



# Real-scale 3D reconstruction from monocular endoscope images

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IEEE/RSJ International Conference on Intelligent Robots and Systems



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# Reconstruction

## Outside vs. Inside the human body

### Outside

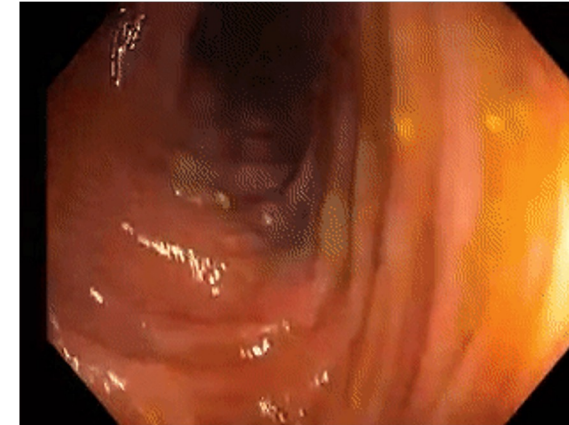
[KITTI (2013)]



- Stereo images

### Inside

[EndoMapper (2022)]



- Monocular images  
! Scale problem

[26] A. Geiger et al. (2013). *Vision meets Robotics: The KITTI Dataset*.

[25] P. Azagra et al. (2022). *EndoMapper dataset of complete calibrated endoscopy procedures*.

# Reconstruction Outside vs. Inside the human body

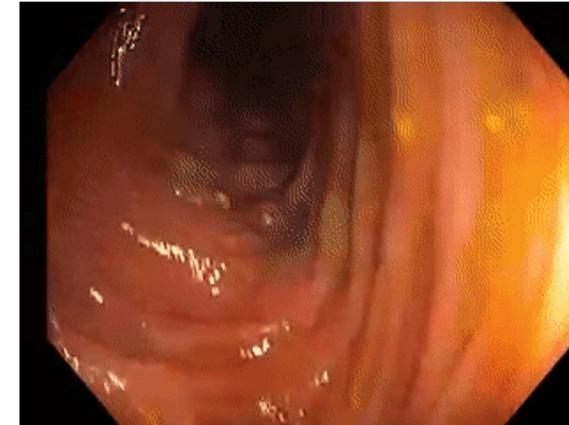
Outside

[KITTI (2013)]



Inside

[EndoMapper (2022)]



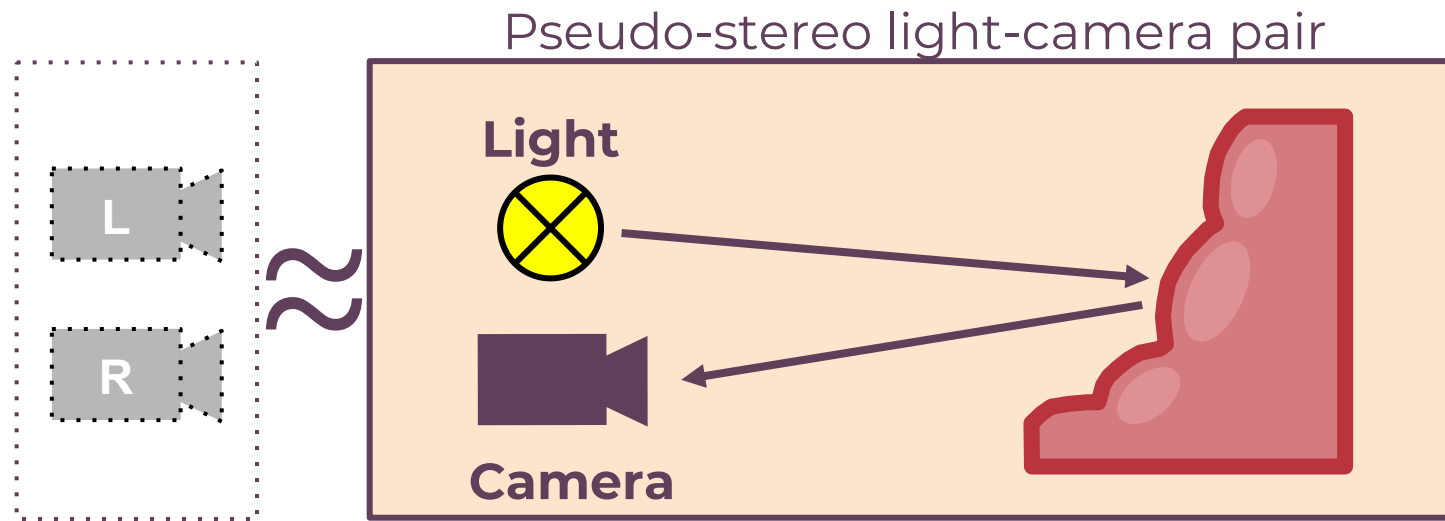
Previously, lighting changes were **dismissed**...

