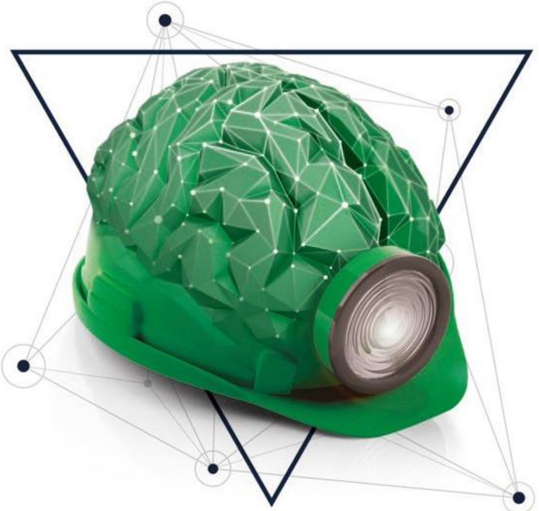


Innovative solutions for and challenges in underwater spaces: sensor development, robotization

Richárd Z. Papp

DIM EESE 2: IMPLEMENTING INNOVATIONS

Dubrovnik, Croatia, 20.10.2021

Supported by

Co-funded by the European Union

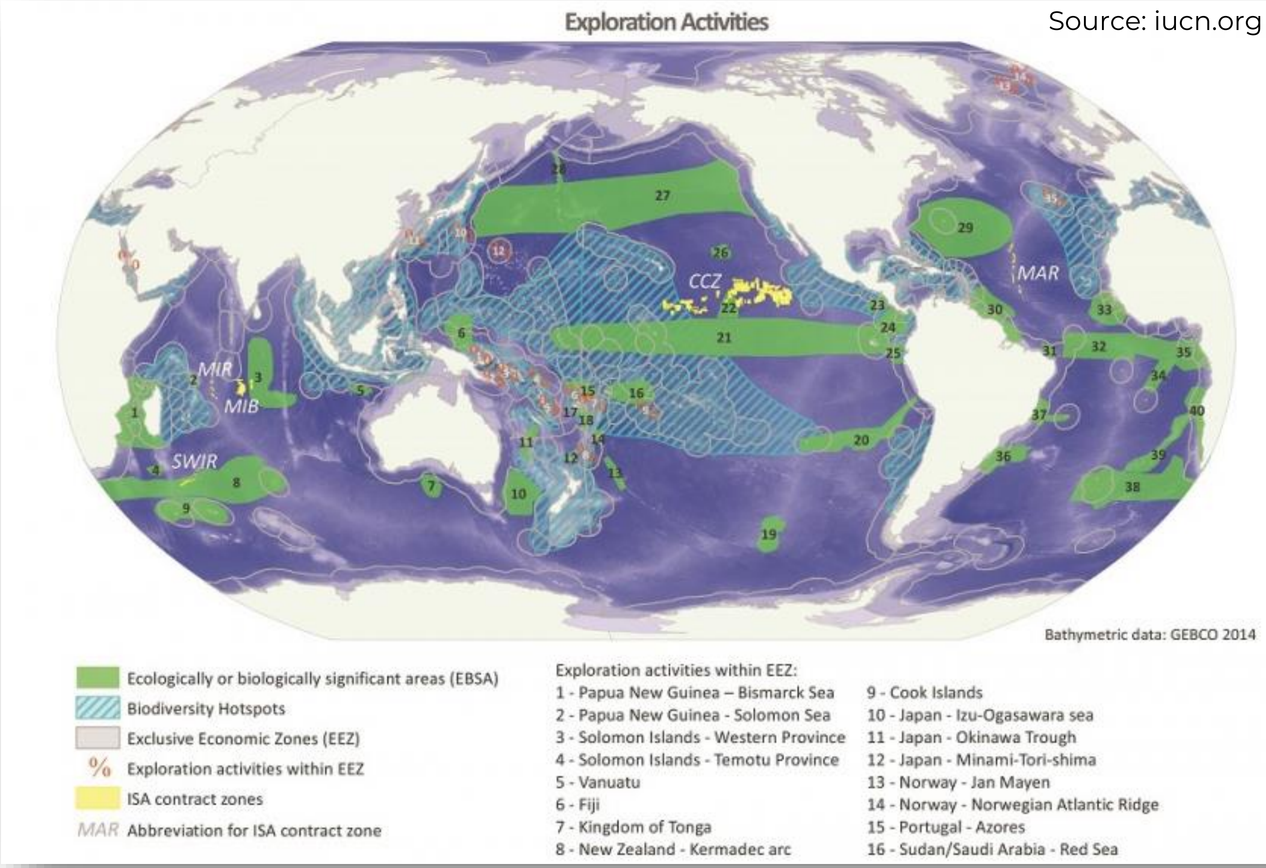
Topics

- Underwater environments
- Robotics
- ROV/AUV
- Market solutions
- UNEXMIN/UNEXUP
- Underwater navigation
- Underwater sensor technology

Underwater environments

- Deep sea mining
- Flooded open-pit mines
- Shallow sea
- Flooded underground mines

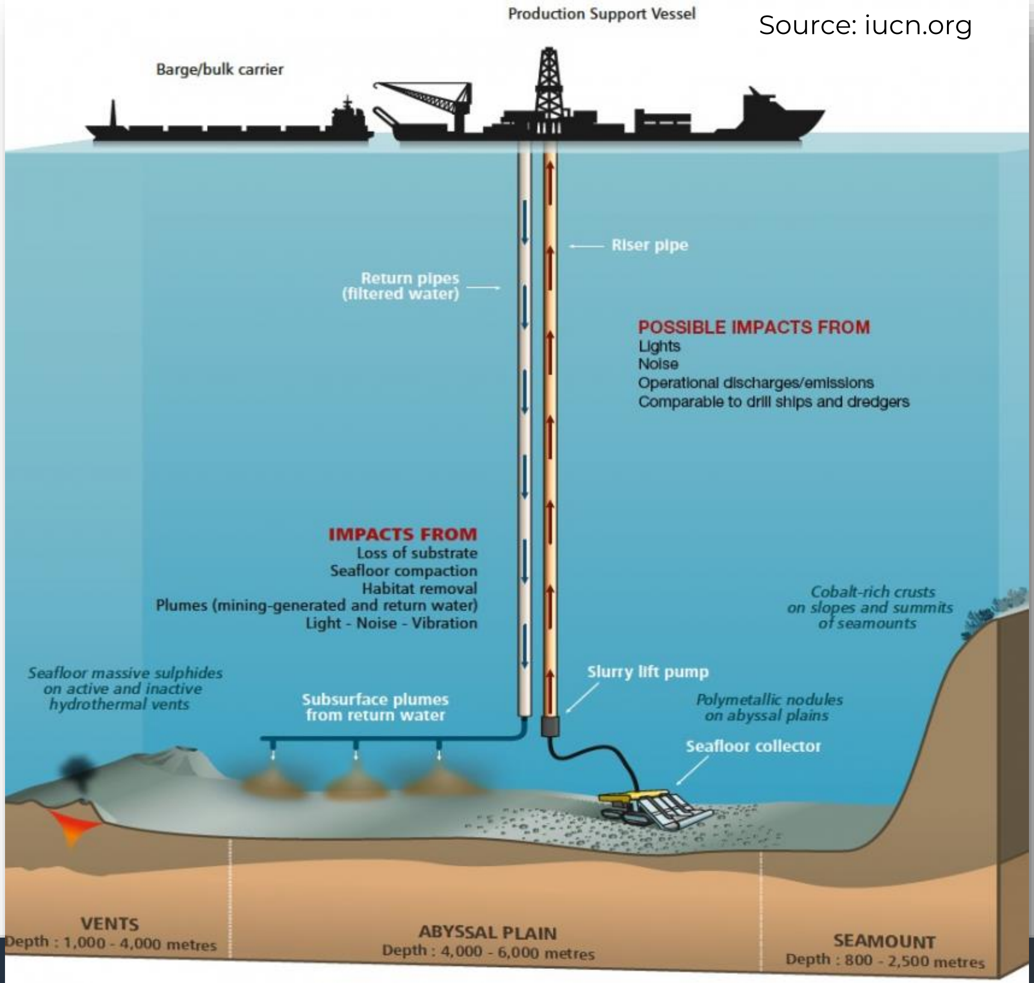
Source: iucn.org



Underwater environments

Deep sea mining

- Where?
  - 200m below the ocean
  - 65% of the Earth surface
- What technology?
- What is the issue?
  - Disturbance of the seafloor
  - Sediment plumes
  - Pollution



Source: iucn.org

Underwater environments

Flooded open-pit mines

Konstantinovsky open-pit coal mine, Russia

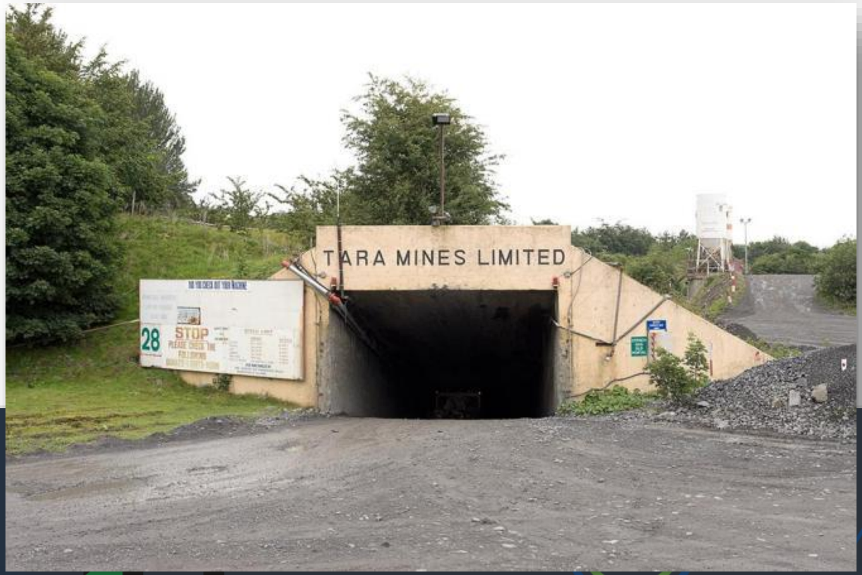
Rudabánya, Hungary

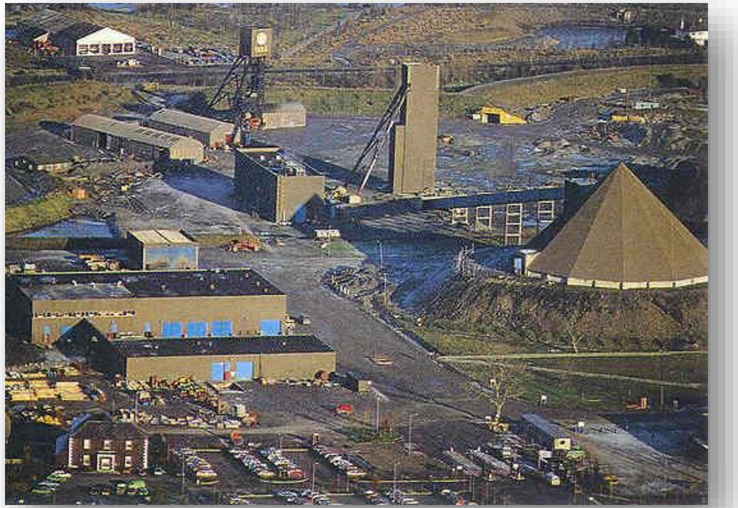
Underwater environments

Shallow sea

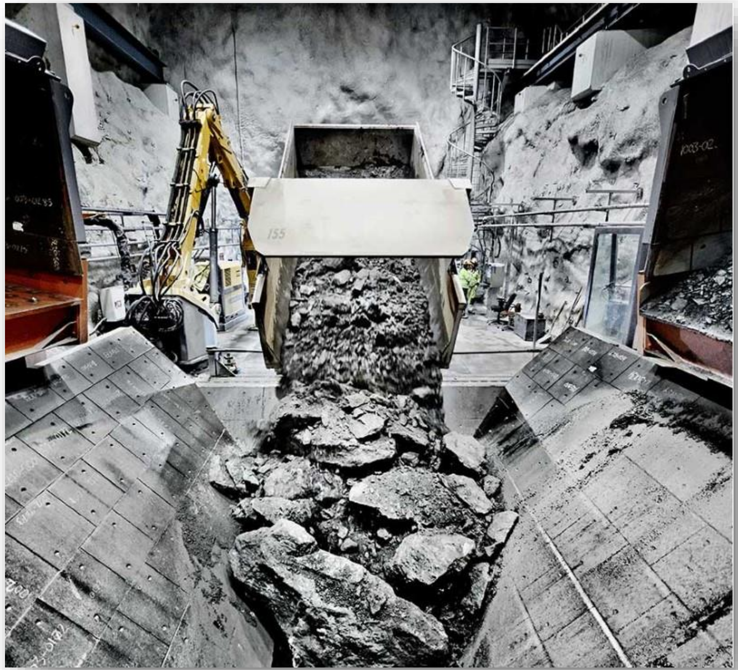
- Up to 200m water depth
- Tara mine - Navan, Ireland (SEDEX Pb-Zn)

Tara mine – Navan, Ireland
Source: timdurham.ie





Tara mine – Navan, Ireland
Source: mining-technology.com



Tara mine – Navan, Ireland
Source: boliden.com

Underwater environments

Shallow sea

- Diamond, Zircon, Ilmenite, Gold, Amber
- Dredgrer boats
- Dredgring the seafloor sediment up to 2-3m thickness
- South Afrika – De Beers Inc.

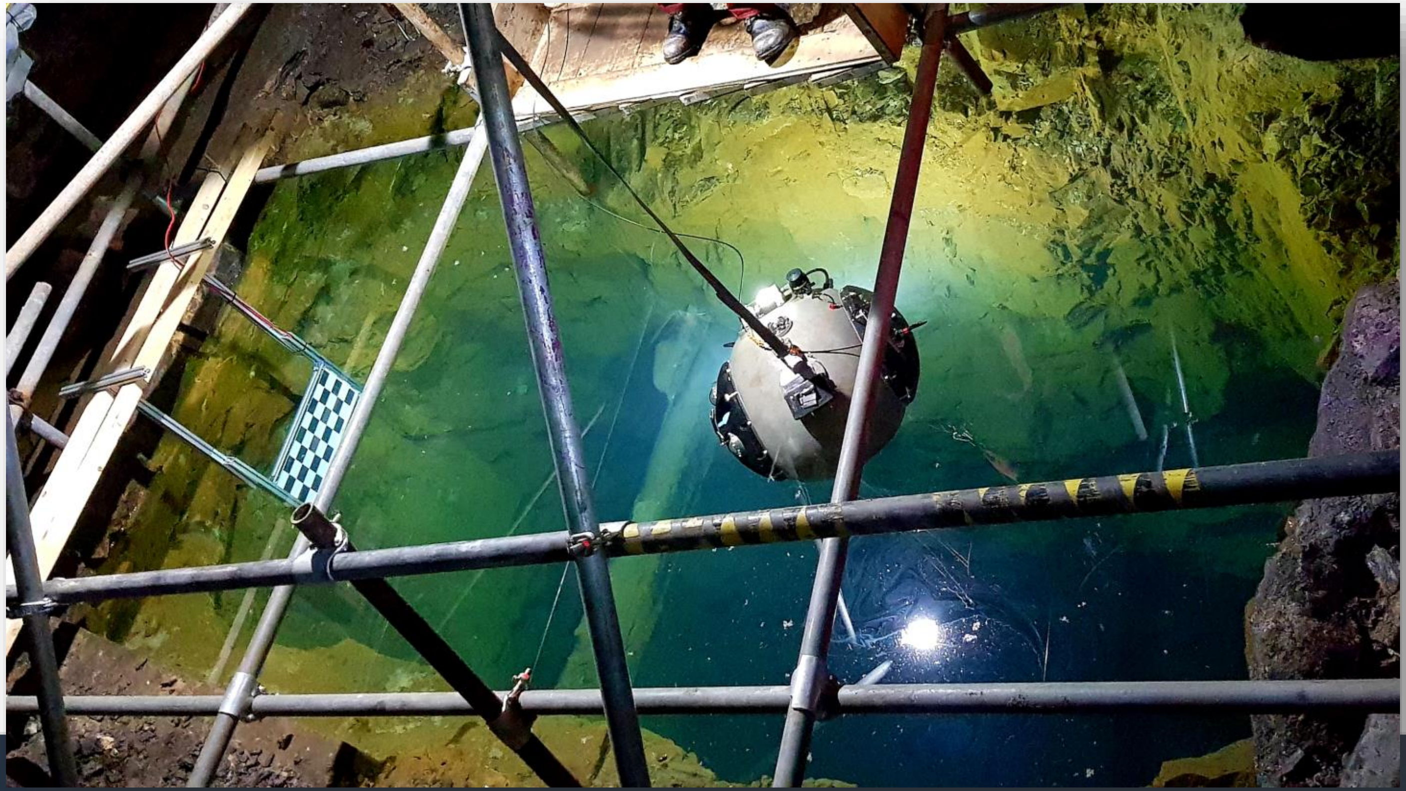
De Beers dredgrer
Source: www.debeersgroup.com

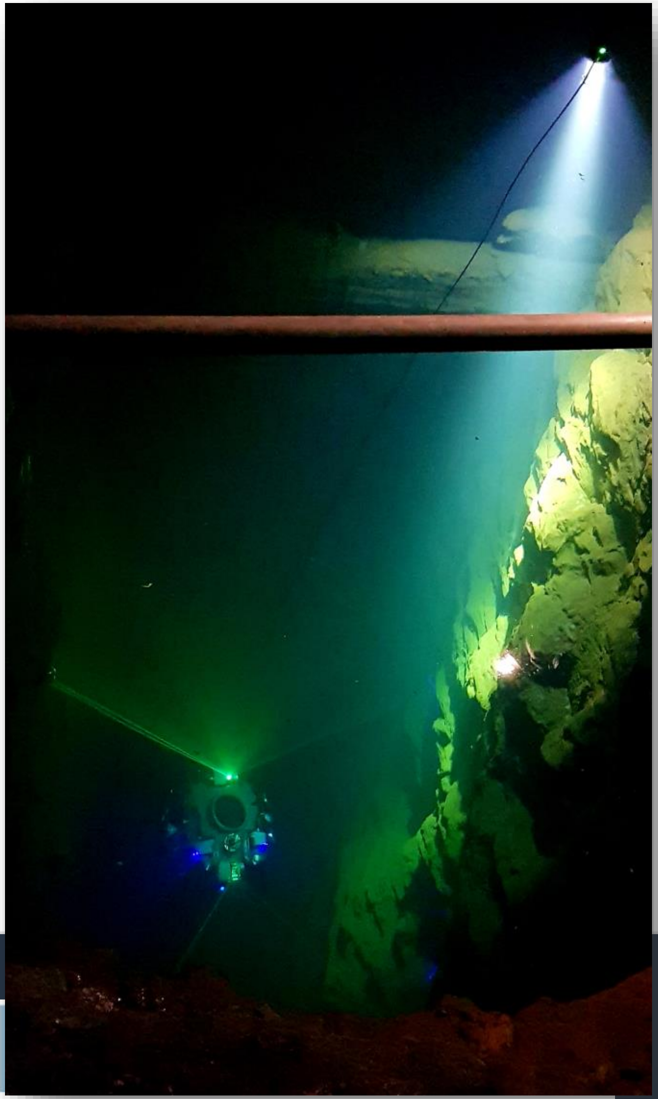
Van Oord Enacts Hopper Dredger Option
Source: www.maritimeprofessional.com

