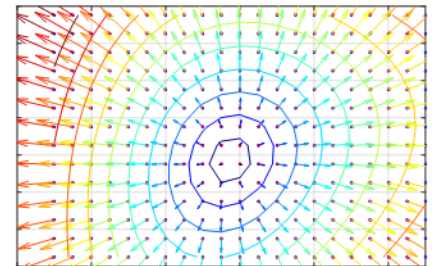
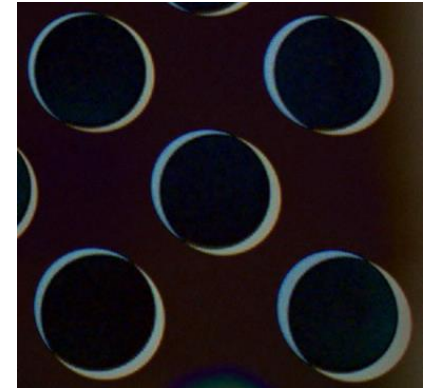
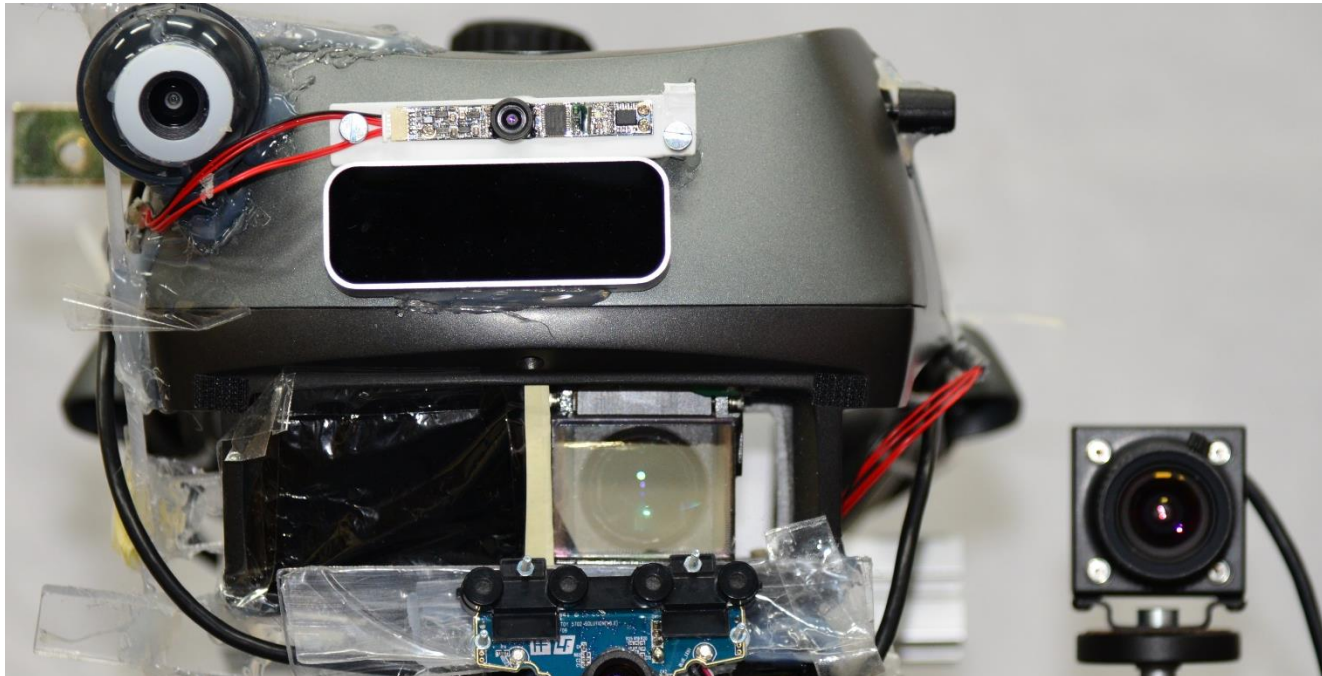


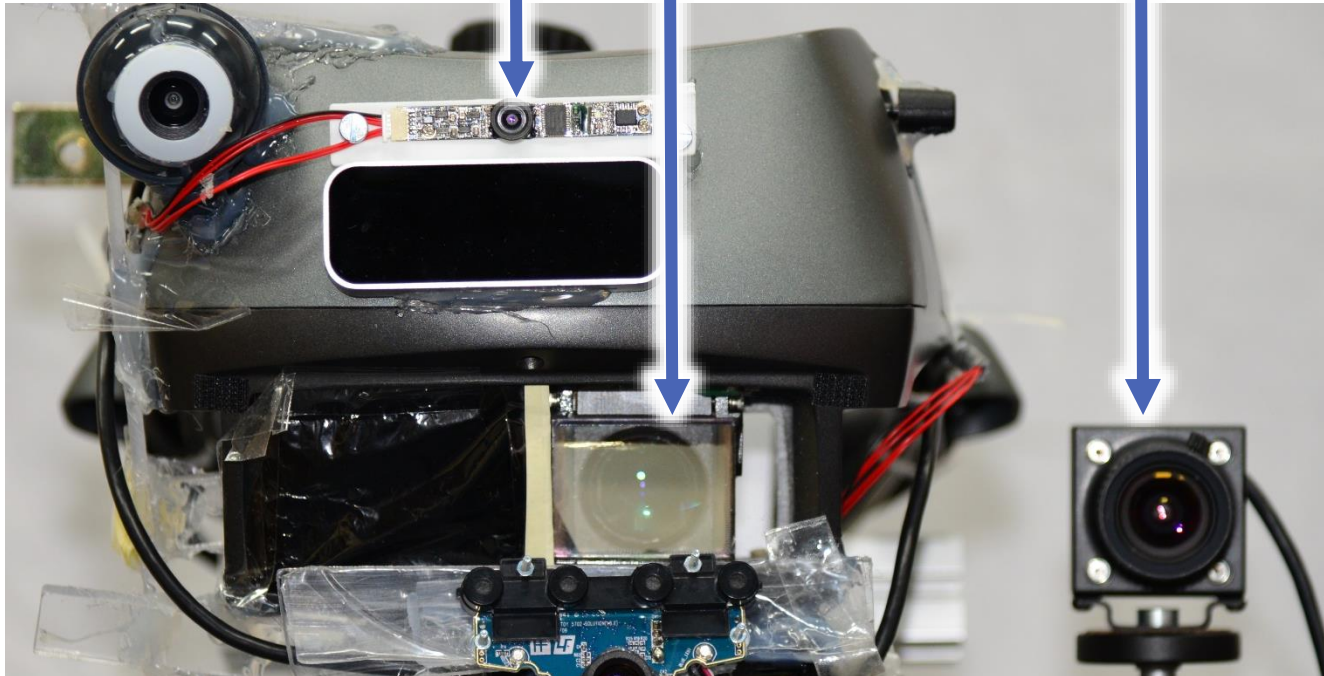
# Light-Field Correction for Spatial Calibration of Optical See-Through HMDs

Yuta Itoh and Gudrun Klinker

TU Munich, IEEE VR 2015, 23<sup>rd</sup> March 2015



This work only uses these...



# Head-Mounted Displays (HMDs)

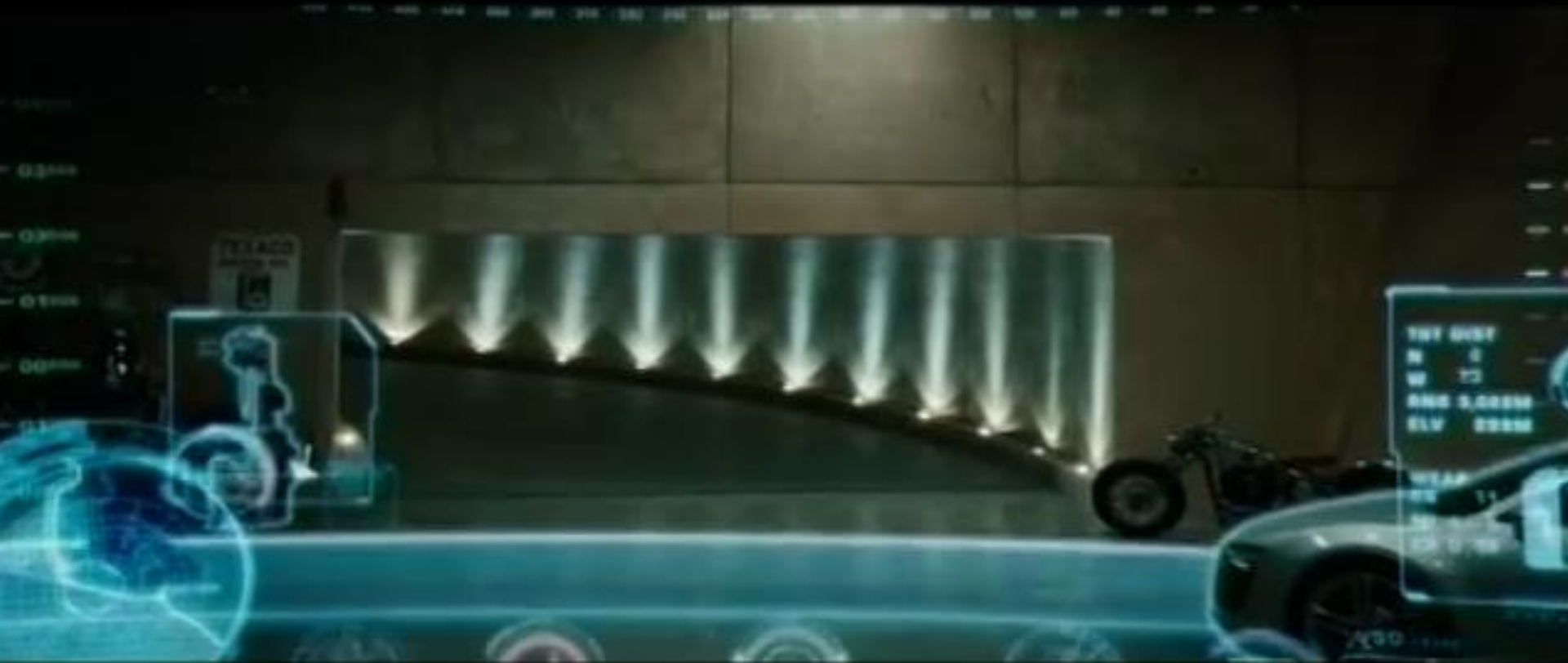
## Non Optical See-Through



## Optical See-Through (OST-HMD)



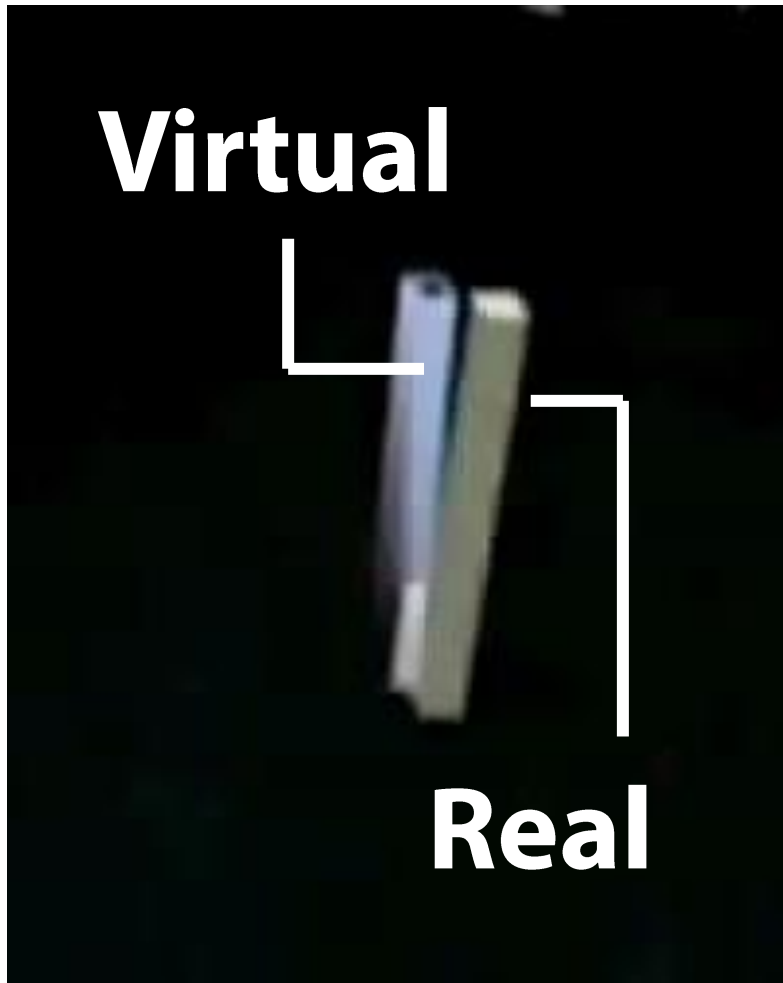
# OST-HMD in science fiction



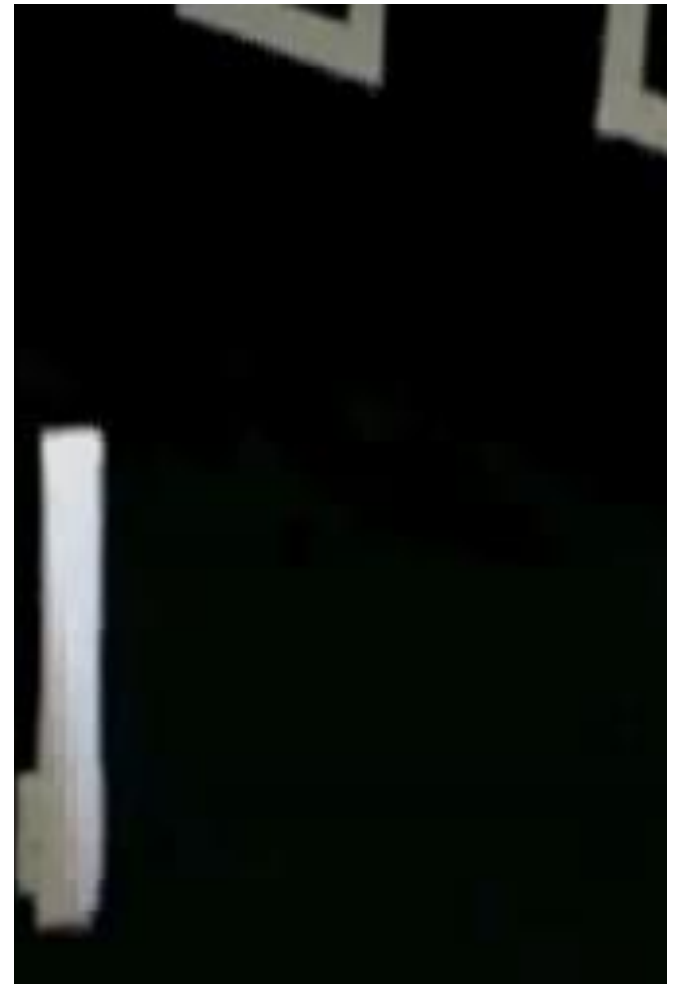
From Ironman, 2008 ©Marvel Entertainment

