COLLEGE OF ENGINEERING
ROBOTICS INSTITUTE
UNIVERSITY OF MICHIGAN

DROP
DEEP ROBOT OPTICAL PERCEPTION Lab

Unsupervised Learning for Underwater Image Restoration

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University of Michigan

Motivation

Bleached coral

Healthy coral

Reference: The Ocean Agency/XL Caitlin Seaview Survey

Expectation…

Photo: Volodymyr Goinyk

…vs. Reality

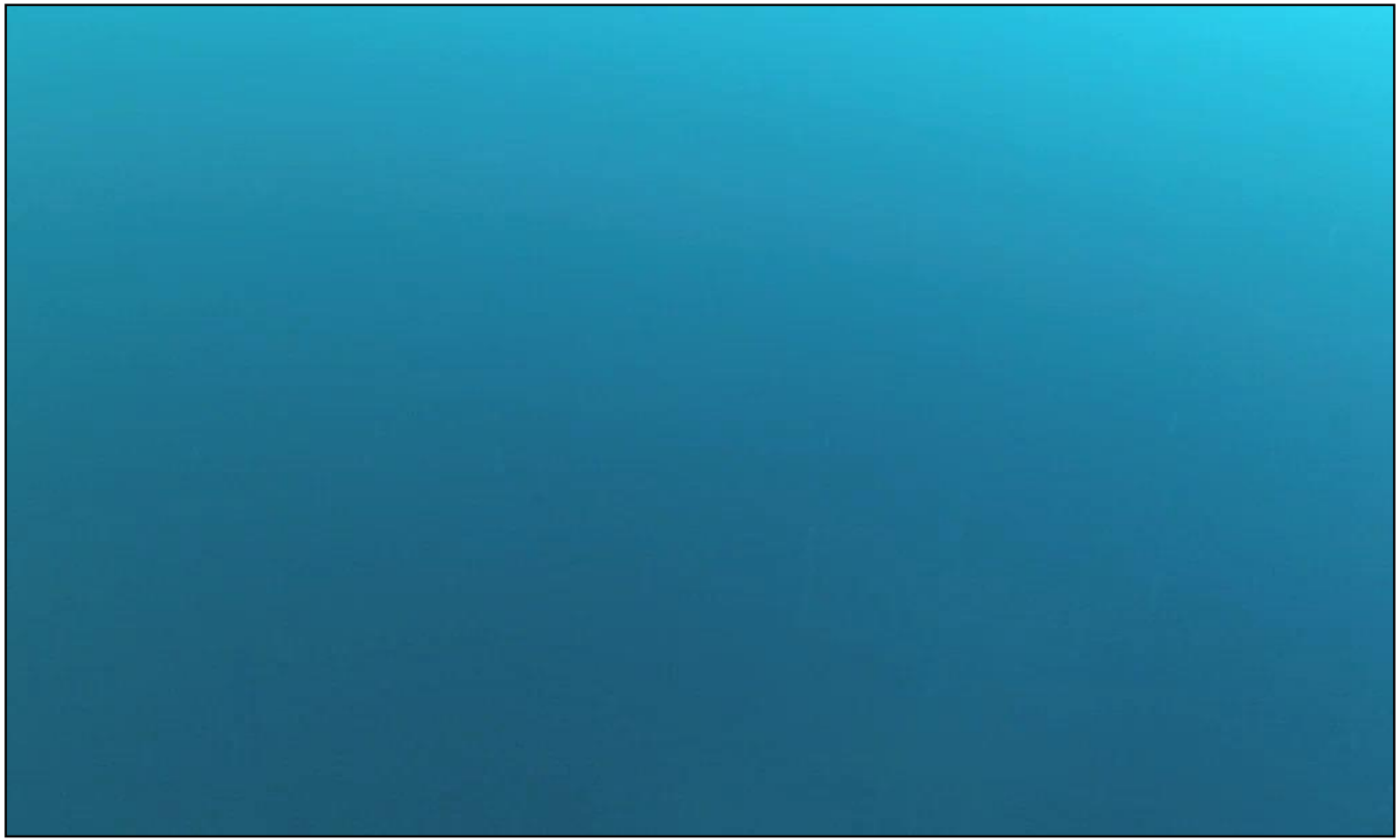
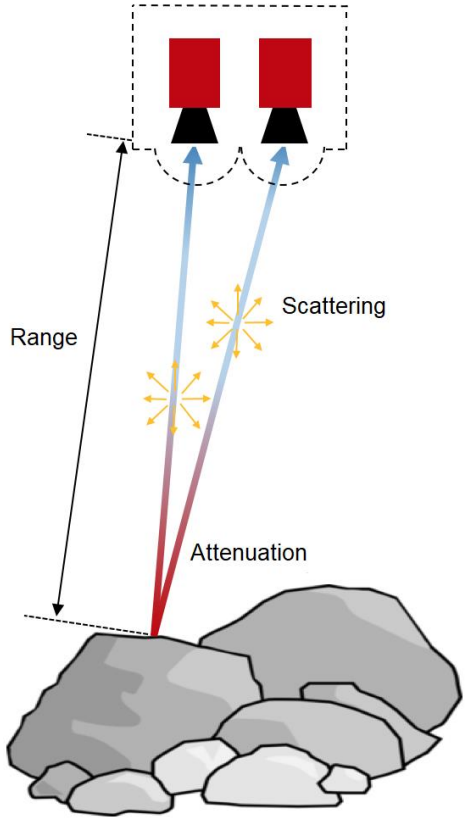


Photo: Australian Centre for Field Robotics (ACFR)

Underwater Image Formation

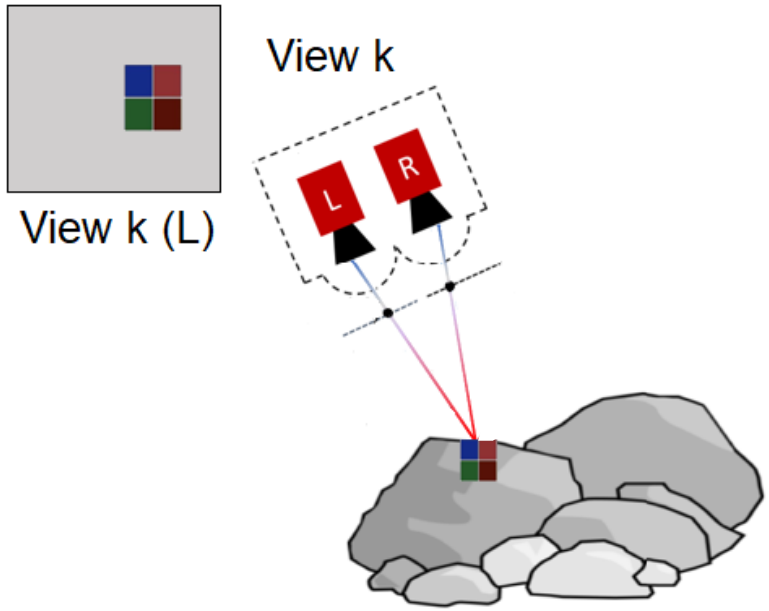
Attenuation and backscattering lead to range-dependent image degradation

Hog Reef, Bermuda



Abstraction of underwater image formation

Computer Vision Challenges: Photometric Consistency



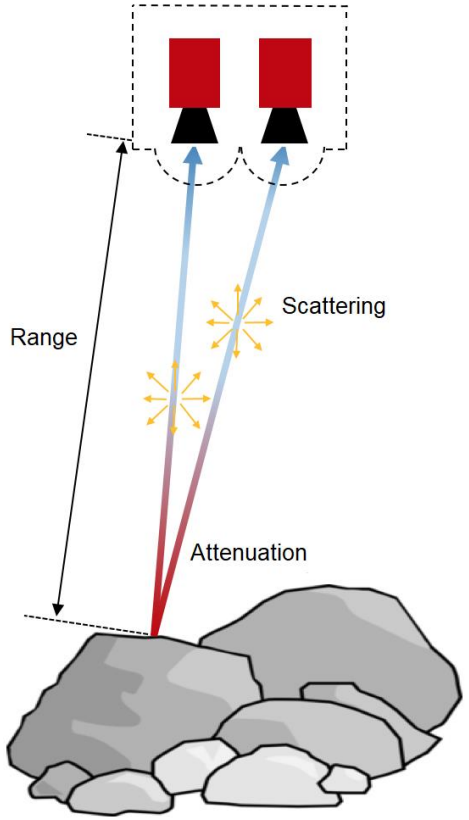
Assumptions used on land break down underwater due to range-dependent water column effects