Gold-dredging boat in Nome, Alaska
Source: www.rcinet.ca

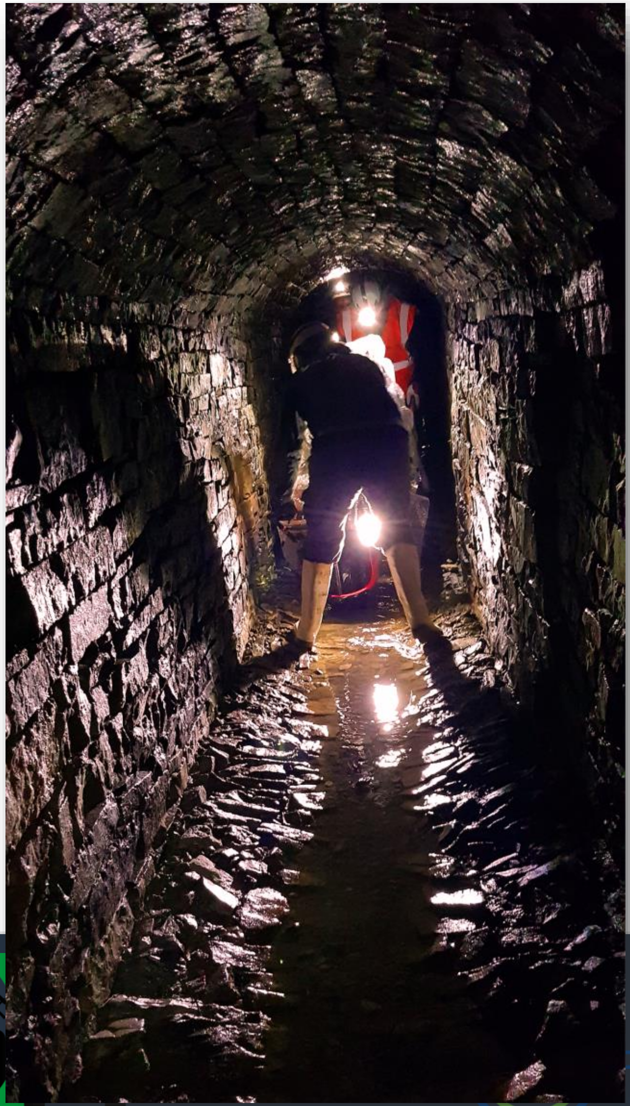
Underwater environments

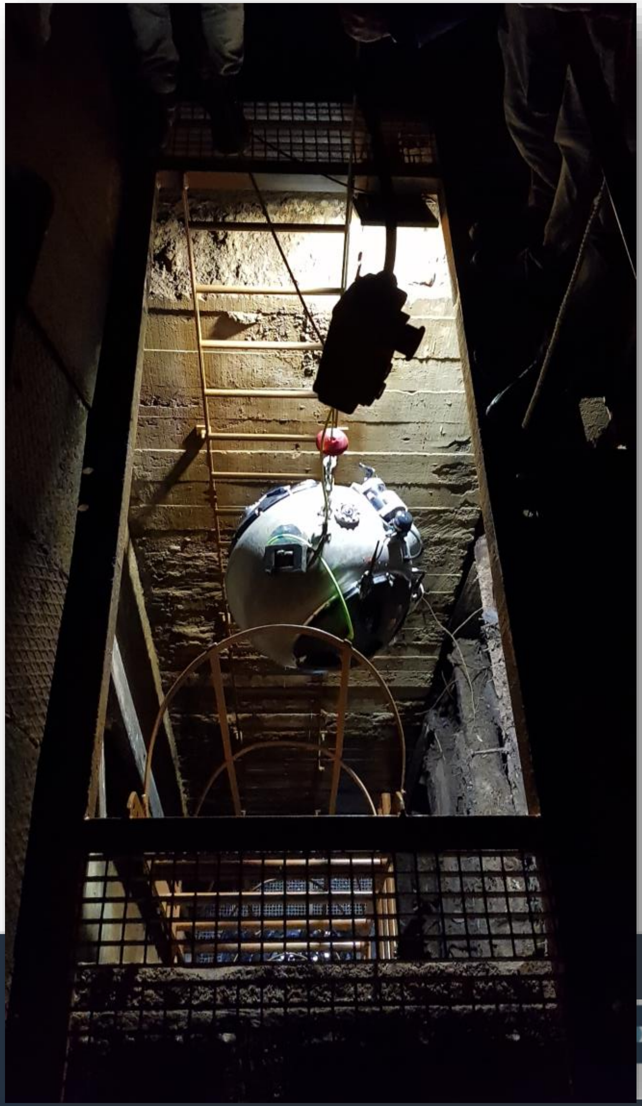
Flooded underground mines





Underwater environments



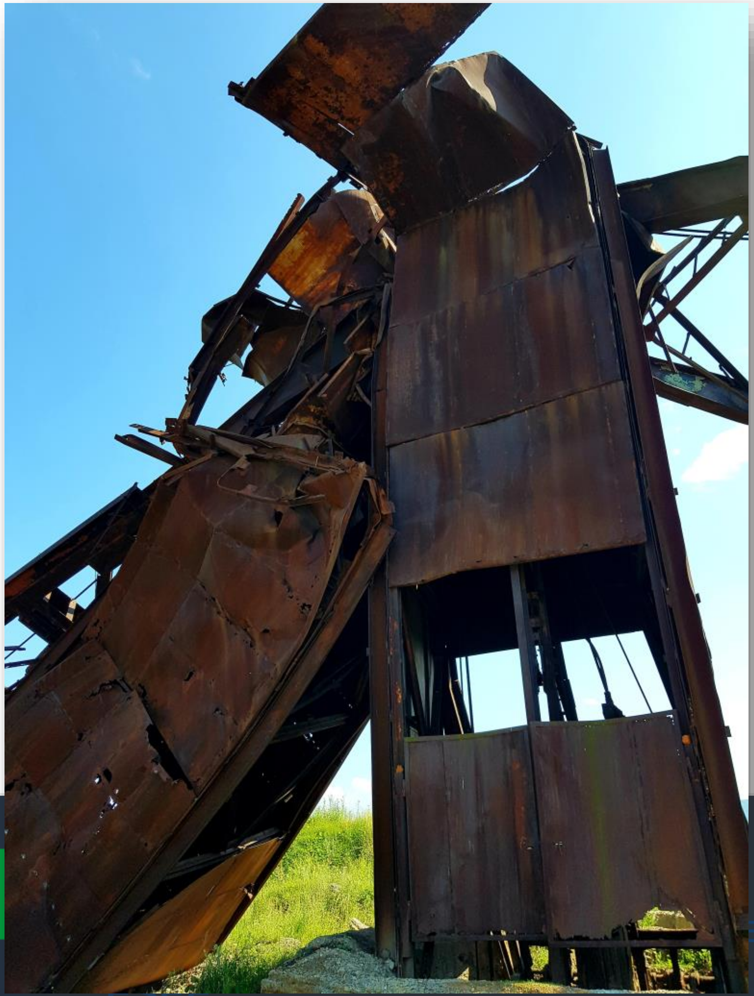


Underwater environments

Flooded underground mines

Underwater environments

Flooded underground mines



Robotics

- Robotics is an **interdisciplinary** field that integrates **computer science** and **engineering**.
- Robotics involves design, construction, operation, and use of robots.
- The goal of robotics is to design machines that can **help** and **assist humans**.
- Robotics develops machines that can **substitute for humans** and **replicate human actions**.

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Laws of Robotics

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

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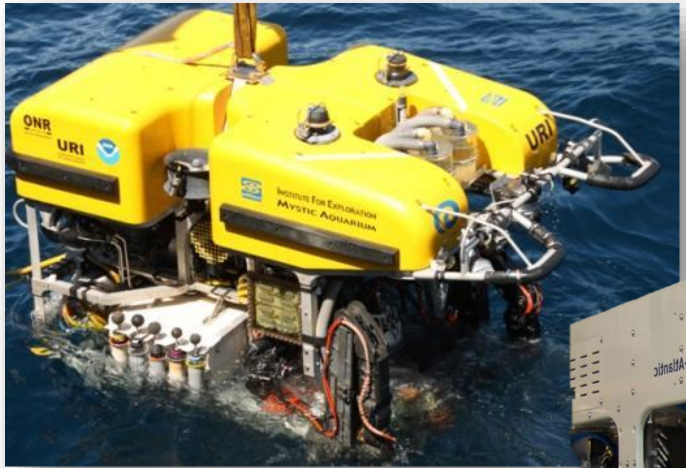
Source: https://www.esa.int/

ROV/AUV

Remotely operated underwater vehicle (ROUV/ROV)

- Tethered underwater mobile device
- Unoccupied, usually highly maneuverable
- Operated by a crew
- Open or Box Frame ROVs
- Torpedo Shaped ROVs
- Mostly external power supply



Source: https://www.usgs.gov/

Source: https://www.subsea-tech.com/

Autonomous underwater vehicle (AUV)

- Travels underwater without requiring input from an operator
- Mostly torpedo shape
- Internal power supply (battery)
- Usually used for mapping
- Simultaneous Localization and Mapping
- Artificial Intelligence

Source: https://sunfishinc.com/

Source: https://www.kongsberg.com/

Source: https://www.subsea-tech.com/

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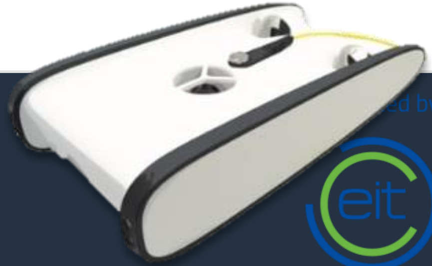
Market solutions

- BlueRobotics
- Deeptrekker
- SUNFISH
- SUBSEA TECH
- fugro
- KONGSBERG
- gysea
- SOFAR
- NAVATICs



Market solutions

General details

- Personnel ROVs
  - <30 cm
  - 3-5kg
  - Price from 1000 EUR
  - Only visual inspections with RGB cameras
  - Internal power supply
  - 30-40 min battery time
- Industrial ROVs/AUVs
  - >50 cm, >30kg
  - Price from 10000 EUR
  - Usual dive depth 200-1000m
  - 3D mapping with sonar (multi-beam)
  - Internal or external power supply
  - 2-100 h battery time (with internal power supply)

Field of application

- Bridge piers
- Ship hulls, shipwrechs
- **Floodes mines, submerged caves**
- Archeological sites
- High-resolution high-speed seabed mapping and imaging
- Pipeline and subsea structure inspection
- Geophysical site inspection
- Environmental habitat mapping
- Underwater filming
- Oceanic exploration
- Recreational
- Aquaculture, fish farms
- Underwater operations
- Public safety & Law Enforcements
- Offshore energy sites
- Port and harbor structures
- Environmental monitoring
- **Marine geological survey**
- Search operations
- Pipeline and cable route analysis and selection

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Market solutions

Available sensors /add-ons

- Only for industrial ROVs/AUVs
- Multi-beam sonar
- High Resolution Iterferometric Synthetic Aperture Sonar
- Scanning sonar
- Pressure and temperature sensor
- Dissolved oxygen sensor
- Multipatameter water chemistry sensor (pH, temp, O2, EC, depth, density, pressure,
- DVL (Doppler Velocity Log)
- CP probe (Assess and monitor corrosion inhibiting systems
- Leak sensor
- RGB cameras and light sources
- Underwater GPS
- Sub-bottom profiler
- Turbidity sensor
- Sidescan sonar
- Methane sensor
- Thickness gauge
- IMU
- Water sampler
- Sediment sampler

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UNEXMIN/UNEXUP Projects

2016-2019

Development and testing of a multi-robotic platform for spatial and geoscientific survey of underwater environments

2020-2022

Commercialization of the robotic technology, while further improving its software, hardware and capabilities

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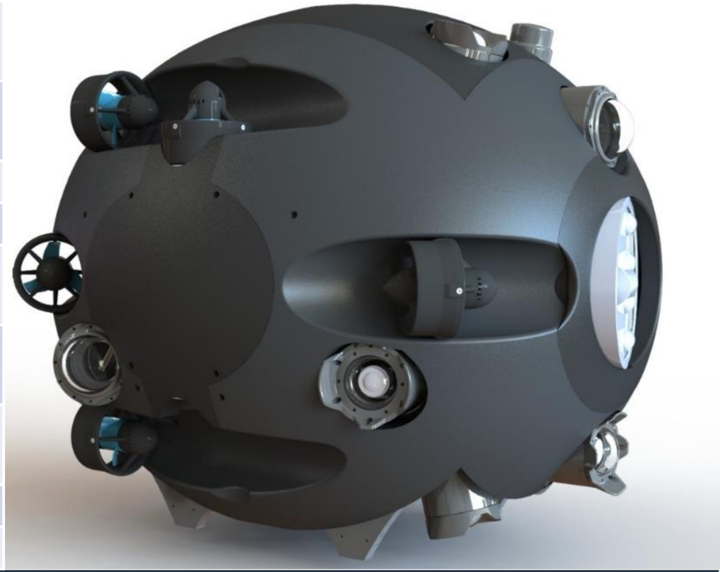
UNEXMIN/UNEXUP Projects

UNEXMIN UX-1	UNEXUP UX-1Neo
Monolithic	Modular
112 Kg	<90 Kg
Limited lateral motion, no pitch stabilization	Pitch stabilization with lateral motion
5DOF (2 with limitations: pitch and lateral)	6DOF
One scanning sonar	Two scanning sonar (additional vertical scanning sonar)
Limited connection	10 Gb fiber-optical umbilical connection
5 Cameras	6 Cameras
4 SLS	6 SLS
SLS Short baseline limits the sensor range	Increased SLS baselines
Internal batteries - charged inside of the robot	Swappable batteries
500 m rated	1000 m (except M3 500m, scanning sonar 750m)
battery capacity: 1450 Wh	battery capacity: 2600 Wh
5h operation	>8h operation



Underwater navigation

SLS - Structured Light Sensor

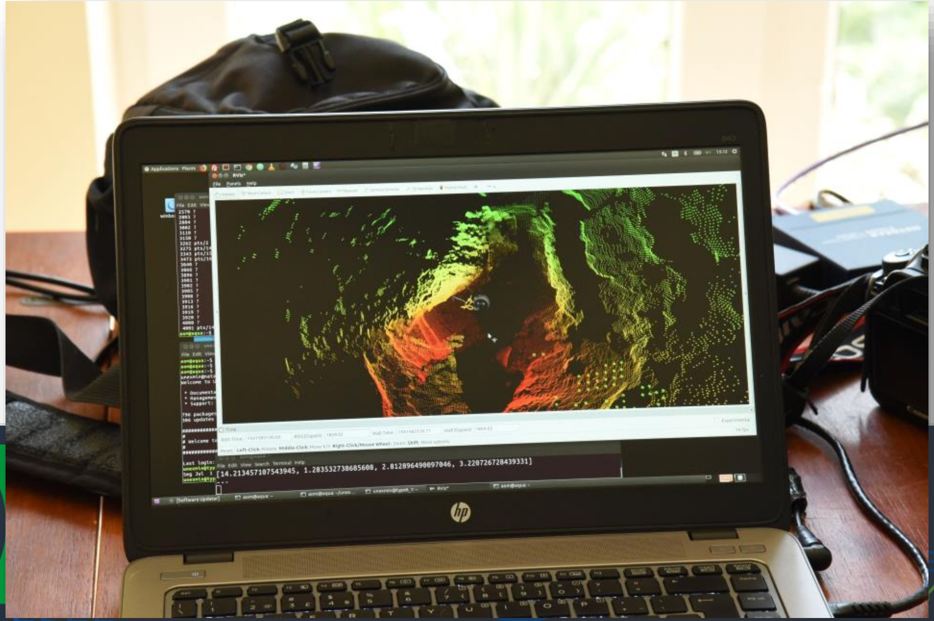
- 3D morphological information of the scanned environment and imaging.
- Laser/light projector unit and dedicated camera.
- Embedded processor - laser line detection and triangulation

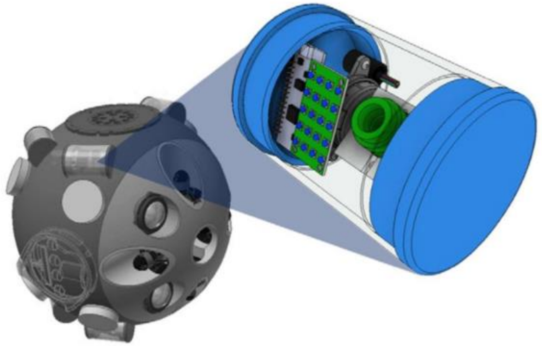
DVL - Doppler Velocity Log

- Acoustic sensor that estimates velocity relative to the bottom
- Accurate position and depth measurements

Kongsberg M3 Sonar	
Vertical FOV	3º
Horizontal FOV	120º
Range	0.2 to 120 m
Update Rate	up to 24 Hz
Material	Aluminum
Depth	500 m

Nortek 1000 DVL	
Max. Operation Depth	4000 m
Long Term Accuracy	+- 0.2% +- 1mm/s
Maximum Altitude	0.3 to 50 m
Velocity Resolution	0.01mm/s
Pressure Sensor Accuracy	0.1 %
Update Rate	8 Hz



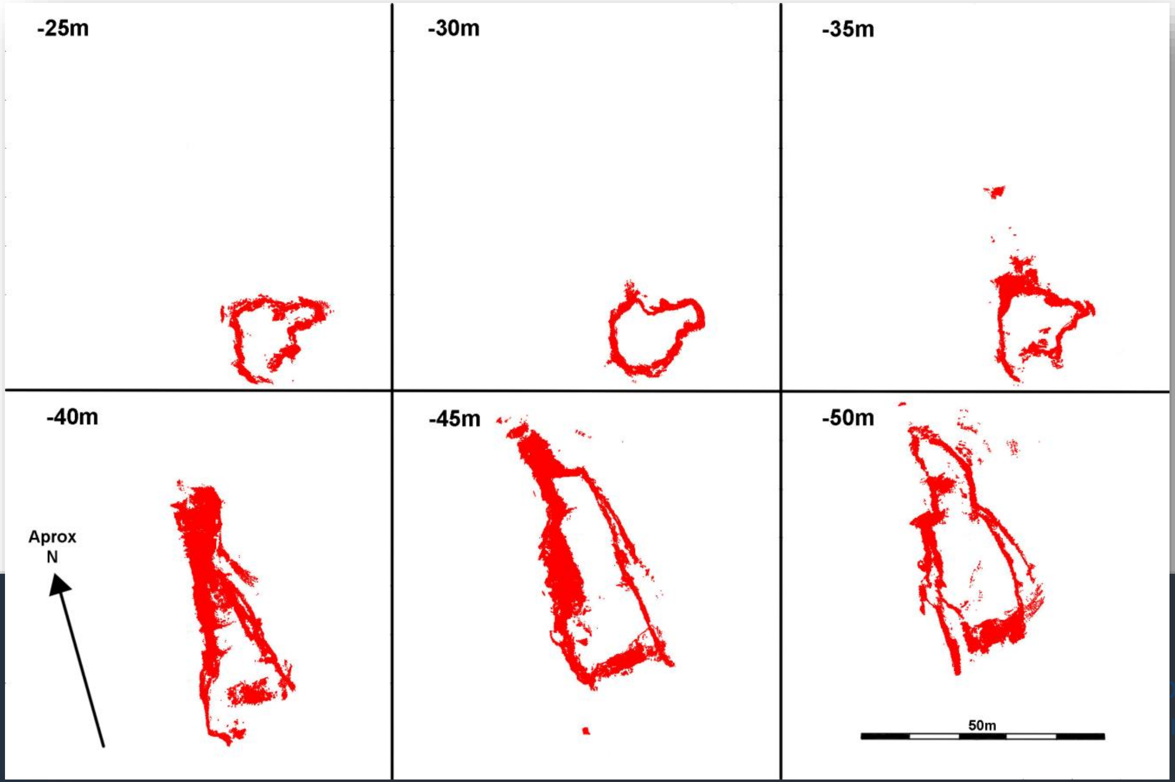


Underwater navigation

Sonar - Kongsberg M3 sonar is the mid/long-range sonar for large mine cavities explorations and mapping.

Tritech Micron sonar is a helpful tool for close to mid-range obstacles detection and avoidance.

Impact subsea sonar has the same objective as the previous sonar, but it is placed in another strategic point for better coverage of the obstacles.

