Advanced spectro-bathymetric mapping of shallow seafloor using UAV imagery and deep learning techniques

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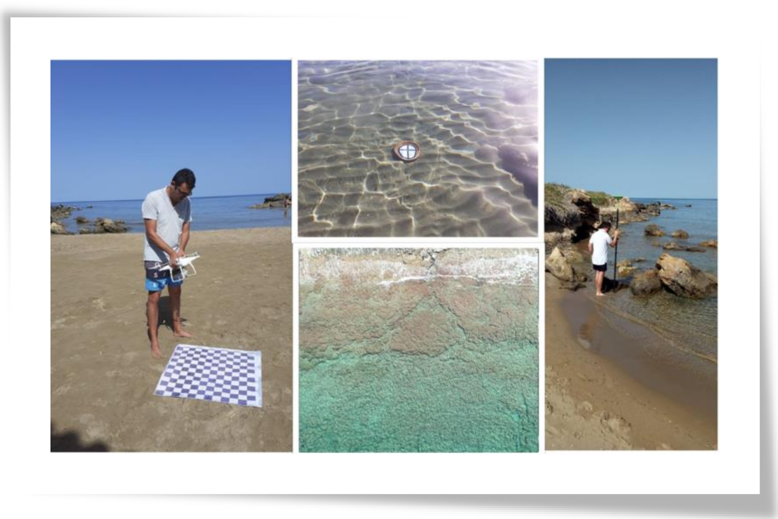
ACTYS is a collaborative project between two top FORTH Institutes:

- **Institute of Mediterranean Studies (IMS)**
- **Institute of Computer Science (ICS)**

The ACTYS project ranked 1st in the 2020 FORTH-Synergy proposal evaluation

> *The goal of the project is to develop an integrated methodology for shallow bathymetry retrieval and detailed mapping of coastal benthic cover of the shoreline*



ACTYS

FORTH INSTITUTE FOR MEDITERRANEAN STUDIES
Lab of Geophysical-Satellite Remote Sensing and Archaeoenvironment

FORTH INSTITUTE OF COMPUTER SCIENCE
COMPUTATIONAL VISION & ROBOTICS LABORATORY

Motivation

Advanced spe**CT**ro-bath**Y**metric mapping of **S**hallow seafloor using UAV imagery and deep learning techniques

Shallow bathymetry is key input to:

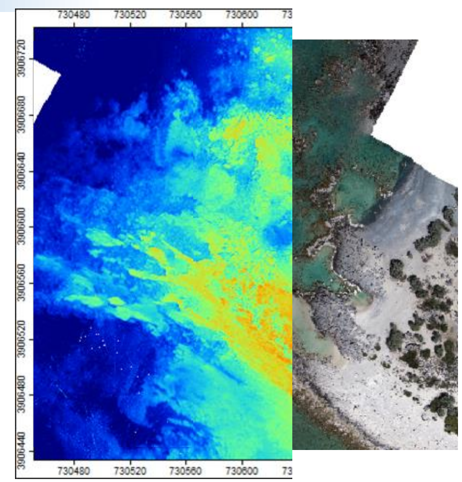
- Coastal management/planning projects
- Ecological mapping

Automated seafloor mapping using uncrewed platforms:

- Versatility
- Repeatability

A deep learning approach for:

- Minimizing fieldwork effort
- Maximizing information from input layers
- Landscape-scale mapping of shallow seafloor

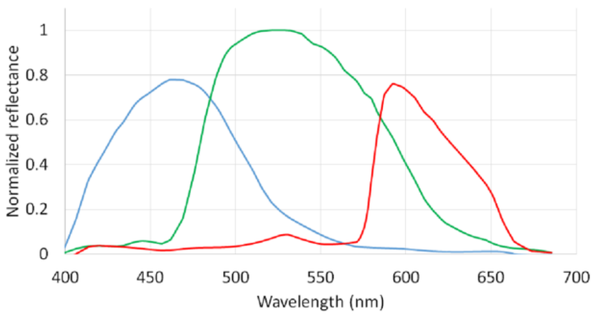


Study areas & data acquisition

Study areas & data acquisition

Drone RGB camera

- DJI Phantom4 Pro©
- 20 mPixels
- 1” sensor size
- 120 m survey altitude
- Nadir images



