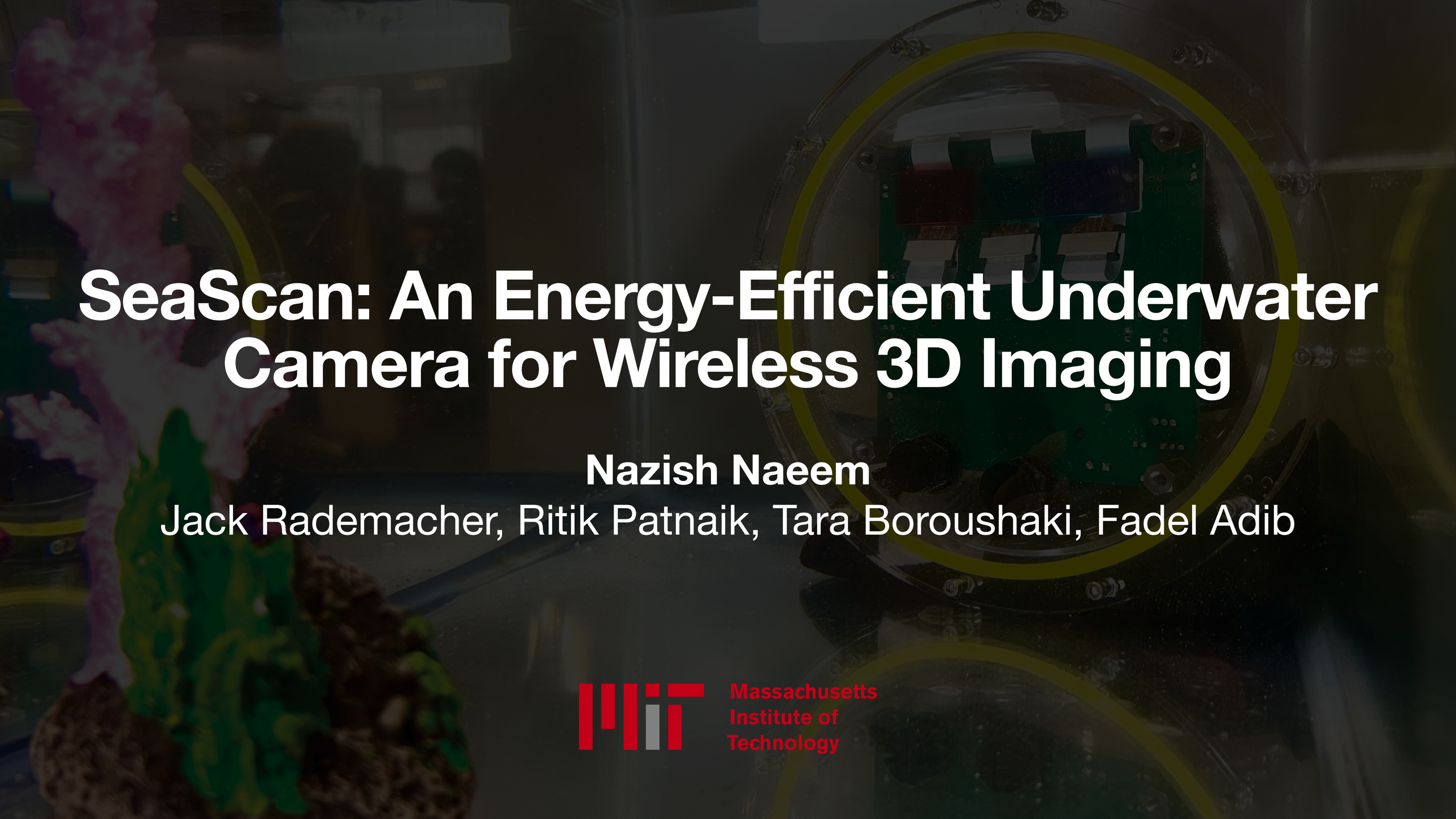


SeaScan: An Energy-Efficient Underwater Camera for Wireless 3D Imaging

Nazish Naeem

Jack Rademacher, Ritik Patnaik, Tara Boroushaki, Fadel Adib

Massachusetts Institute of Technology

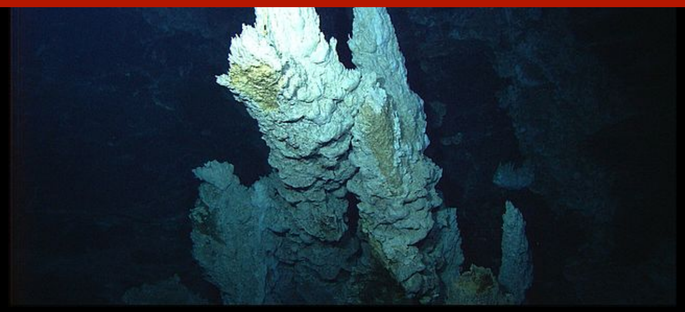
Why Do We Need Longterm Underwater Imaging?







