Development and Deployment of THEIA: A Compact Underwater Multispectral Imaging System

Sotiris Spanos[1], Christos Antoniou[1], **Valsamis Ntouskos**[2,1], Angelos Mallios[3], Paraskevi Nomikou[4], Konstantinos Karantzalos[1]

[1] Remote Sensing Lab, National Technical University of Athens, Greece

[2] Department of Engineering and Sciences, Universitas Mercatorum, Rome, Italy

[3] Ploa Technology Consultants S.L., Girona, Spain

[4] Department of Geology and Geoenvironment, National and Kapodistrian University of Athens, Greece

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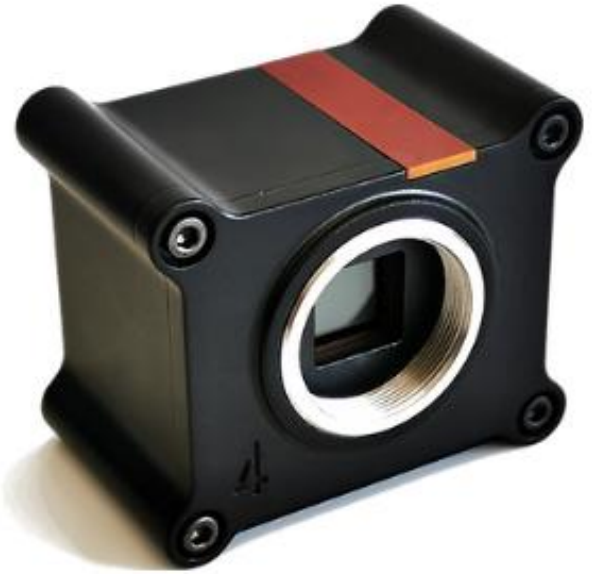
Objectives

- Develop a multispectral underwater imager
- 950 meters depth rating
- Real-time (inspection) / Off-line(3D mosaicking)
- Multi-purpose – AUVs, ROVs, Divers

Hardware Design

Multispectral Field-Array Camera

- Array type: CMOS
- 8 spectral bands + 1 Panchromatic
- Resolution Raw 2048 (H) x 2048 (V)
- Resolution (spectral images) 682 (H) x 682 (V)
- Optical format: 1”
- 12mm lens



Hardware Design

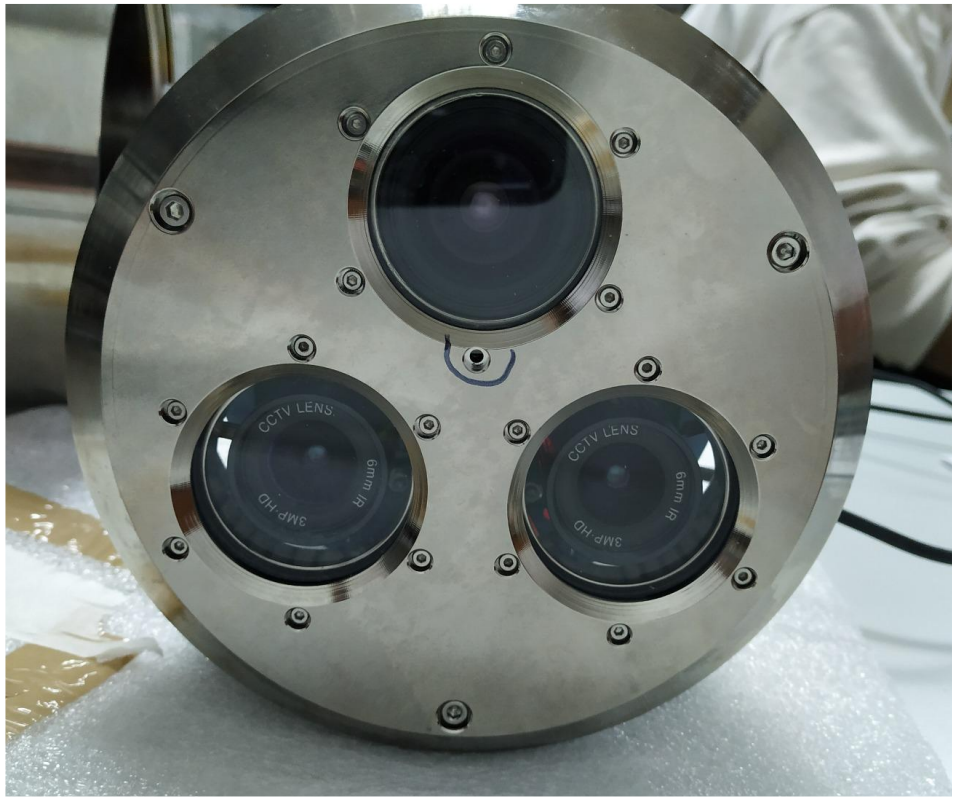
Arducam Stereo Camera Kit

- Expansion Kit of Raspberry Pi 4
- Frame-synchronized acquisition
- Synchronized 12.3MP RGB pair
- Array type: CMOS (Sony IMX477)
- Optical format: 1/2.3”
- 6mm lens

