Subsea 3D Laser Imaging: New Developments

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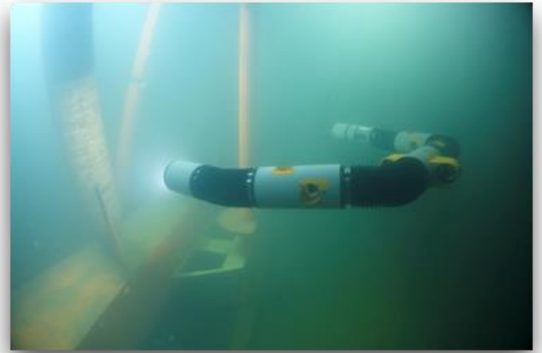


CONVENTIONAL IMAGES FROM UNDERWATER SUFFER OF:

- Low Contrast
- Limited range
- Colors alteration

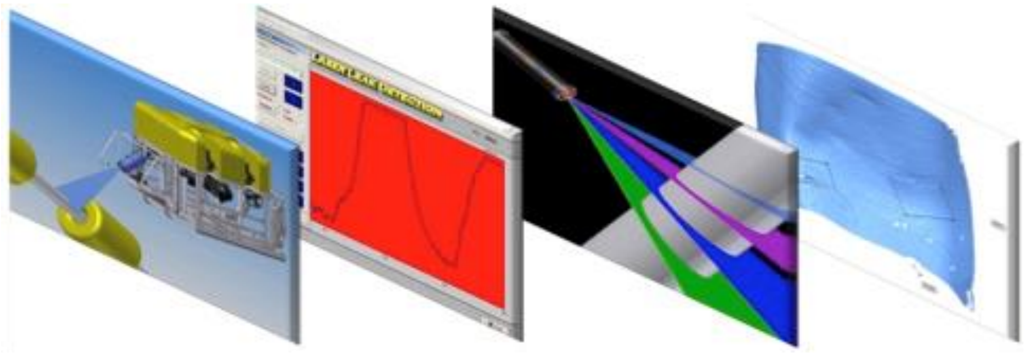
Post-acquisition processing allows for image enhancement in terms of contrast and precise coloring.

Original Image

After image enhancement

SMART IMAGING IN SUBSEA ENVIRONMENT GOES BEYOND CONVENTIONAL PASSIVE IMAGE ACQUISITION AND PAVES THE WAY TO A NEXT LEVEL OF USEFUL INFORMATION.

