Underwater photogrammetry for mapping and monitoring

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Center for Digital Industry - Fondazione Bruno Kessler

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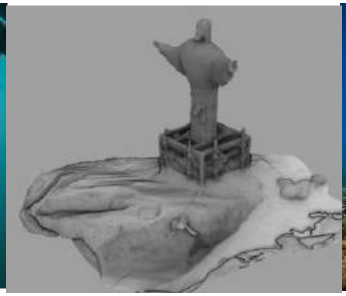
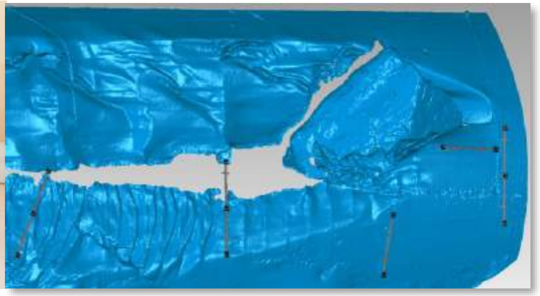
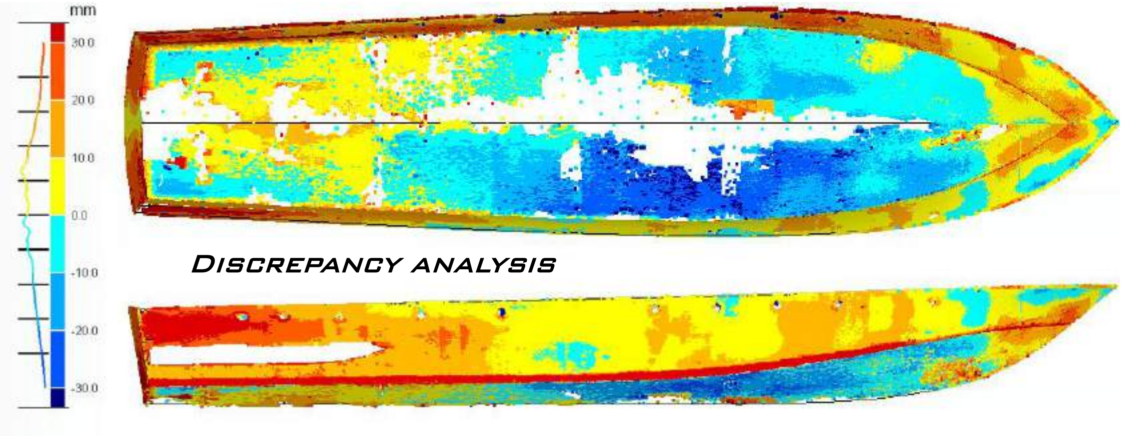


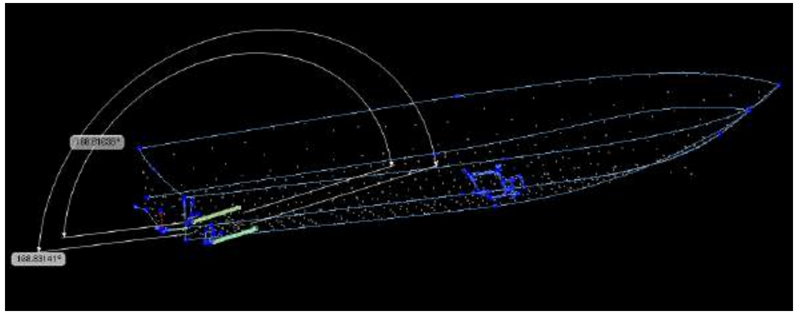
- Project started in 2006 at the Parthenope University as an interdisciplinary work
- Since 2011 supported by 3DOM – FBK
- Optical metrology and 3D reverse engineering techniques for supporting shipbuilding firms, naval architects and designers …

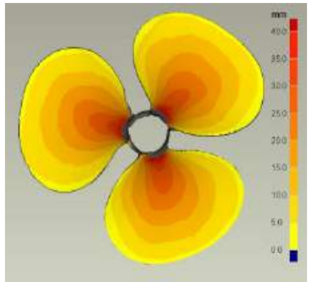
OptiMMA - OPTical Metrology for Maritime Applications

COLLABORATION WITH THE ITALIAN NAVY IN LA SPEZIA (2008) – INDUSTRIAL PHOTOGRAMMETRY

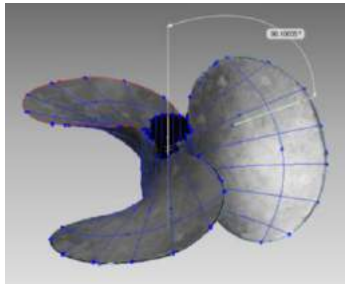


Shipbuilding and naval architecture applications – the nave "Argo" -

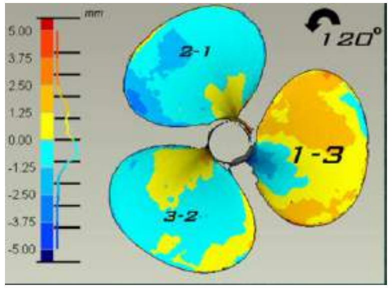




thickness of the right screw



Inclination of the generatrix



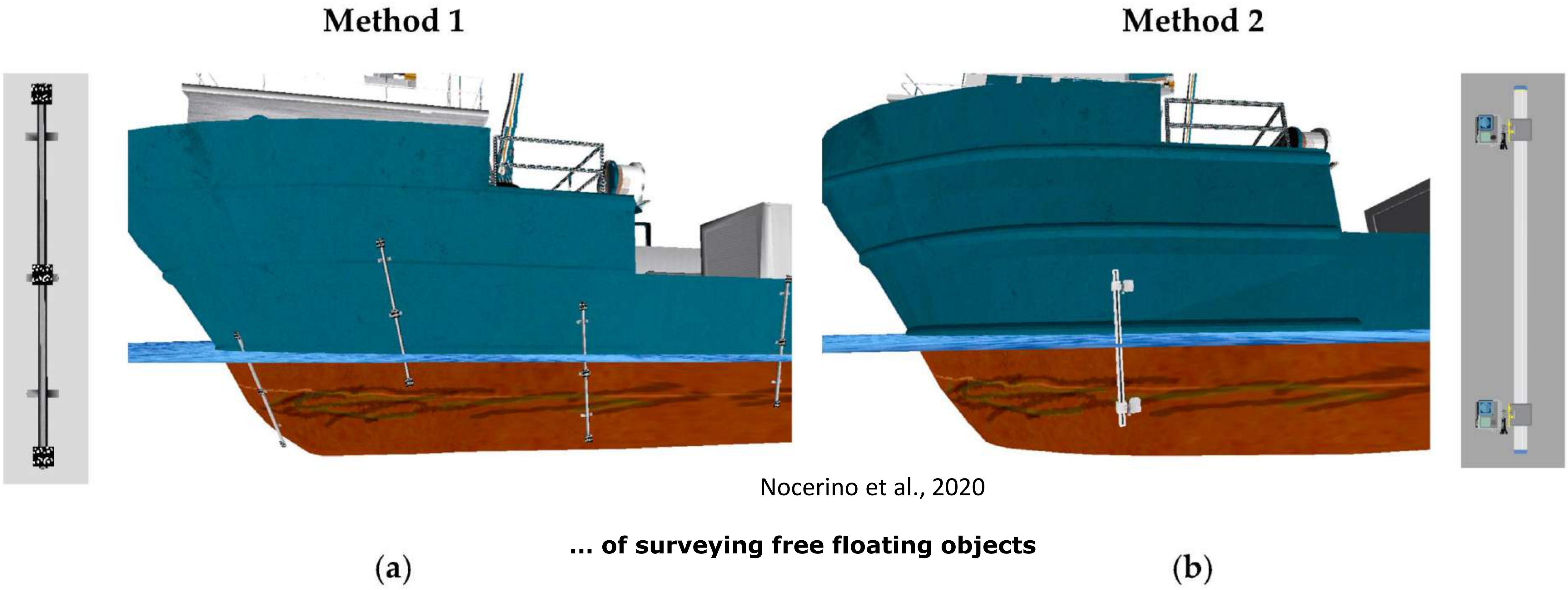
Per blade geometric analysis

Develop a photogrammetric solution to the specific problem …

… of surveying free floating objects

OptiMMA - OPTical Metrology for Maritime Applications

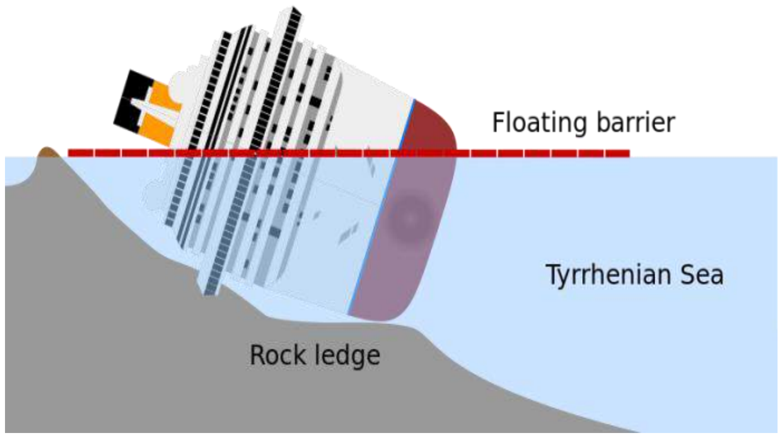
Develop a photogrammetric solution to the specific problem …

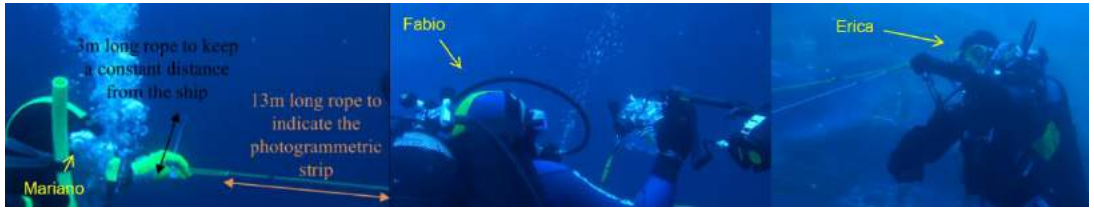


Nocerino et al., 2020

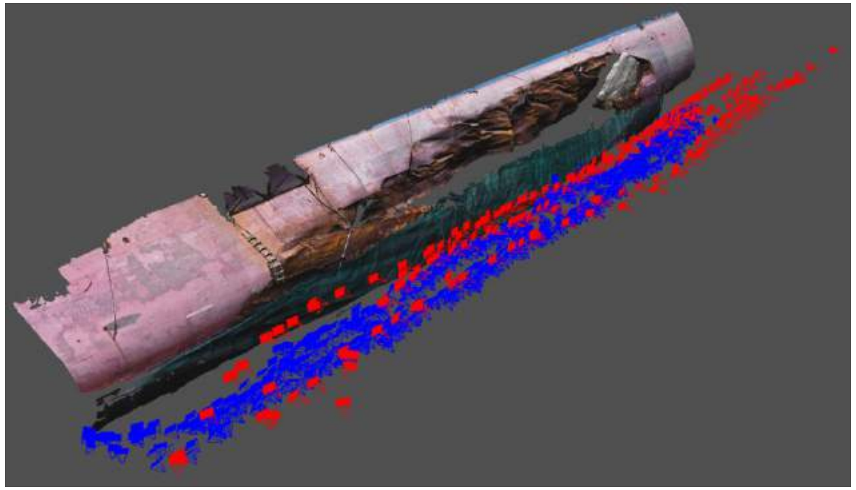
… of surveying free floating objects

Costa Concordia shipwreck

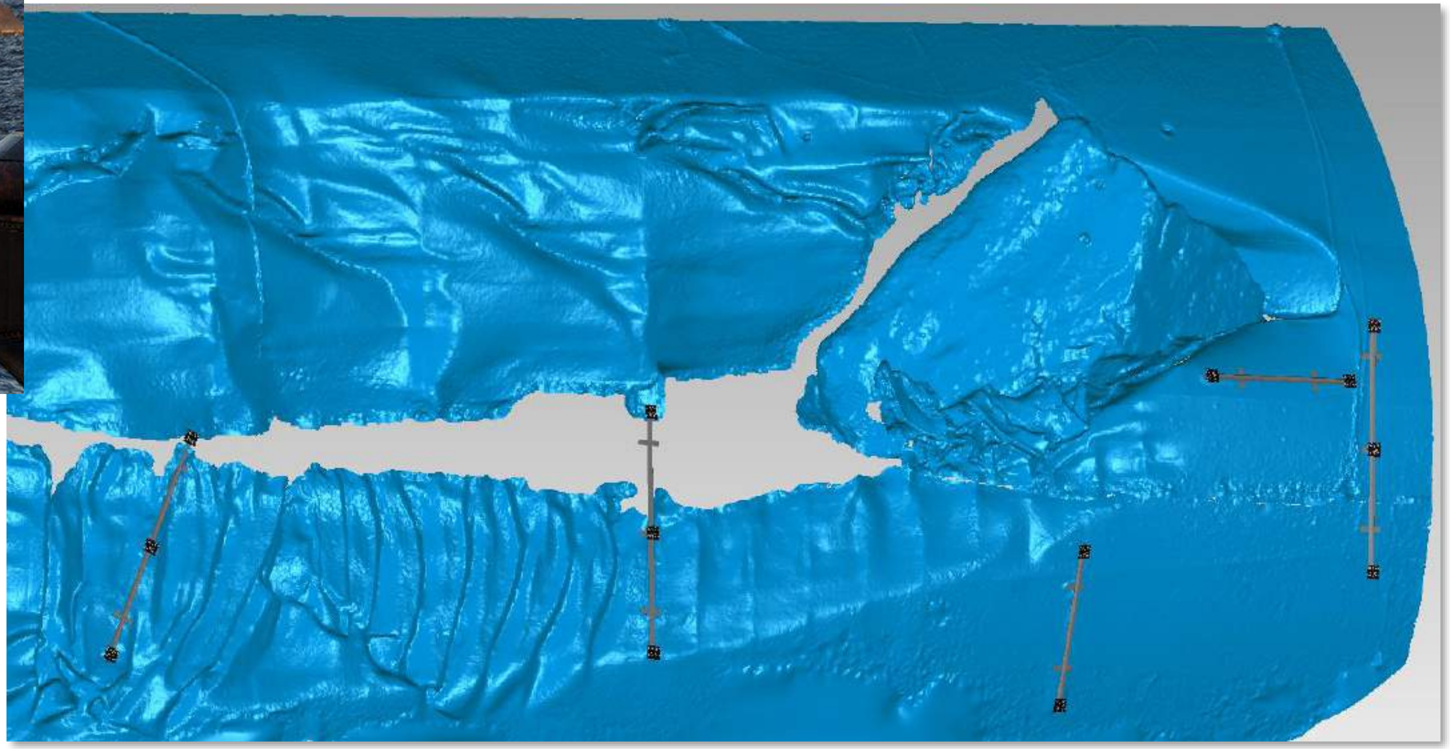




(Menna et al., 2013, Nocerino and Menna, 2020)



Costa Concordia shipwreck



(Menna et al., 2013, Nocerino and Menna, 2020)

Measuring the world across the water…



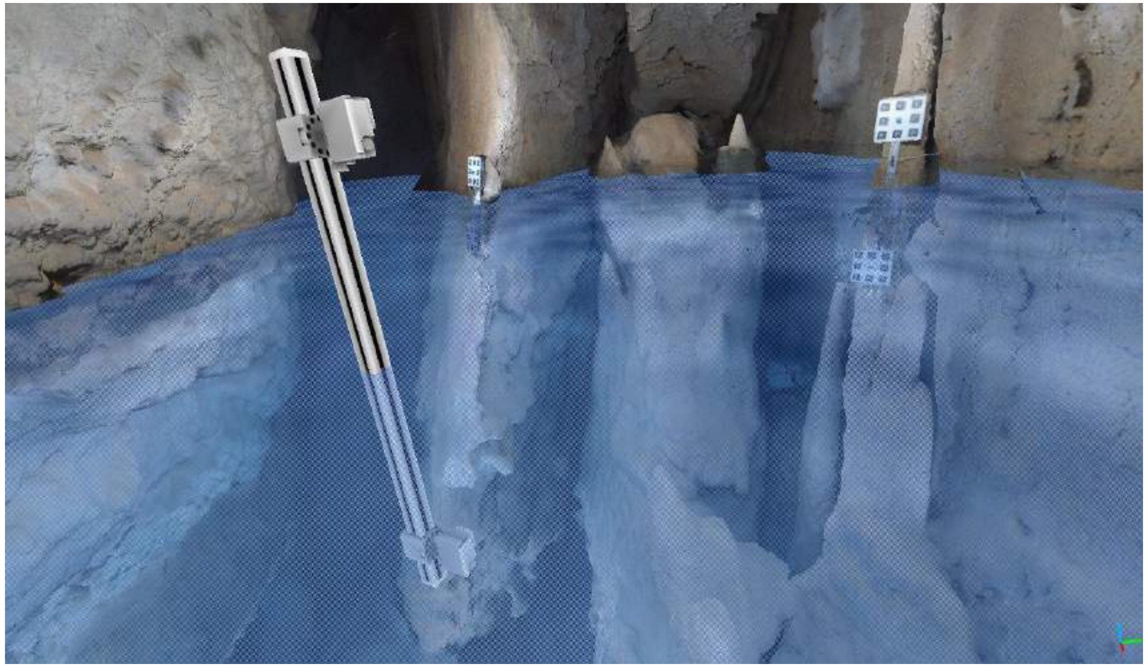


…it's a big challenge!