Hardware Design

Optical Configuration

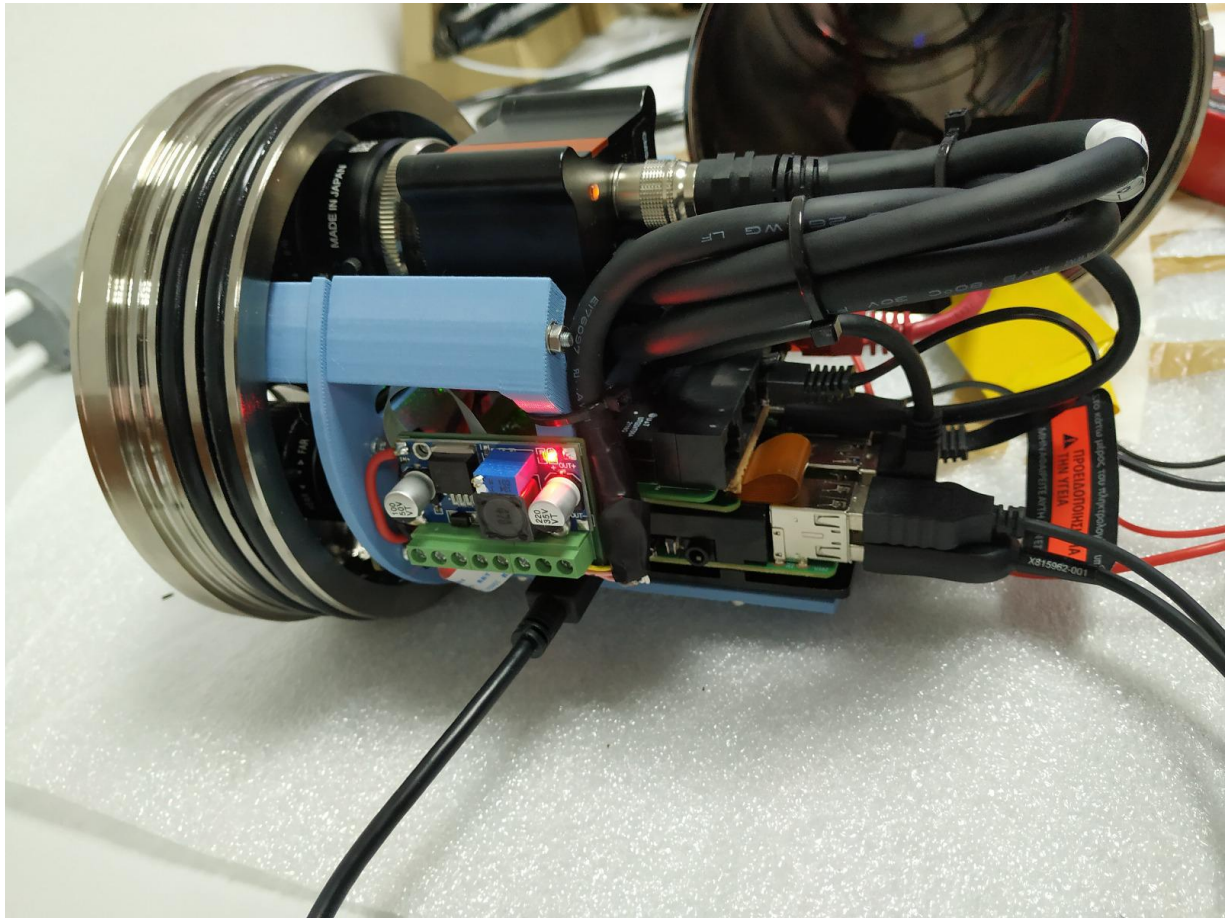
- Equilater triangle configuration
- 60mm side
- 4cm Ø flat ports
- 8mm thick
- Stereo: 48° diag. FoV (in the water)
- MSFA: 49° diag. FoV (in the water)
- Depth resolution: <1.5cm up to 2m



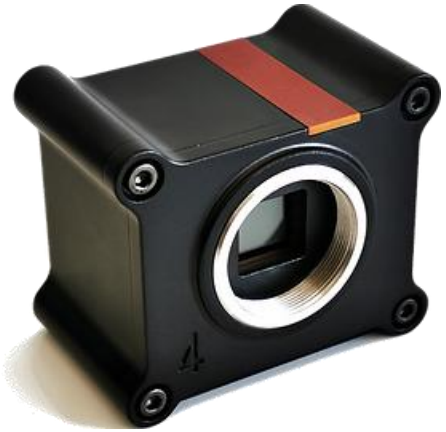
Hardware Design

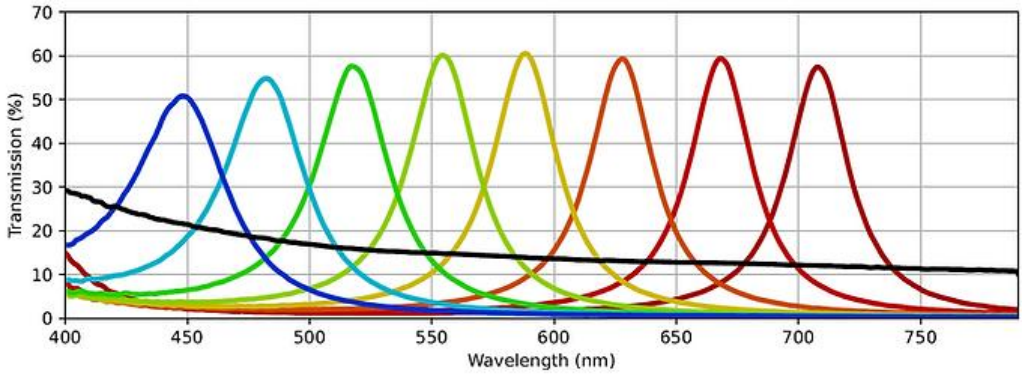
Additional aspects

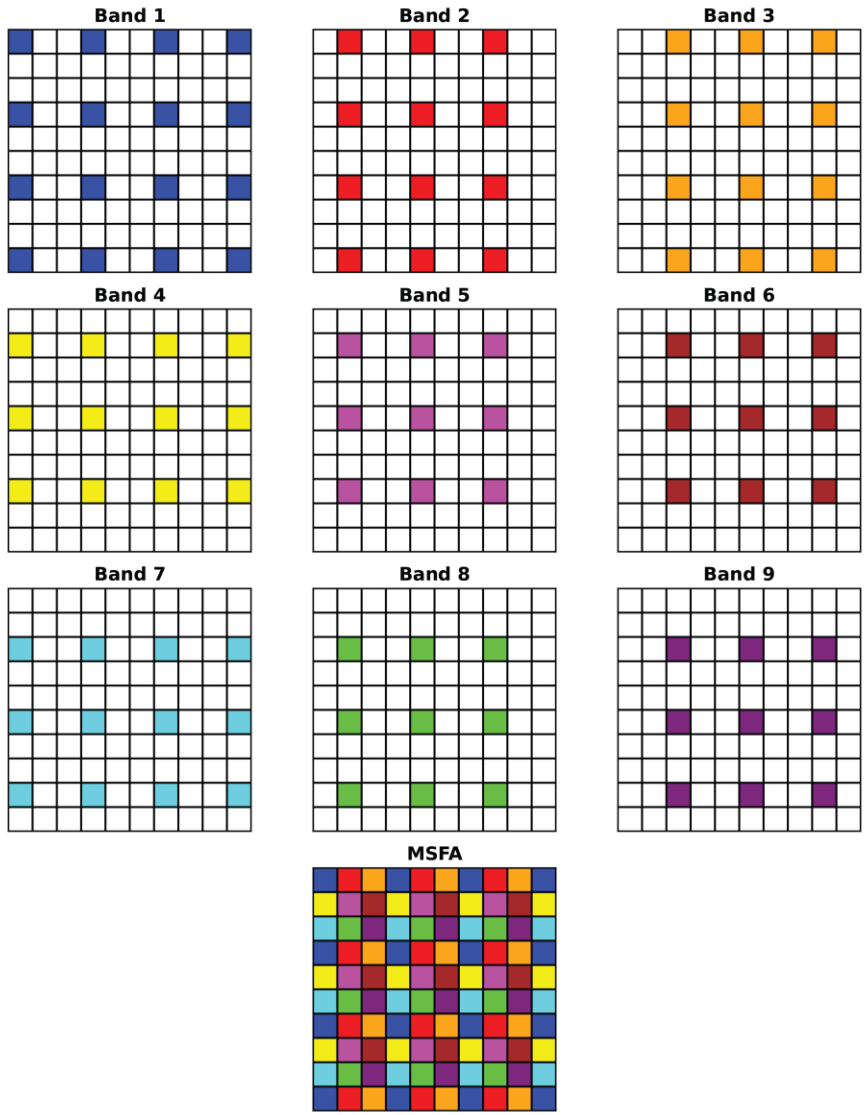
- 3D-printed support frame
- Aluminum alloy housing
- Power/comm connectors
- Raspberry Pi 4 SBC
- Storage on SSD drive
- Cooling fan



