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

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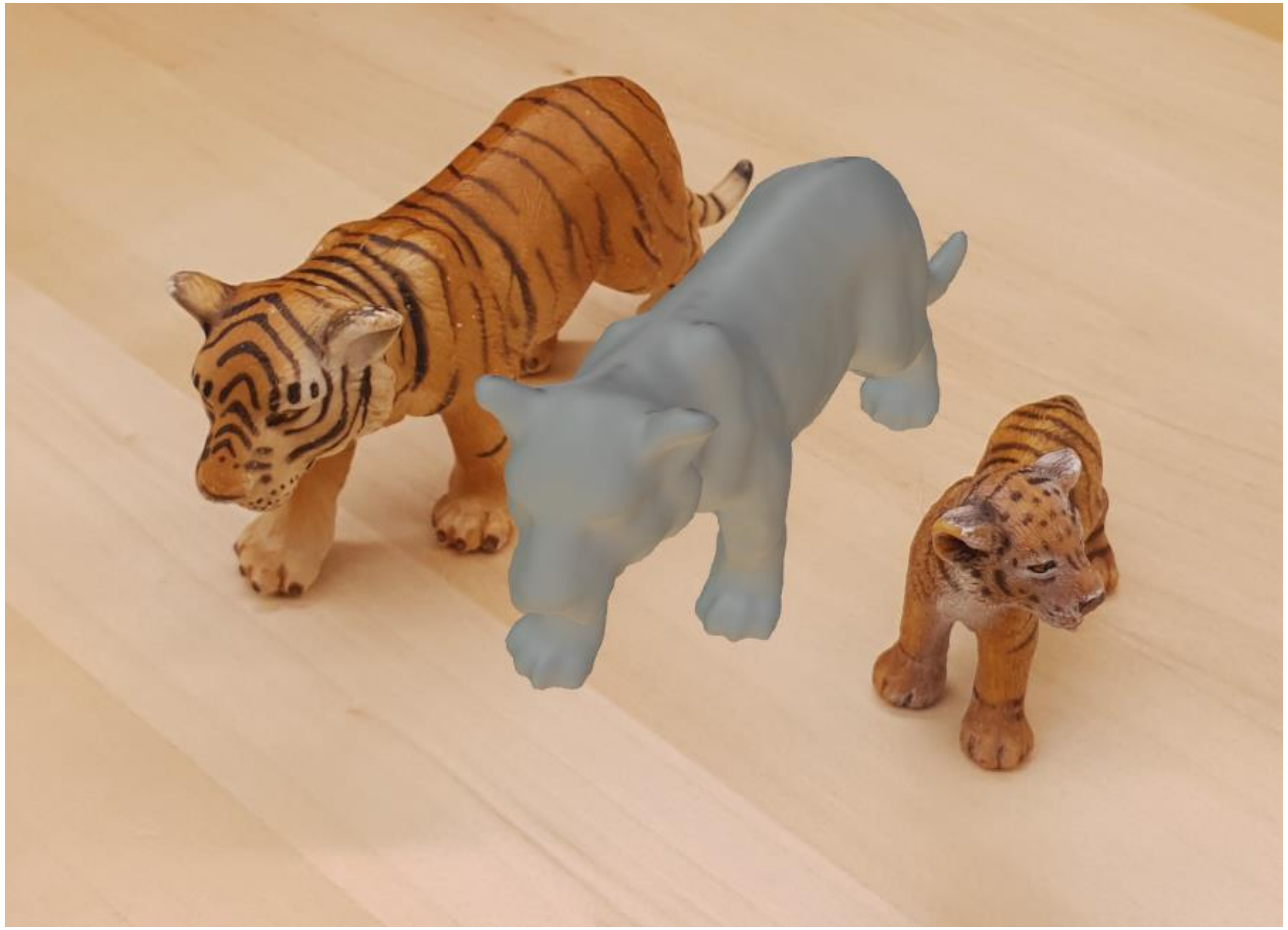
Coherent Rendering in Mixed Reality

What is needed?

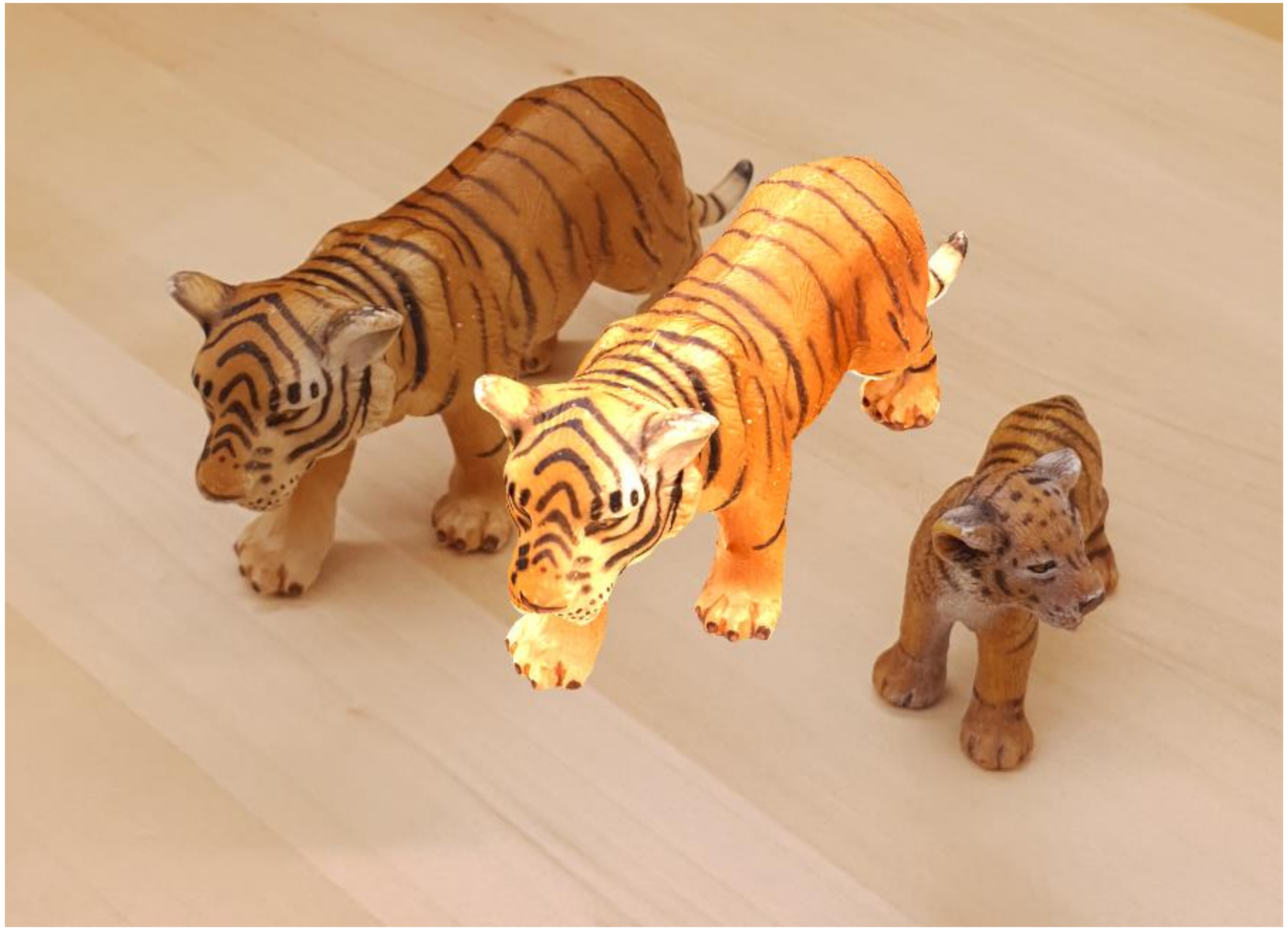
- Geometry & Registration



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

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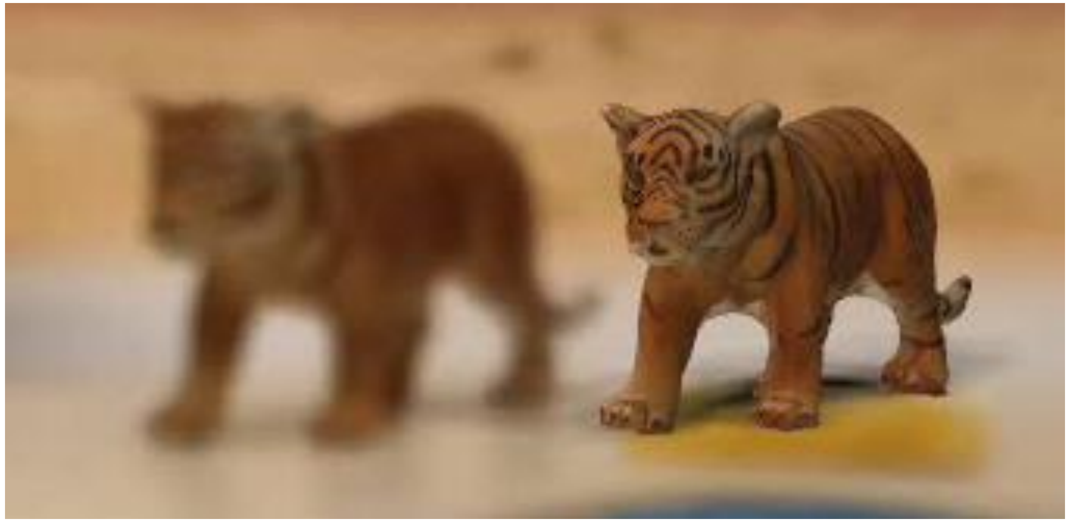
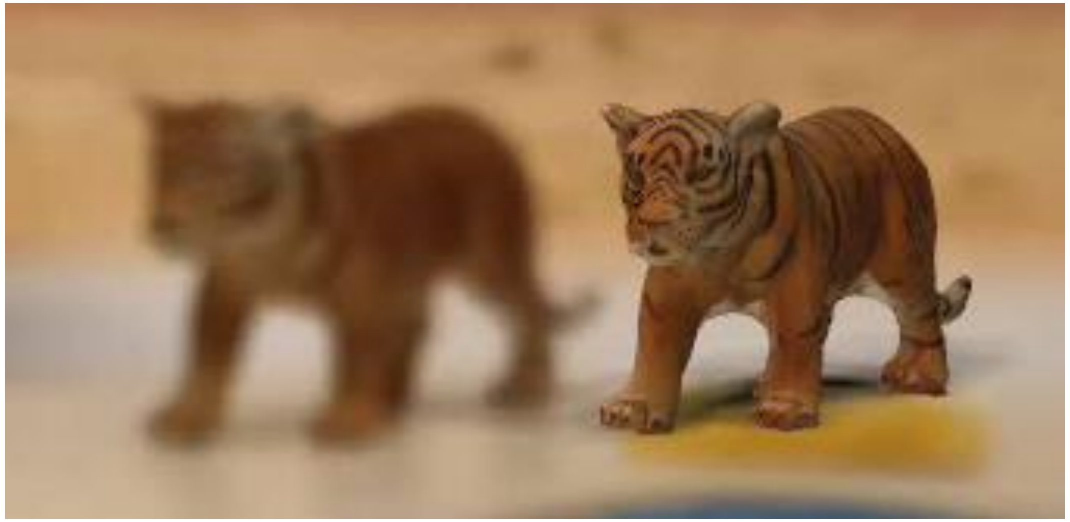
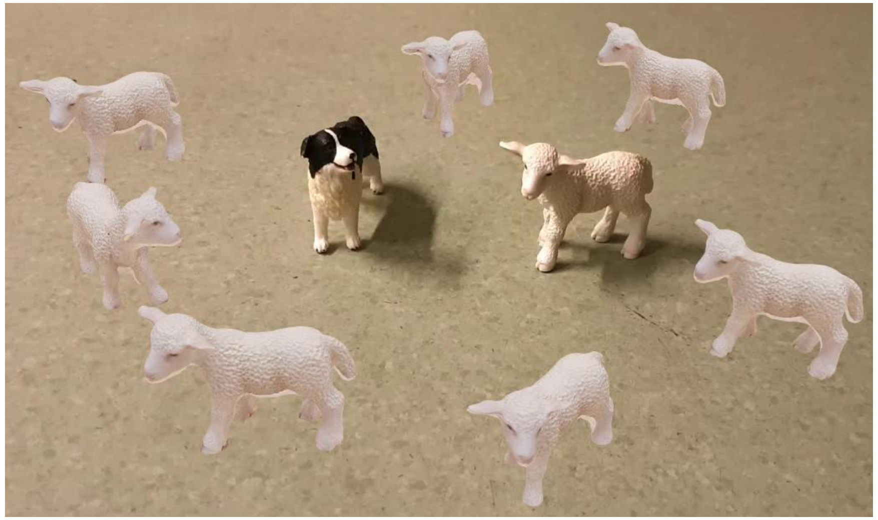
  - Missing lens effects (Depth of field)



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

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- Finetuning for each camera required

Solution

- Capture images to infer parameters
- Simulate camera using deep learning
- Can be applied to every camera