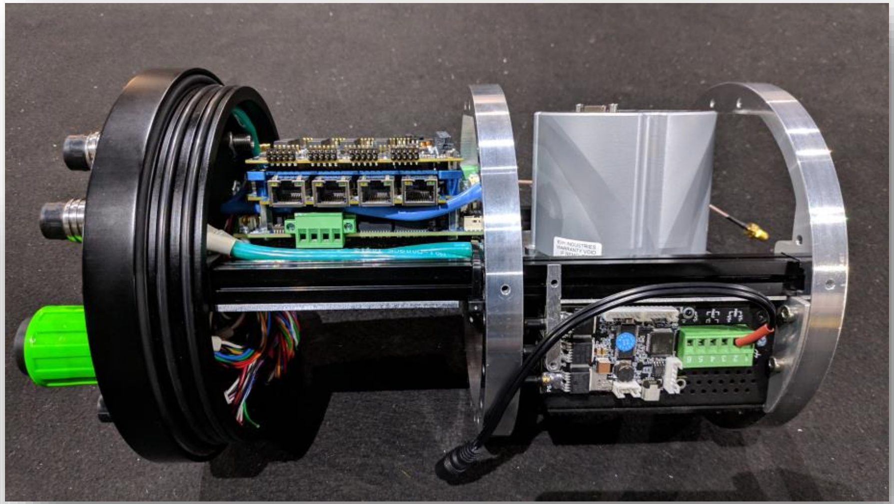


Tritech Micron Sonar	
Vertical FOV	35º
Horizontal FOV	3º
Range	0.3 to 75 m
Update Rate	24 Hz

Imaging Sonar	
Vertical FOV	23º
Horizontal FOV	2.2º
Range	0.15 to 90 m
Update Rate	Up to 24 Hz

Underwater navigation

IMU - KVH IMU sensor is a high-resolution navigational sensor that is used for the position and orientation calculations of the robotic system.



KVH 1775 FOG IMU	
Gyroscopes	
Bias Instability	<0.1, 1 omega (max)
Bias Offset	<0.1, 1 Ω(max)
Random Walk	<0.012º $\sqrt{hr}$
Accelerometers	
Bias Instability	<0.05 mg, 1 Ω
Bias Offset	0.5 mg
Random Walk	0.12 mg $\sqrt{hr}$

T200 Thruster	
Operating Voltage	7-20 V
Full Throttle	6.7 / 5.05 kg f
Minimum Thrust	0.02 kg f
Full Throttle Power	645 W

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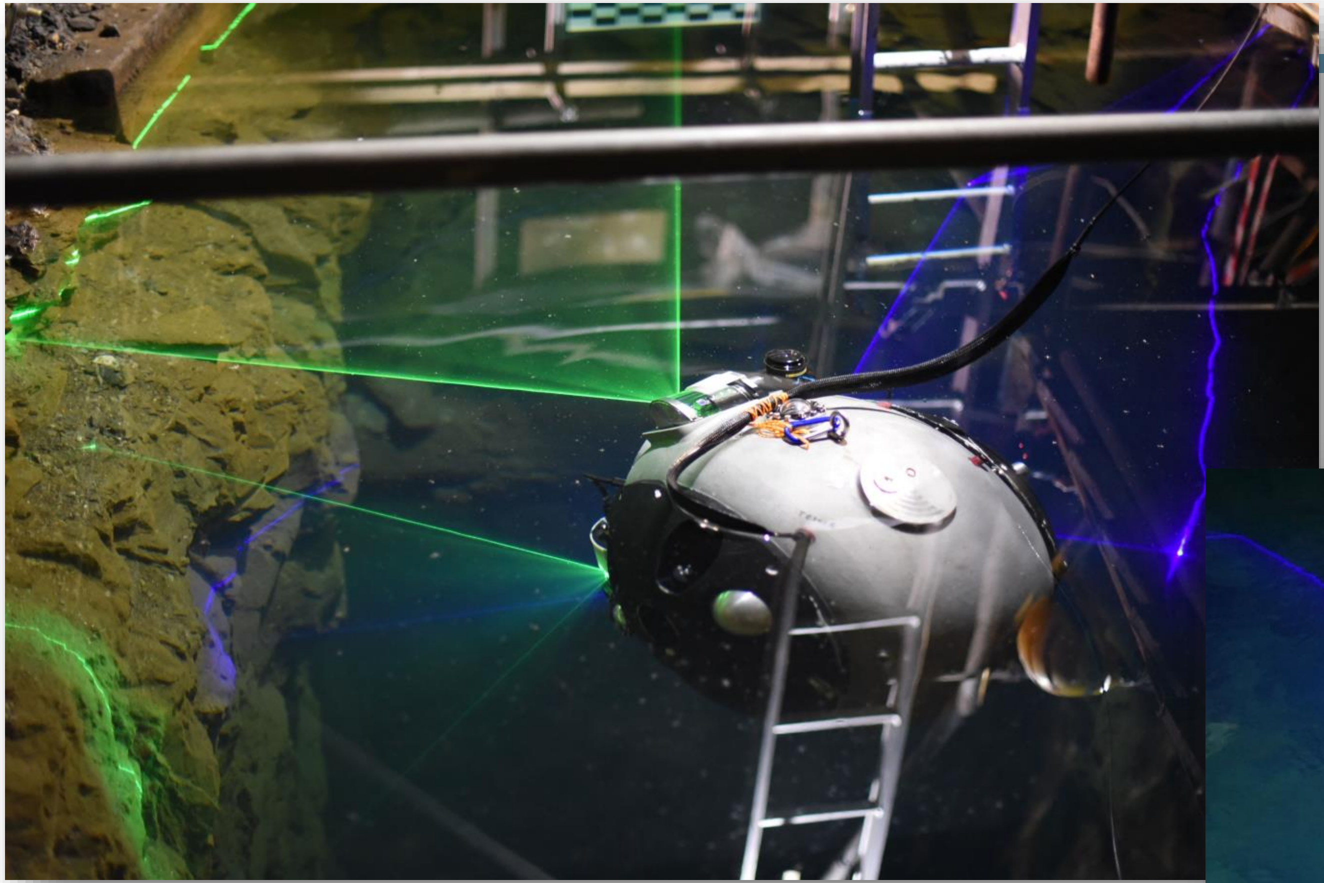
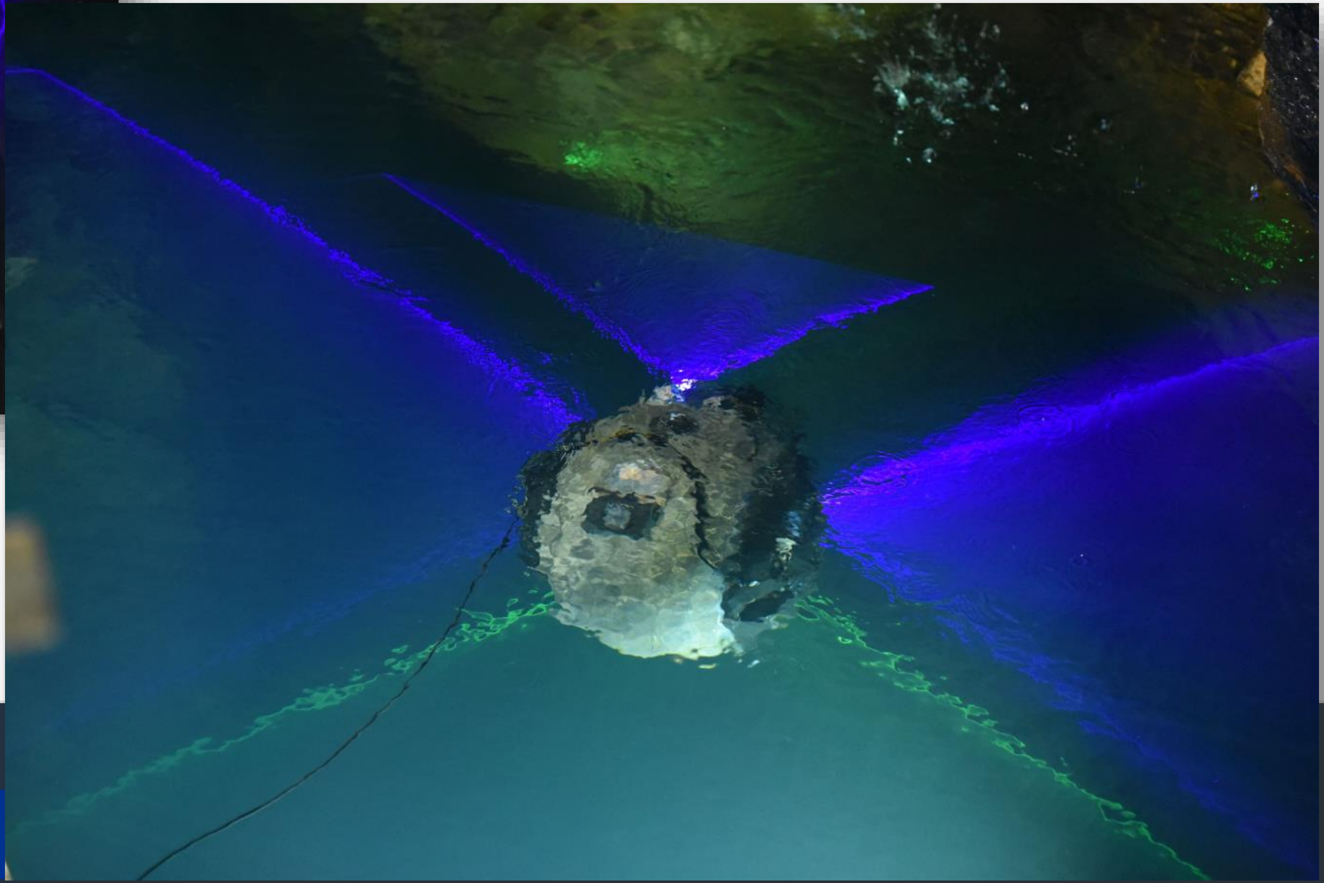


Photo: Rocky Shore Pictures

Underwater navigation

Photo: Rocky Shore Pictures



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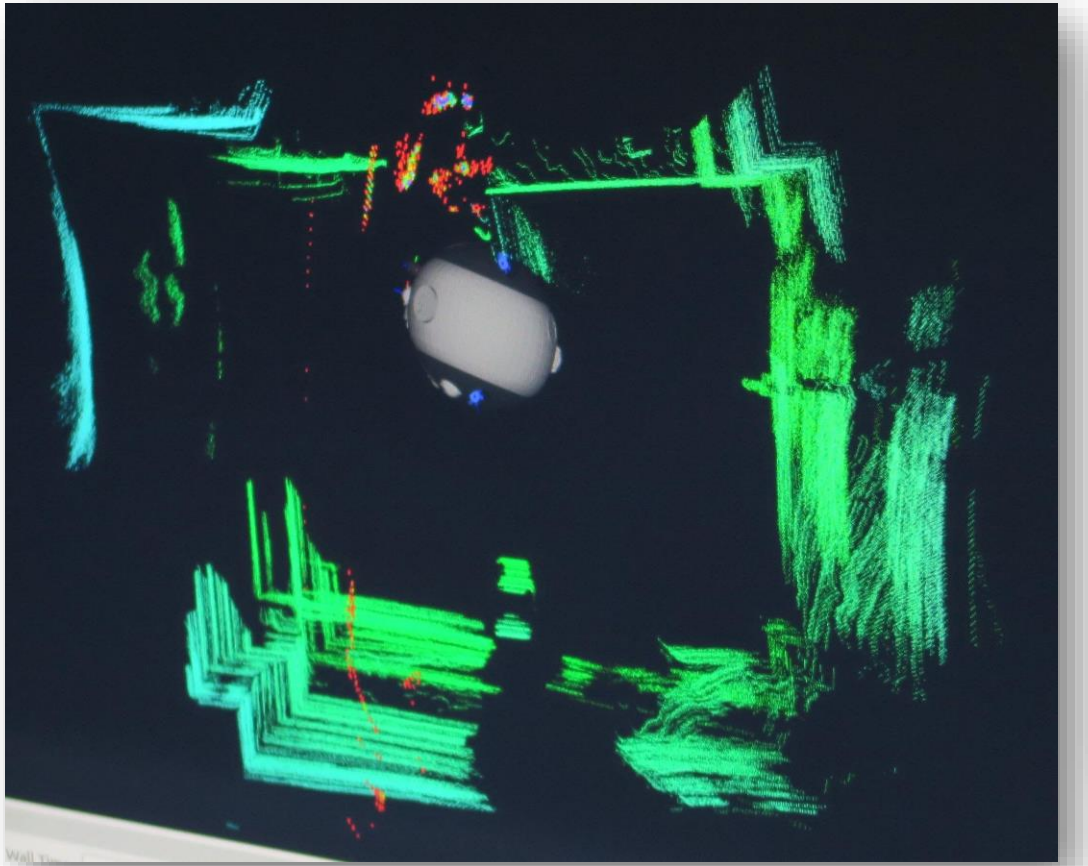

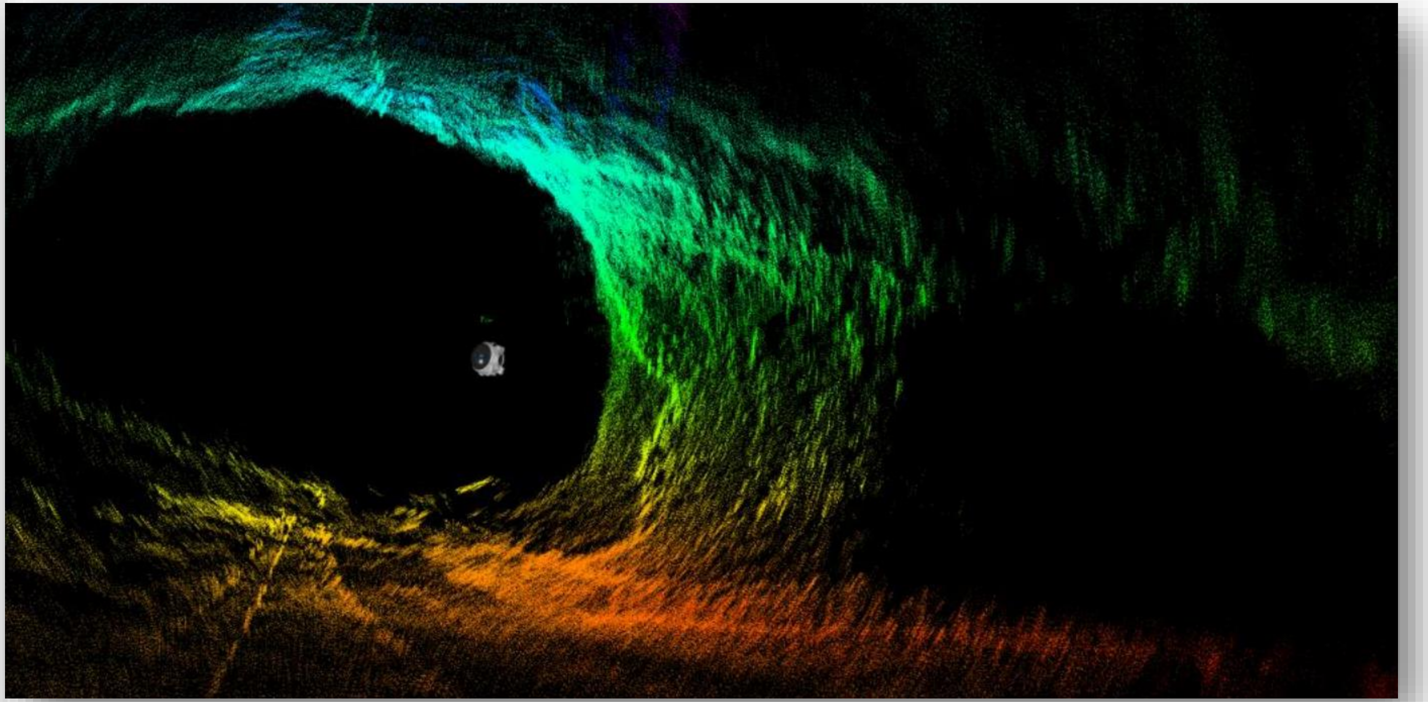

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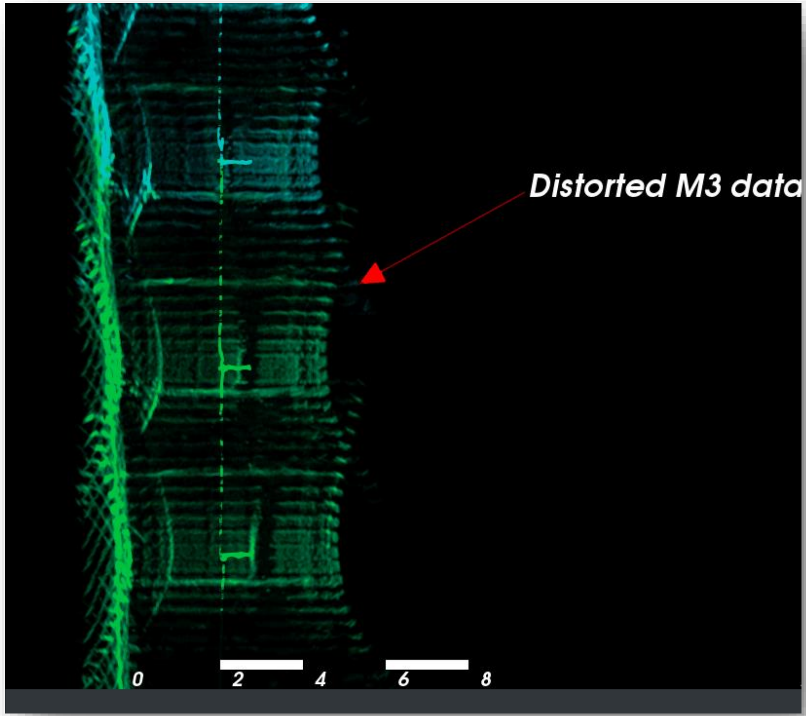