Model-based vs. Data-driven

Model-based

- Explicit rules
- Interpretable
- Structured solutions
- Limited complexity

➢ Varying environmental conditions



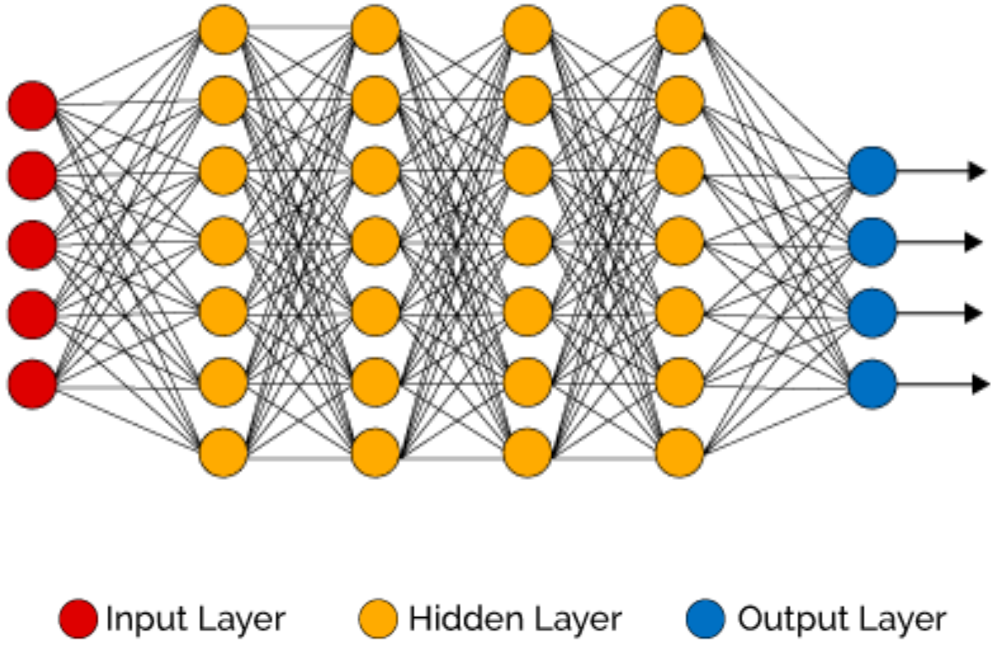
Abstraction of underwater image formation

Model-based vs. Data-driven

Data-driven

- Complex systems
- Training data
- Labels
- “Black box”

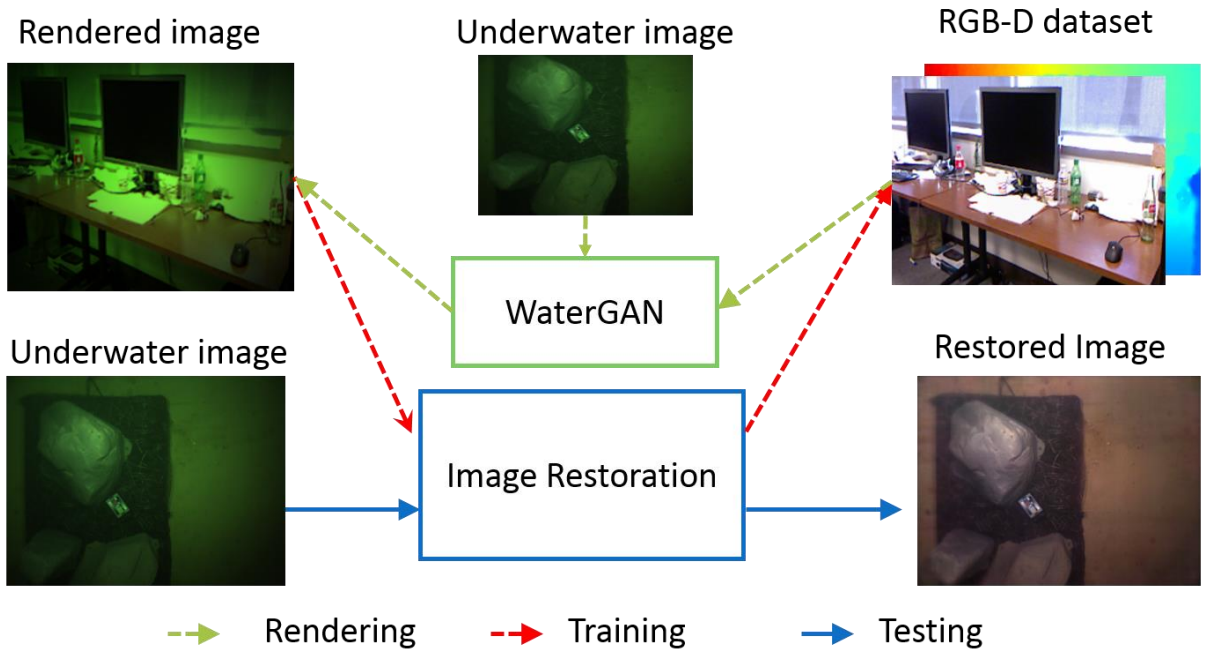
➢ Lack of ground truth



Reference: Favio Vázquez

- Integrate structure and insight from model-based approaches to enable unsupervised learning
- Hybrid model-based, data driven approach

WaterGAN: Unsupervised Generative Network to Enable Real-time Color Correction of Monocular Underwater Images



Jie Li*, Katherine A. Skinner*, Ryan Eustice and Matthew Johnson-Roberson, "WaterGAN: Unsupervised generative network to enable real-time color correction of monocular underwater images." In IEEE RA-L, 2017.
*The authors contributed equally to this work.

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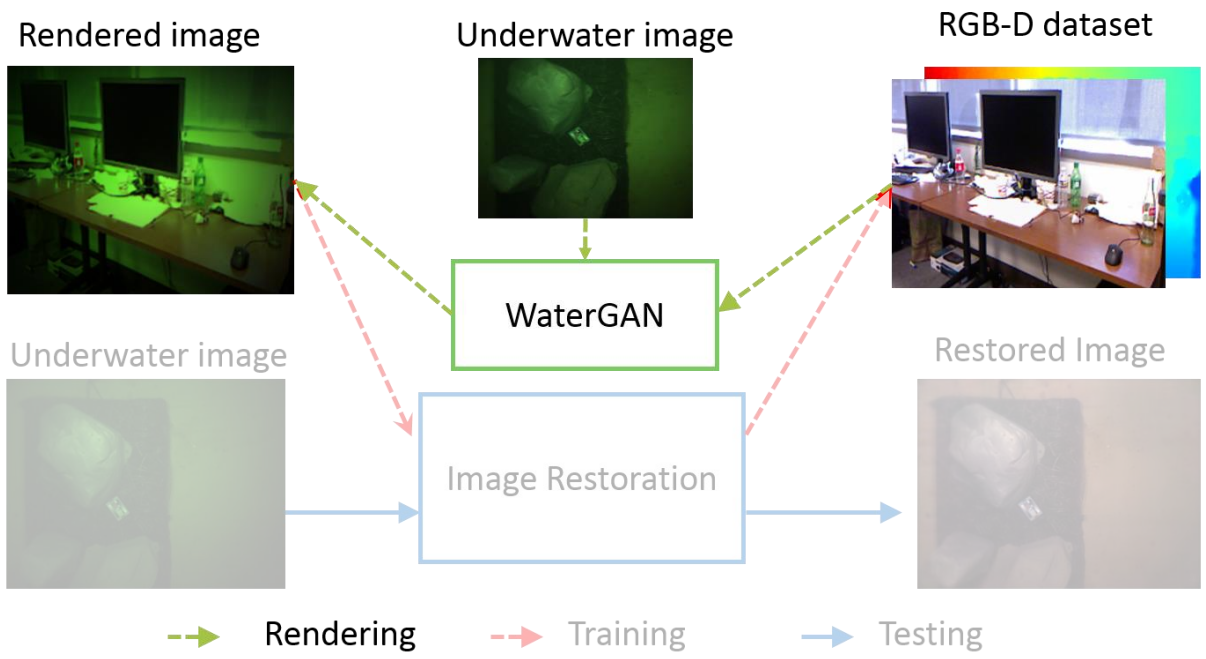

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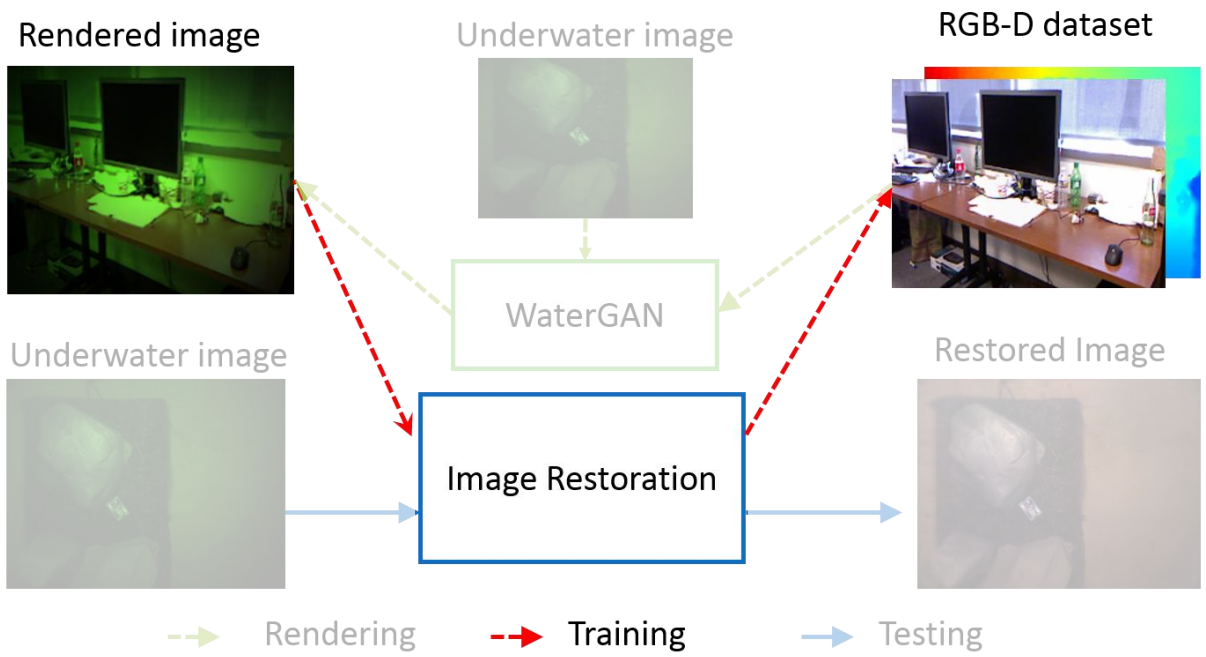