Today’s underwater cameras are too power hungry & only last for a few minutes on batteries

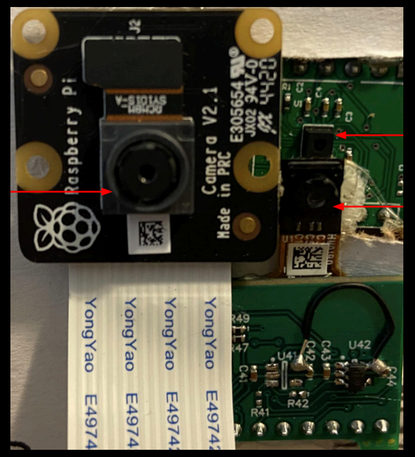


SubSea Geology



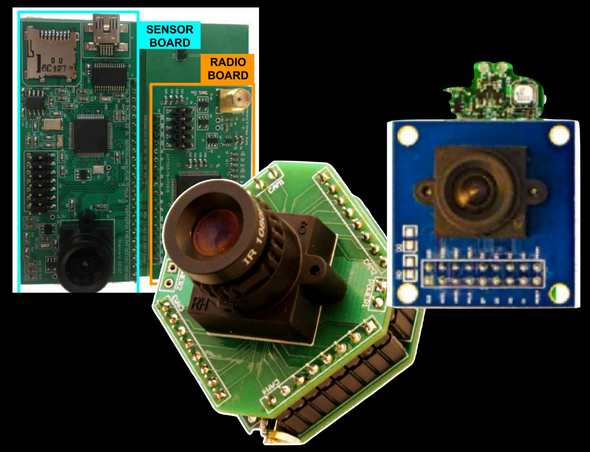
Impact of Human Activity

Existing Low-Power (in-air) COTS Camera Designs Aren't Suitable Underwater



High Throughput Streaming

[MobiCom'23]



Low Power Grayscale Imaging

[NSDI'18, IEEE RFID'15]

Proposed designs for low-power color imaging require specialized circuits [NSDI'18, IEEE'18]

Can we build an underwater color imaging system using commercial off the shelf components that can run on a battery for years?

SeaScan

- The most energy-efficient wireless color imaging system for the underwater environments that uses COTS sensors
- Consumes sub-joule of energy and can last for 4 years on a coin cell battery

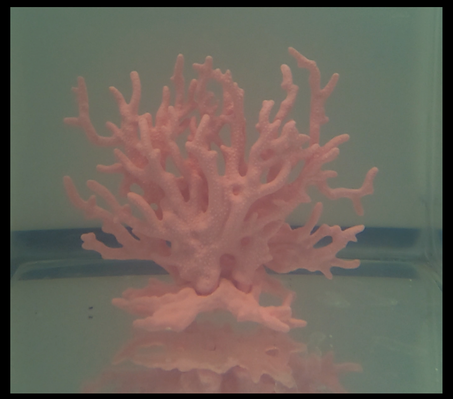
Achieving Color Imaging

SeaScan achieves energy efficient color imaging by relying entirely on COTS grayscale sensor

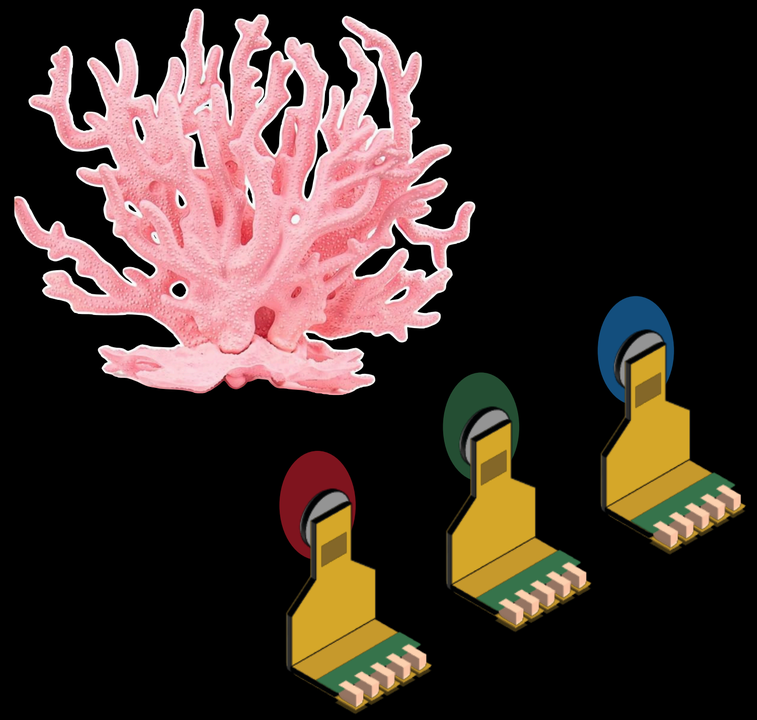
Why not color cameras?