Source: Burggraaff et al., 2019

Uncrewed Surface Vehicle (USV) with: Sonar sensor / GoPro waterproof camera

- Sonarmite© BTX single-beam echo-sounder (SBES)
- Transmitter frequency: 235 kHz
- Sampling rate: 2 Hz
- Connectivity: Bluetooth with RTK GPS

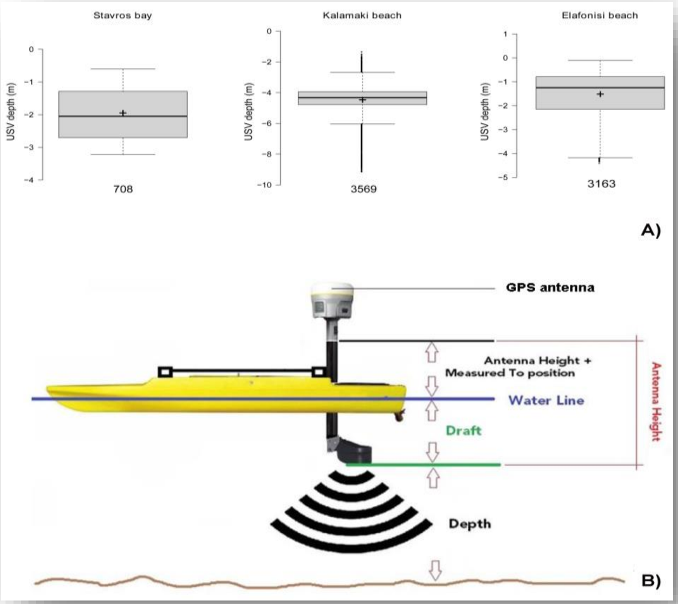
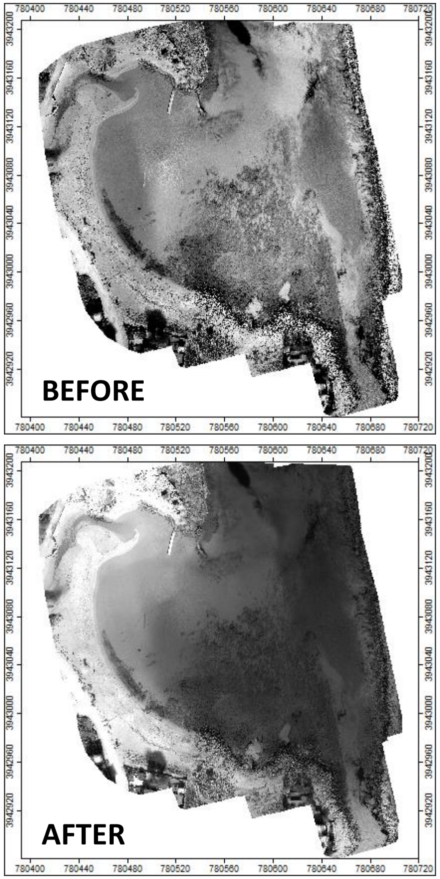


Image pre-processing

DJI P4P, Green band



Alevizos & Alexakis, 2022
https://doi.org/10.1080/2150704X.2022.2030068

<u>Geometric corrections</u>

- ➢ Camera calibration with checkerboard
- ➢ Camera position from EXIF metadata
- ➢ Ground control points with RTK GPS measurements onshore