Smart Imaging Generation → Powerful Information

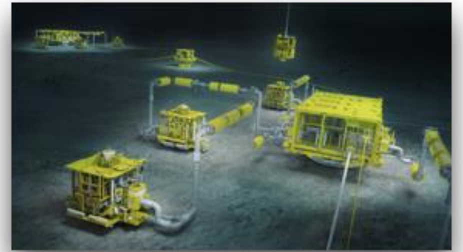


Inspect → Analyze → Report

Some Applications

Marine Biology

Subsea Oilfields

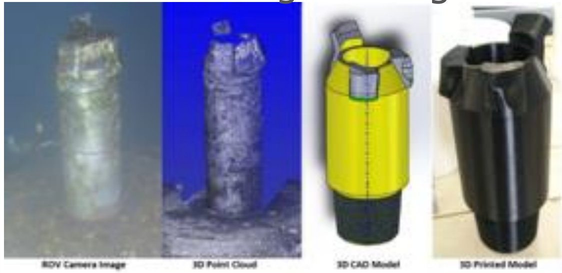


Marine Archaeology

Nuclear incidents

Mooring chains inspections

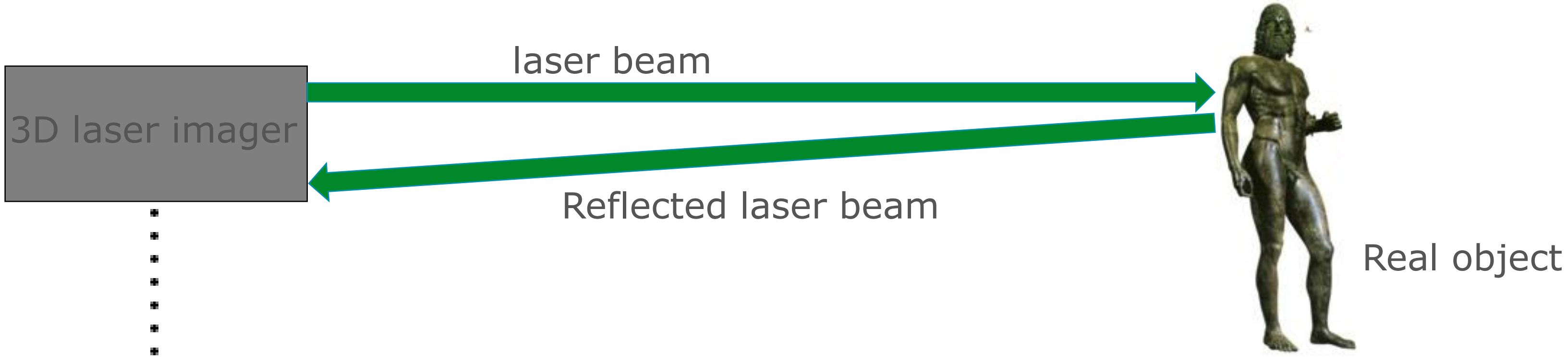
Reverse Engineering



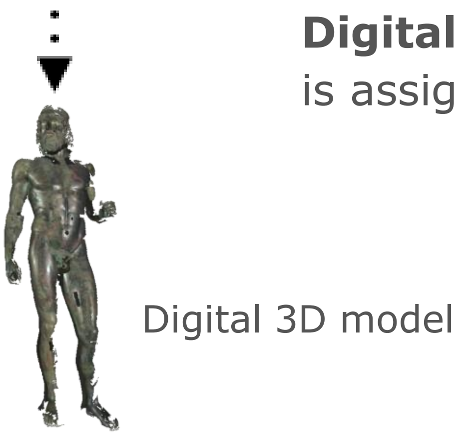
Recovery in naval disasters

A 3D LASER IMAGING SYSTEM ANALYSES BY MEANS OF A LASER BEAM A REAL OBJECT TO COLLECT DATA ON ITS SHAPE AND POSSIBLY ITS APPEARANCE (E.G. COLOUR).

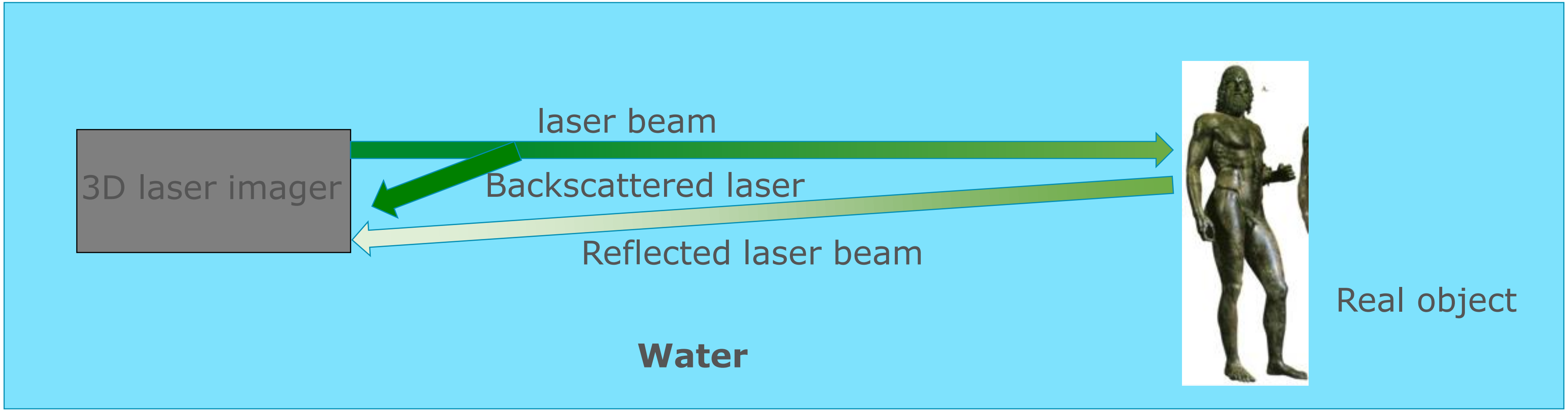
THE COLLECTED DATA CAN THEN BE USED TO CONSTRUCT DIGITAL 3D MODELS.