Semi-submerged caves: Grotta Giusti 3D project




Semi-submerged caves: Grotta Giusti 3D project



Nocerino et al., 2020

https://ariadne1.isti.cnr.it/3d/grotta-giusti-0?standalone

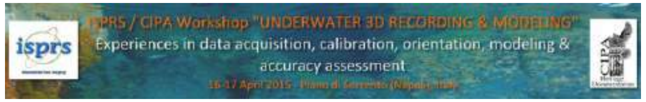
ISPRS WG II/7 Underwater Data Acquisition and Processing

Tutorial on UNDERWATER PHOTOGRAMMETRY: METHODS AND CHALLENGES FOR MAPPING AND MONITORING

Workshops organized at

CIPA 2023

ISPRS GEOSPATIAL WEEK 2023



ISPRS/CIPA Sorrento 2015

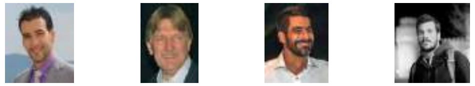
ISPRS WG II/9

Underwater Data Acquisition and Processing

Our Mission

ISPRS Working Group II/9 aims to develop, evaluate and promote methods for underwater photogrammetry data acquisition and processing in the fields of environmental monitoring, heritage recording and industrial measurement. WG II/9 will foster the interdisciplinary exchange of the latest developments and achievements in 3D sensors, image and range techniques for measurement and modeling, the effective use of autonomous and human guided vehicles, and applications of photogrammetry underwater.

WG II/9 will organise workshops to exchange the latest developments on underwater photogrammetry and related disciplines, and in particular collaborate interdisciplinarily with experts from the marine archaeology, engineering and exploration, marine science, fisheries and aquaculture communities. The WG will also liaise with academics, standards institutes, users and manufacturers working in the underwater domain to promote the appropriate and effective use of photogrammetric image and range based solutions. The WG will strengthen the co-operation and involvement of industrial partners in ISPRS activities related to underwater image and range based systems.



ISPRS WG II/7

Underwater Data Acquisition and Processing

Our Mission

ISPRS Working Group II/7 wants to contribute to the global goals for an ocean science for sustainable development, by fostering geomatic methods for through- and under-water data acquisition and processing.

WG II/7 will promote an interdisciplinary exchange in the fields of environmental monitoring and ecology, heritage recording, industrial measurement and hydrodynamics, with a view to increase our current knowledge of the underwater world and its response and resilience to, and impact on climate change. For this purpose, WG II/7 will boost the development, testing and operability of 3D image and range-based sensors and techniques for measurement and virtualization of inland, coastal and open sea underwater environments, also through the effective use of autonomous and human guided vehicles.

WG II/7 will organise and support in-presence and on-line workshops and events on through- and under-underwater photogrammetry and related disciplines, seeking for contributions of experts from the marine archaeology, engineering, robotics, marine science, fisheries and aquaculture communities. WG II/7 activities include collecting, organising and sharing benchmark datasets to stimulate genuine competition between researchers towards innovative solutions to problems relevant to the community. To make its actions more effective, WG II/7 will work in close collaboration with ICGW II/I and the other WGs from TCII.

ISPRS SI NAUTILUS

https://www2.isprs.org/commissions/comm2/wg7/become-a-member/

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  - ICWG II/Ia
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ISPRS WG II/7

Individuals who apply geospatial technologies in underwater data acquisition and processing as well as other related studies, and interested to collaborate with other multi-disciplinary professionals in this area are invited to join:

First Name *

First Name

Surname *

Surname

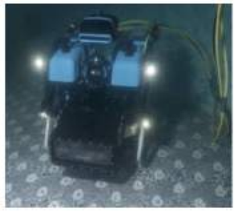
Country *

Country

Full Address *

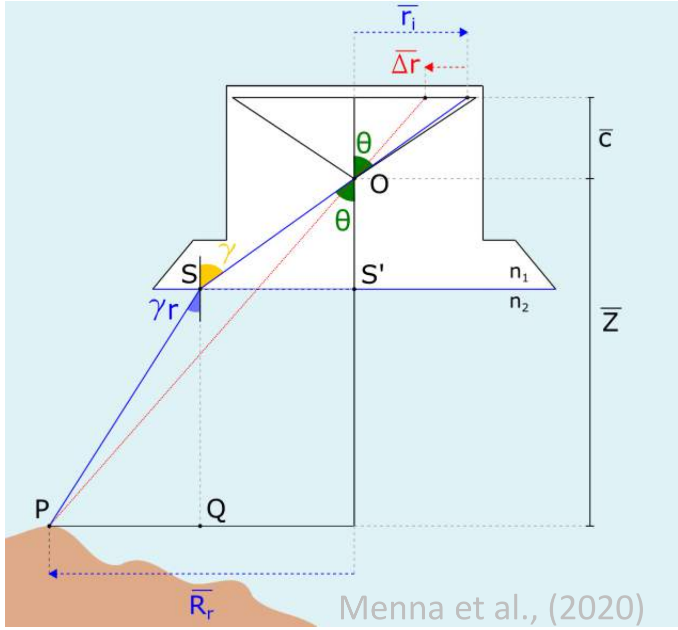
Full Address

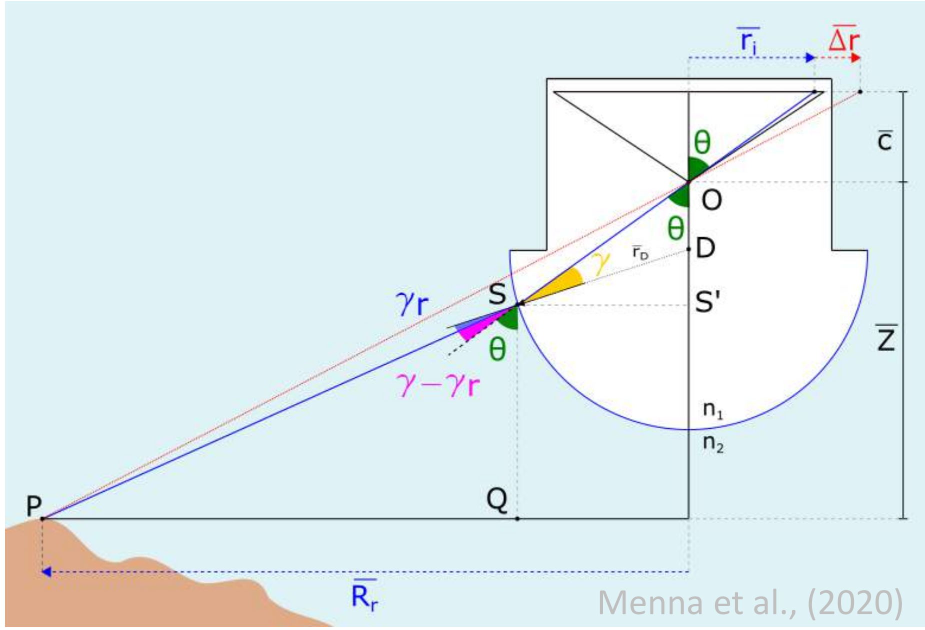
WG II/7



MODELLING THE REFRACTION IN FLAT AND DECENTERD DOME PORTS

Flat port





Decentered dome port $(O \neq D)$

The submerged point P is projected on the sensor at the distance $\overline{r_i}$ from the principal point following the blue path according to **Snell's law**.

In air the red collinearity line would instead directly link the object point P with its image projection on the sensor, differing by the quantity $\overline{\Delta r}$ with respect to the submersed case.

$\overline{\Delta r}$ is function of the distance $\bar{Z}$

Menna et al. (2020), Nocerino et al. (2021)

Unmodelled refraction and systematic errors

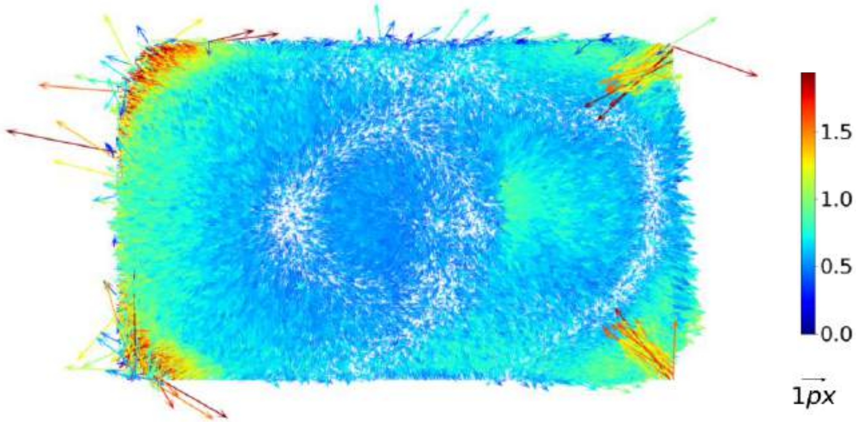
Errors in a measurement process:

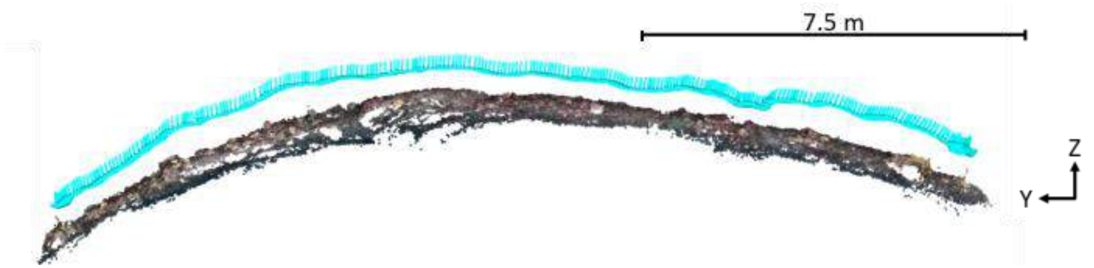
- Errors in the observations → random and gross errors
- Errors in the functional or stochastic model → **systematic errors**

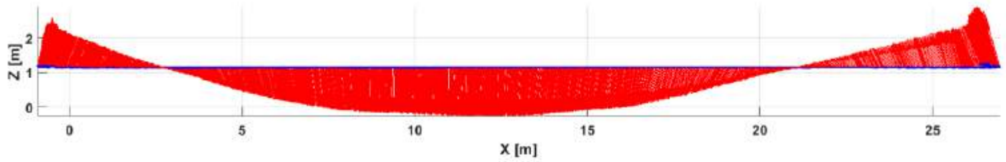
Camera calibration with the Brown/Beyer model satisfactorily compensates for systematic errors in most typical cases in aerial as well as close-range photogrammetry but does not consider phenomena such as refraction in multimedia photogrammetry.

Uncompensated systematic errors:

- may appear as systematic residual patterns in image observations
- produce deformations of the photogrammetric model in object space

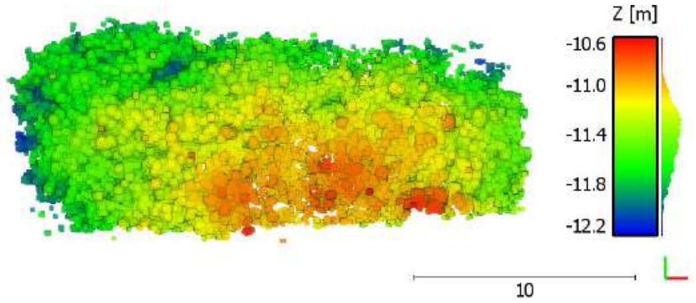




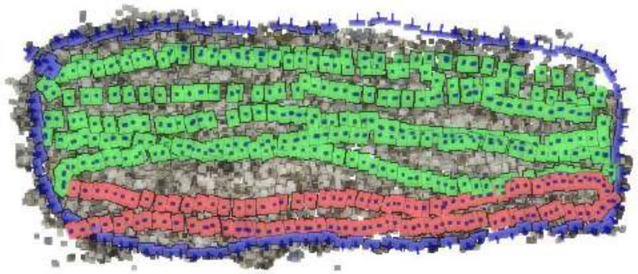


Menna et al. (2020), Nocerino et al. (2021)

2D image observations generated in MATLAB using



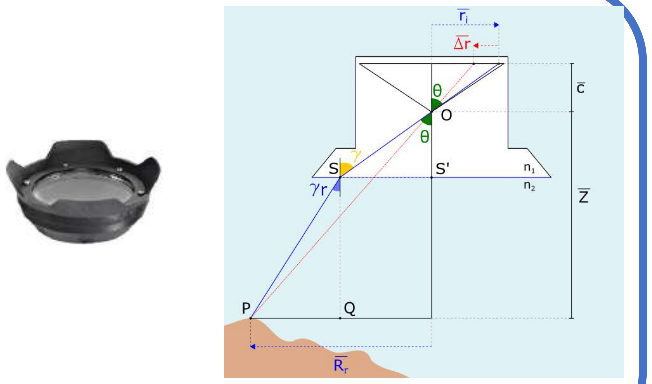
Subsampled 3D point cloud (1 point/20cm)



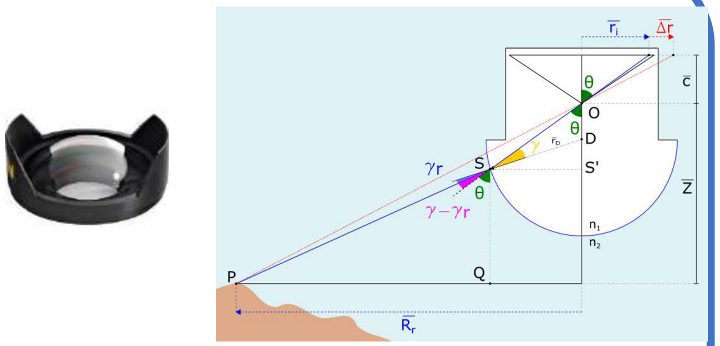
EO parameters

+

nominal IO parameters without distortions



flat port

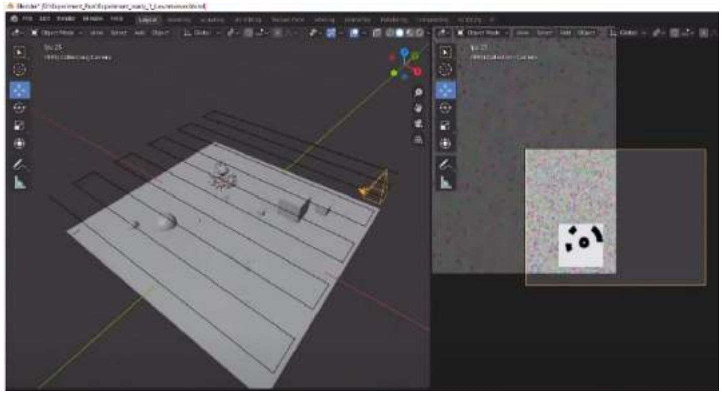


decentered dome

water refraction index of 1.34 and port thickness neglected

POSER: an oPen sOurce Simulation platform for tEaching and tRaining underwater photogrammetry

2024 ISPRS Educational and Capacity Initiatives



- An integrated framework to evaluate photogrammetry data, quantifying overlap, resolution, angular coverage, individual image quality, and deviation from baseline.