<u>Radiometric corrections</u>

RGB Image calibration

- ➢ DN to radiance

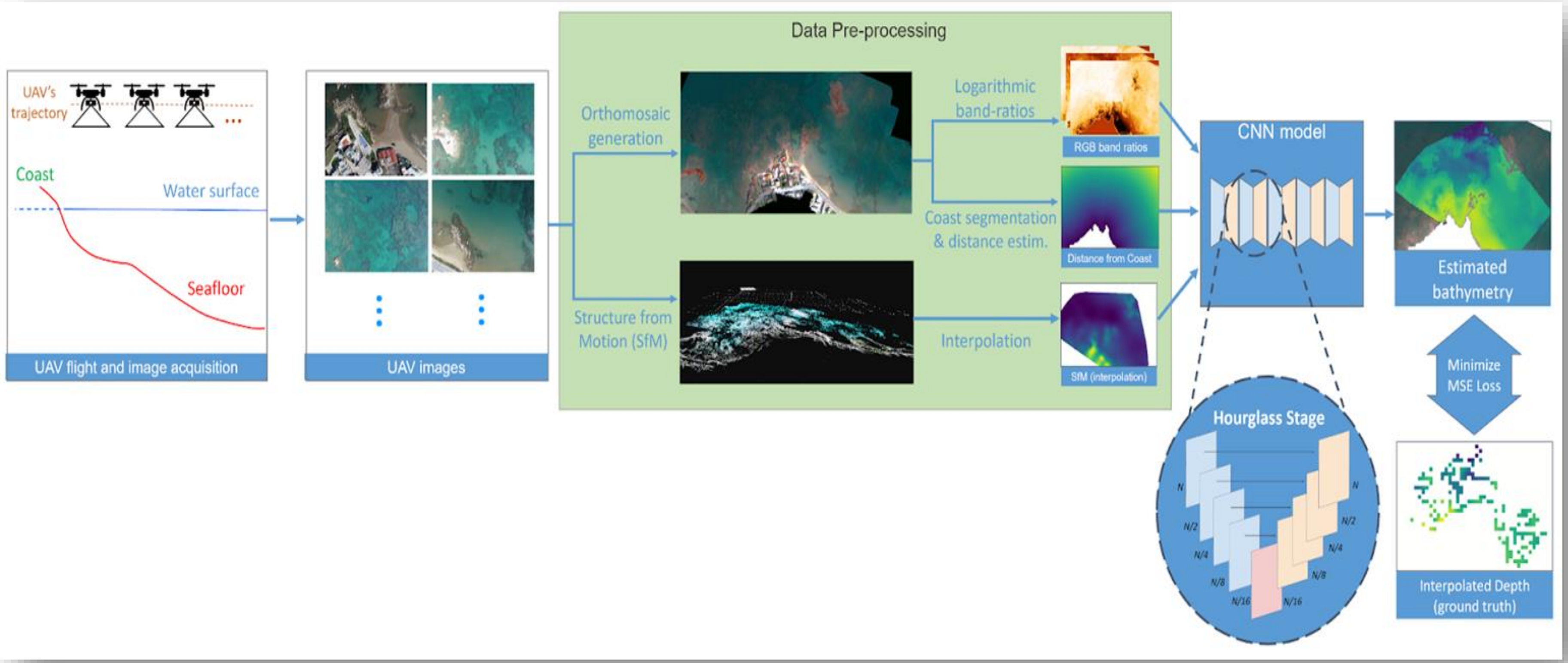
(dark pixel, vignette, exposure, gain, using Pix4D© software)

- ➢ Radiance to reflectance

(with reference reflectance panel in Pix4D© software)