# Spatial consistency of OST-HMDs

Not consistent



Consistent



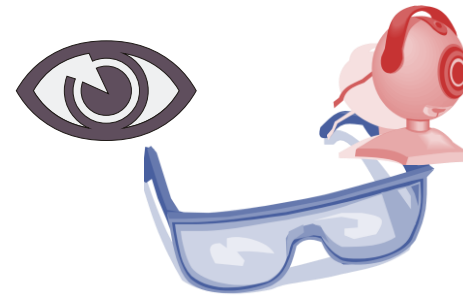


# For accurate spatial calibration

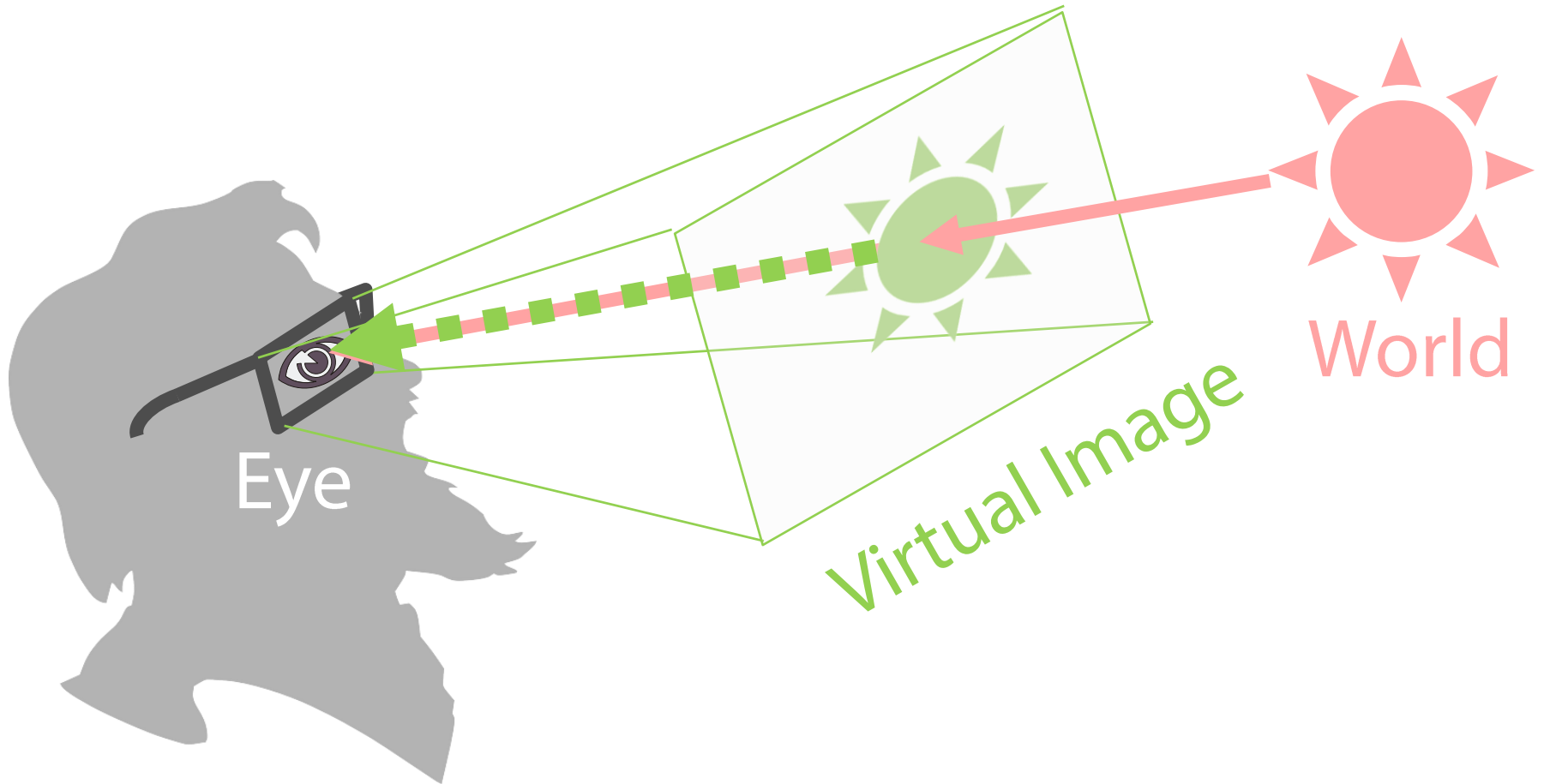


□ **World** to Eye

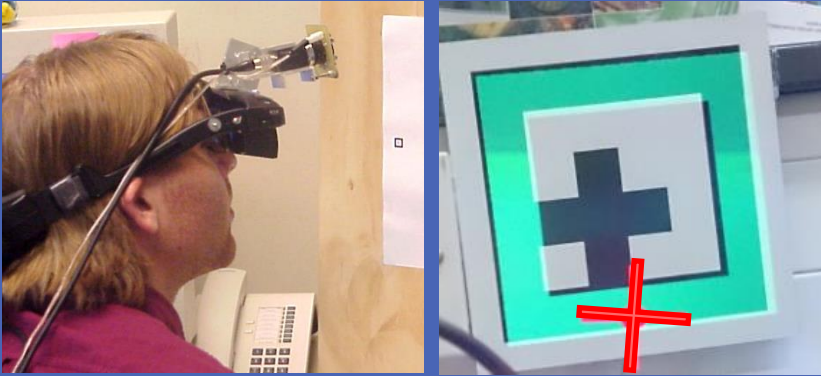
□ **OST-HMD** to Eye



# Eye and HMD calibration



# Manual method user interaction required

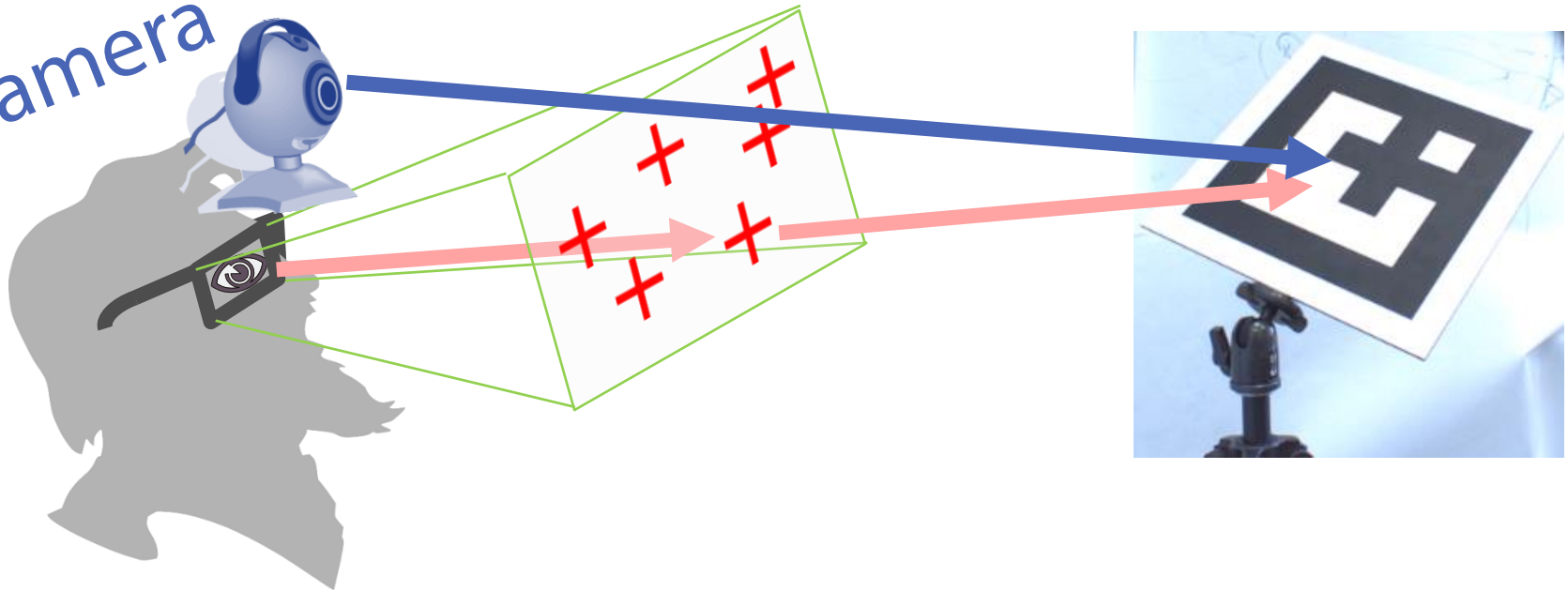


SPAAM

Single Point Active  
Alignment Method

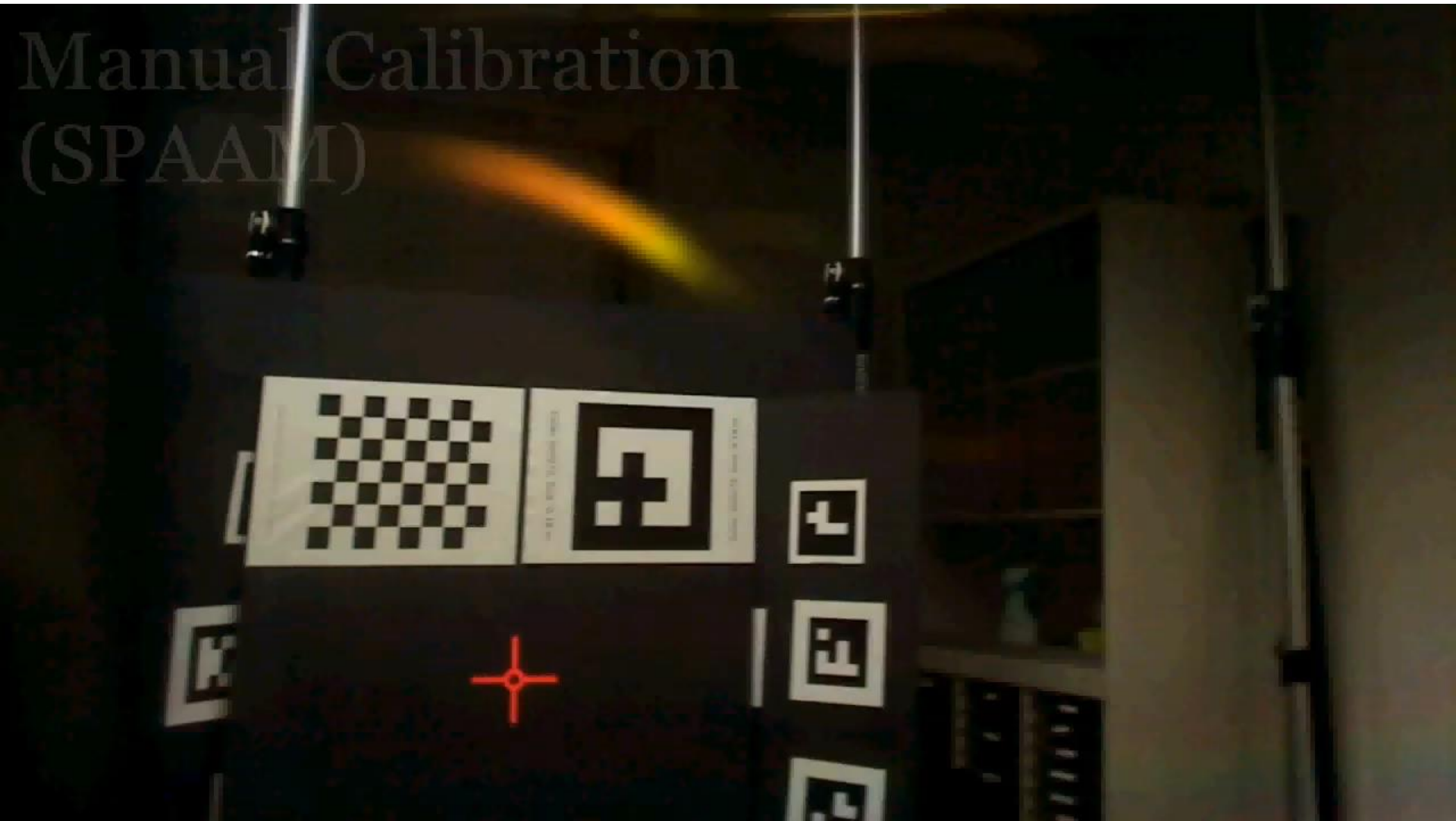
[Tuceryan '00] [Genc '02]