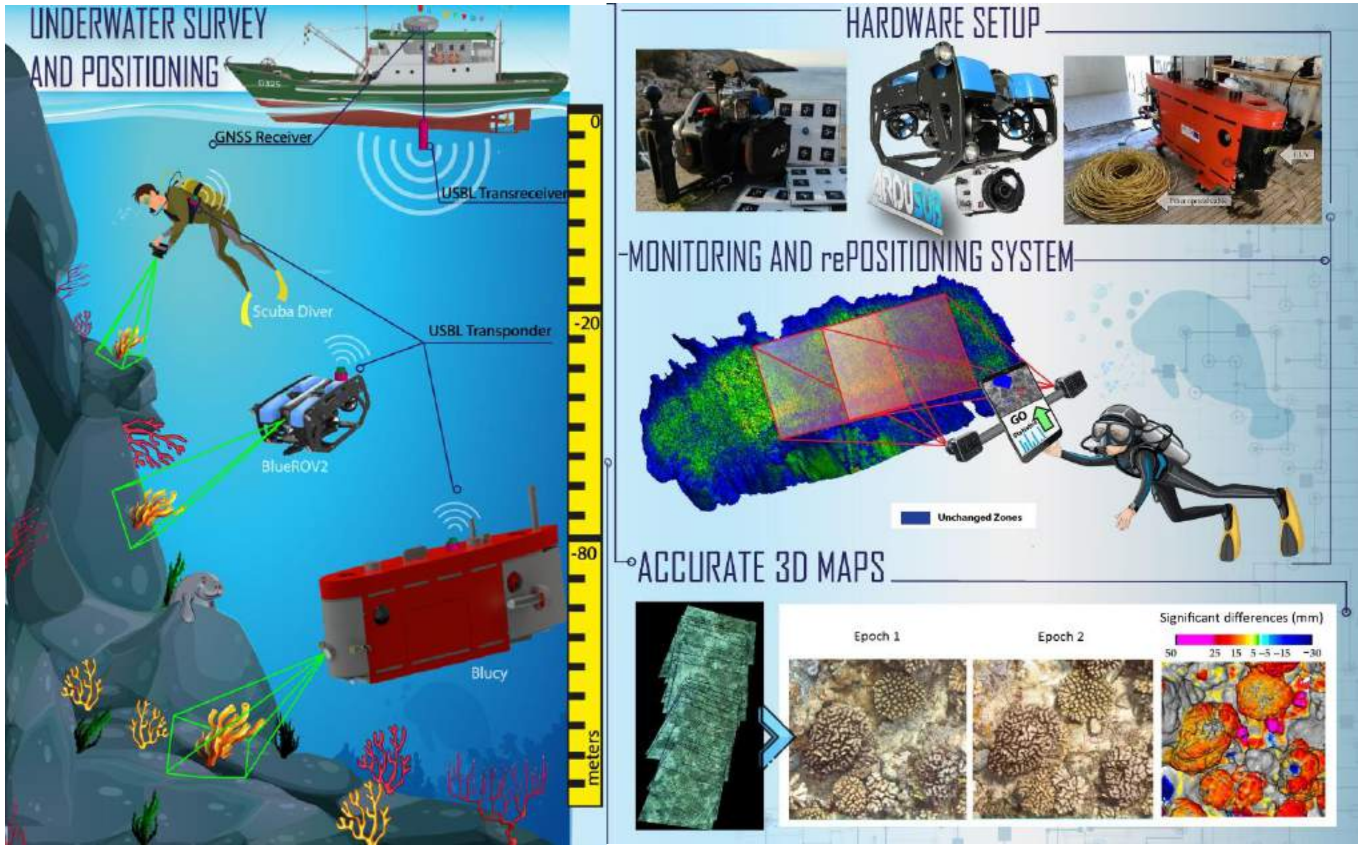
- An integrated framework to replicate water refractive effects into a virtual environment

- An integrated framework to simulate light dropoff and surface caustics

- An integrated framework for SCUBA dive planning to enhance non decompression limits and air consumption awareness (using for example the open source project Subsurface)

- …

Monitoring and mApping of mariNe hAbitat with integrated gEomatics technologiEs



UNISS UNIVERSITÀ DEGLI STUDI DI SASSARI

UNIVERSITY OF NAPLES PARTHENOPE

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

With A. Calantropio, S. Del Pizzo, S. Troisi, L. Vittuari, A. Lambertini

MUR Ministero dell'Università e della Ricerca
Bando PRIN 2022

PRIN 2022 PNRR

MUR

multitemPOral SEagrass mapping and monitoring of posIDONia meadows and banquettes for blue carbon conservation

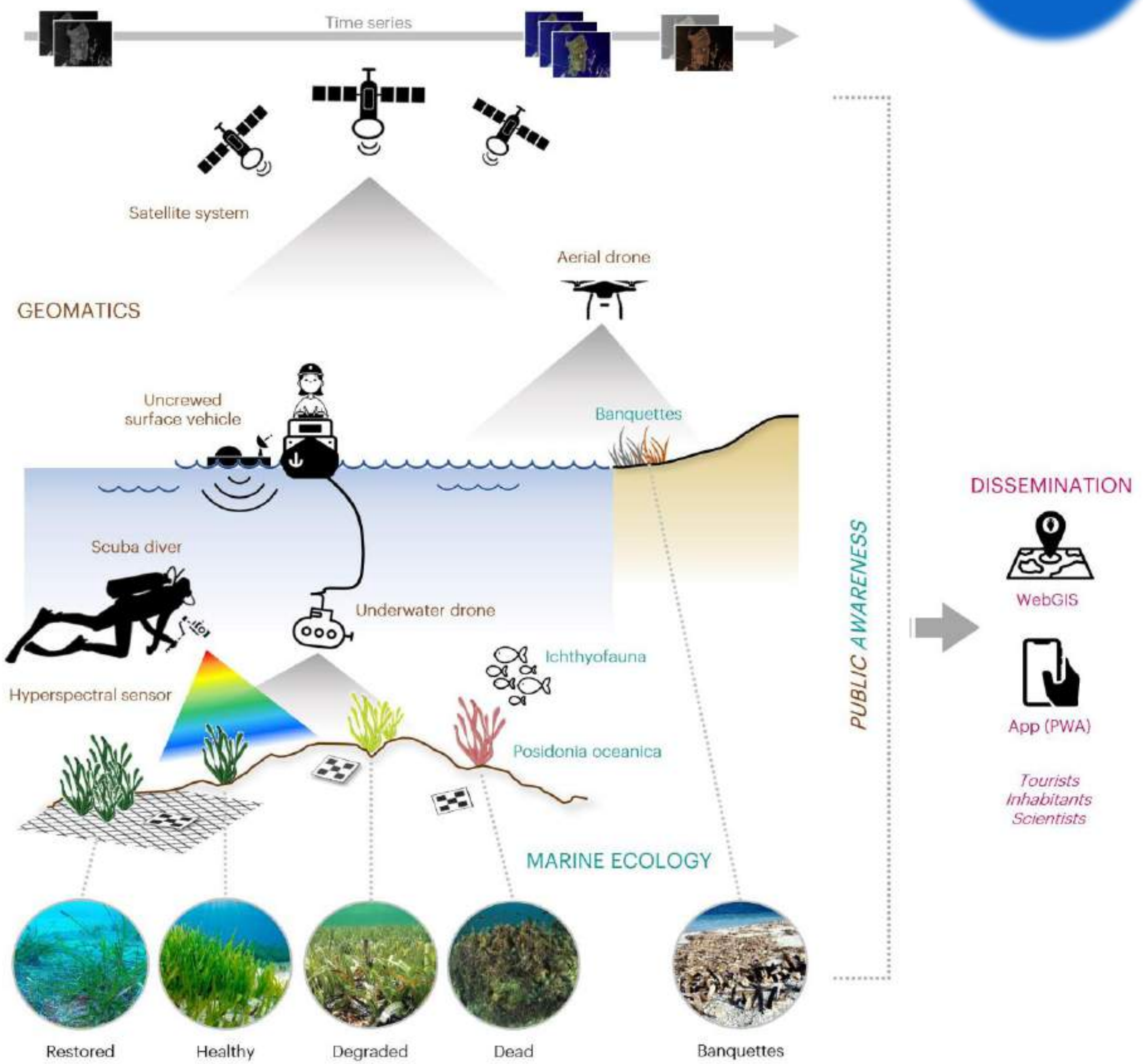
Politecnico di Torino

UNISS UNIVERSITÀ DEGLI STUDI DI SASSARI

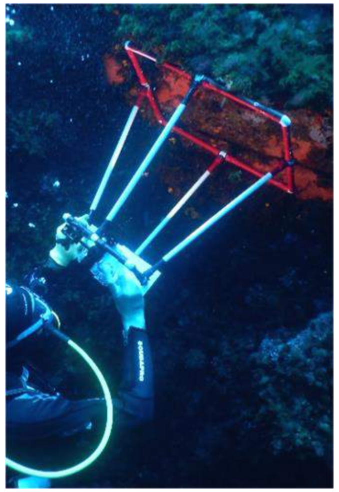
ROMA TRE UNIVERSITÀ DEGLI STUDI

With A. Lingua, F. Chiabrando, F. Matrone, G. Ceccherelli, M. Scalici, S. Secco, and many more

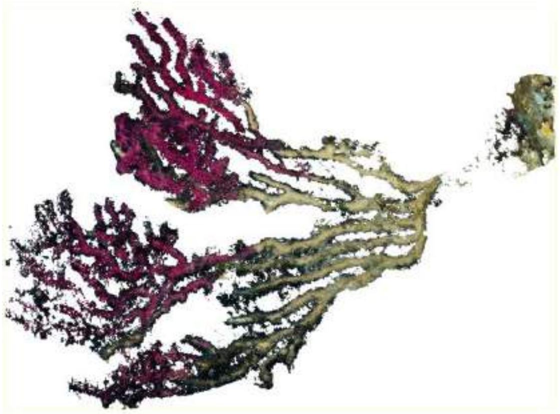
Outline of POSEIDON methodology



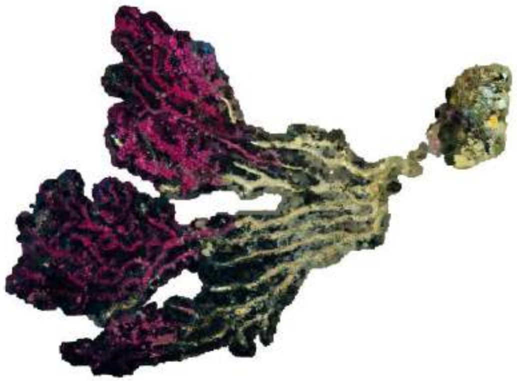
Monitoring paramuricea



Developing a photogrammetry-based method as an alternative to the traditional STAR method currently used

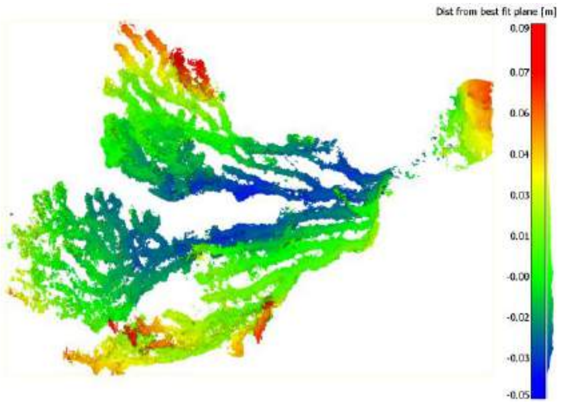


L_{direct} = 59 cm
$L_{geodetics}$ = 64 cm



Area Best fitting plane = 0.11 m^2
Area Poisson = 0.29 m^2

Necrosis Poisson = 0.13 m^2 (45%)



Non-planarity

With G. Ceccherelli and many more

NATIONAL BIODIVERSITY FUTURE CENTER
Ministero dell'Università e della Ricerca
Italiadomani
Finanziato dall'Unione europea NextGenerationEU

isprs
information from imagery

3DOM
3D OPTICAL METROLOGY

Cyprus University of Technology

Università Iuav di Venezia

TU WIEN

TECHNISCHE UNIVERSITÄT BERLIN

Politecnico di Torino

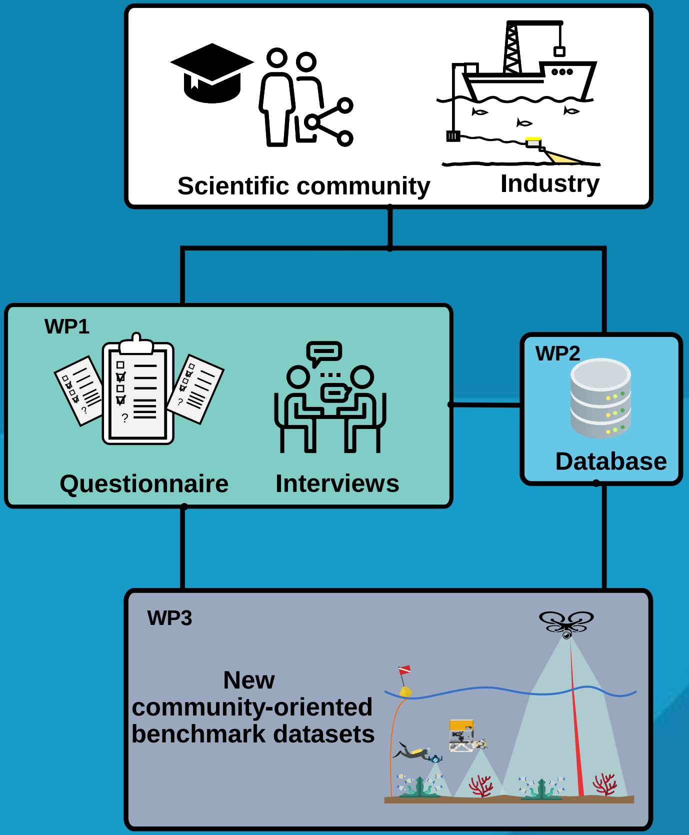
NAUTILUS

uNder And throUgh waTer datasets for geospatIaL stUdieS

NAUTILUS is a **Scientific Initiative** founded by the **ISPRS**. Its aims are:

(1) to **collect available underwater benchmark datasets** and make them available through a single website or geoportal;

(2) to **collect actual needs and gaps** that might be filled by designing a brand-new benchmark dataset.



https://nautilus-isprs.fbk.eu/

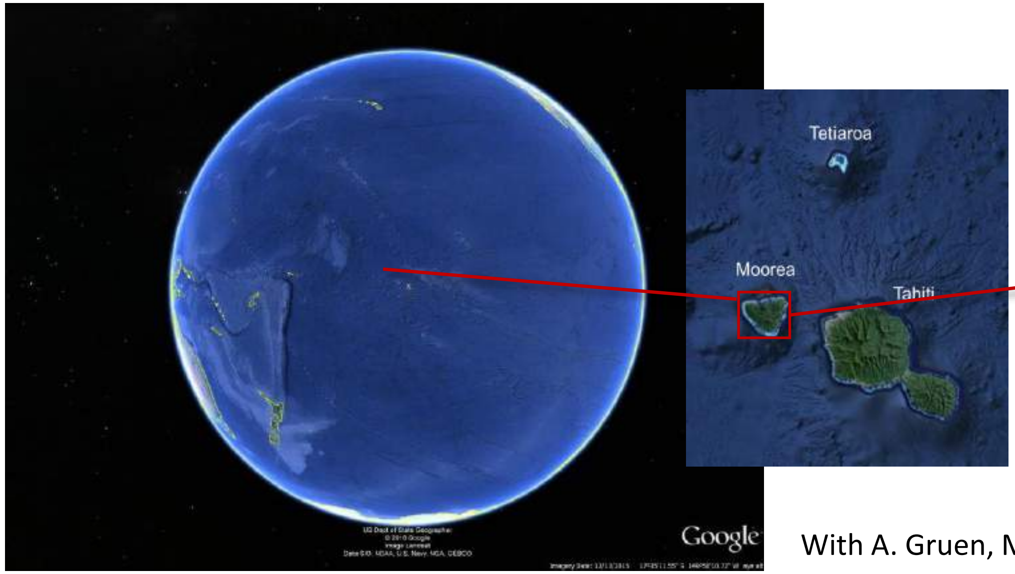
ISPRS WG II/7 & NAUTILUS

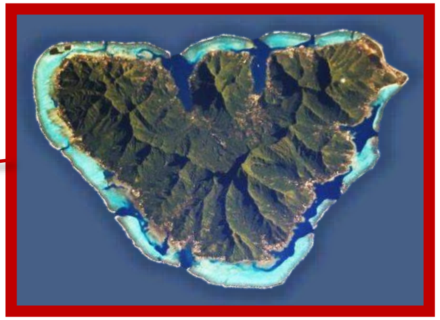
Online User Meeting on 15 Jan

- Two sessions
- 26 presenters
- ≈ 100 participants from 18 countries

With A. Calantropio, D. Skarlatos, C. Balletti, F. Chiabrando and A. Lingua

Underwater long-term monitoring with geomatics

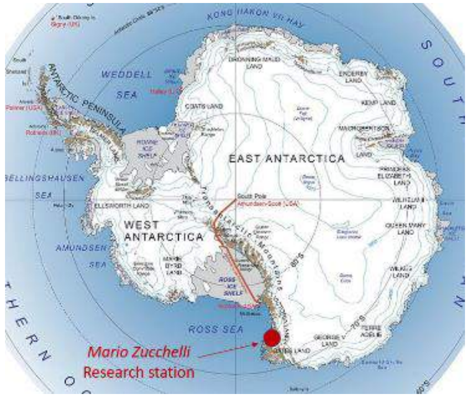




The Moorea IDEA and Moorea Coral Reef LTER projects

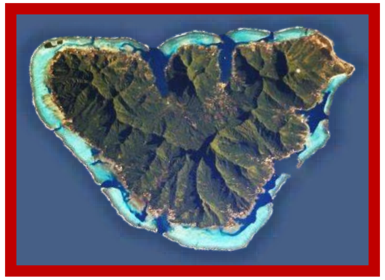
With A. Gruen, M. Troyer, A. Capra, C. Castagnetti, P. Rossi, A. J. Brooks, R. J. Schmitt, S. J. Holbrook

A cooperative international project at "Mario Zucchelli" station in Antarctica



With F. Remondino, S. Schiaparelli, P. Piazza, S. Malek

Underwater long-term monitoring with geomatics



Moorea

- warm water (≈27 Celsius degrees in August) (☺)
- possible swell (☹)
- crystal clear water (☺)
- plots of different size recorded with ground sample distance (GSD) < 1mm
- still images (time-lapse) and fixed focus
- permanent targets installed at the seabed
- change detection – expected growth 10-14 mm/year

Antarctica

- -1.8 Celsius degrees polar water (☹)
- 3m thick ice (☹)
- crystal clear water (☺) (November)
- 20 m transects recorded with ground sample distance (GSD) < 1mm
- videos (used also for other scientific analyses) and autofocus (point and shot setup)
- no permanent targets installed at the seabed
- counting and measuring benthic species (≈2-3mm)

Our geomatic approach for coral reef monitoring in Moorea

PERMANENT, UNDERWATER GEODETIC NETWORKS

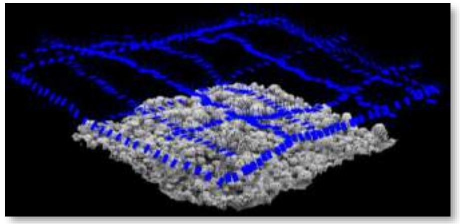
Temporally stable and common reference datum and, also, an independent quality check for the photogrammetrically derived multi- temporal 3D models of the reef structure

EVALUATION OF UNDERWATER CAMERA SYSTEMS

Test for accuracy potential estimate with action cameras, low-cost and professional-grade off-the-self underwater cameras

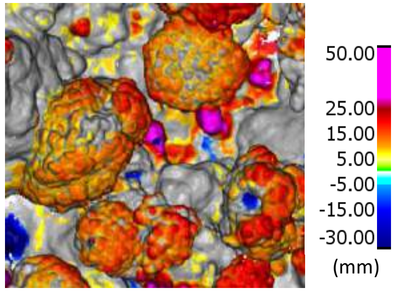
RELIABLE CAMERA NETWORK GEOMETRY

To minimize the deformations of photogrammetrically derived 3D coral reef models due to accumulation of non-compensated systematic errors



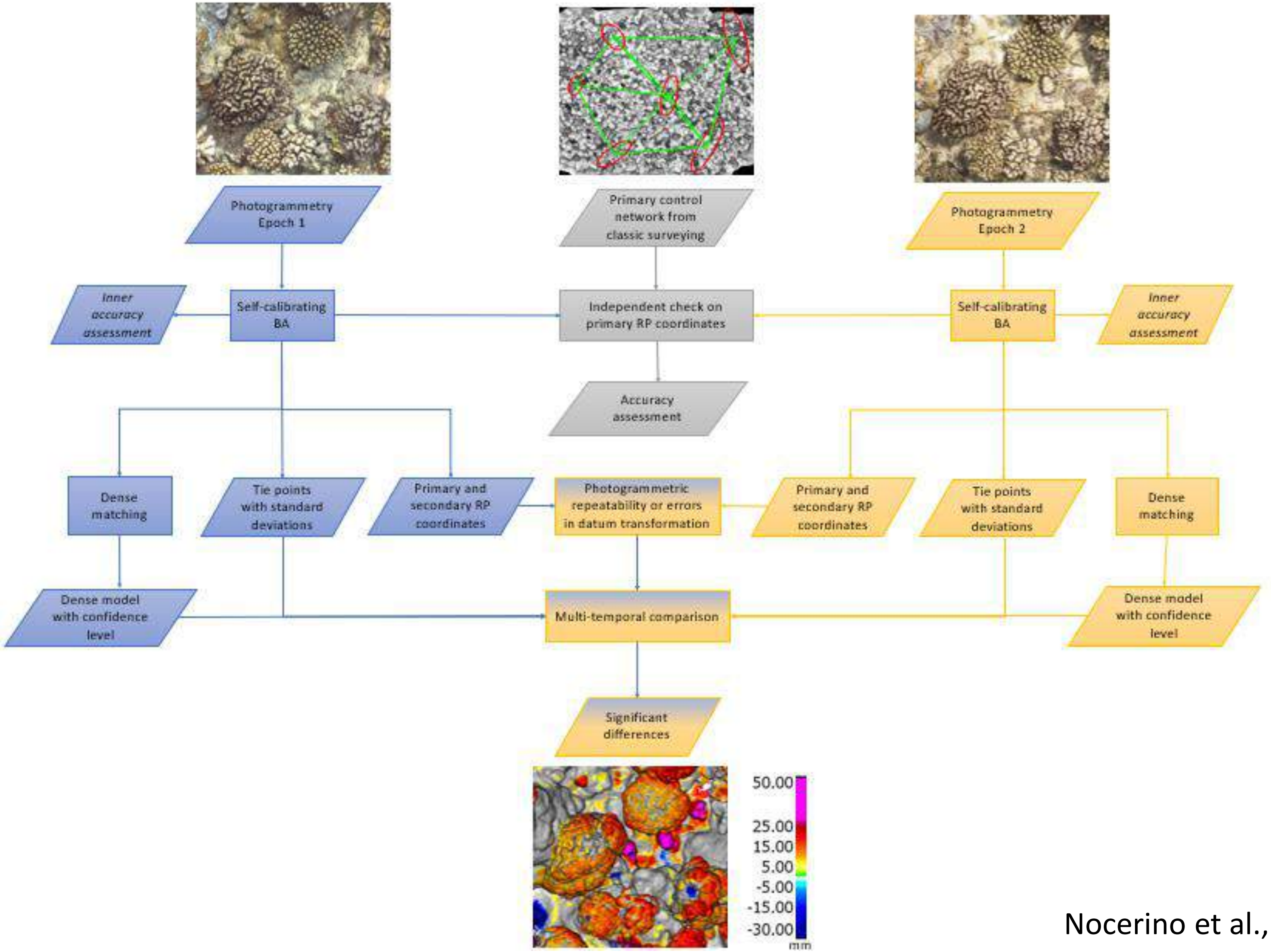
PROPAGATION OF MEASUREMENT AND MODELING UNCERTAINTIES

Throughout the photogrammetric workflow to identify statistically significant changes over time



Nocerino et al., 2020

Propagation of measurement and modeling uncertainties

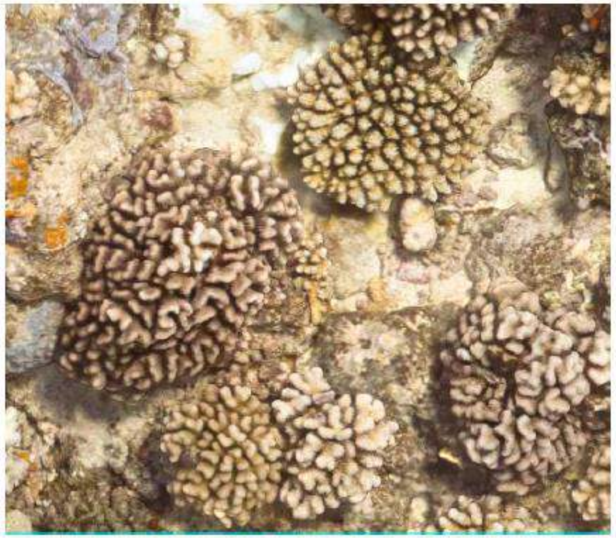


Nocerino et al., 2020

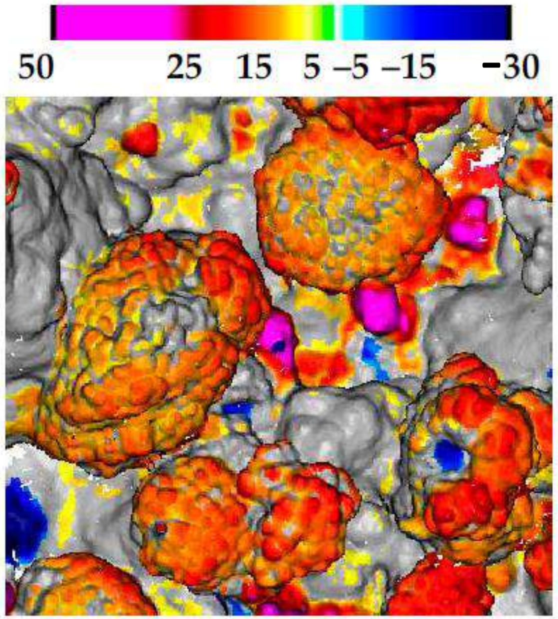
Propagation of measurement and modeling uncertainties

Epoch 1

Epoch 2



Significant differences (mm)



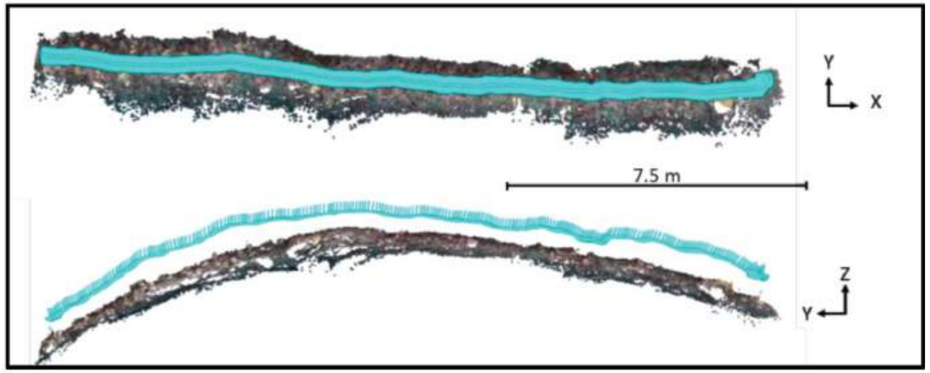
Grey values represent distances that do not exceed the required 95% confidence interval

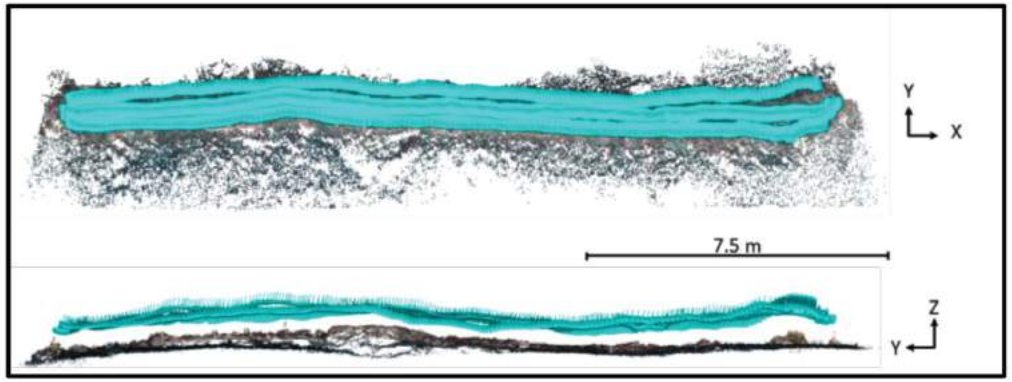
Nocerino et al., 2020

Long-term monitoring in Antarctica with underwater photogrammetry and image understanding