Image resampling for noise reduction

Bathymetry prediction



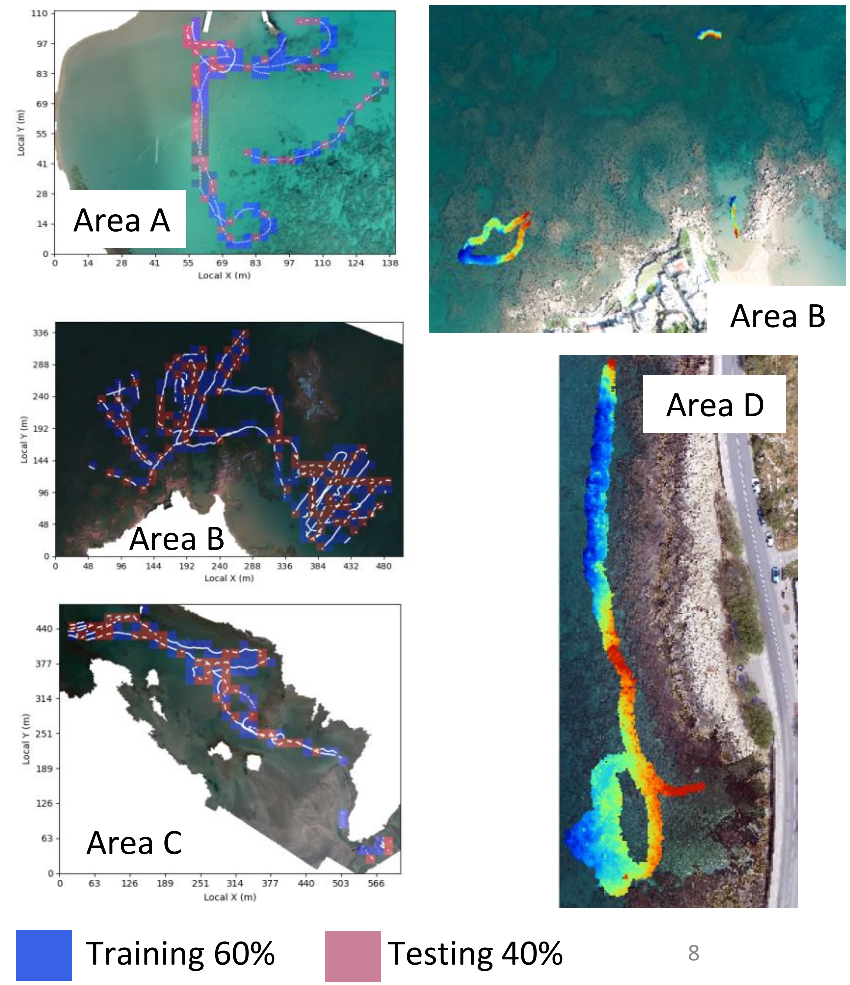
- Architecture that has been successfully applied in related depth estimation problems (face/hand depth estimation from RGB images).
- Each module consists of Convolutional layers, a bottleneck layer, and Deconvolutional layers.
- A network with 6 stacked hourglass modules.

Bathymetry prediction

The multichannel input of the CNN model consists of several image patches of size 128 × 128 pixels that includes five channels input rasters:

- **three channels rasters** for the logarithmic band-ratios (Blue/Green, Blue/Red and Green/Red),
- **one for the approximate SfM surface,**
- **and one with the distance from coast information**.

2D sonar data (interpolation) 3D underwater SfM

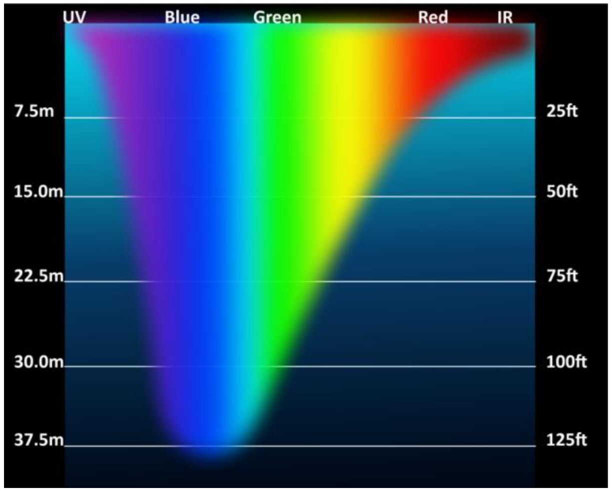


Training Dataset

Concept based on Stumpf et al., (2003) band-ratio model* :