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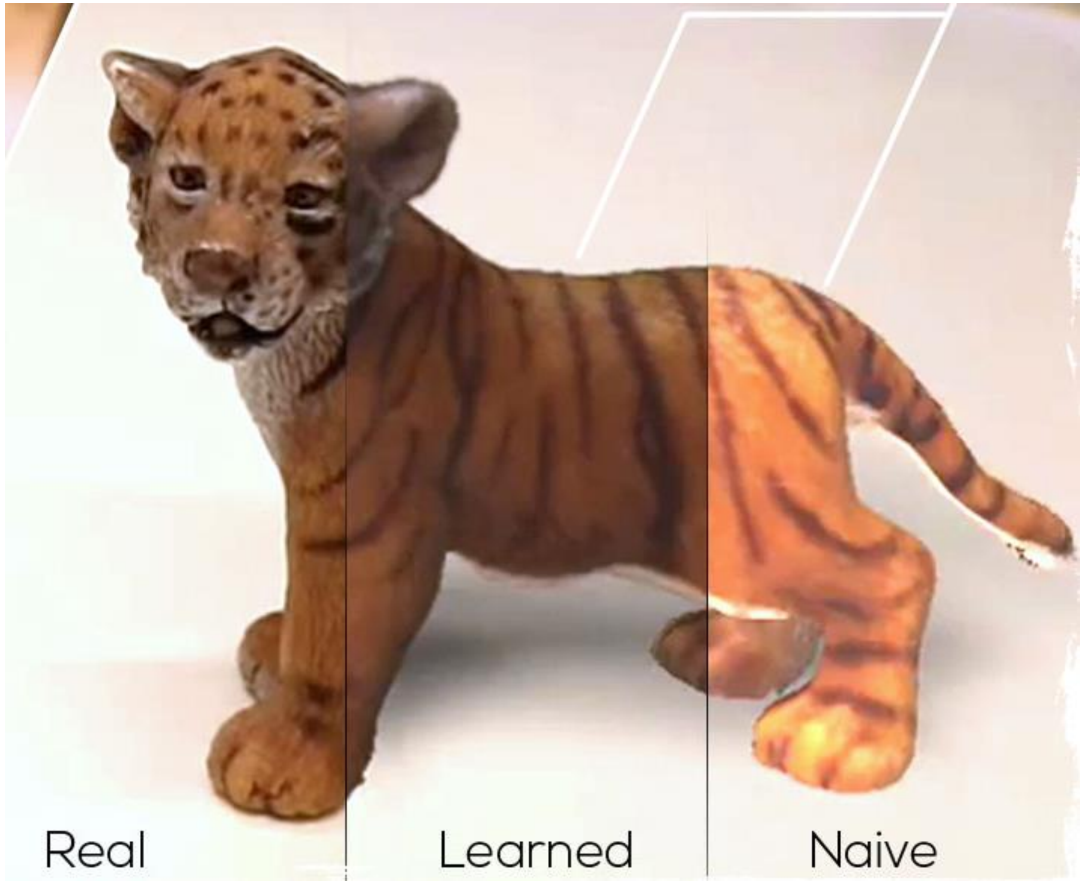
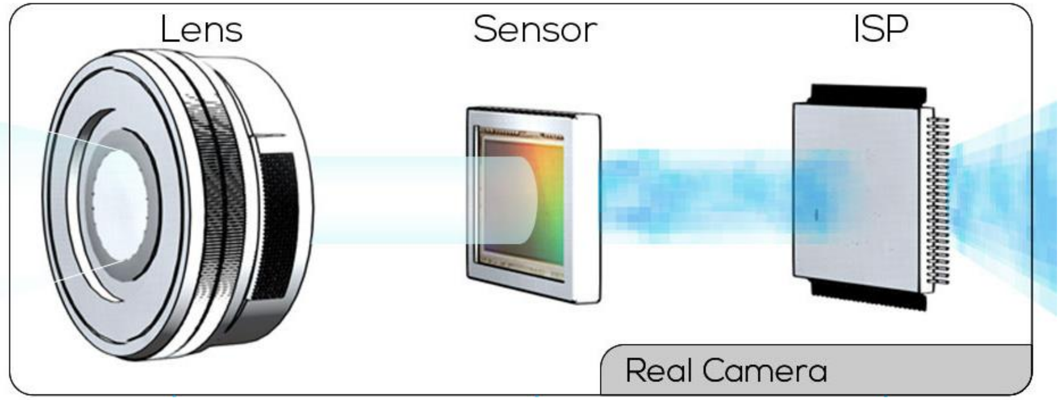
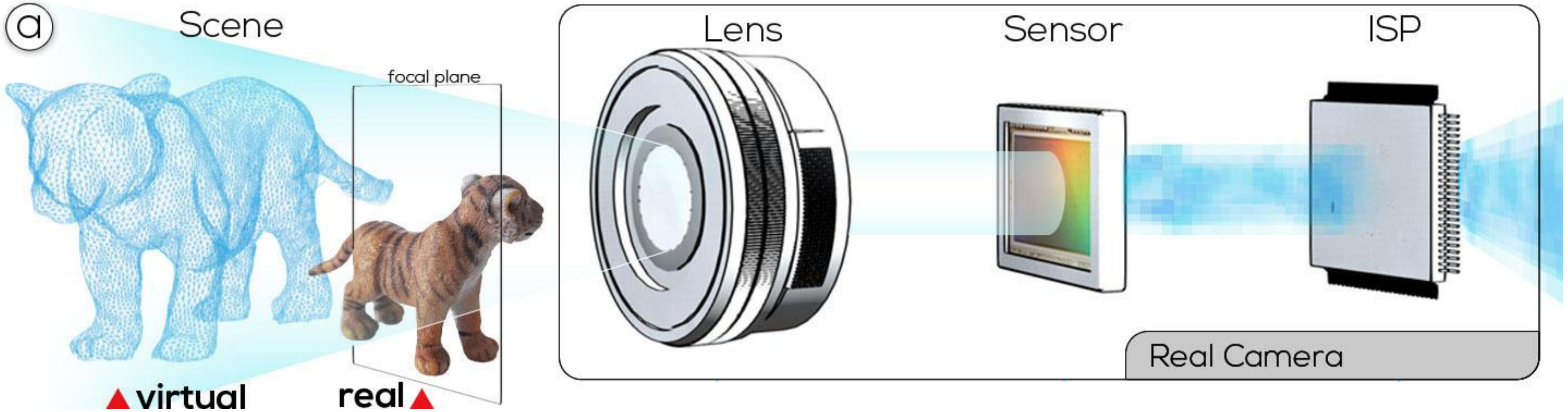