We introduced a new image acquisition protocol, camera system and quality control

20m long transects are recorded with three strips (one nadir, two later oblique strips pointing inward)





Improved camera network for self-calibration

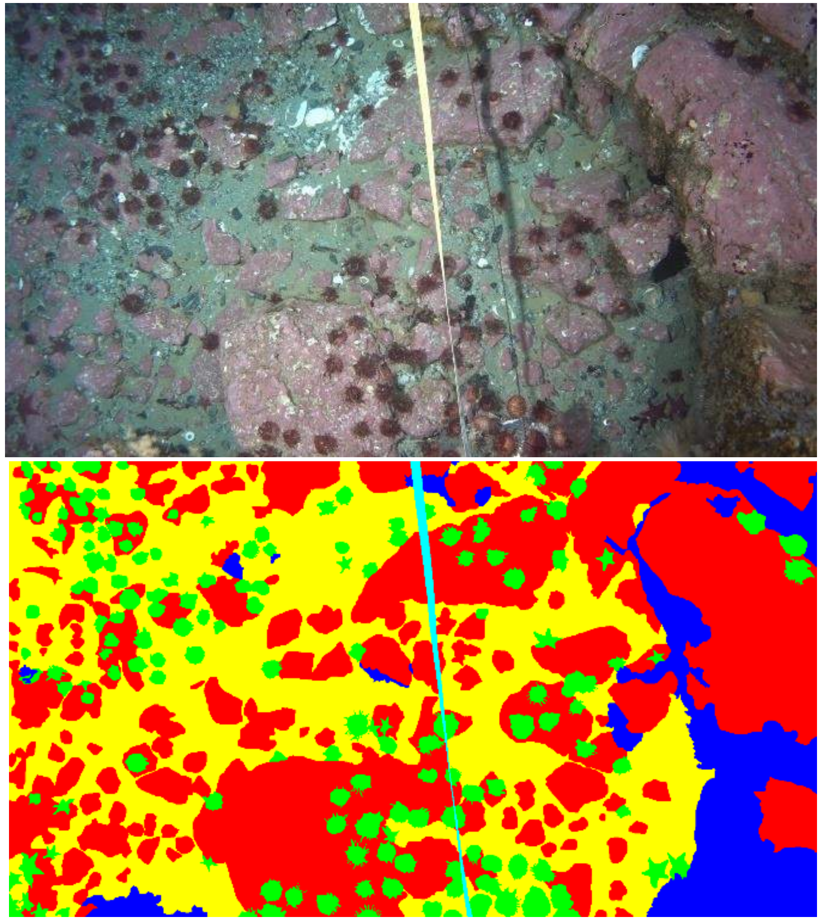
Piazza et al. (2018)

Long-term monitoring in Antarctica with underwater photogrammetry and image understanding

The current multi-temporal processing provides co-registered 3D point clouds between successive years without control points nor direct georeferencing methods

CNN deep learning approach to semantically segment:

- **sand**, gravel and markers (yellow)
- **pink coral alga** *Tethysphytum antarcticum Sciuto*, Moschin & Moro 2021 (Sciuto et al., 2021), whose growth rate is estimated less than a mm/year (red)
- **tape meter** (cyan)
- **crawling benthic species** like sea urchins and sea stars (green)
- **soft algae** and animal turf (blue)



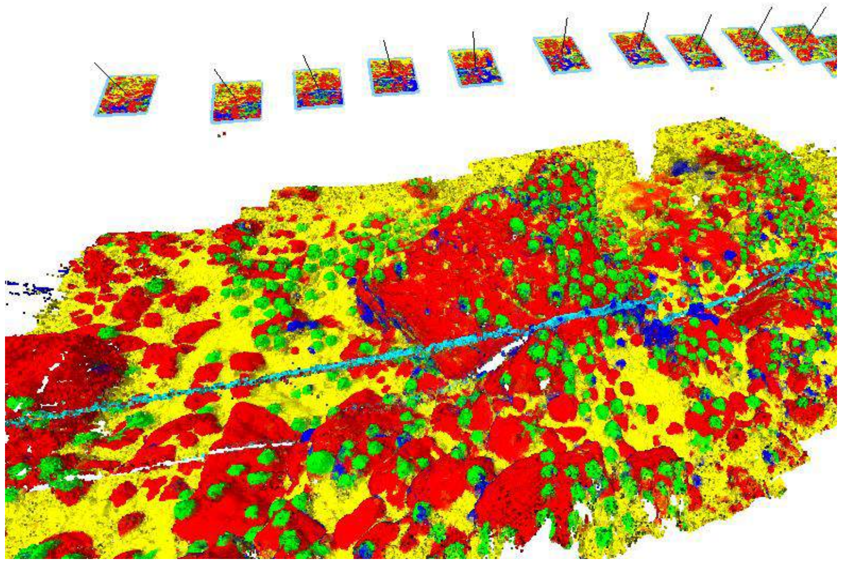
For details, see Menna et al. (2022)

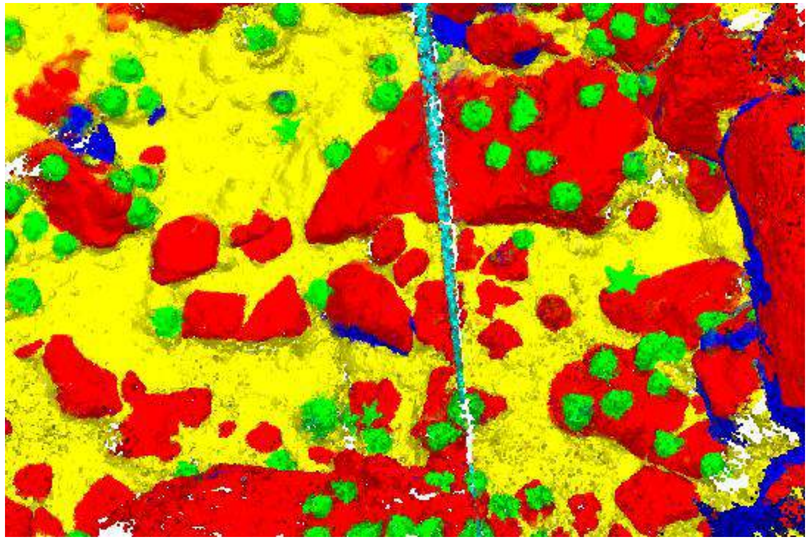
Long-term monitoring in Antarctica with underwater photogrammetry and image understanding

Selective masks of potentially unstable areas of the image → outlier reduction and speed improvement (30 to 70%)

We propagated the semantic segmentation to the point cloud (details of the procedure in the paper)

We automatize quality checks by generating a different dense point cloud for each strip or epoch and compare only classes considered stable (e.g. corals between different years)





For details, see Menna et al. (2022)

Lesson learnt 1/2

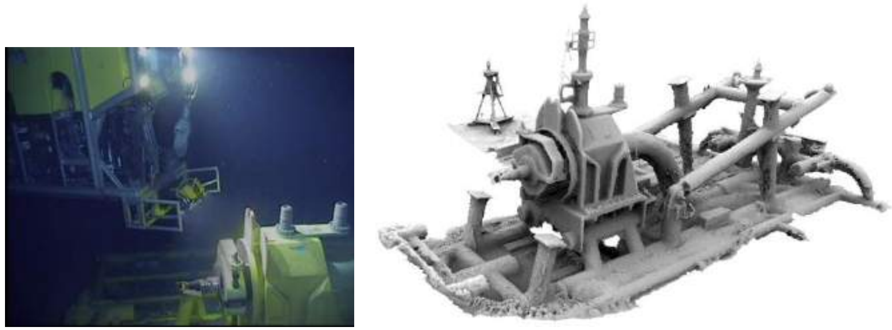
1) Real-time support during data acquisition

- Above the water, in **GNSS enabled** environments, precise positioning systems (RTK/inertial) can support **automatic photogrammetric surveys** with great effectiveness and at **low-cost**.

→ Direct georeferencing aerial-like nadir image acquisitions are common using off-the-shelf UAV platforms in different application domains.

- Under the water, positioning solutions have existed for long time, but their cost and implementation may still be unpractical or prohibitive in many applications.

→ Little, if no feedback at all is given in real-time (distance, next pose, motion blur, exposure…) during the survey as it is processed only hours/days after the image acquisition.



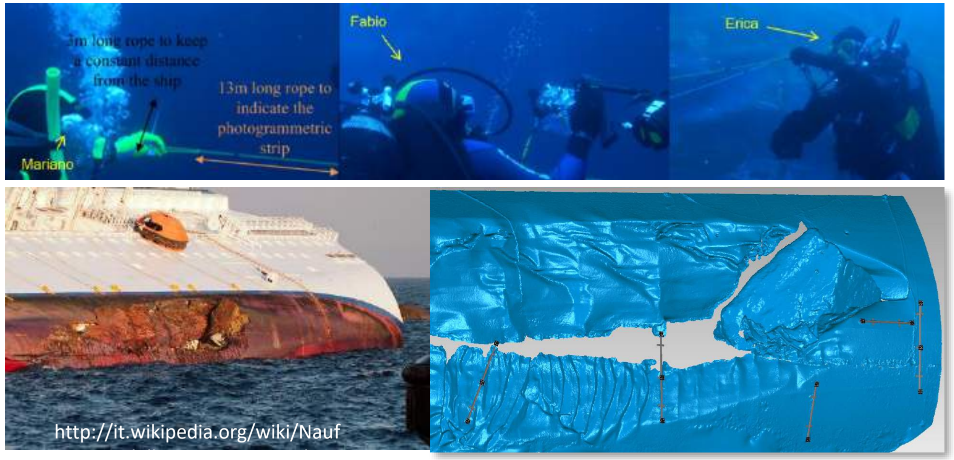
Menna et al (2019)

Piazza et al. (2018)

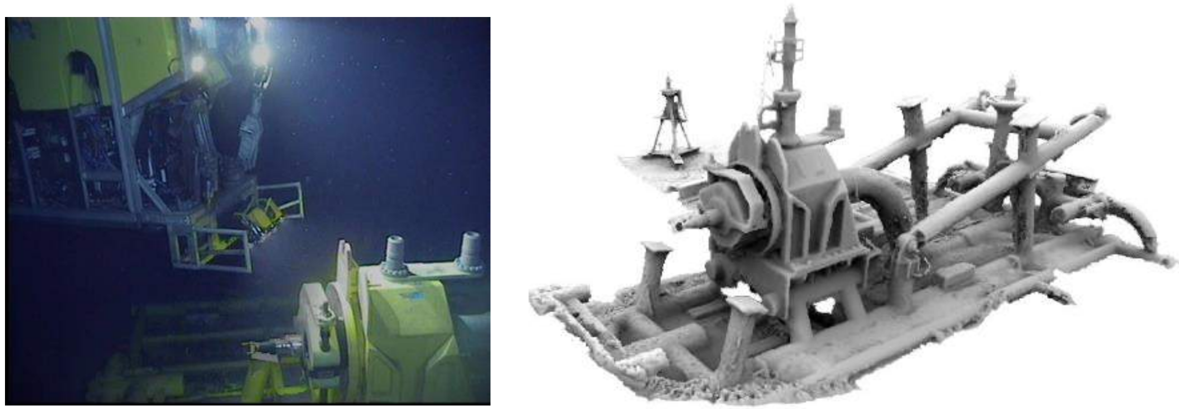
2) Minimal ground control underwater

- Ground control underwater is expensive, unsafe or even impossible
- Minimal control survey is desirable
- Sensor integration is beneficial

Nocerino et al. (2019)



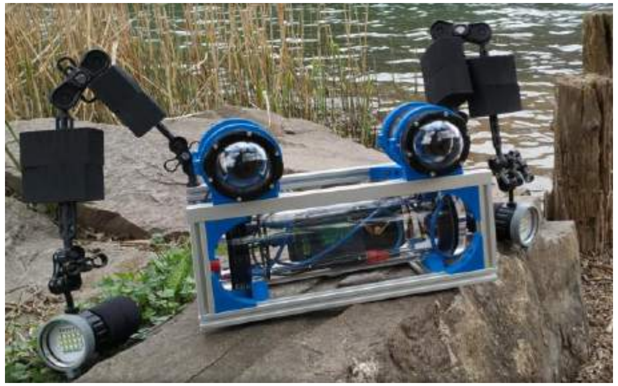
(Menna et al., 2013, Nocerino and Menna, 2020)



Menna et al (2019)

1) Real-time support during data acquisition

FROG



Menna et al (2023)

2) Minimal ground control underwater

PRINSY – PRessure INertial SYstem

Menna et al (2021)

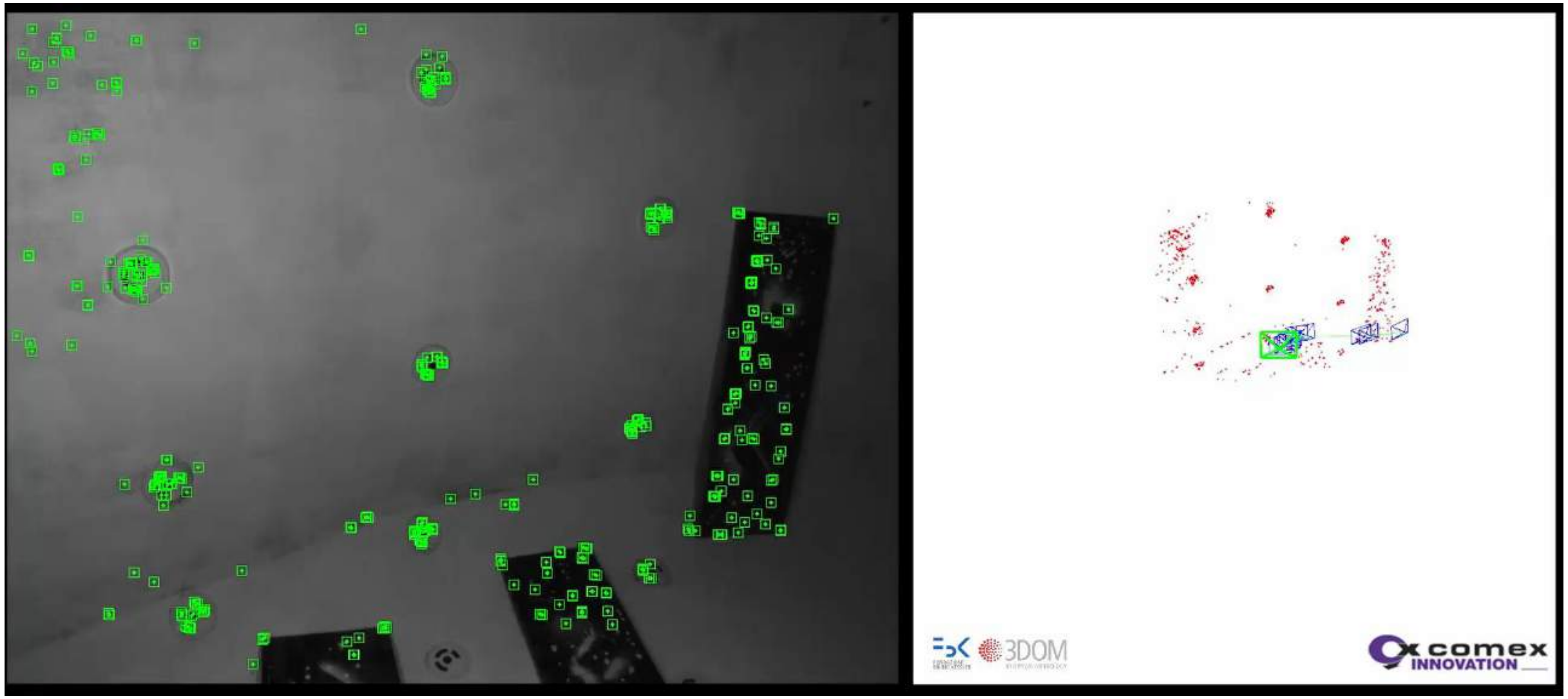
Visual Odometry (VO) and **visual Simultaneous Localization And Mapping (vSLAM)** provide 6DoF of the agent using only visual information from cameras.