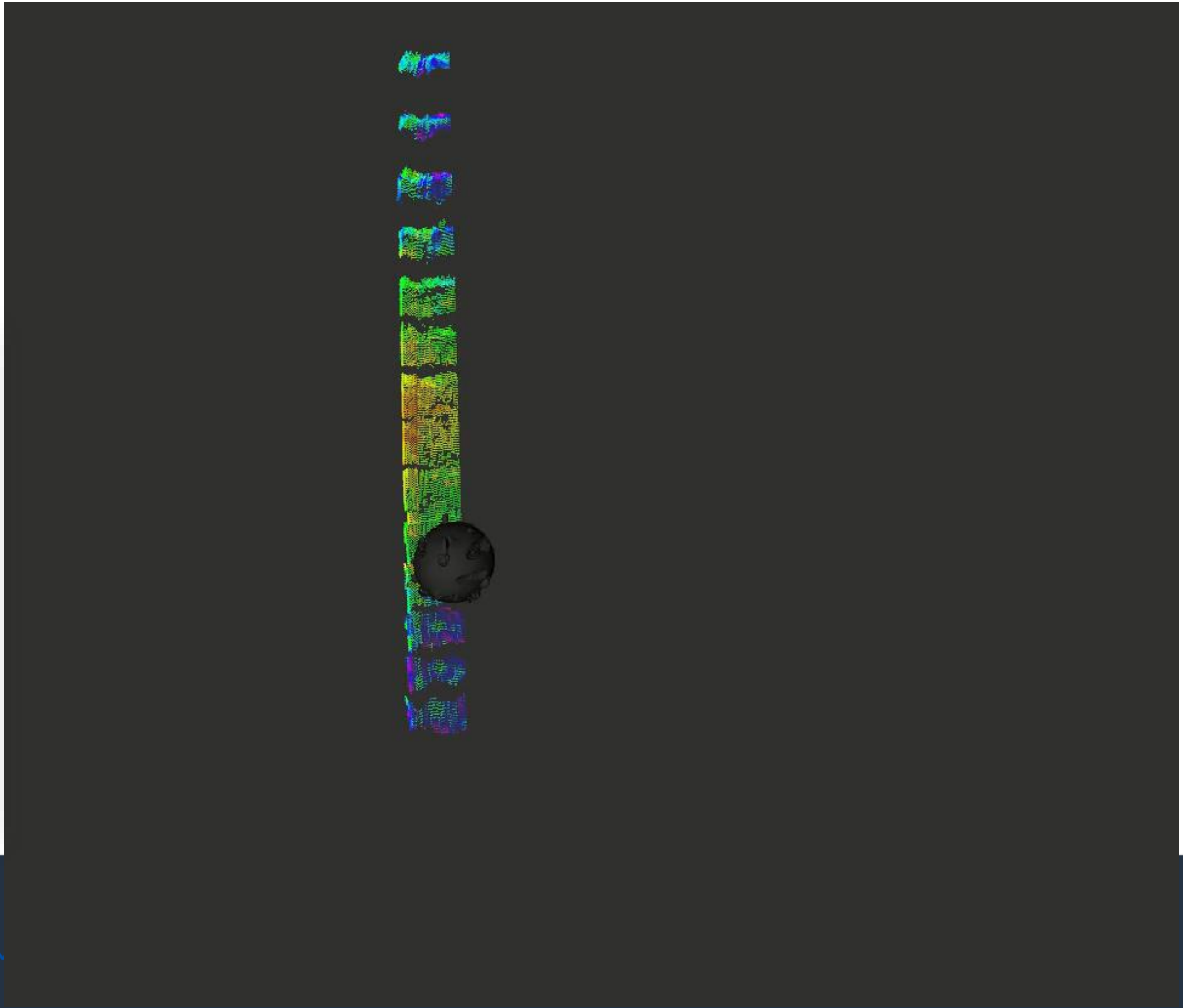

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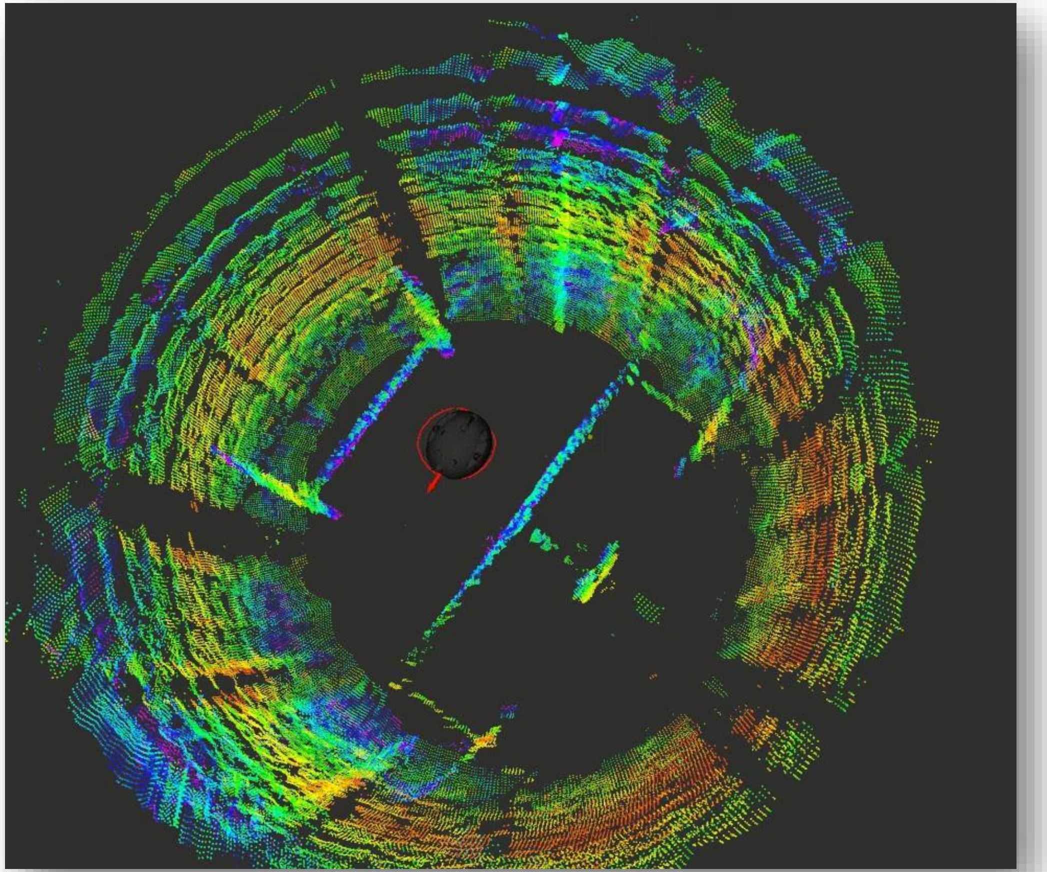

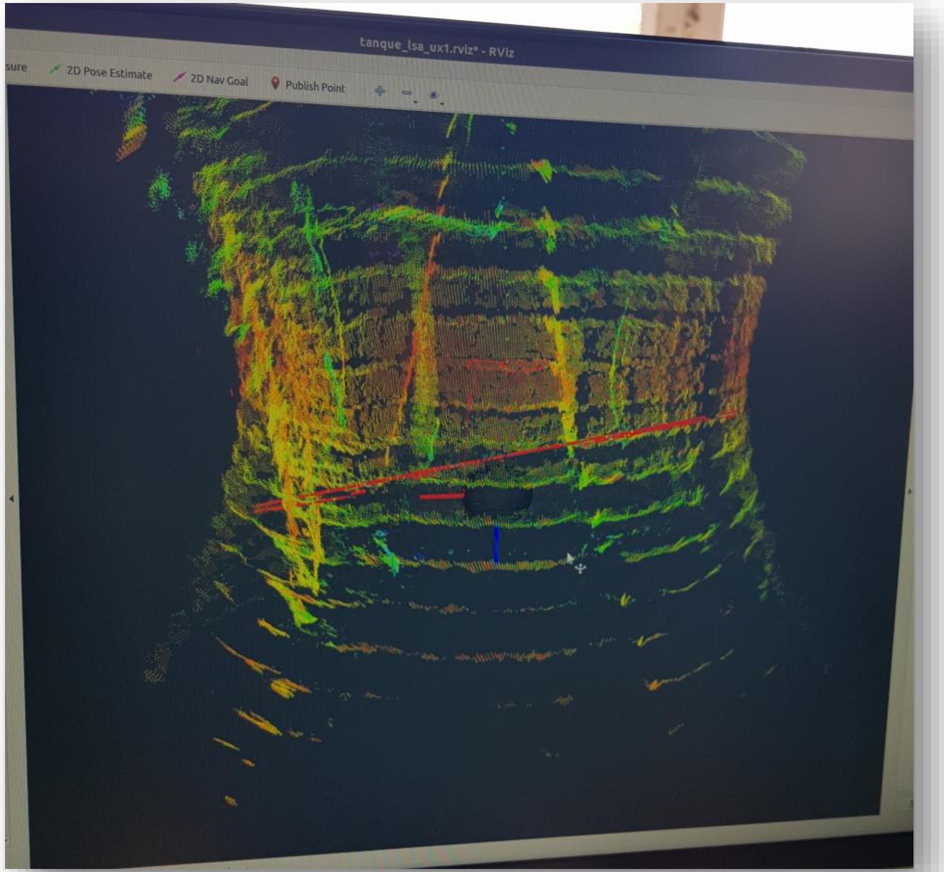

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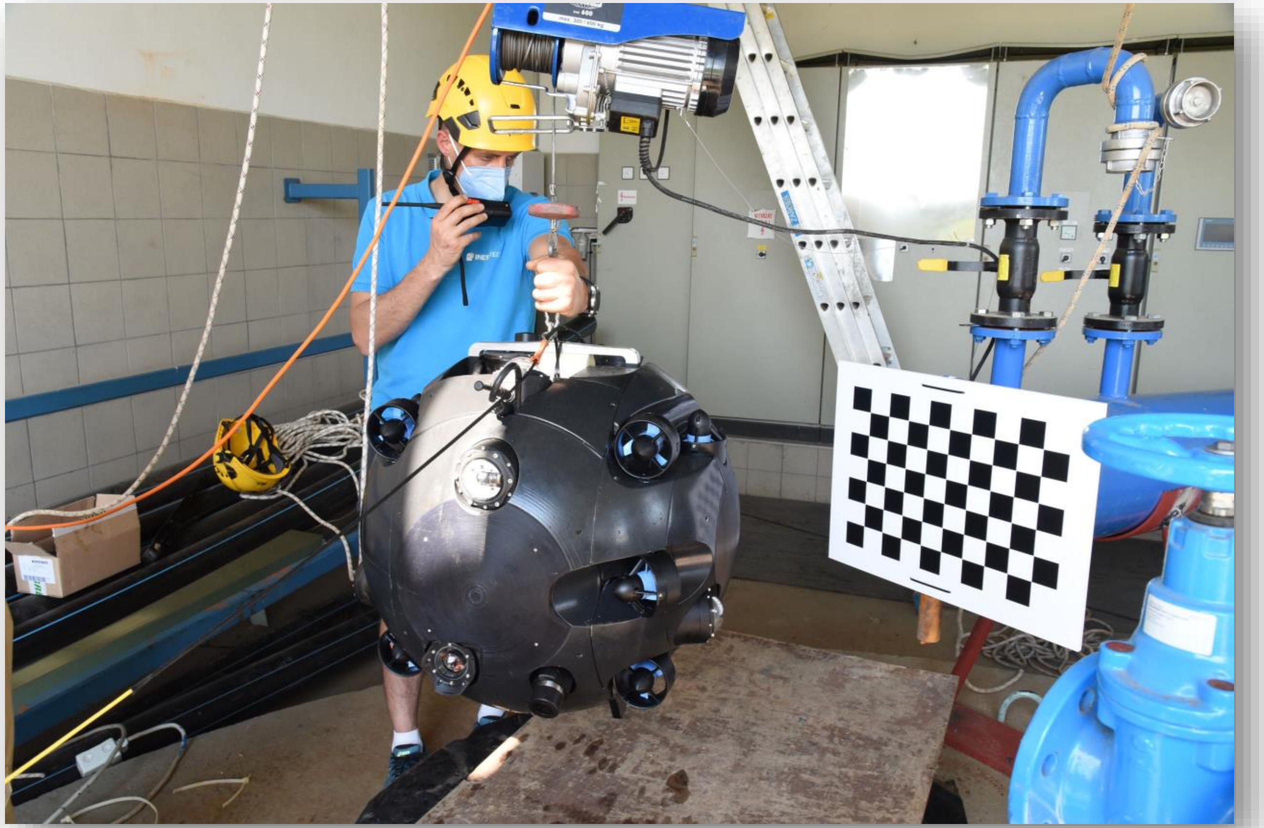

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Underwater navigation

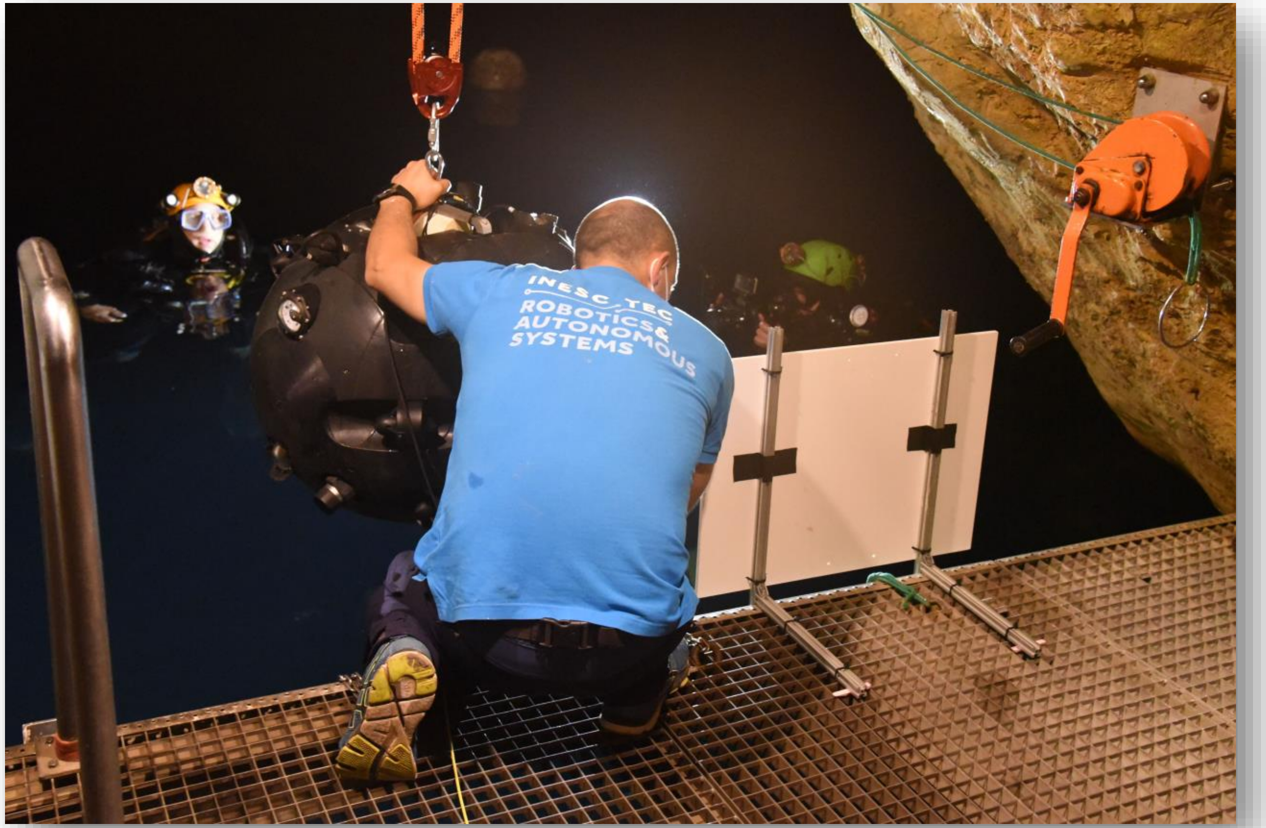


Photo: Rocky Shore Pictures

Photo: Rocky Shore Pictures

Underwater navigation

- ¡VAMOS! Project
- Underwater beeper
- 4 corner of the platform
- Triangulation
- ‚Underwater GPS’

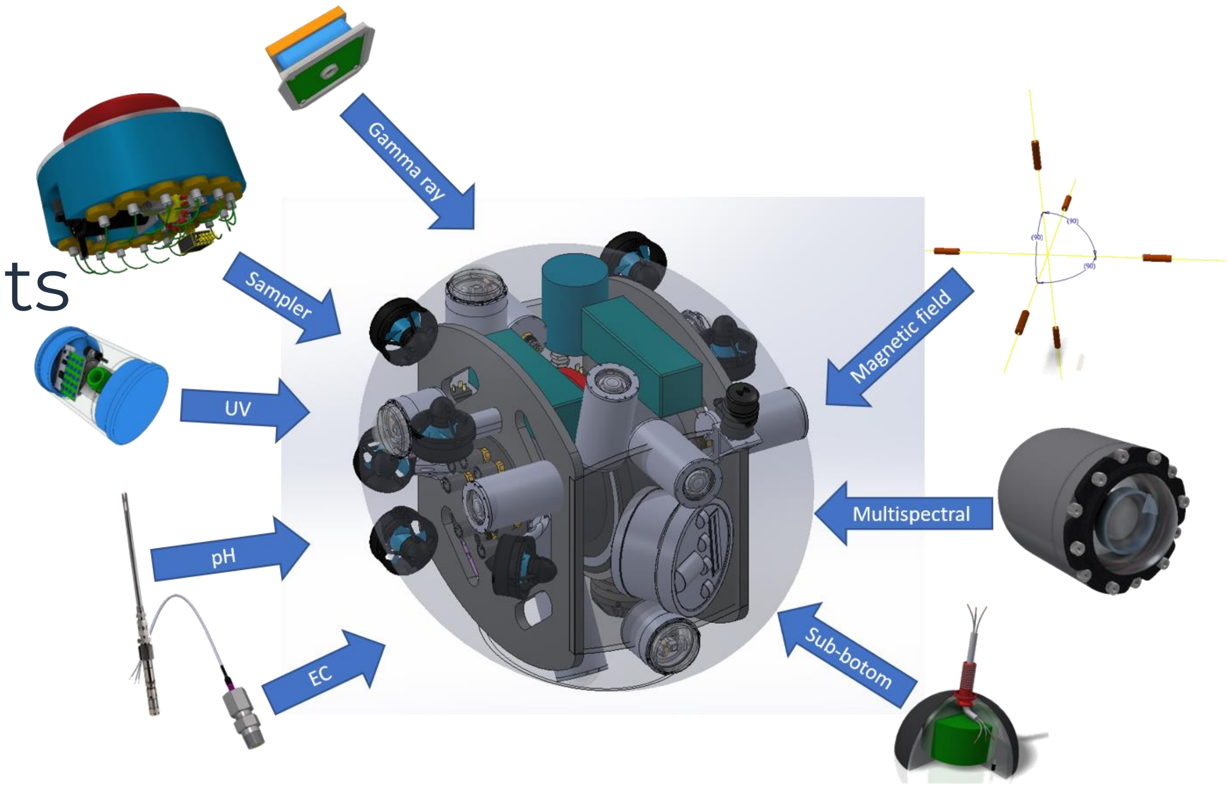
Conceptual desing of the platform
Source: www.damen.com

Virtual reality scene of the ¡VAMOS! underwater mining system with the created terrain surface model of the Bejanca mine.
Source: www.semanticscholar.org

The ¡VAMOS! mining machine
Source: www.semanticscholar.org

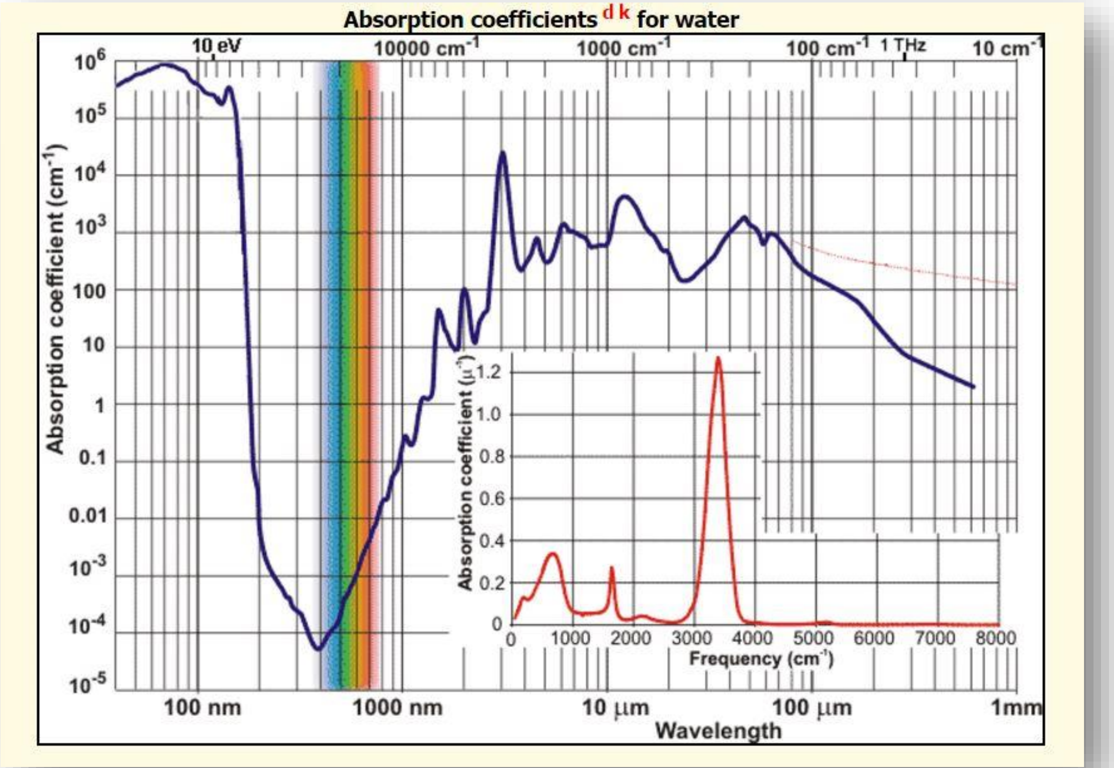
Underwater sensor technology

- Multi/hyperspectral imaging
- Sub-bottom sonar
- Water parameter measurements
- Water sampling
- Underwater rock sampling
- Gamma measurements
- Flux-gate magnetometer



