

July 8-11, Wien

# 3D Underwater Mapping from Above and Below

3rd International Workshop

## Underwater Heritage documentation using photogrammetry: the CRAB system

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# INTRODUCTION

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1.3 Centring and settings of the cameras

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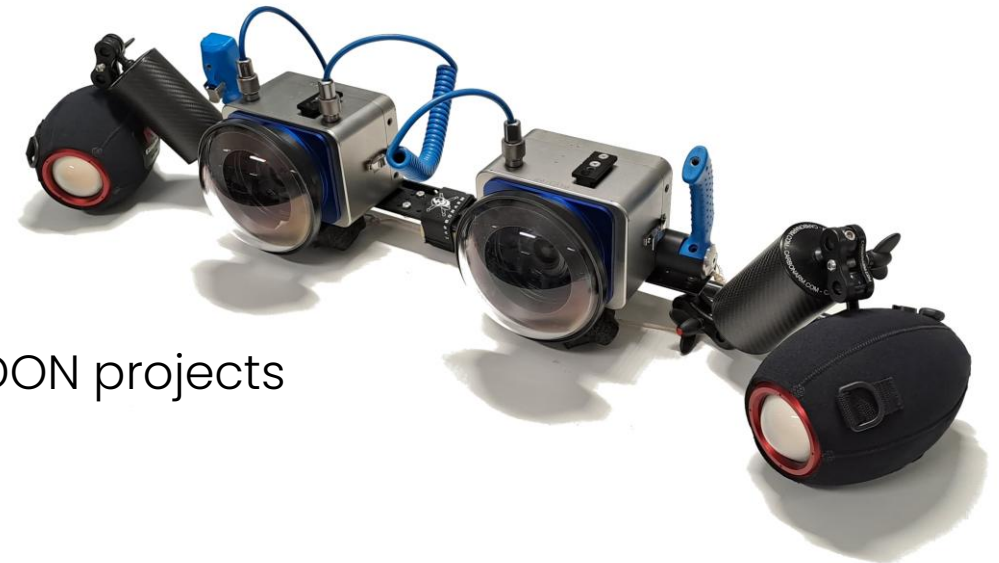
3

# INTRODUCTION

- Submerged cultural heritage has ecological, scientific, educational, and economic value, requiring careful conservation and enhancement  
→ modern documentation technologies support expert knowledge sharing and public engagement through 3D modelling and virtual tools.
- Increased demand for high-resolution 3D models faces challenges: site location, depth, vulnerability, and complex environmental conditions  
→ need for an accurate, portable and scalable solution for documenting the underwater cultural heritage

## **CRAB (Calibrated Rig for Aquatic photogrammetric Bicamera system)**

developed under the ARCHIM3DES and the POSEIDON projects



# SYSTEM DESIGN AND DEVELOPMENT

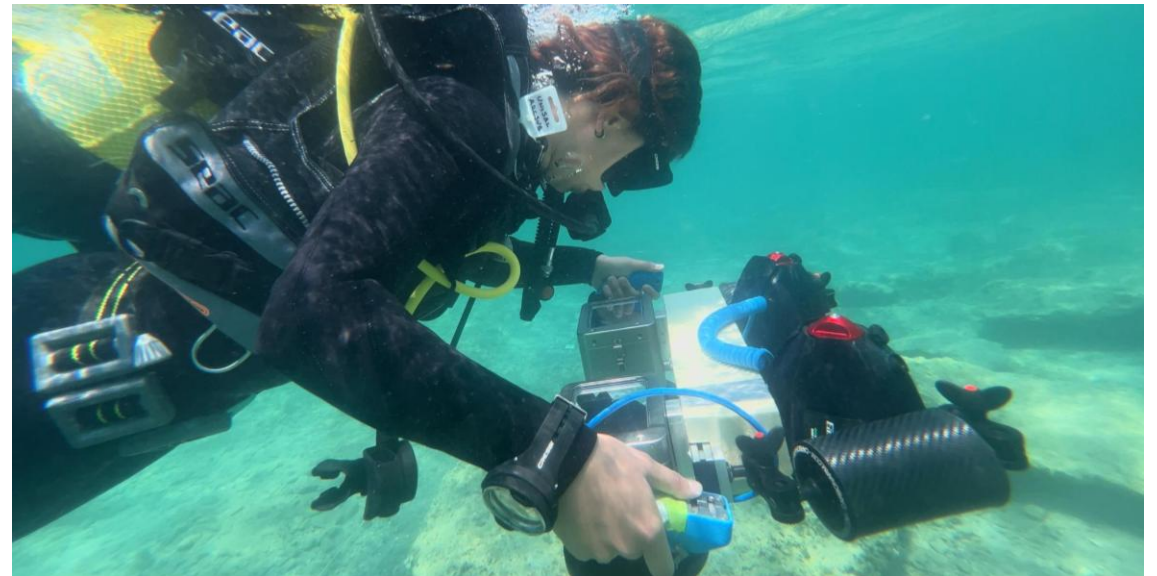
- 1.1 CRAB architecture
- 1.2 Cameras' synchronisation and trigger control
- 1.3 Centring and settings of the cameras

