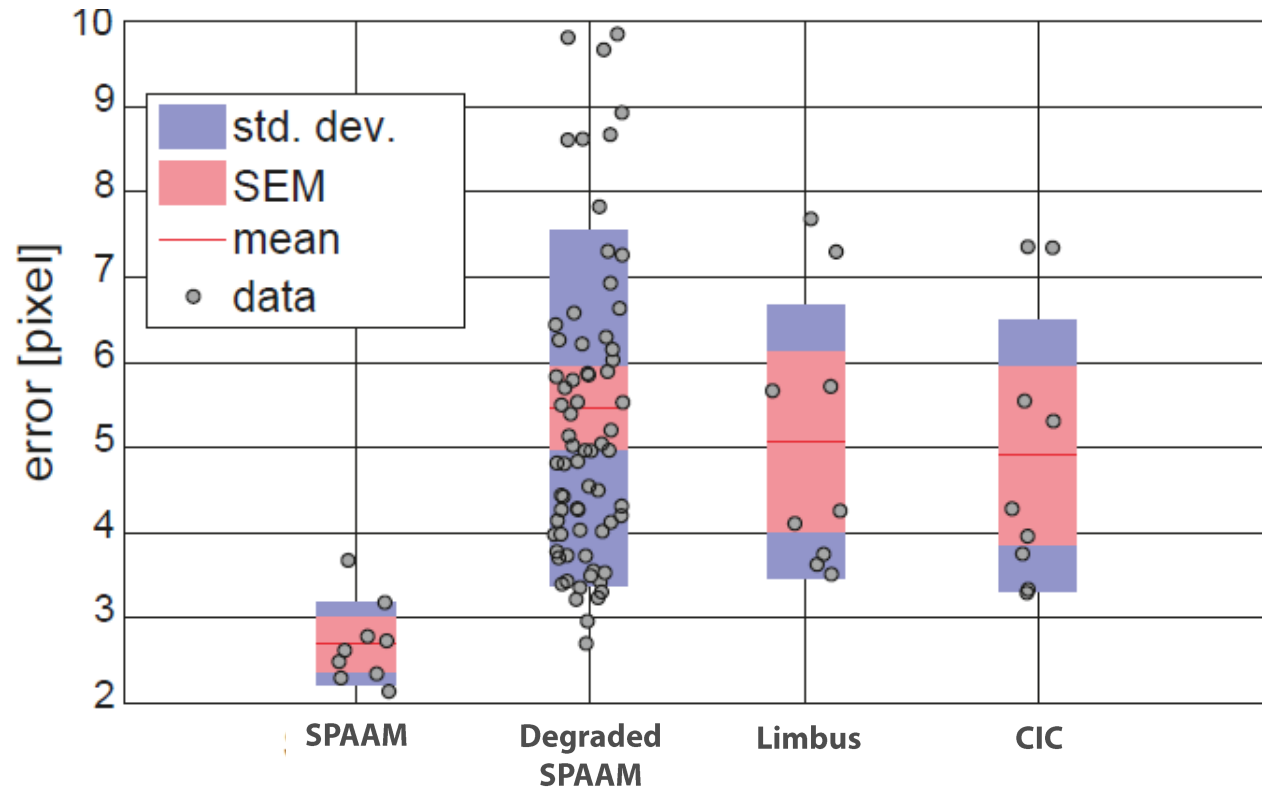
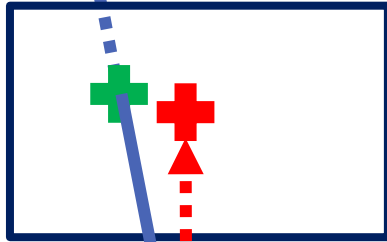
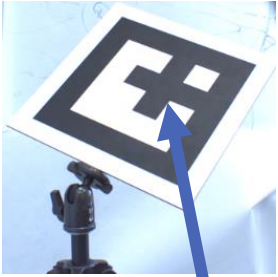
CIC and Limbus