Underwater sensor technology

Multi/hyperspectral imaging



Underwater sensor technology

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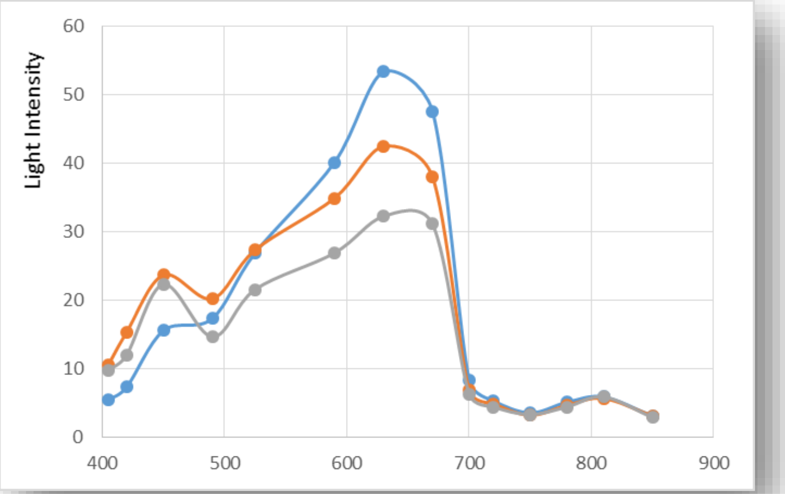
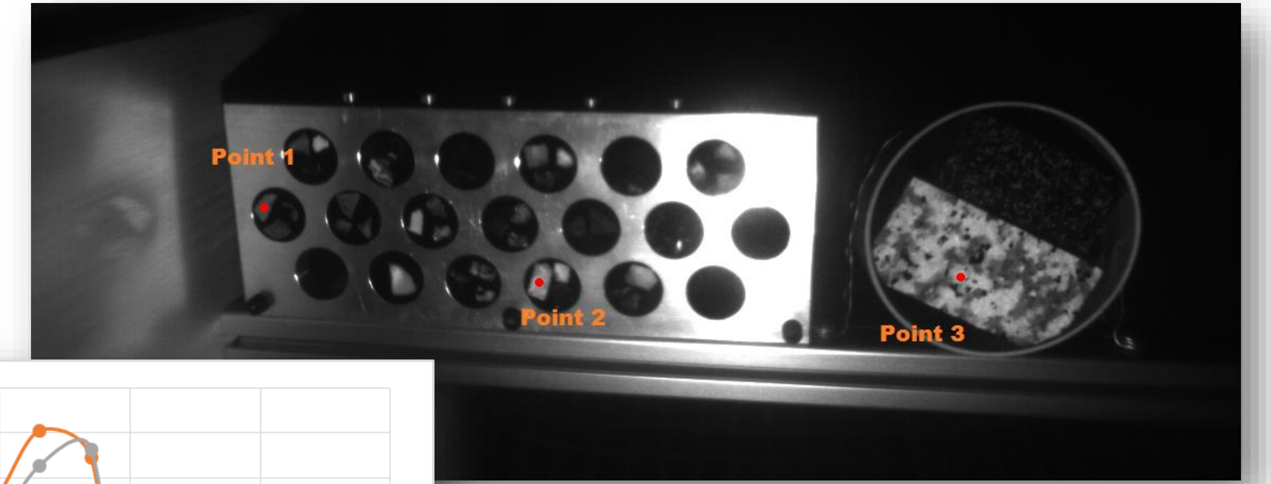
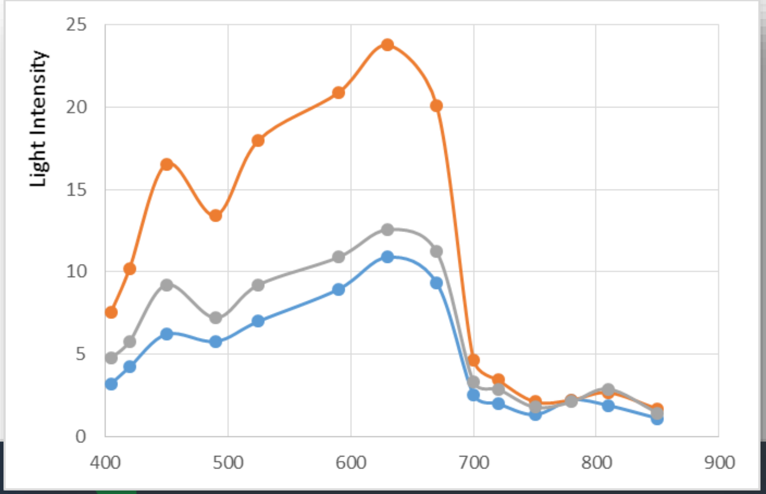
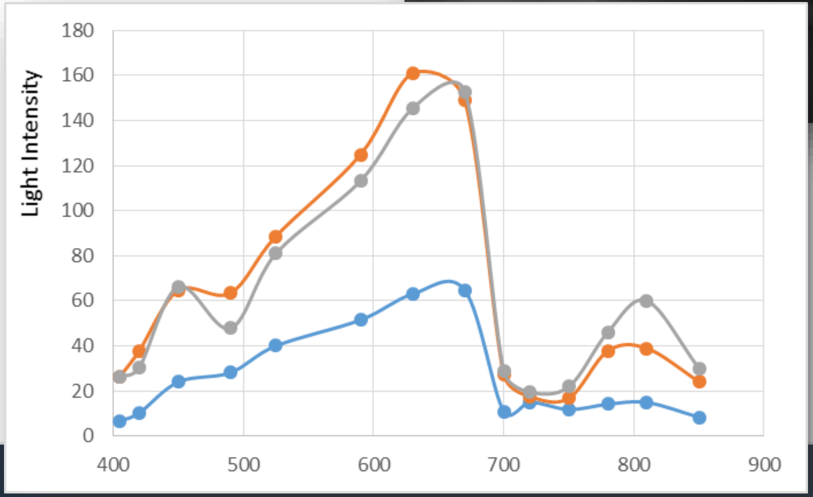
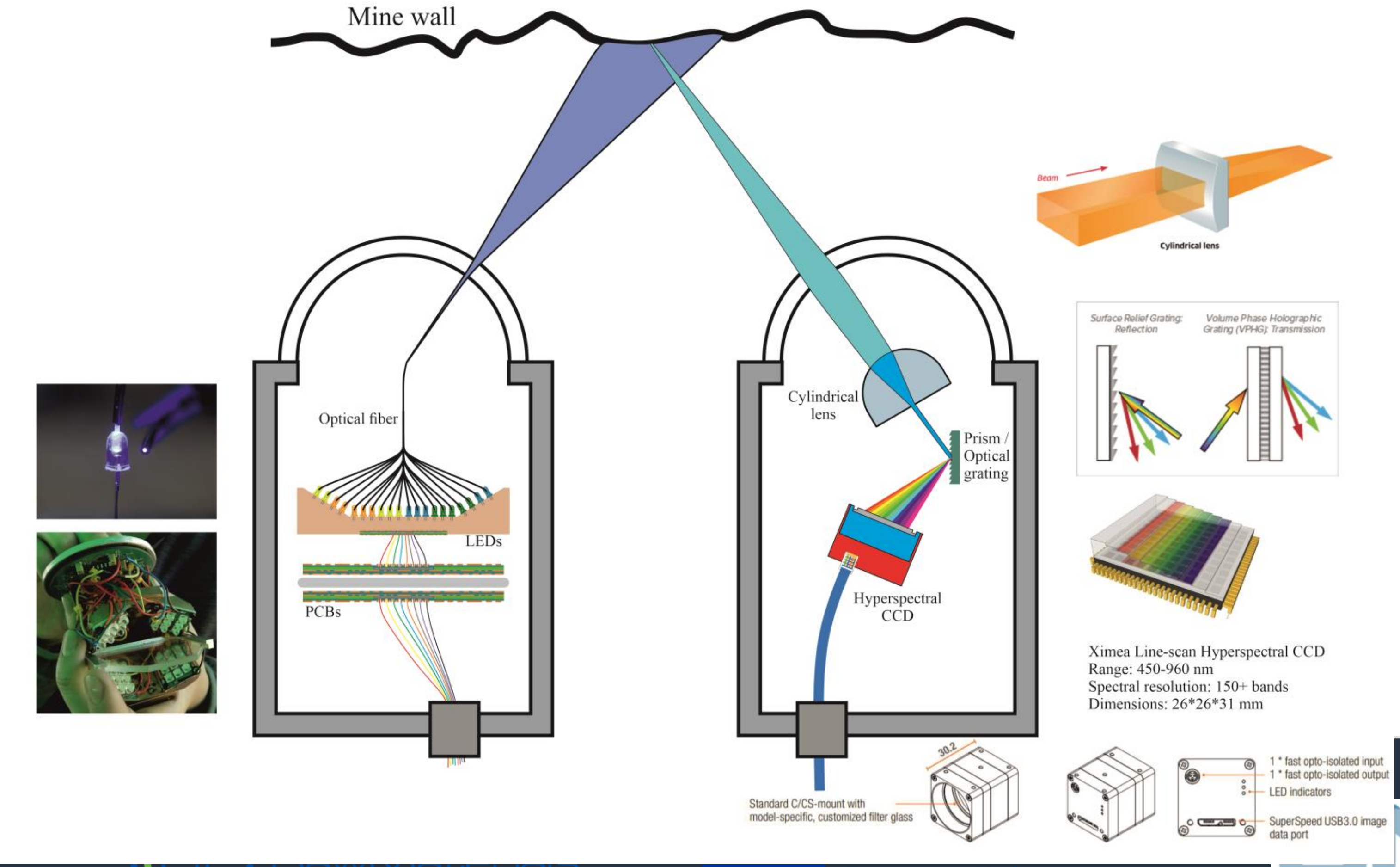






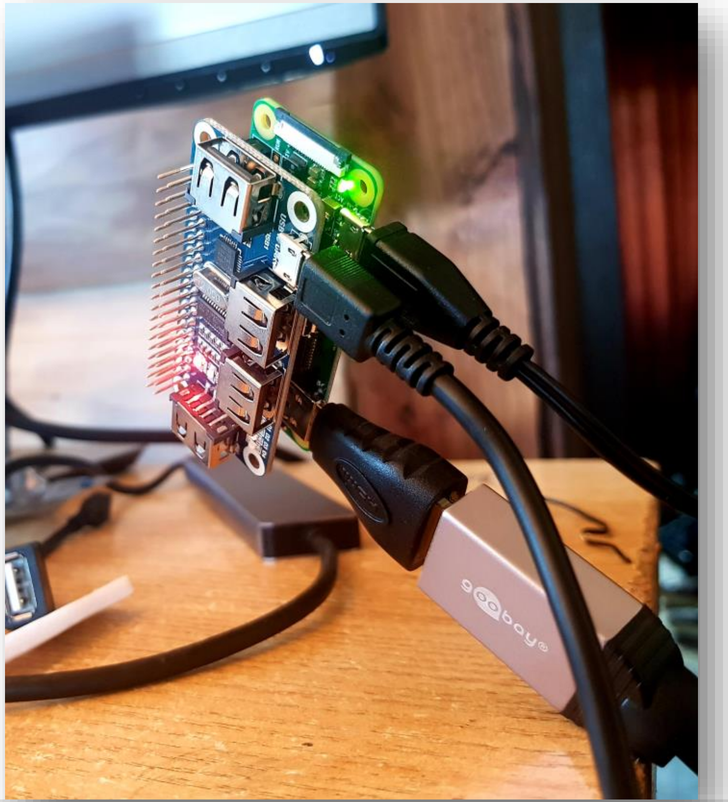


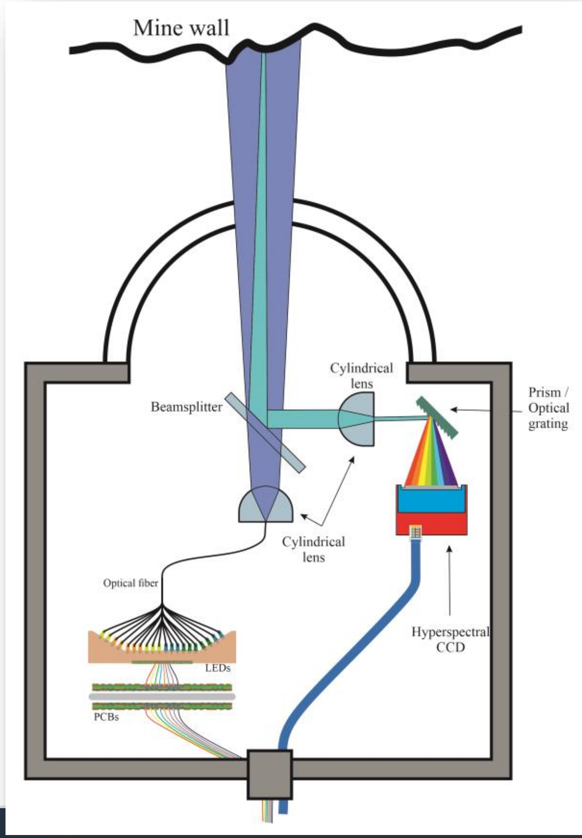
Underwater sensor technology
Multi/hyperspectral imaging