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0$$

* machine learning implementation using multiple ratios



Relative depth penetration of light wavelengths in clear coastal waters

PROS

- Works well for mixed seafloor types
- It is computationally simple and fast

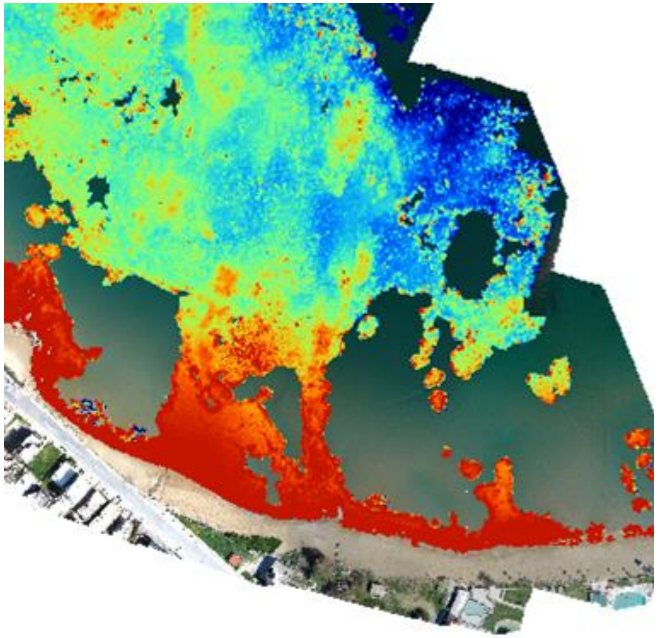
CONS

- Requires input ground-truth depth data
- Requires water-column transparency

Training/testing datasets

3D SfM reconstruction (drone)

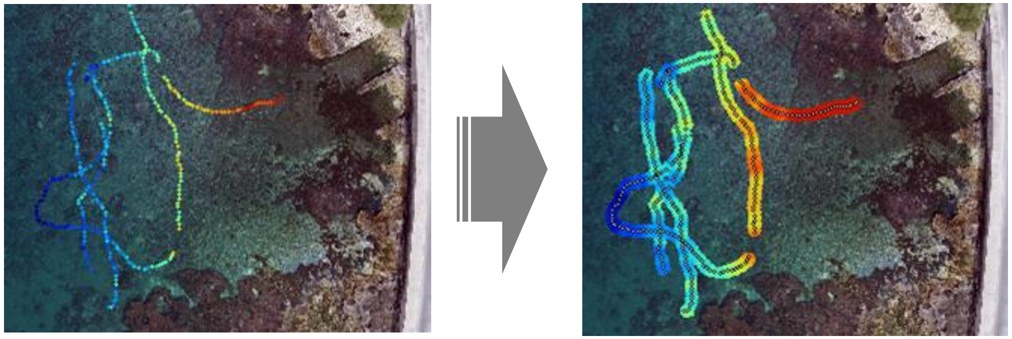
- Minimal effect of refraction (very shallow water, nadiral images)
- Use as explanatory variable
- Requires seafloor types with texture (e.g.: rocky reefs)



2D sonar measurements (USV)

- In-situ depth (±10 cm)
- Interpolation for creating train (ground truth) patches for deep network
- Output validation on original soundings