Digital 3D model: 2D image where at each pixel is assigned a set of 3 spatial coordinates.



Terrestrial 3D laser imaging is a mature technique and a market worth billions of dollars.

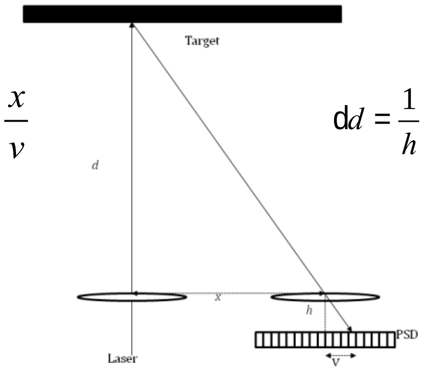


Scientific and Technological Challenges

- Laser light is absorbed & diffused in seawater
  - Limitation to the operational range
  - Limitation to image resolution and quality
- The device must be installed onboard an ROV and/or deployed by a Scuba
  - Pressure resistant housing
  - Remote control
  - Effects due to ROV instability

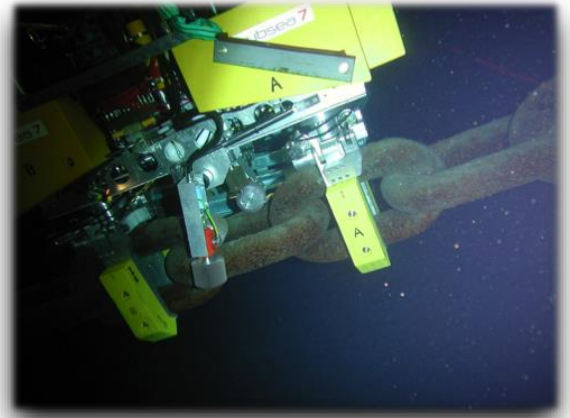
Triangulation
(CW Laser, Laser Line)