- Assuming **constant illumination**
- Using **invariant feature points**

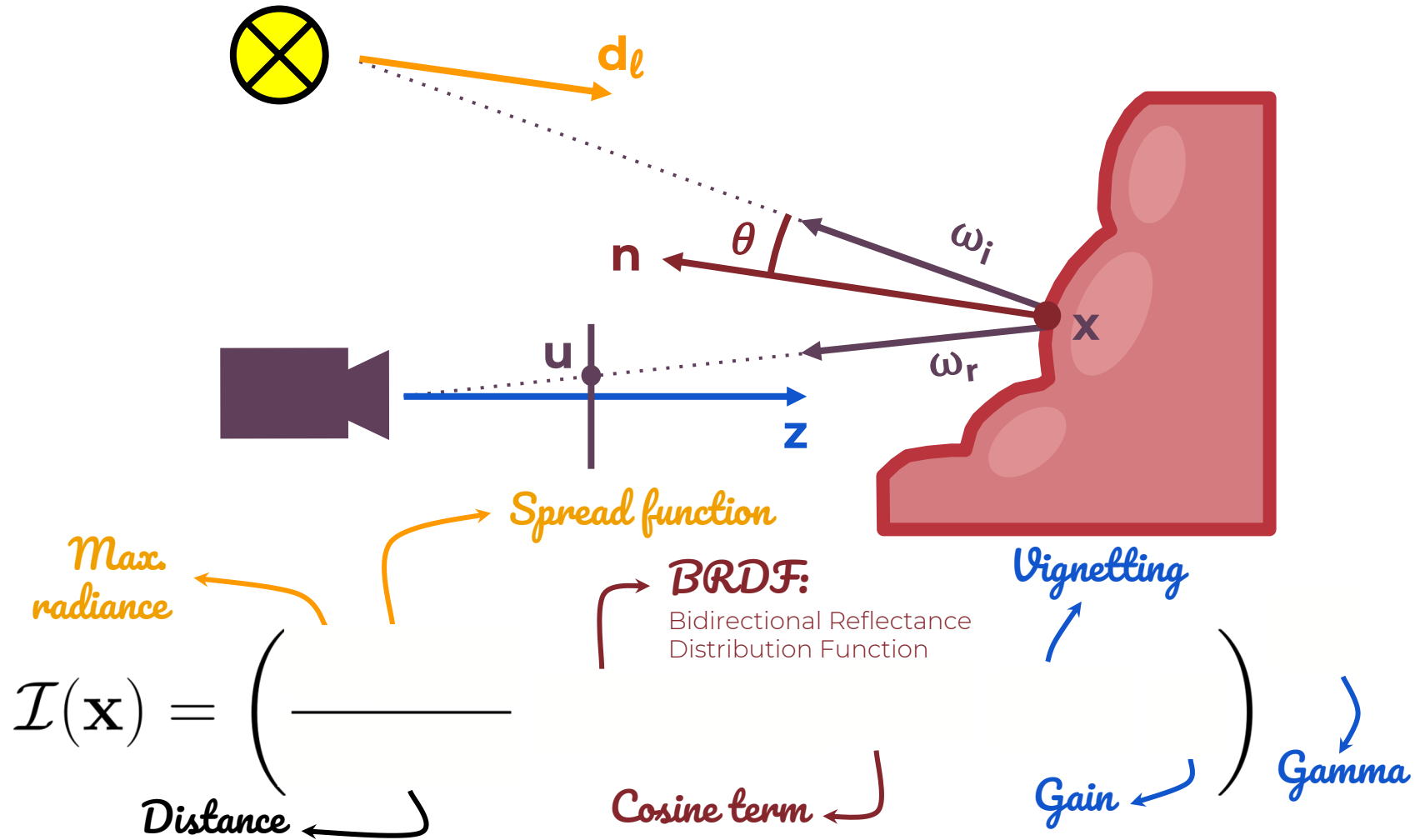
*Our main goal:*

# Take profit of light changes

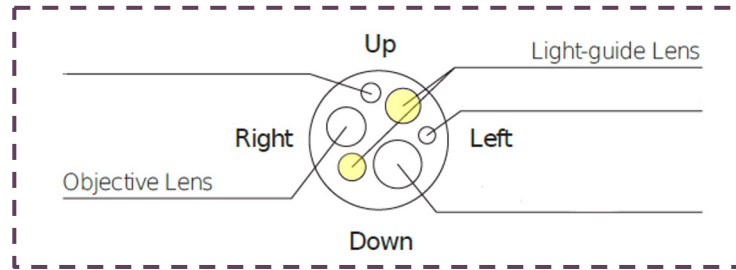
To get dense, **real-scale** reconstructions  
from **monocular** sequences.