## 1.1

## CRAB architecture

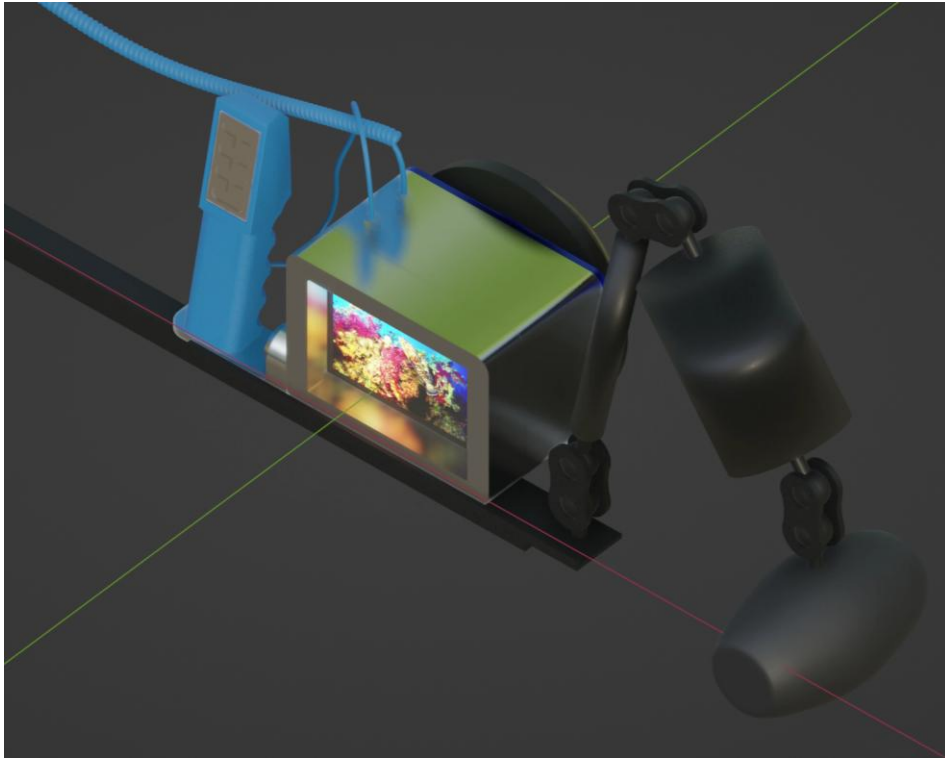
The aim is to provide a portable, scalable, and accurate solution for **very high-resolution 3D reconstruction of submerged cultural heritage without Groud Control Point (GCP)**

- Fixed stereo baseline
  - High-resolution synchronised cameras
- ...underwater...
- Waterproof cases
  - Optically calibrated dome port
  - Buoyancy system
  - Lighting system



## 1.1

# CRAB architecture



## SONY ILX-LR1

Pixel size	3,8 $\mu\text{m}$
Sensor Type	CMOS Exmor R 35.7 x 23.8 mm
Images resolution	9504 x 6336 pixels
Weight	243 g
Dimensions (LxWxH)	100 x 42,5 x 74 mm