$$d = h\frac{x}{v}$$

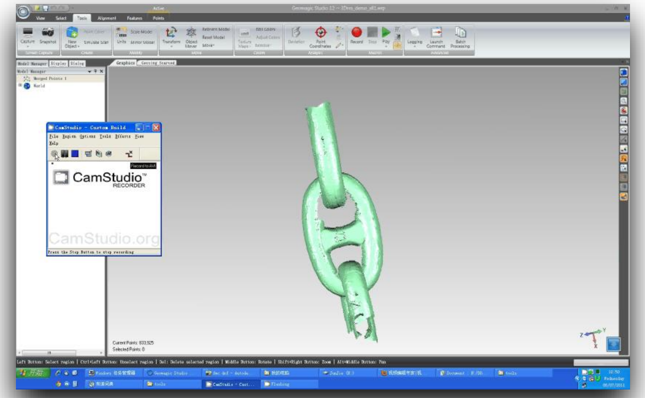


$$\mathrm{d}d = \frac{1}{h} \times \frac{d^2}{x}\mathrm{d}v$$

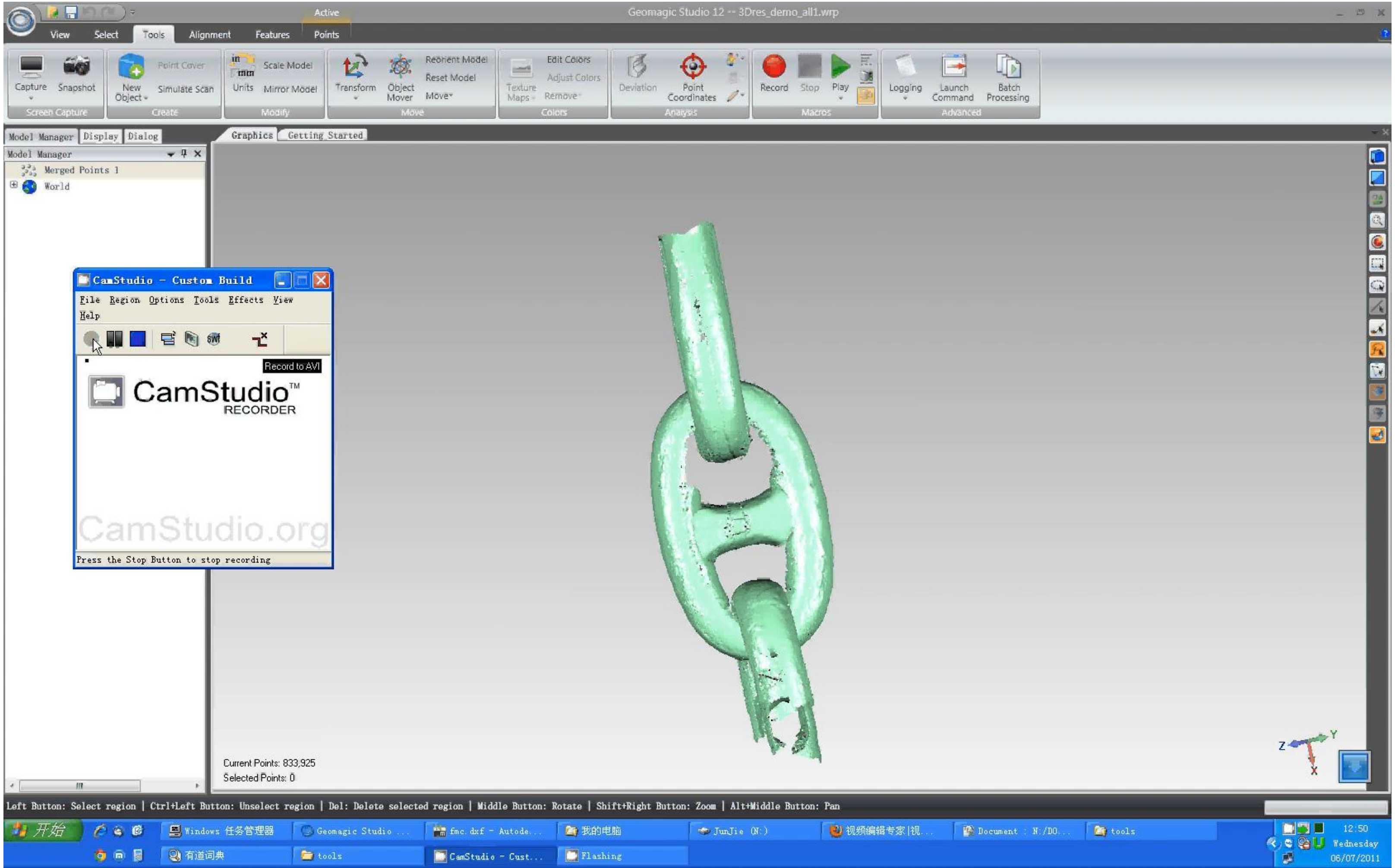
Range accuracy dd scales with square of range d