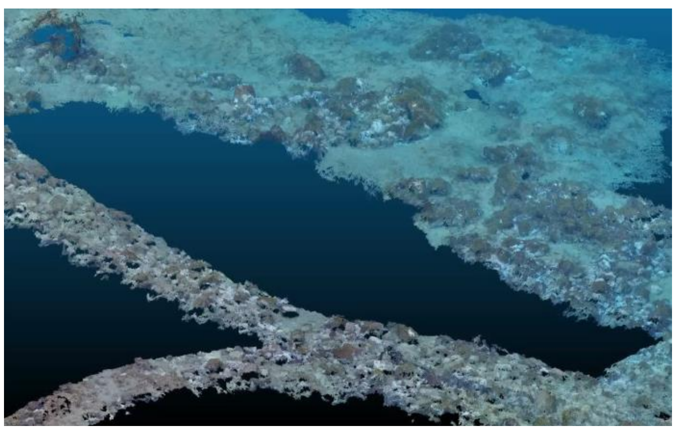
Original soundings *Interpolation   (IDW)*

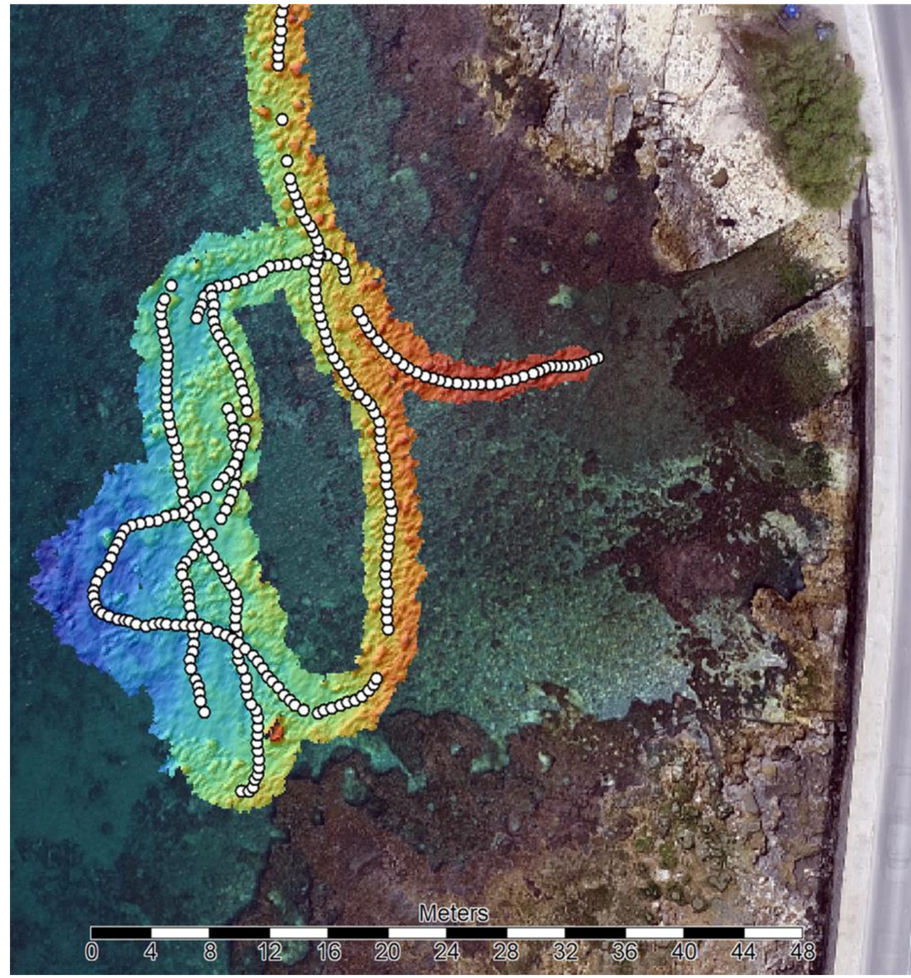


Training/testing datasets

3D SfM reconstruction (underwater video)

- Sonar data augmentation (MBES of the poor)
- Detailed seafloor texture
- Refraction-free





Experimental Evaluation

Ablation study to show the benefits of the architecture choices and input rasters.
Most related work approaches follow a Single Stack CNN architecture model.