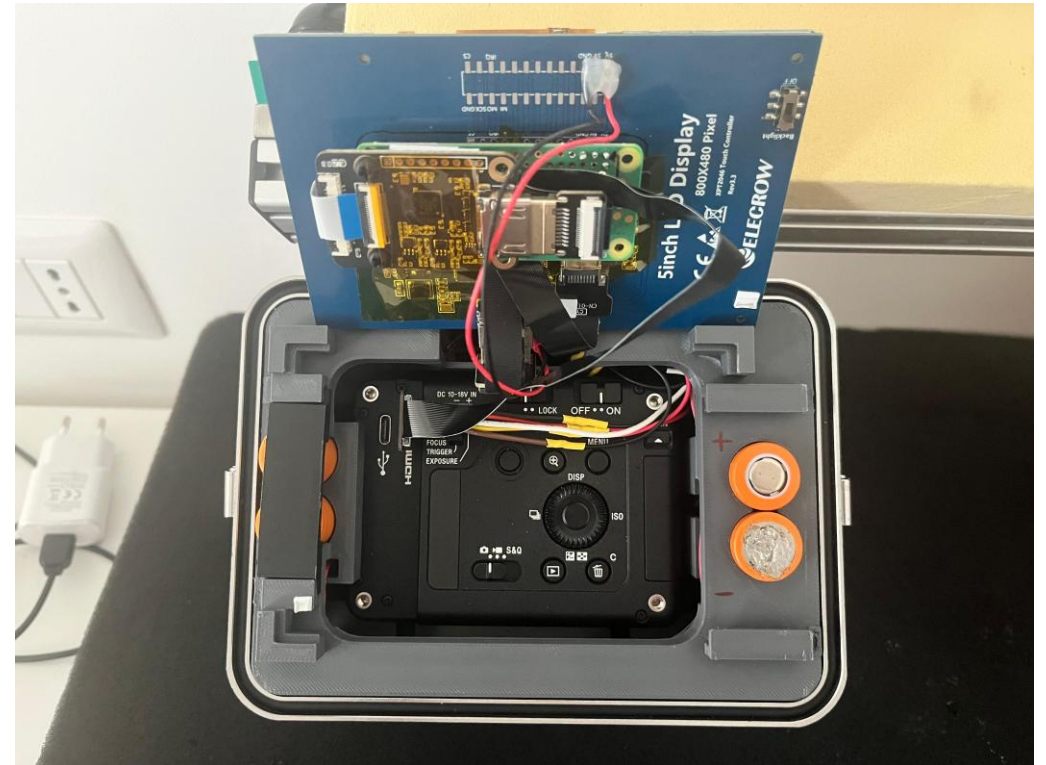
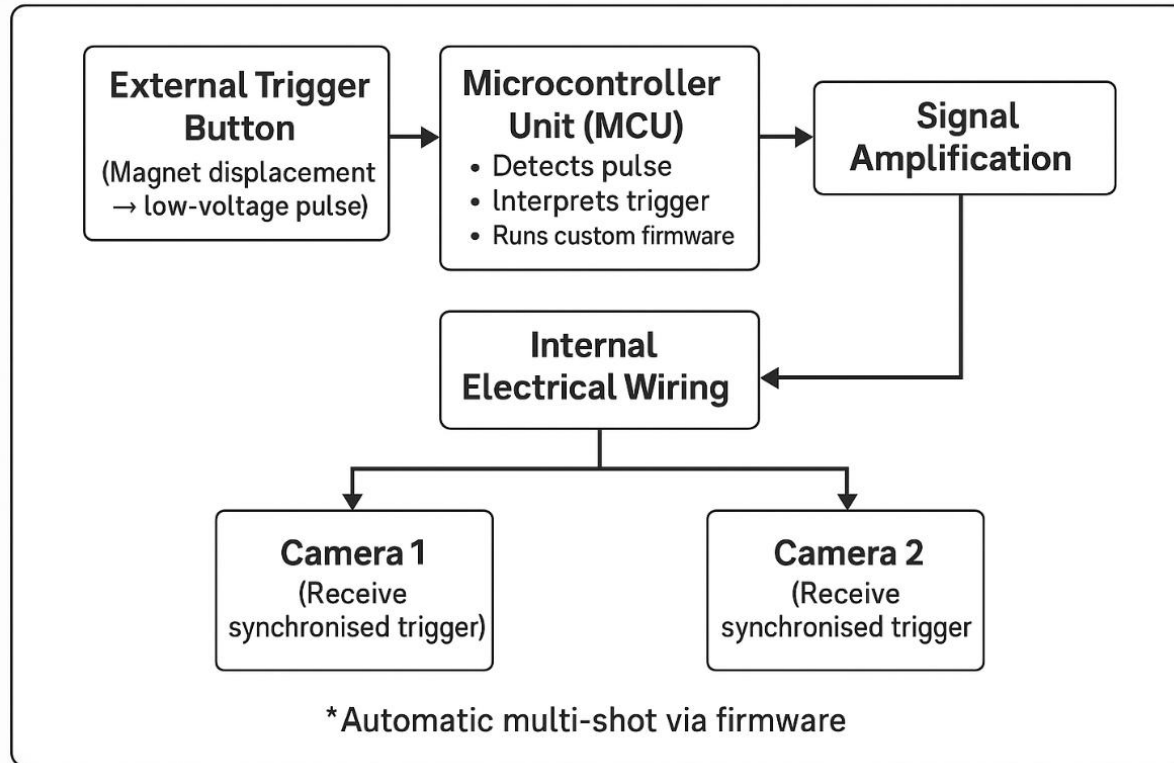


## SIGMA 17mm F4 DG DN

Focal Length	17 mm
Weight	220 g
Dimensions ( $\varphi$ x L)	64 x 48,8 mm

## Cameras' synchronisation and trigger control

The synchronisation is managed by a **microcontroller unit** (MCU), running a custom firmware specifically developed for this application, ensuring the cameras are synchronised within 0.01–0.02 seconds.