Camera

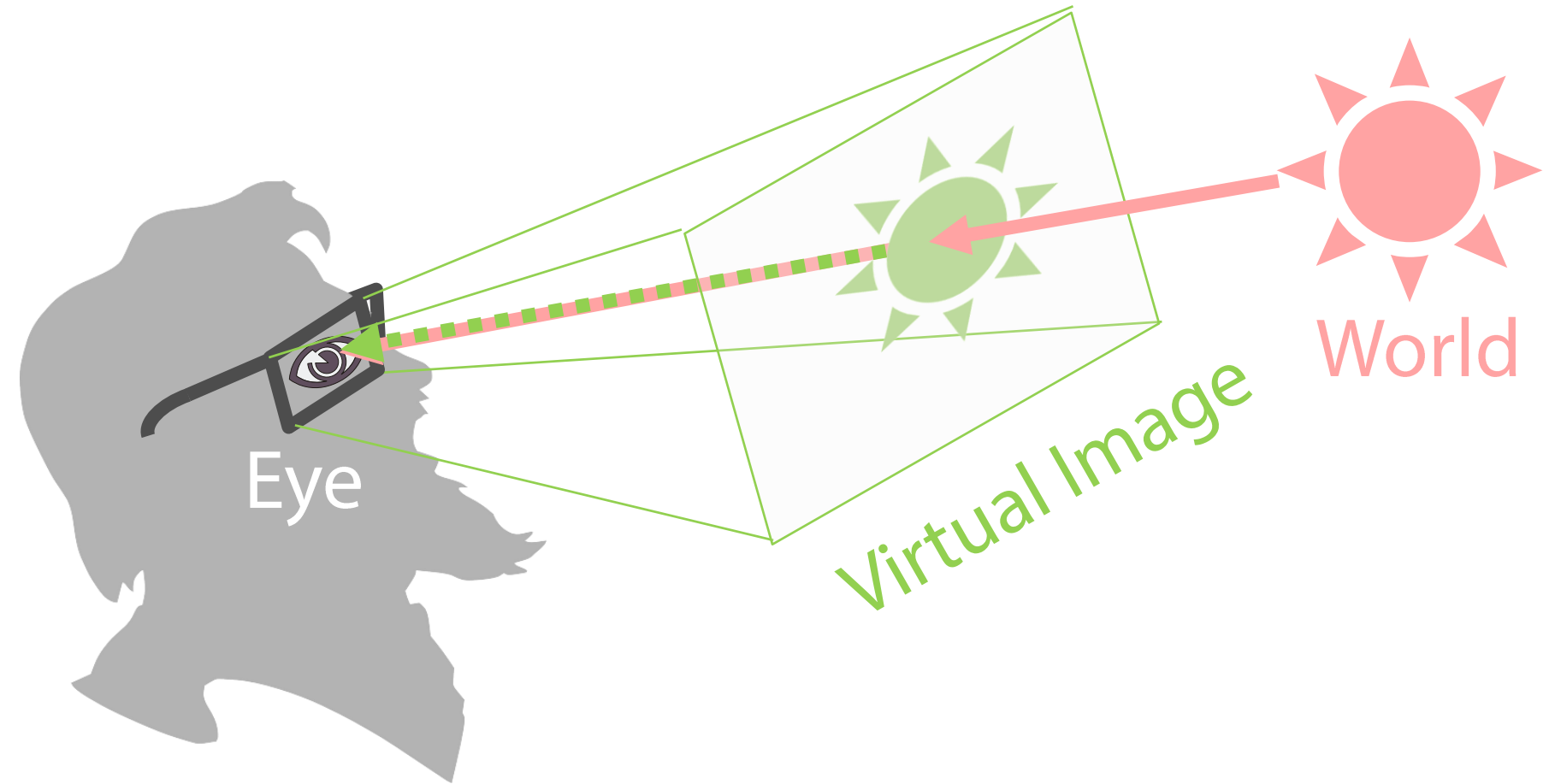




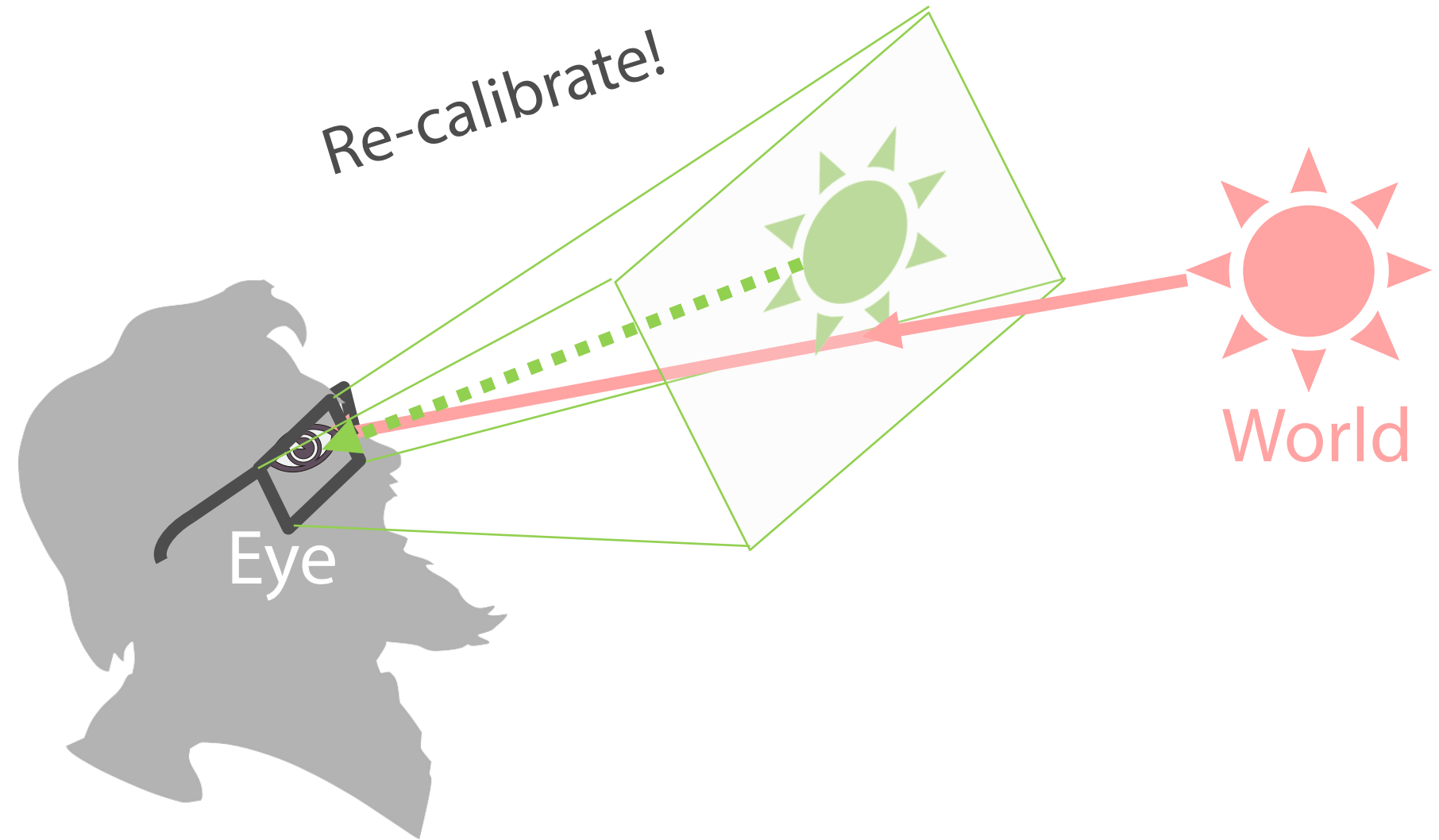
# SPAAM (Manual Calibration) video



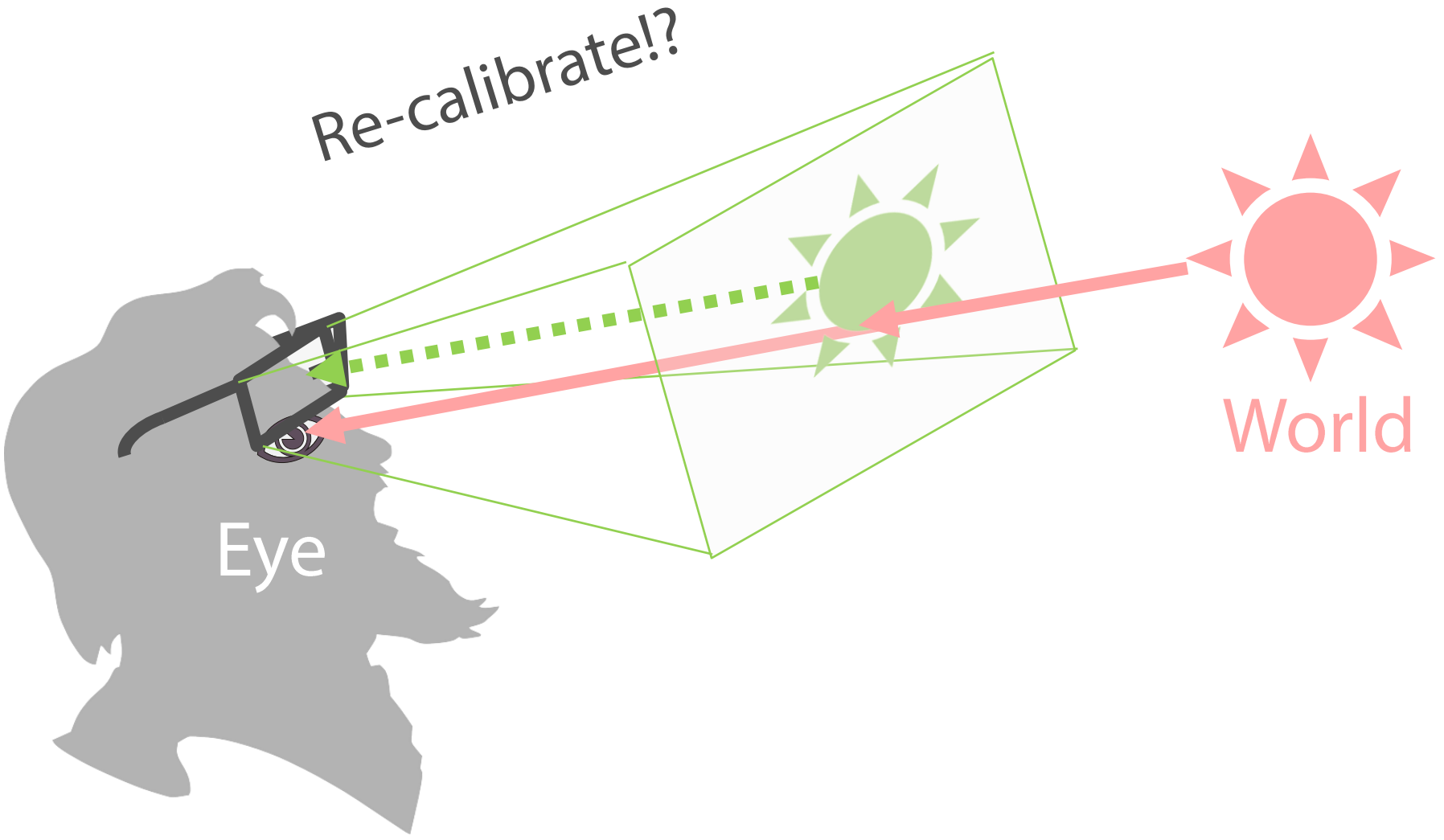
# Eye and HMD calibration



# Eye and HMD are **dynamic**



# Eye and HMD are **dynamic**



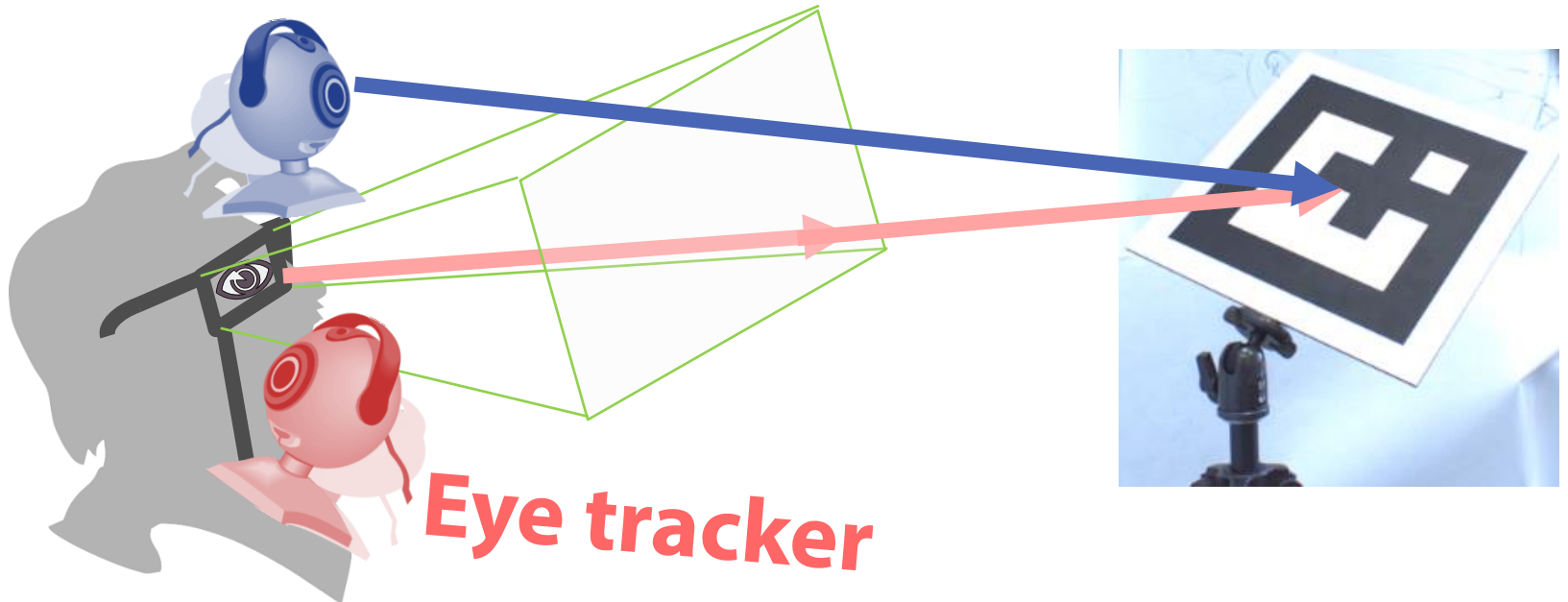
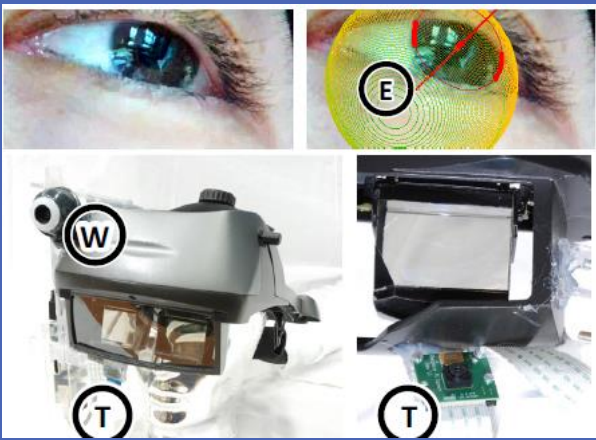
# Automated method

**interaction-free**

~~INDICA~~

INteraction-free

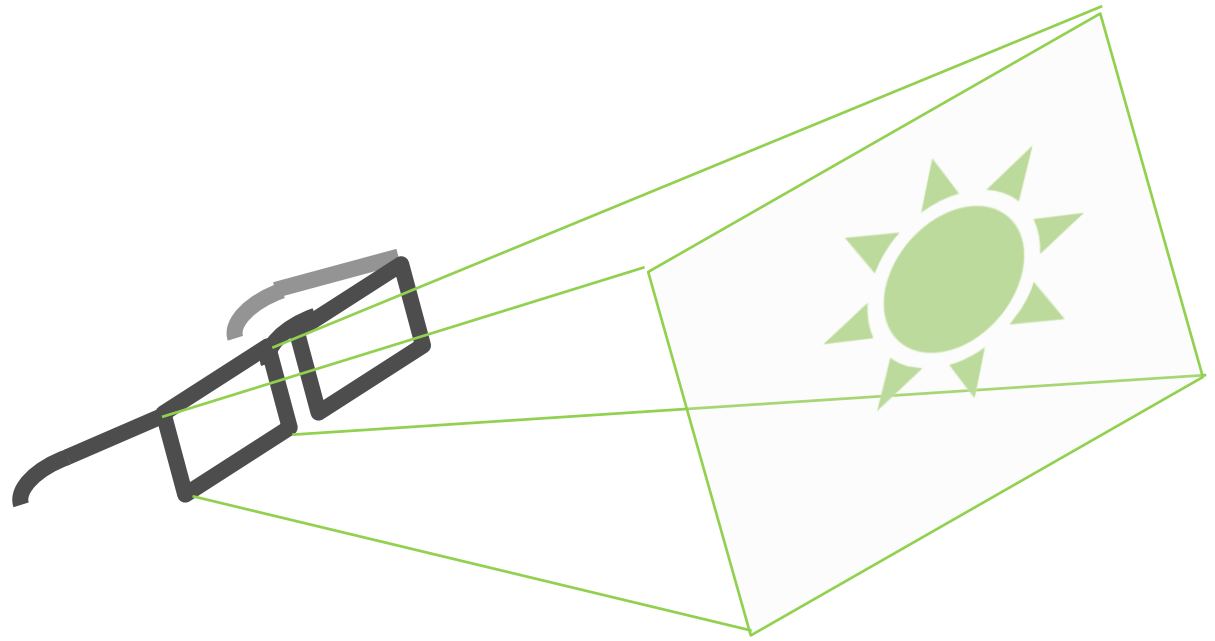
DI splay CA libration [Itoh '14]



**Eye tracker**

# Dividing the eye-HMD system

1. *HMD* model



2. *Eye* position

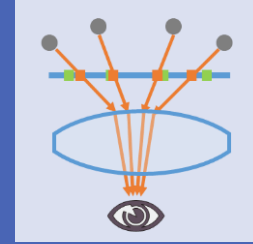
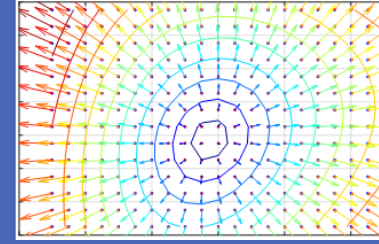
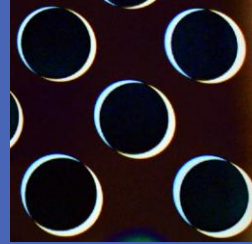




# Summary of our 3 talks



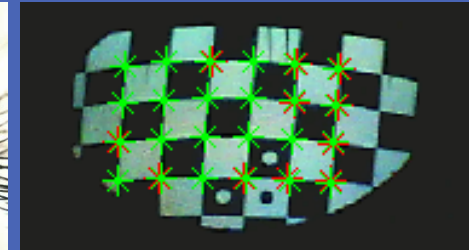
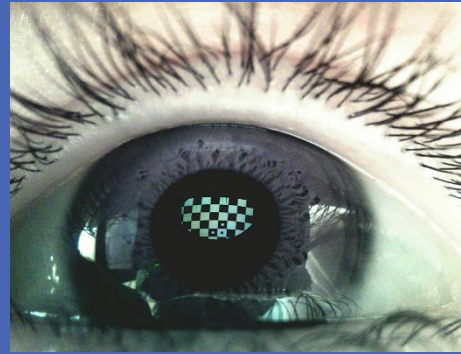
## 1. Better *HMD* model



By Yuta



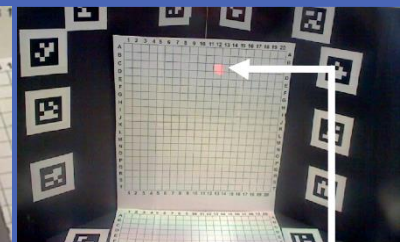
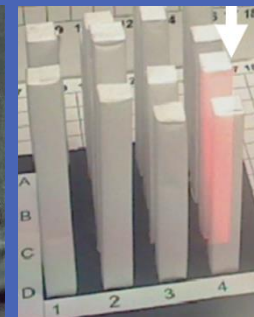
## 2. Better *Eye* position



By Alex



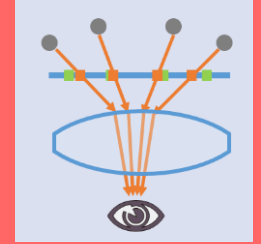
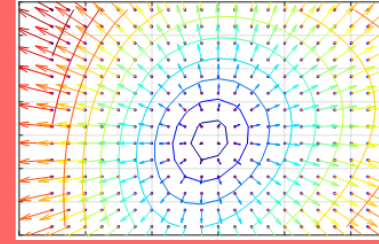
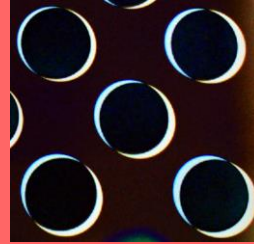
## 3. Formal *User* study



By Kenny

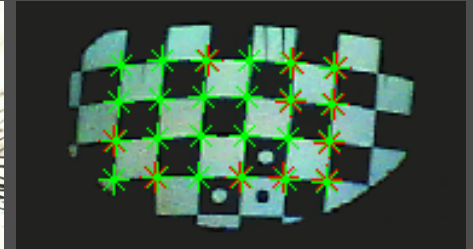
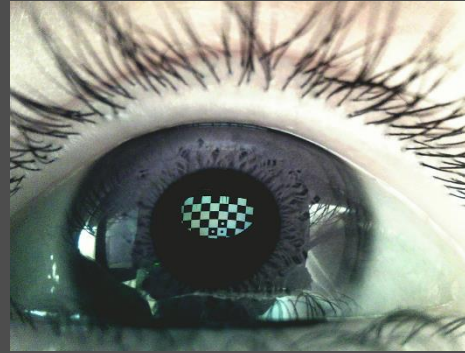
# Summary of our 3 talks

## 1. Better *HMD* model



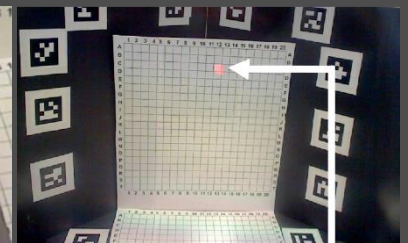
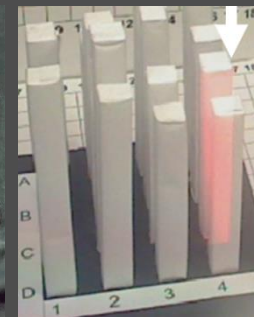
By Yuta