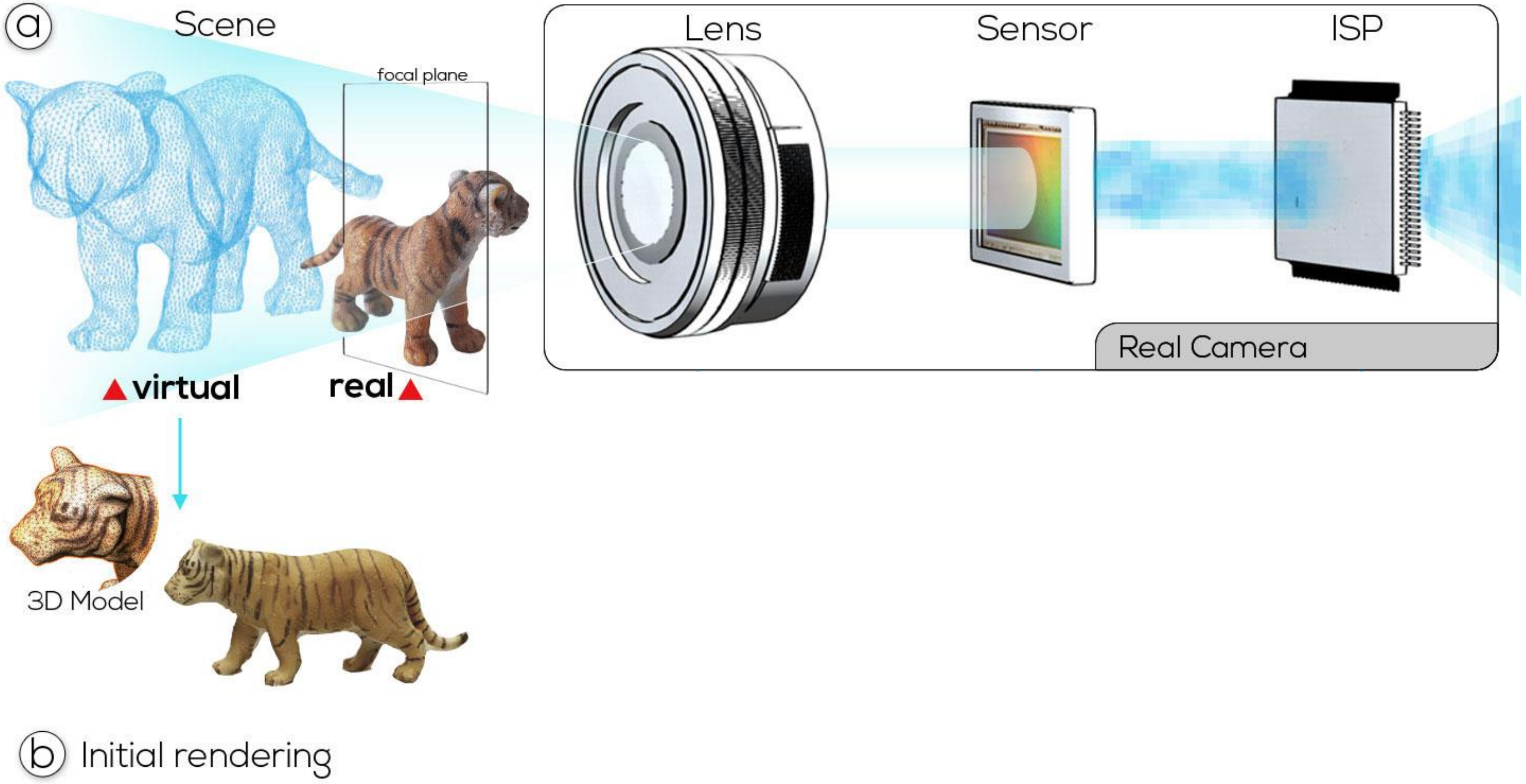
System Overview


Lens
Sensor
ISP
Real Camera

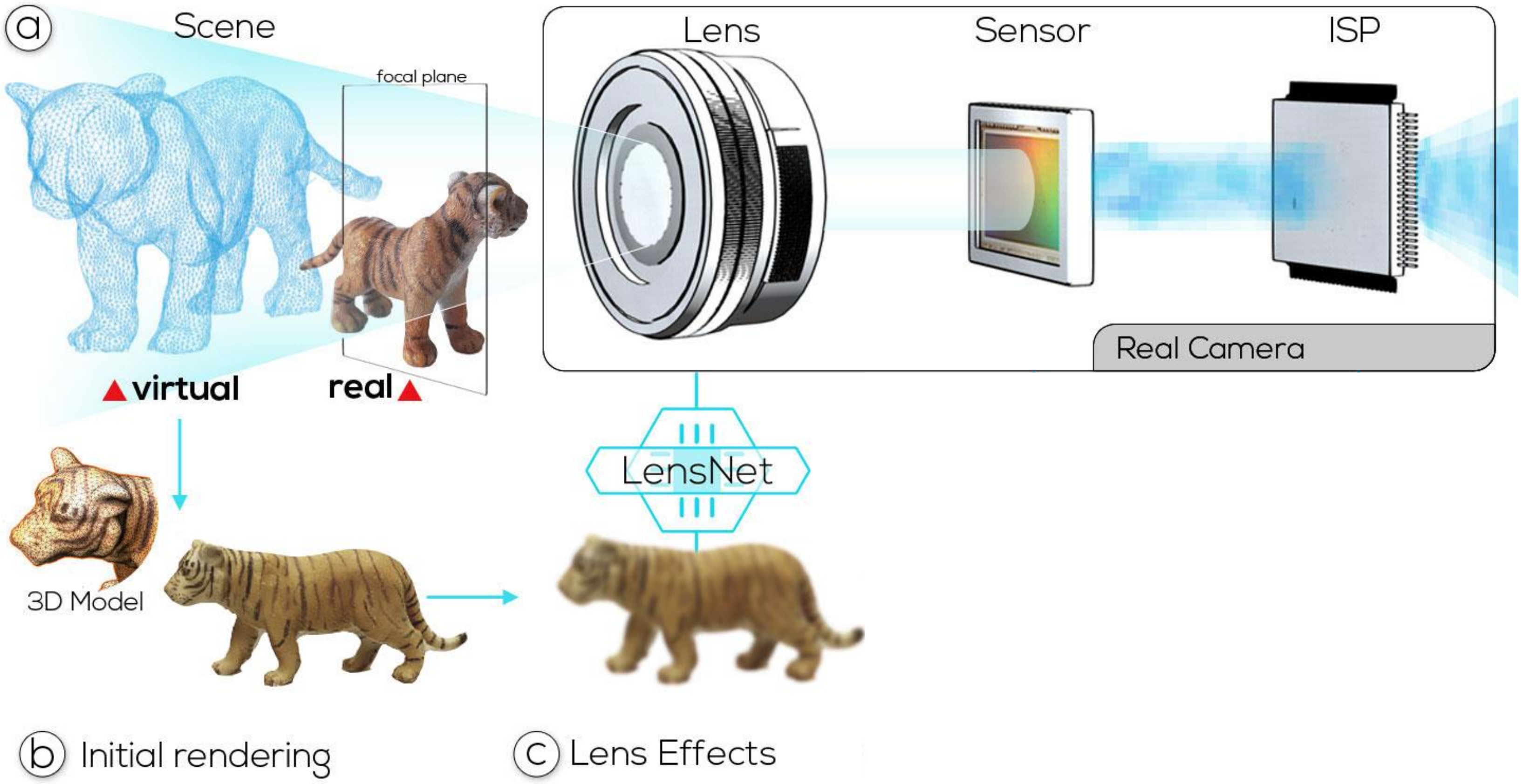
System Overview


a
Scene
focal plane
virtual
real
Lens
Sensor
ISP
Real Camera

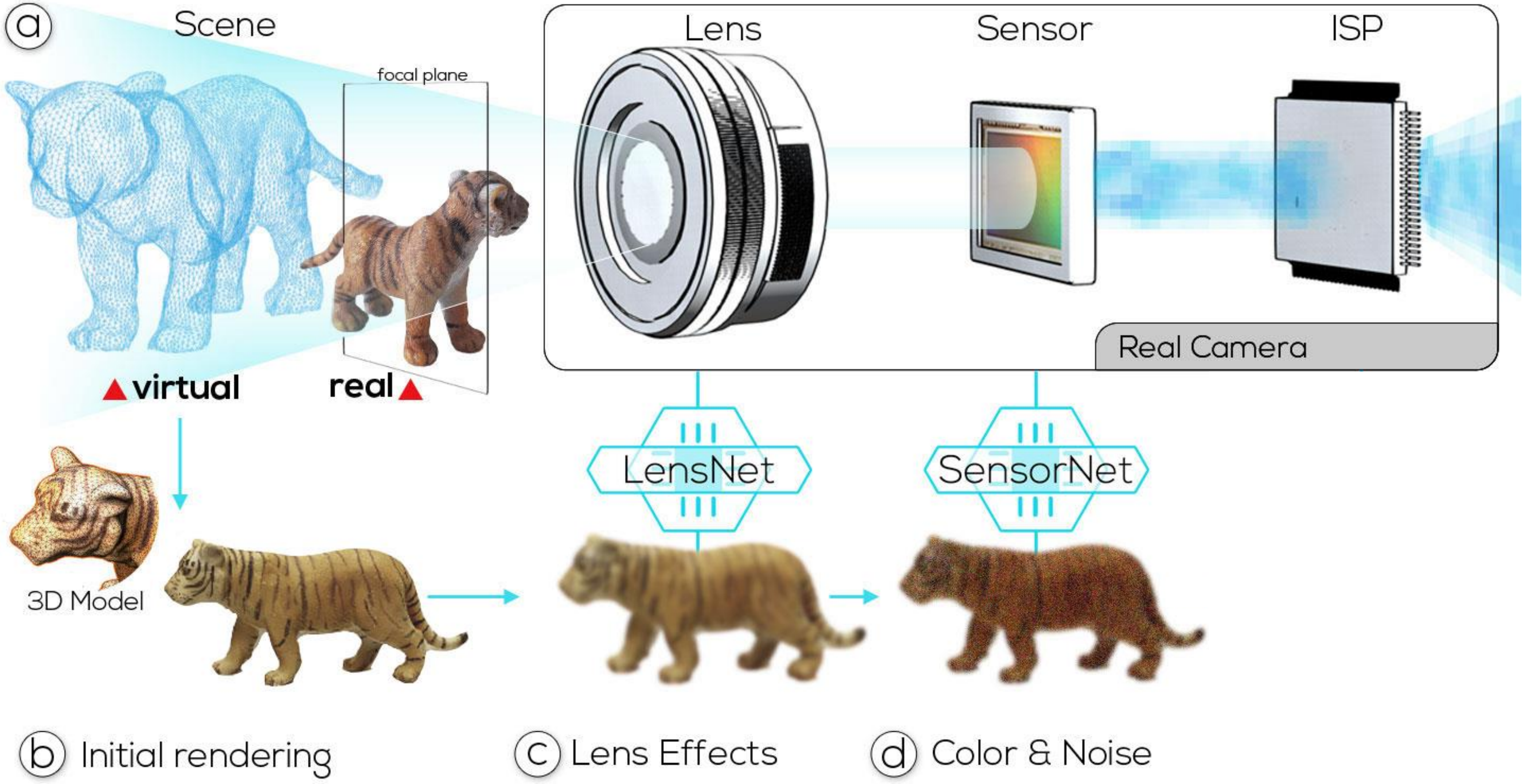
System Overview


ⓐ
Scene
focal plane
▲virtual
real▲
Lens
Sensor
ISP
Real Camera
3D Model
ⓑ Initial rendering

System Overview


ⓐ
Scene
focal plane
▲virtual
real▲
Lens
Sensor
ISP
Real Camera
LensNet
3D Model
ⓑ Initial rendering
ⓒ Lens Effects

System Overview


ⓐ
Scene
focal plane
▲virtual
real▲
Lens
Sensor
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Real Camera
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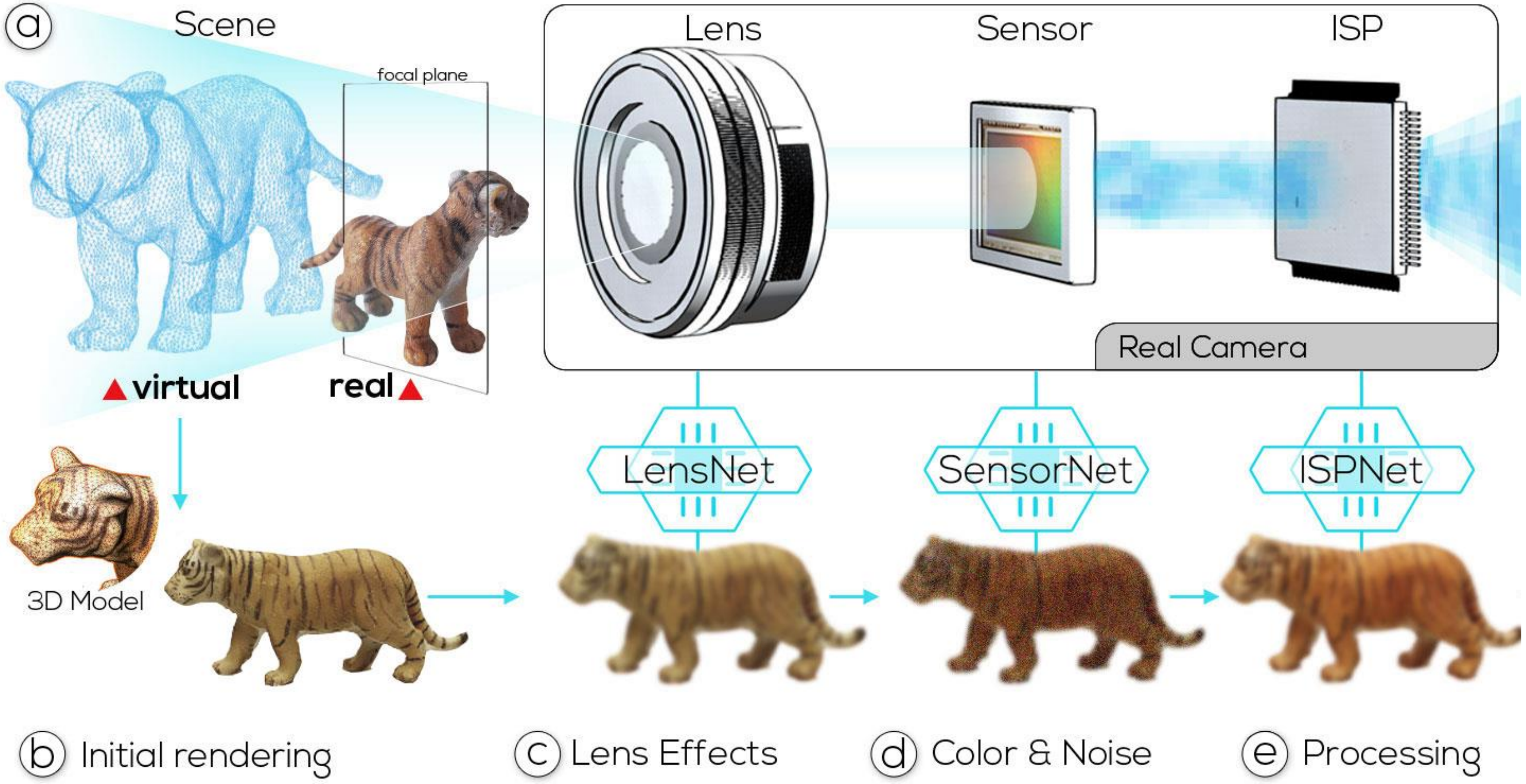
SensorNet
3D Model
ⓑ Initial rendering
ⓒ Lens Effects
ⓓ Color & Noise

System Overview


ⓐ Scene
focal plane
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Real Camera
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SensorNet
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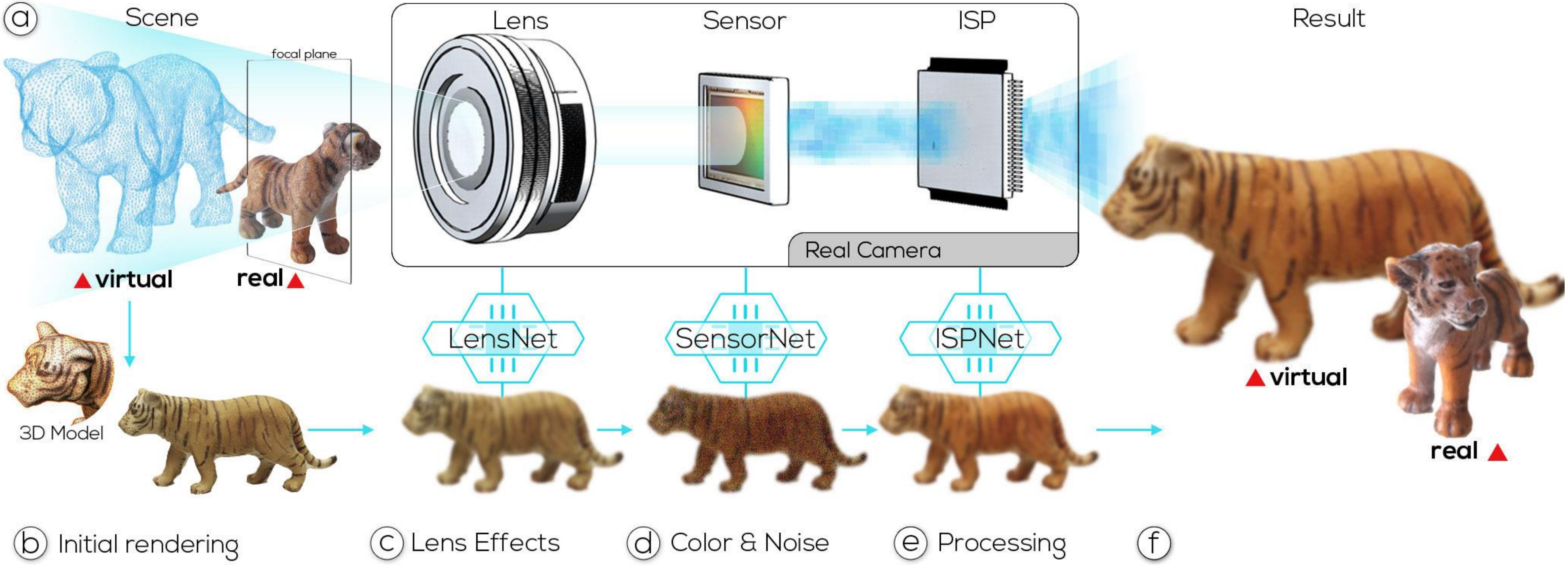
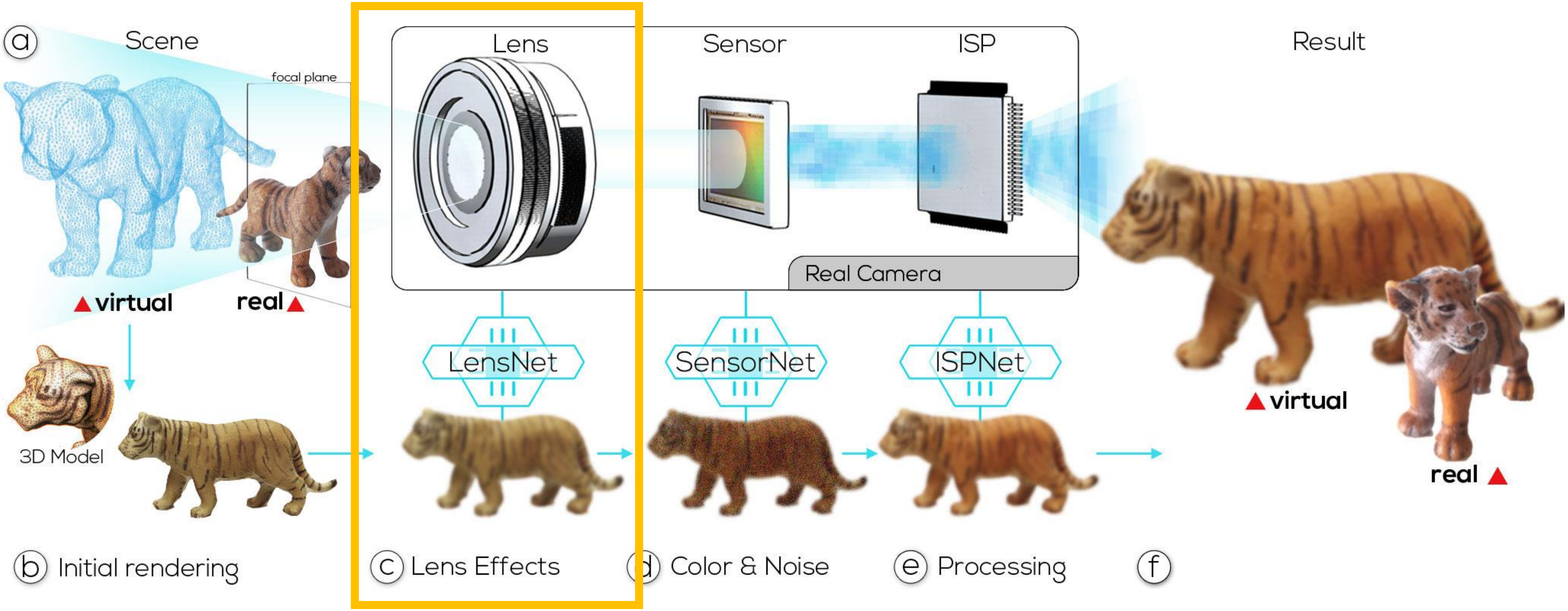
3D Model
ⓑ Initial rendering
ⓒ Lens Effects
ⓓ Color & Noise
ⓔ Processing

System Overview


ⓐ Scene
focal plane
▲virtual
real▲
Lens
Sensor
ISP
Real Camera
Result
3D Model
LensNet
SensorNet
ISPNet
▲virtual
real ▲
ⓑ Initial rendering
ⓒ Lens Effects
ⓓ Color & Noise
ⓔ Processing
ⓕ