real time trajectory estimation in a subsea metrology scenario

COMEX ORUS 3D (3000m)

subsea metrology system

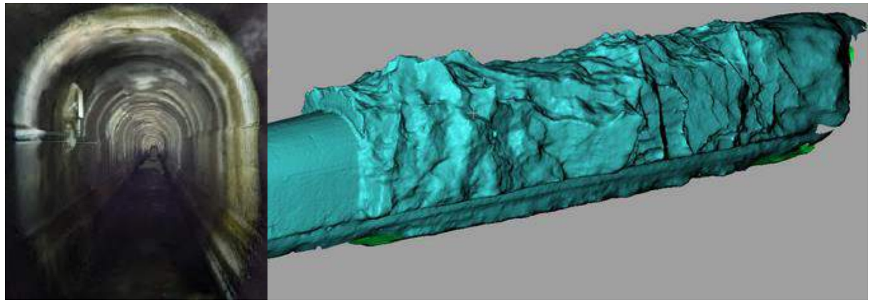
for Oil&Gas industry



Menna et al (2019)

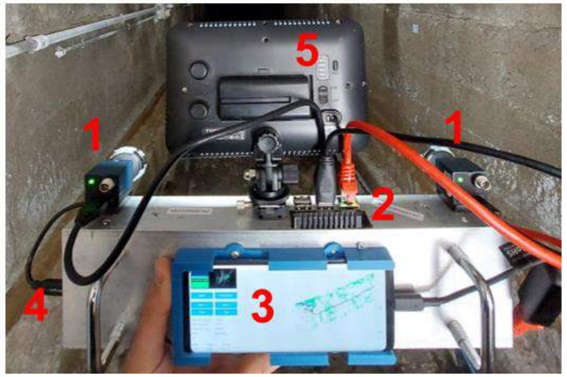
To develop a real-time image acquisition system based on vSLAM that is:

- Modularity → lenses, focus, baseline, axis configuration, underwater
- Portable → mobile applications, especially indoor/underwater
- Low-cost → ideally less than 2k euro
- Lightweight → less than a professional DSLR
- Real-time quality control → GSD, accuracy, reliability estimates
- Easy to use → ideally start/stop, traffic light style visual feedback
- Memory efficient→ smart image capturing, local/global map management
- Robust to dynamic scenes → public spaces, underwater
- Energy saver → run on a common USB power bank, can be carried on a plane (max 100Wh)



GuPho - Guided Photogrammetry concept

Guided Photogrammetry – GuPho developed prototypes



GuPho "alpha" prototype

main hardware components

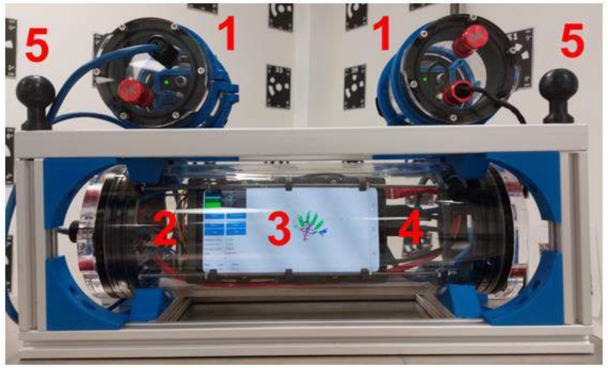
	IMAGING		
	Model	**Sensor**	**Lenses**
1	Daheng Imaging MER-131-210U3C USB3.0 Cameras (x2)	1/2" Global shutter CMOS1280x1024 (pixel size 4.8µm)	4.0 mm rectilinear wide angle 1.85 mm fisheye lens

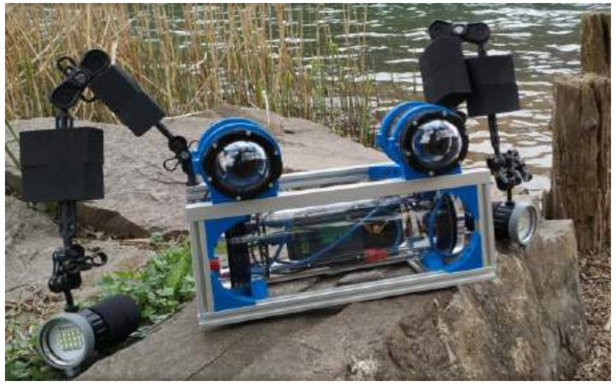
	COMPUTING UNIT			
	Model	**CPU**	**RAM**	**Disk**
2	Raspberry Pi 4 model B	Cortex-A72 1.5 GHz	8GB	128 GB SD

	VISUALISATION AND CONTROL			
	Model	**CPU**	**RAM**	**GPU**
3	Samsung S9 (6.2 inches screen)	Qualcomn 845	6GB	Adreno 630

	BATTERY	WEIGHT
4	5V/3A 10400mAh power bank	1.4 kg without light (terrestrial version) 5.3 kg above the water without lights (underwater version) 0 Kg (neutral buoyancy) with lights once immersed in fresh water (underwater version)

Menna et al (2023)



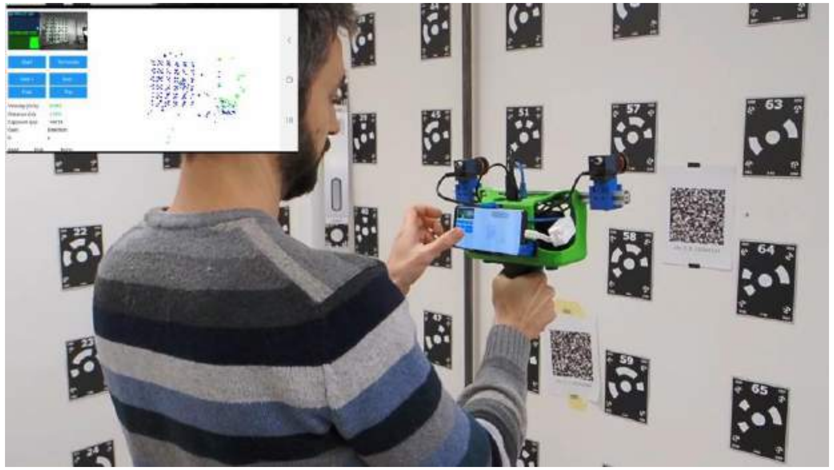


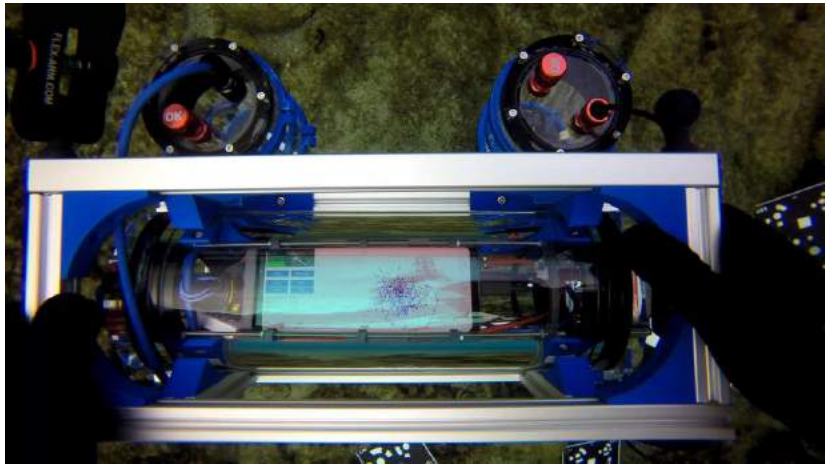
FROG – the GuPho underwater prototype

GuPho/FROG stereo calibration

GuPho “beta” prototype

Frog, GuPho’s UW prototype





3DOM lab testfield (video)

Temporary test-field of targets and scale bars (video)

1) Image orientation (SfM or vSLAM)
2) Target measurement and triangulation
3) Simultaneous self-calibrating bundle adjustment (**BROWN Model**) for Left and Right cameras (interior + lens distortion ki, Pi) with/without baseline constraints

→

↓

Asymmetric relative orientation from EO parameters

$$P^R = \begin{bmatrix}X\\Y\\Z\end{bmatrix}^R = R_G^R \cdot \begin{bmatrix}X - X_{oR}\\Y - Y_{oR}\\Z - Z_{oR}\end{bmatrix}^G = R_G^R \cdot (P^G - O_R^G)$$

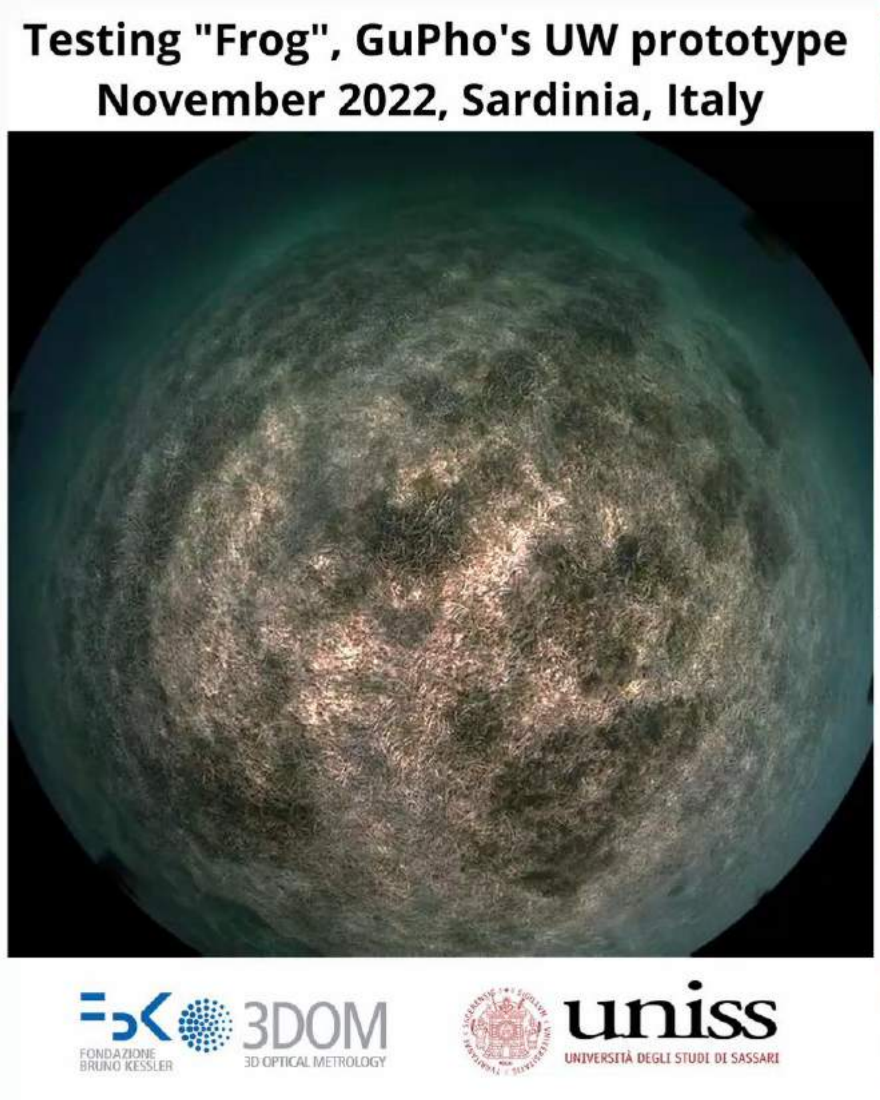
$$R_G^R = \begin{bmatrix} c\varphi\, ck & c\omega\, sk + s\omega\, s\varphi\, ck & s\omega\, sk - c\omega\, s\varphi\, ck \\ -c\varphi\, sk & c\omega\, ck - s\omega\, s\varphi\, sk & s\omega\, ck + c\omega\, s\varphi\, sk \\ s\varphi & -s\omega\, c\varphi & c\omega\, c\varphi \end{bmatrix}$$

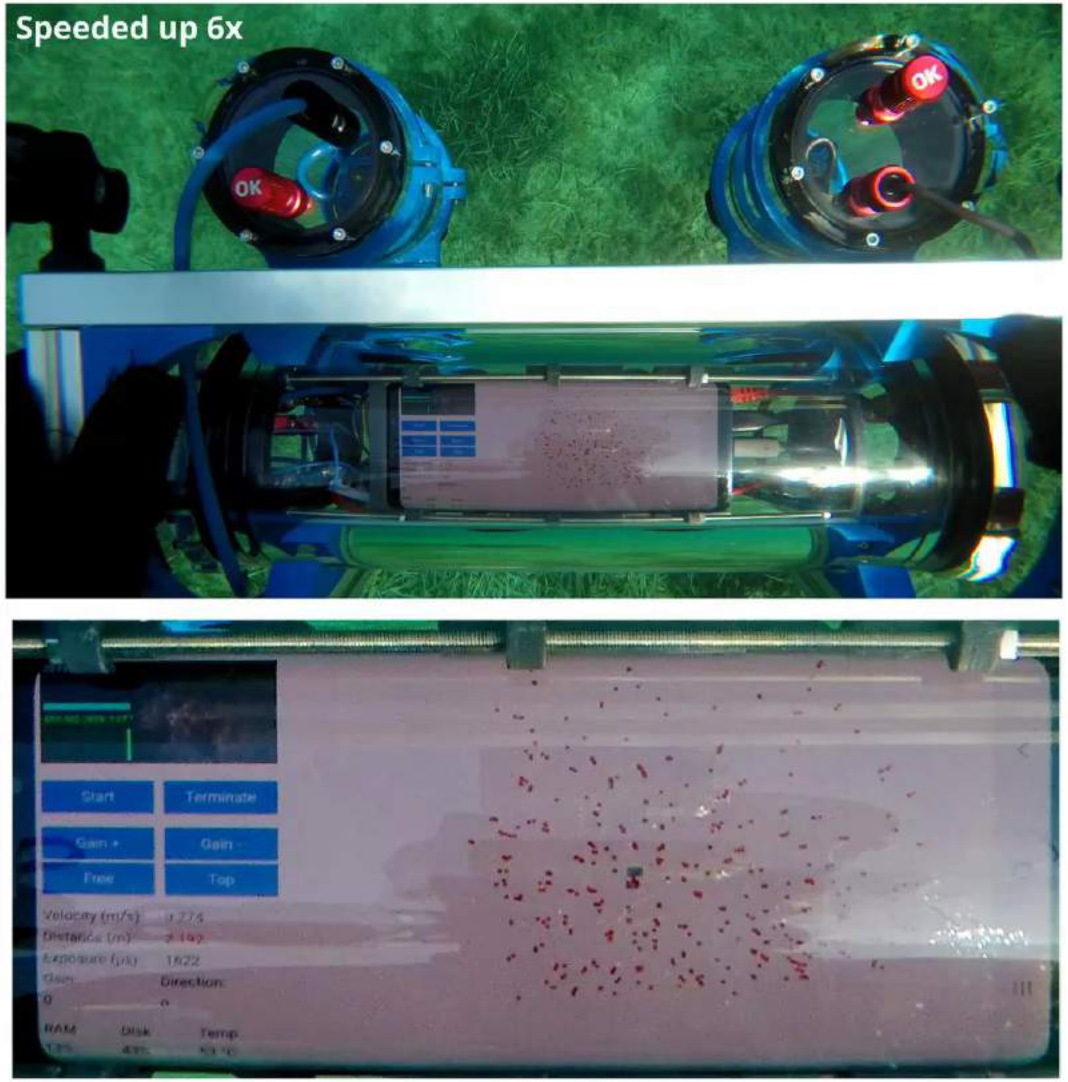
←

RIGHT CAMERA ASYMMETRIC RELATIVE ORIENTATION

[mm]	[deg]		
$b \pm \sigma_b$	$\omega \pm \sigma_\omega$	$\varphi \pm \sigma_\phi$	$\kappa \pm \sigma_\kappa$
Rectilinear - terrestrial			
245.32 ± **0.11**	-0.094 ± **0.039**	-22.112 ± **0.012**	-0.024 ± **0.034**
Fisheye - terrestrial			
305.93 ± **0.17**	0.405 ± **0.013**	1.970 ± **0.016**	0.042± **0.007**
Fisheye - underwater			
244.09 ± **0.24**	-0.175 ± **0.048**	-0.929 ± **0.025**	2.754 ± **0.042**