Multispectral Demosaicing







$$\hat{I} = \arg\min_{u} \Phi(u) + \lambda \|\mu(u) - I^{MSFA}\|_{L_2}^2$$

$$\hat{I} = f(z;\theta^*), \quad \theta^* = \arg\min_{\theta} \|\mu(f(z;\theta)) - I^{MSFA}\|_{L_2}^2.$$

Spanos, Ntouskos, Karantzalos, 2024. MD²IP: Training-free Multispectral Demosaicing with Deep Image Priors. *IGARSS*

Multispectral Demosaicing

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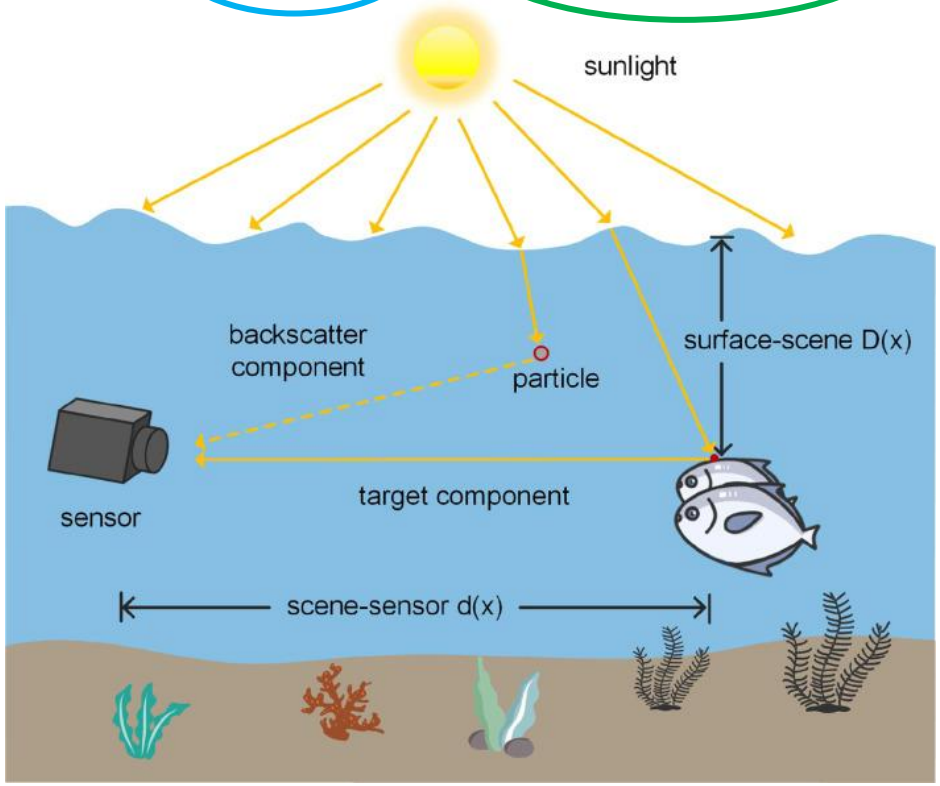
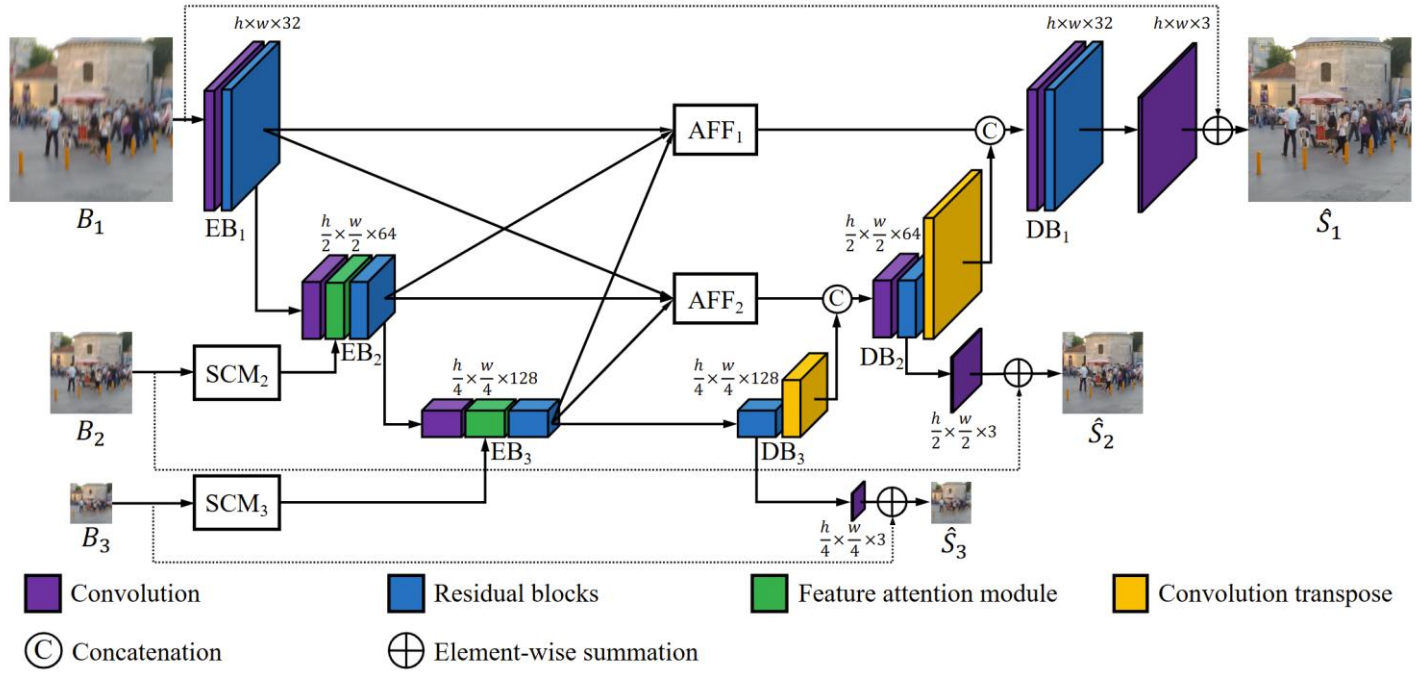
Underwater Image Enhancement

$$I_c = J_c e^{-\beta_c^D(z)z} + B_c^{\infty}\left(1 - e^{\beta_c^B(z)z}\right)$$