Lens Effects


ⓐ Scene
focal plane
▲virtual
real▲
3D Model
Lens
Sensor
ISP
Real Camera
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ISPNet
Result
▲virtual
real ▲
ⓑ Initial rendering
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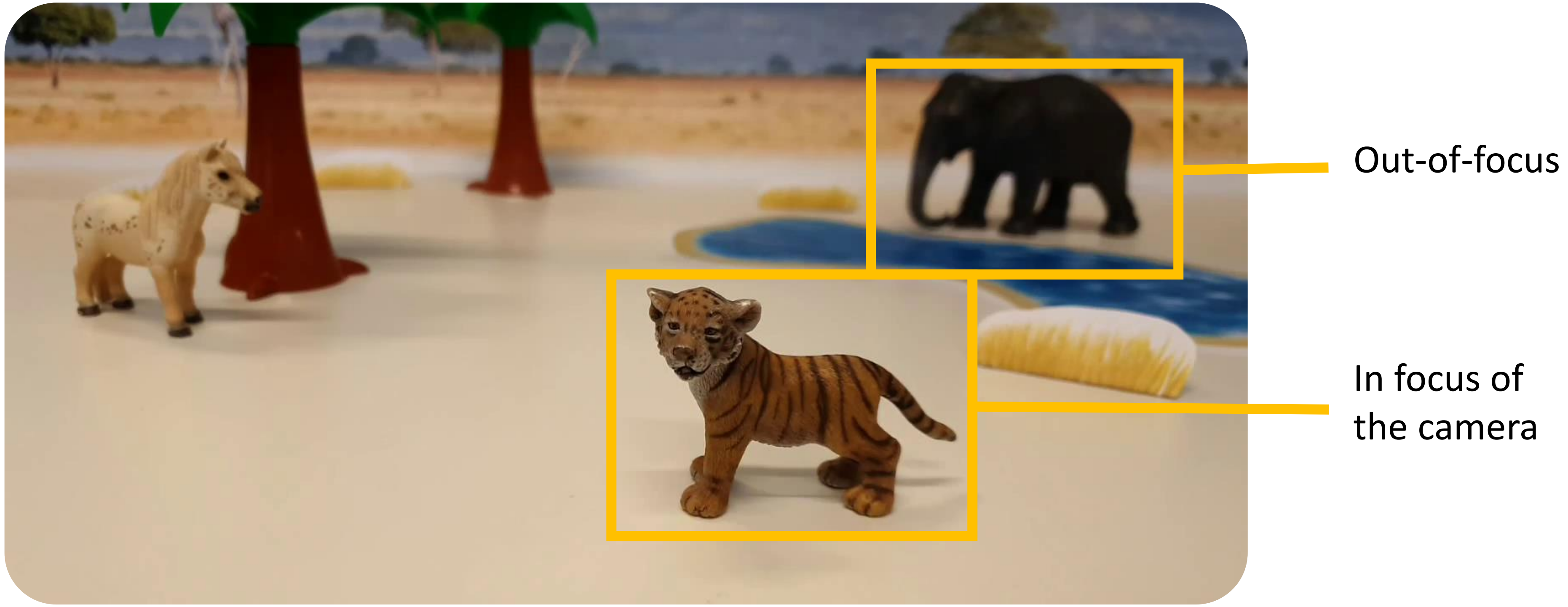
ⓓ Color & Noise
ⓔ Processing
ⓕ

Lens Effects

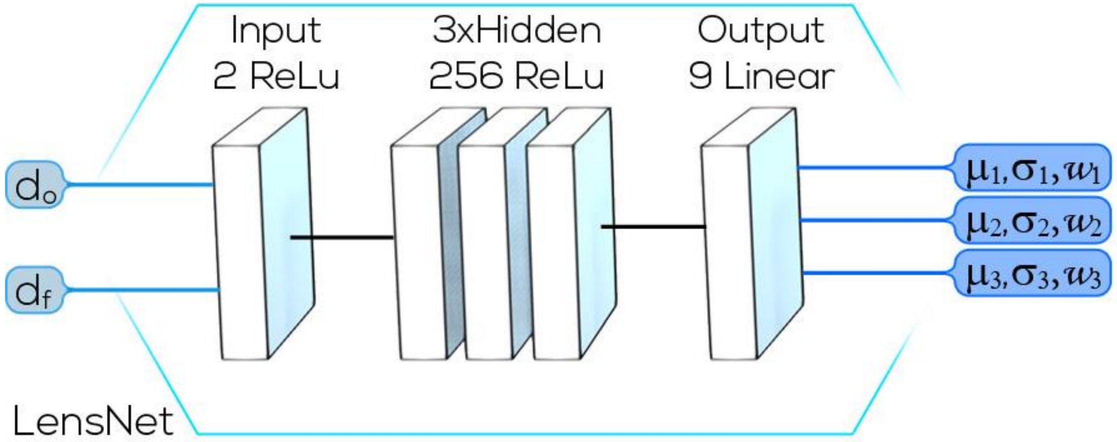
- Prominent effect is out-of-focus blur
- Parts of the scene which are not at the foucs plane


Out-of-focus
In focus of the camera

Lens Blur Network

LensNet (MLP)

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


Input
2 ReLu
3xHidden
256 ReLu
Output
9 Linear
d_o
d_f
μ_1, σ_1, w_1
μ_2, σ_2, w_2
μ_3, σ_3, w_3
LensNet

Lens Blur Network

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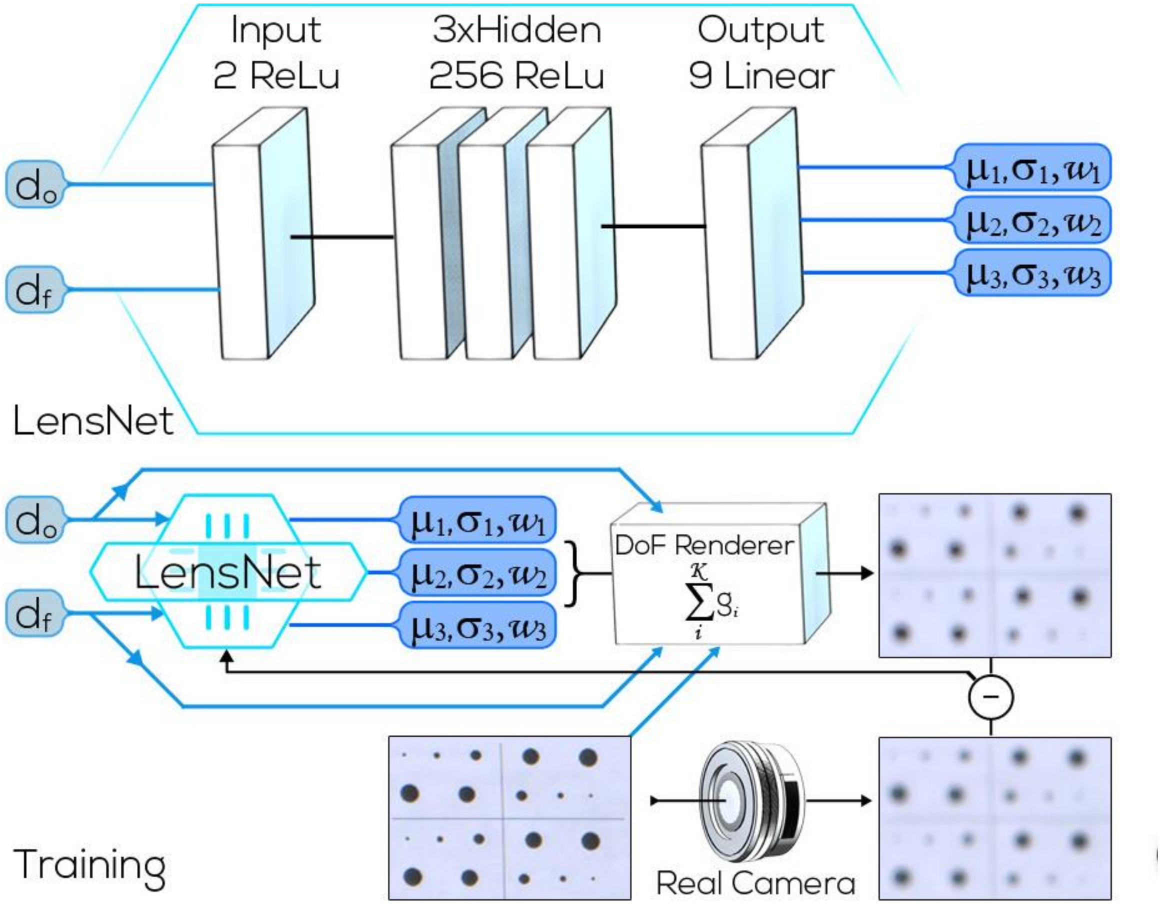
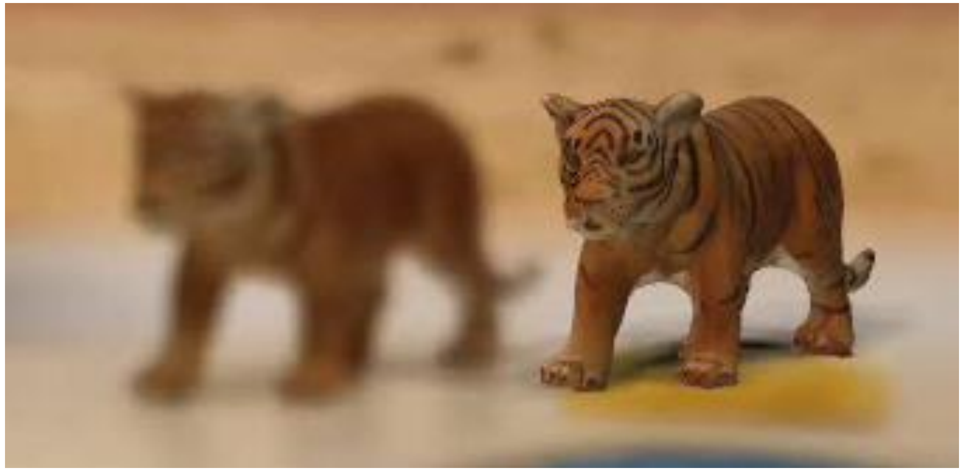
- Input depth & focus distance
- Output parameters for GMM
- Render with GMM (k=3)

Training

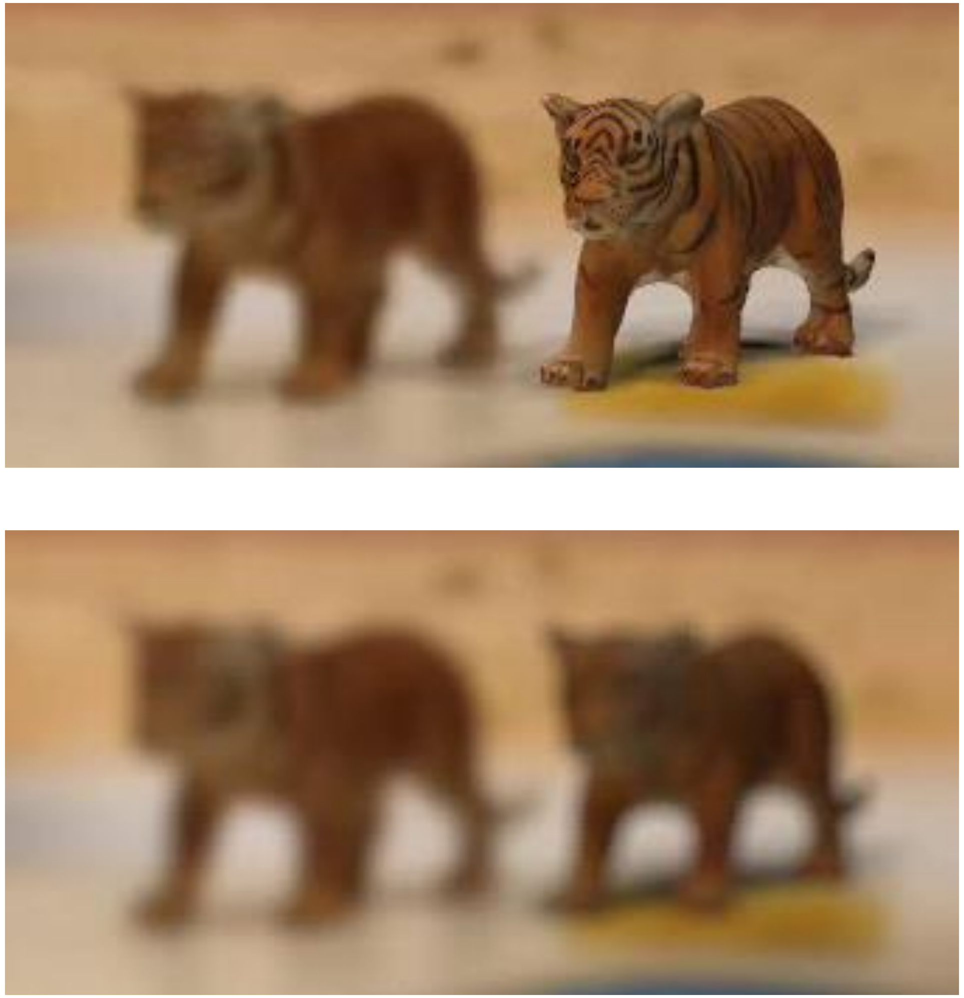
- Calibration images
- Varying depth and focus
- Compute loss on result


Input
2 ReLu
3xHidden
256 ReLu
Output
9 Linear
d_o
d_f
μ_1, σ_1, w_1
μ_2, σ_2, w_2
μ_3, σ_3, w_3
LensNet
d_o
d_f
LensNet
μ_1, σ_1, w_1
μ_2, σ_2, w_2
μ_3, σ_3, w_3
DoF Renderer
$\sum_i^K g_i$
−
Training
Real Camera