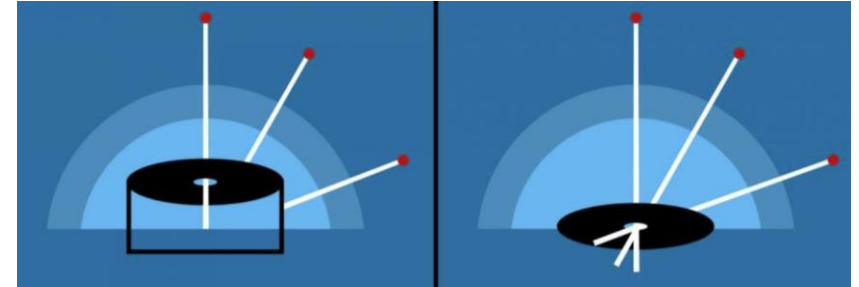


## 1.3

# Centring and settings of the cameras

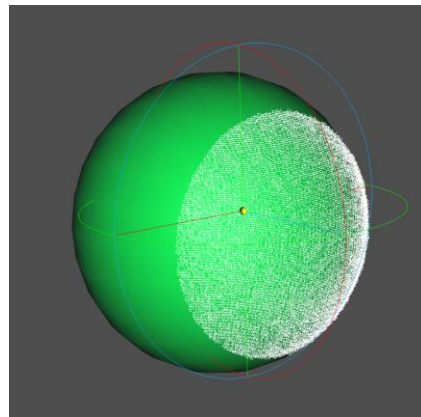
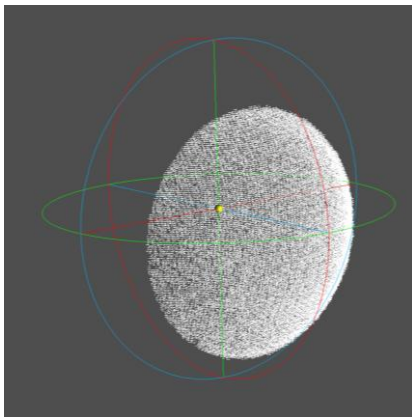


Align the **entrance pupil** with the **center of curvature** of the dome port.

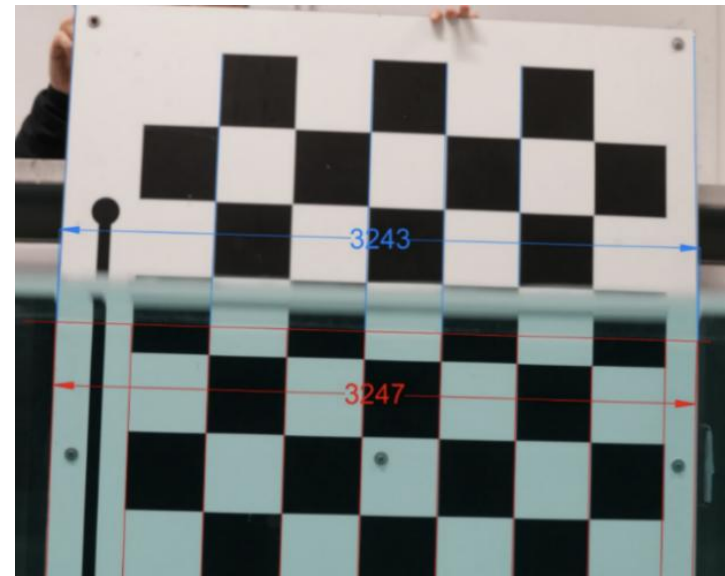


Incorrect

Correct



Computing of the dome port curvature radius and center of curvature



Empirical verification of the camera centering with respect to dome port

# **DATA ACQUISITION AND PROCESSING**

- 2.1 Case study and survey campaign
- 2.2 Camera calibration and colour correction
- 2.3 3D model generation

2.1

## Case study and survey campaign

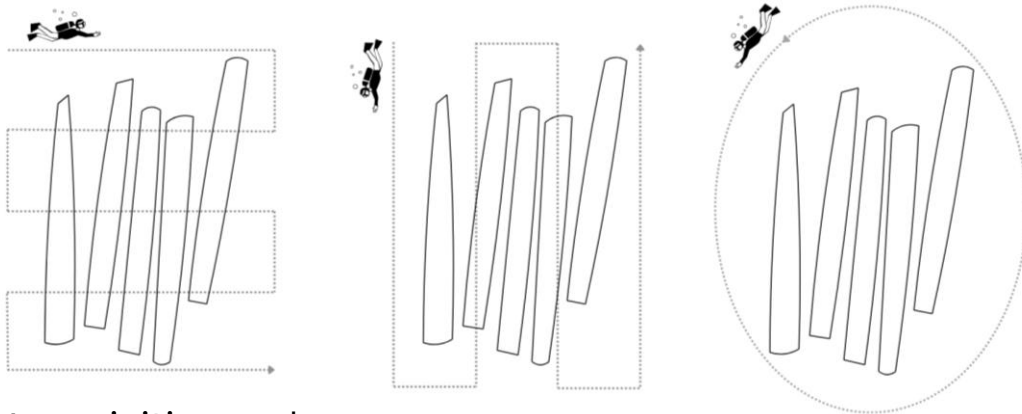
Marine Protected Area (MPA) of Porto  
Cesareo – Torre Chianca