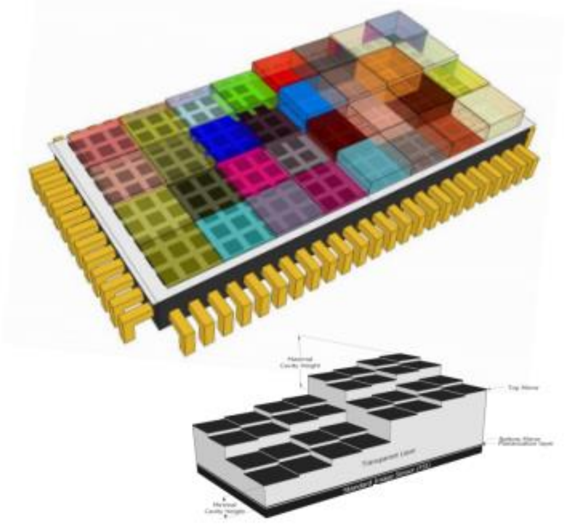
Underwater sensor technology

Multi/hyperspectral imaging



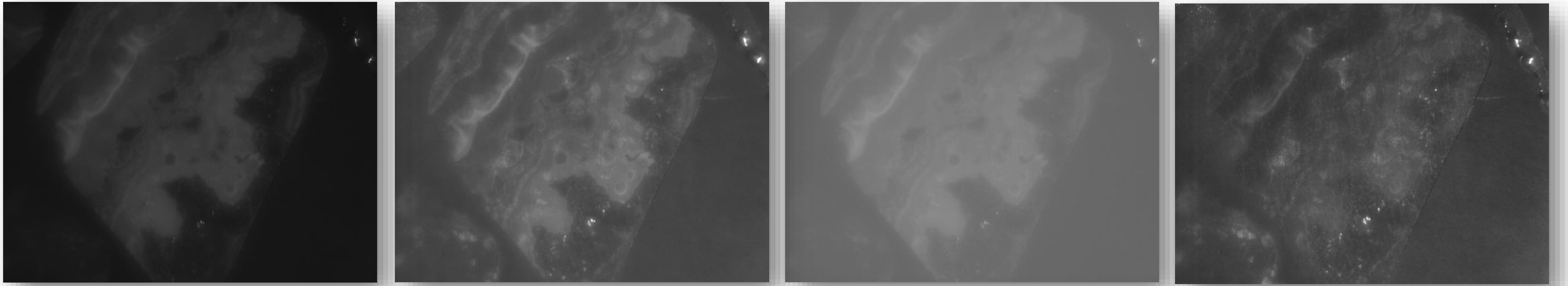


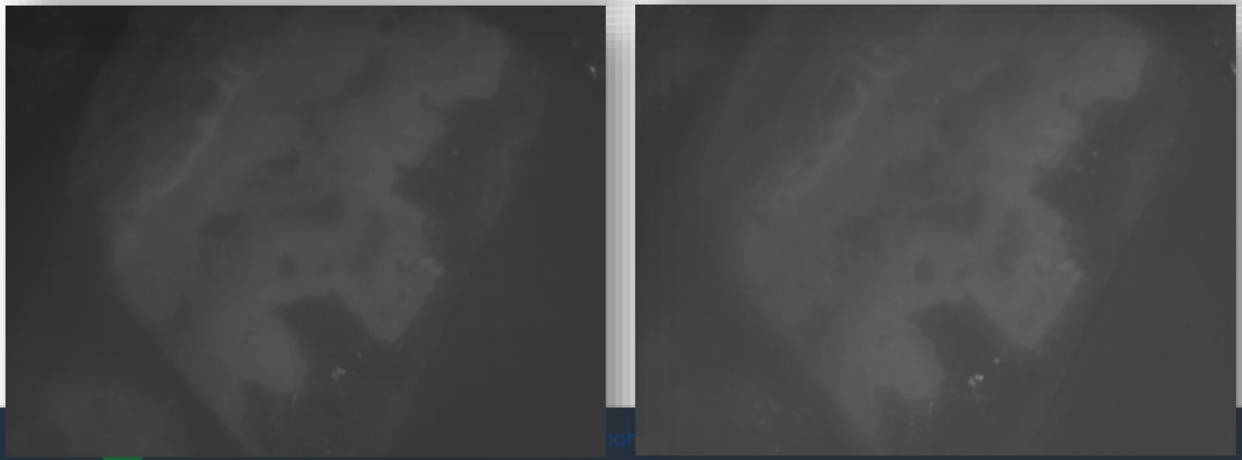
Snapshot design

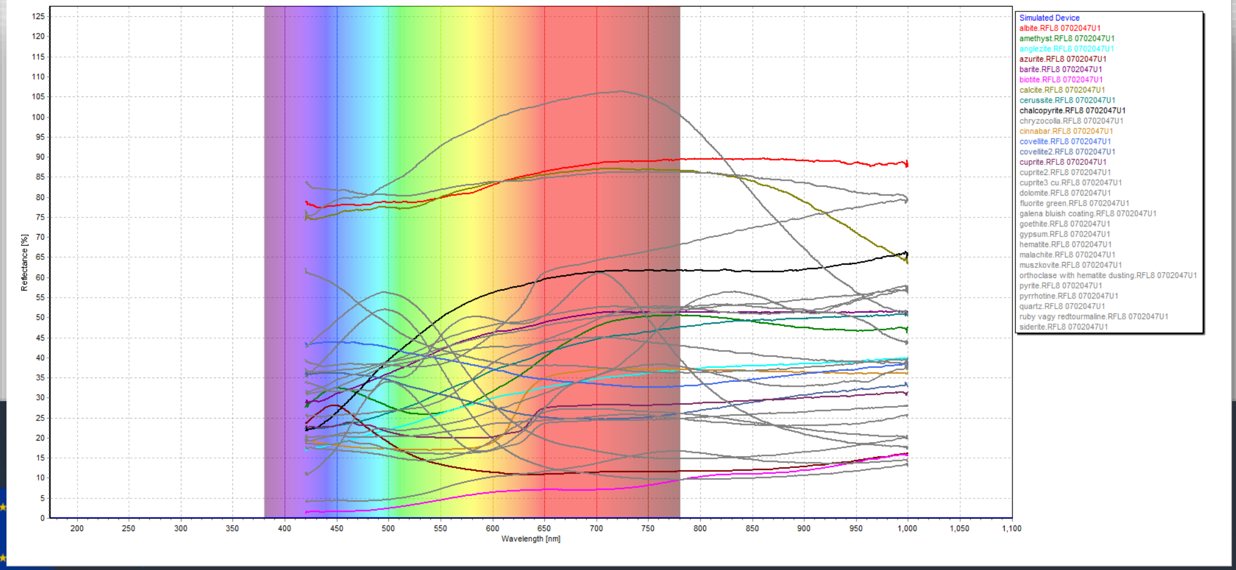


Underwater sensor technology

Multi/hyperspectral imaging

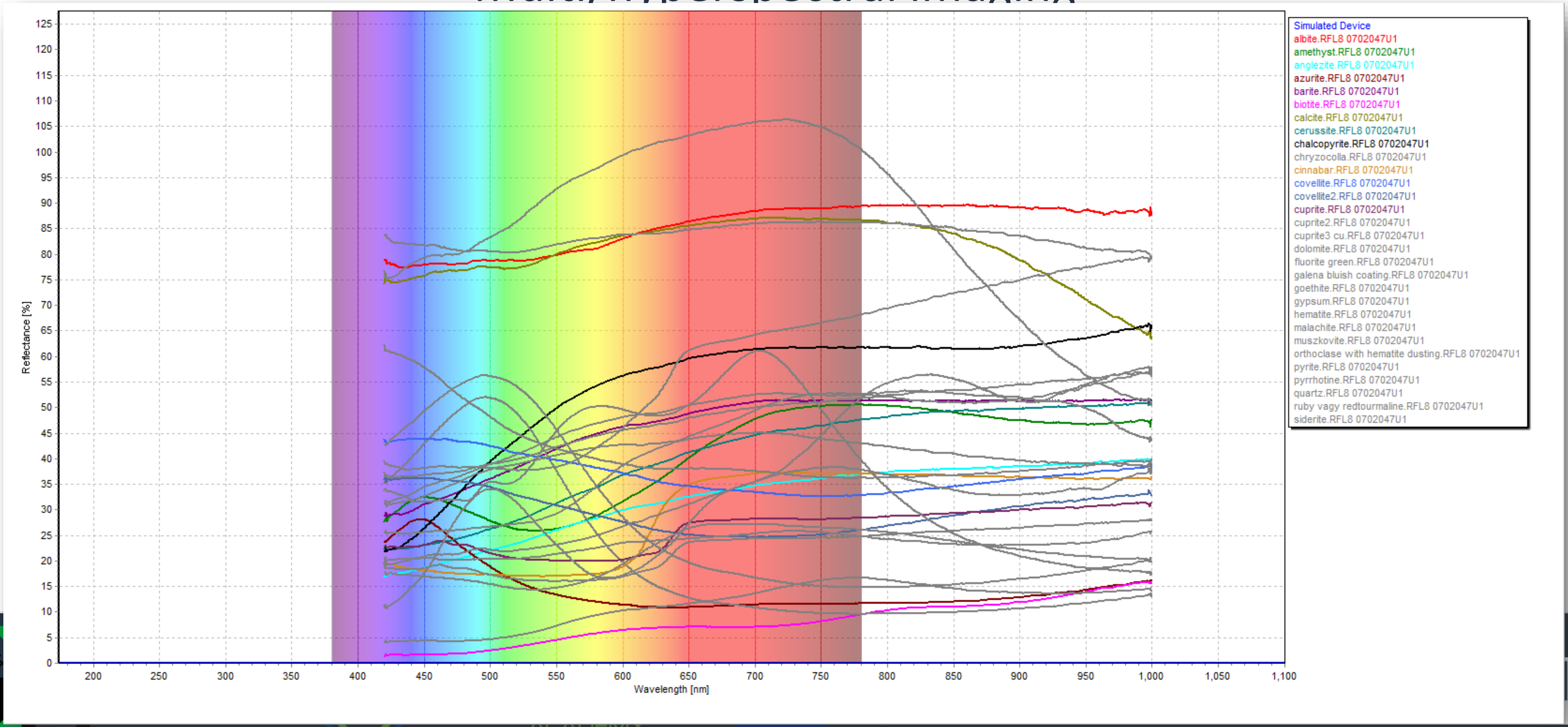






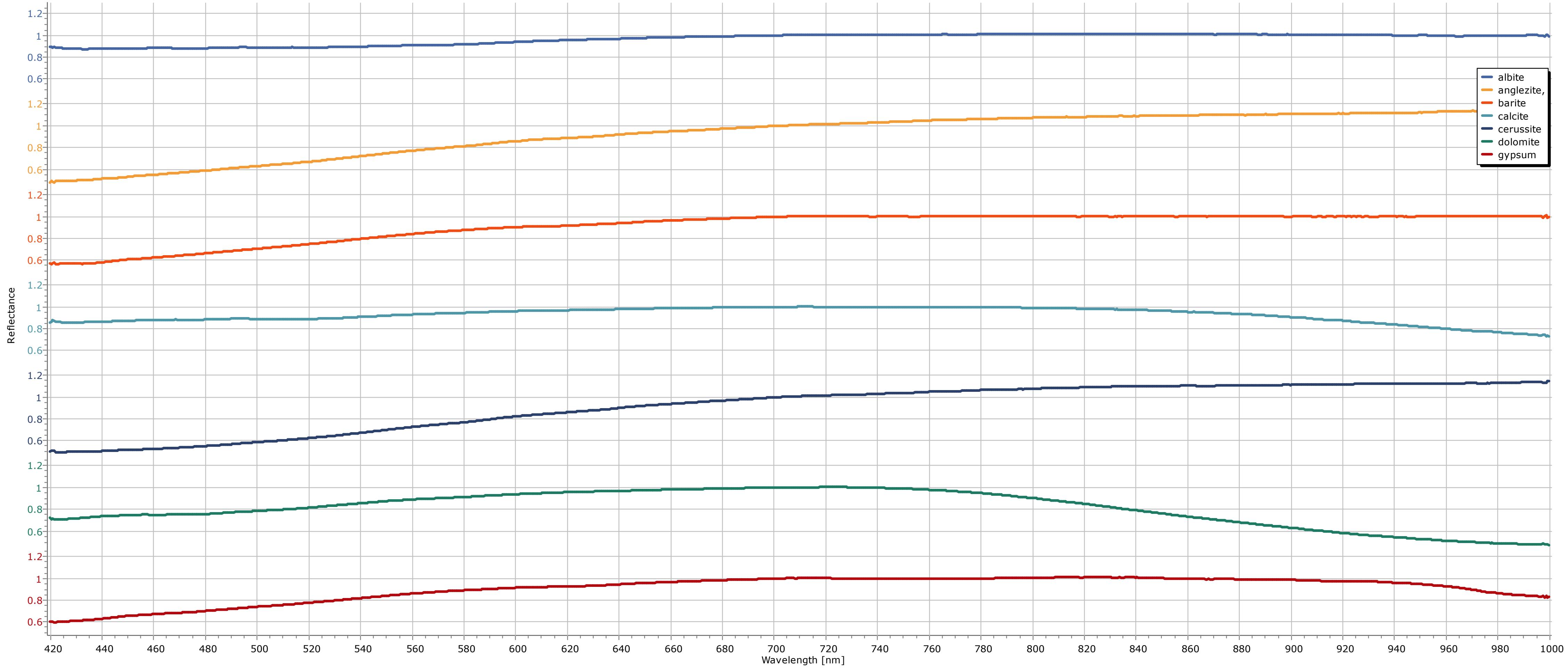
Underwater sensor technology

Multi/hyperspectral imaging



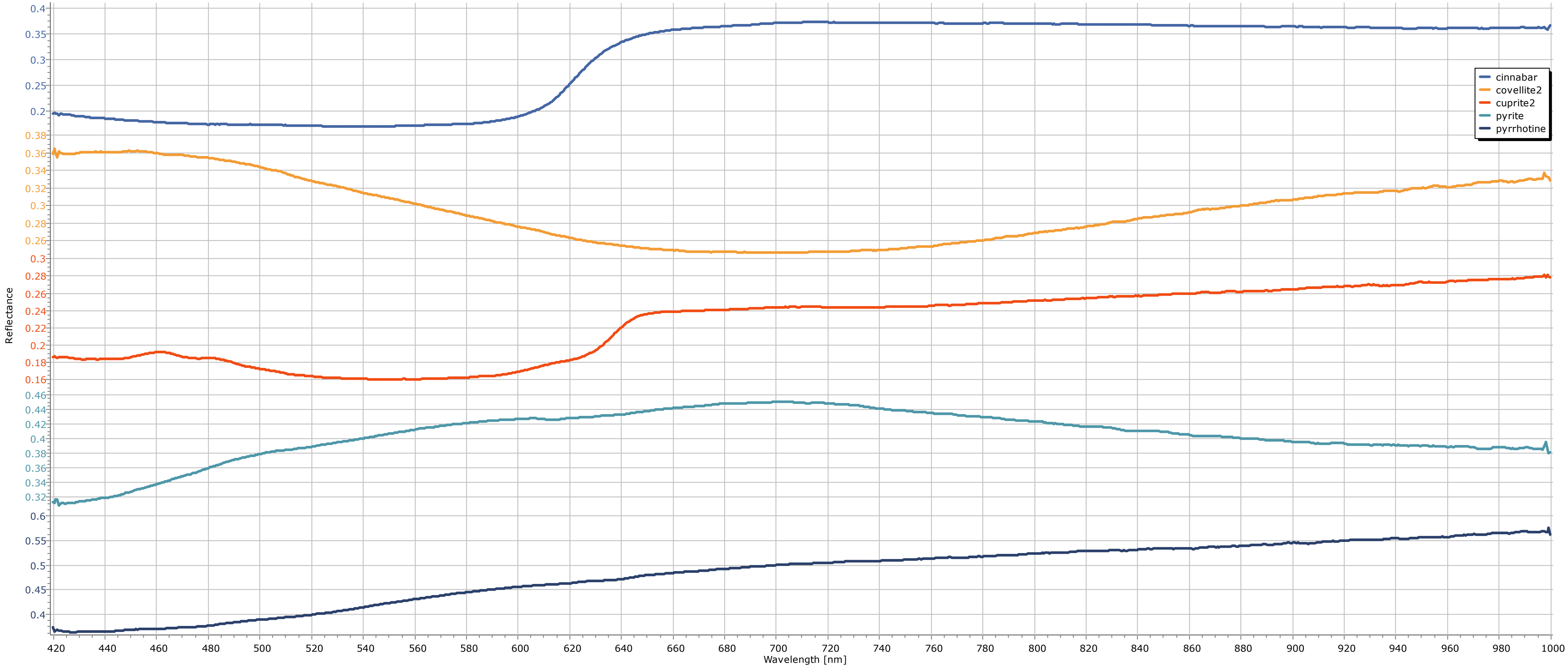
Underwater sensor technology

Multi/hyperspectral imaging



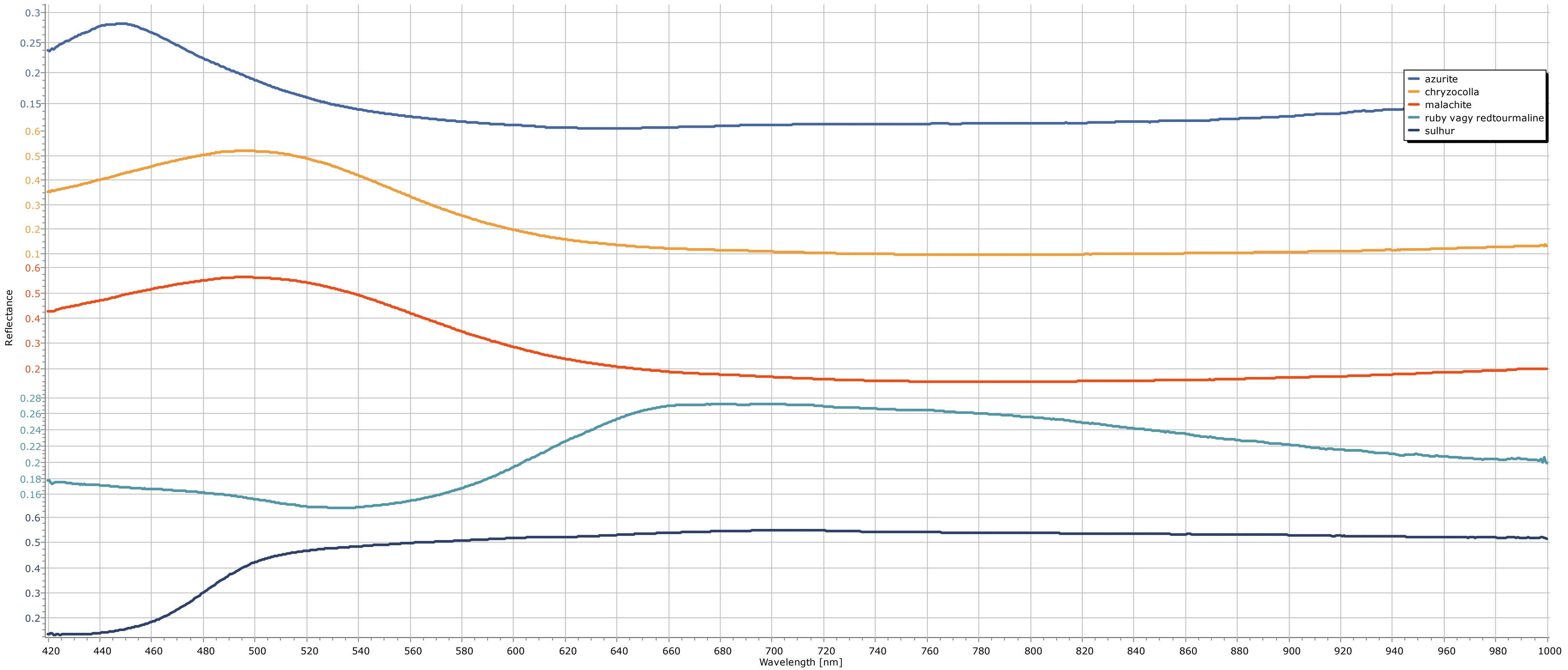
Underwater sensor technology

Multi/hyperspectral imaging



Underwater sensor technology

Multi/hyperspectral imaging



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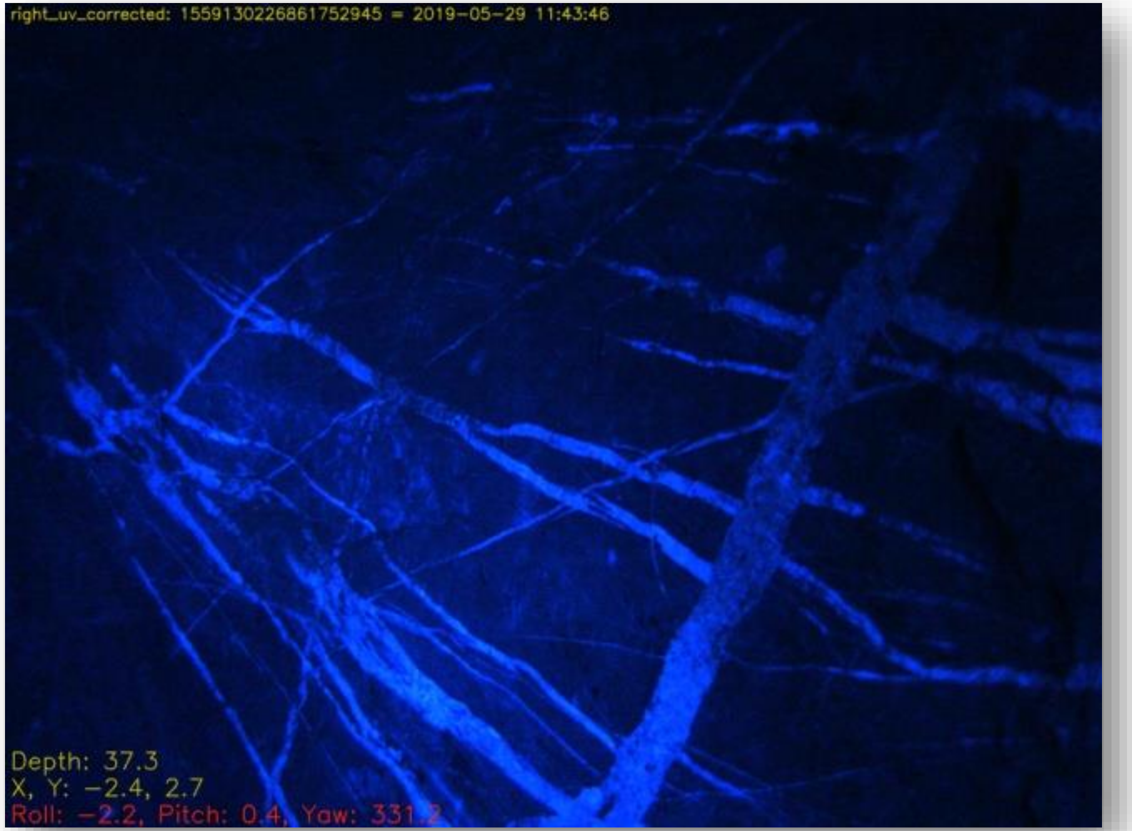
Underwater sensor technology