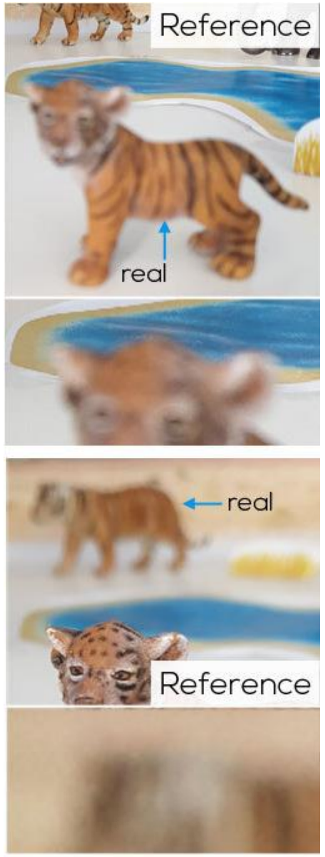
Lens Blur results



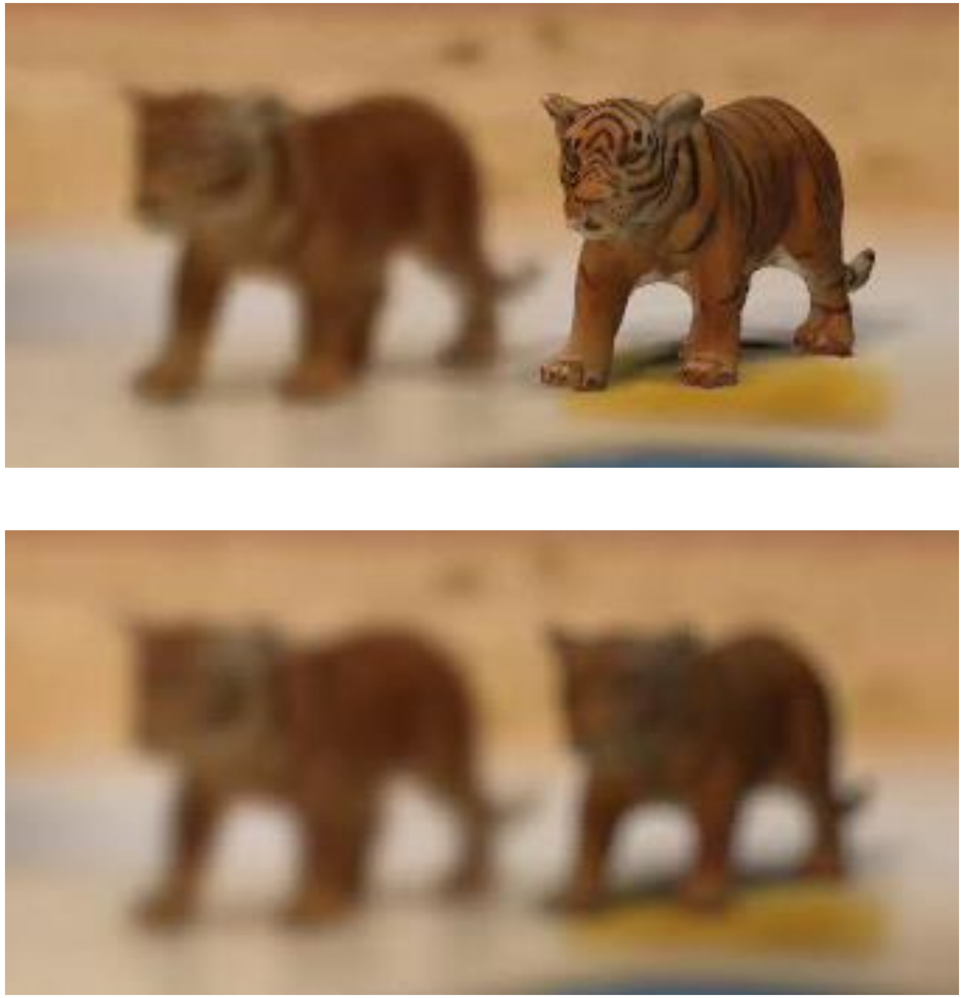
Lens Blur results



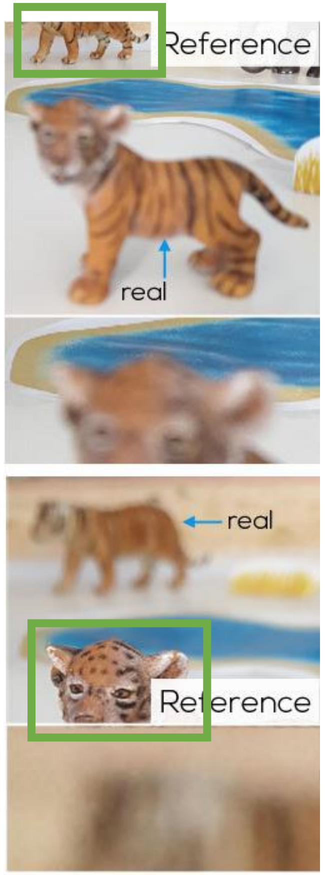
Lens Blur results


Reference
real
real
Reference

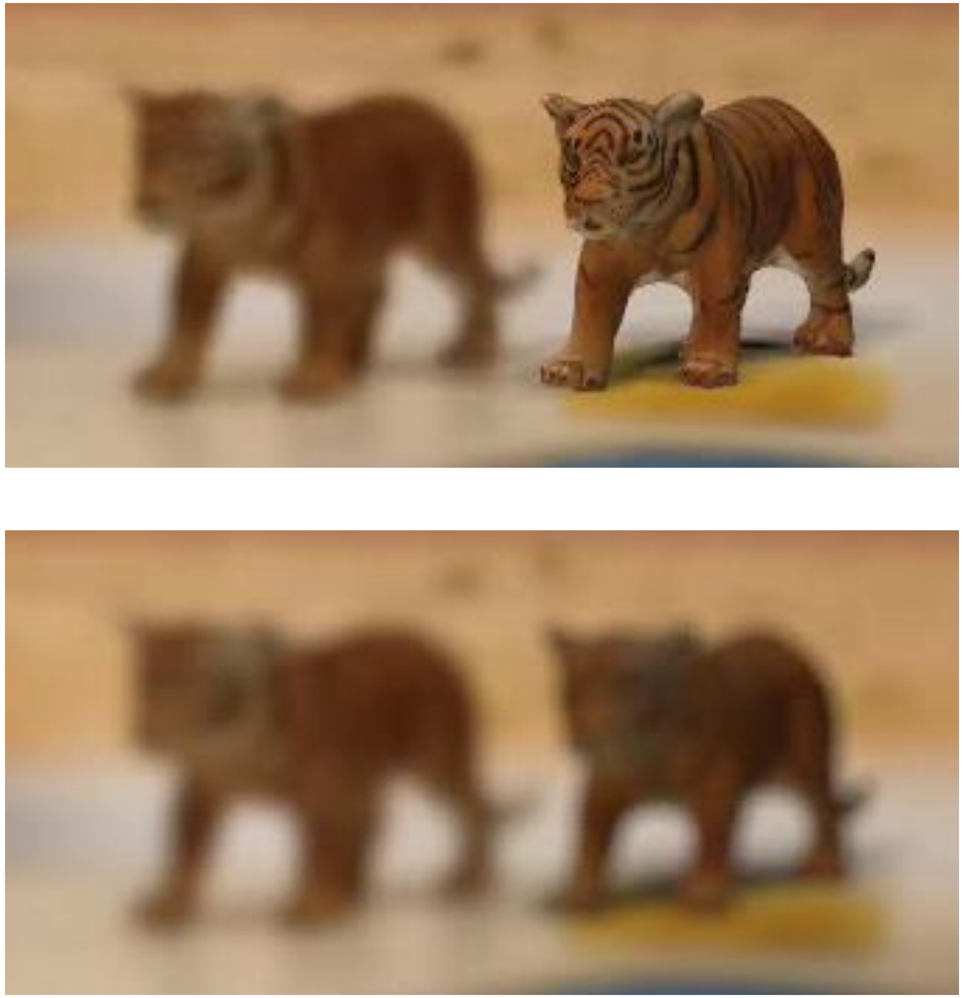
Real Lens



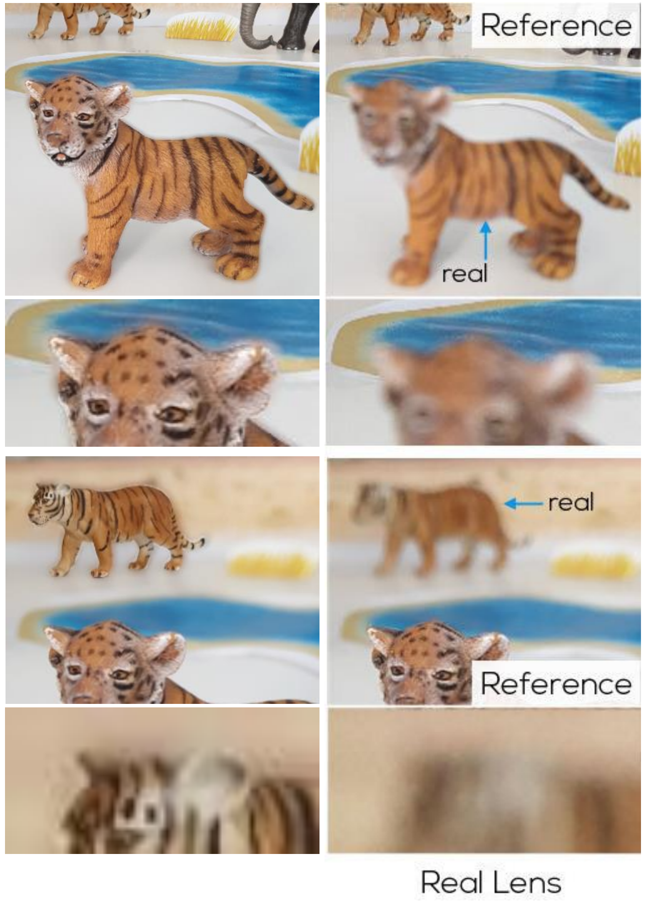
Lens Blur results


Reference
real
real
Reference

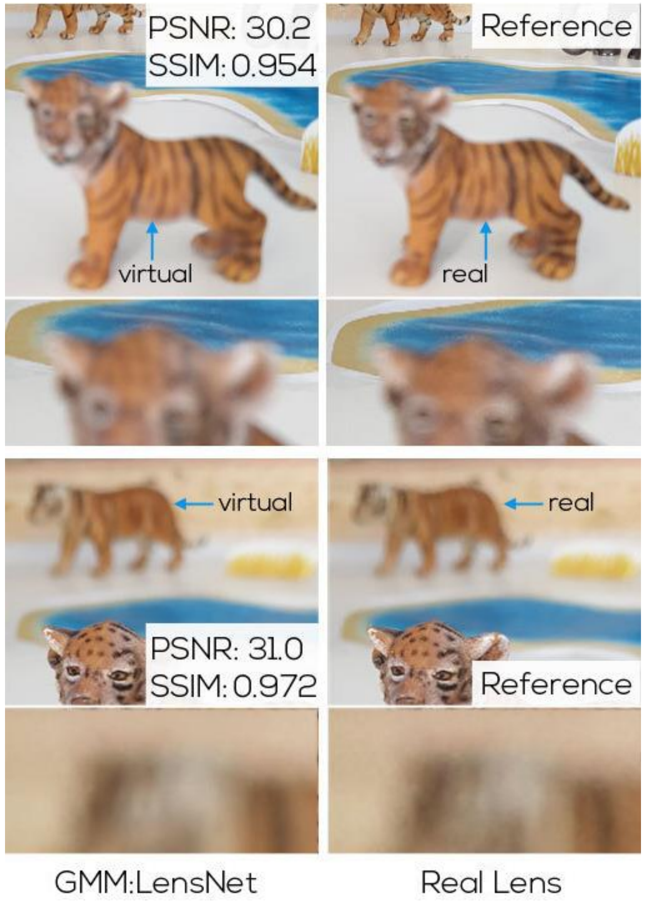
Real Lens



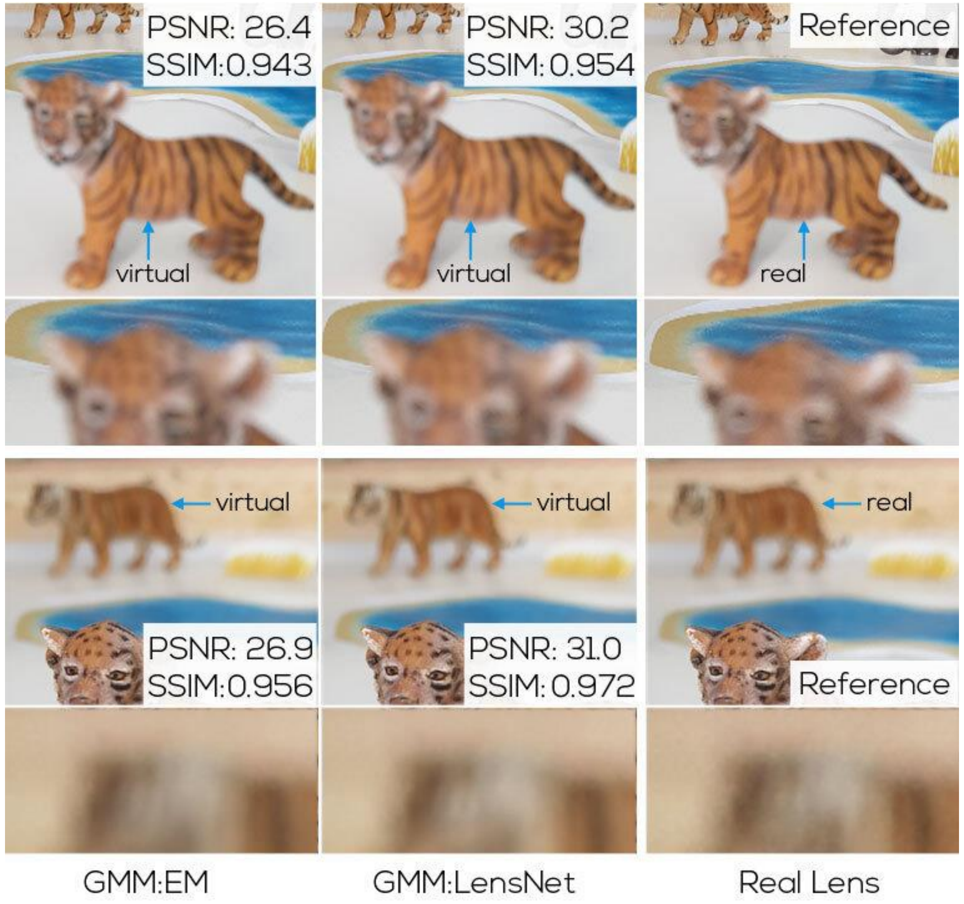
Lens Blur results


Reference
real
real
Reference
Real Lens

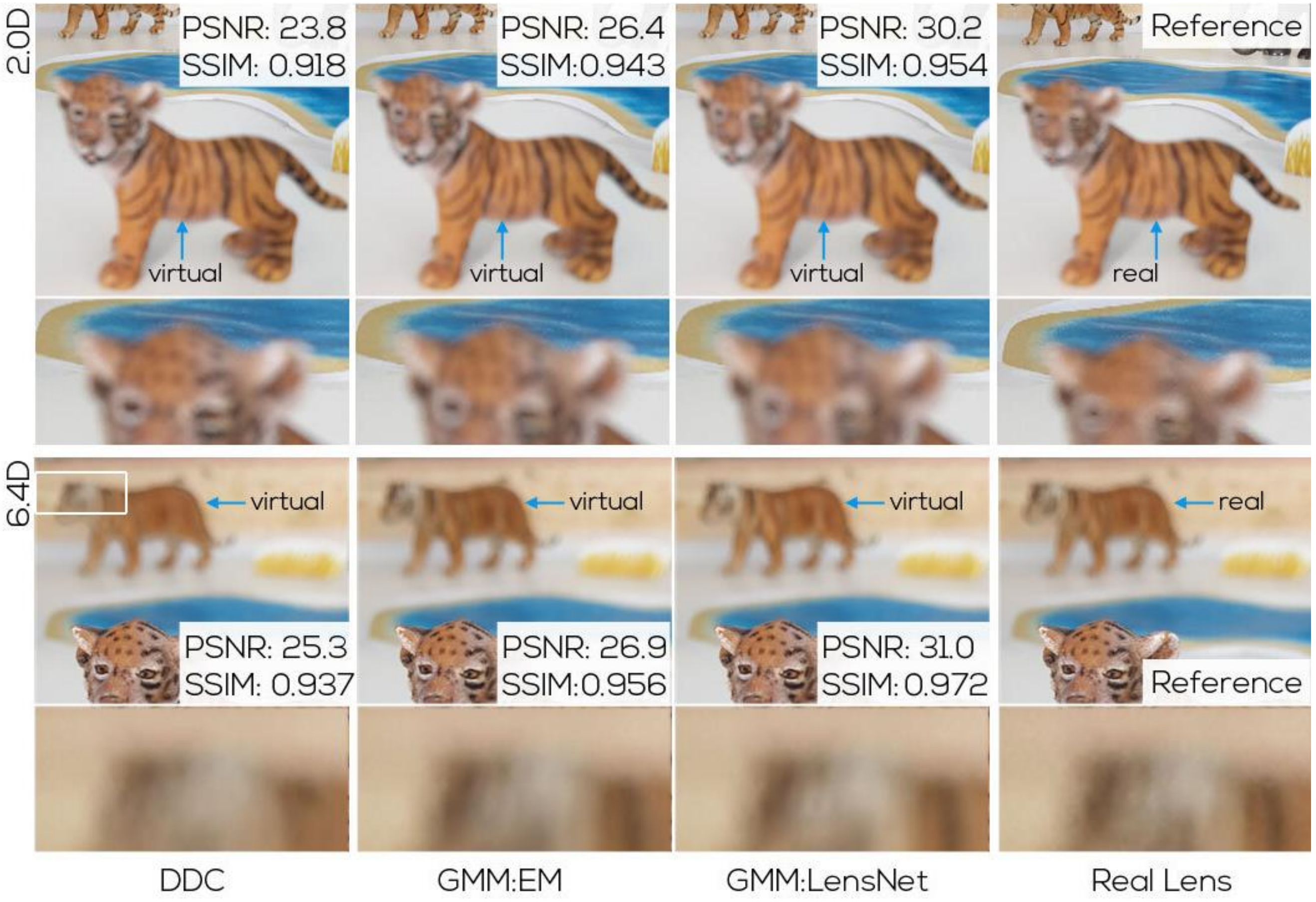
Lens Blur results

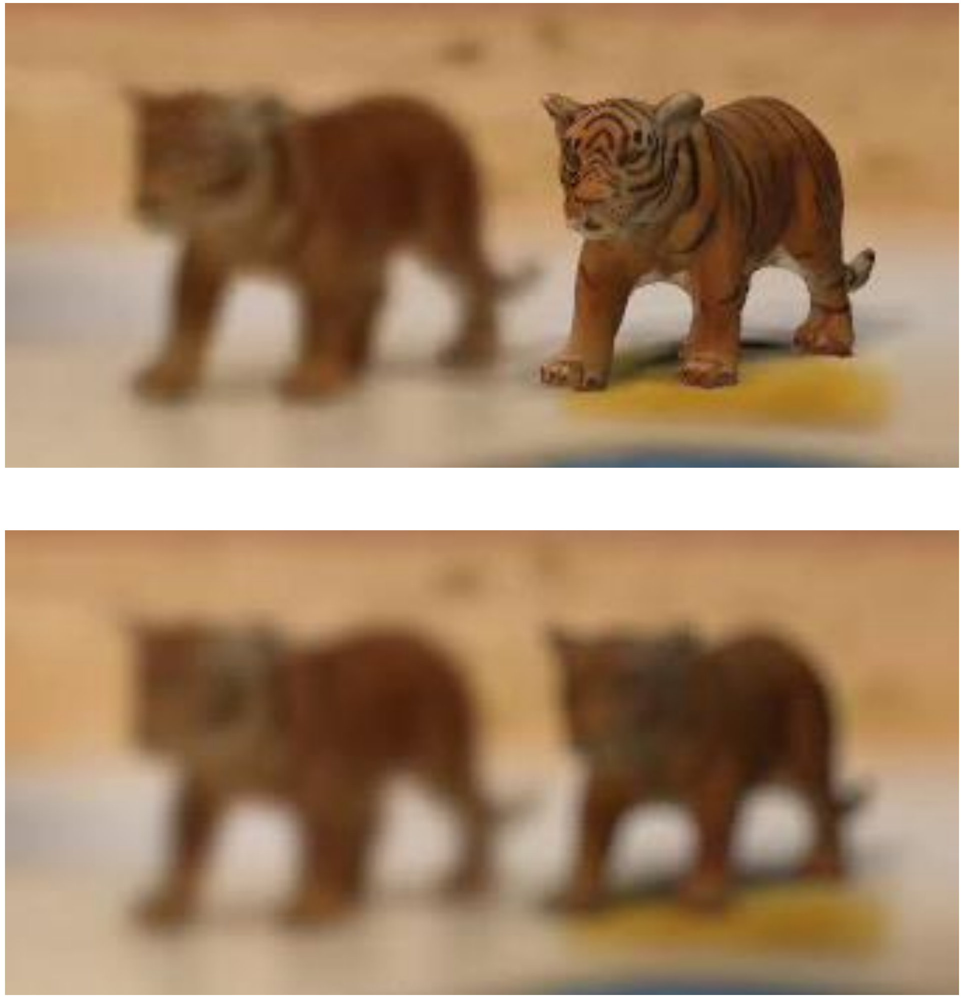

PSNR: 30.2
SSIM: 0.954
Reference
virtual
real
virtual
real
PSNR: 31.0
SSIM: 0.972
Reference
GMM:LensNet
Real Lens

Lens Blur results

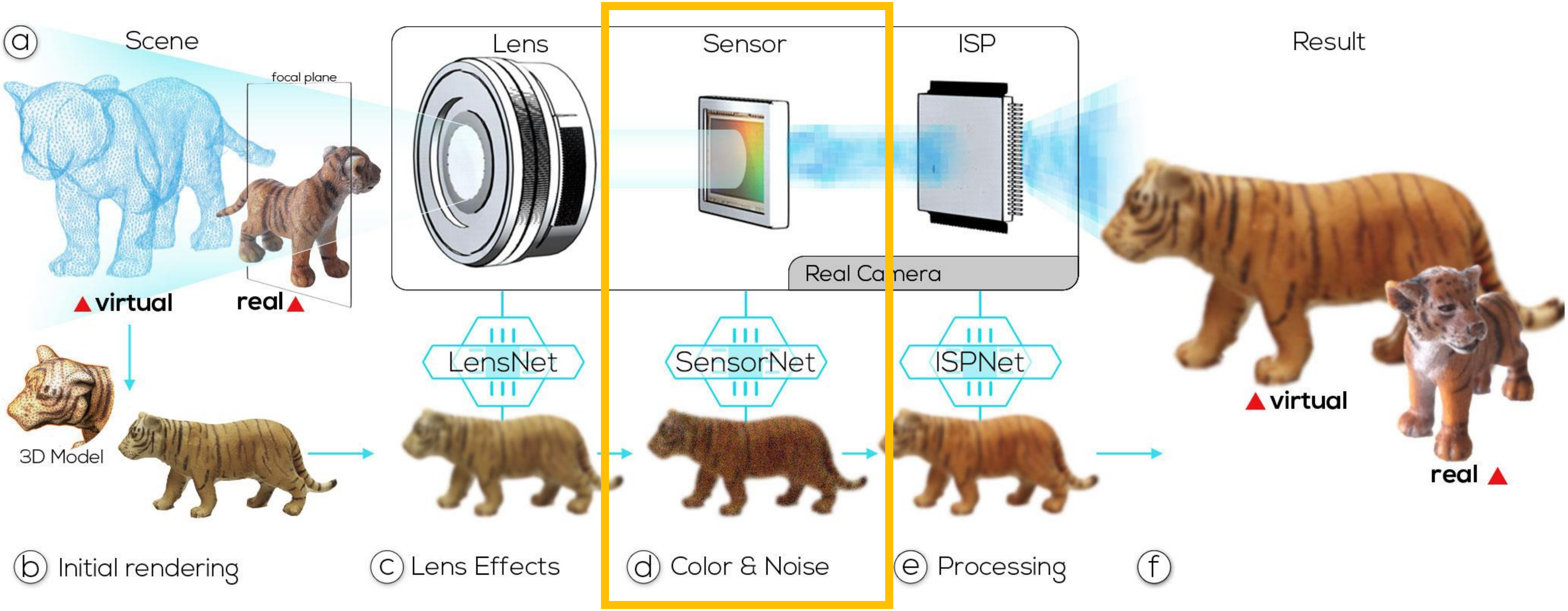

PSNR: 26.4
SSIM:0.943
virtual
PSNR: 30.2
SSIM: 0.954
virtual
Reference
real
virtual
PSNR: 26.9
SSIM:0.956