Five large monolithic columns (9 m long  
70-100 cm diameter)  
Depth: 4-5 m

### Data acquisition (July 2024)

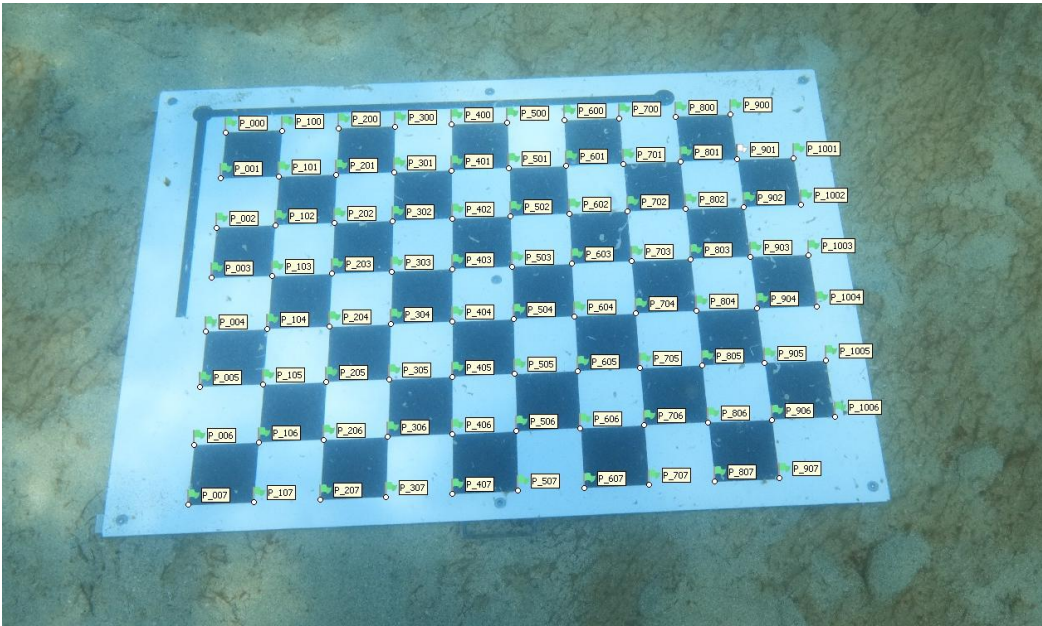
- 2632 synchronized images (1316 stereo pairs),  
both nadiral and oblique (approximately 45°)
- Working distance from the object: 2-2.5 m



Acquisition scheme



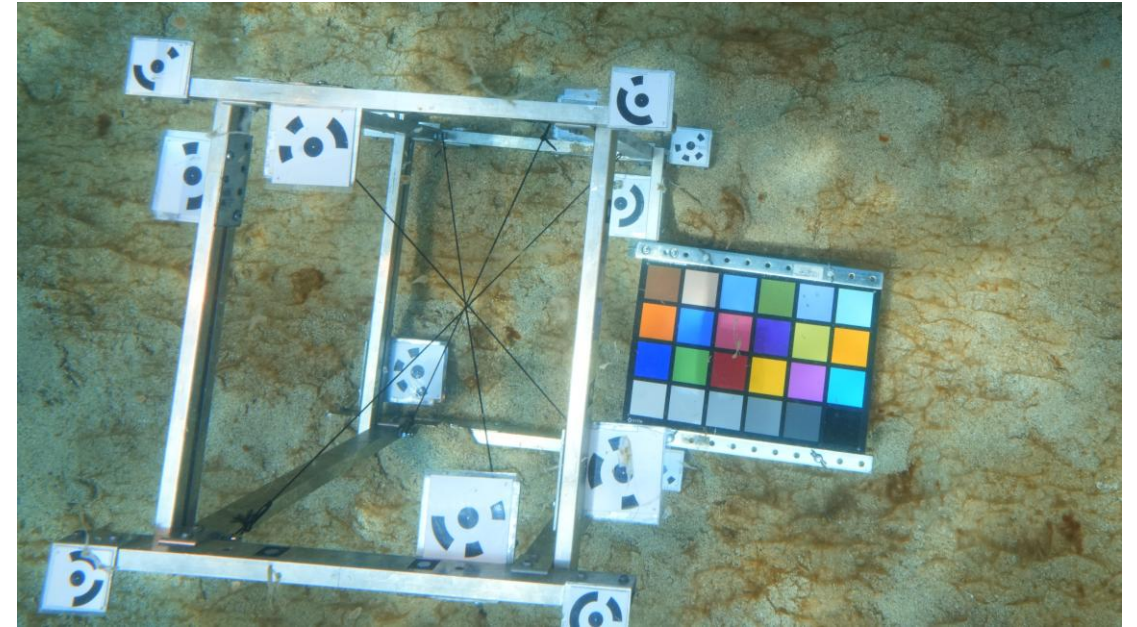
## Camera calibration and colour correction



120x85 cm checkerboard panel

→ Agisoft Metashape

- Pre-calibrated approach: initial estimation of the intrinsic parameters ( $f$ ,  $c_x$ ,  $c_y$ ,  $k_1$ ,  $k_2$ ,  $k_3$ ,  $p_1$ ,  $p_2$ ,  $b_1$ ,  $b_2$ ), then refined during the processing.