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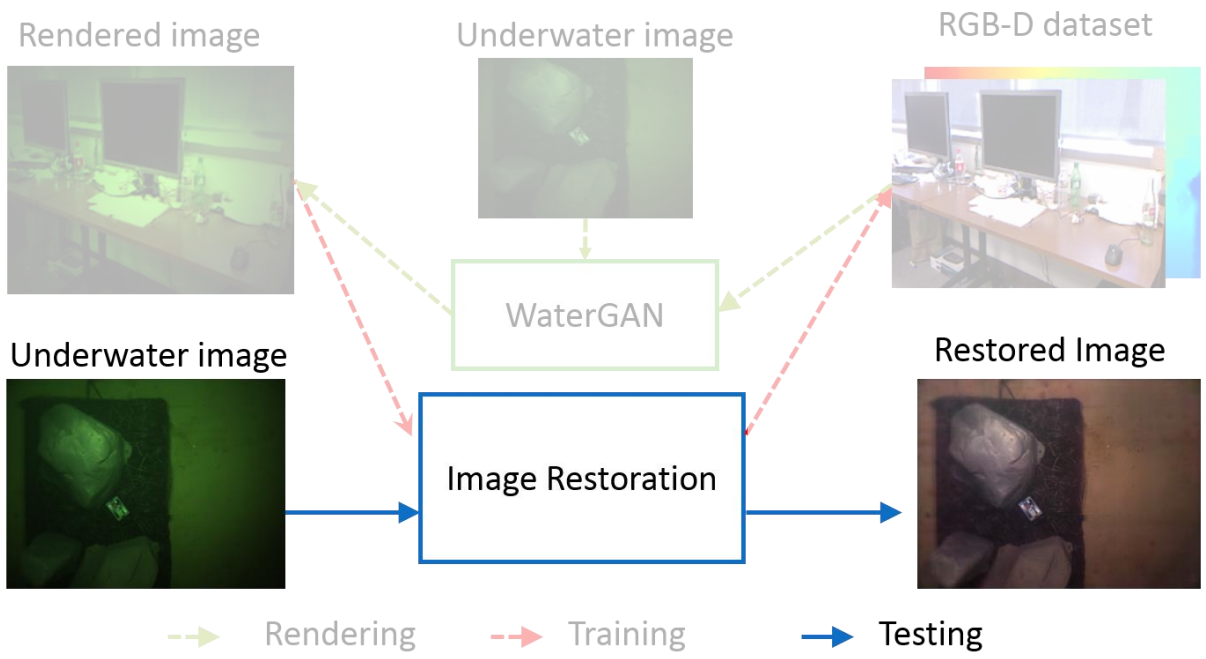

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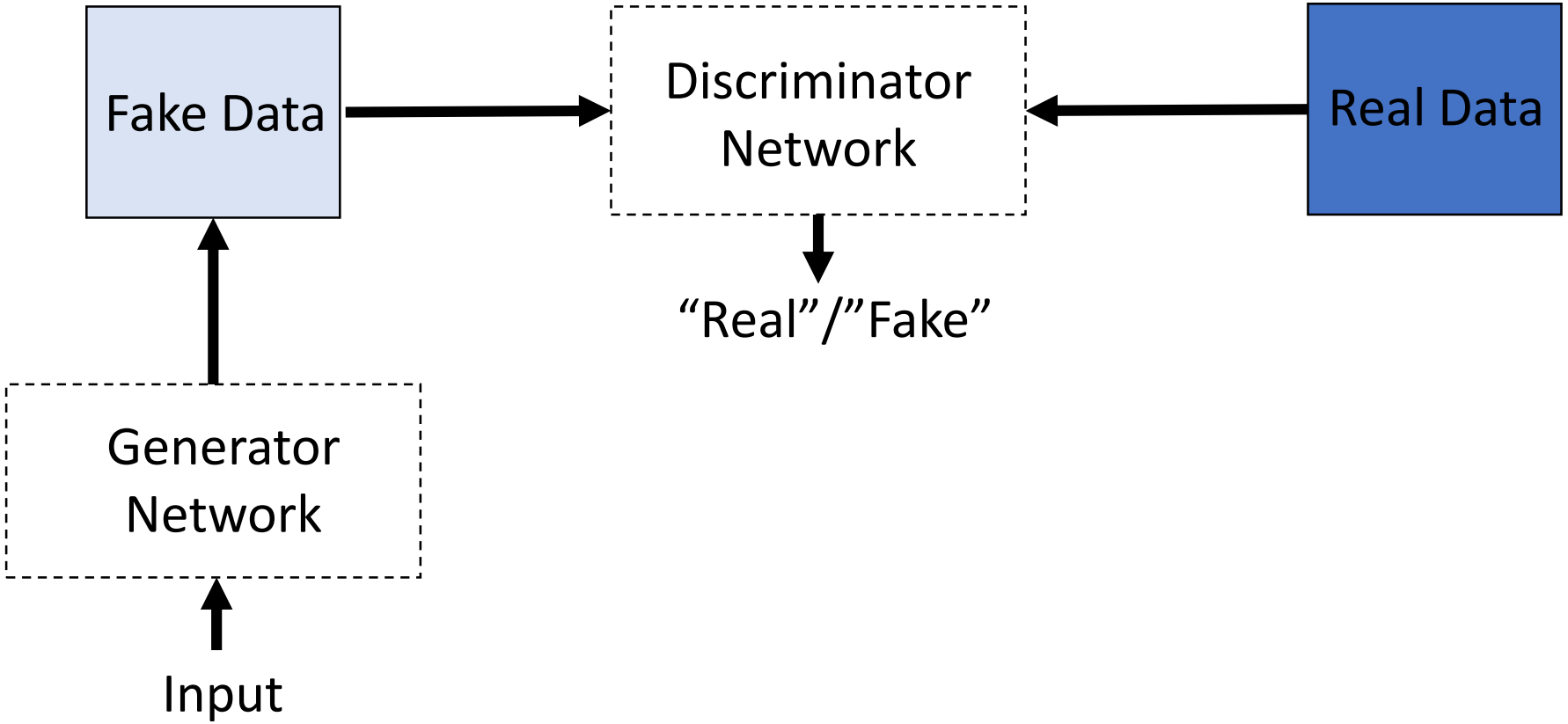
Generative Adversarial Networks (GANs)



Reference: I. J. Goodfellow, et al. "Generative adversarial networks," *NIPS*, 2014.

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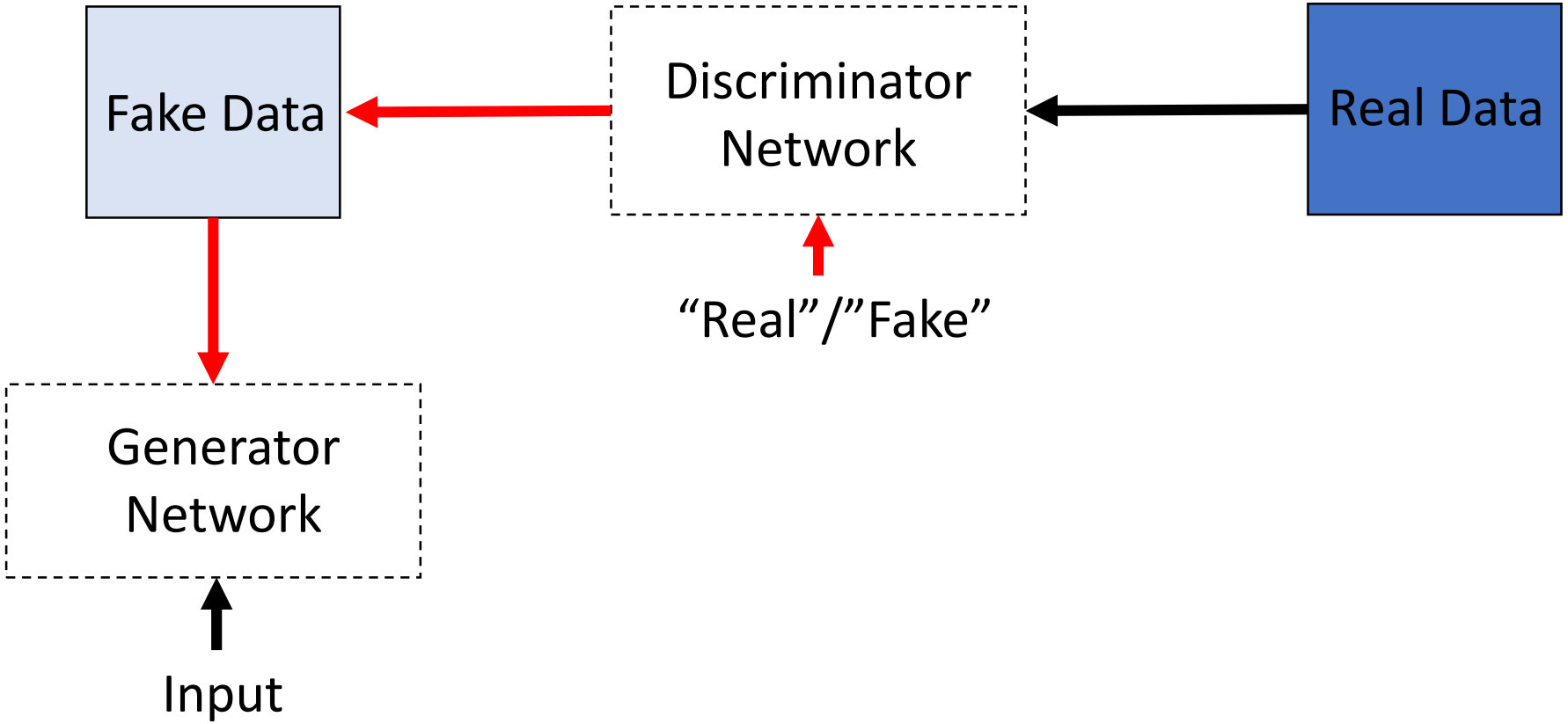