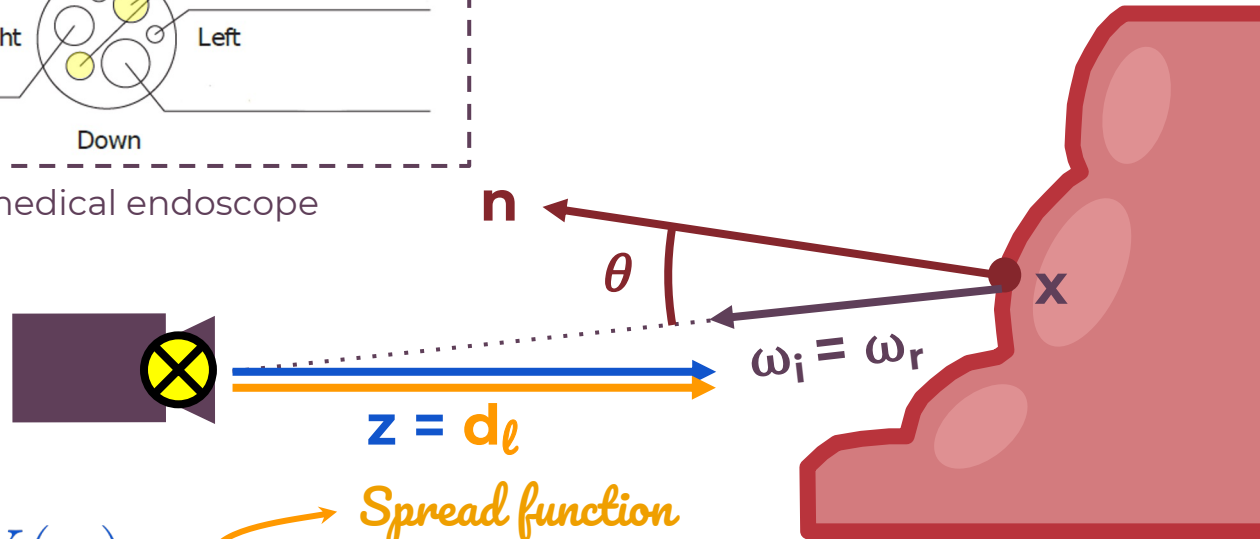
# General photometric model



# Simplification: light at optical center



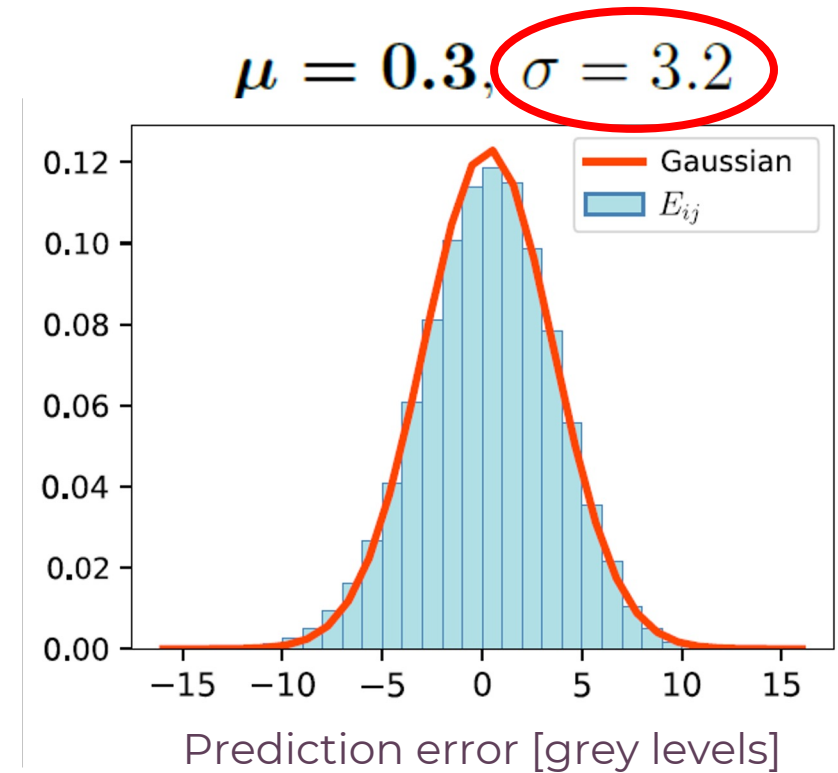
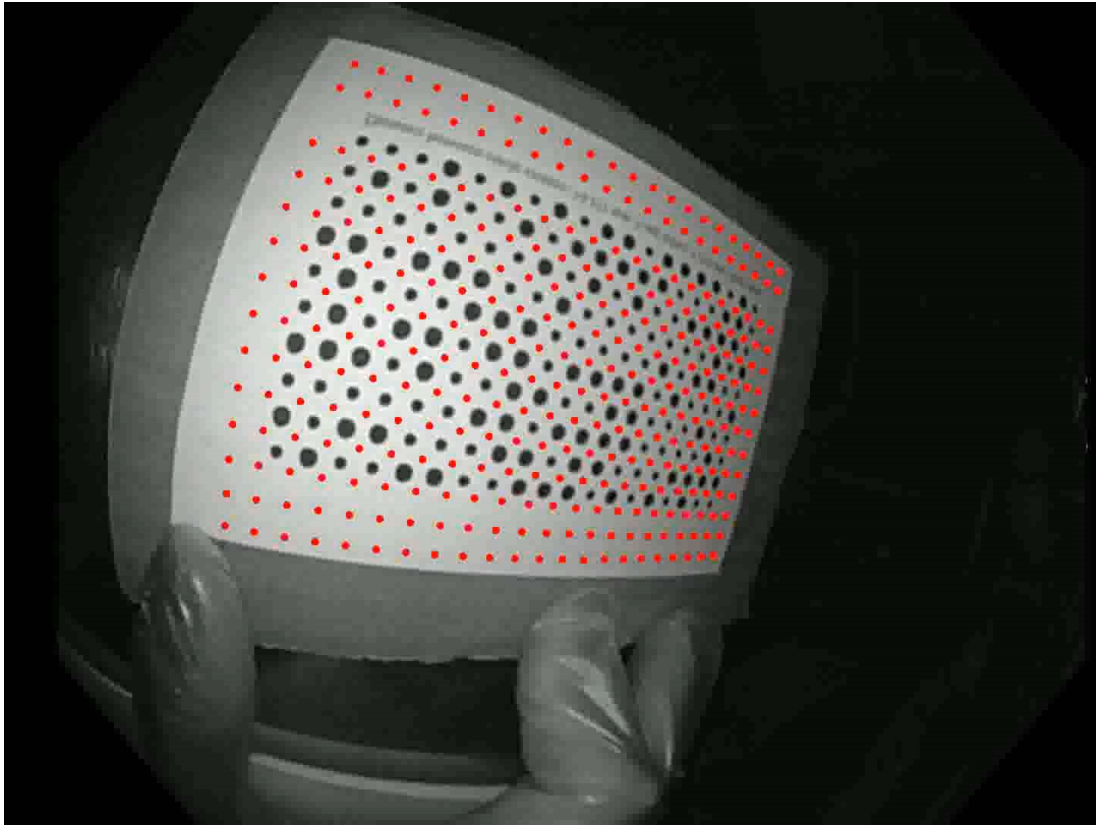
Real medical endoscope