X-Rite ColorChecker

→ MATLAB

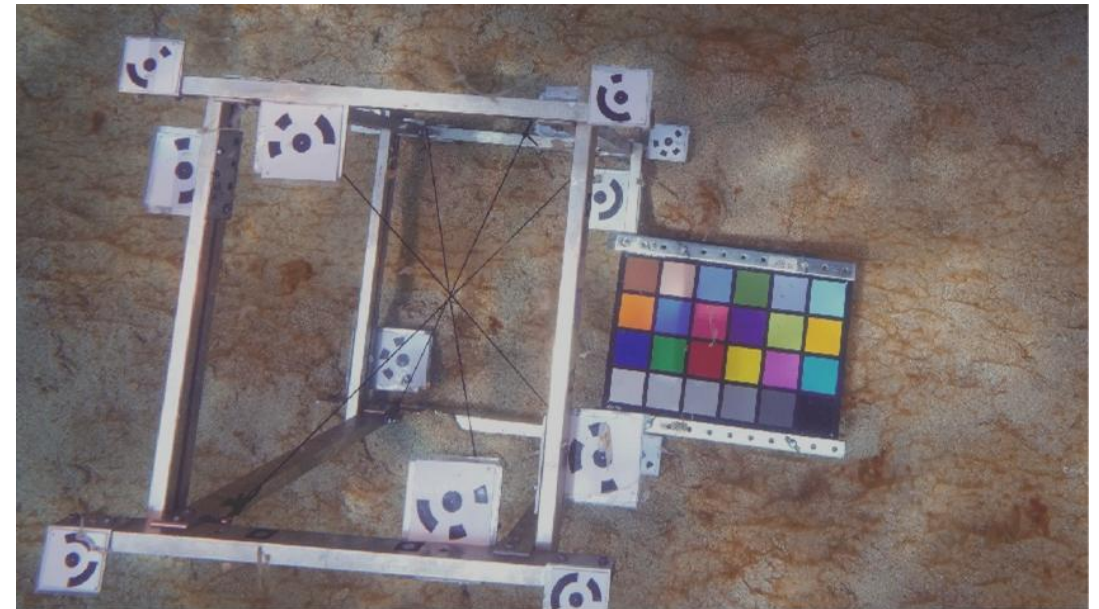


## Camera calibration and colour correction

### CIELAB color space – $L^*a^*b^*$

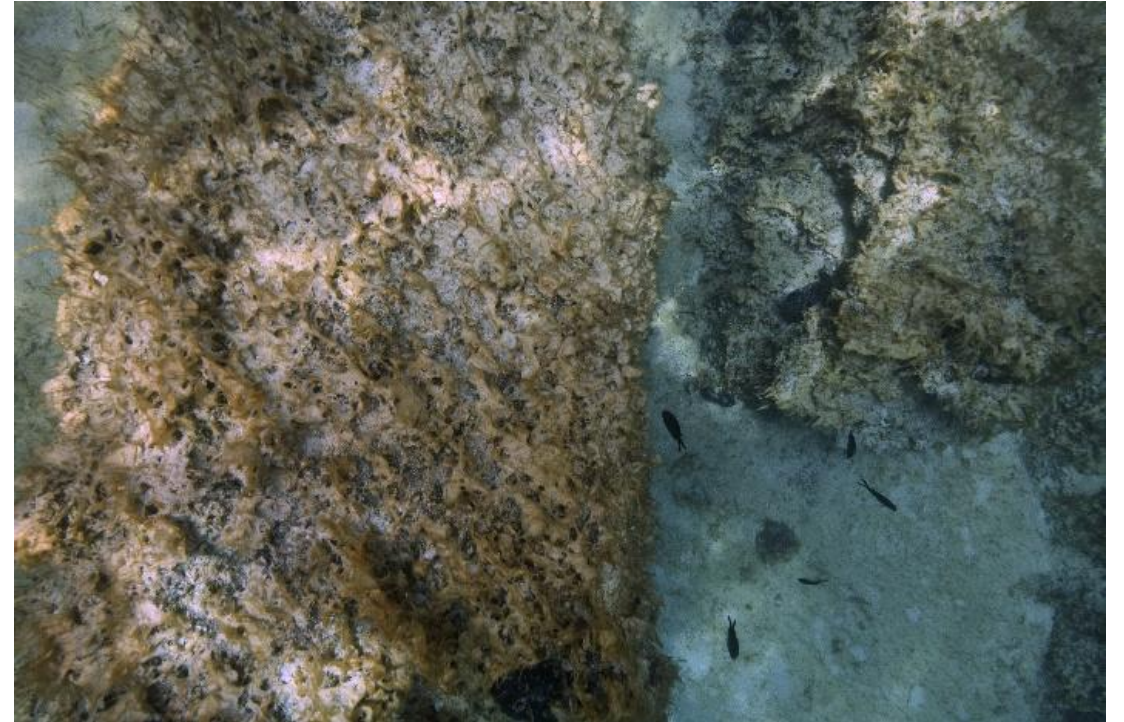
Computing of the colour difference ( $\Delta E$ ) between the measured and reference  $L^*a^*b^*$  values and correction of the distortions using a second-order polynomial regression model