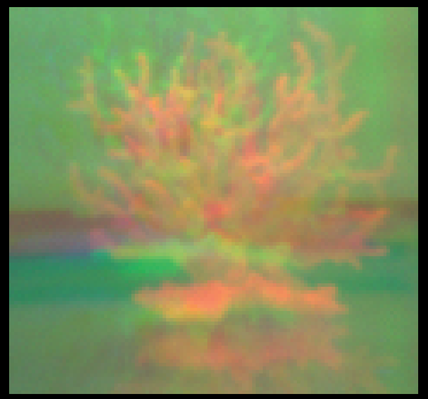
COTS color sensors 17-35x higher power consumption compared to grayscale sensors

Our Idea: Trinocular Lensing system with Passive Filters



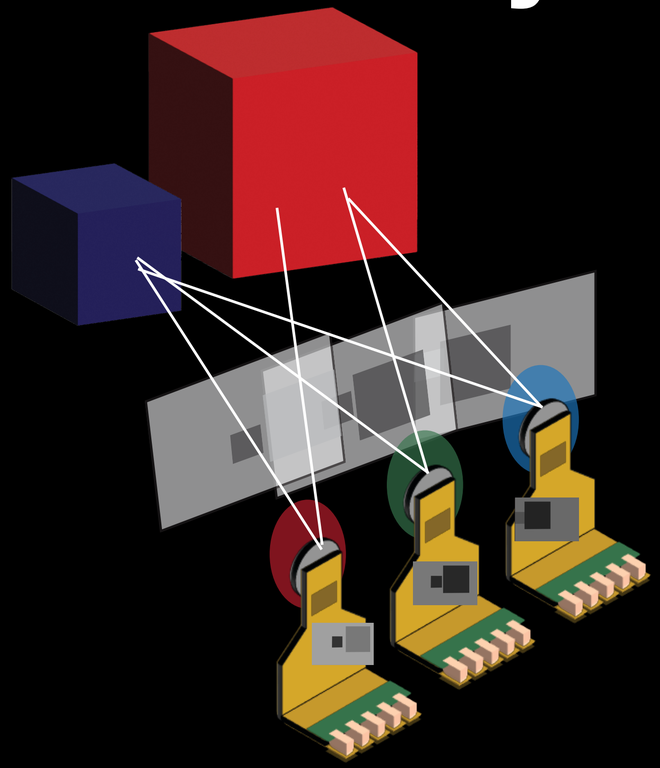
Expected
Color Image

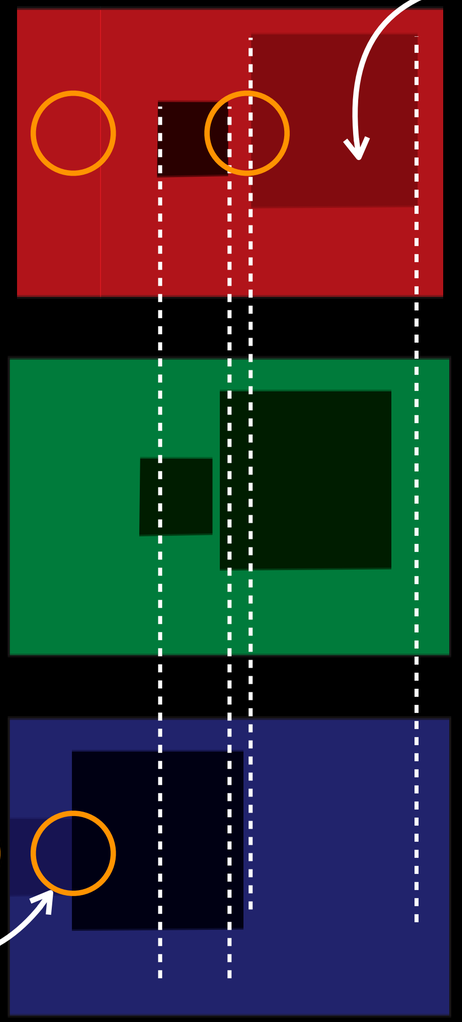


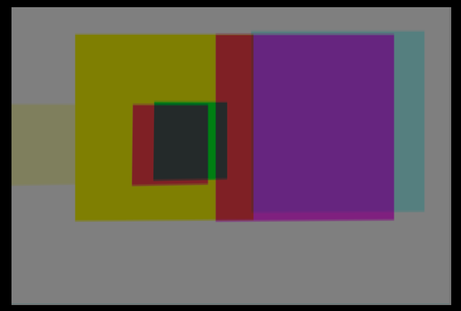


Direct Combination
Result

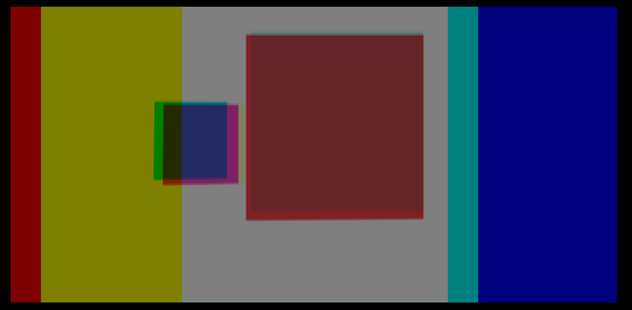
Why Do We See Distorted Colors?