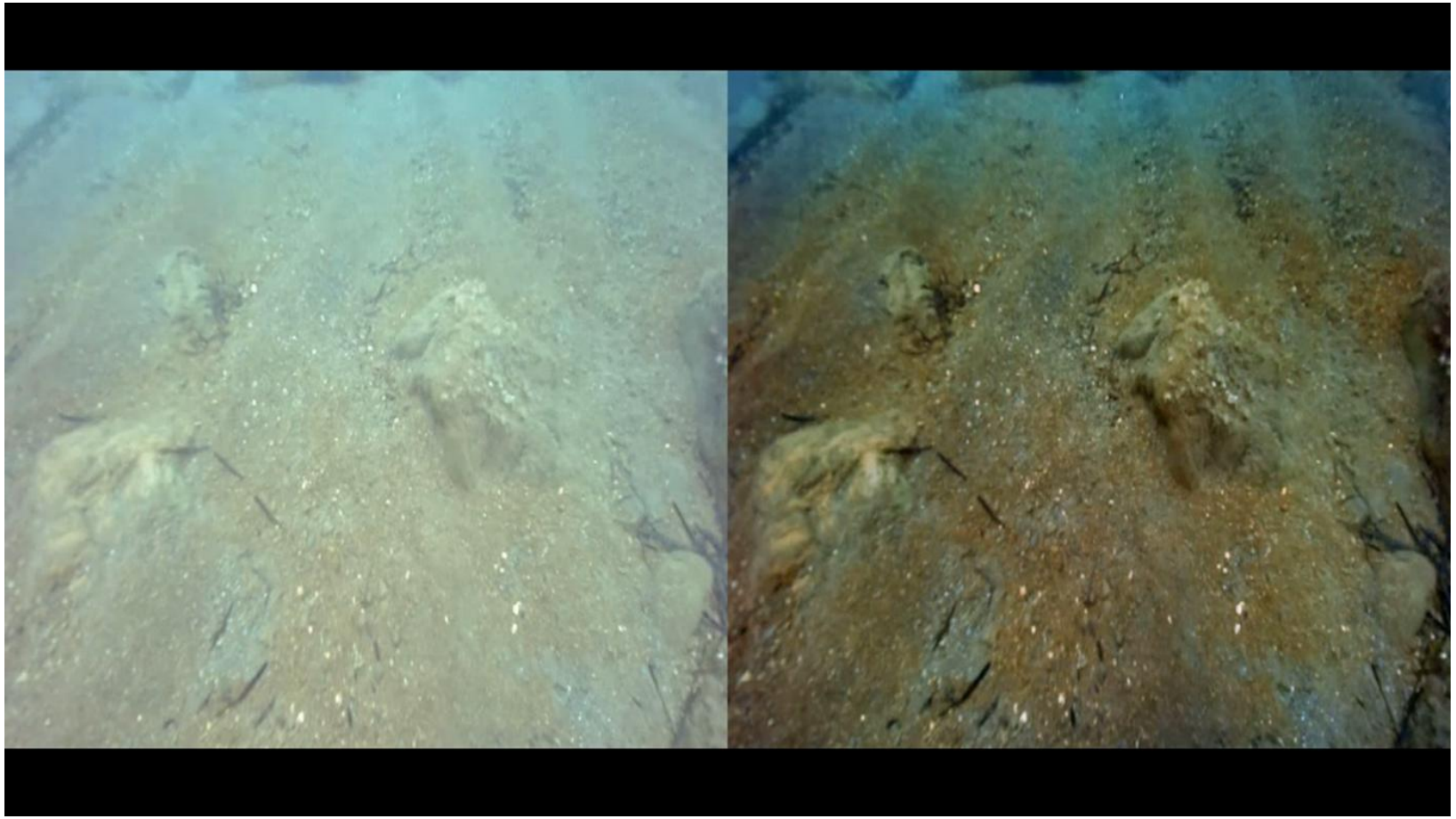


Ding *et al., "*A unified total variation method for underwater image enhancement", Knowledge-based systems 2022



Cho *et al.*, "Rethinking coarse-to-fine approach in single image deblurring", ICCV 2021

Underwater Image Enhancement

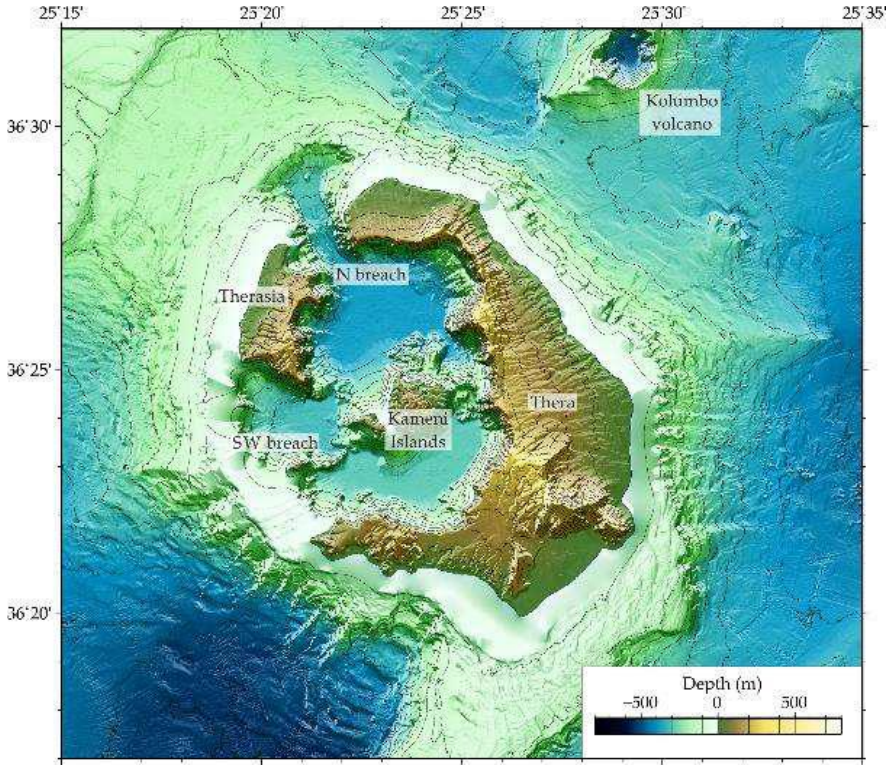


Antoniou, Spanos, Vellas, Ntouskos, Karantzalos, 2024. StreamUR: Physics-informed Near Real-Time Underwater Image Restoration. *ISPRS Archives*