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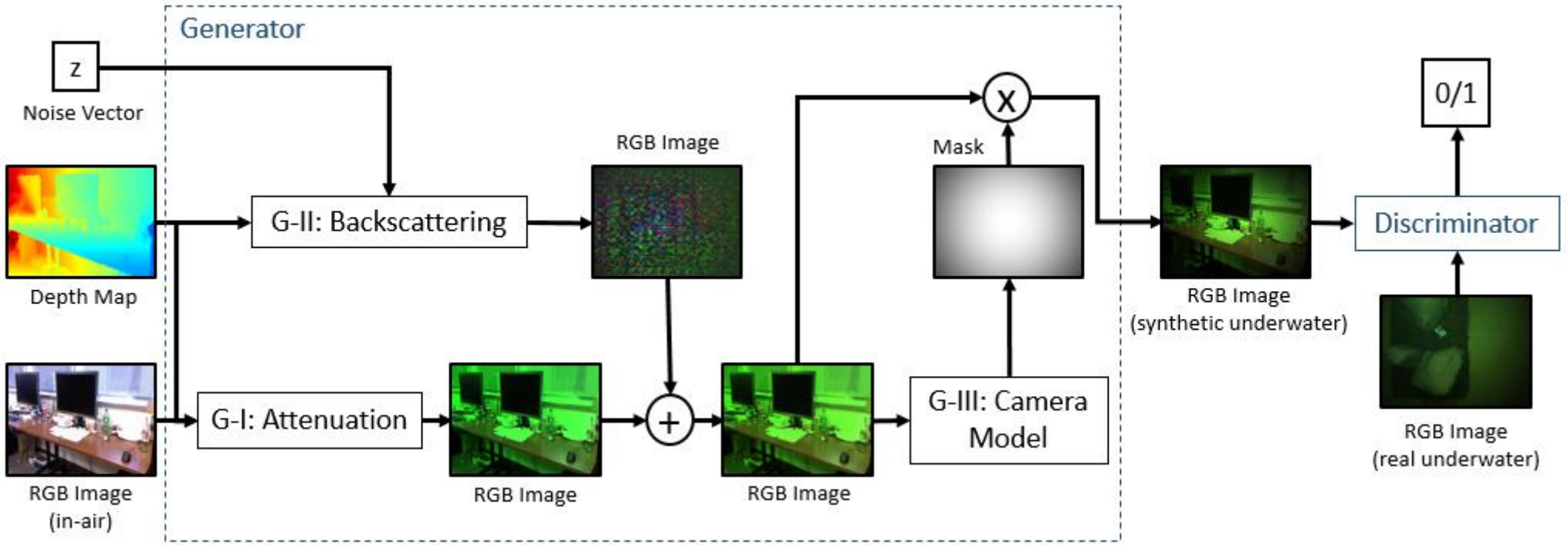
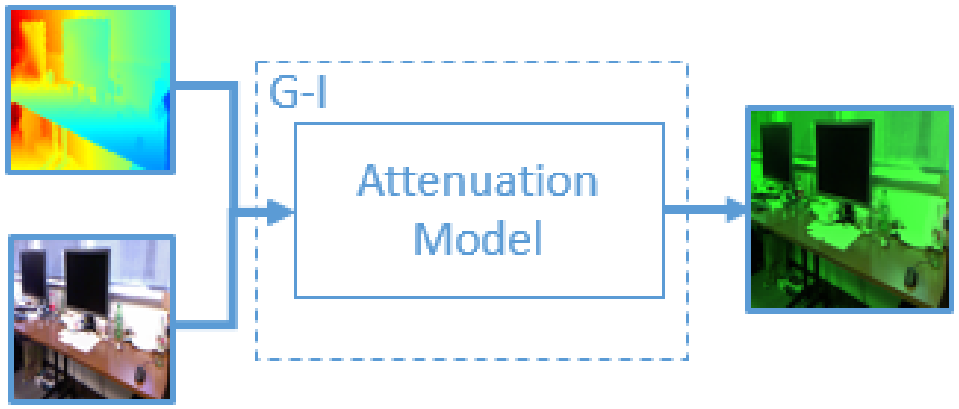
Generating Realistic Underwater Images



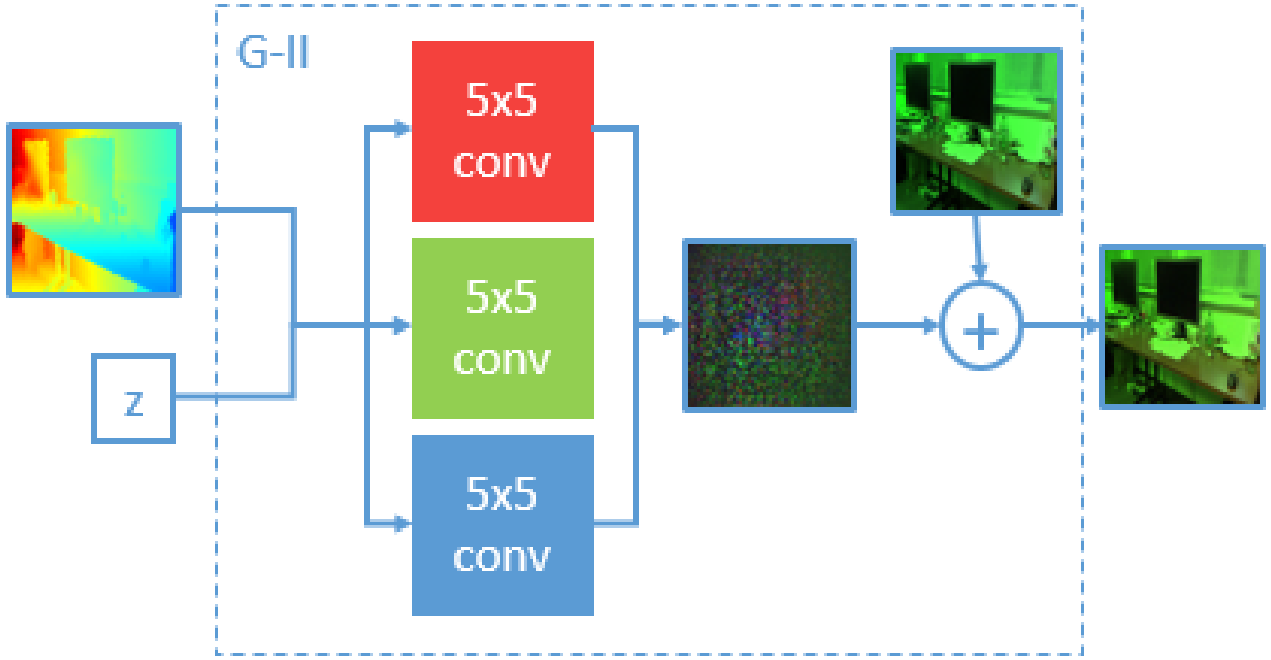
Stage G-I: Attenuation



$$G_{1,C} = I_{air,C} e^{-\beta_C \Delta z}$$

Δz = Distance along line of sight
β_C = Effective wideband atten. coeff.
I = Image
C = Color channel