## 2. Better *Eye* position



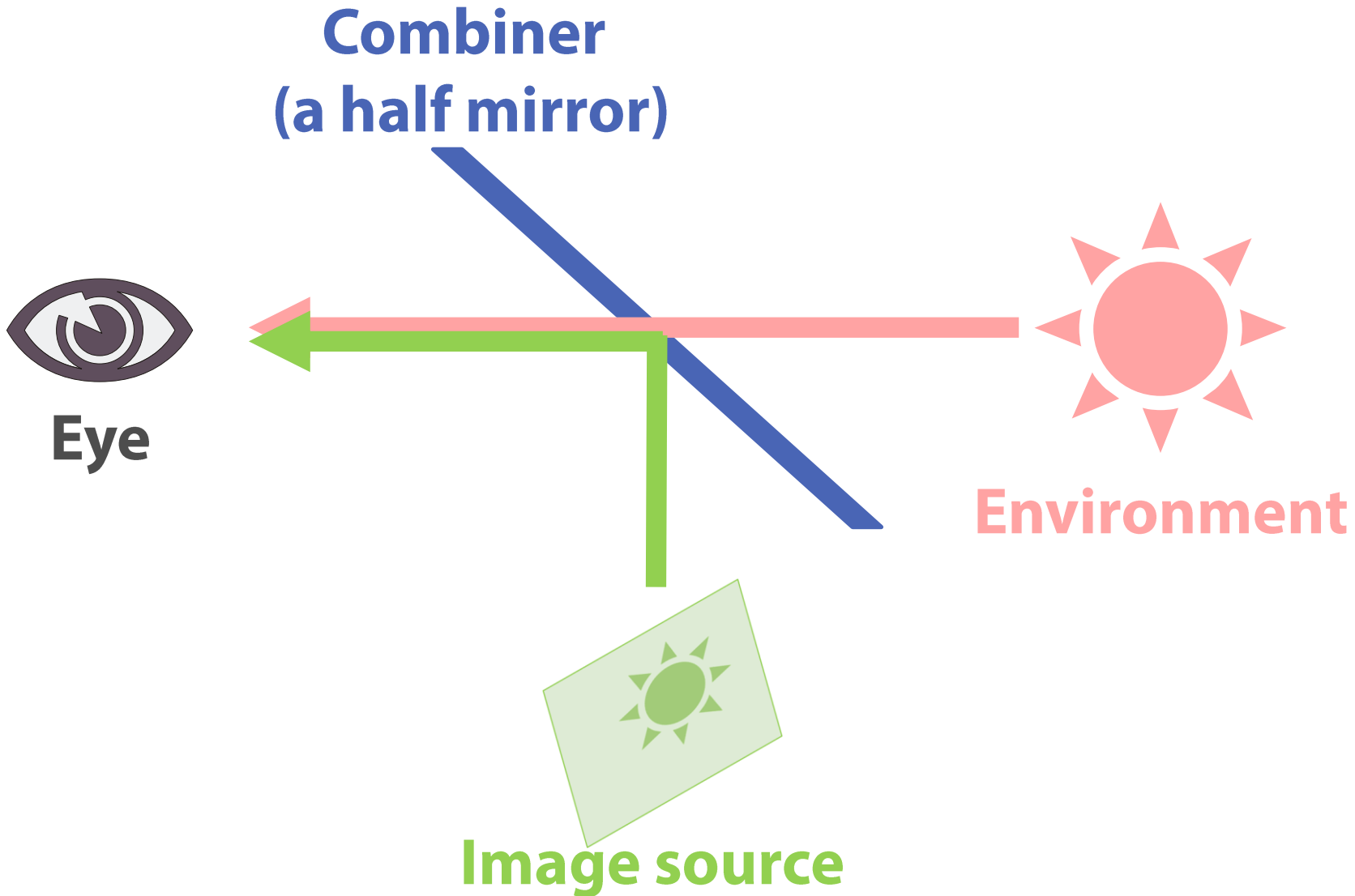
By Alex

## 3. Formal *User* study

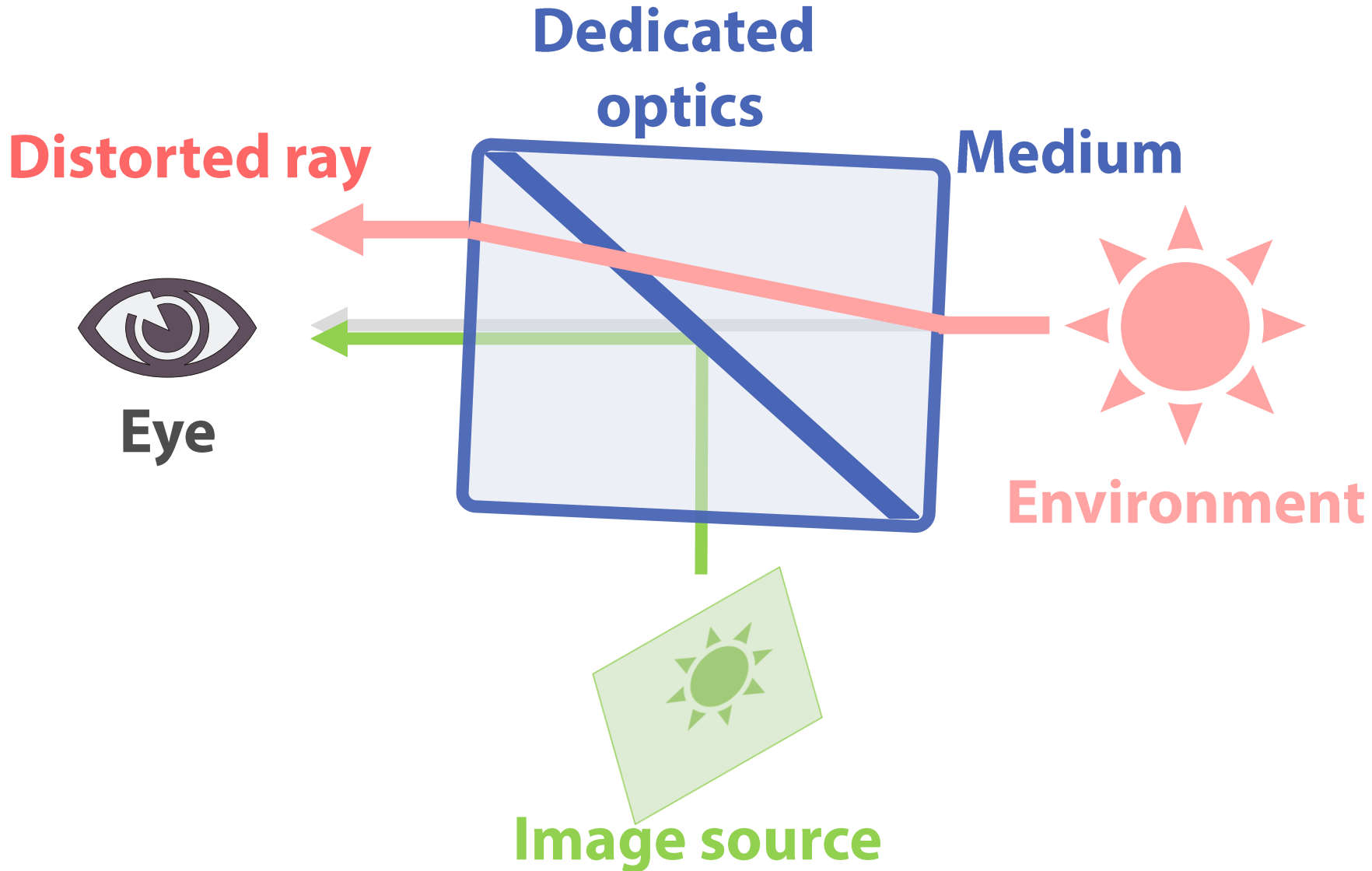


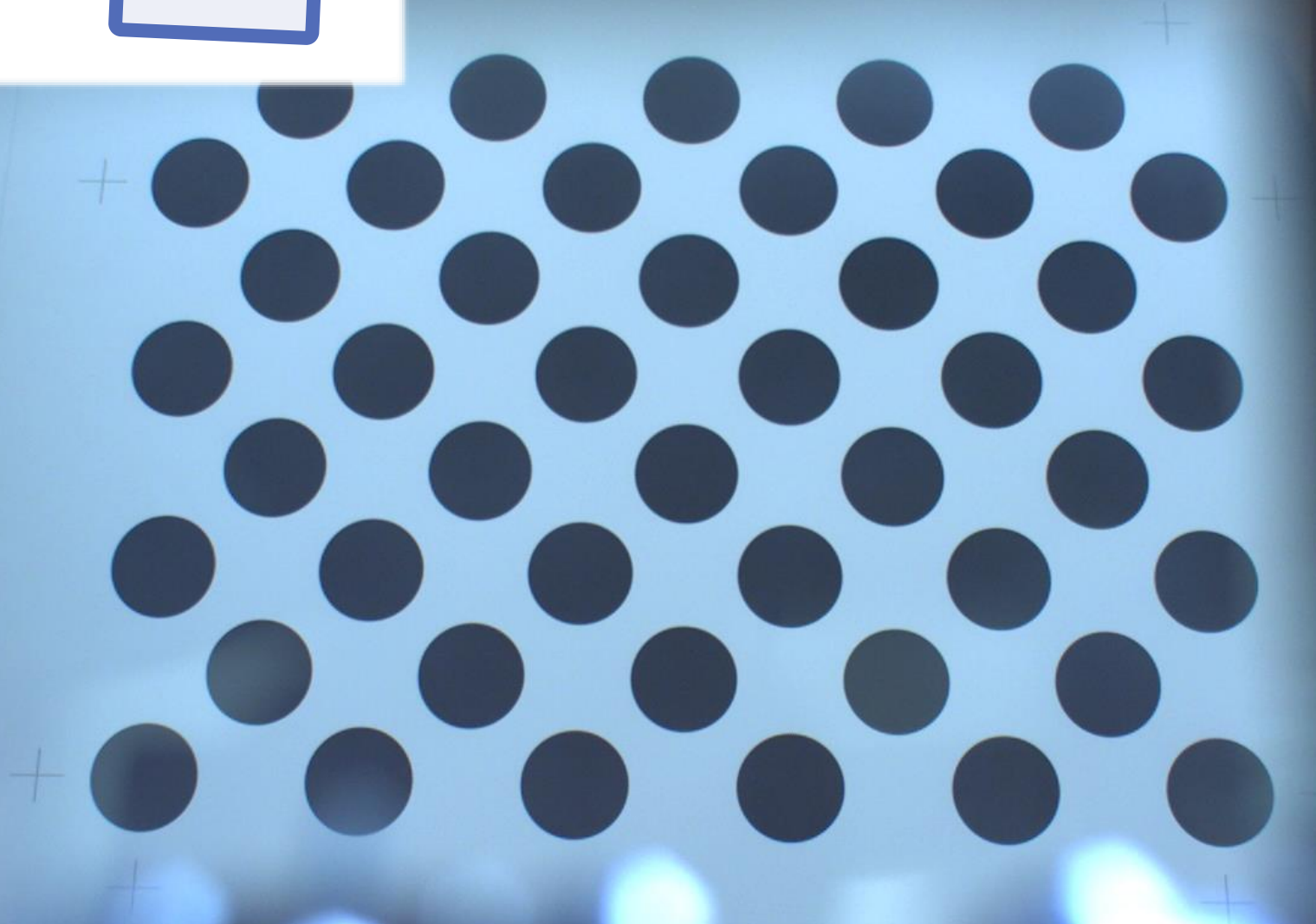
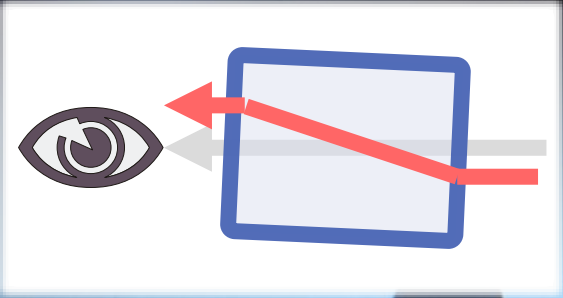
By Kenny

# An ideal eye-HMD system

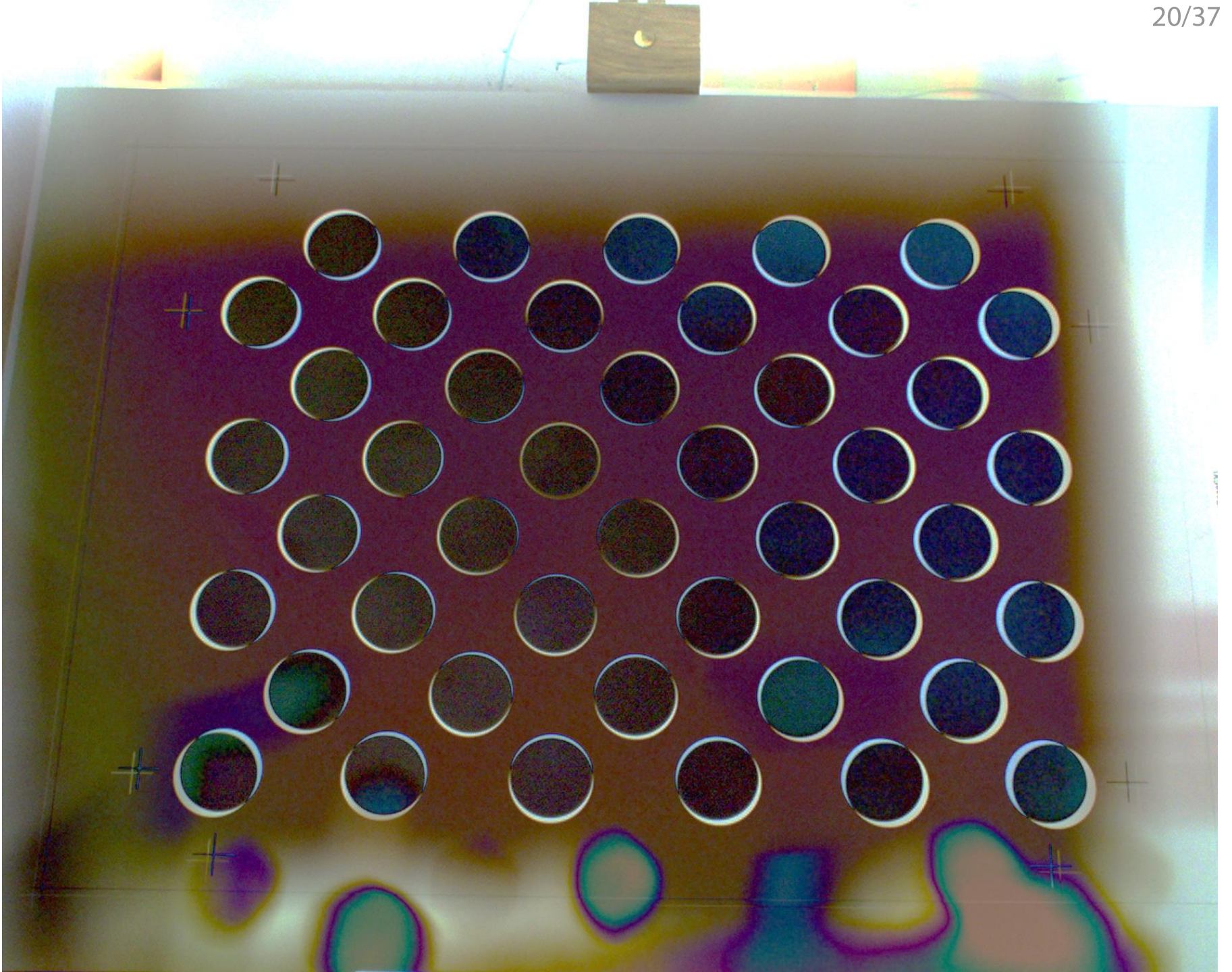


# The real world is **CRUEL**



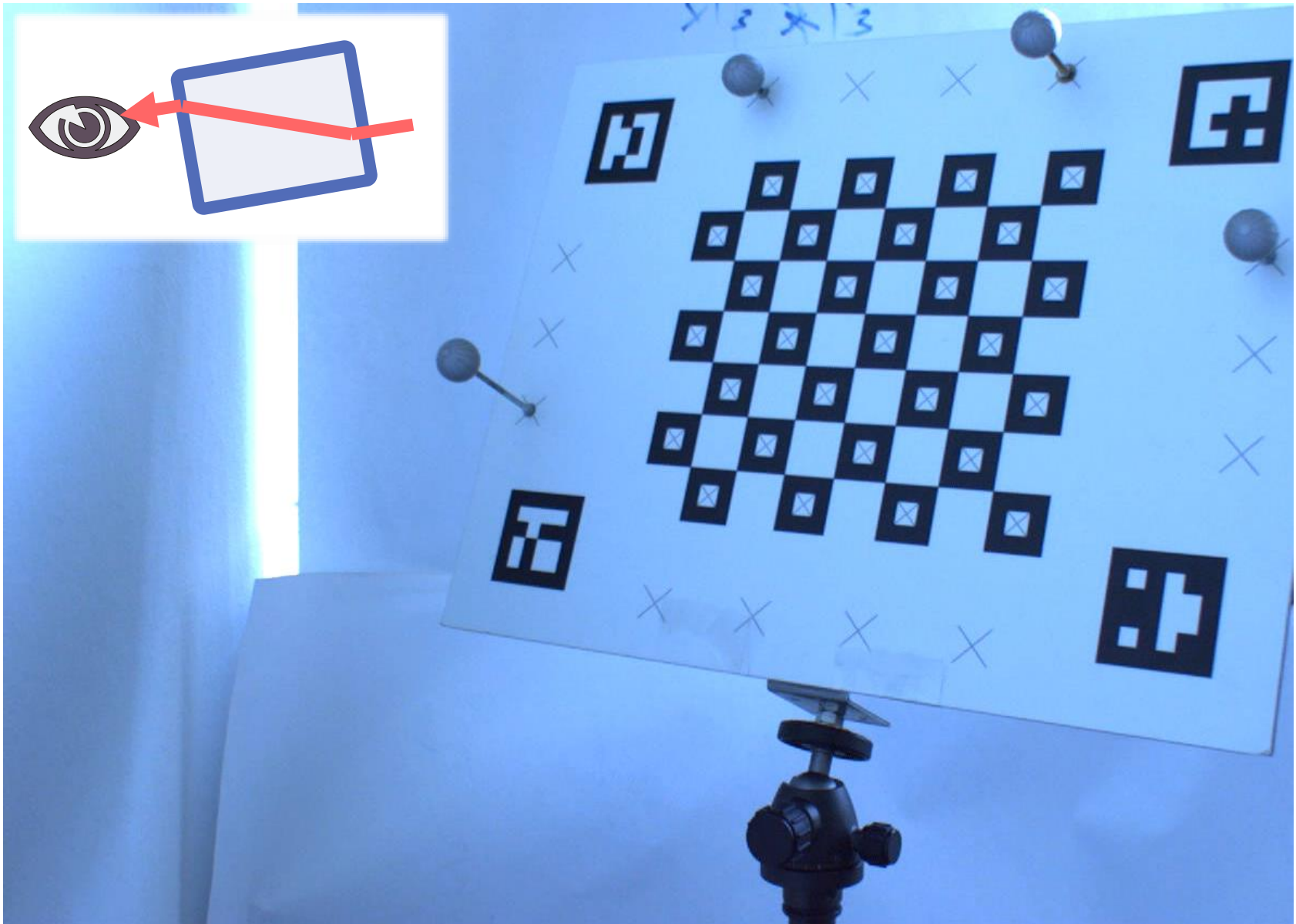




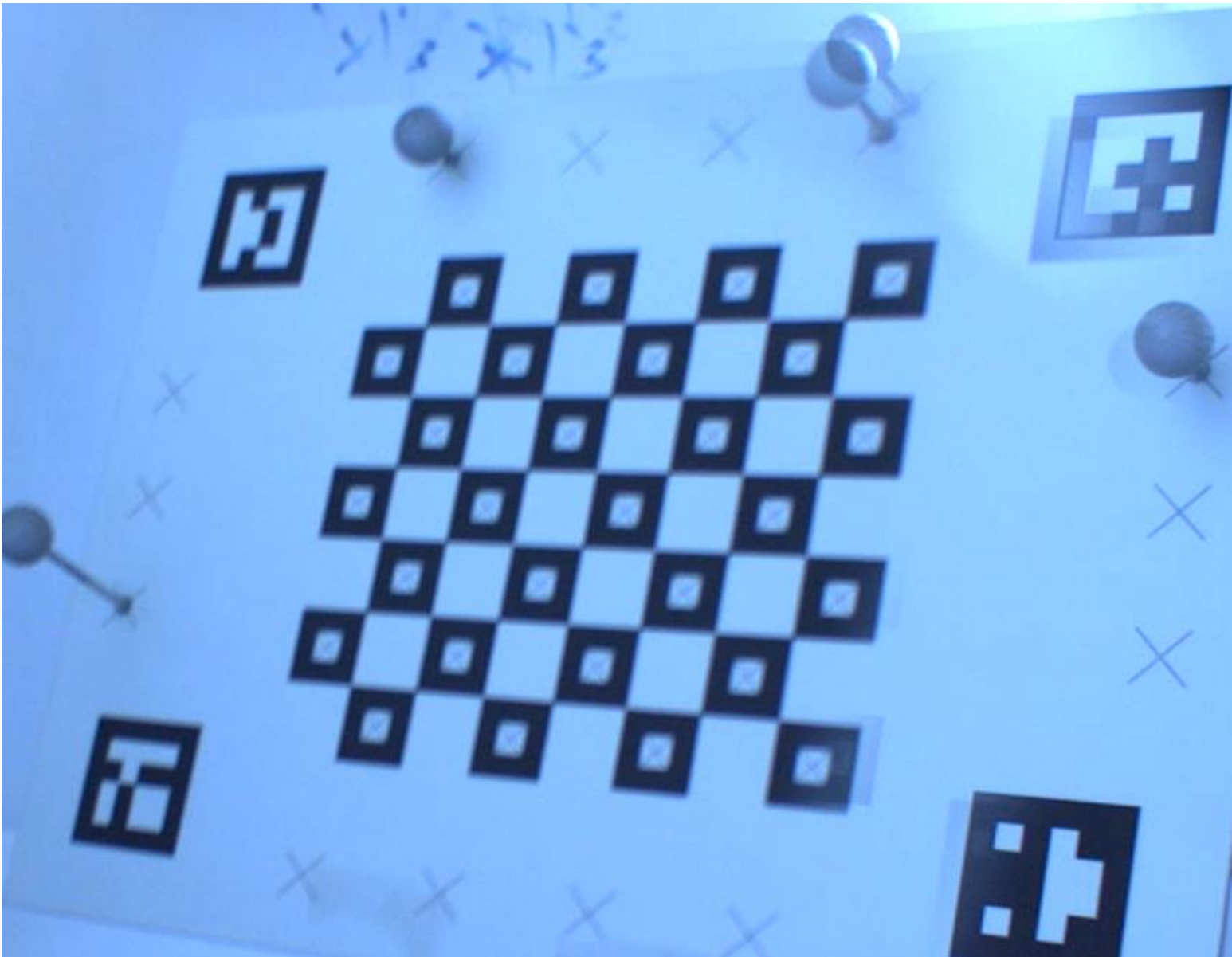




# View-dependent distortions

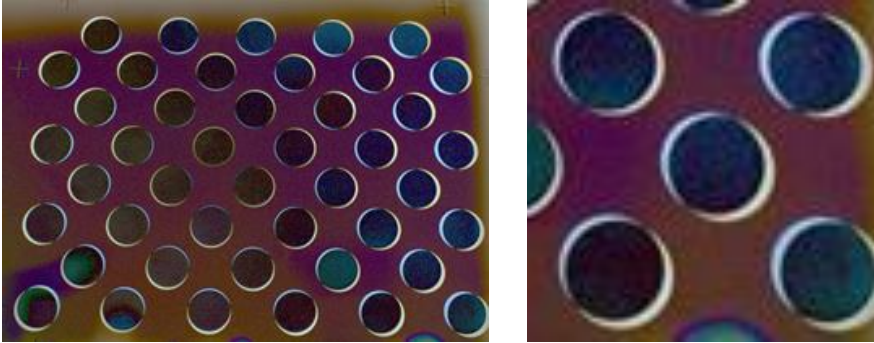


# View-dependent distortions

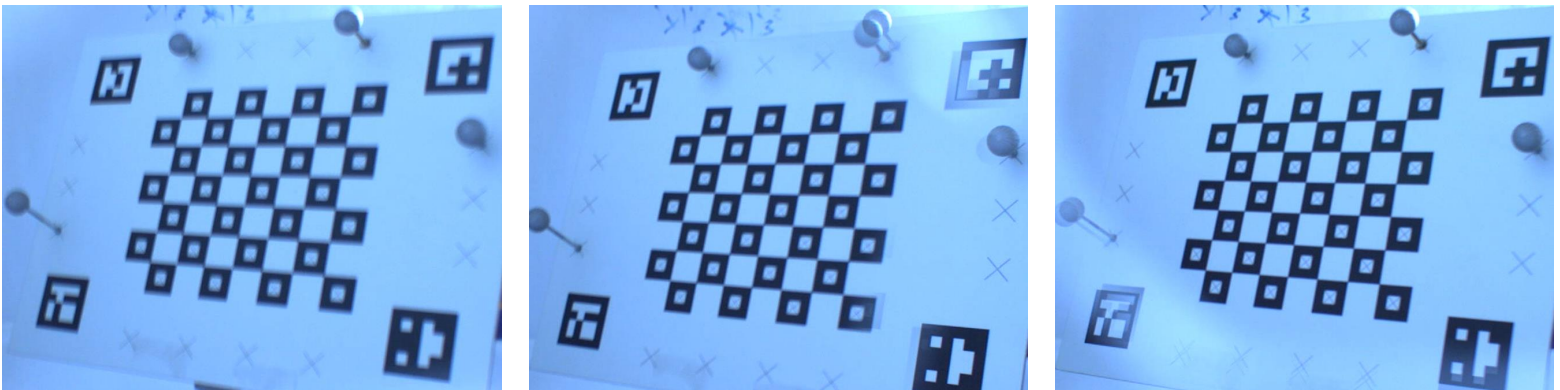


# What do we need to correct?

- **Non-linear** distortion



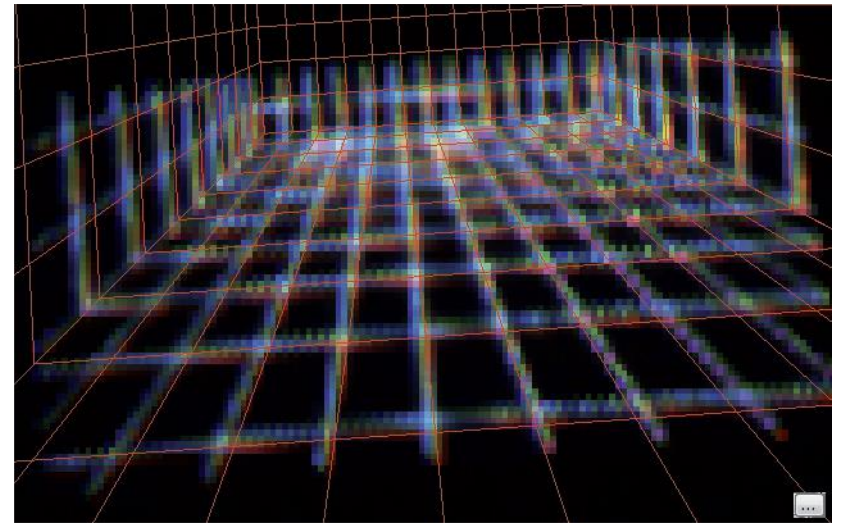
- **View-point** dependent distortion



# Calibration of Head-Up Displays

[Wientapper et al., ISMAR'13]