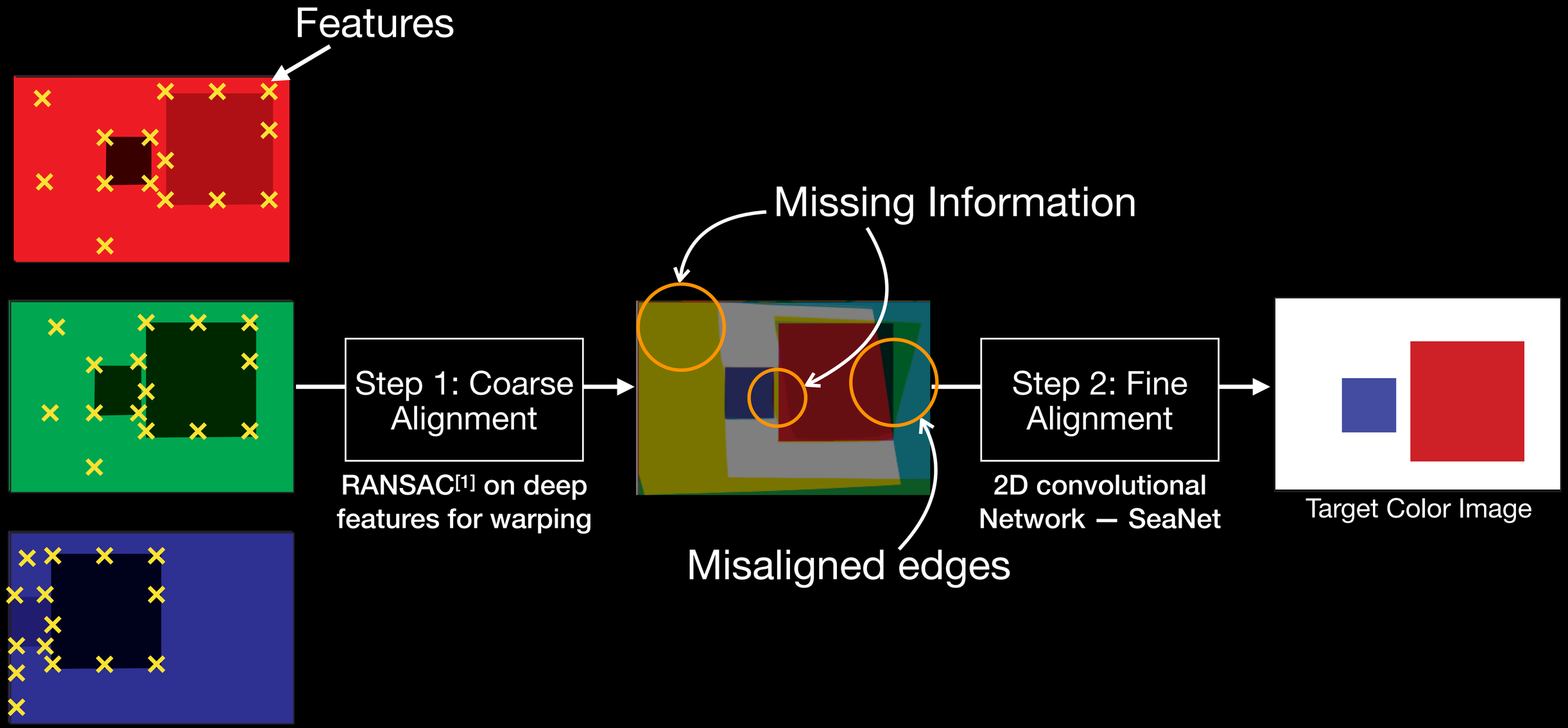


Direct Combination



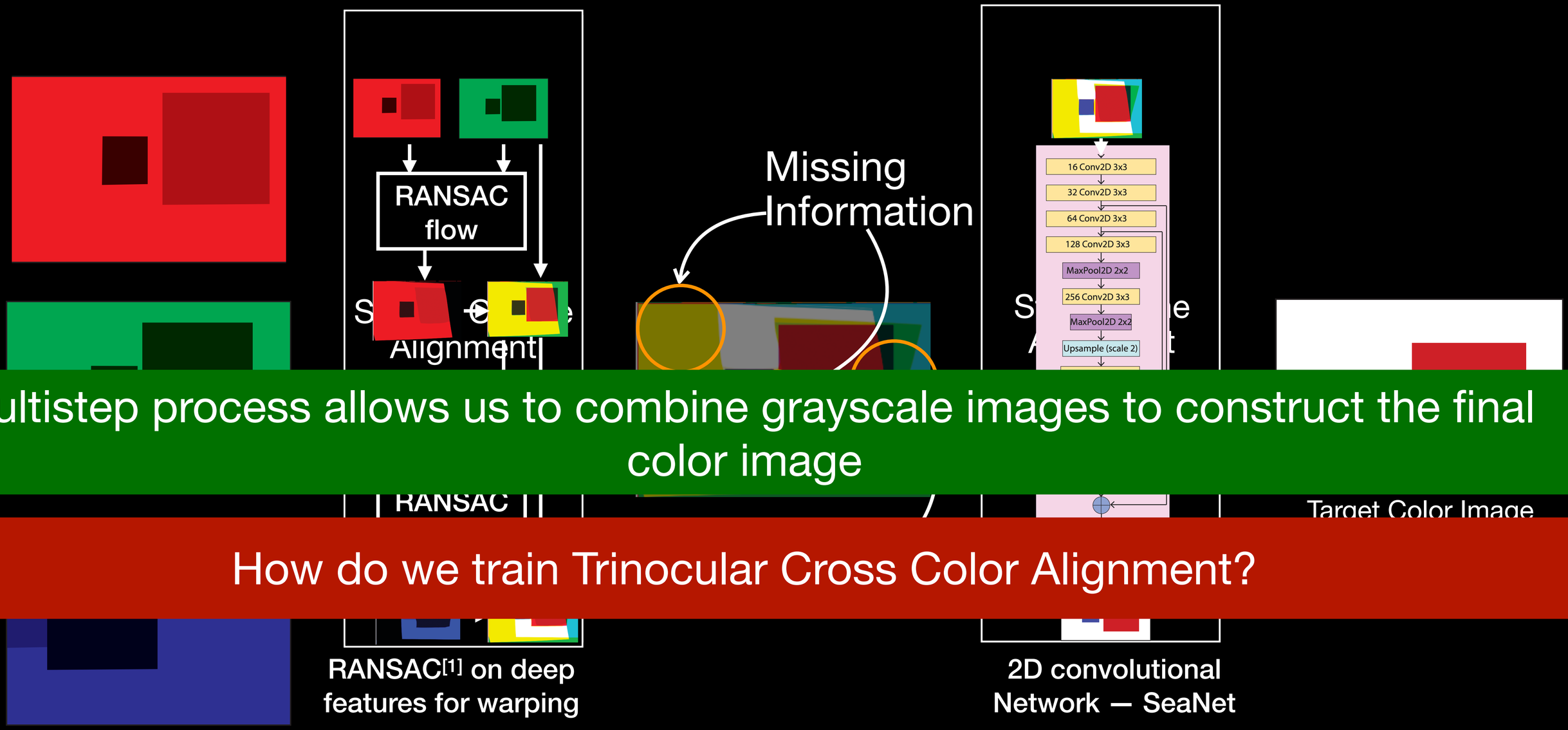
Linear Transformation

Our Solution: Trinocular Cross Color Alignment



[1] Shen, Xi, et al. "Ransac-flow: generic two-stage image alignment." ECCV 2020: 16th European Conference, Glasgow, UK, August 23–28, 2020, Proceedings, Part IV 16. Springer International Publishing, 2020.