Stage G-II: Backscattering



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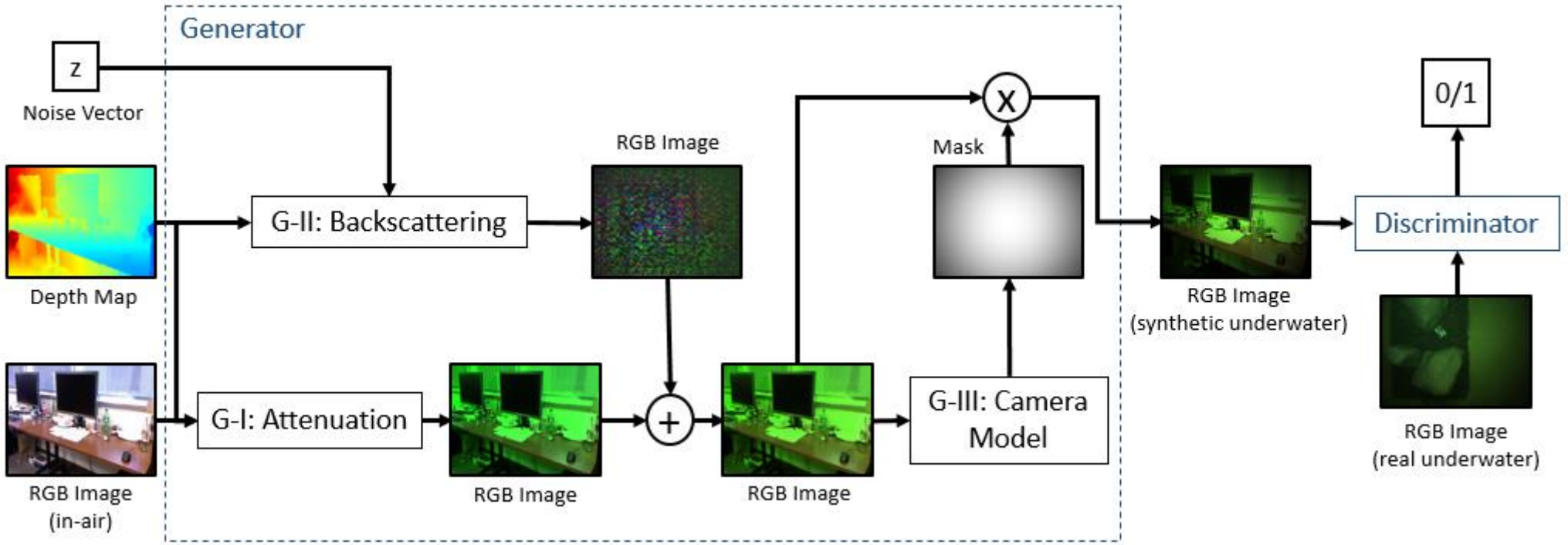
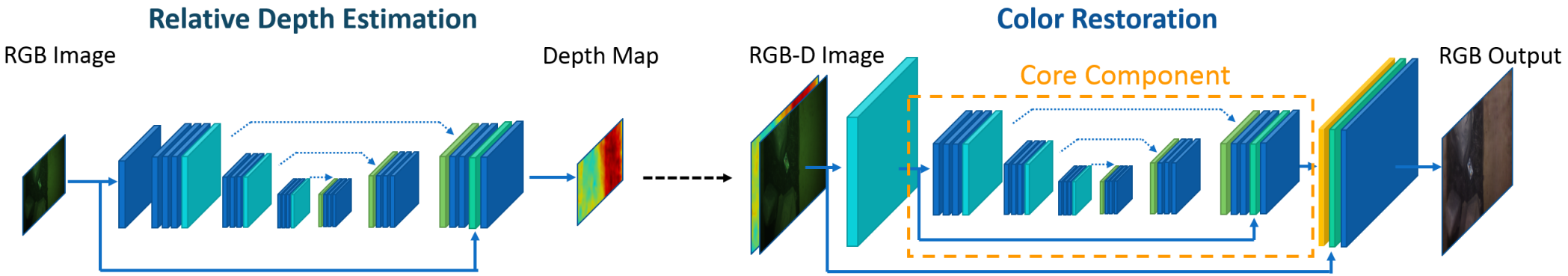


Underwater Image Restoration Network



Dr. Jie Li

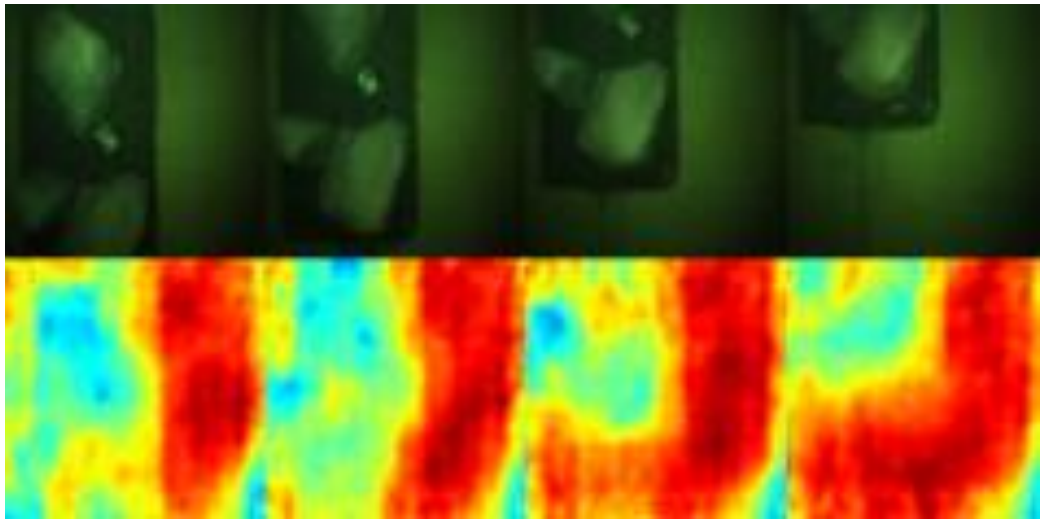
Experiments

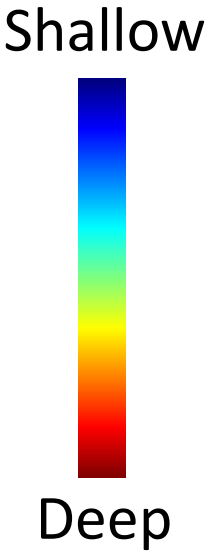
Results

Color Consistency

Raw | Histogram Equalization | Gray World | Modified Jaffe-Mcglamery | Shin et al. | WaterGAN

Monocular Depth Estimation





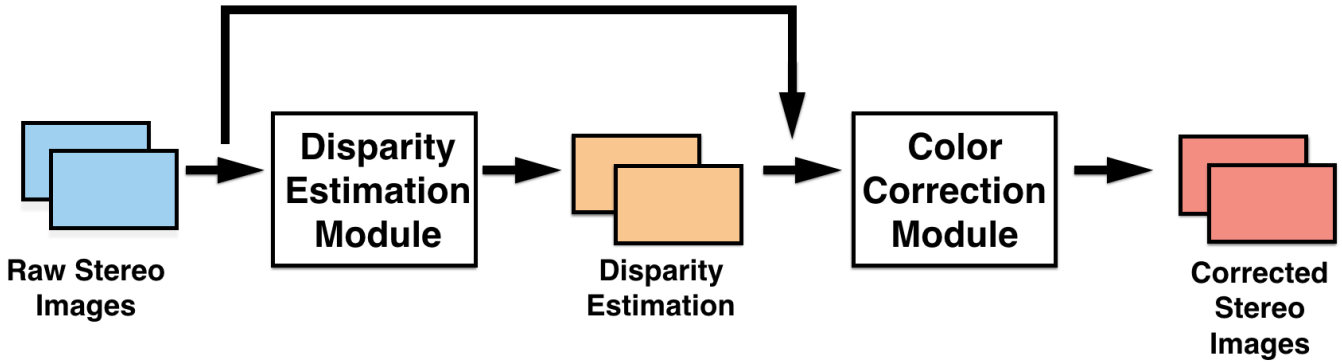
Results for WaterGAN depth estimation

Monocular Underwater Image Restoration

Underwater Stereo Vision

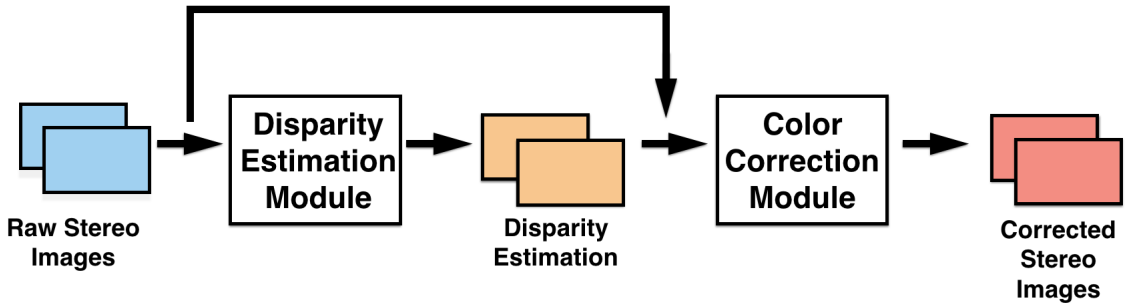
Towards Real-time Underwater 3D Reconstruction

UWStereoNet: Unsupervised Learning for Depth Estimation and Color Correction of Underwater Stereo Imagery



Katherine A. Skinner, Junming Zhang, Elizabeth Olson and Matthew Johnson-Roberson, “UWStereoNet: Unsupervised learning for depth estimation and color correction of underwater stereo imagery." Submitted to ICRA, 2019.