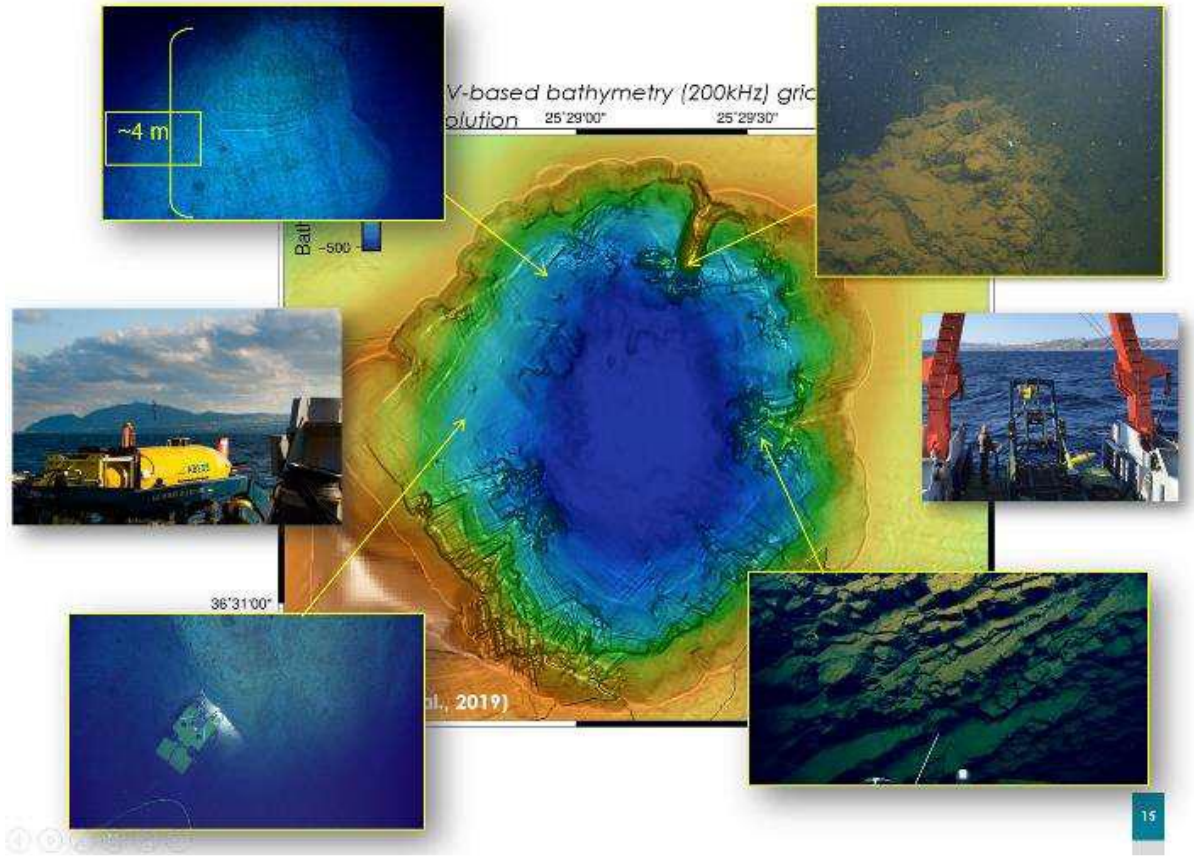
Processing Workflow

1. Acquisition and Synchronization
   - Stereo: GStreamer + OpenCV → Depth estimation
   - Multispectral: Custom C++ ROS node → Band separation
2. Offline Multispectral Demosaicing and Enhancement
   - MSFA demosaicing (MD^2IP)
   - Image restoration (StreamUR)
3. 3D Scene Modeling
   - Depth-informed 3D reconstruction using stereo disparity maps
   - 3D reconstruction using 3D Gaussian Splatting (Kerbl et al., 2023)

Kolumbo Monitoring



Nomikou, P., Druitt, T., Hübscher, C. et al. Posteruptive flooding of Santorini caldera and implications for tsunami generation. Nat Commun 7, 13332 (2016).



Nomikou P., Hannington M. et al., (2019): Advanced mapping of Kolumbo submarine volcano (Santorini) using AUV "Abyss". BGSG, Sp. Pub. 7, p. 618-619

Kolumbo Monitoring - Preparation

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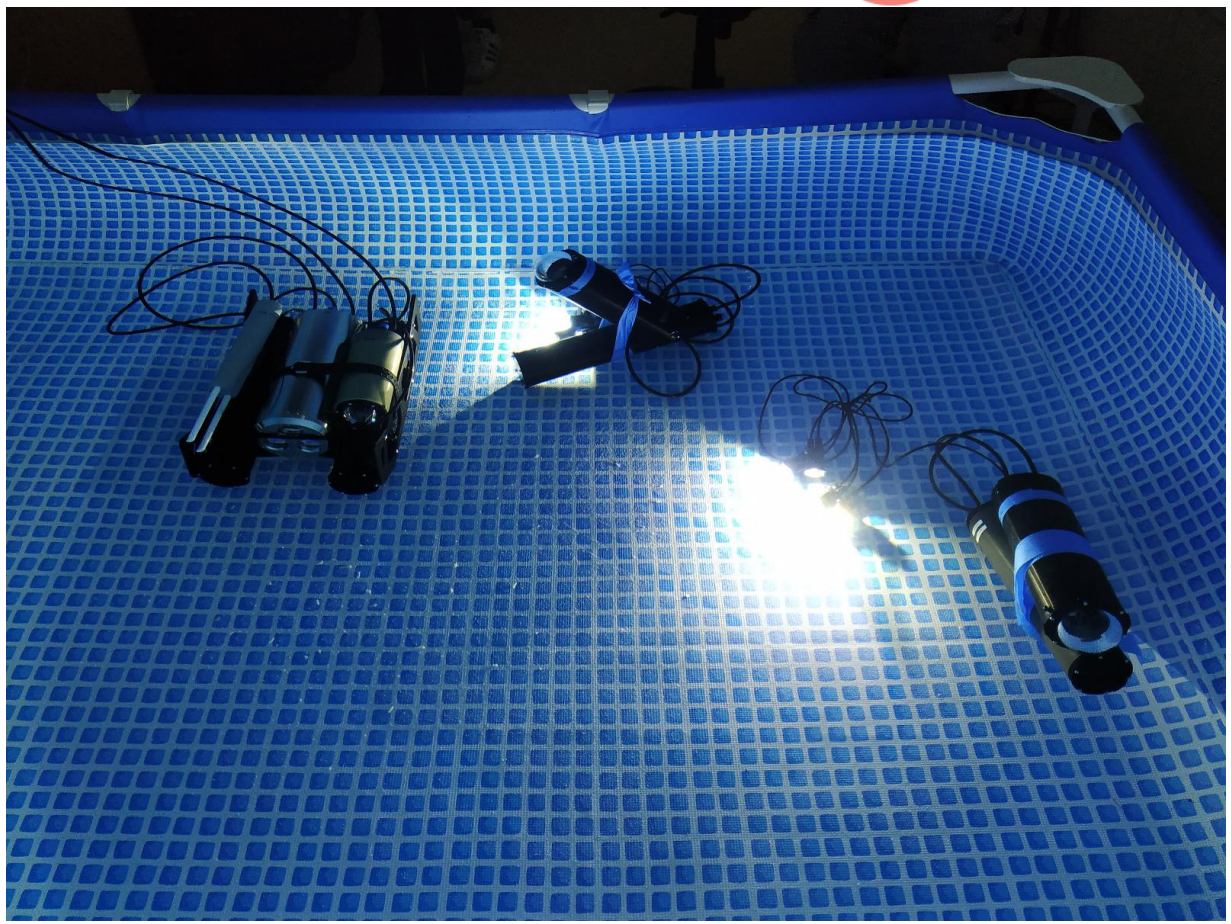
- Lab tested in underwater tank
- Long duration submersion
- Pressure-rated LED lights
- Optical calibration
- Color fidelity: 4x6 colorchecker