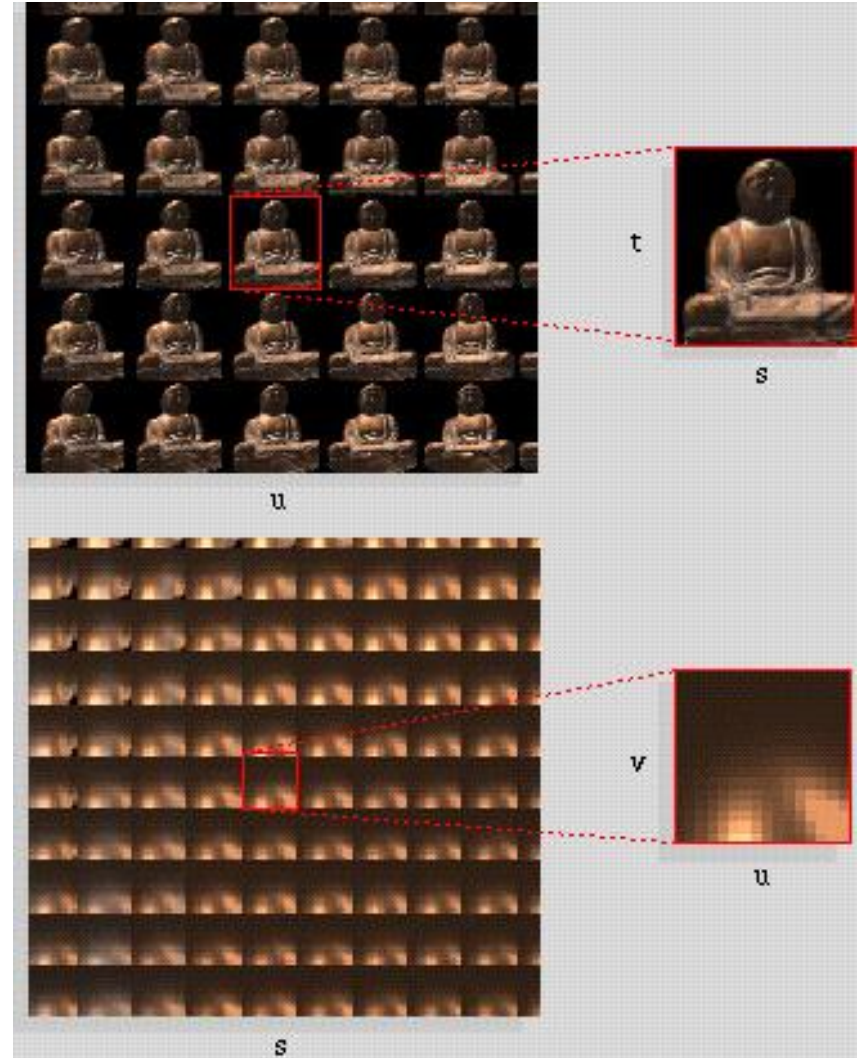
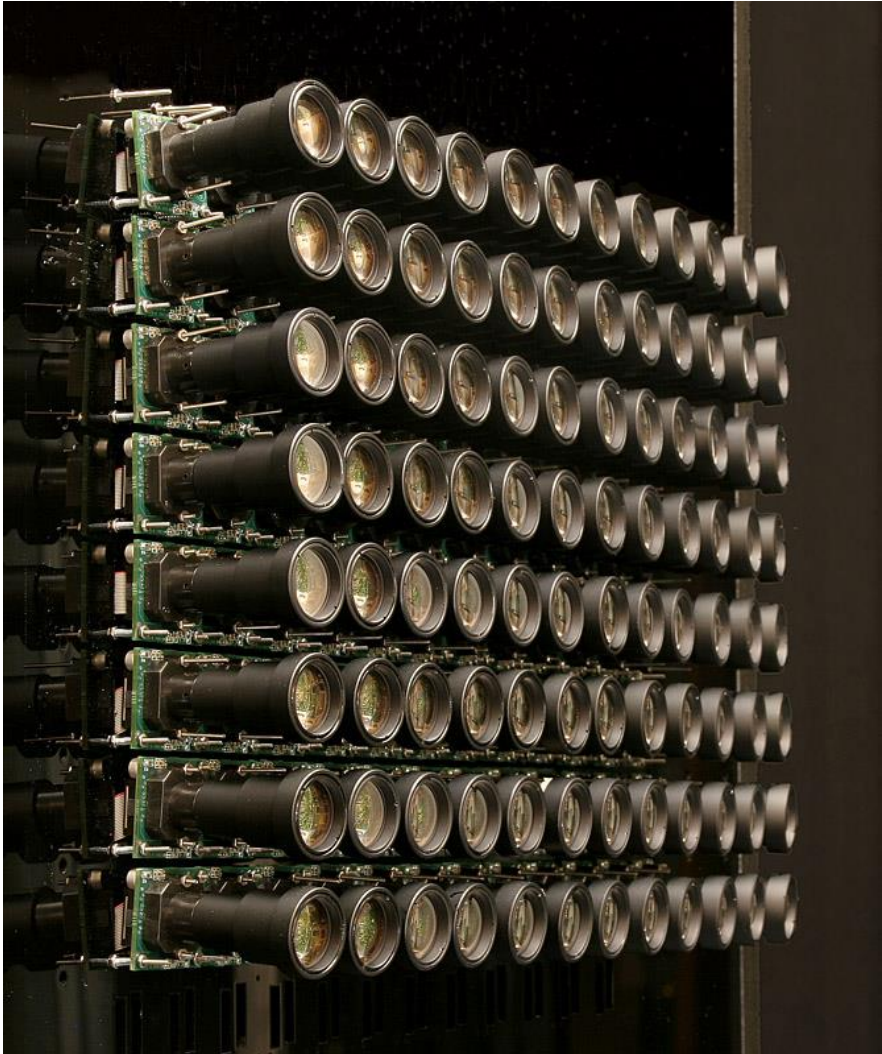
- Learn **Non-linear** 2D warping, as a function of **view points**
- Ad-hoc image undistortion, & does not handle **physical model**



[A camera-based calibration for automotive augmented reality head-up-displays](#)  
F Wientapper, H Wuest, P Rojtberg... ISMAR 2013 - [ieeexplore.ieee.org](http://ieeexplore.ieee.org)

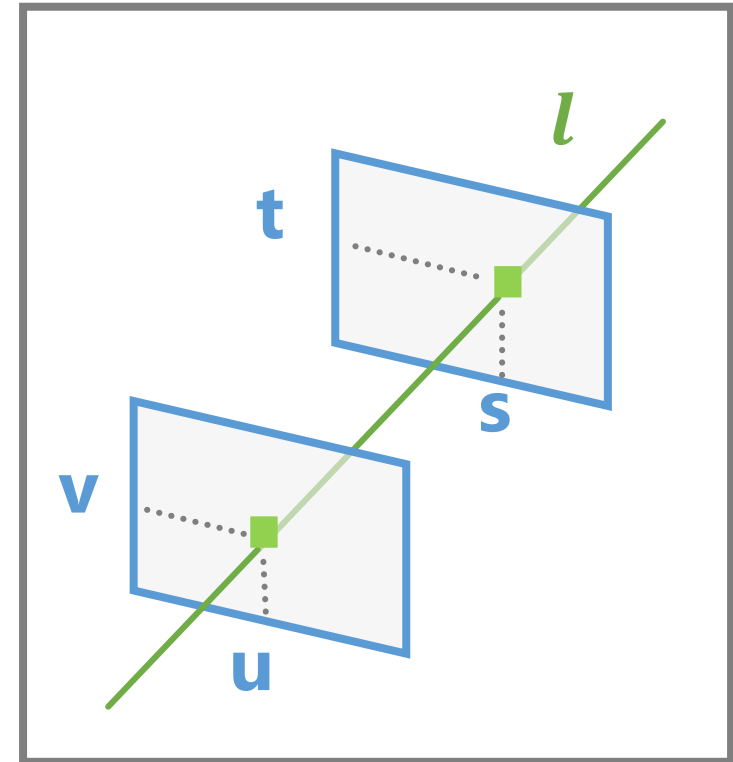
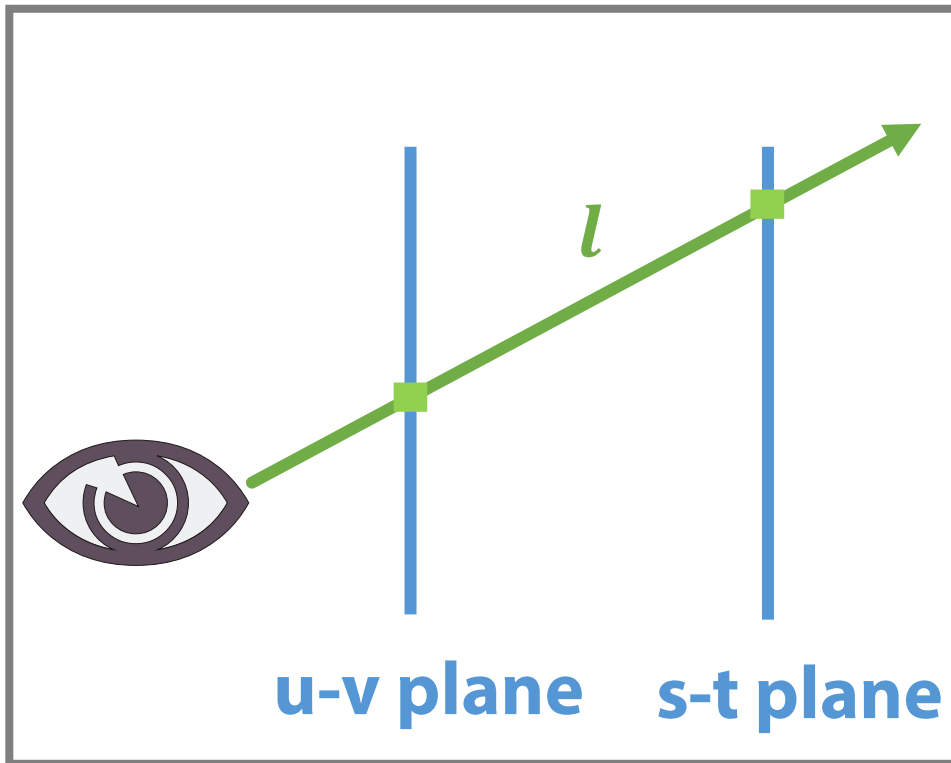


# Light field



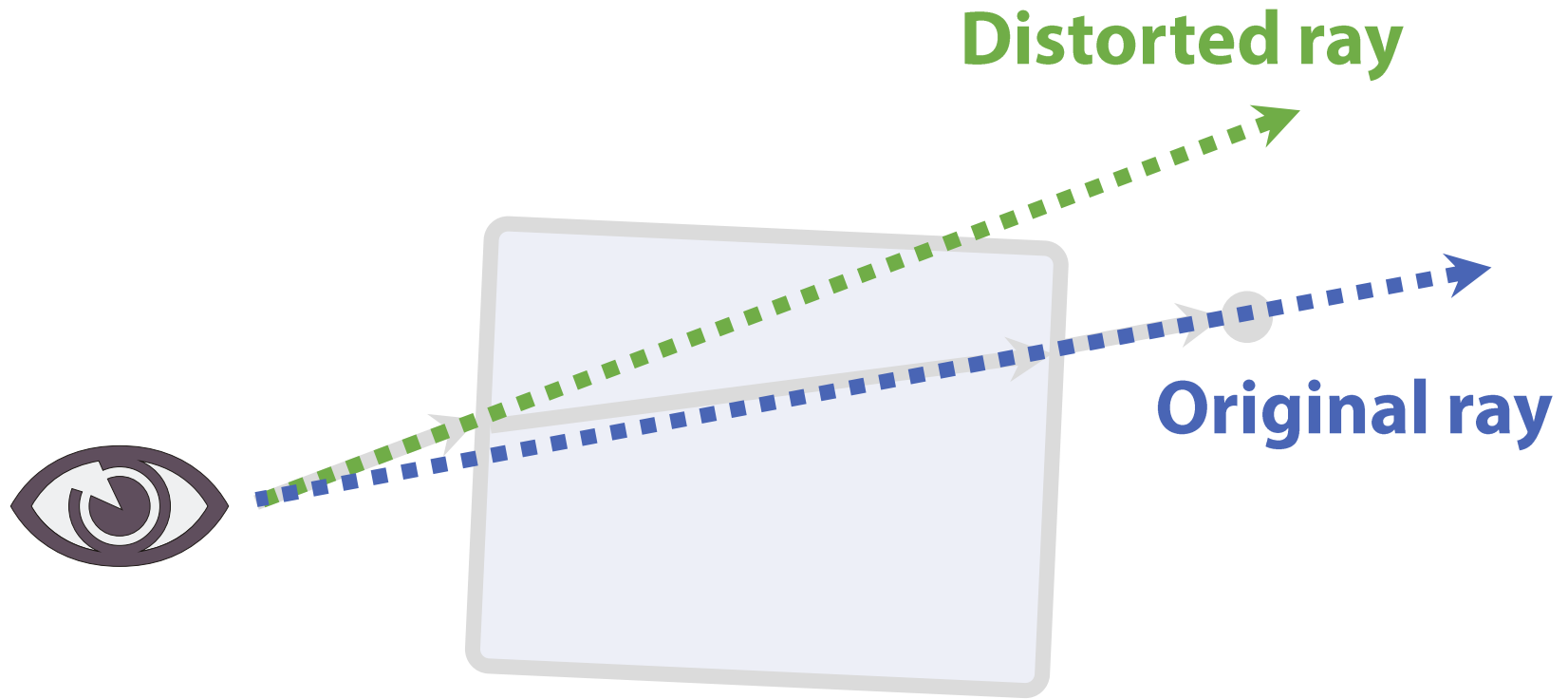
# Light field as Lumigraph [Gortler et al., '96]