Patch 1 $\Delta E = 22.3$	Patch 2 $\Delta E = 33.3$	Patch 3 $\Delta E = 32.7$	Patch 4 $\Delta E = 26.3$	Patch 5 $\Delta E = 35.1$	Patch 6 $\Delta E = 25.2$
Patch 7 $\Delta E = 7.7$	Patch 8 $\Delta E = 28.5$	Patch 9 $\Delta E = 27.9$	Patch 10 $\Delta E = 58.9$	Patch 11 $\Delta E = 17.8$	Patch 12 $\Delta E = 13.5$
Patch 13 $\Delta E = 47.4$	Patch 14 $\Delta E = 16.0$	Patch 15 $\Delta E = 25.8$	Patch 16 $\Delta E = 8.3$	Patch 17 $\Delta E = 42.7$	Patch 18 $\Delta E = 36.0$
Patch 19 $\Delta E = 23.7$	Patch 20 $\Delta E = 22.3$	Patch 21 $\Delta E = 23.7$	Patch 22 $\Delta E = 27.4$	Patch 23 $\Delta E = 27.4$	Patch 24 $\Delta E = 16.0$



2.2

## Camera calibration and colour correction



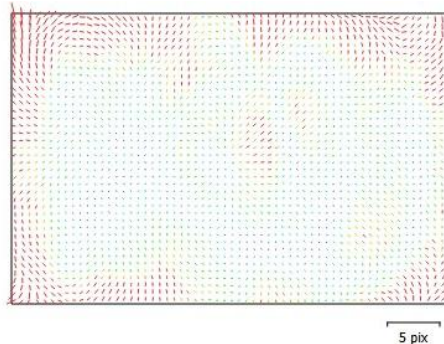
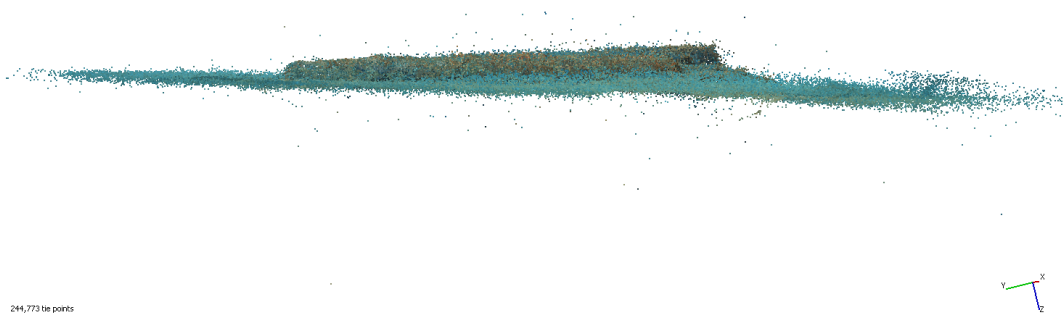
2.3

# 3D model generation

Different processing approaches

## WITH BASELINE CONSTRAINT (350 mm)

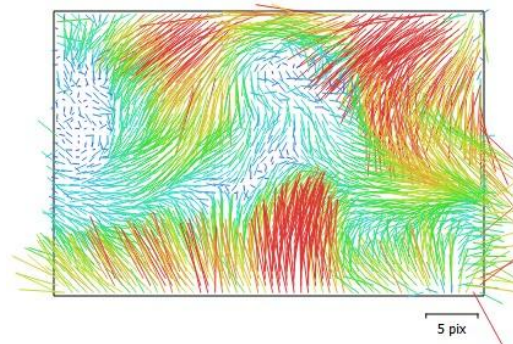
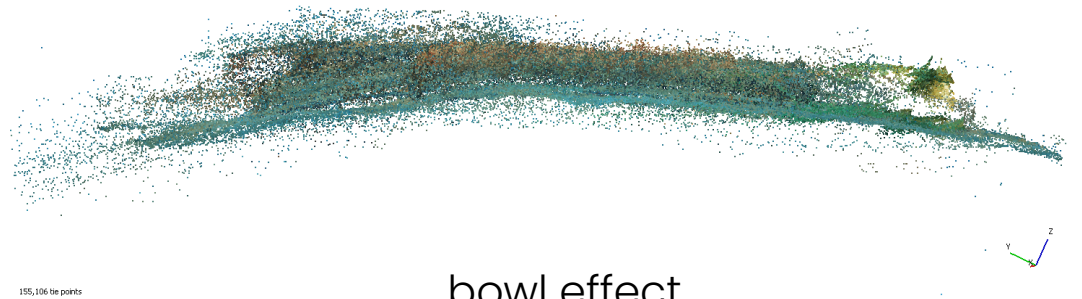
Aligned images: 1312/1316



