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

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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
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

Eye

Combiner (a half mirror)

Image source

Environment
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

- 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
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 (*)

$\{l\} \rightarrow l' = f(l) \rightarrow \{l'\}$

(*) 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

Proposed (Distortion Compensated)
SPAAM calibration error

![Graph showing reprojection error comparison between conventional and proposed methods. The proposed method shows lower error variance compared to the conventional method.](image-url)
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
For indistinguishable AR!

Slides & code (yet): http://goo.gl/nDLdwi

P.S. I’ll be finishing my Ph.D. by 03.2016
Appendix
Evaluation via user-based SPAAM
Evaluation via user-based SPAAM

Bias
Additional data
Optical ray definition

Virtual Screen

We learn this

Original

Not this
(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

$f_{abr}$
“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
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. \( E \) \( \rightarrow \) \( B \)

2. \( W \)

\( R_{BW}, t_{BW} \)

\( S \)

\( R_{EW}, t_{EW} \)

3. \( W \) \( \rightarrow \) \( S \)

\( x_W \)

\( l \)

\( l' \)

Optics

Direct user-view: \( I \)

via the HMD: \( I' \)

\( u_E \)

\( u_{E'} \)