Kolumbo Monitoring

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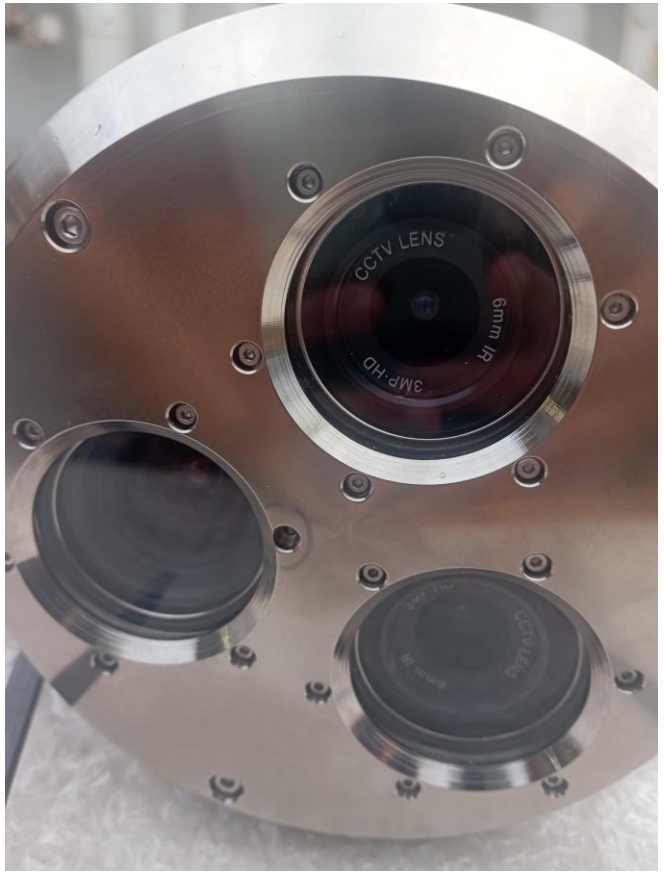