$$\mathcal{I}(\mathbf{x}) = \left( \frac{\mu'(\mathbf{x})}{\|\mathbf{x} - \mathbf{x}_l\|^2} \right) f_r(\theta) \cos \theta \left( g_i \right)^{1/\gamma}$$

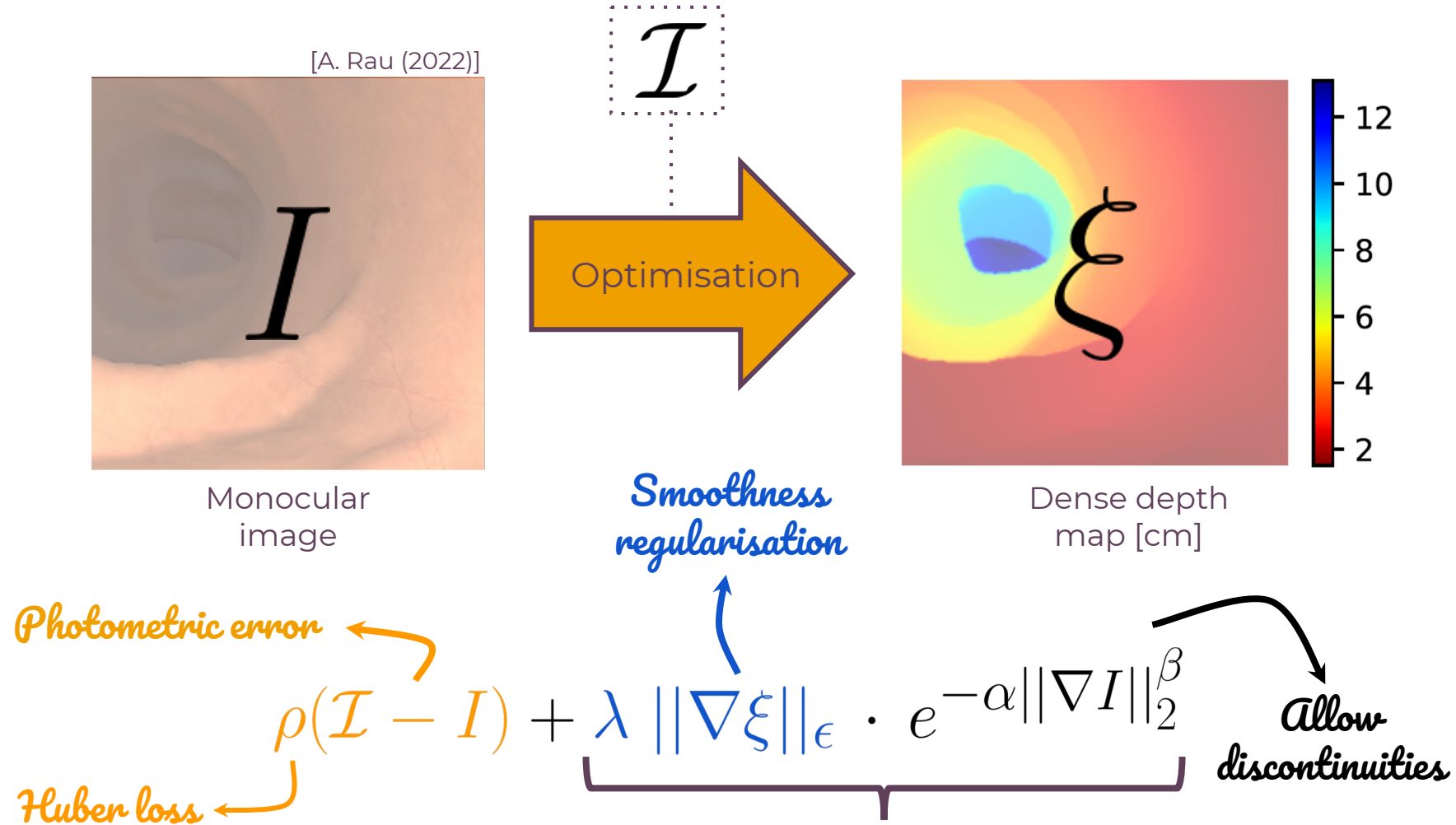
$\mu(\mathbf{x}) \cdot V(\mathbf{u})$  ← Spread function  
 $f_r(\theta)$  ← BRDF: Bidirectional Reflectance Distribution Function  
 $\cos \theta$  ← Cosine term  
 $g_i$  ← Gain  
 $1/\gamma$  ← Gamma

