Neural Cameras: Learning Camera Characteristics for Coherent Mixed Reality

David Mandl, Peter Mohr, Tobias Langlotz, Christoph Ebner, Shohei Mori, Stefanie Zollmann, Peter M. Roth, Denis Kalkofen
Coherent Rendering in Mixed Reality

What is needed?
• Geometry & Registration
Coherent Rendering in Mixed Reality

What is needed?
• Geometry & Registration
• Material
Coherent Rendering in Mixed Reality

What is needed?
• Geometry & Registration
• Material
• Light & Shadows
Coherent Rendering in Mixed Reality

What is needed?
• Geometry & Registration
• Material
• Light & Shadows
• Camera effects!
Camera Effects in Mixed Reality

• Rendering not consistent with real camera
Camera Effects in Mixed Reality

• Rendering not consistent with real camera
  • Missing lens effects (Depth of field)
Camera Effects in Mixed Reality

- Rendering not consistent with real camera
  - Missing lens effects (Depth of field)
  - Wrong lighting/shadows (Exposure, ISO)
Camera Effects in Mixed Reality

• Rendering not consistent with real camera
  • Missing lens effects (Depth of field)
  • Wrong lighting/shadows (Exposure, ISO)
  • Wrong colors (Whitebalance)
Simulating Camera Effects

Problems

• Parameters needed often unknown
• Finetuning for each camera required
Simulating Camera Effects

Problems

• Parameters needed often unknown
• Finetuning for each camera required

Solution

• Capture images to infer parameters
• Simulate camera using deep learning
• Can be applied to every camera
Simulating Camera Effects

Problems
• Parameters needed often unknown
• Finetuning for each camera required

Solution
• Capture images to infer parameters
• Simulate camera using deep learning
• Can be applied to every camera
System Overview
System Overview

(a) Scene

Lens  Sensor  ISP

Real Camera

virtual  real

3D Model

(b) Initial rendering
System Overview

(a) Scene
- Scene elements: real and virtual
- Focal plane

(b) Initial rendering
- 3D Model
- Real tiger

(c) Lens Effects
- LensNet
- Real Camera

Lens
Sensor
ISP
System Overview
System Overview
System Overview

(a) Scene
(b) Initial rendering
(c) Lens Effects
(d) Color & Noise
(e) Processing
(f) Result

LensNet → SensorNet → ISPNet → Real Camera

3D Model → virtual → real
Lens Effects

- Prominent effect is out-of-focus blur
- Parts of the scene which are not at the focus plane
Lens Blur Network

LensNet (MLP)
• Input depth & focus distance
• Output parameters for GMM
• Render with GMM (k=3)
Lens Blur Network

LensNet (MLP)
• Input depth & focus distance
• Output parameters for GMM
• Render with GMM (k=3)

Training
• Calibration images
• Varying depth and focus
• Compute loss on result
Lens Blur results
Lens Blur results
Lens Blur results
Lens Blur results
Lens Blur results
Lens Blur results

PSNR: 30.2  
SSIM: 0.954
Reference

virtual

real

virtual

real

PSNR: 31.0  
SSIM: 0.972
Reference

GMM: LensNet

Real Lens
Lens Blur results

PSNR: 26.4
SSIM: 0.943

PSNR: 30.2
SSIM: 0.954

Reference

virtual

virtual

real

PSNR: 26.9
SSIM: 0.956

GMM:EM

virtual

virtual

real

PSNR: 31.0
SSIM: 0.972

GMM:LensNet

Reference

Real Lens
Lens Blur results

2.0D
PSNR: 23.8
SSIM: 0.918

PSNR: 26.4
SSIM: 0.943

PSNR: 30.2
SSIM: 0.954

Reference

virtual

virtual

virtual

real

6.4D
PSNR: 25.3
SSIM: 0.937

PSNR: 26.9
SSIM: 0.956

PSNR: 31.0
SSIM: 0.972

Reference

DDC

GMM.EM

GMM:LensNet

Real Lens
Camera Sensor
Sensor (Color & Noise)

SensorNet (MLP)

- **Input**: RGB + ISO, exposure
- **Output**: color correction + noise
- **Multi-Layer Perceptron**
Sensor (Color & Noise)

SensorNet (MLP)
• Input: RGB + ISO, exposure
• Output: color correction + noise
• Multi-Layer Perceptron

Training
• Images of known colors (sRGB)
• Training with varying ISO, exposure
Sensor Results

ISO 100
Exposure 50

Naive
Sensor Results

ISO 100
Exposure 50

ISO 100
Exposure 50
ISO 1250
Exposure 10

(a) Naive

(b) Color Correction
Sensor Results

![Sensor Results Diagram](image-url)
Image Signal Processor (ISP)
Image Signal Processor (ISP)

ISPNet (CNN)
- Adapted from Raw2Jpg [1]
- SensorNet result input
- Images from camera in YUV

Training
- RAW and JPG images
- Feature vector
- Circular loss + individual loss

Results Processor

SensorNet only

ISPNet only
Results Processor

- SensorNet only
- ISPNet only
- SensorNet & ISPNet
Results Processor

SensorNet only vs ISPNet only vs SensorNet & ISPNet

Caption:
- Artificial light
- Daylight
- Real vs. Real
Results

(a) Real, ours, shading, naive

(b) Ours, shading, naive

(c) Error visualization
Results
Limitations & Future Work

Camera Effects
• Chromatic aberration
• Motion blur
• Vignetting

Scene Simulation
• Material estimation
• Light source detection
• Shadows