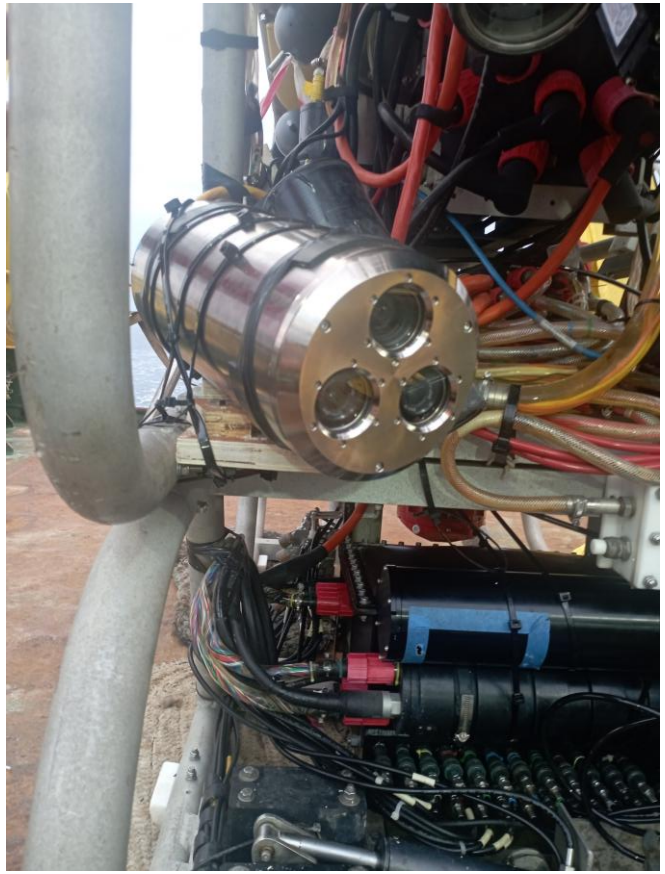

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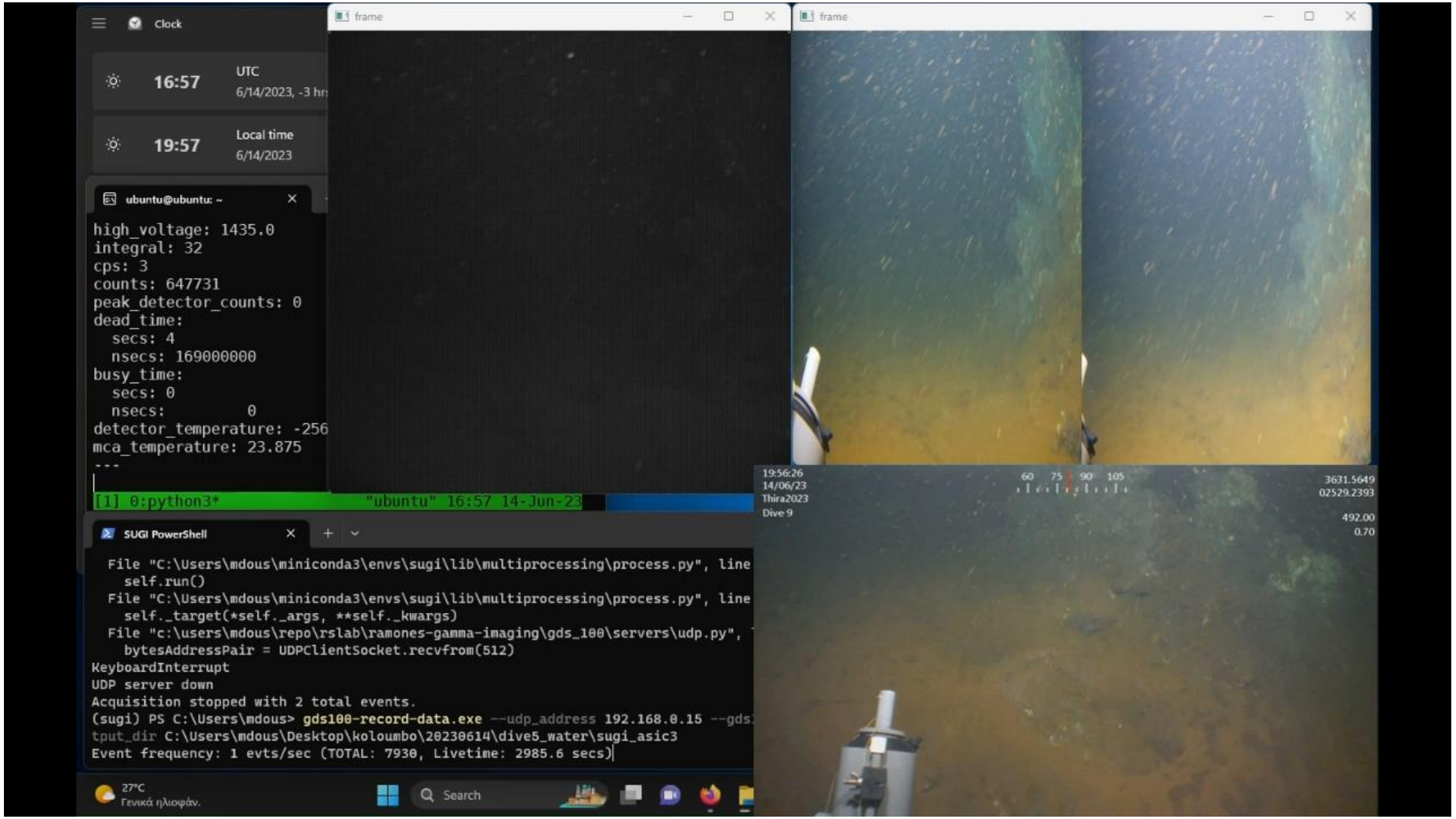

Results

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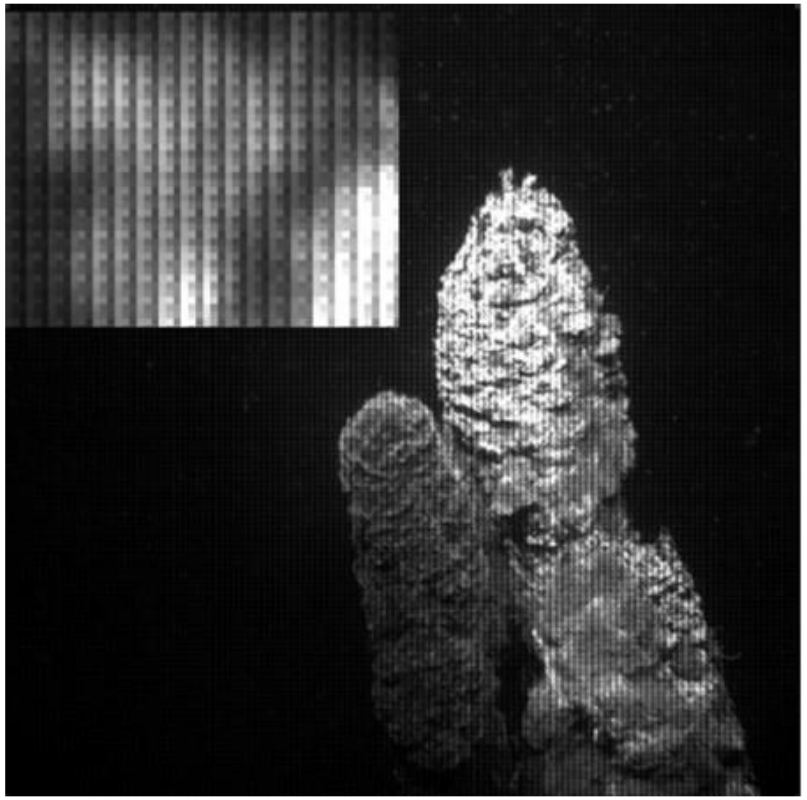
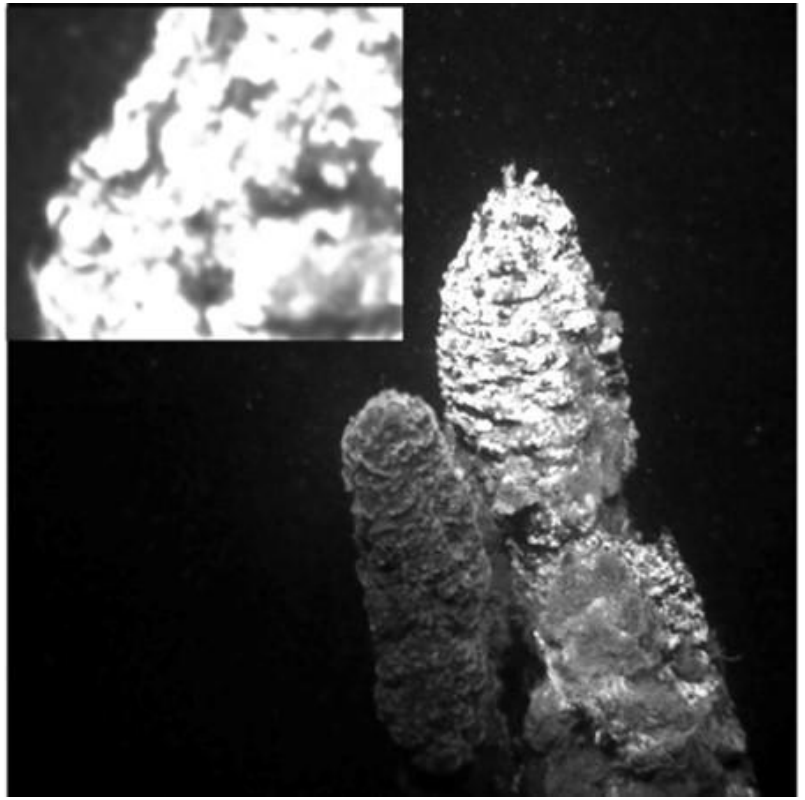
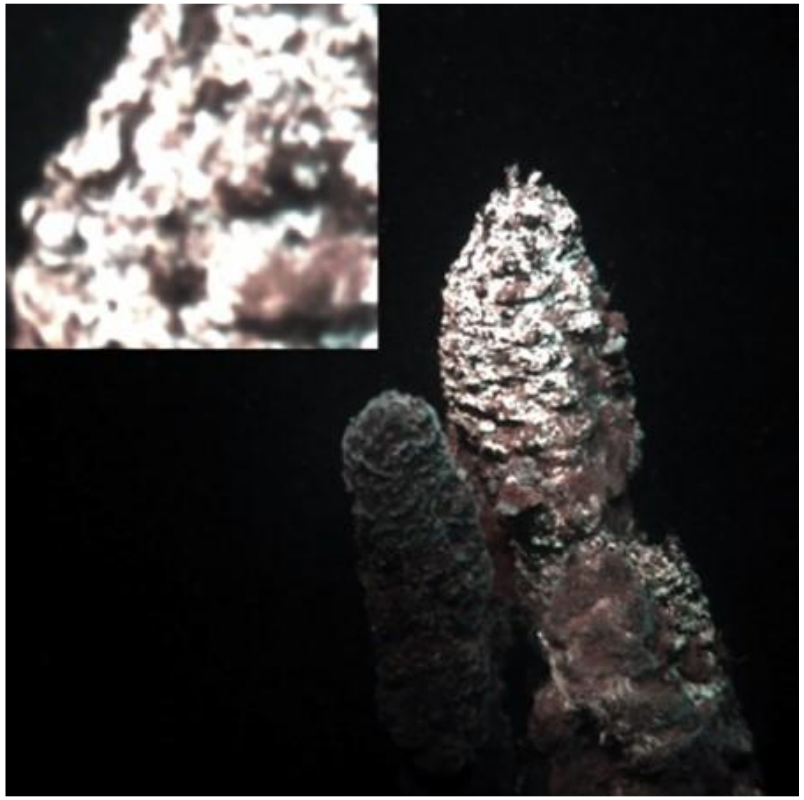
Original