# Endoscope calibration



[25] P. Azagra et al. (2022). *EndoMapper dataset of complete calibrated endoscopy procedures.*

# Depth estimation

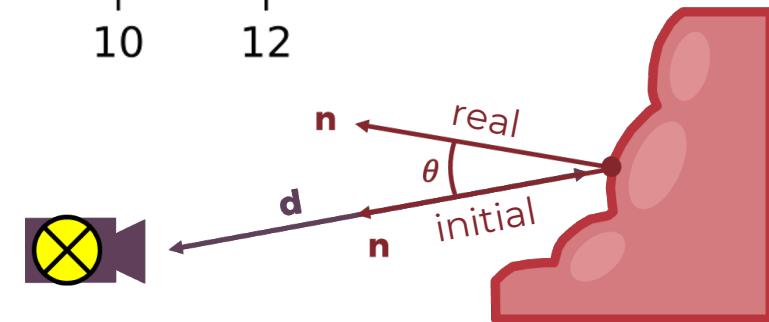
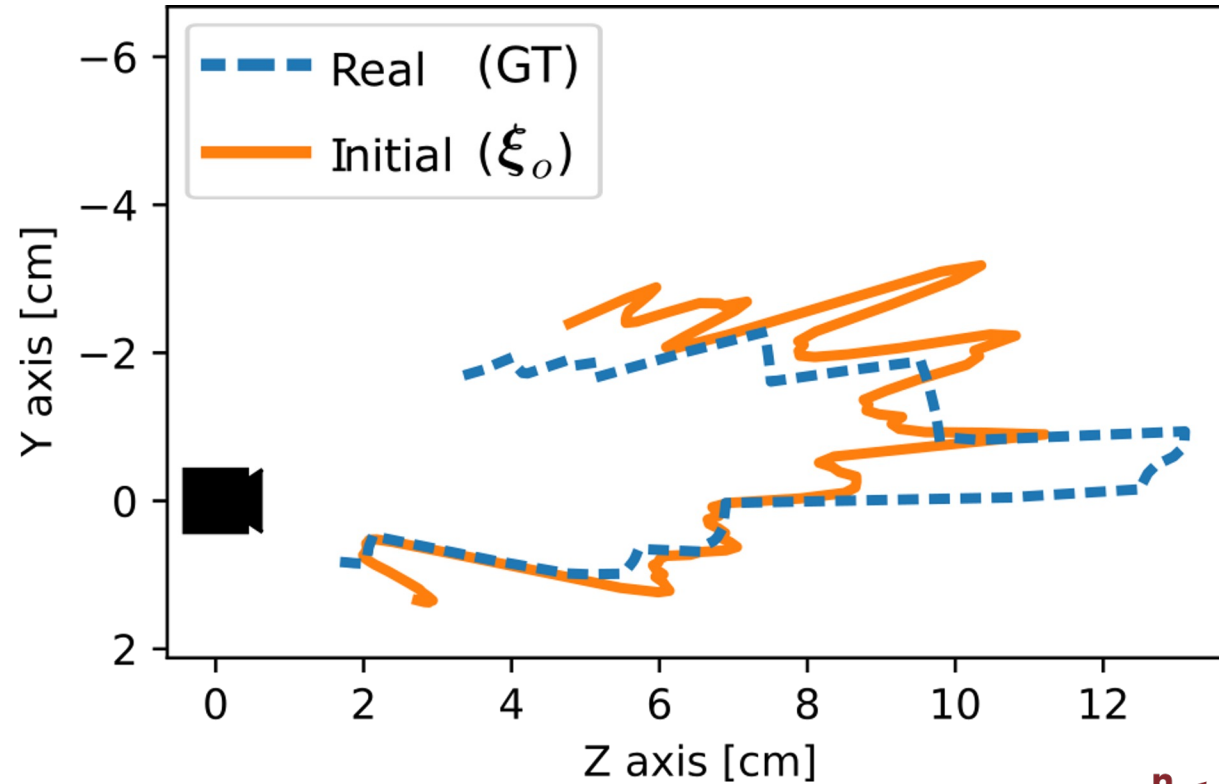
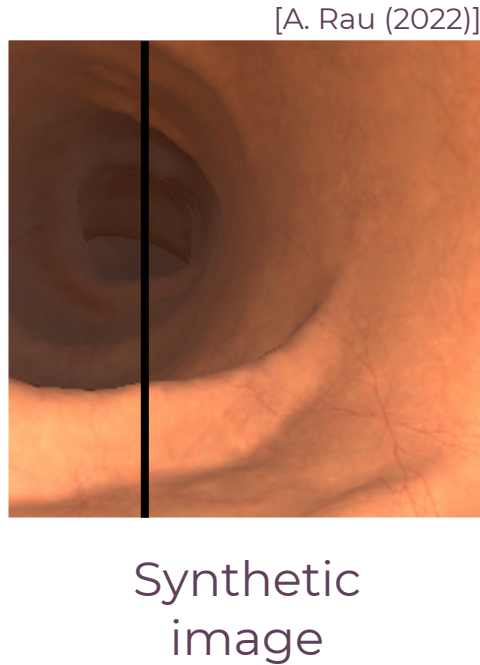


[10] R. A. Newcombe et al. (2011) *DTAM: Dense Tracking and Mapping in Real-Time*.