Unsupervised Learning for Stereo Vision

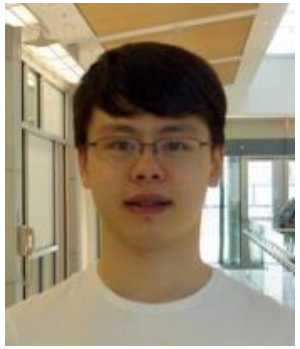


Disparity Estimation

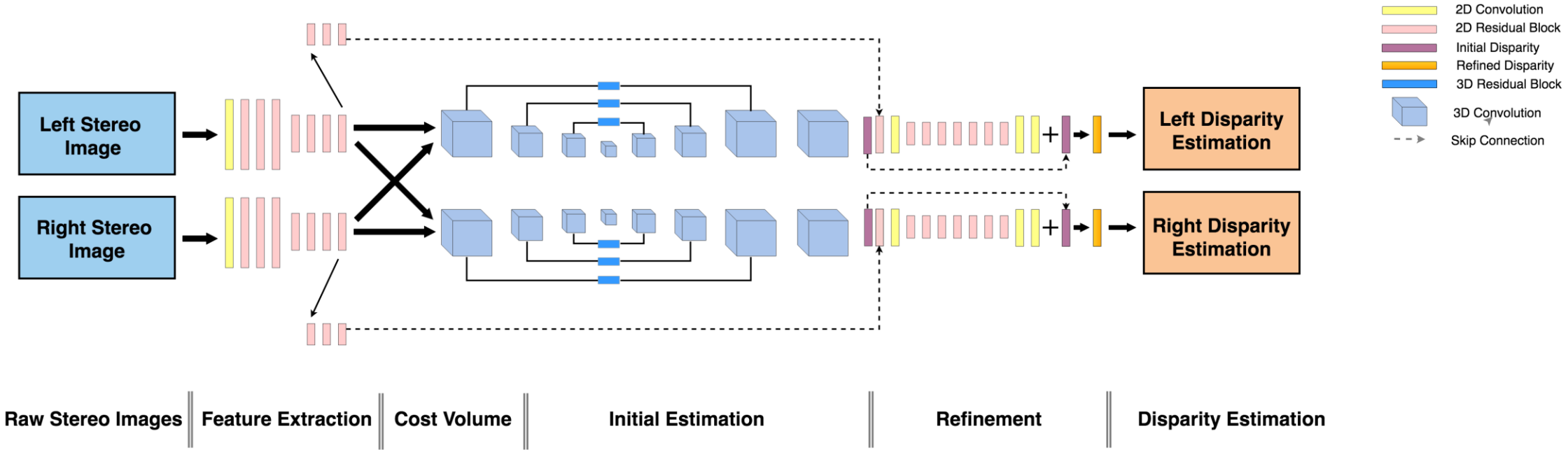
$$Loss = \alpha_1 L_{disp\_init} + \alpha_2 L_{disp\_ref}$$

$$L_{disp\_init} = \beta_1 L_{disp\_warp} + \beta_2 L_{consist} + \beta_3 L_{reg}$$

$$L_{disp\_ref} = \gamma_1 L_{disp\_warp} + \gamma_2 L_{consist} + \gamma_3 L_{smooth}$$

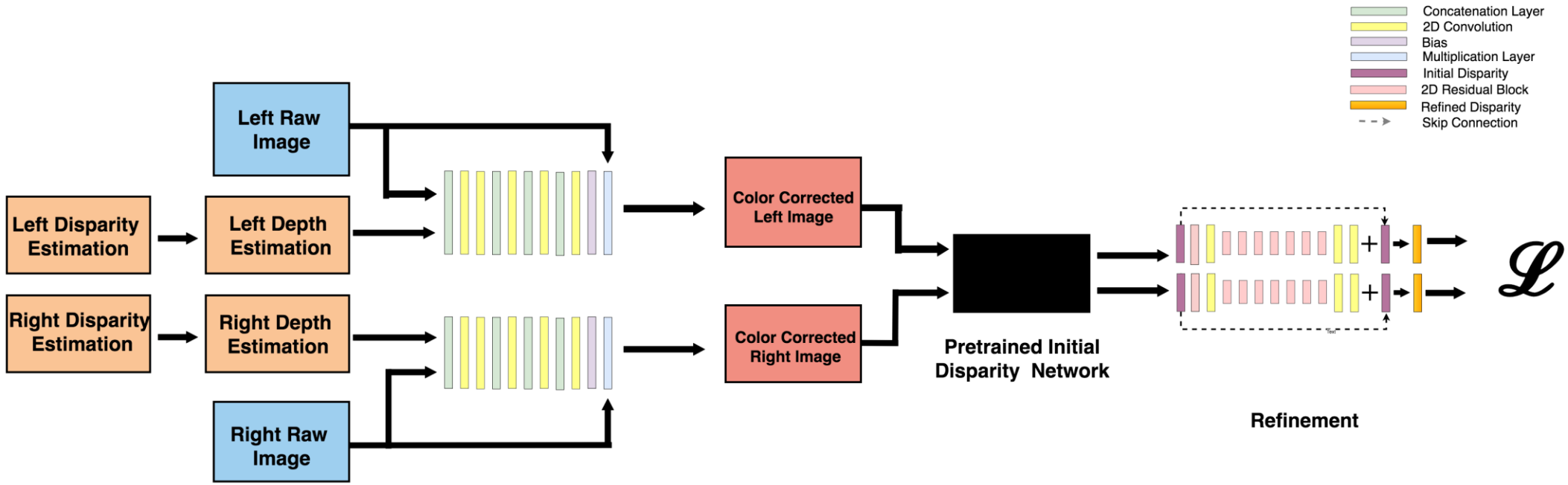


Junming Zhang

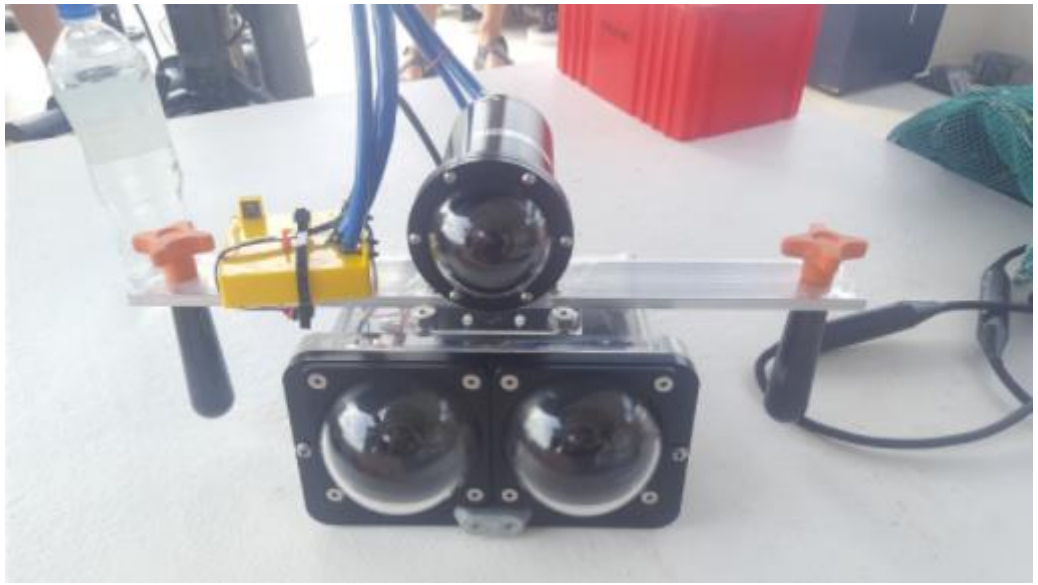


Color Correction

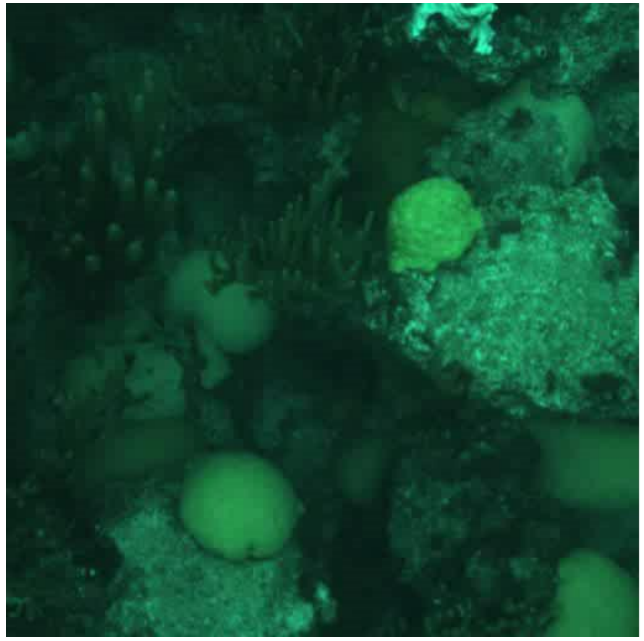
$$Loss = \theta_1 L_{gray} + \theta_2 L_{IQ} + \theta_3 L_{color\_warp} + \theta_4 L_{color\_cyc} + \theta_5 L_{disp\_ref}$$