virtual
PSNR: 31.0
SSIM: 0.972
real
Reference
GMM:EM
GMM:LensNet
Real Lens

Lens Blur results


2.0D
PSNR: 23.8
SSIM: 0.918
virtual
PSNR: 26.4
SSIM:0.943
virtual
PSNR: 30.2
SSIM: 0.954
virtual
Reference
real
6.4D
virtual
virtual
virtual
real
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



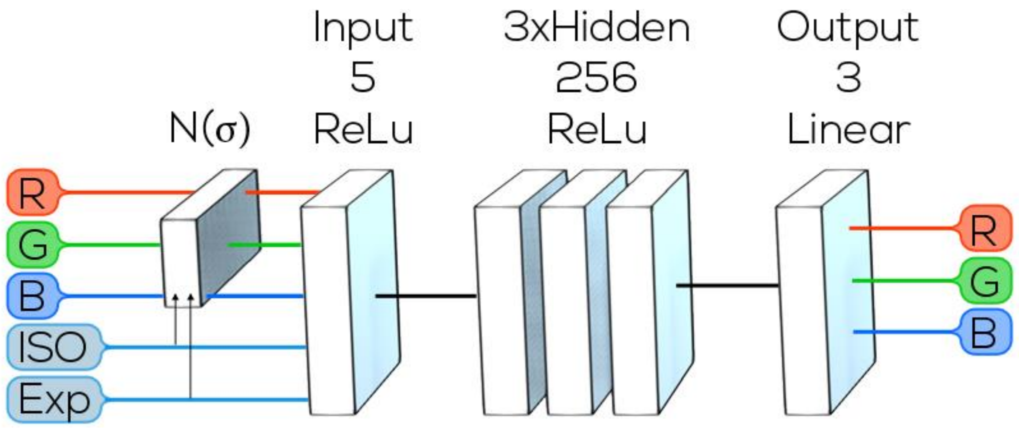
Camera Sensor


a
Scene
focal plane
virtual
real
Lens
Sensor
ISP
Real Camera
Result
virtual
real
3D Model
LensNet
SensorNet
ISPNet
b Initial rendering
c Lens Effects
d Color & Noise
e Processing
f

Sensor (Color & Noise)

SensorNet (MLP)

- Input: RGB + ISO, exposure
- Output: color correction + noise
- Multi-Layer Perceptron


Input
5
ReLu
3xHidden
256
ReLu
Output
3
Linear
N(σ)
R
G
B
ISO
Exp
R
G
B

Sensor (Color & Noise)

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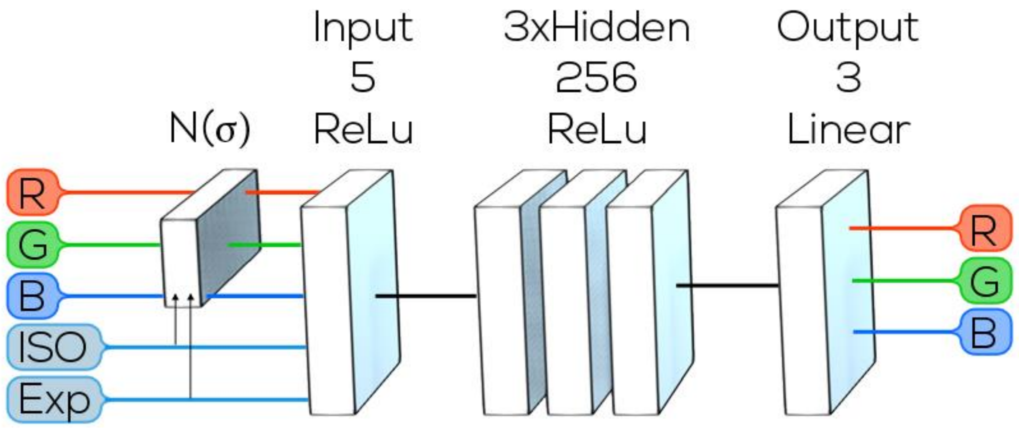
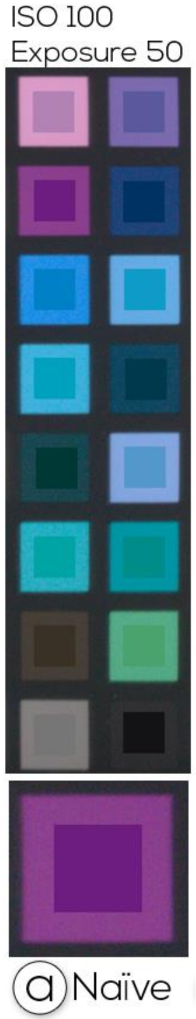

