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

Yuta Itoh and Gudrun Klinker
TU Munich, IEEE VR 2015, 23rd 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

Virtual

Real

Consistent
For accurate spatial calibration

- World to Eye
- OST-HMD to Eye
Eye and HMD calibration

Eye

Virtual Image

World
Manual method [user interaction required]

SPAAM
Single Point Active Alignment Method
[Tuceryan ’00] [Genc ’02]
SPAAM (Manual Calibration) video
Eye and HMD calibration
Eye and HMD are dynamic

Re-calibrate!

Eye

World
Eye and HMD are **dynamic**

Re-calibrate!?
Automated method interaction-free

INDICA

Interaction-free Display Calibration [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

Combiner (a half mirror)

Eye

Image source

Environment
The real world is **CRUEL**

- Distorted ray
- Dedicated optics
- Medium
- Environment
- Eye
- Image source
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
Light field

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

An optical ray = a 4D vector \((s,t,u,v)\)
Learn optical rays

Distorted ray

Original ray
Learn optical rays

Camera

World points
Learn optical rays

Camera

World points
Learn optical rays

Camera

World points
Light field (4D-to-4D) mapping

Non-linear regression (*)

\[ l' = f(l) \]

(*) Gaussian Kernel Least Squares Regression
World camera

User-view camera

Target board

(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

A  B  C
Evaluation via a camera-based SPAAM

Collect ground truth 2D-3D correspondences
Visualization of calibrated points

Example:

SPAAM

Proposed
(Distortion Compensated)
SPAAM calibration error

Expected Reprojection Error [pixel]

Conventional

Proposed (Distortion Compensated)
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

Mean Reprojection Error [pixel]

- SPAAM
- Degraded
- Recycled
- Full INDICA
- Proposed

1 Std. Dev.
95% Conf.
mean
data
Evaluation via user-based SPAAM

Bias
Additional data
Optical ray definition

Original

Not this

We learn this

Virtual Screen

Optical Element
(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

[Kiyokawa ‘01]  [Liu ‘08]  [Lee ‘09]

Social

Don't be a Glasshole

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

Spatial

[Azuma ‘95]  [Tuceryan’00] [Genc ‘02]
If we have an **ultimate** OST-HMD

- Vision Enhancement
  - Augmented Human 2015 best paper
Defocus correction via OST-HMDs

Eye aberration (defocus)

Compensation layer
“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

![Diagram of human eye](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

1. $R_{BE}, t_{BE}$

2. $R_{BW}, t_{BW}$

3. $W, S$

Direct user-view: $I$

via the HMD: $I'$