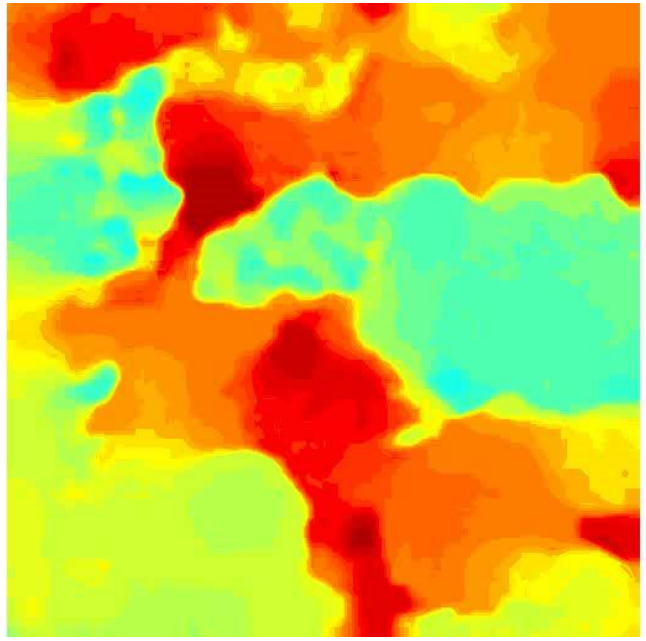
Experiments



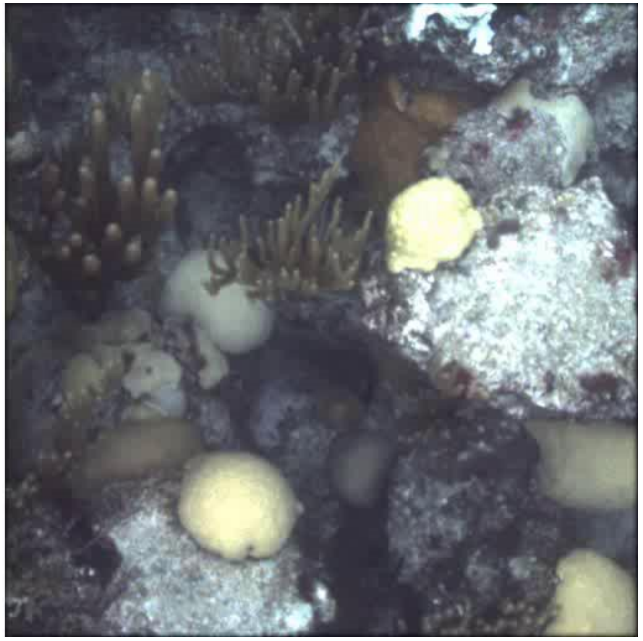
Results



Raw Image



Depth Map

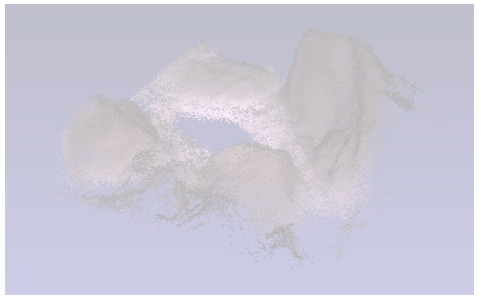


Corrected Color

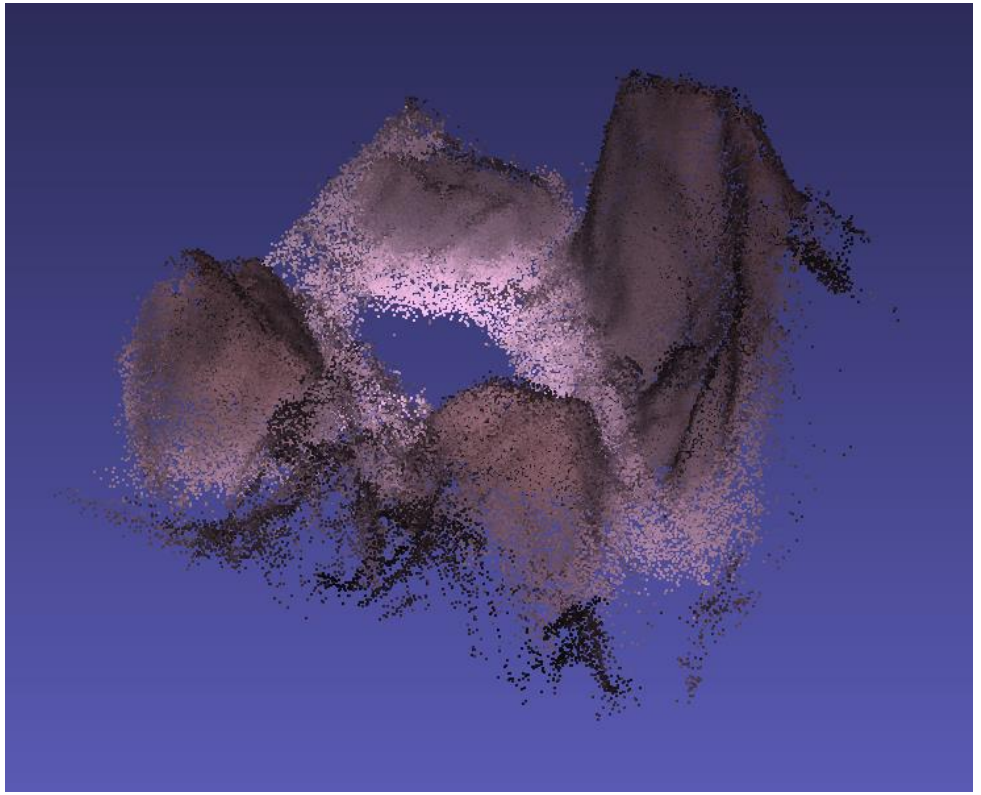
Monocular Underwater Image Restoration

Underwater Stereo Vision

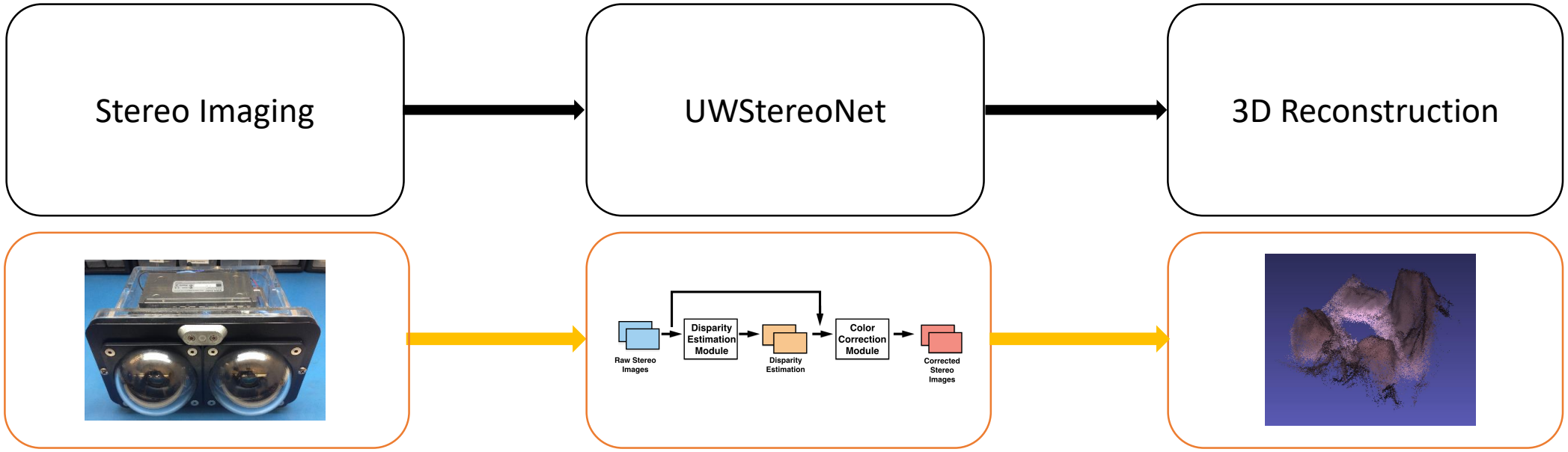
Towards Real-time Underwater 3D Reconstruction



Towards Real-Time Underwater 3D Reconstruction with Stereo Cameras

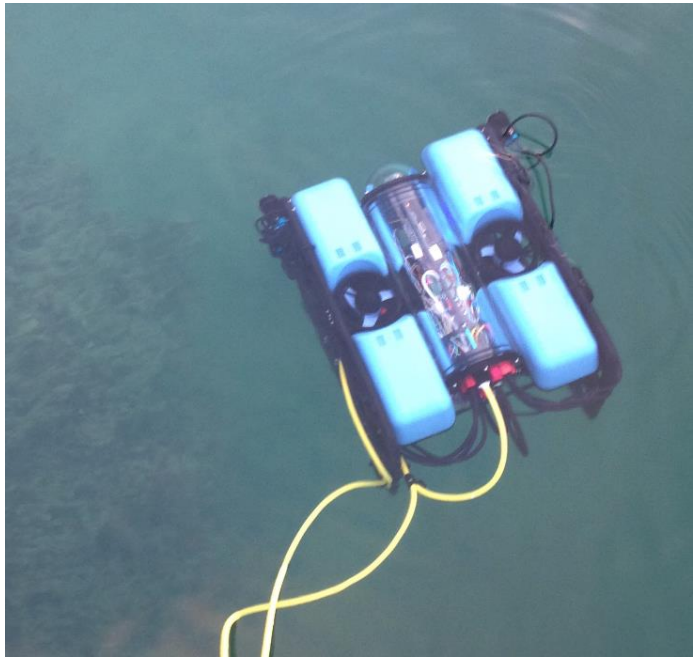


Overview



Reference: T. Whelan, et. al, “ElasticFusion: Dense SLAM Without A Pose Graph." RSS, 2015.