North Sea - Mooring chains inspection with a crawler



Pros: Compact Systems
Fast acquisitions
Cost effective
Cons: Limited range



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Simulate Scan
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Mirror Model
Modify
Transform
Object Mover
Reorient Model
Reset Model
Move
Texture Maps
Edit Colors
Adjust Colors
Remove
Colors
Deviation
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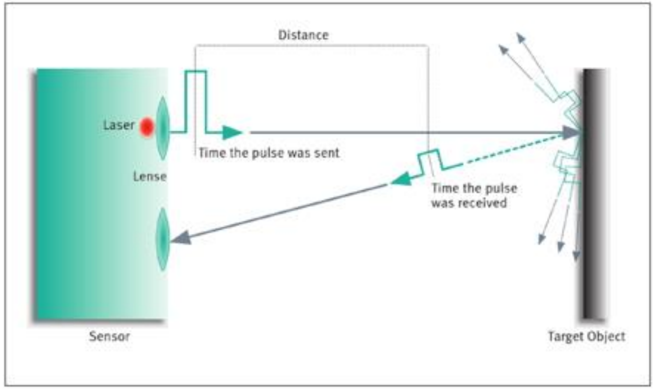
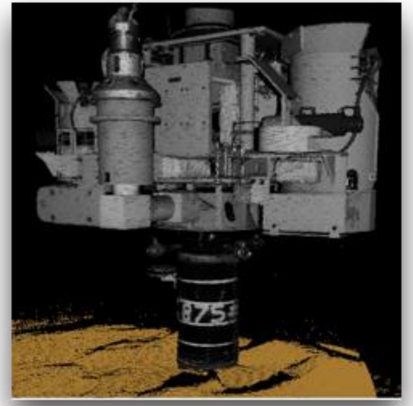
Time of Flight (Pulsed laser)



L=(c/n)T
L=range
n= index of refraction of water
T=transit time

Pros: Efficient backscattering rejection
Monostatic configuration
Cons: Limited resolution

Deployed on a industrial class ROV



3D model of a Subsea XTree

THE IDEAL FEATURES OF A 3D LASER IMAGING SYSTEM FOR SUBSEA APPLICATIONS AND WHAT ENEA IS DOING TO MEET THESE TASKS

Operation at short and long range
High resolution (accuracy)

Use of intensity modulated laser beams

Very compact (Operation onboard observation class ROVs)
Autonomous (Operation onboard AUVs)

Development of fit for purpose electronics

Simultaneous registration of 3D shape and colors

RGB technology

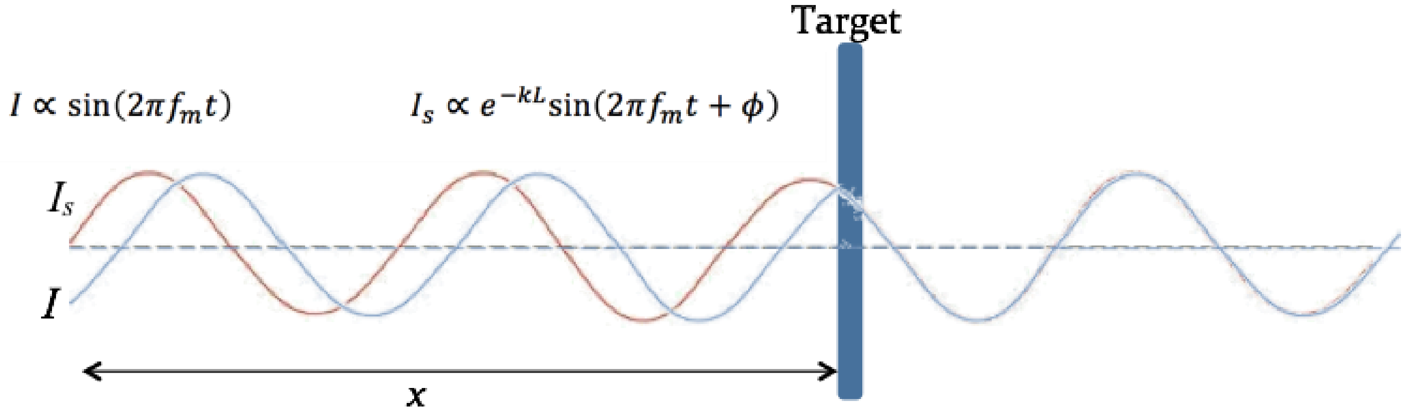
Operation in harsh environment (i.e radioactively contaminated seawaters)