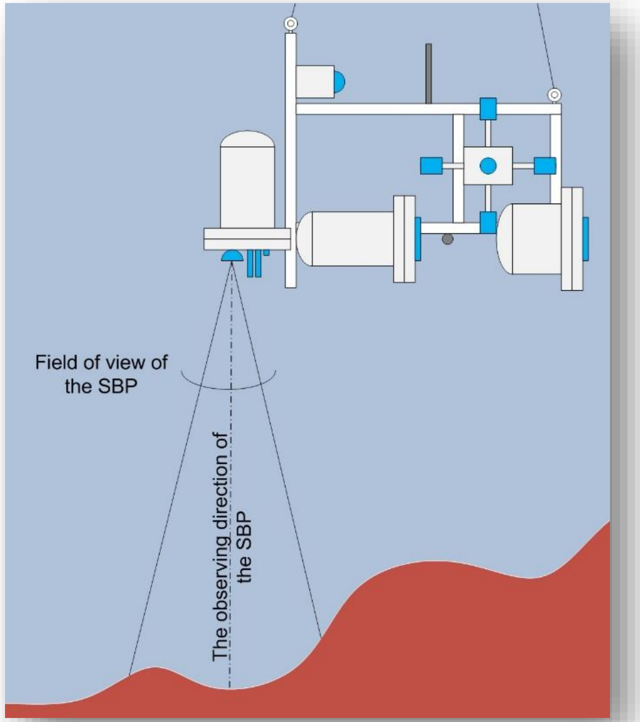
Multi/hyperspectral imaging

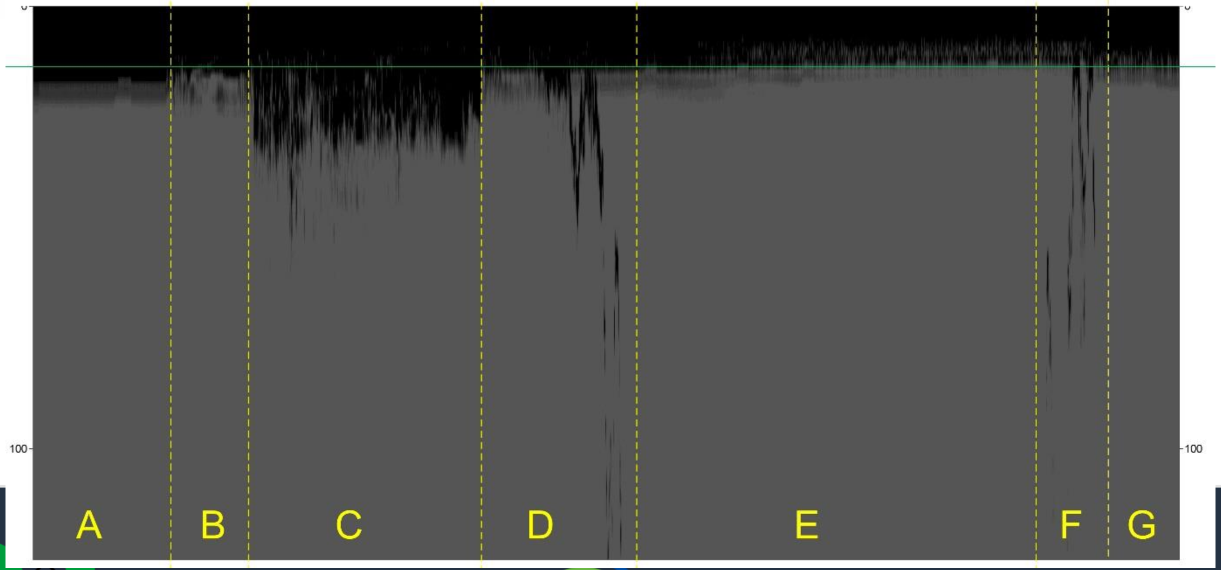


Underwater sensor technology

Sub-bottom sonar

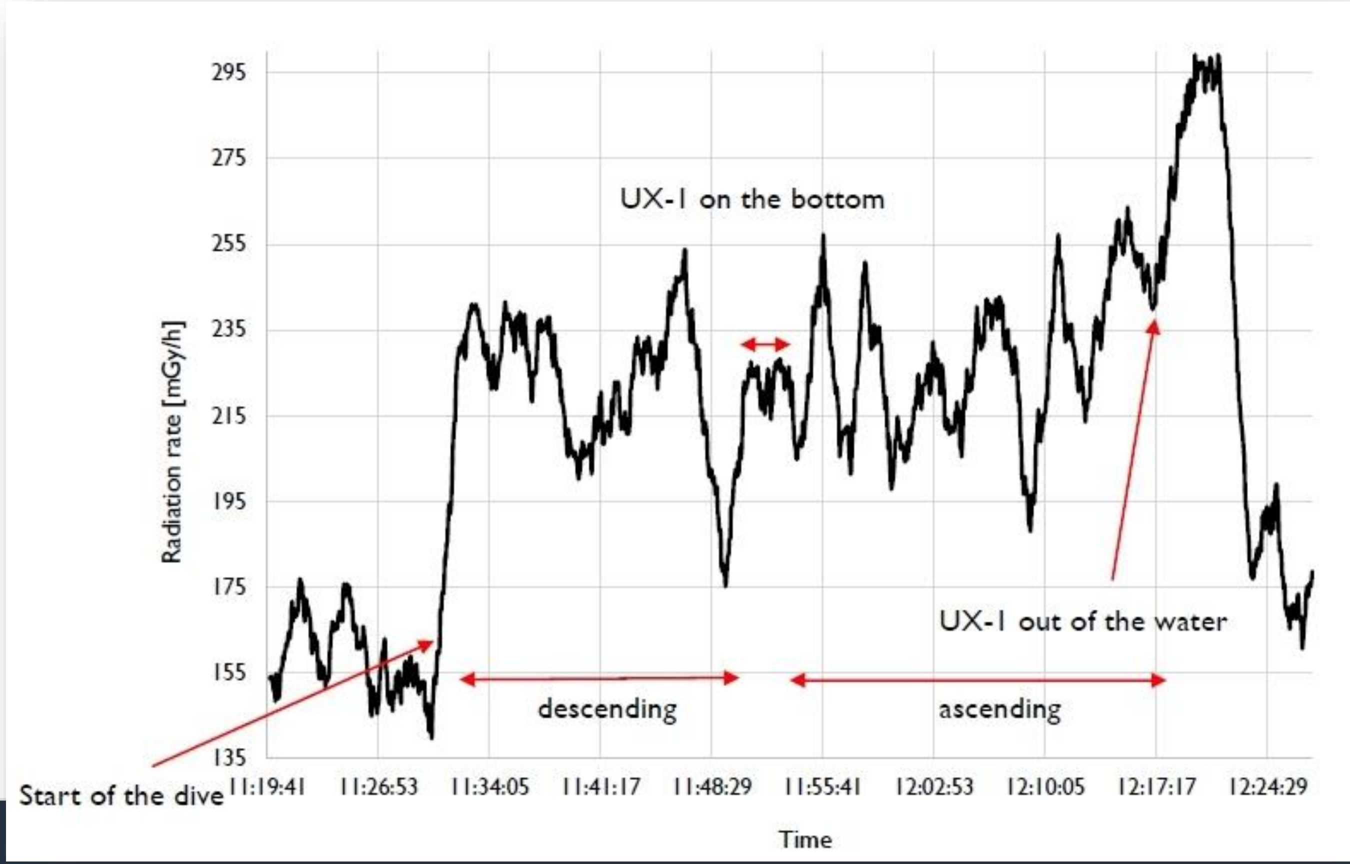
- Sediment thickness profiling
- Rock fracturing test





Underwater sensor technology

Gamma-ray detector



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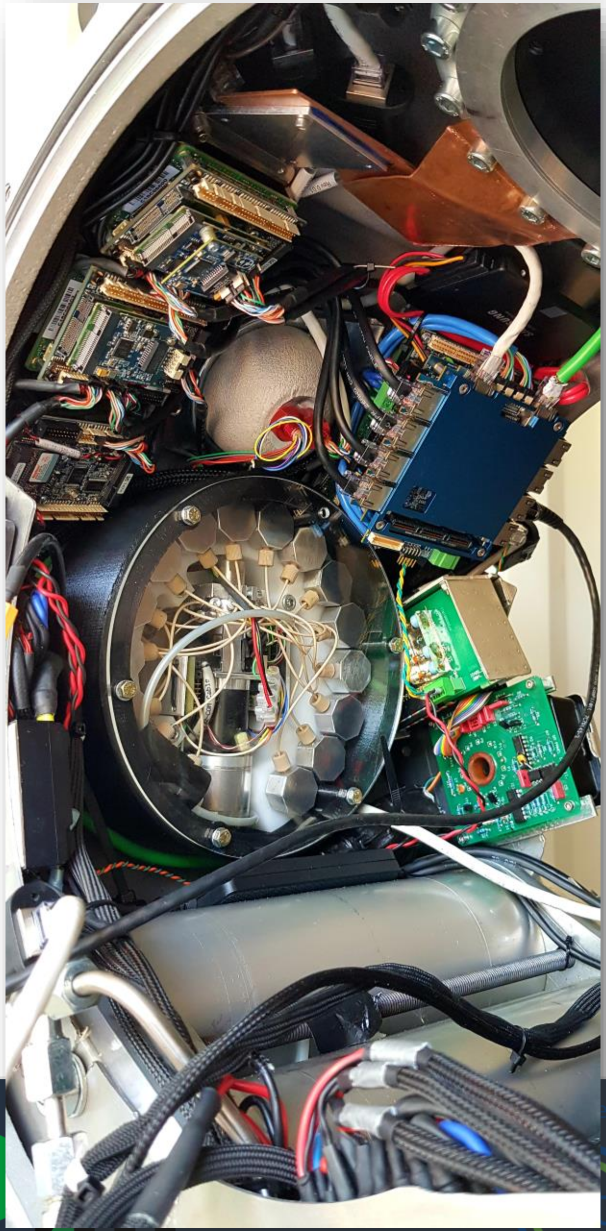
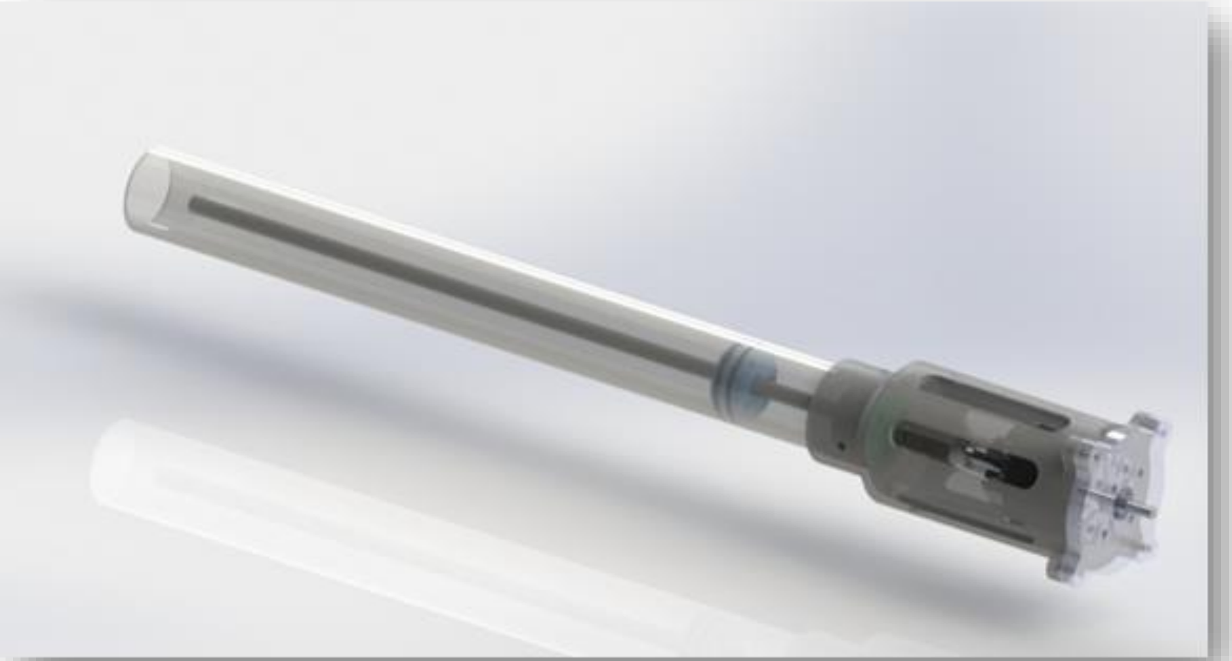


Underwater sensor technology

Water sampler unit

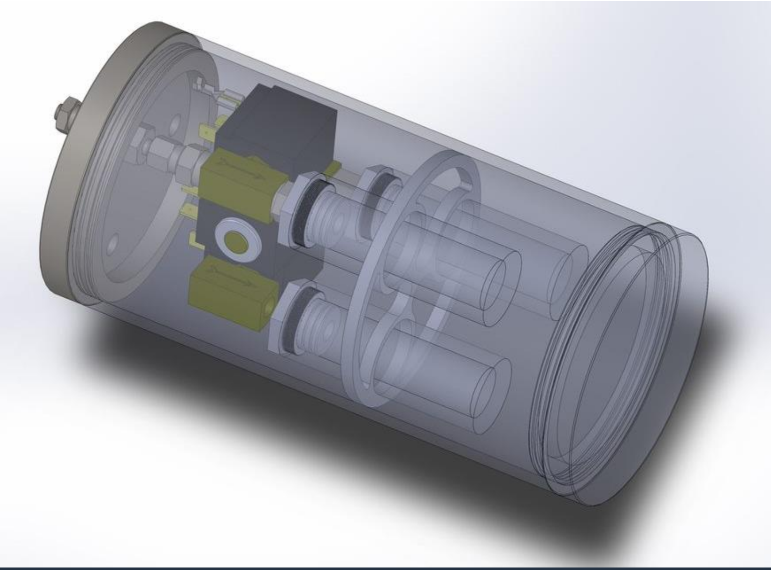
- Energy consumption: ~ 4 A peak, 2 A constant @ 12 VDC
- Sampling time: ~ 4-5 s
- Dry mass: ~ 250-300 g
- Dimensions: 410x70 mm (length x diameter)
- Interface: RS-485
- Planned max. operational depth: 1500 m

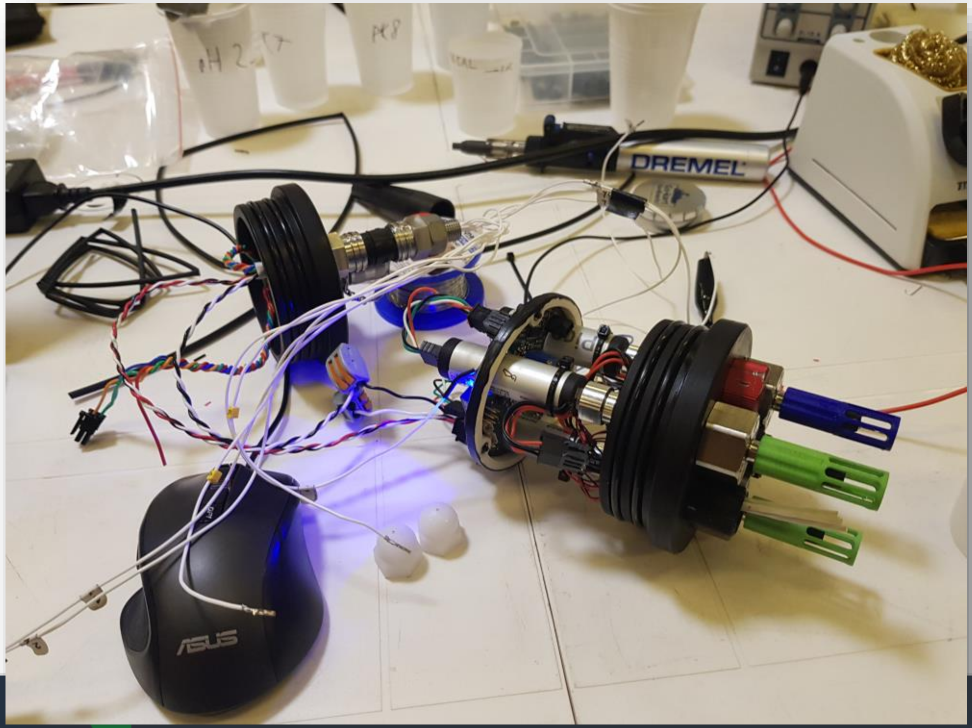


Underwater sensor technology

Water parameter unit

- Energy consumption: 500 mA constant
- Dry mass: ~1.4 kg
- Dimensions: 180x80 mm (length x diameter)
- Interface: RS-485
- Max. operational depth: 1000-2000 m





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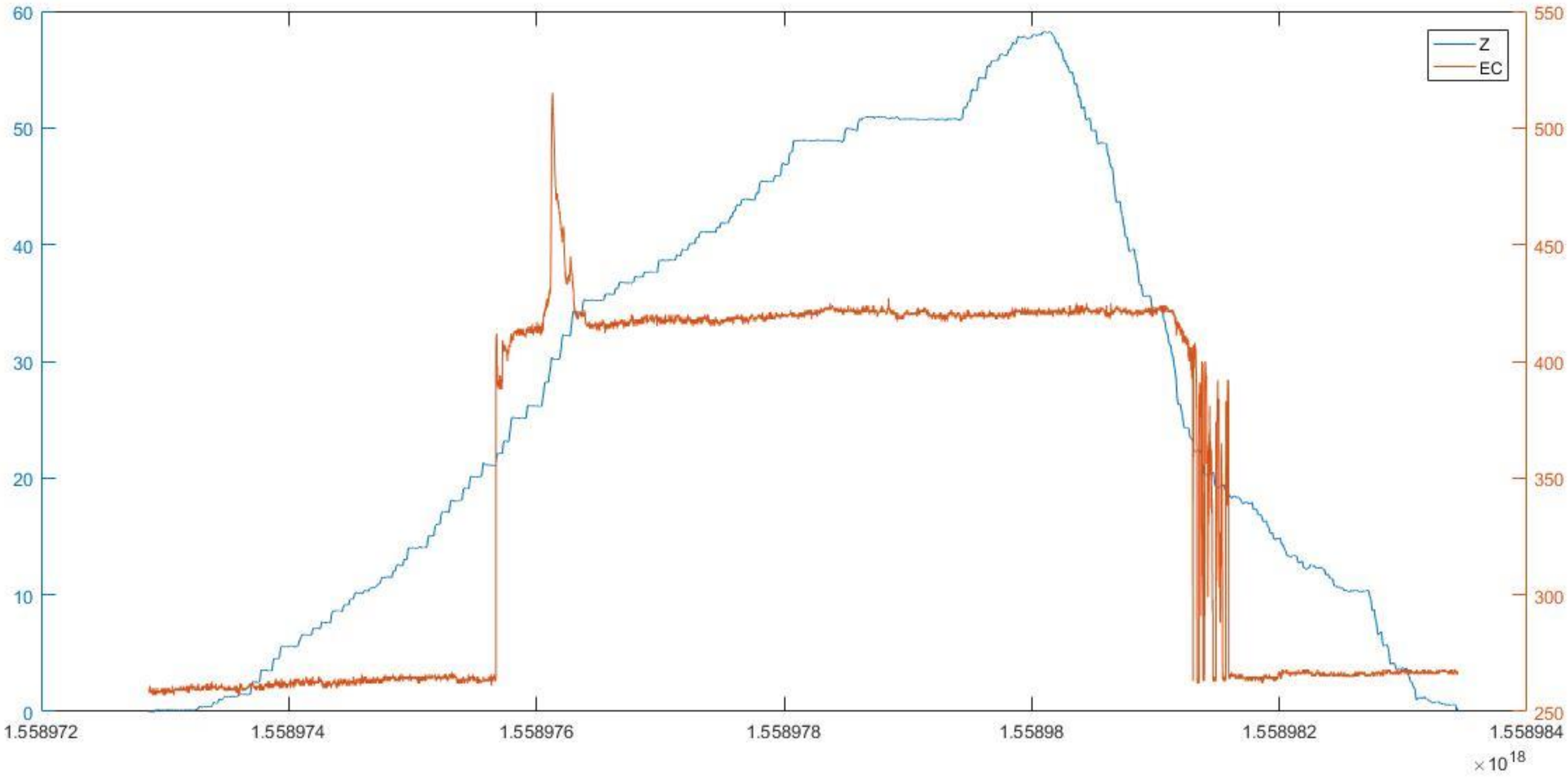
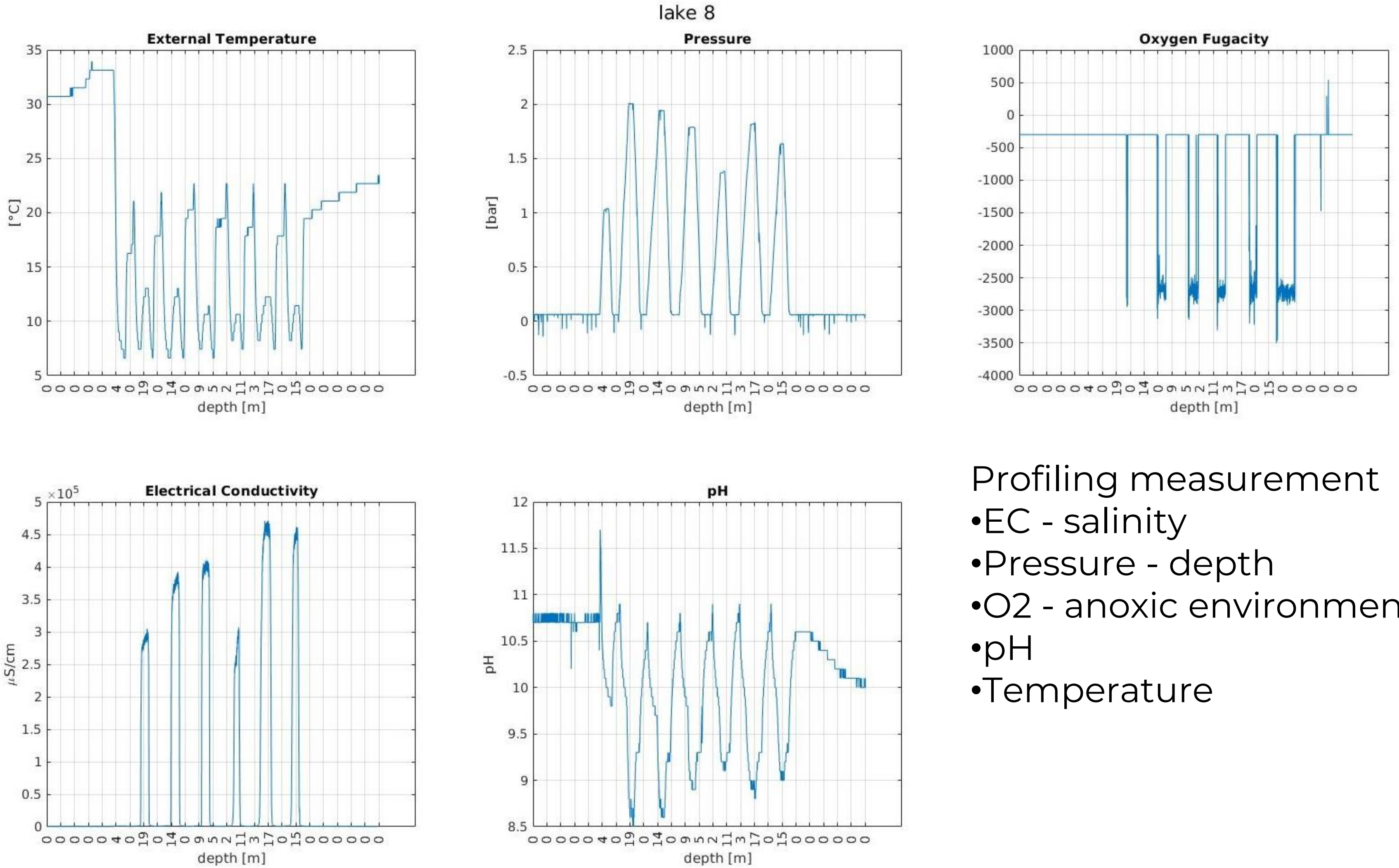
Underwater sensor technology
Water parameter unit