# EXPERIMENTAL RESULTS

# Simulated colon dataset

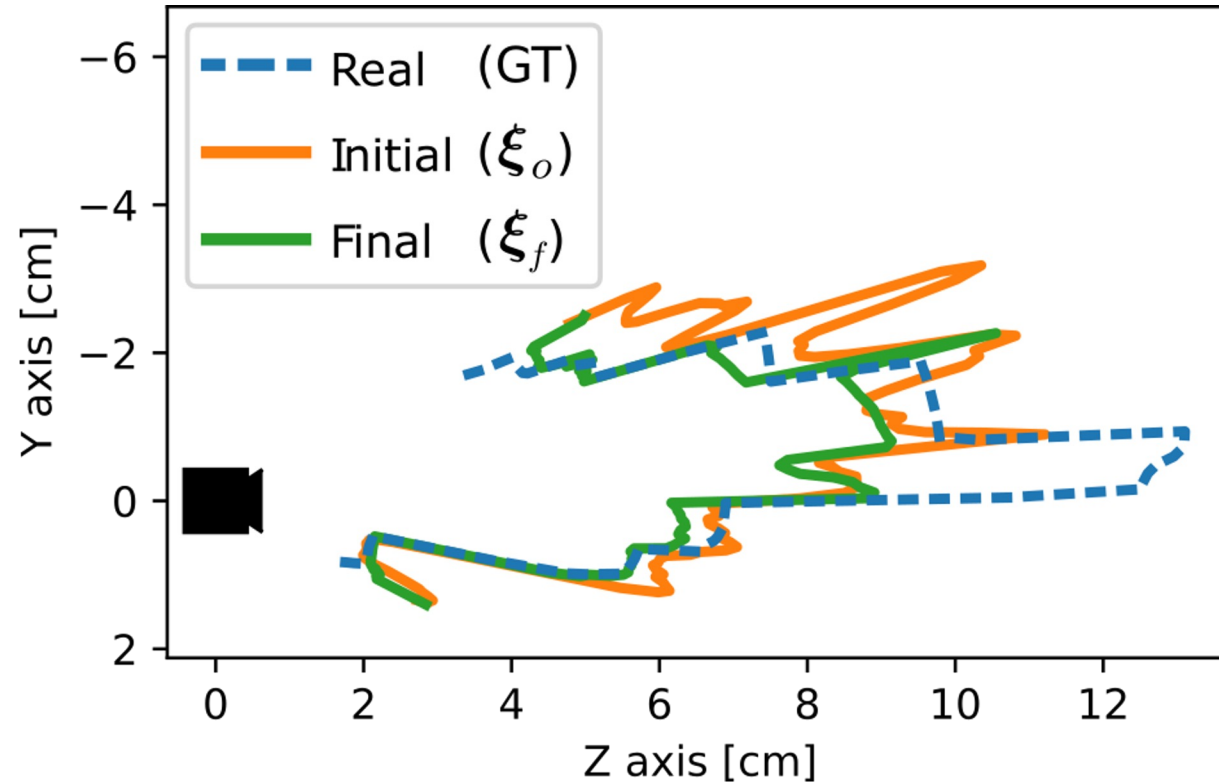


[24] A. Rau et al. (2022) *Bimodal camera pose prediction for endoscopy*.

# Simulated colon dataset



Synthetic image

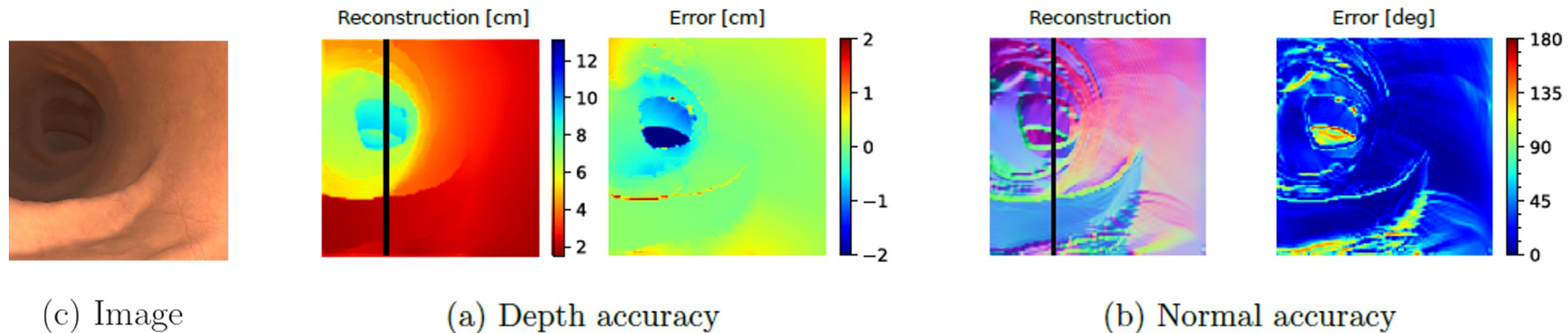


$$\rho(\mathcal{I} - I) + \lambda \|\nabla \xi\|_{\epsilon} \cdot e^{-\alpha \|\nabla I\|_2^{\beta}}$$