Our Solution: Trinocular Cross Color Alignment



Multistep process allows us to combine grayscale images to construct the final color image

How do we train Trinocular Cross Color Alignment?

RANSAC[1] on deep features for warping

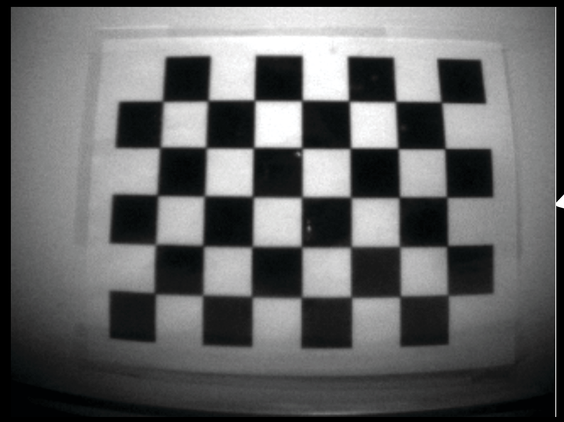
2D convolutional Network — SeaNet

[1] Shen, Xi, et al. "Ransac-flow: generic two-stage image alignment." ECCV 2020: 16th European Conference, Glasgow, UK, August 23–28, 2020, Proceedings, Part IV 16. Springer International Publishing, 2020.

[2] Fabio Tosi, Alessio Tonioni, Daniele De Gregorio, and Matteo Poggi.2023. Nerf-supervised deep stereo. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition . 855–866

Training Using Existing in-Air Trinocular Stereo Dataset [1]