GuPho’s outputs and visual quality control

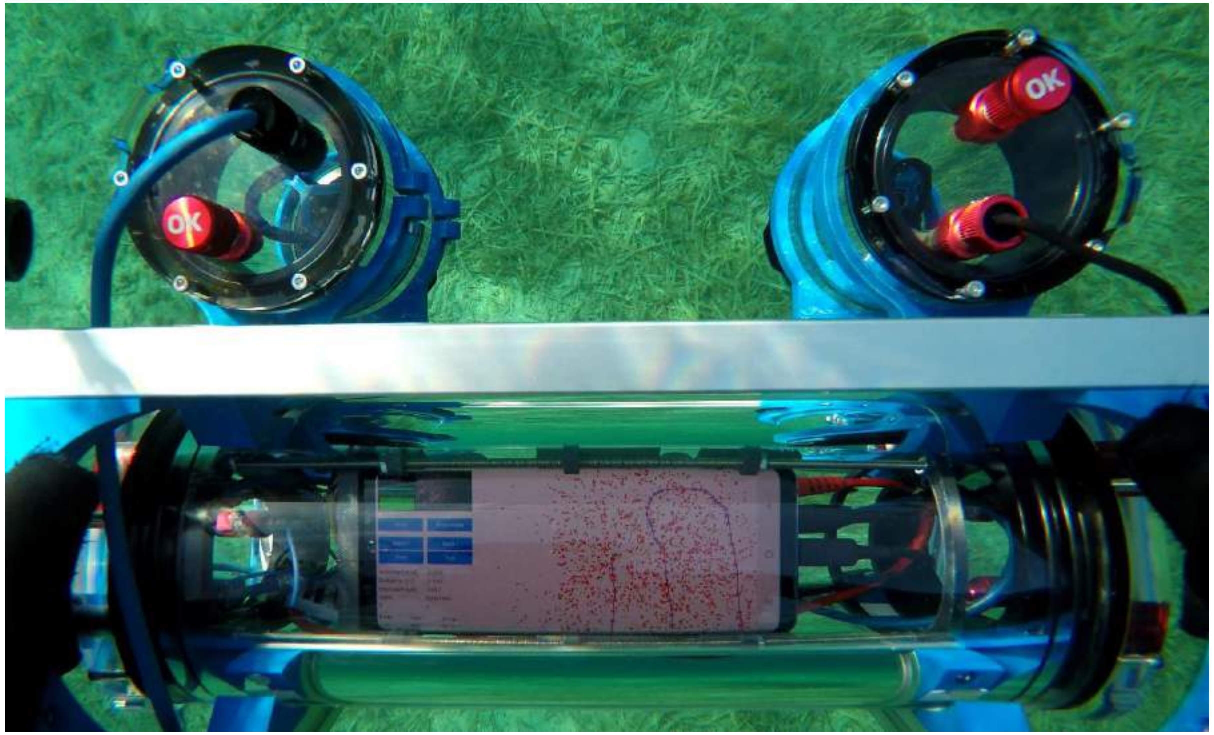


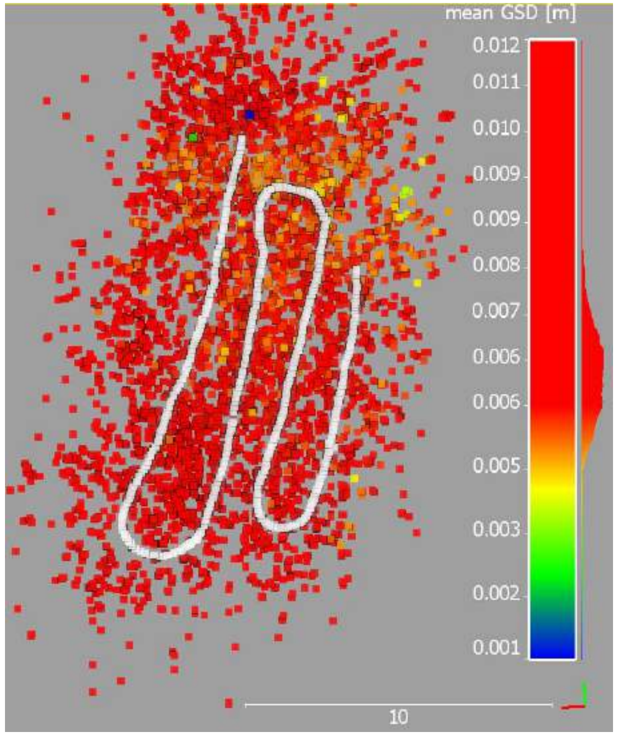


video

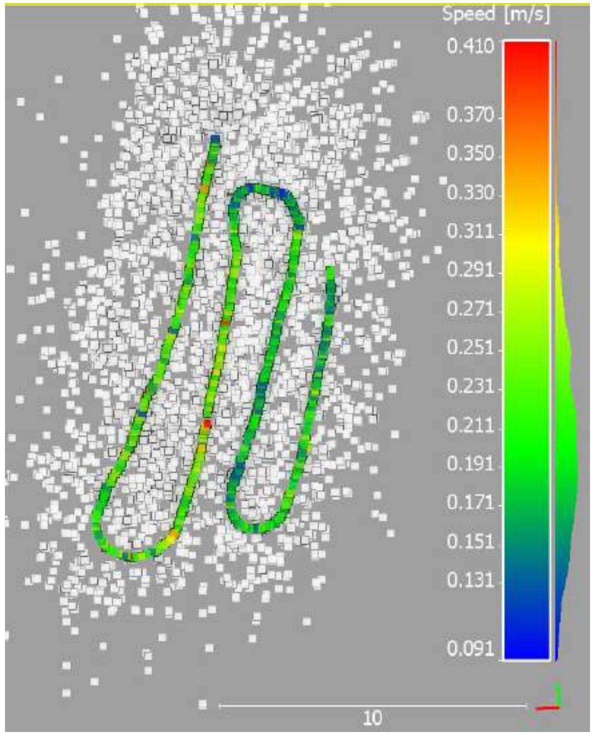
Menna et al (2023)

GuPho's outputs and visual quality control





Mean GSD

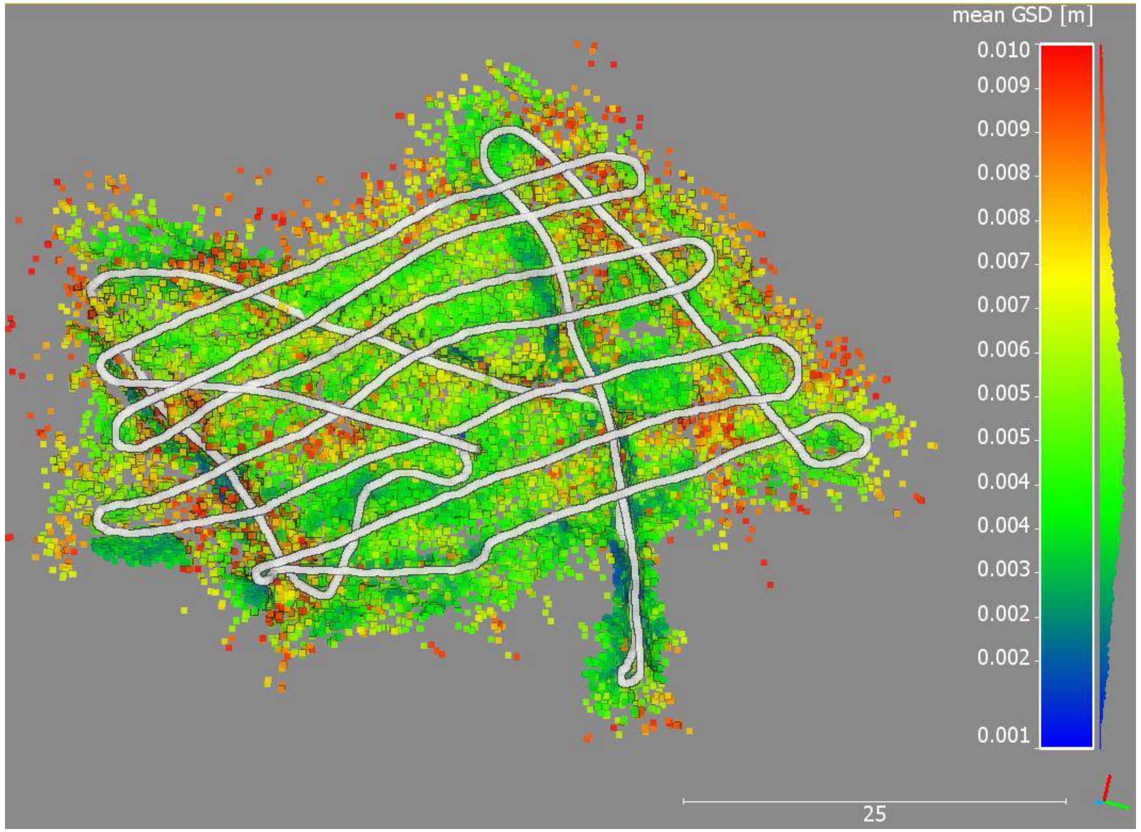


Speed

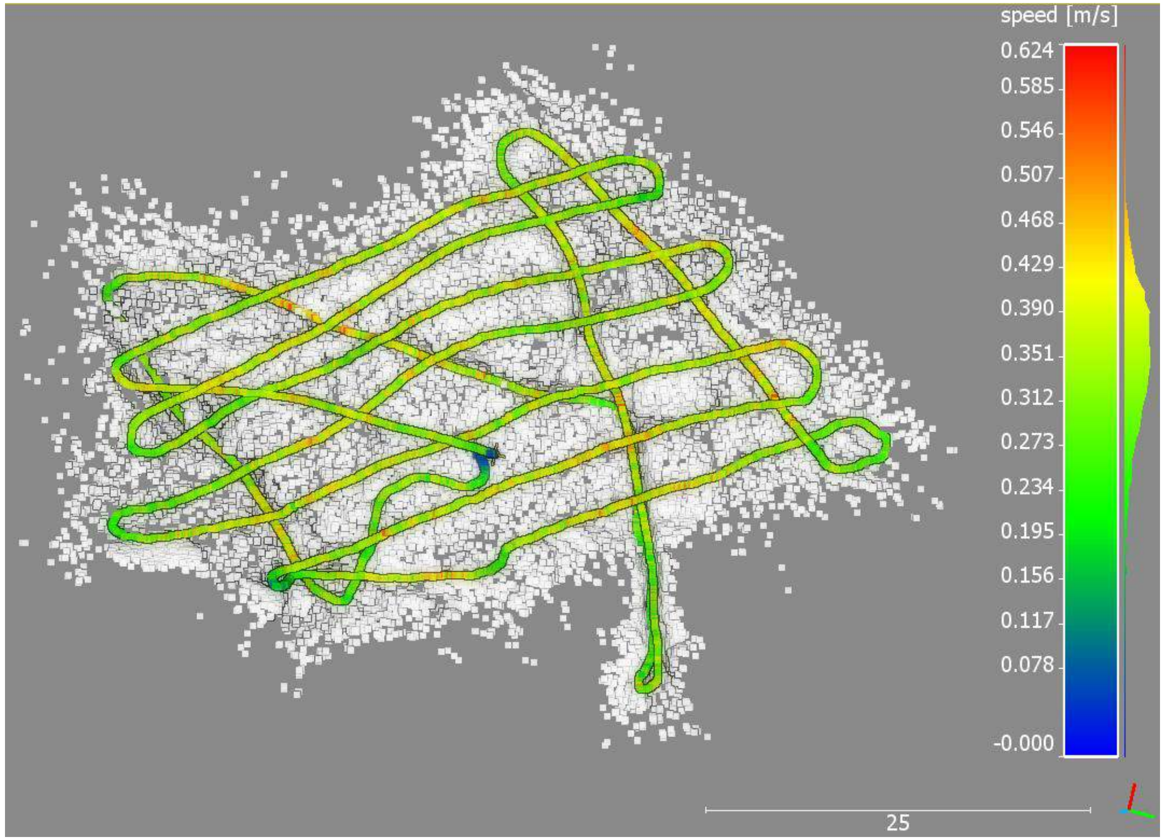
Other metadata (e.g. multiplicity, camera exposure time, …) can be visualized

FROG in action – ARGENTIERA case study

vSLAM sparse real time 3D reconstruction with color coded metadata information (45x35m^2, depths: 1.5-9 m)