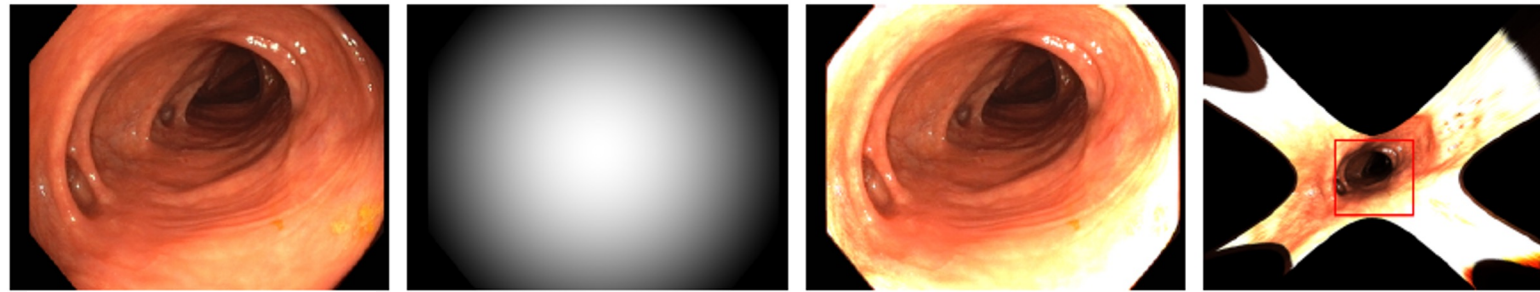
# Simulated colon dataset

$\xi$	Reg.	# iter.	Depth error [cm]		Depth error [%]		Normals error [deg]	
			Mean	Median	Mean	Median	Mean	Median
$1/z$	$\nabla$	44 500	0.53	0.23	10.60	7.41	30.63	23.77
	$\nabla^2$	8 900	0.51	0.40	15.09	11.86	36.06	29.26
$d$	$\nabla$	20 000	0.33	0.16	7.90	4.98	26.21	18.75
	$\nabla^2$	44 500	0.38	0.20	9.57	6.37	32.00	23.56
$1/d$	$\nabla$	44 500	0.28	0.16	7.32	5.01	27.89	19.69
	$\nabla^2$	5 400	0.51	0.40	15.16	12.05	35.86	28.89

Table 5.2: Reconstruction accuracy on the simulated colon dataset.



# Real colon dataset



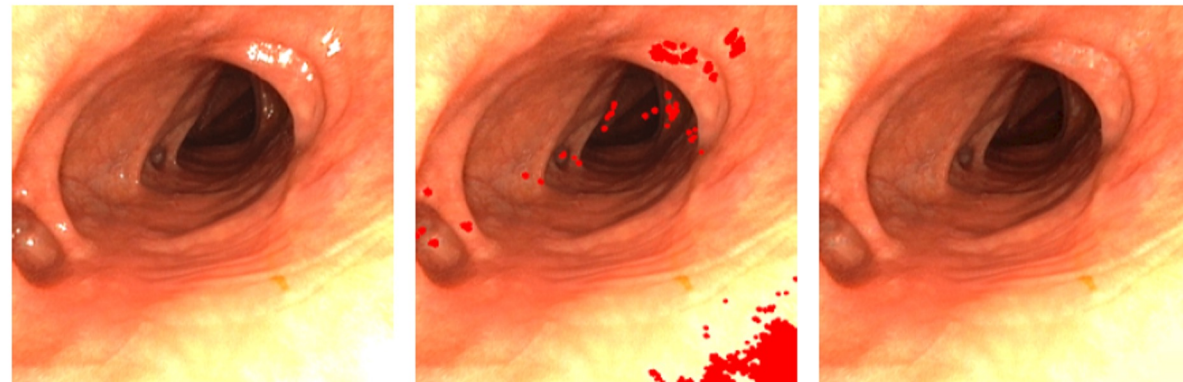
(a) Input frame

(b) Vignetting &  $\mu(x)$

(c) Canonical

(d) Undistorted

*EndoMapper*



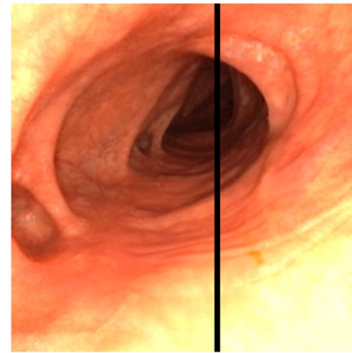
(a) Original frame

(b) Highlight mask

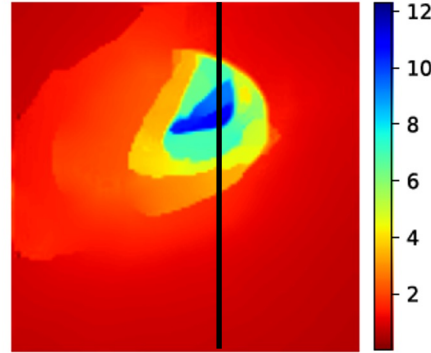
(c) Inpainted frame

[25] P. Azagra et al. (2022). *EndoMapper dataset of complete calibrated endoscopy procedures.*