# Experiment



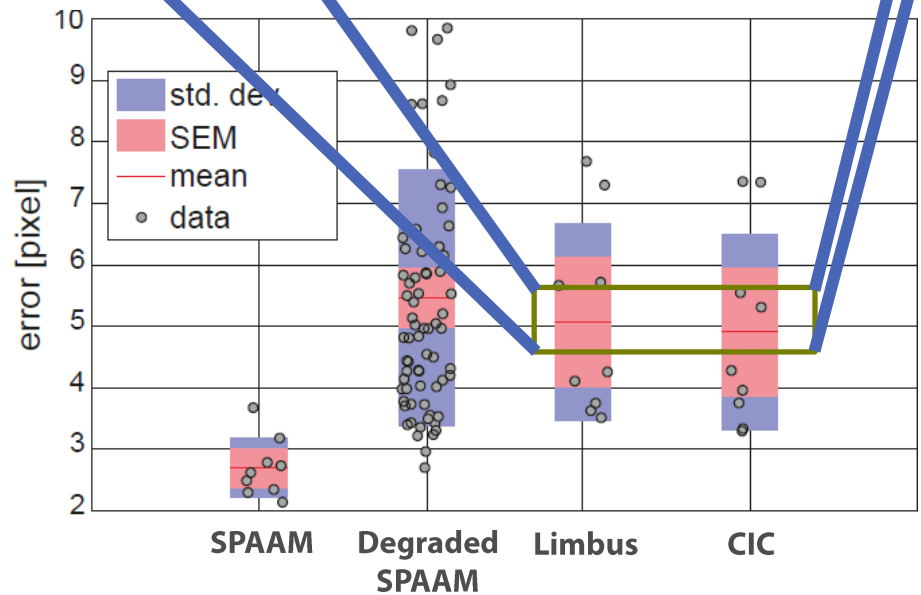
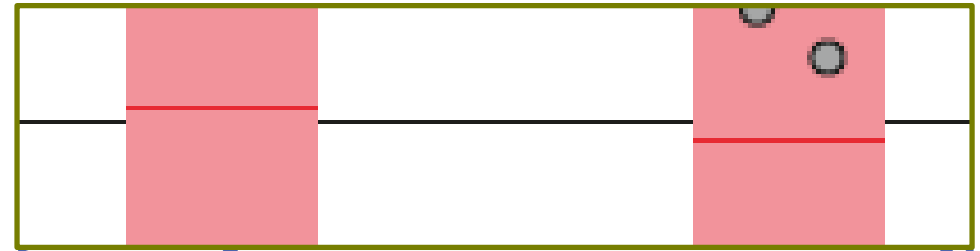
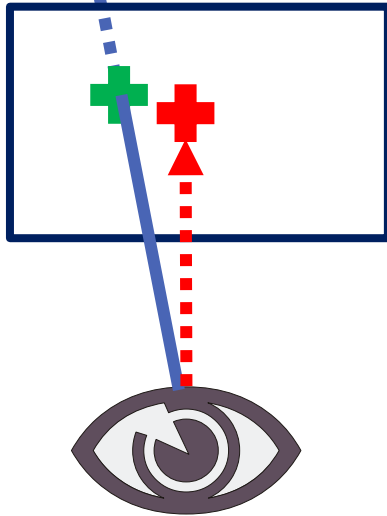
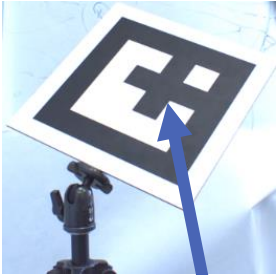