N(σ)
Input
5
ReLu
3xHidden
256
ReLu
Output
3
Linear
R
G
B
ISO
Exp
R
G
B

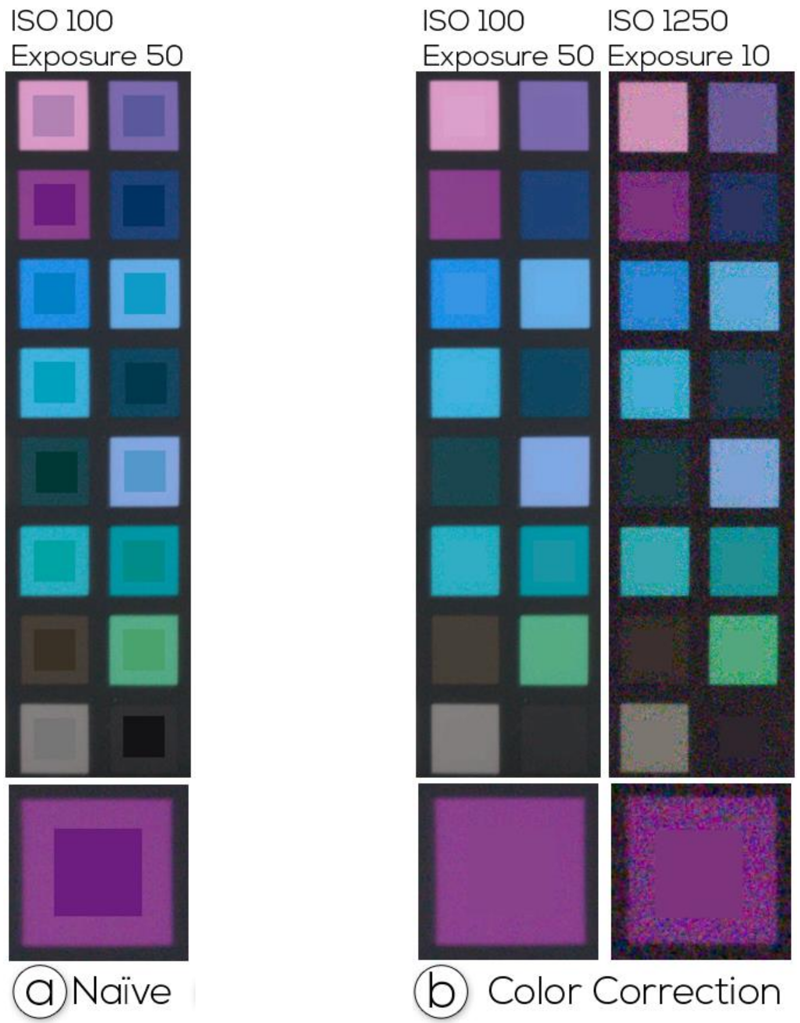
Training

- Images of known colors (sRGB)
- Training with varying ISO, exposure

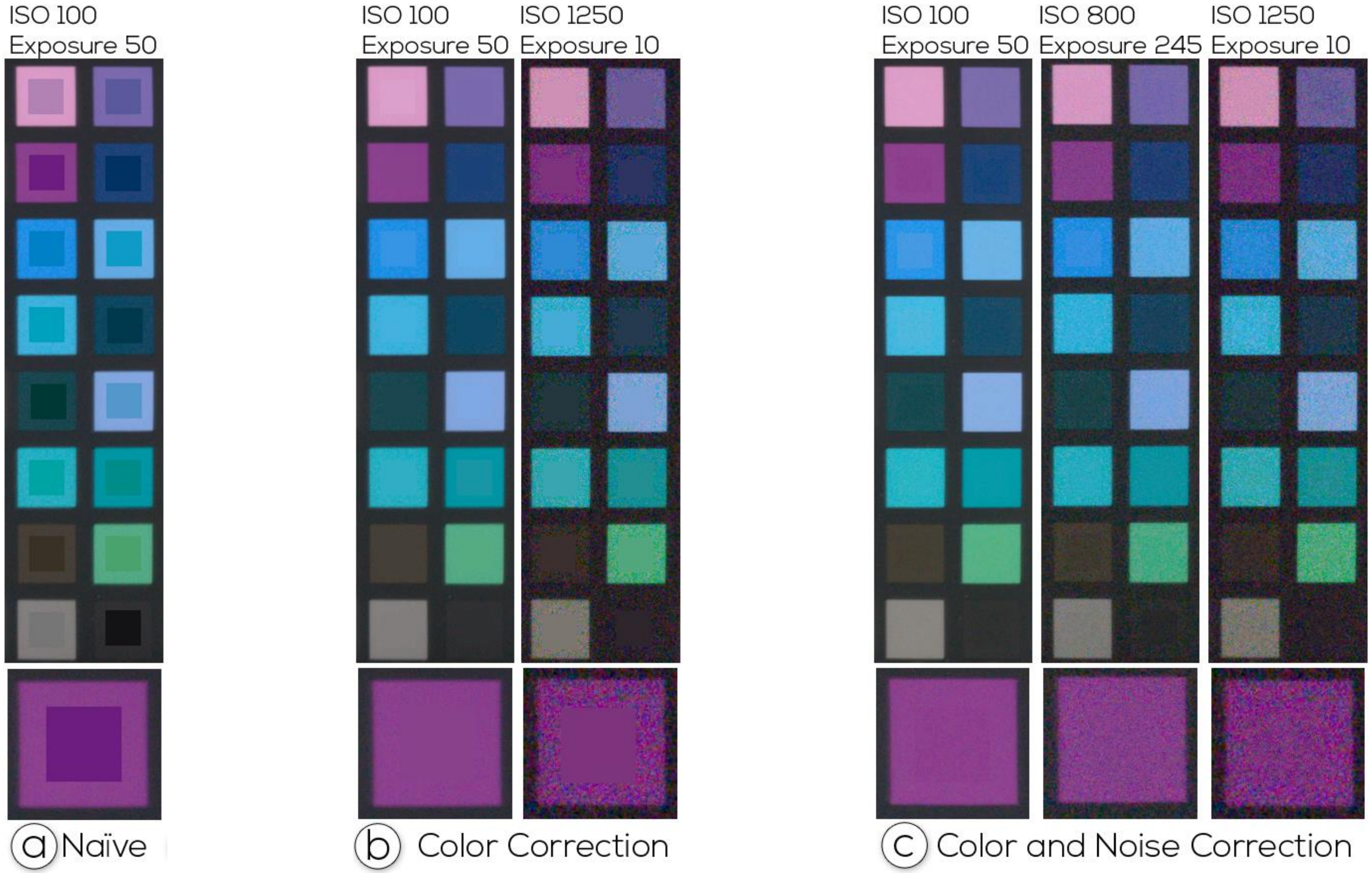
Sensor Results


ISO 100
Exposure 50
ⓐ Naïve

Sensor Results


ISO 100
Exposure 50
ISO 100
Exposure 50
ISO 1250
Exposure 10
ⓐ Naïve
ⓑ Color Correction

Sensor Results


ISO 100
Exposure 50
ISO 100
Exposure 50
ISO 1250
Exposure 10
ISO 100
Exposure 50
ISO 800
Exposure 245
ISO 1250
Exposure 10

ⓐ Naïve ⓑ Color Correction ⓒ Color and Noise Correction

Image Signal Processor (ISP)

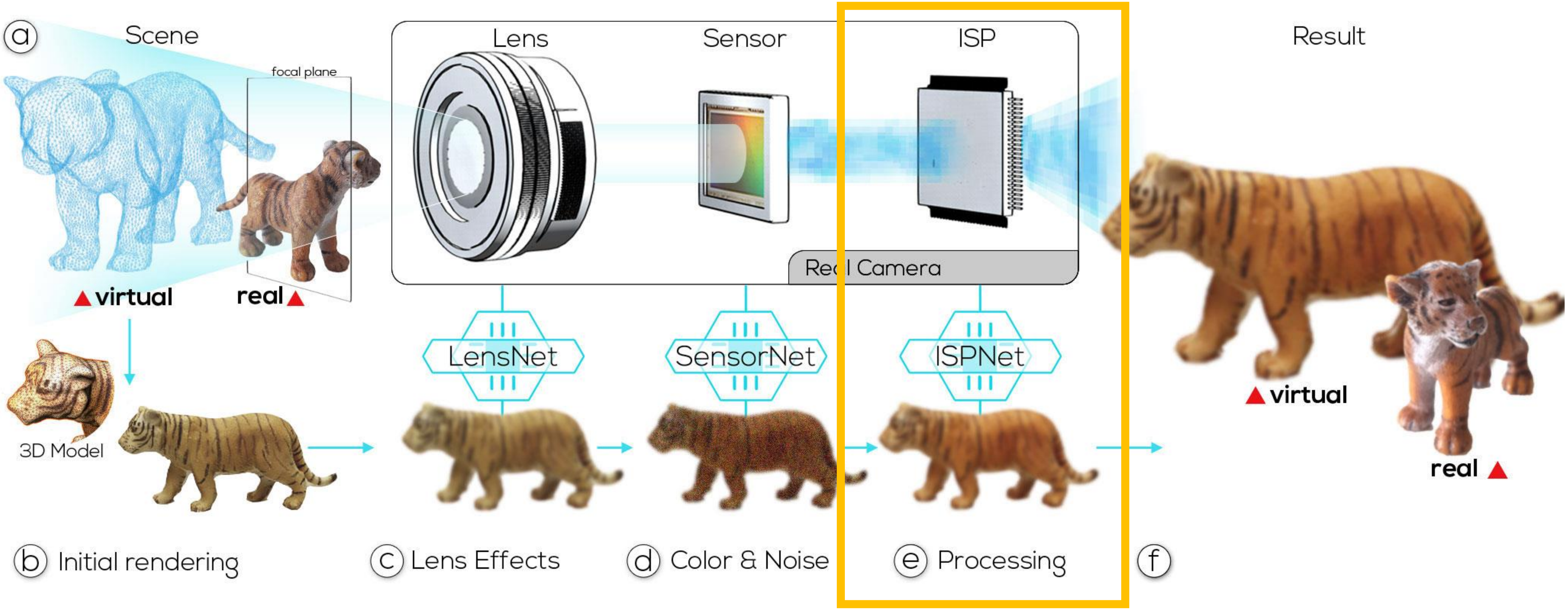

ⓐ Scene
focal plane
▲virtual
real▲
Lens
Sensor
ISP
Real Camera
Result
LensNet
SensorNet
ISPNet
3D Model
▲virtual
real ▲
ⓑ Initial rendering
ⓒ Lens Effects
ⓓ Color & Noise
ⓔ Processing
ⓕ

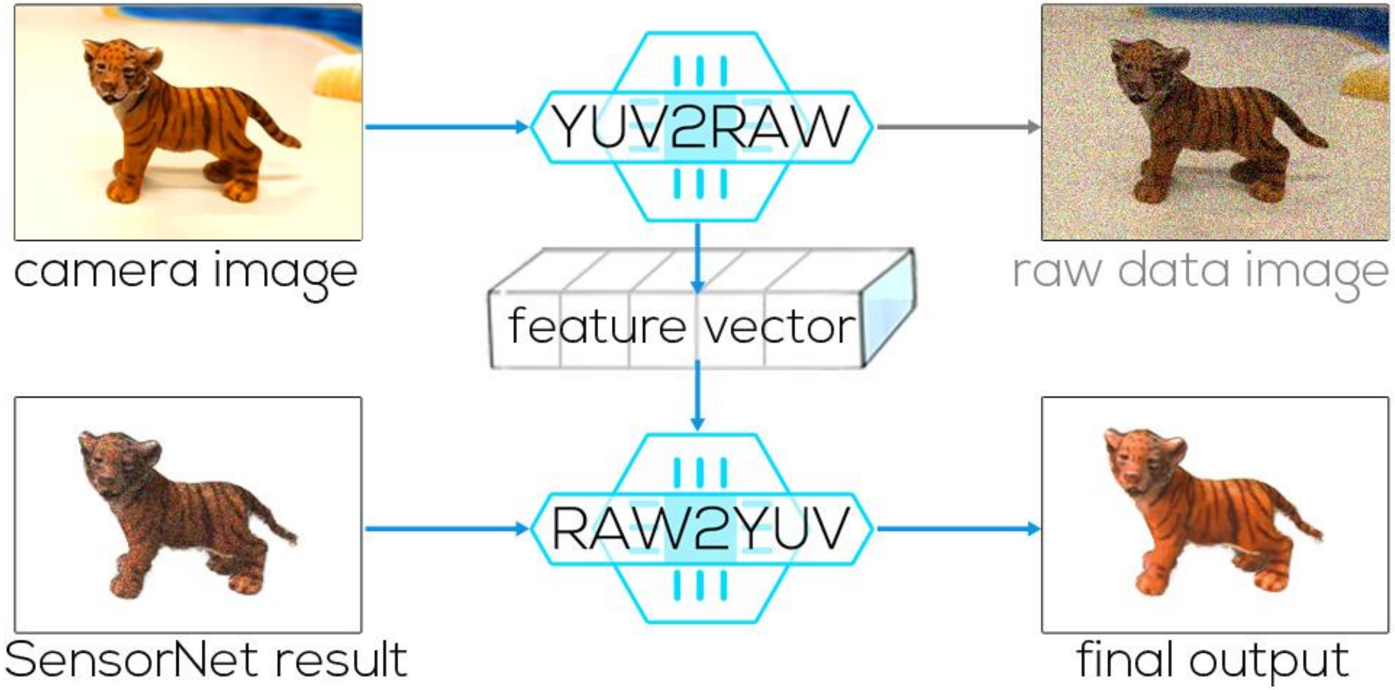
Image Signal Processor (ISP)