Key Difference: Our low-power COTS image sensor suffers from radial distortion



Barrel Distortion

Distorted Images from the monochrome sensors

Wide angle lens

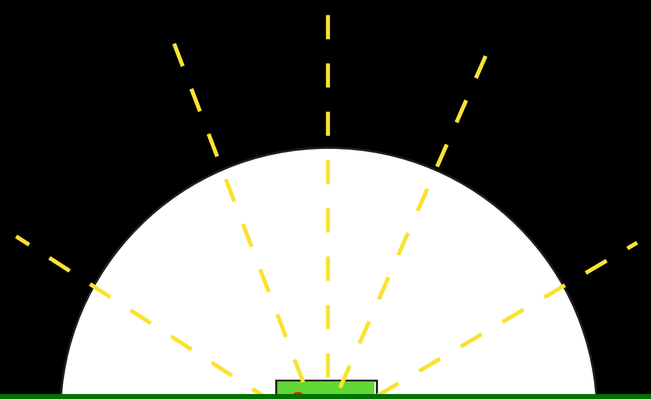


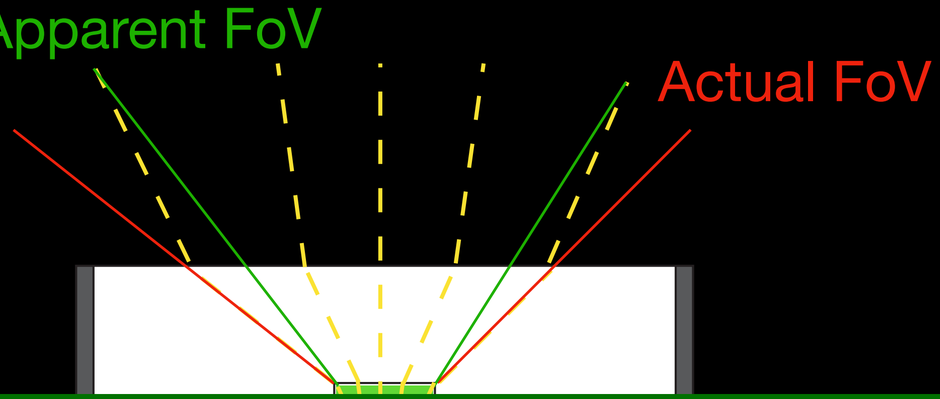
Poor Performance

Low-Power CMOS sensor HM01B0

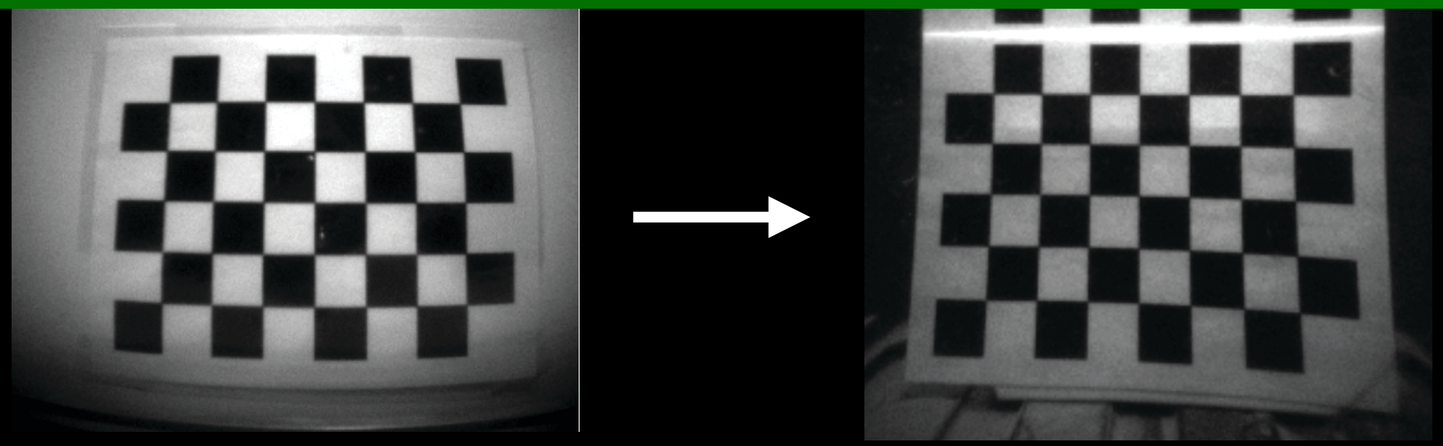
Need complex mathematical modeling and complex lens design to remove barrel distortion

Water as a Lens



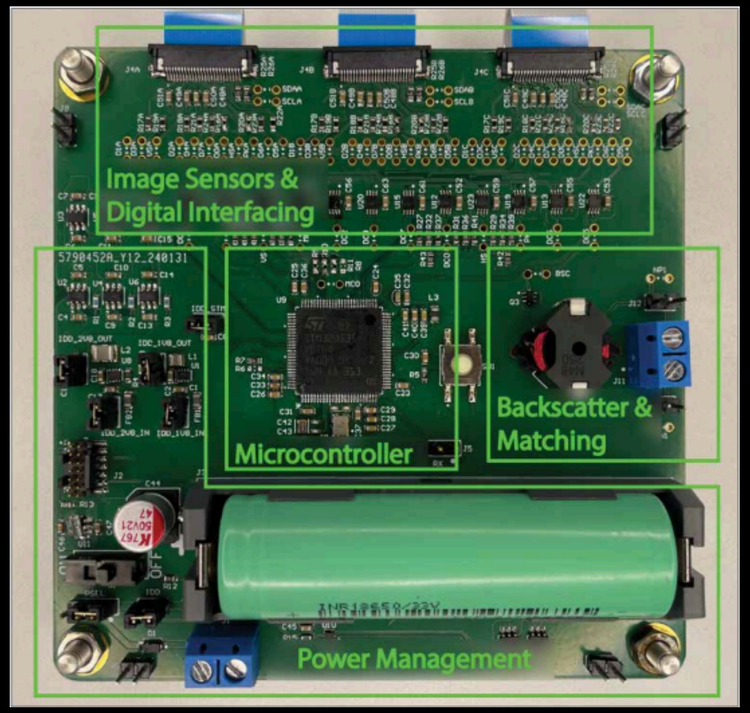


SeaScan’s flat encapsulation allows us to leverage the cross medium refraction of light to compensate for barrel distortion