# Calibration Quality

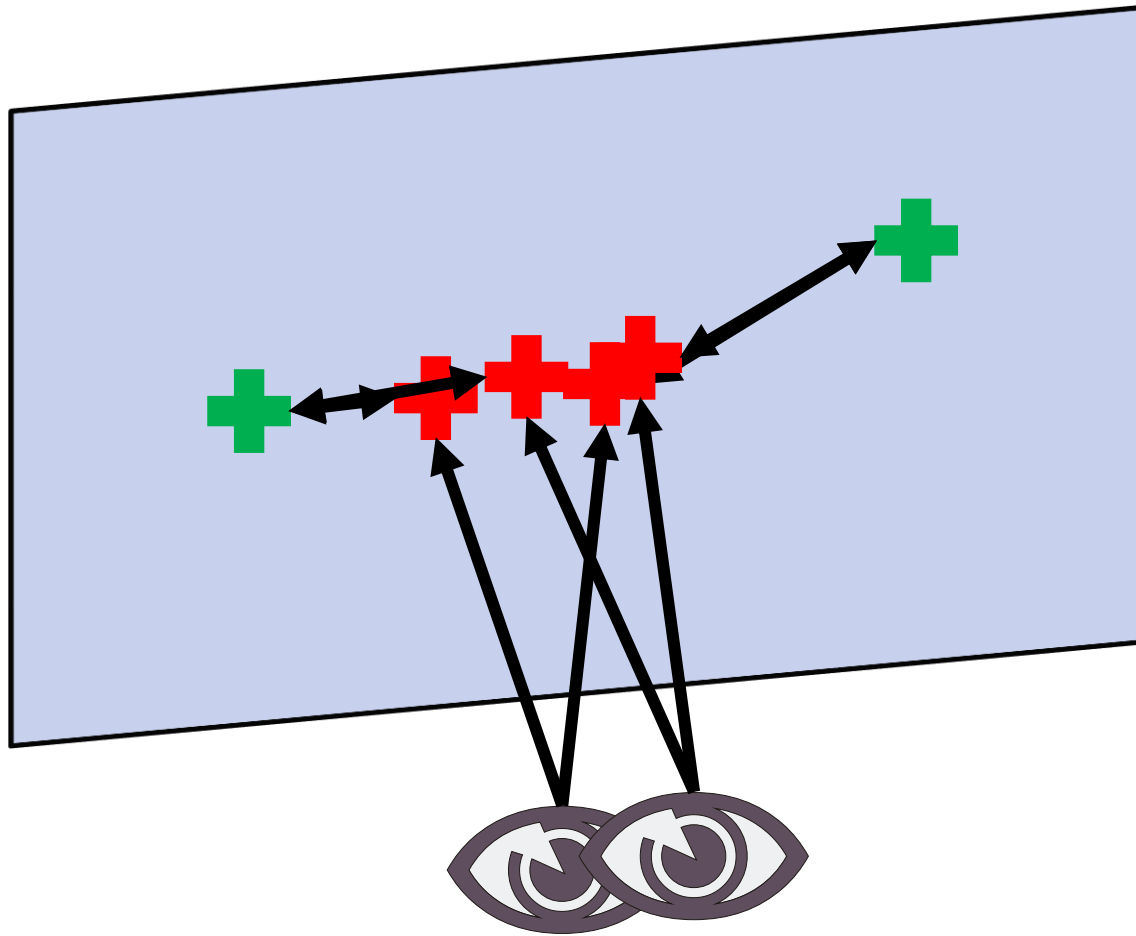




# Calibration Quality

No Difference?