Panchromatic



Natural Color



Results

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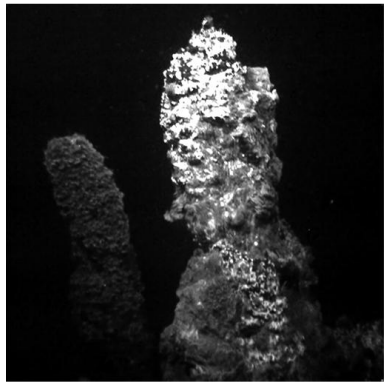
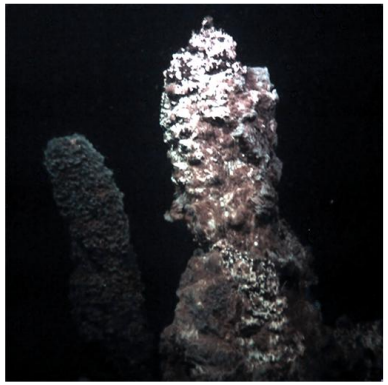
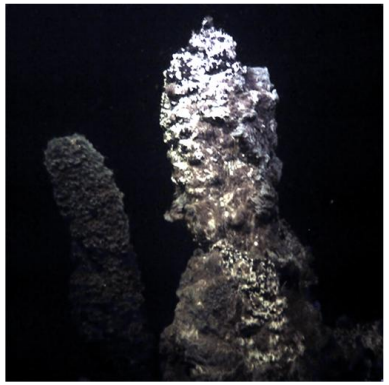
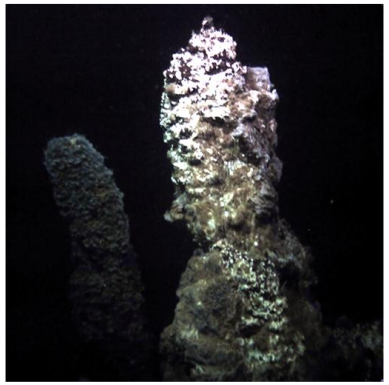
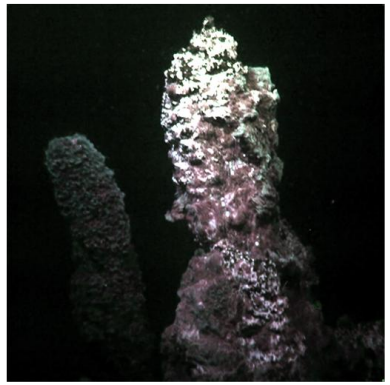
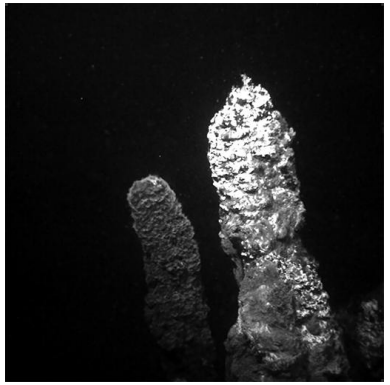
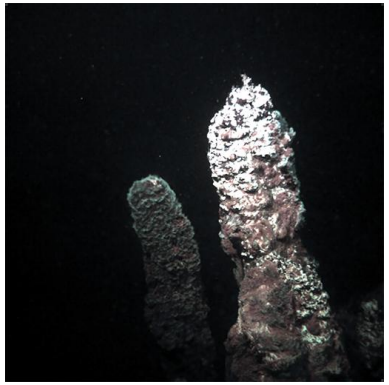
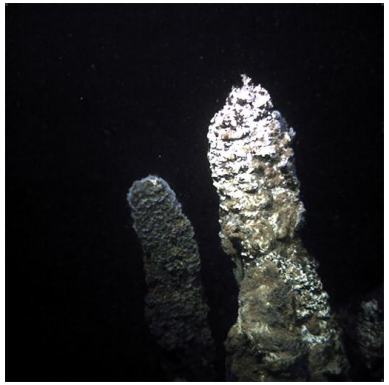
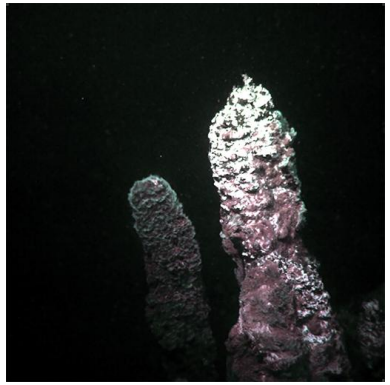
Panchromatic	Natural color	Blue-Green-Yellow	L.Blue-Yellow-Red	Green-L.Blue-Orange
				
				

Results

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Conclusions / Future Directions

Findings

- Results are satisfactory
- House degradation due to corrosive environment

Future directions

- Examine different alloys/surface finish
- Integrate dedicated lighting modules
- Near real-time processing

Thank you!