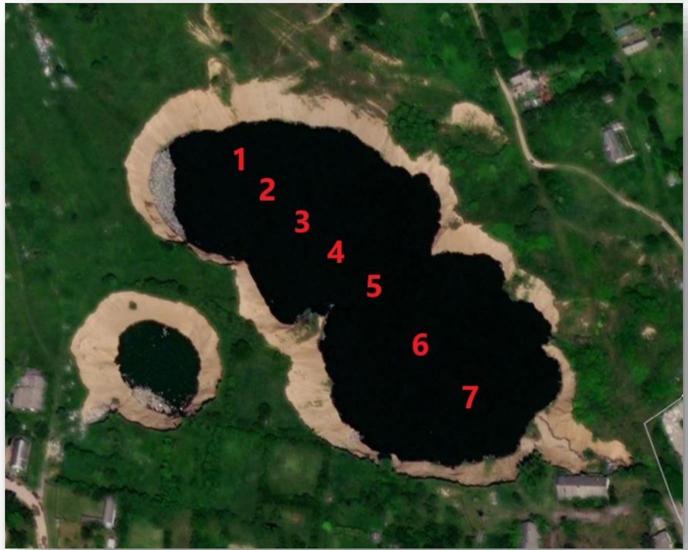


ESEE

Underwater sensor technology

Water parameter unit



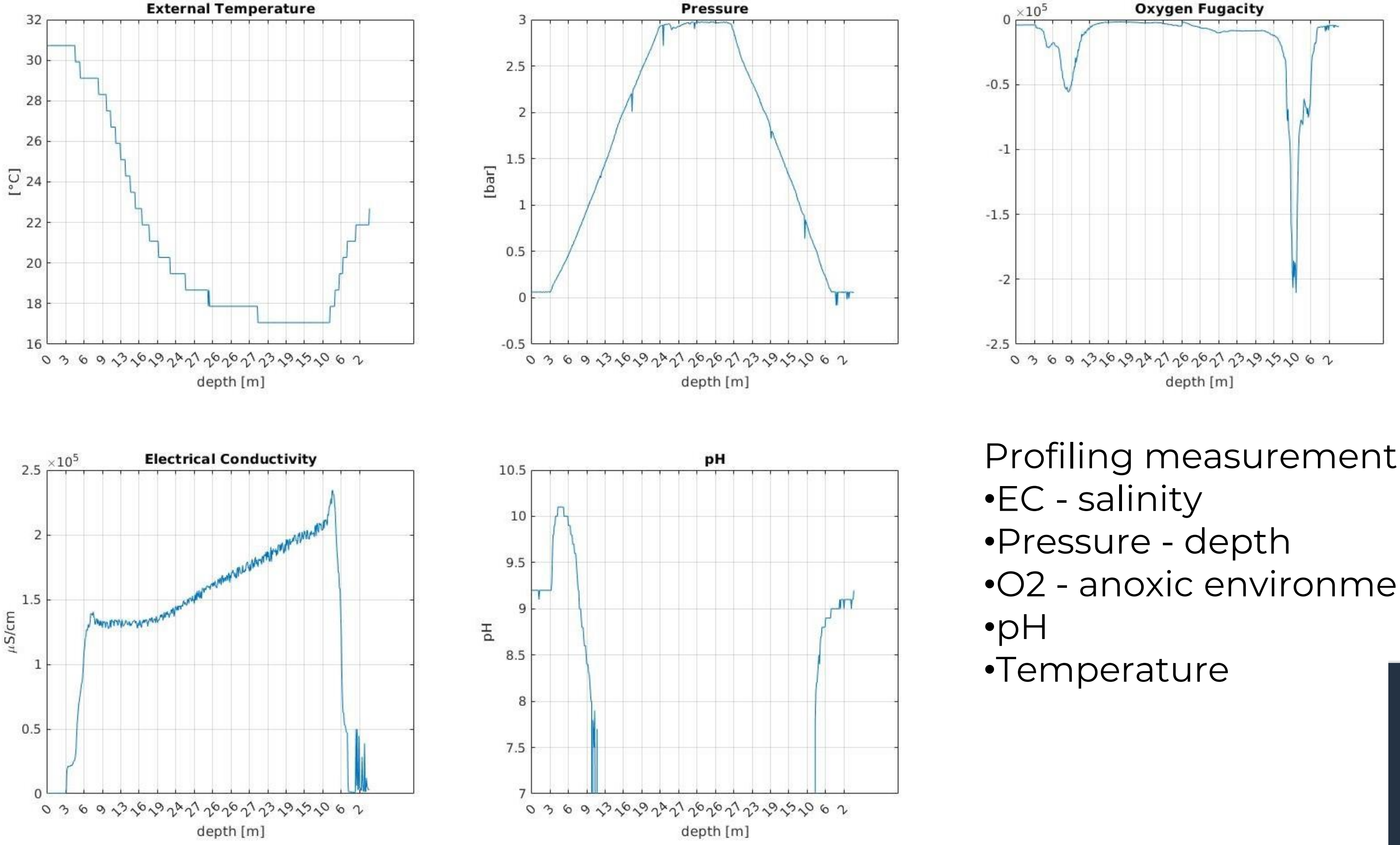


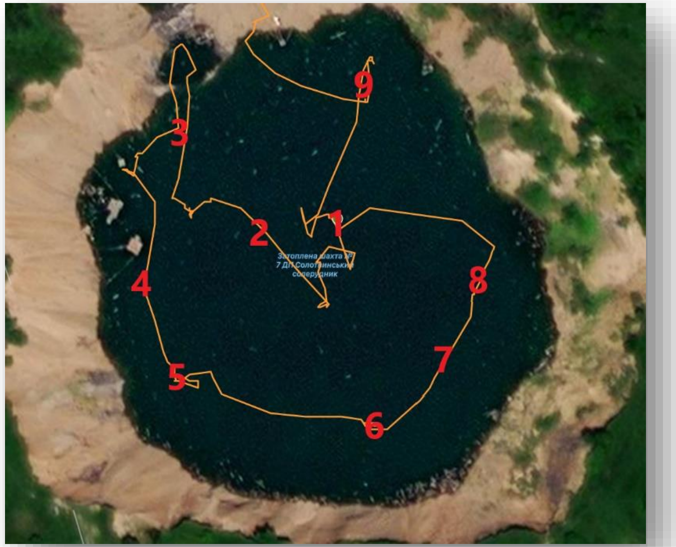
Profiling measurement
- EC - salinity
- Pressure - depth
- O2 - anoxic environment
- pH
- Temperature

Underwater sensor technology

Water parameter unit

Sample 1



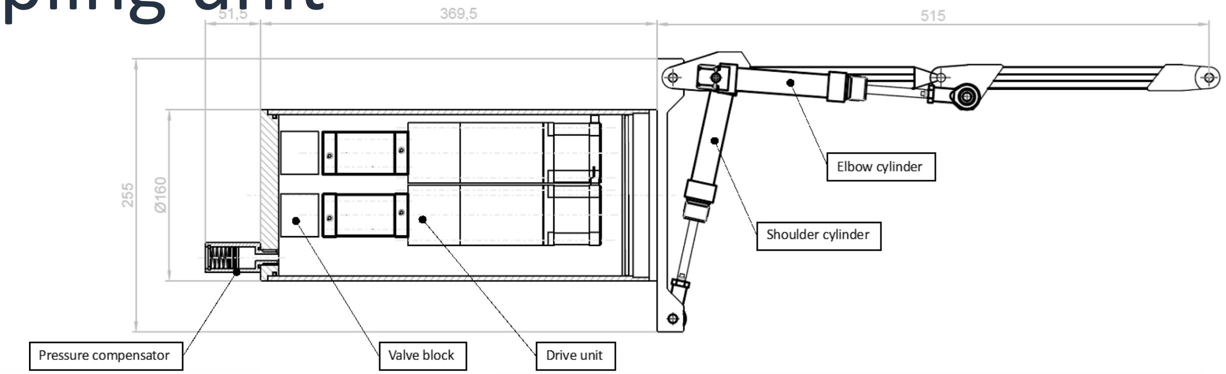


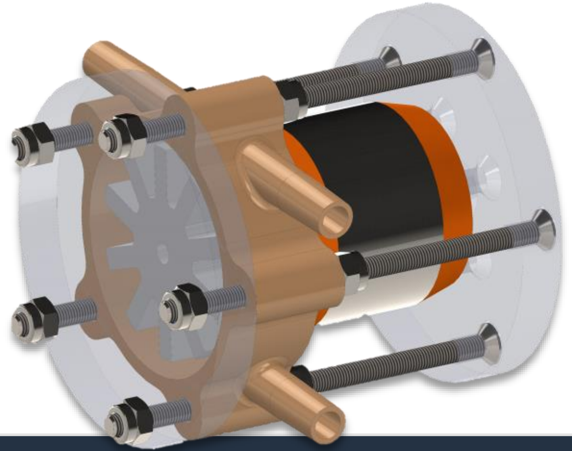
Profiling measurement
- EC - salinity
- Pressure - depth
- O2 - anoxic environment
- pH
- Temperature

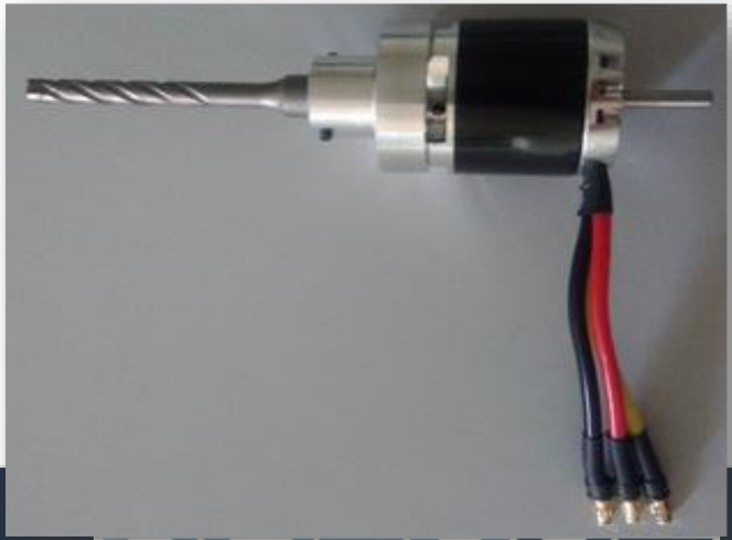
Underwater sensor technology

Rock sampling unit

- Pump: ~ 4 A peak, 2 A constant @ 12 VDC
- Dry mass: ~ 300 g
- Interface: RS-485
- Max. operational depth: 1500 m
- Water pump (fully immersed)
- Filter on inlet side
- 3D printed + acryl parts

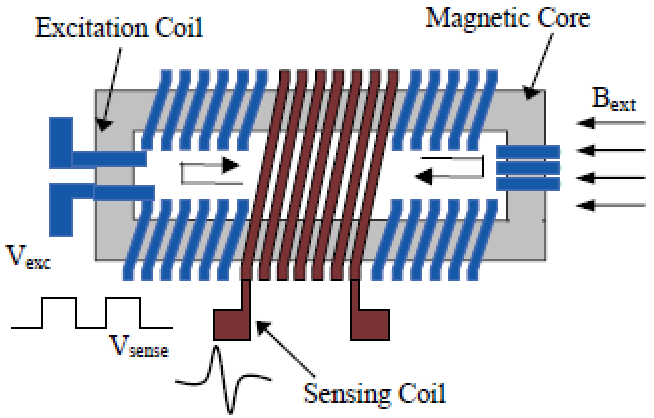




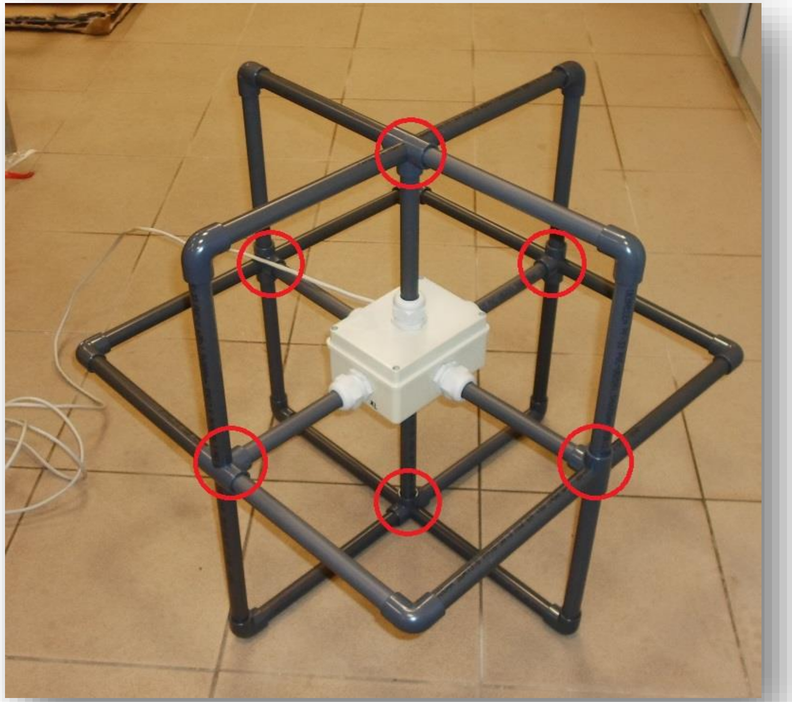


Underwater sensor technology

Fluxgate magnetometer



- Fluxgate compasses and gradiometers measure the direction and magnitude of magnetic fields
- The device that serves for the vectorial measurement of low intensity magnetic fields.
- It is relatively simple but allows to reach resolutions of the order of the nanotesla.



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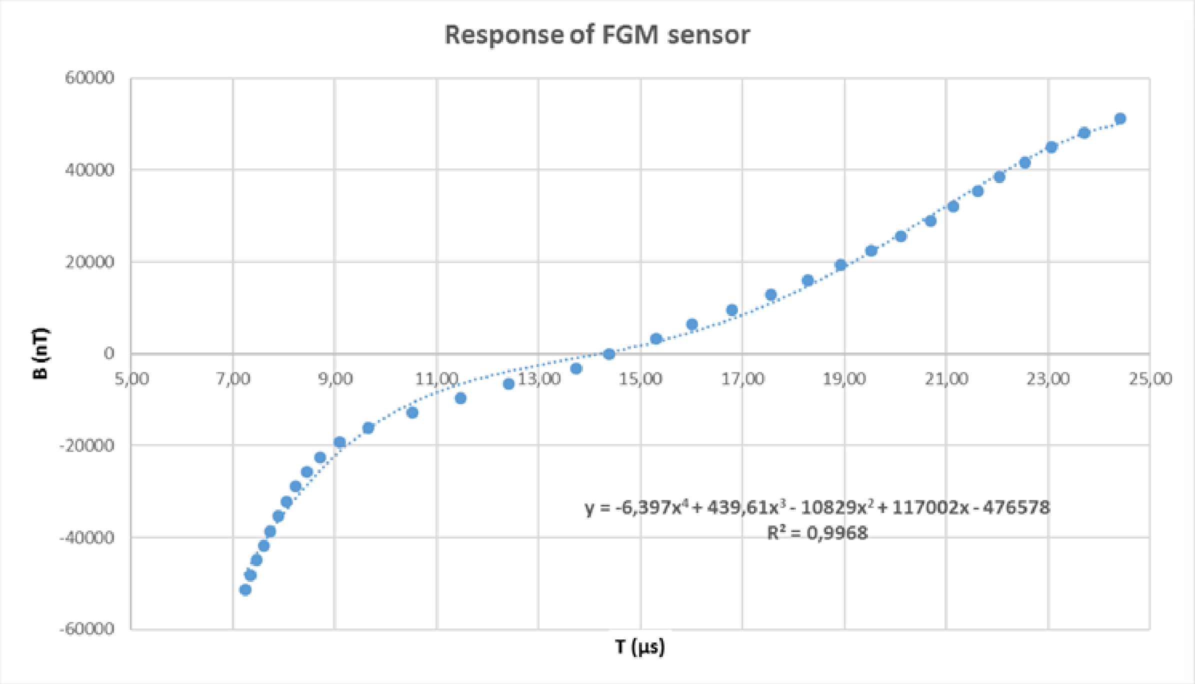
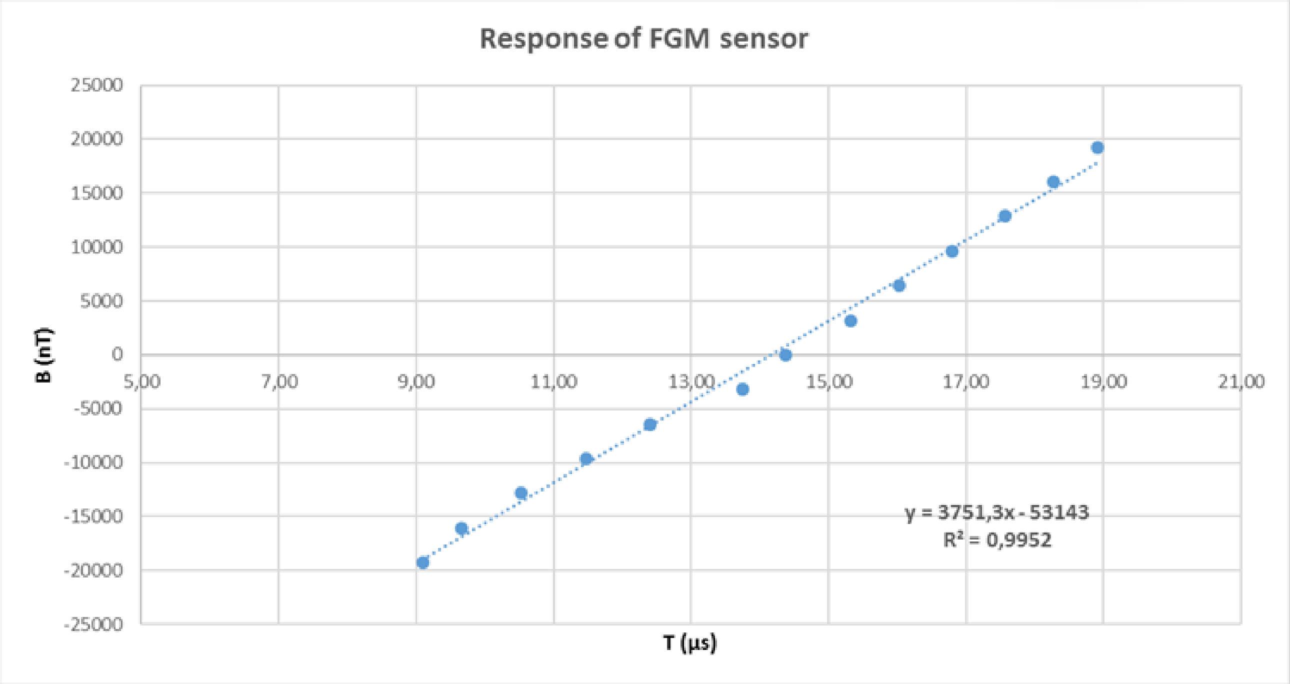
Underwater sensor technology

Fluxgate magnetometer





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UNEXUP

Summary

- Underwater environments
- Robotics
- ROV/AUV
- Market solutions
- UNEXMIN/UNEXUP
- Underwater navigation
- Underwater sensor technology

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