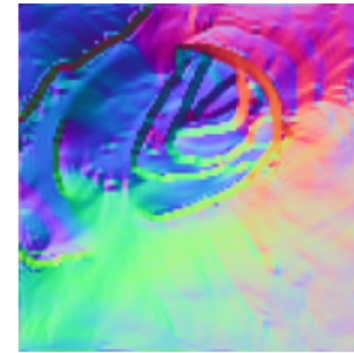
# Real colon dataset



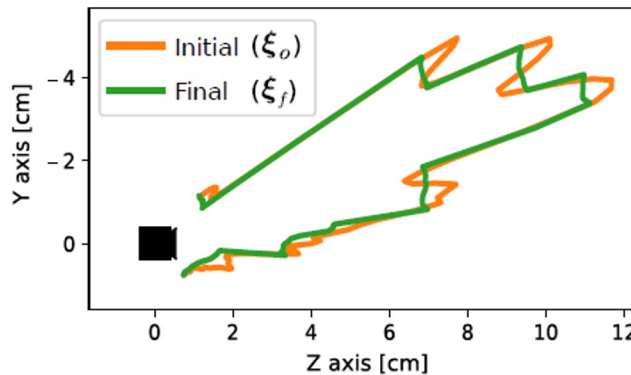
(a) Input frame



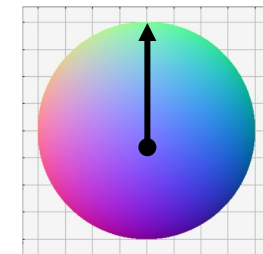
(b) Estimated depth

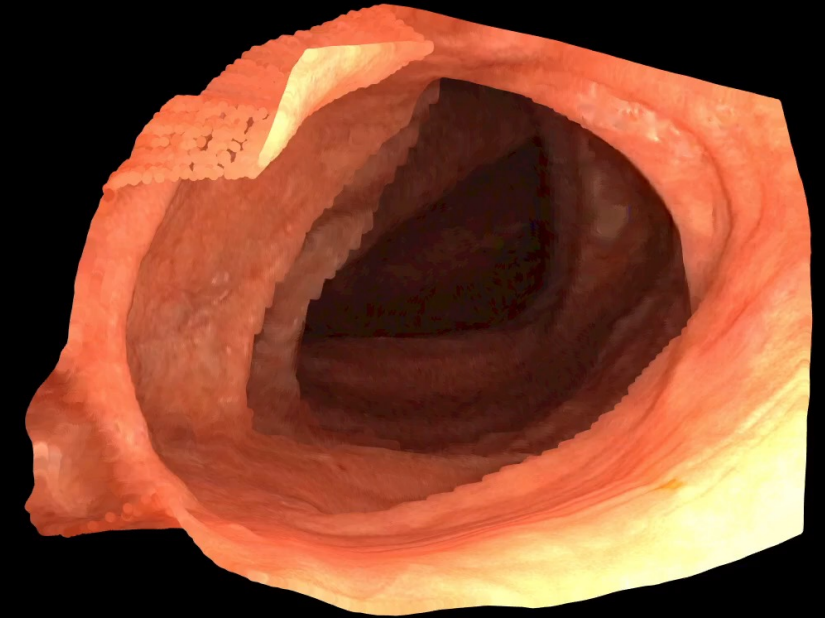
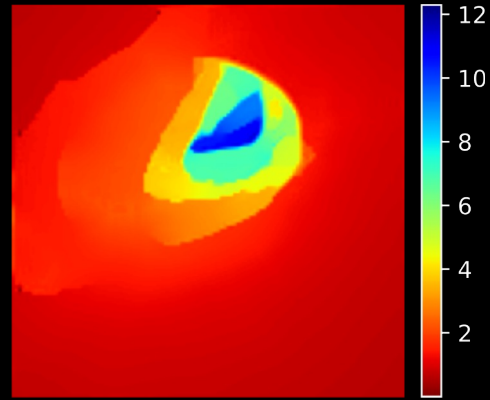
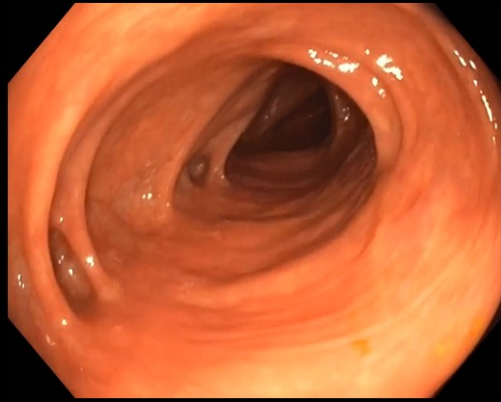


(c) Estimated normals



(d) Cross-section along black line





**3D reconstruction**

[25] Azagra, P et al. (2022).  
*EndoMapper dataset of complete calibrated endoscopy procedures.*

- (1) We can **reconstruct the 3D scene's real-scale** from monocular images.  
*when surface BRDF and camera gain are known.*
- (2) Depth estimation with **7% error (3 mm).**