Single Stack Hourglass model		
Rasters used	**RMSE**	**R^2**
RGB	0.66 m	62.2%
RGB + SfM	0.62 m	67.7%
RGB + DistCoast	0.51 m	74.6%
RGB + SfM + DistCoast	0.43 m	85.4%
Full Stack Hourglass model		
RGB	0.49 m	79.5%
RGB + SfM	0.48 m	81.4%
RGB + DistCoast	0.42 m	83.8%
RGB + SfM + DistCoast	0.35 m	89.4%

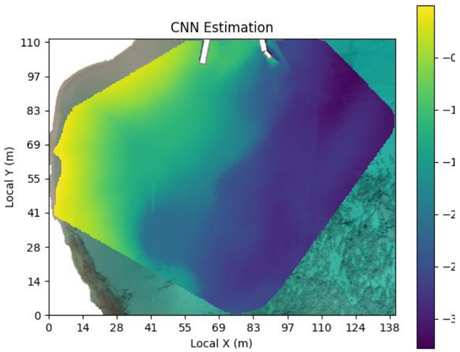
Comparison of our CNN model with conventional Machine Learning approaches. (Random Forest, Support Vector Machines)

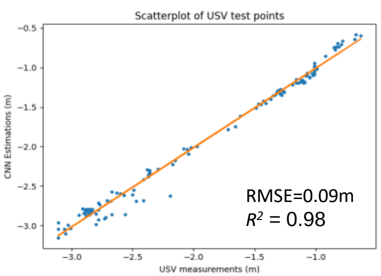
	Our pipeline, with CNN (full model)	Our pipeline, with RF	Our pipeline, with SVM
RMSE	0.346m	0.432m	0.599m
R^2	89.4%	84.1%	67.5%

We trained our CNN model on all patches of each study area and then we applied the model on the remaining two areas again for all their image patches

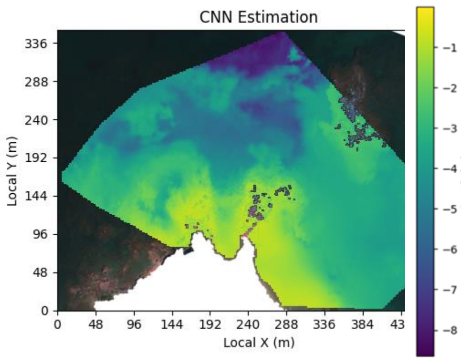
	Trained on Stavros	Trained on Kalamaki	Trained on Elafonisi
Tested on Stavros	*0.043m*	0.753m	0.698m
Tested on Kalamaki	1.754m	*0.248m*	1.058m
Tested on Elafonisi	0.630m	0.773m	*0.138m*