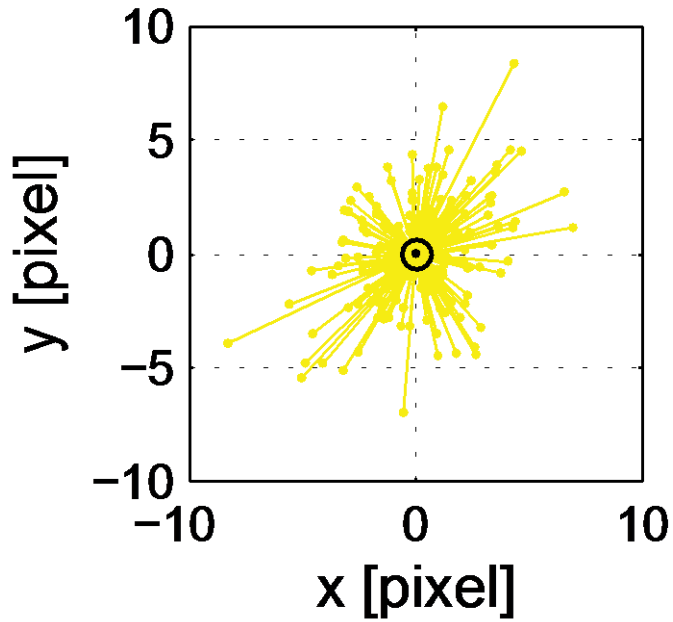
# Error Vectors



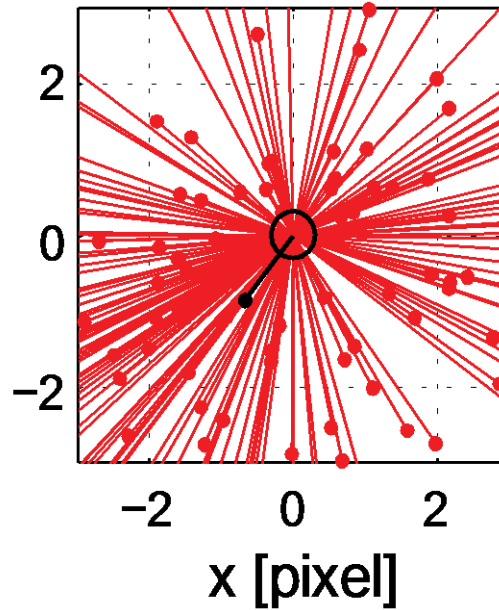
-  Ground truth
-  Estimated

# Error Distribution

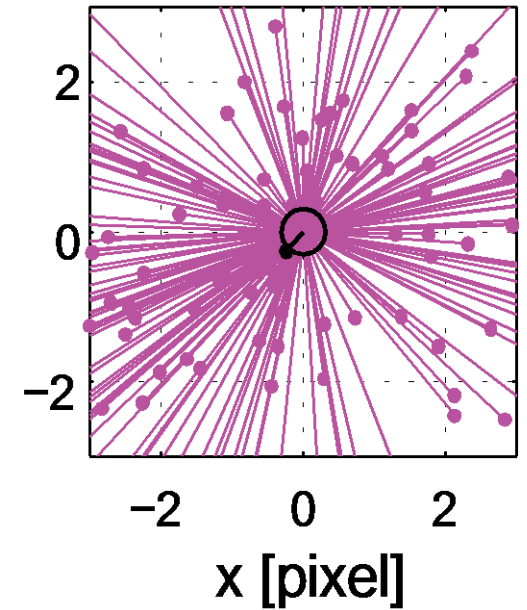
## SPAAM



## LIMBUS



## CIC

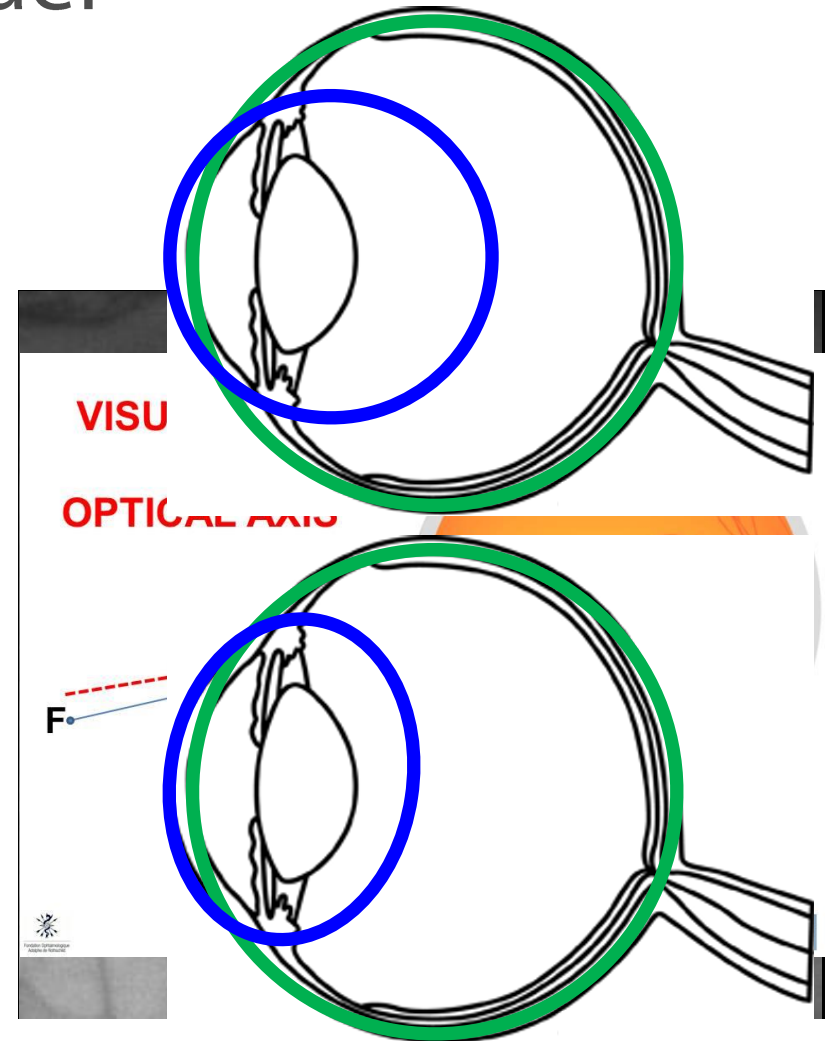


# Summary

- Eye Position estimated from the calibrated HMD-screen and Corneal Imaging
- No need for IR light sources
- Improved stability
- Improved calibration accuracy

# Future?

- ❑ Improved Screen Model
- ❑ Improved Tracking
- ❑ Improved Eye Model
- ❑ Personal Parameters



# Thank you! Questions?