Experiments



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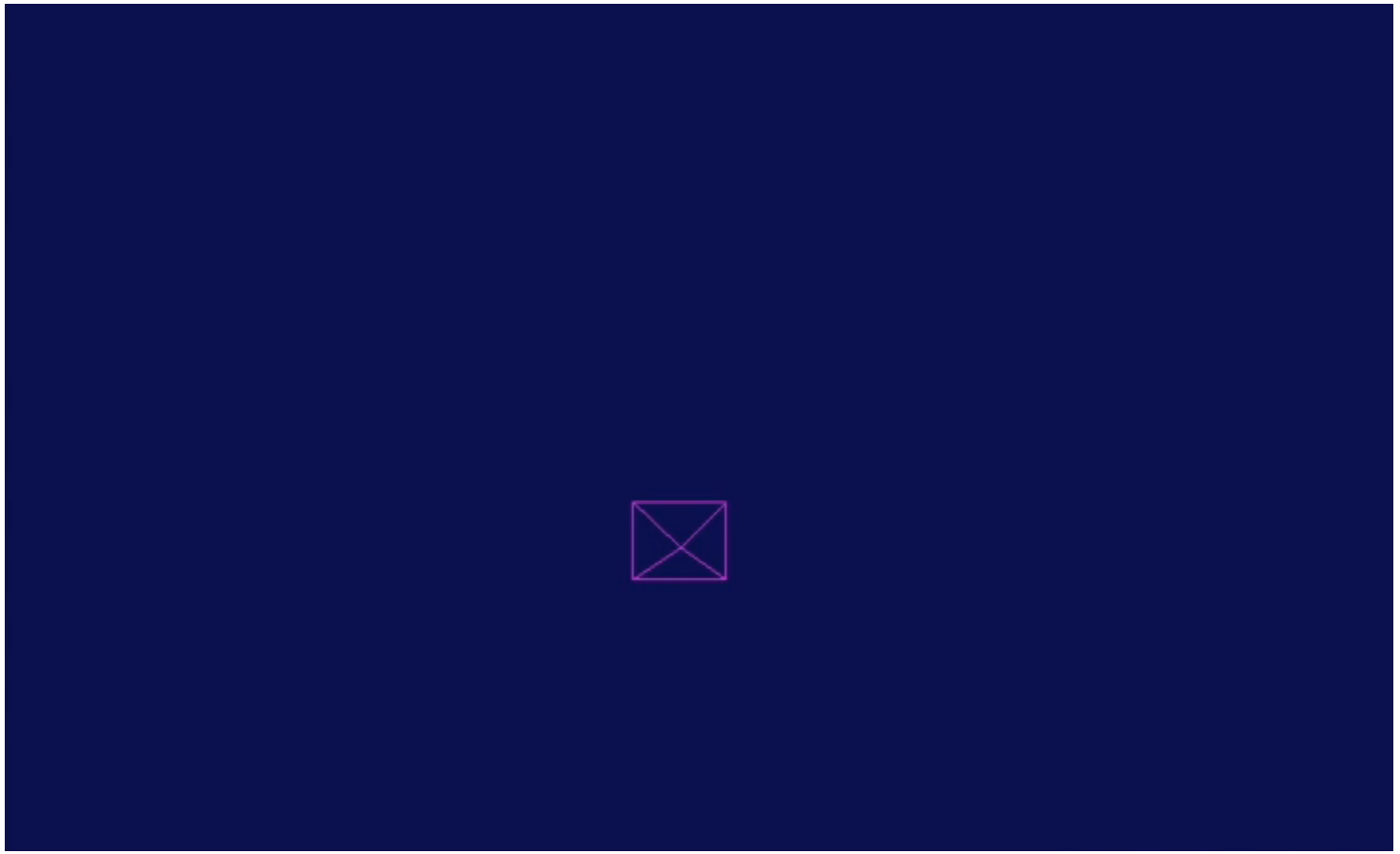
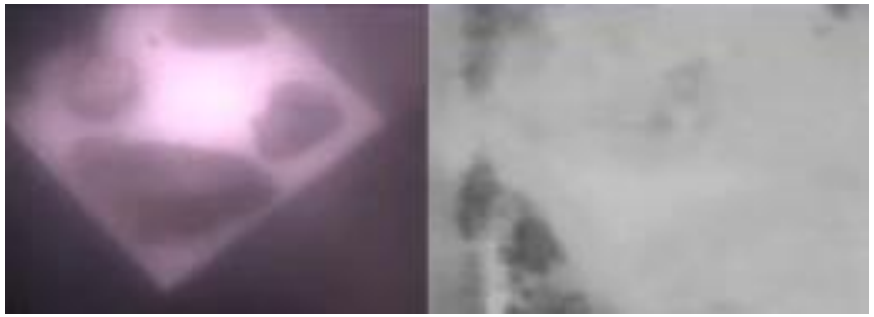
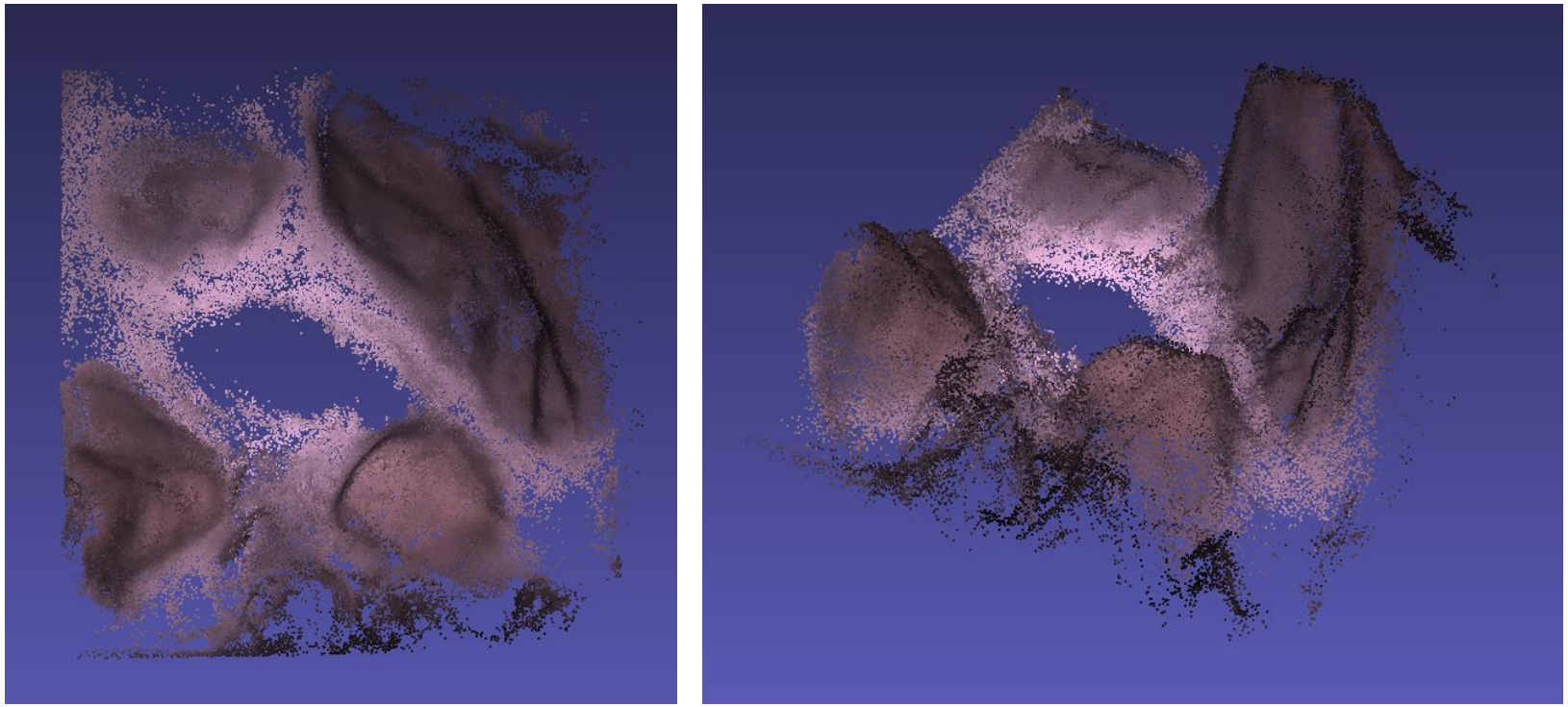




Input RGBD

Results



Summary

- Lack of ground truth
  → Leverage physics-based models, geometry, and image processing constraints
- System integration of learning-based approaches
  → Modular approaches vs. end-to-end learning

Future Directions

- Eliminating the need for hand-labelled data
  - Generating synthetic data through augmentation
  - Training from simulated data
  - Automated labelling with multi-modal datasets
- Generalizability
- Open source data and benchmark evaluation

Thank you!