An optical ray = a 4D vector  $(s, t, u, v)$

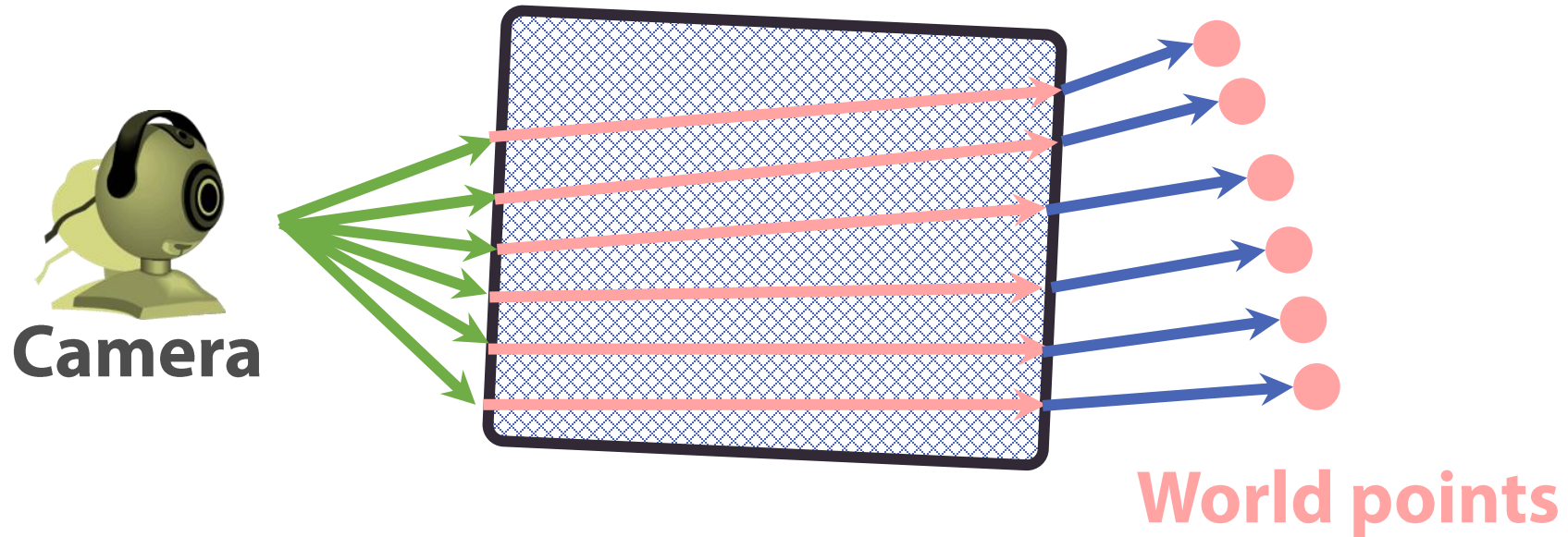




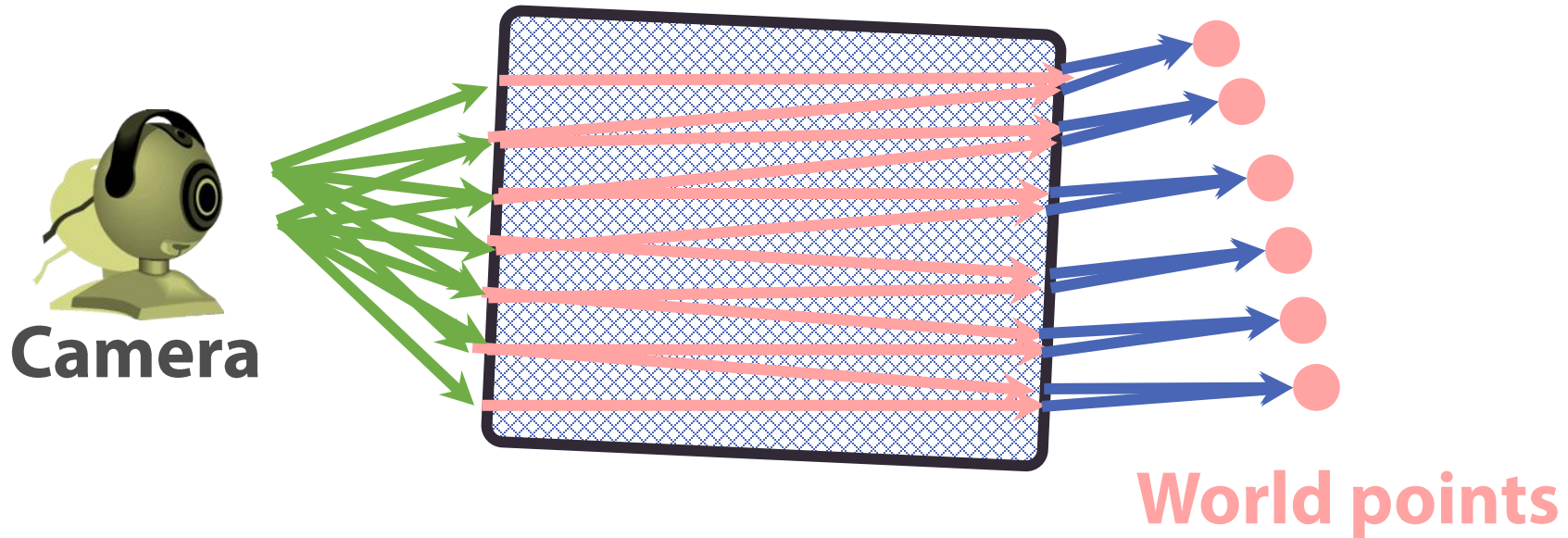
# Learn optical rays



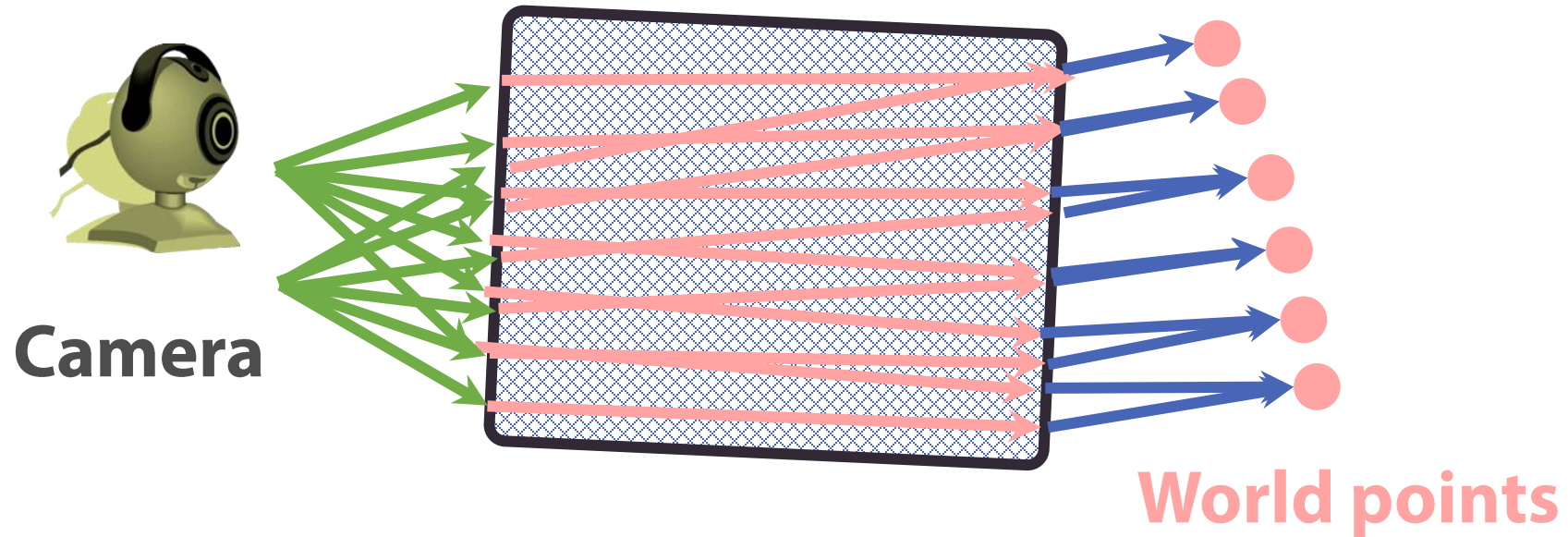
# Learn optical rays



# Learn optical rays

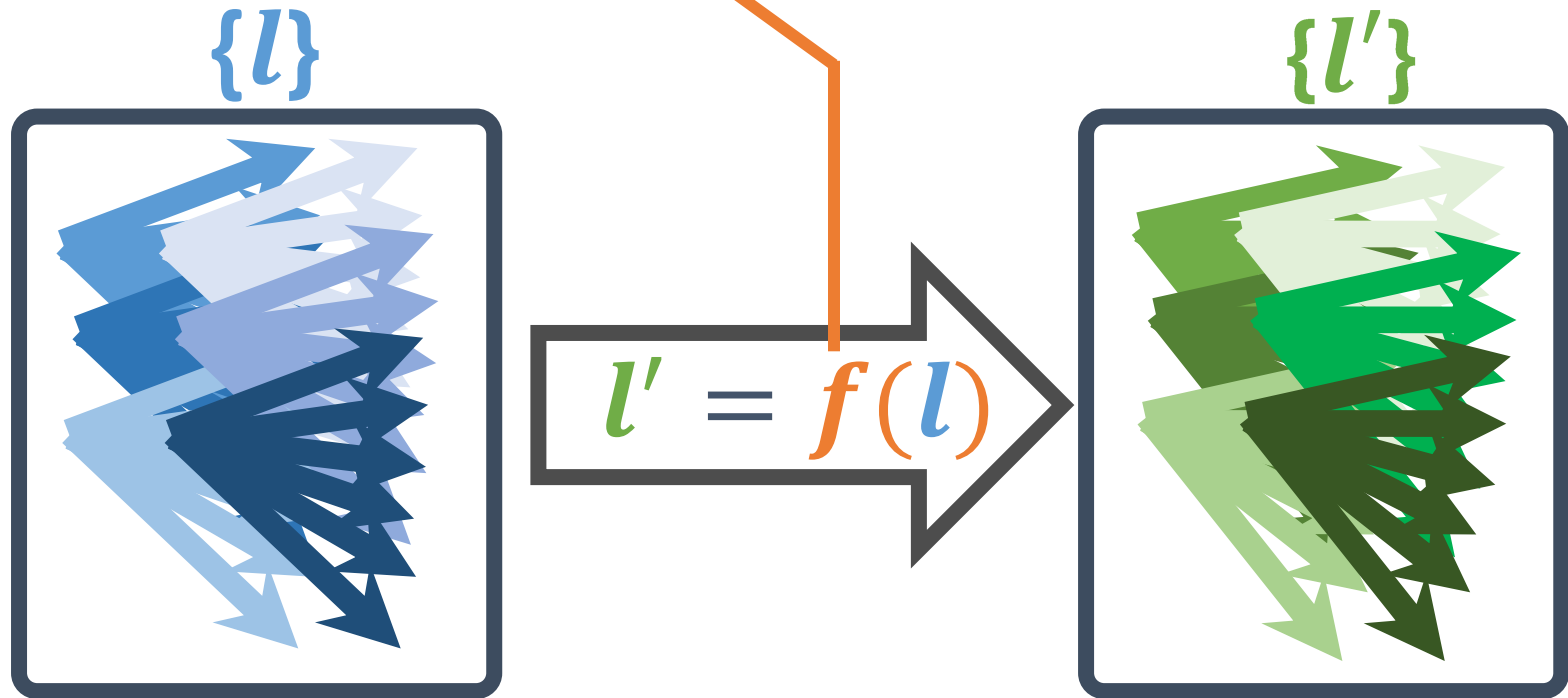


# Learn optical rays



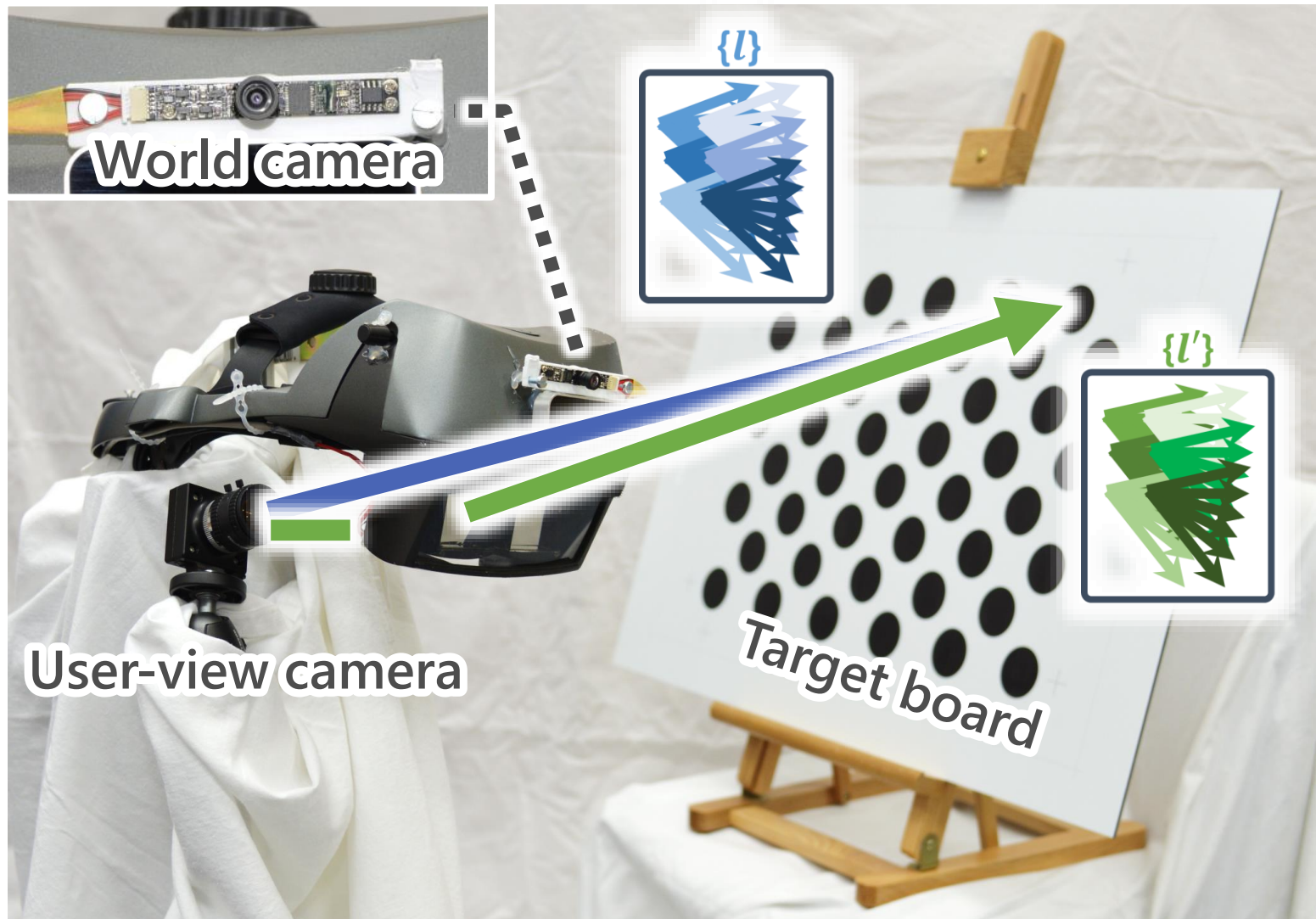
# Light field (4D-to-4D) mapping

Non-linear regression (\*)



(\*) Gaussian Kernel Least Squares Regression

# Experiment setup

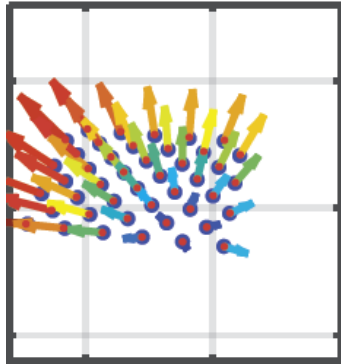


(HMD: nVisor ST60, Camera: iDS and Delock)

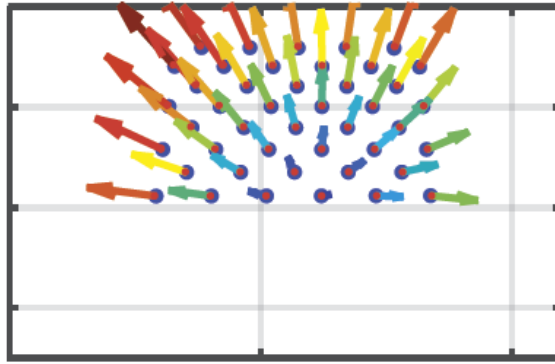


# Learned distortion maps

Single view point

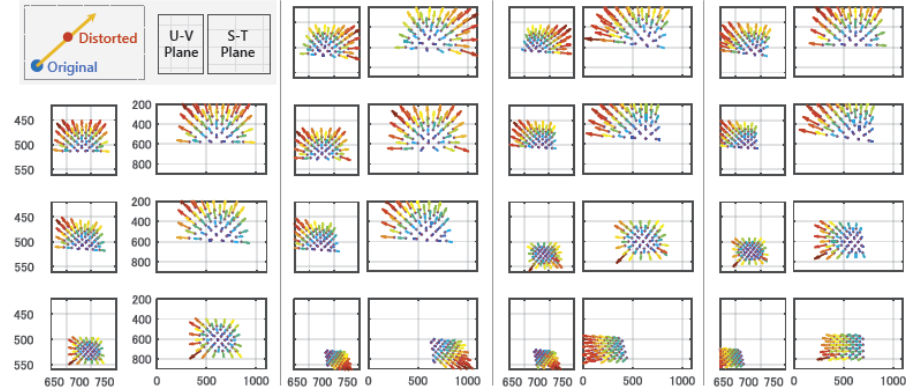


UV-plane

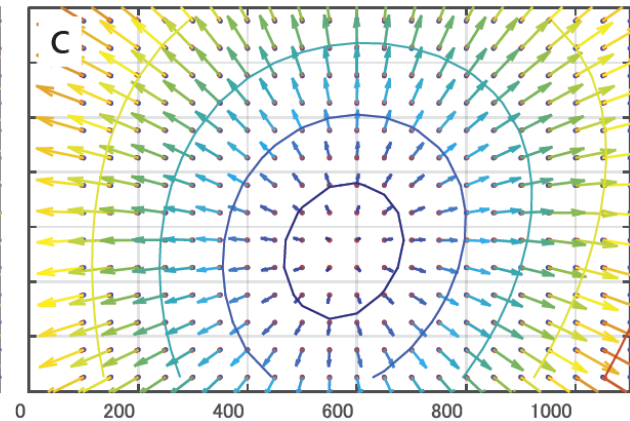
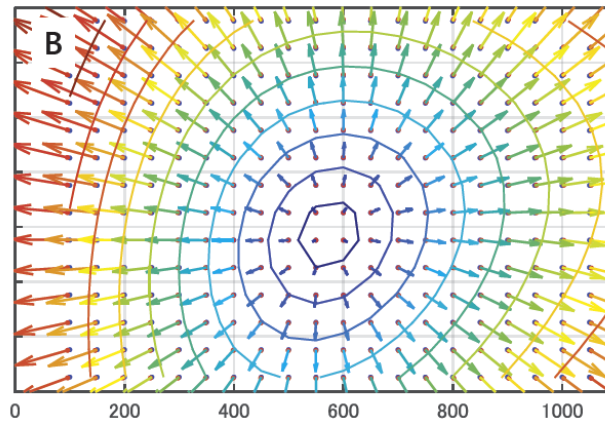
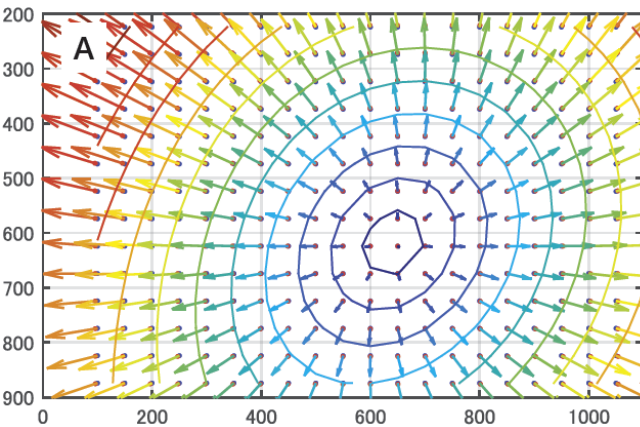