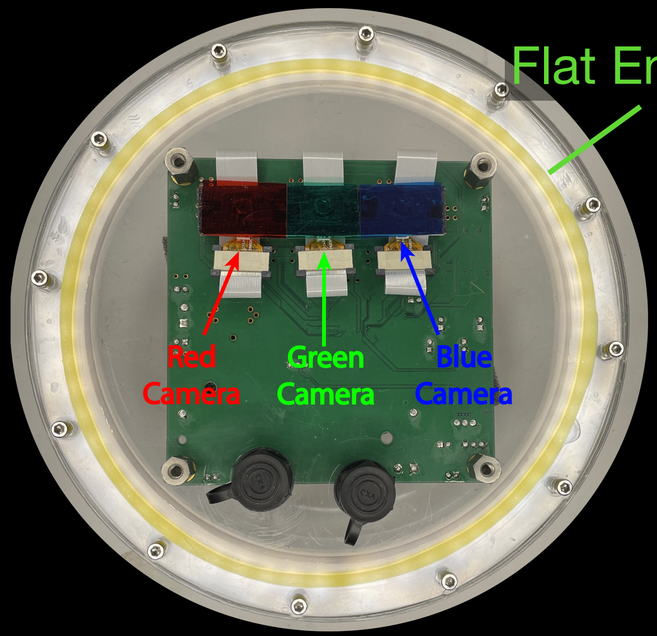


4x improvement

Implementation



Custom Hardware Design

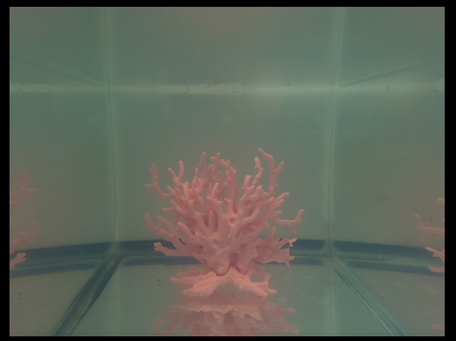
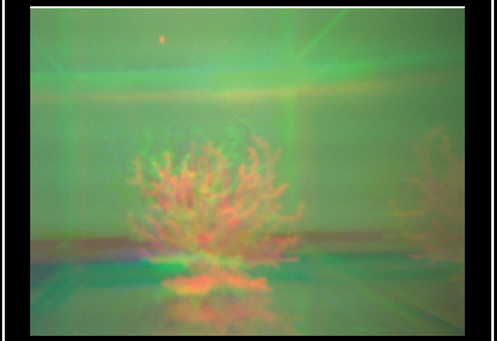
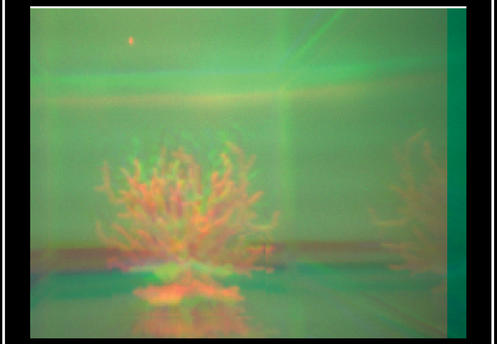
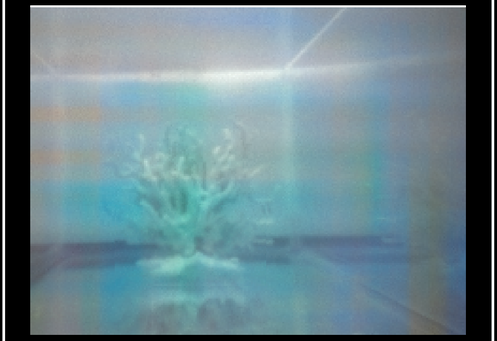
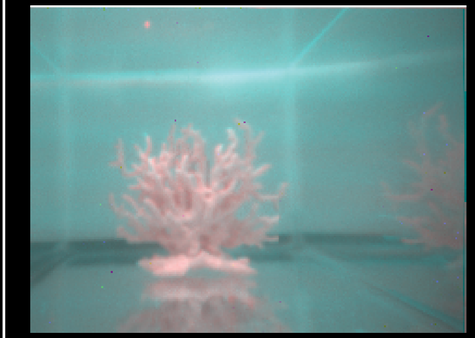


Encapsulated Camera PCB



Backscatter Node

SeaScan Results

Ground Truth	Direct Combination	Linear Combination	Colorization[2]	Our Method
				

SeaScan shows a 37x improvement in the energy consumption as compared to the SOTA[1] and can run for ~4 years on a coin cell battery

[1] Afzal, Sayed Saad, et al. "Battery-free wireless imaging of underwater environments." *Nature communications* 13.1 (2022): 5546.
[2] Zhang, Richard, Phillip Isola, and Alexei A. Efros. "Colorful image colorization." Computer Vision–ECCV 2016: 14th European Conference, Amsterdam, The Netherlands, October 11-14, 2016, Proceedings, Part III 14. Springer International Publishing, 2016.