RMS residual error  
Camera A: 3.83 pixels  
Camera B: 3.16 pixels

## WITHOUT BASELINE CONSTRAINT

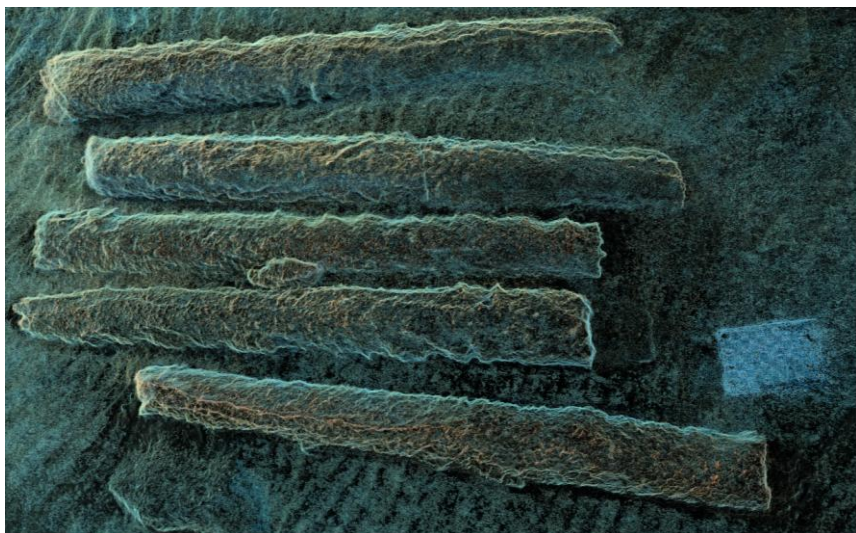
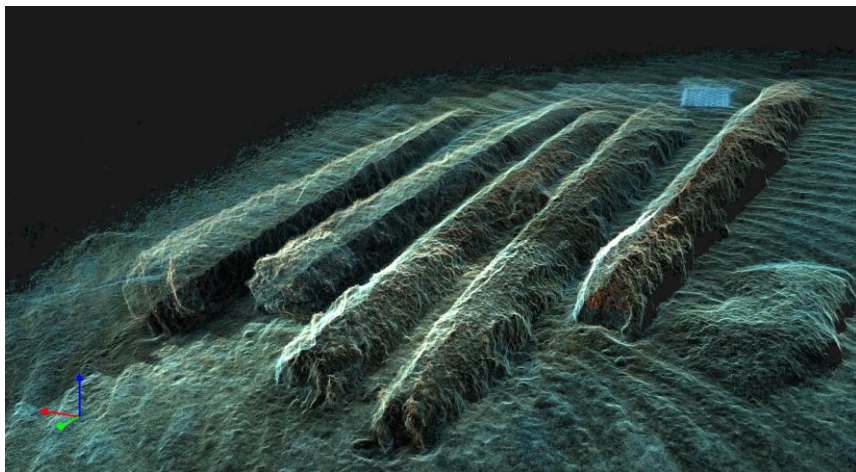
Aligned images: 534/1316



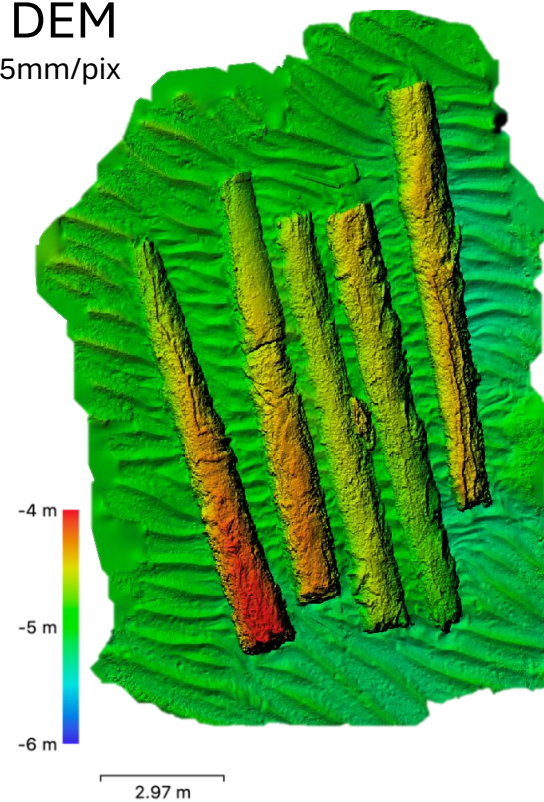
RMS residual error  
Camera A: 32.6 pixels  
Camera B: 28.5 pixels

2.3

## 3D model generation



DEM  
5mm/pix



Ortophoto  
5mm/pix



# **DISCUSSION AND CONCLUSIONS**

3.1 Evaluation of results

3.2 Closing remarks and further developments

## Evaluation of results

- The CRAB system delivered high-quality results, producing over 2600 high-resolution images that enabled a dense and accurate 3D reconstruction of the site. Applying the fixed baseline constraint proved essential, ensuring stable alignment of nearly all images and avoiding geometric distortions in the point cloud.
- Operationally, the system performed well in an active excavation context, being manageable for a small dive team and compatible with standard protocols. However, challenges remain with environmental factors like turbidity and the lack of integrated georeferencing for absolute positioning.

## Closing remarks and further developments

- CRAB has proven to be a robust, high-resolution tool for underwater heritage documentation, effectively reducing geometric distortion and alignment issues through stereo acquisition and pre-calibrated optics.
- Field deployment at Torre Chianca produced accurate 3D reconstructions, confirming the value of a fixed baseline and structured acquisition planning in real-world conditions.
- The system's modular, portable design allows use in varied contexts, including shipwrecks, submerged architecture, and infrastructure inspections. The colour correction process integrated in the workflow enhances output quality for research and public dissemination.
- Future improvements will focus on better radiometric calibration, integrating inertial navigation for georeferencing, and adapting to challenging environments like low-visibility or deep-water sites

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