ST-plane

Many view points

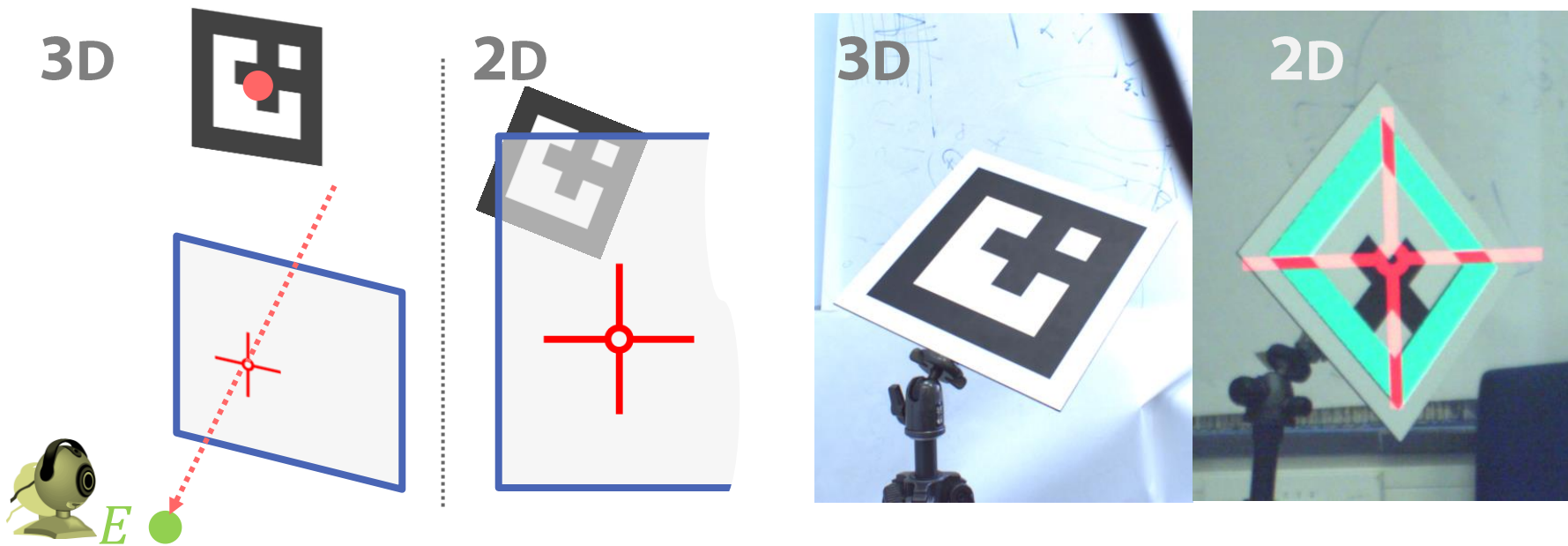


Estimated **non-linear** maps for **new view points**



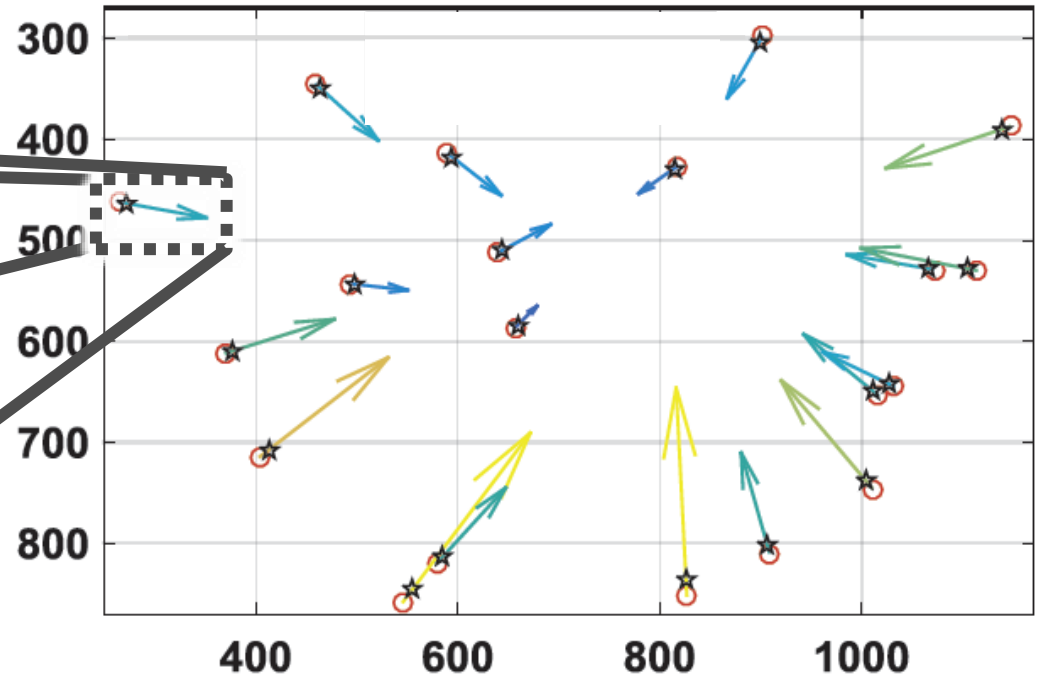
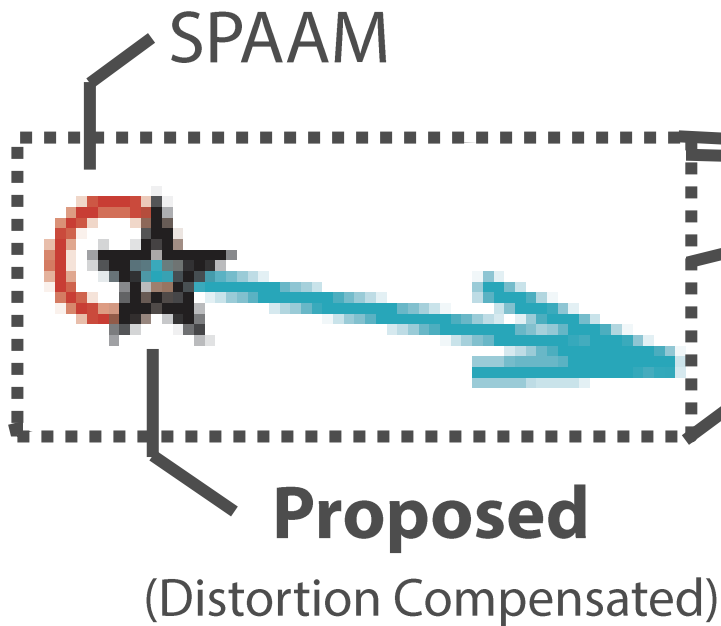
# Evaluation via a camera-based SPAAM

Collect ground truth 2D-3D correspondences

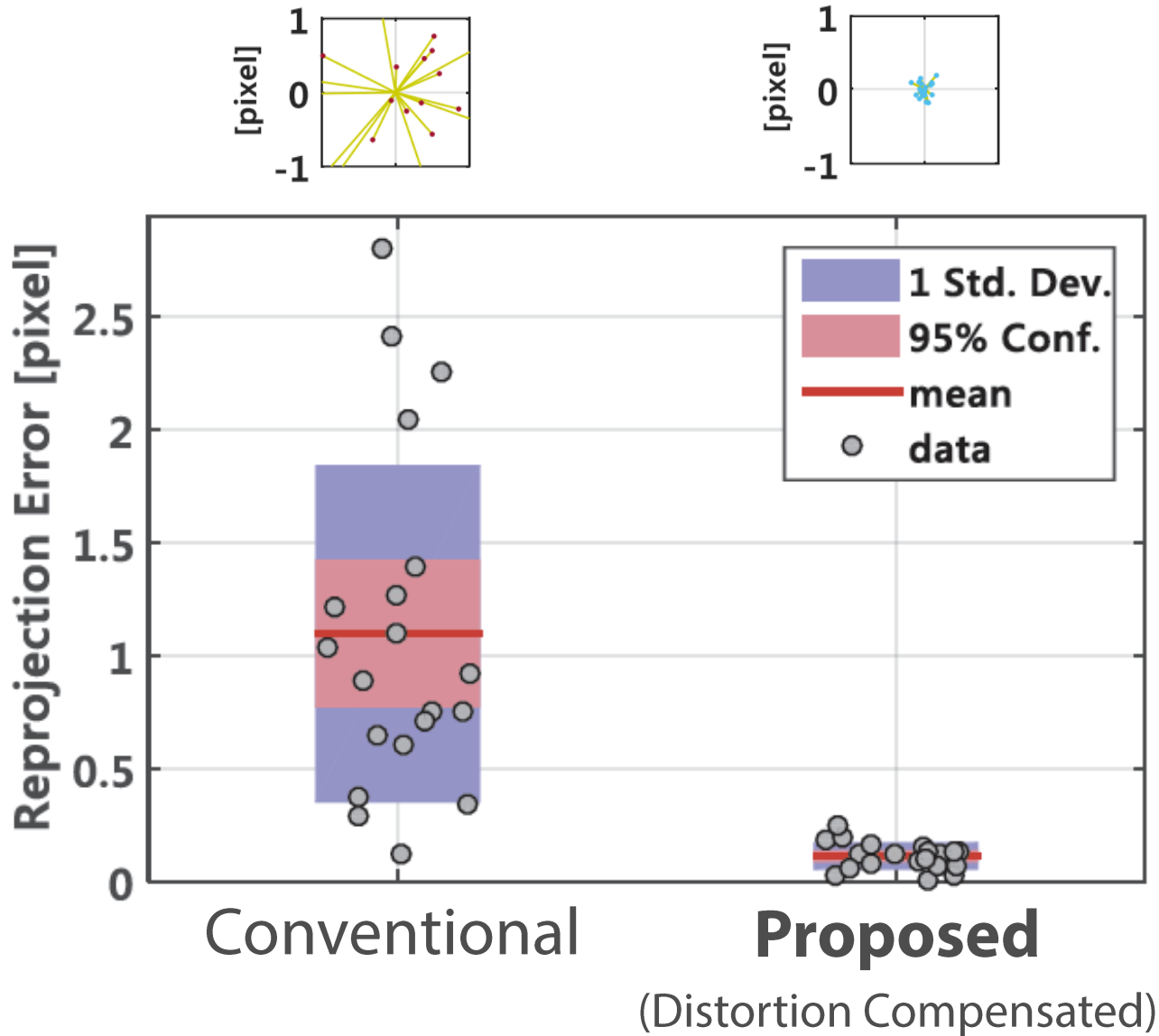


# Visualization of calibrated points

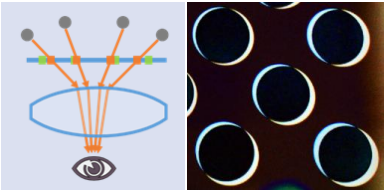
Example:



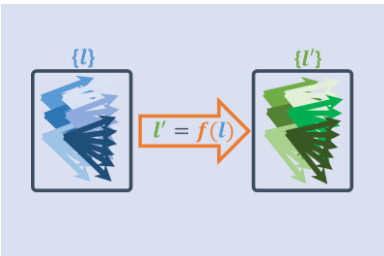
# SPAAM calibration error



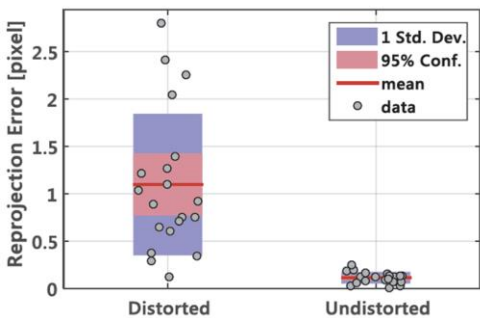
# Summary



Modeling **lens distortion** caused by OST-HMD



Providing distortion correction as a 4D-4D **light-field** mapping

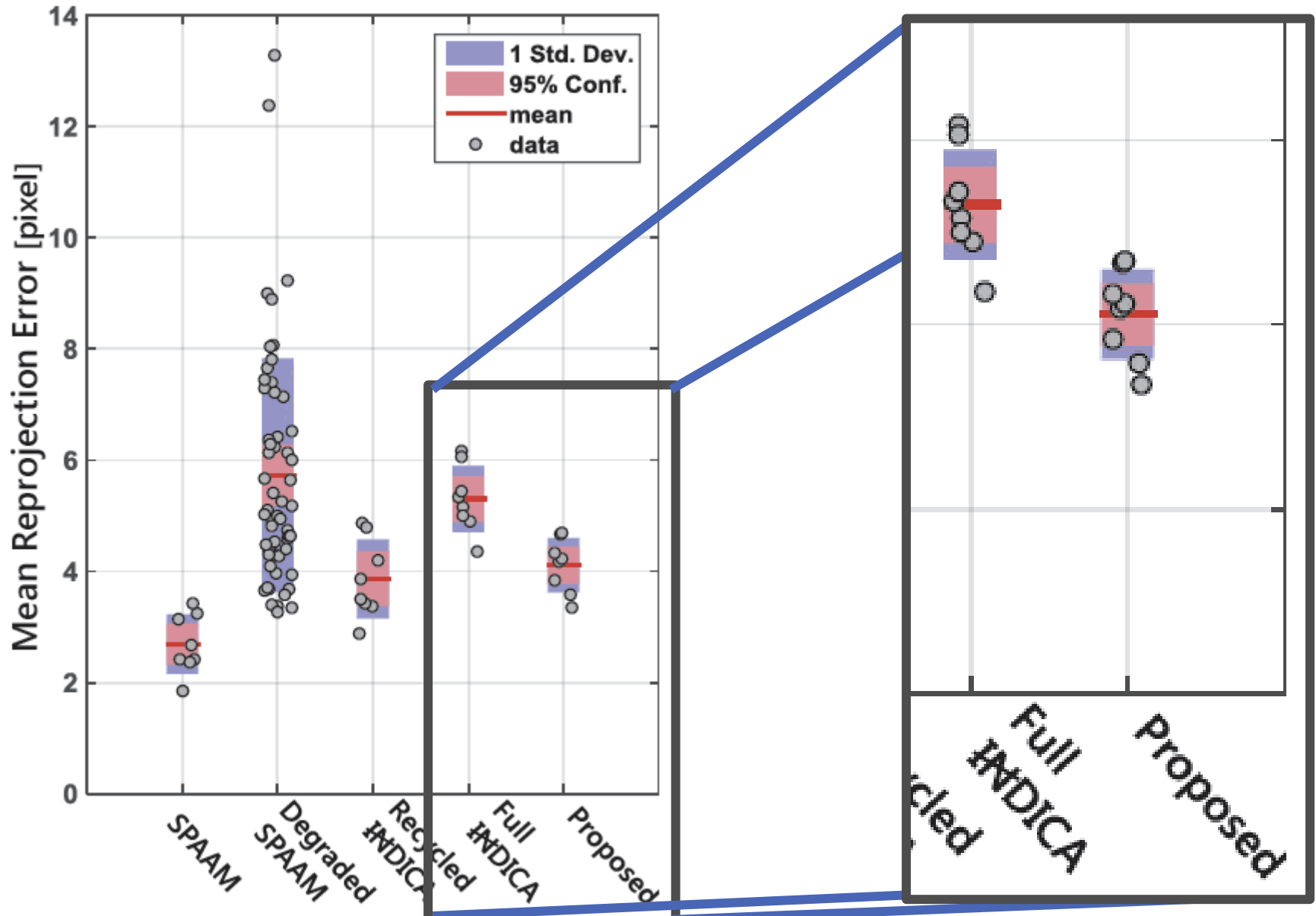


Demonstrating our method improves **accuracy** and reduces systematic error

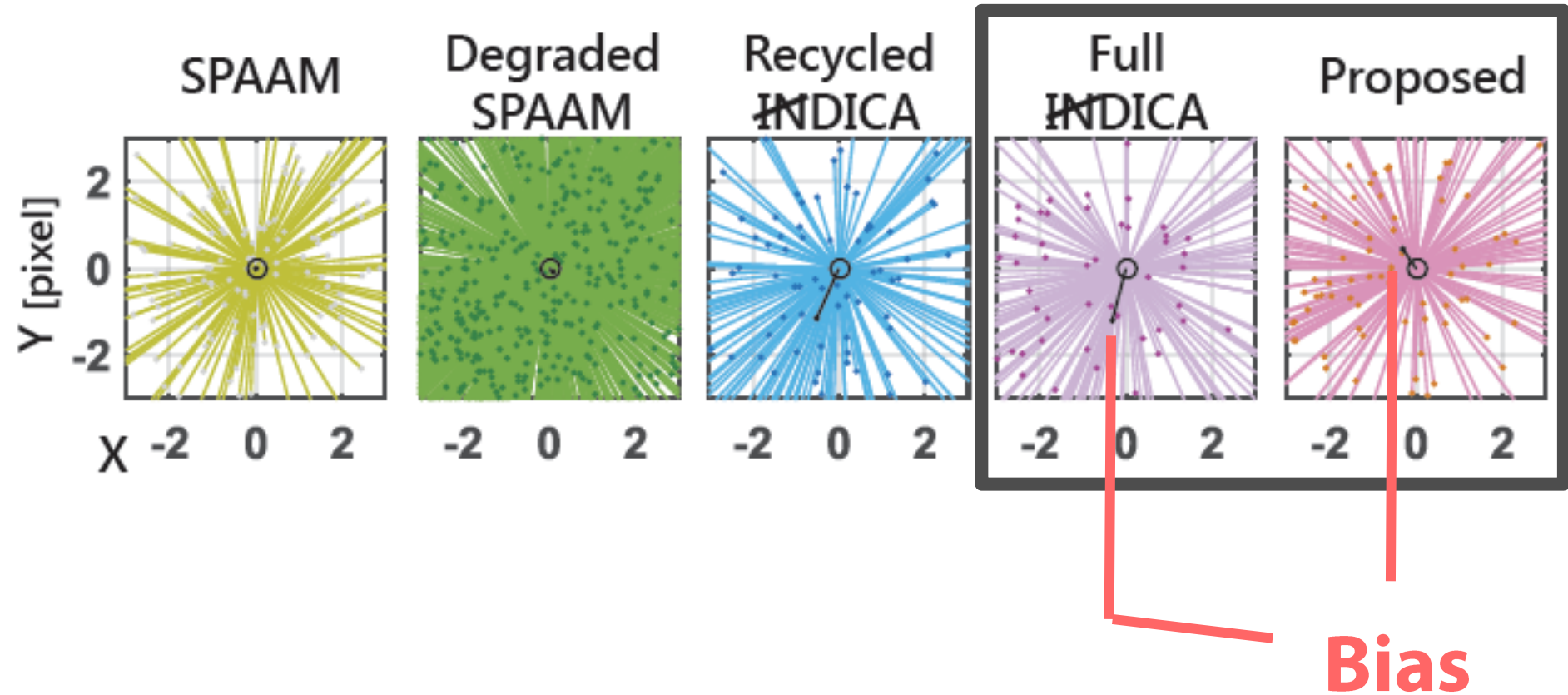


# Appendix

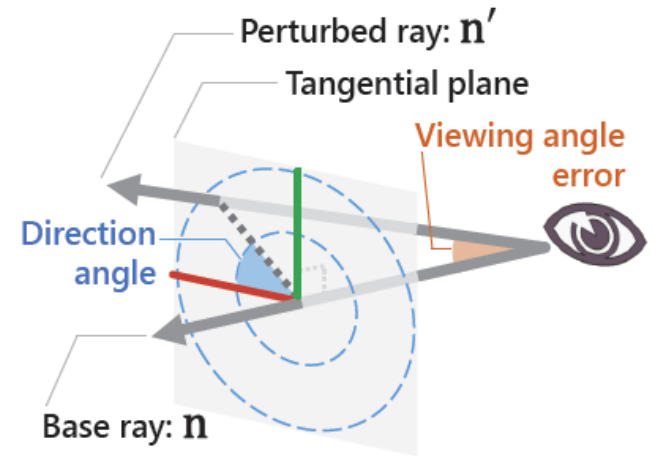
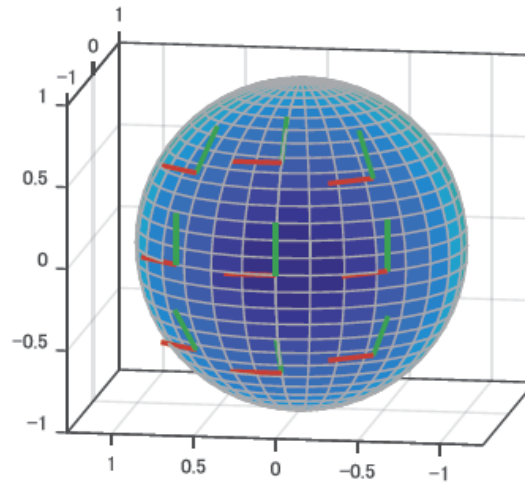
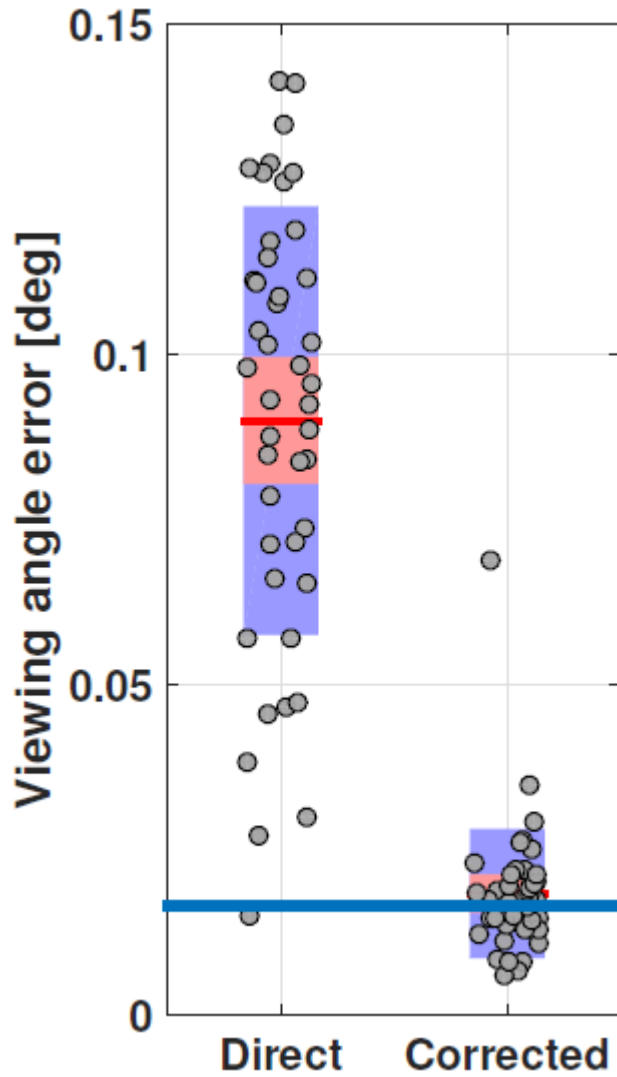
# Evaluation via user-based SPAAM