Real-time point cloud colored according to the GSD



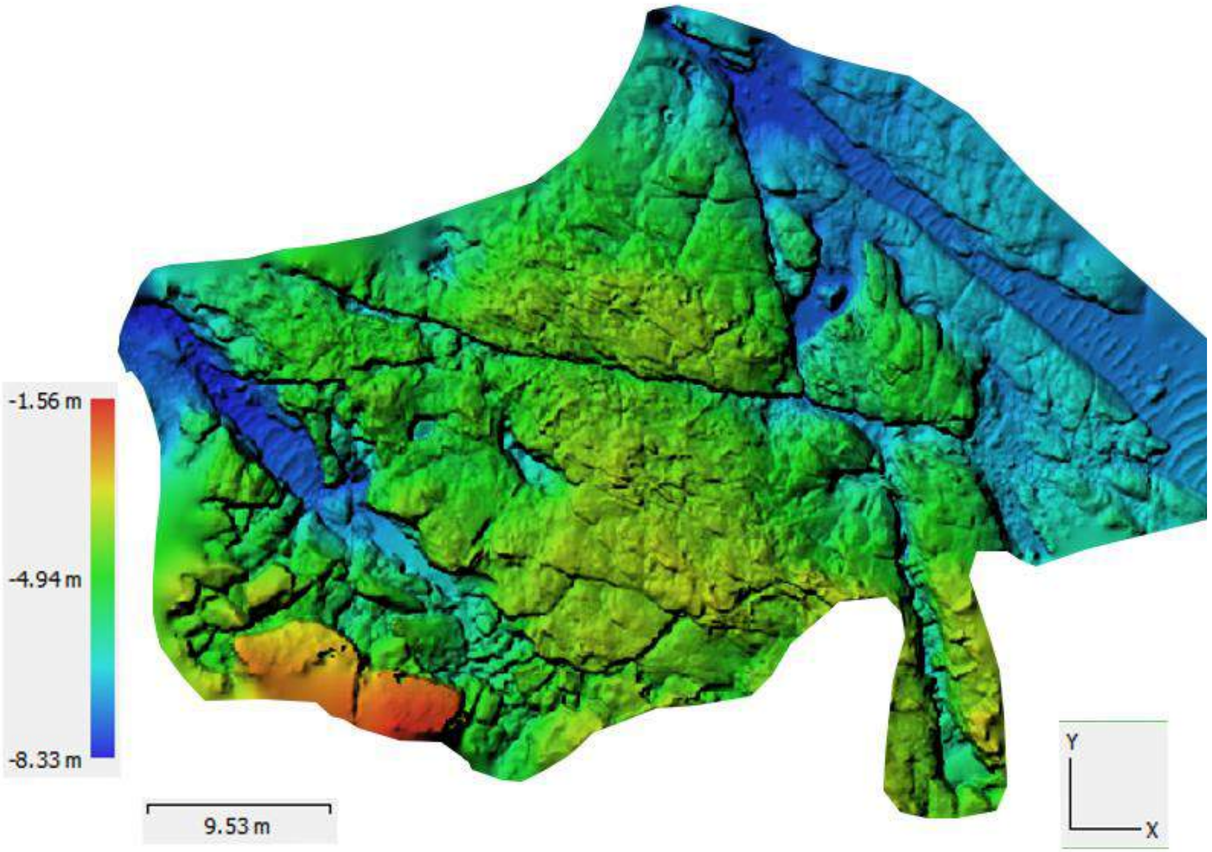
Real-time trajectory colored according to speed

…others available… redundancy, number of image observations per photographs, exposure time…

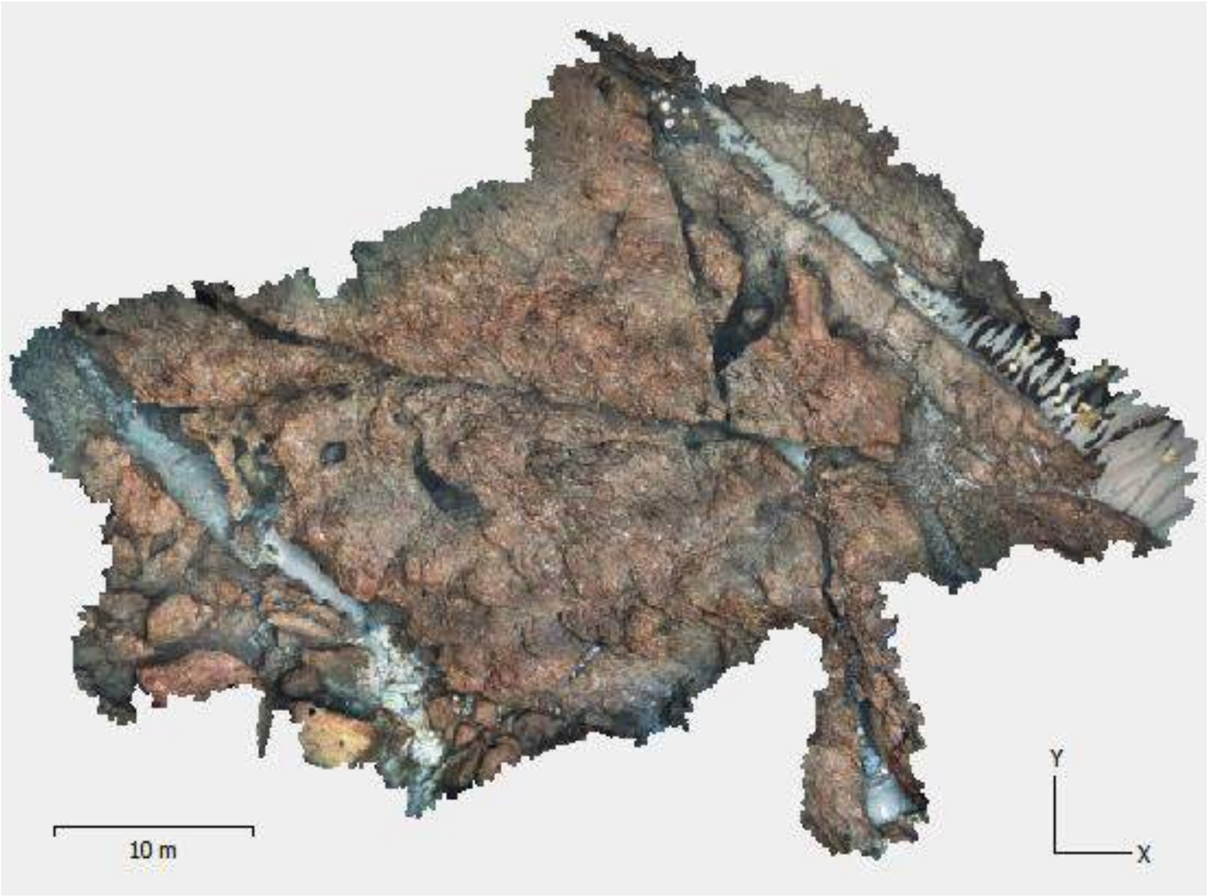
Menna et al (2023)

FROG in action – ARGENTIERA case study

Bundle adjustment (Free network with fixed system calibration), 3D point cloud densification, and mapping products



DEM (1cm)



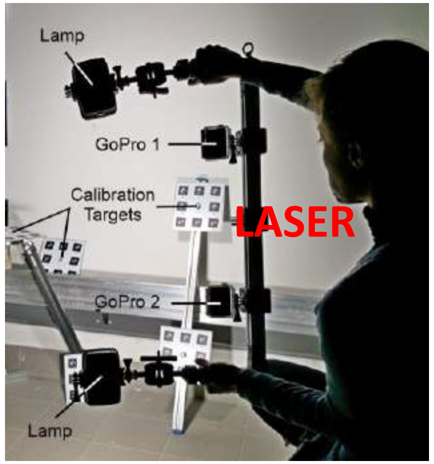
OTHOPHOTOMOSAIC (1cm)

($45x35m^2$, depths: 1.5-9 m)

SCALING IN UNDERWATER PHOTOGRAMMETRY

STEREO AND MULTI-CAMERA SYSTEMS

- ➕ Great flexibility
- ➕ Ability to measure dynamic scenes
- ➖ Require synchronization
- ➖ Increased cost
- ➖ Heavier and more cumbersome

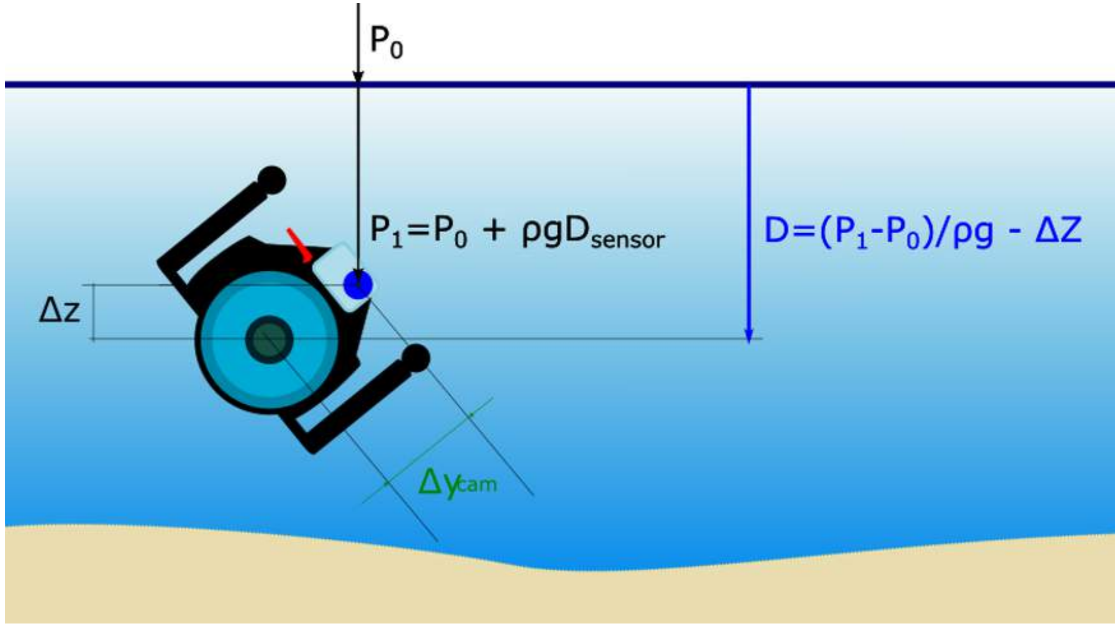


LASER “SCALERS”

- ➕ Low cost
- ➕ Do not require synchronization
- ➖ Backscattering and speckle artifacts
- ➖ Require a further alignment and calibration process
- ➖ Laser spot visible in 3D models and orthophotos

Based on the principle of hydrostatic pressure

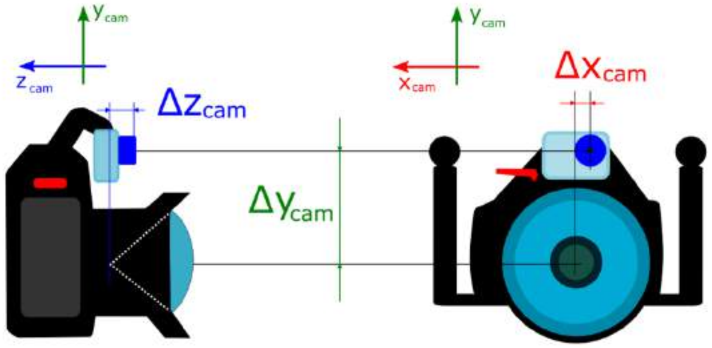
Hydrostatic pressure to depth D



Sensor depth

to entrance pupil depth

is a function of camera exterior orientation !



Menna et al (2021)

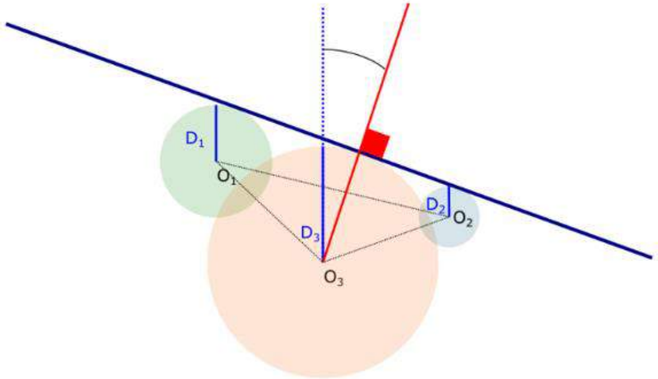
PRINSY – PRessure INertial SYstem

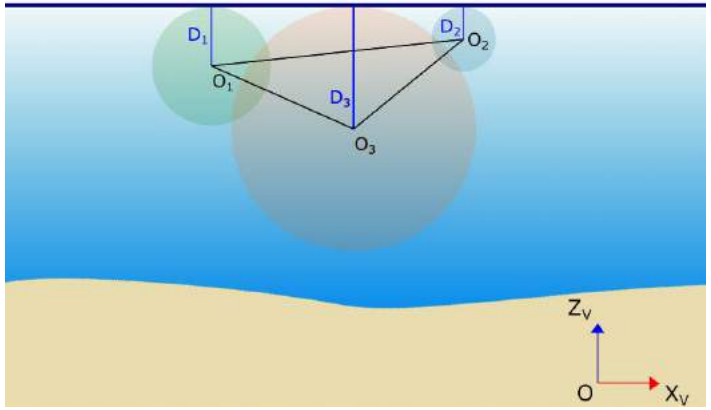
Version 1 : Pressure sensor only

Version 2 : Pressure + AHRS

Scaling accuracy about 1:1000
Local vertical direction accuracy 1/100 degree

four depths from four non-coplanar points are necessary to level and scale the 3D photogrammetric model using pressure measurements





Menna et al (2021)

Back to the 80s….(from Newton, 1984)

Underwater photogrammetry is still in its infancy

The future will bring changes in equipment and operating techniques

New developments in ROV's particularly of the small, less expensive type are constantly emerging.

Will the future see the introduction of a metric camera in an underwater housing?

Research is underway to investigate whether a measurement capability can be introduced into a stereo system

More work is needed to investigate the influence of the underwater camera behaviour

What's next?

…. there is still a ***need for guidance*** *on how* ***to apply*** *novel* ***3D technologies for marine applications****. Multiple teams from around the world are leading the application of 3D photogrammetry in the marine environment. The widespread adoption of 3D methodologies produces a* ***growing need for agreed standards to assess the quality of 3D data*** *(e.g., error metrics). Similarly, standardized techniques where possible, will ensure* ***collaboration and compatibility of 3D data across space and time*** …… (adapted from Ferrari et al., 2022)

What's next?


guidance
uuv
hybrid
lidar
quality
XR
autonomous
AI
caustics
feedback
positioning
real-time
auv
datum
acoustic
navigation
ROV
dynamic

https://www2.isprs.org/commissions/comm2/wg7/become-a-member/

isprs
Information from imagery

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  - WG II/5
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  - WG II/7
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ISPRS WG II/7

Individuals who apply geospatial technologies in underwater data acquisition and processing as well as other related studies, and interested to collaborate with other multi-disciplinary professionals in this area are invited to join:

First Name *

First Name

Surname *

Surname

Country *

Country

Full Address *

Full Address

WG II/7

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Advances in Positioning, Navigation and 3D Mapping of Underwater Environments

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Deadline for manuscript submissions: 26 May 2024

https://www.mdpi.com/journal/remotesensing/special_issues/Z4F99FEM28

Special Issue Information

The future of our planet depends on our oceans' health and inland water resources. In the United Nation Decade of Ocean Science for Sustainable Development, there is a compelling need for efficient and effective scientific methods for studying and understanding our oceans. Three-dimensional mapping is, in this regard, a main priority, and several projects to accomplish full 3D mapping of the ocean floor have been initiated over the last few years, leveraging the state-of-the-art technologies currently available. From inland streams of water to rivers and lakes to the ocean shores and down to the deepest unexplored crevices of our oceans, challenges abound that require prompt scientific and technological answers. Three-dimensional mapping is an invaluable means by which to understand the complex dynamics of the most important element for life. Although accurate solutions for 3D mapping exist, many are still costly and time-consuming.

This Special Issue aims to collect contributions on advances in positioning, navigation, and 3D mapping of underwater environments focusing on innovative, low-cost, effective, and efficient methods.

Research manuscripts, reviews, and technical notes are welcome. Topics of interest include, but are not limited to: methods related to underwater 3D mapping, such as through-water airborne photo-bathymetry; lidar bathymetry; acoustic and optical positioning; underwater geodetic surveying; underwater photogrammetry; visual inertial simultaneous localization and mapping; subsea metrology, multi- and hyperspectral imaging; satellite remote sensing; and autonomous unmanned as well tethered systems.

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