ISPNet (CNN)

- Adapted from Raw2Jpg [1]
- SensorNet result input
- Images from camera in YUV

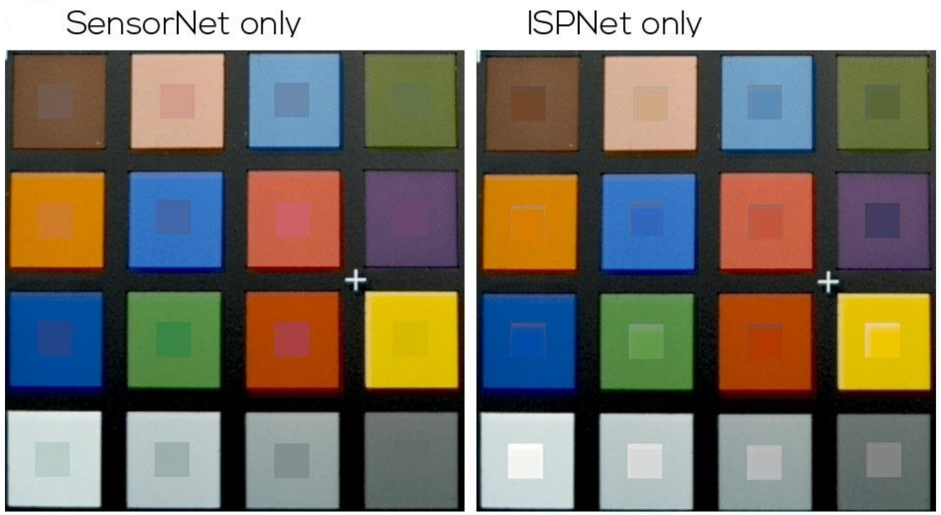
Training

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


camera image
YUV2RAW
raw data image
feature vector
SensorNet result
RAW2YUV
final output

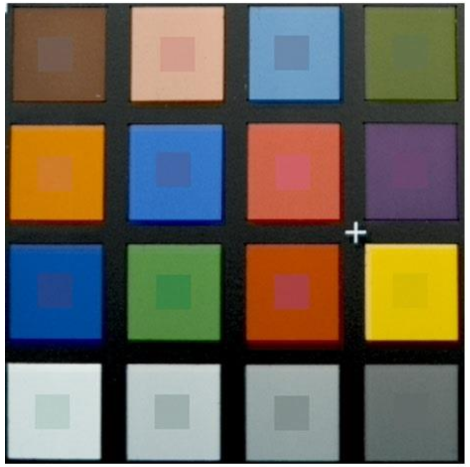
[1] J. Gao, X. Li, L. Wang, S. Fidler, and S. Lin. Mimicking the in-camera color pipeline for camera-aware object compositing. arXiv:1903.11248, 2019.

Results Processor

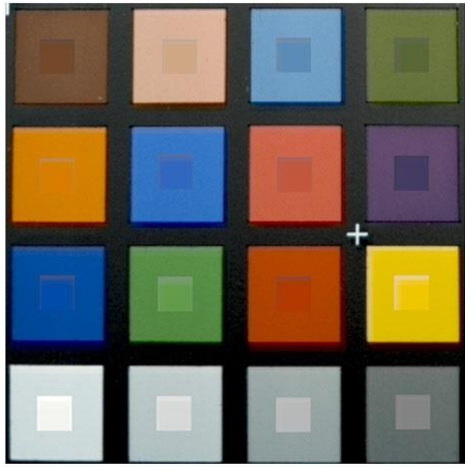

SensorNet only
ISPNet only

Results Processor

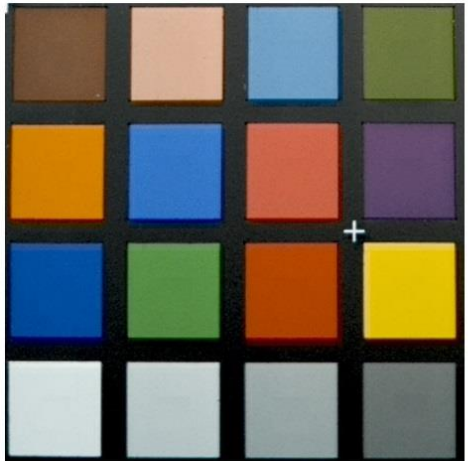
SensorNet only



ISPNet only

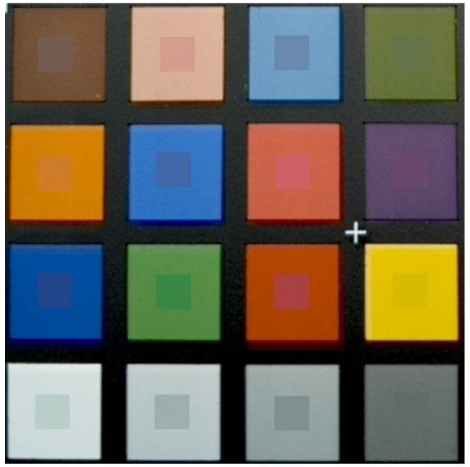


SensorNet & ISPNet

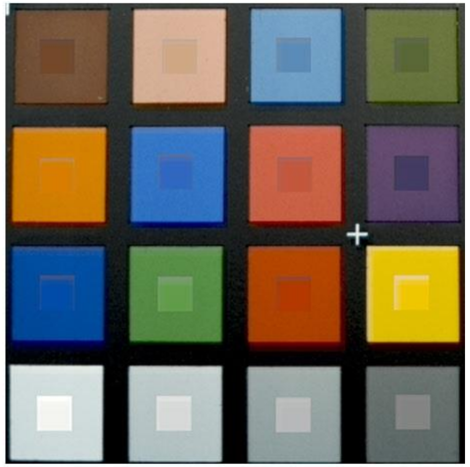


Results Processor

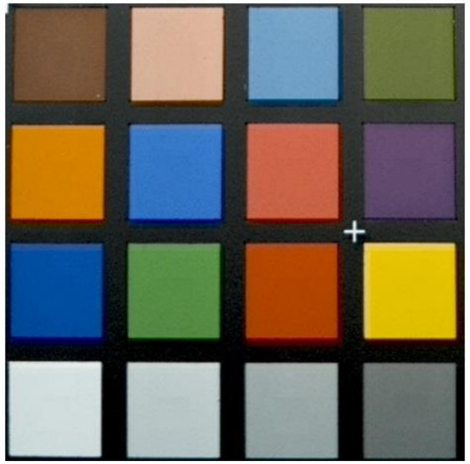
SensorNet only

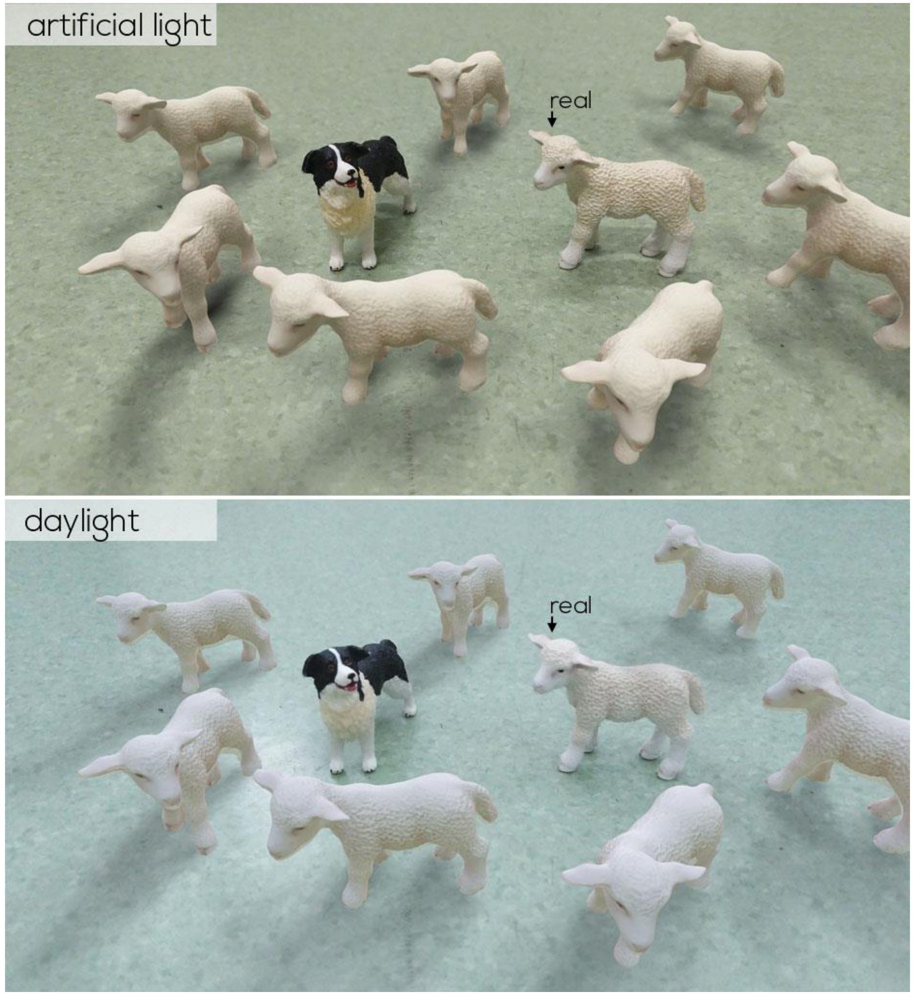


ISPNet only

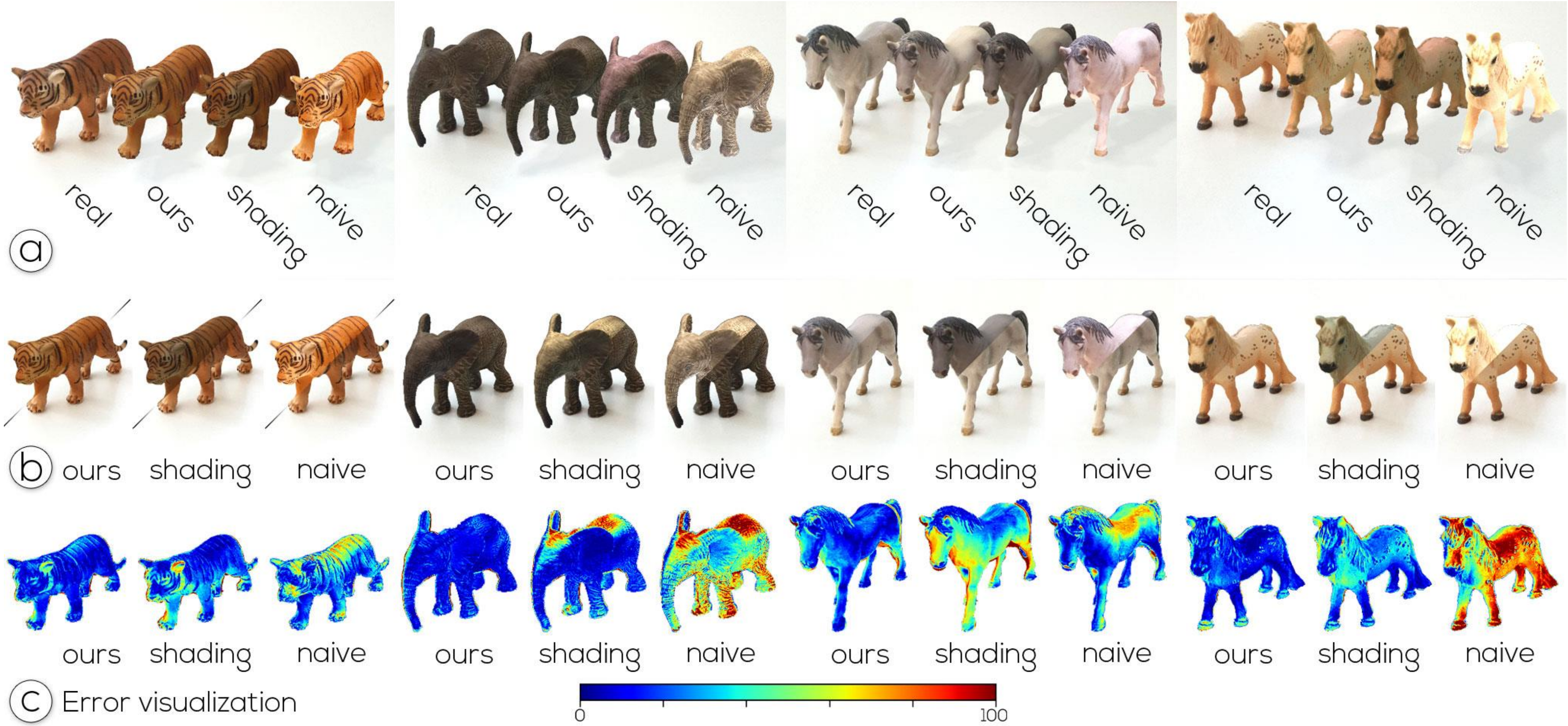


SensorNet & ISPNet




artificial light
real
daylight
real

Results


real
ours
shading
naive
real
ours
shading
naive
real
ours
shading
naive
real
ours
shading
naive
(a)
(b) ours
shading
naive
ours
shading
naive
ours
shading
naive
ours
shading
naive
ours
shading
naive
ours
shading
naive
ours
shading
naive
ours
shading
naive
(c) Error visualization
0
100

Results

Limitations & Future Work

Camera Effects

- Chromatic aberration
- Motion blur
- Vignetting

Scene Simulation

- Material estimation
- Light source detection
- Shadows

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