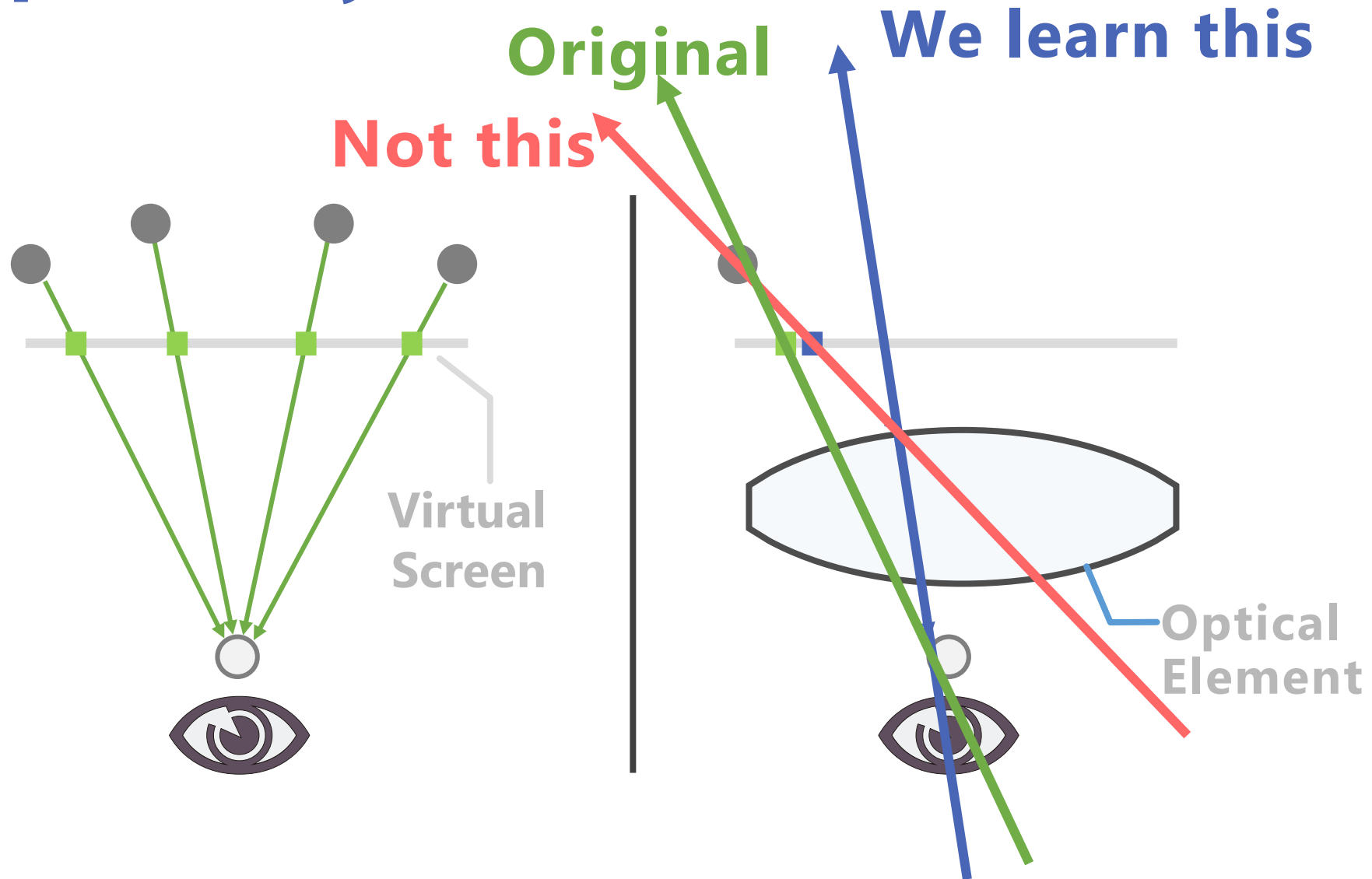
# Evaluation via user-based SPAAM



# Additional data



# Optical ray definition





# (Future) work

## □ Fundamentals

- Optical + Image distortion (under review)
- Visual consistency (under review)
- Temporal consistency

## □ Applications

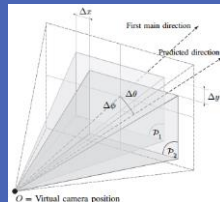
- Vision enhancement (AH'15 best paper)
- Real-time calibration

# Consistency issues in OST-HMDs

## Temporal



[Zheng '14]



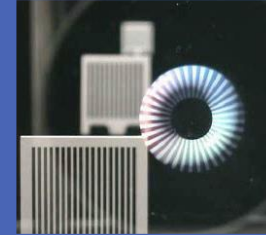
[Didier '05]

## Visual



D) Final result

[Kiyokawa '01]



[Liu '08]



[Lee '09]

## Social



Image from Google  
Glass: Don't Be A  
Glasshole | Mashable

## Spatial

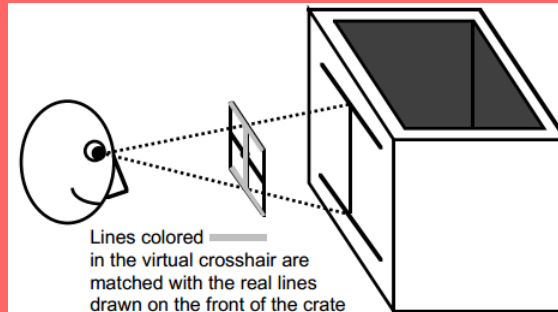
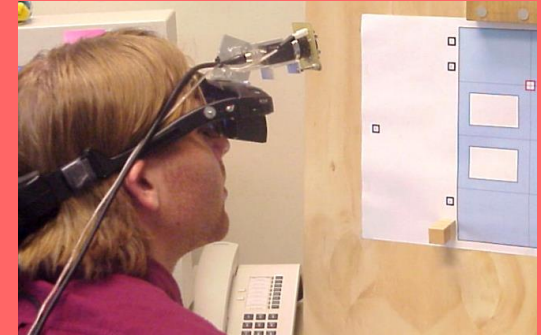


Figure 3.21: Conceptual diagram of FOV calibration

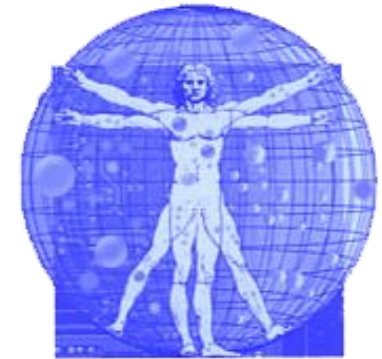
[Azuma '95]



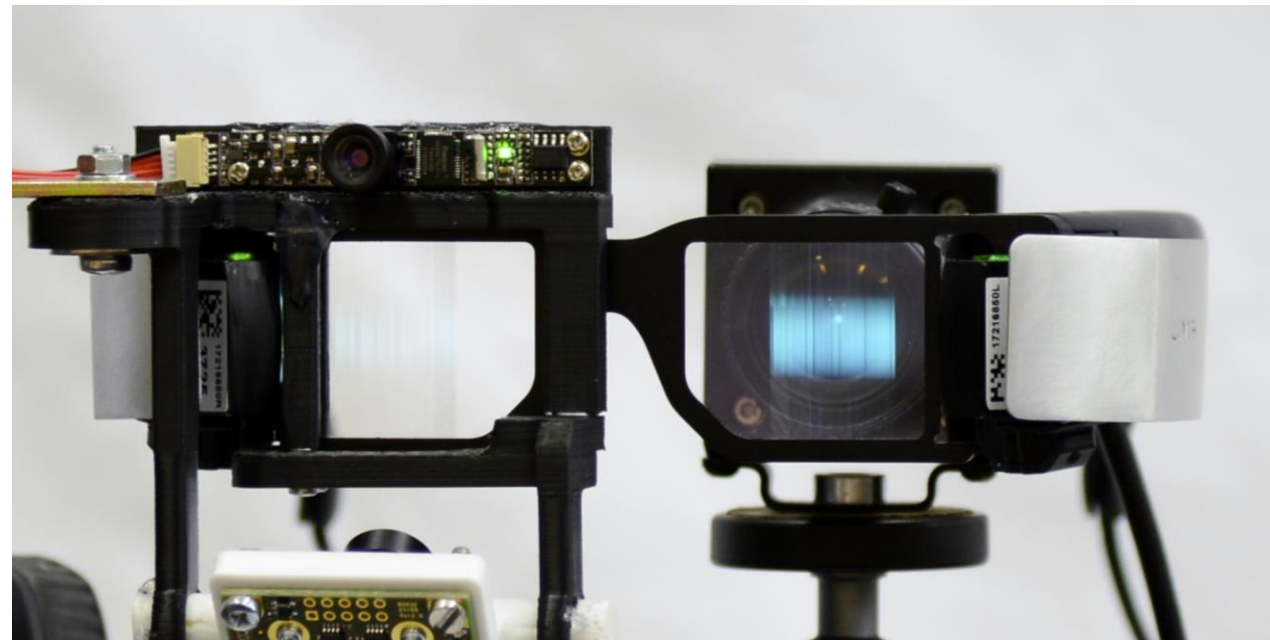
[Tuceryan '00] [Genc '02]

# If we have an **ultimate** OST-HMD

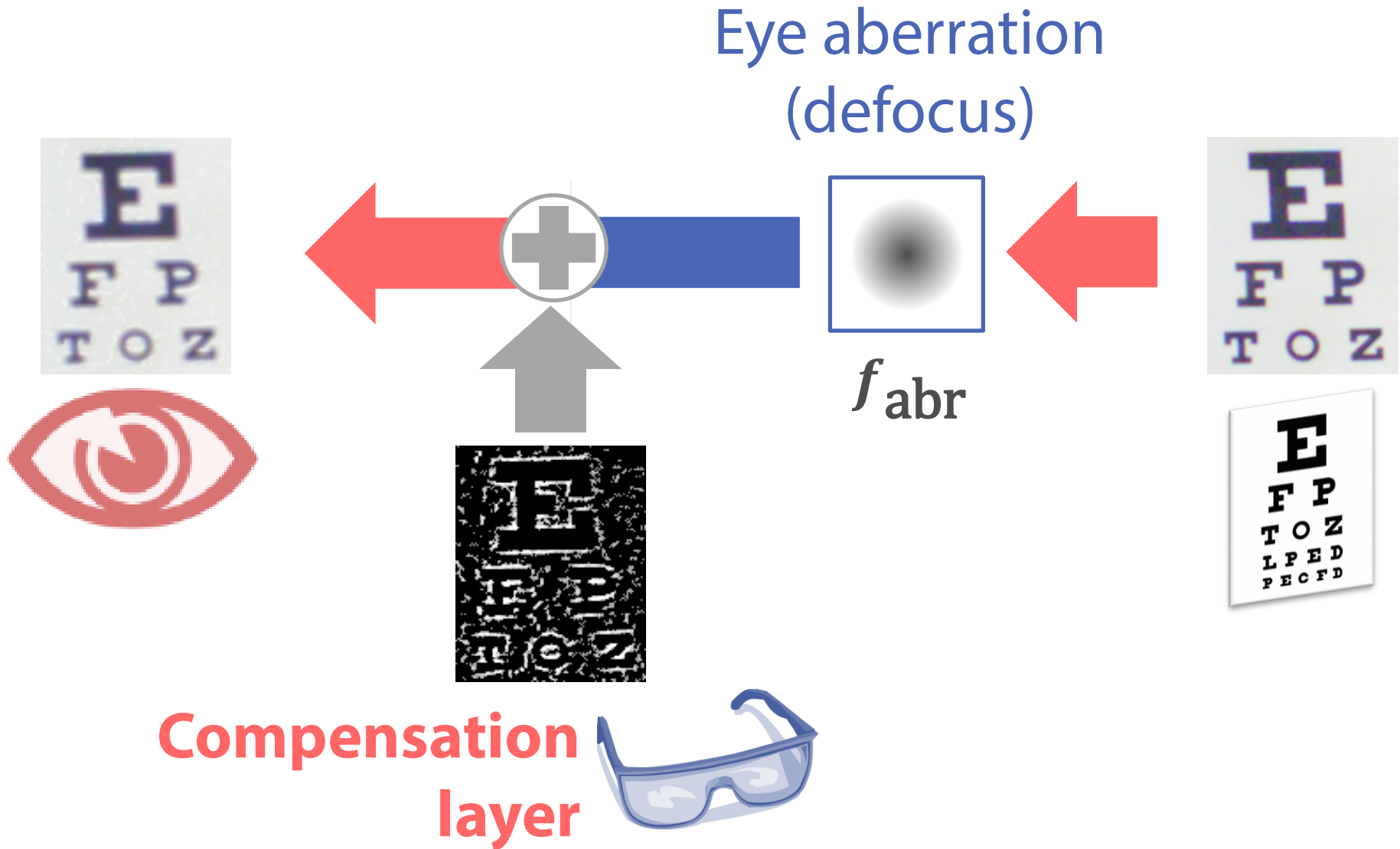
- Vision Enhancement
  - Augmented Human 2015 **best paper**



**AUGMENTED HUMAN**



# Defocus correction via OST-HMDs



# “Eye-HMD” camera modeling

- Is really a pinhole camera?
  - Human eyes are not simple
    - Optical and visual axes
  - HMD screens are not planer [Owen '04]
    - Retinal, Light-field

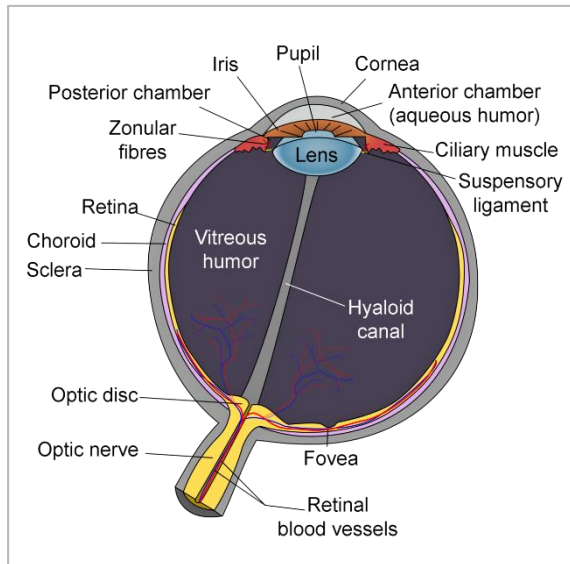
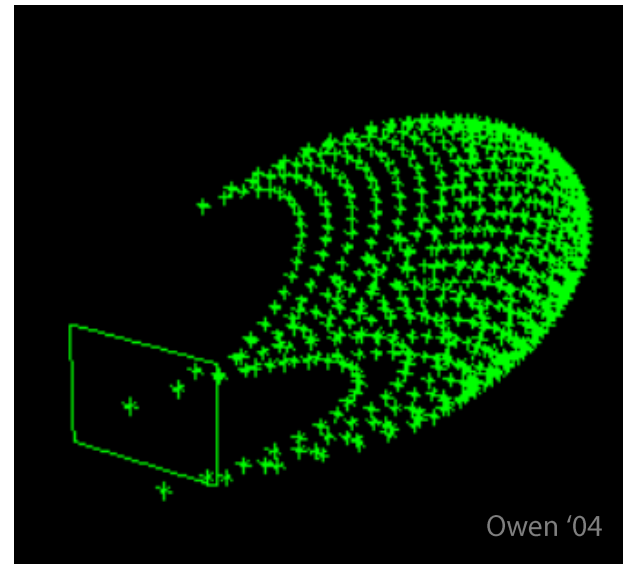


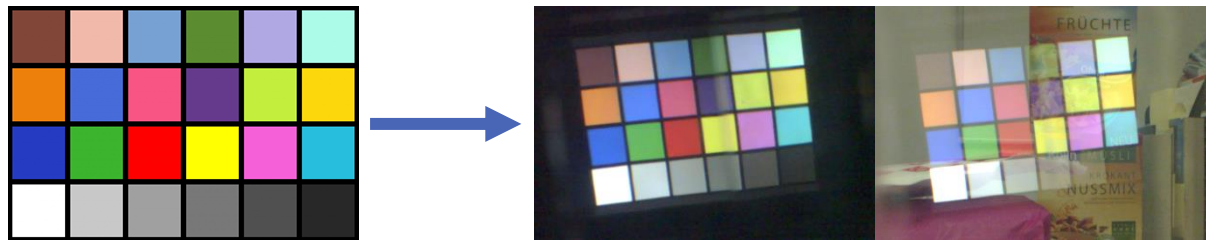
Image by Soerfm





# Color reproduction

- Optical See-Through HMD (OST-HMD) *distorts* digital color while rendering



- For **visually consistent** AR experiences, we want to *undistort* this effect
- We assume opaque OST-HMDs

# Light field collection