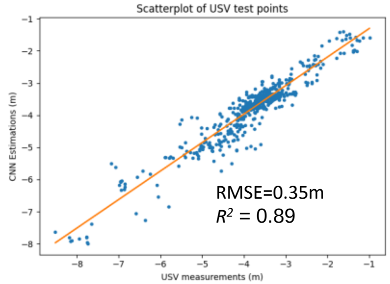
Results



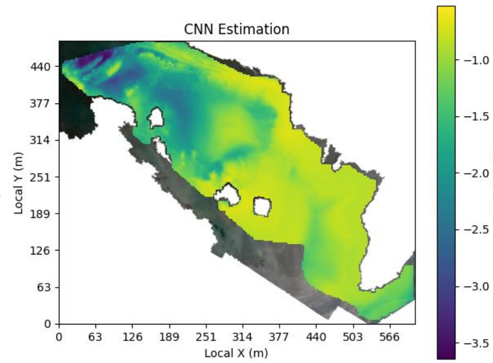


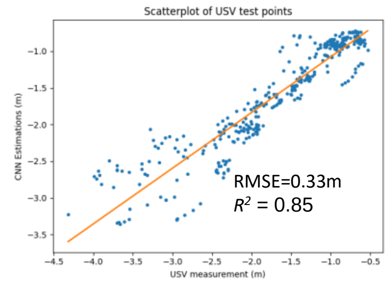
Area A



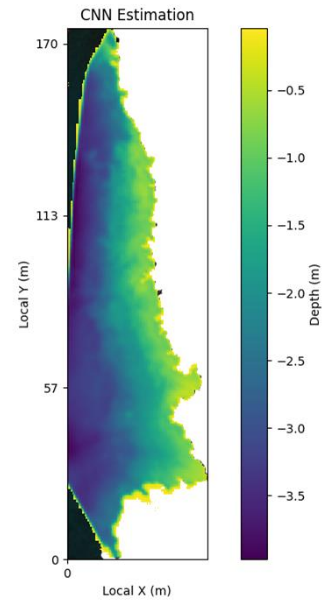


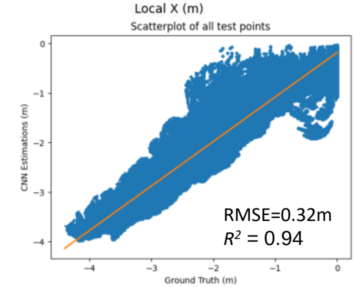
Area B





Area C





Area D

Training Data = 60%, test data=40%

Publications

- 4 pa
- 3 pr
- 3 pa

peer-r

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Assessment of PRISMA Level-2 Hyperspectral Imagery for Large Scale Satellite-Derived Bathymetry Retrieval

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Article

Integration of photogrammetric and spectral techniques for advanced drone-based bathymetry retrieval using a deep learning approach

Evangelos Alevizos[1], Vassilis C. Nicodemou[2], Alexandros Makris[2], Iason Oikonomidis[2], Anastasios Roussos[2] and Dimitrios D. Alexakis[1]

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Extracting high resolution, shallow bathymetry from drone-based imagery using empirical methods is a novel approach that gains increasing interest. However, due to the rapidly expanding character of this field, there are not sufficient guidelines for optimal pre-processing of drone-based imagery regarding bathymetry retrieval. This study explores the suitability of imagery resulted from commonly used drone cameras in terms of producing good correlation with ground-truth depth measurements obtained from an unmanned surface vehicle (USV). Thus, imagery with similar spectral responses, from two commercial sensors (DJI Phantom 4 Pro and MicaSense-RedEdge multispectral camera), is examined along with and without radiometric corrections applied, using proprietary software. The results show that radiometric image corrections using a reference reflectance panel, greatly enhance the correlation coefficient between bathymetry data and single-band or band-ratio reflectance mosaics at two study areas with mixed seafloor types. However, it was observed that the Red band and its associated logarithmic band ratios (Blue/Red, Green/Red) from both sensors show good correlation with depth as well, regardless of radiometric corrections. This result applies mainly to areas with favourable optical properties of water. This study suggests that radiometric calibration is crucial in empirical bathymetry retrieval from drone-based imagery. Furthermore, radiometric corrections applied on common Red, Green, Blue (RGB) cameras provide useful reflectance mosaics at lower costs compared to multispectral cameras.

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Geomorphometric analysis of nearshore sedimentary bedforms from high-resolution multi-temporal satellite-derived bathymetry

Evangelos Alevizos, Anastasios Roussos & Dimitrios D. Alexakis

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Conclusions & Future goals

- Accurate depth reconstruction with minimal need for in-situ data- low cost
- Seamless bathymetry prediction over different areas/seafloor types
- Low RMSE values (<0.5m)

- Apply pre-trained model in unknown areas with similar water properties
- Unify entire processing chain into a single software tool
- Require greater amount of ground truth data

Looking forward to future collaborations and extension of the project

Acknowledgements

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Thank you very much for attending!