Radiation hardened components

Autonomous Underwater Vehicle

THE SUBSEA 3D LASER IMAGING SYSTEM DEVELOPED AT ENEA IS BASED ON AN AMPLITUDE MODULATED LASER BEAM

The intensity of the sounding laser beam (blu) is modulated sinusoidally at a frequency f_m

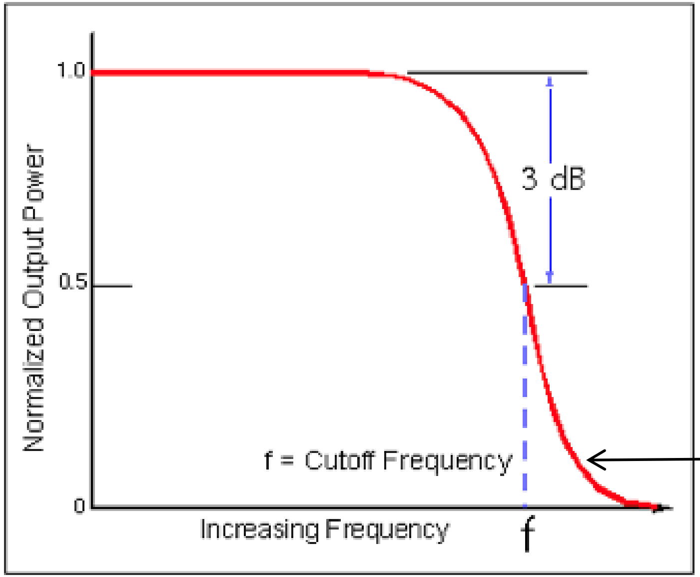


The reflection from the target (red) has a phase shift φ which is related to the range x

$$x = \frac{c\phi}{4\pi n f_m}$$

ADVANTAGE OF USING AN INTENSITY MODULATED LASER BEAM

The intensity of the backscattered laser has a low pass filter dependence on the modulation frequency f_m.



low pass filter

$$I_{back} \propto I_0 \frac{1}{\sqrt{1+\left({f_m}/{f_c}\right)^2}}$$

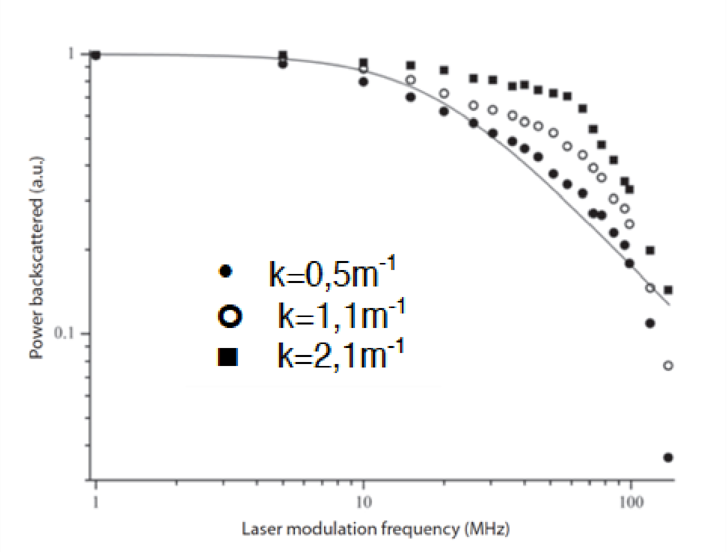
$$f_c = {kc}/{2\pi n}$$

Cut-off frequency

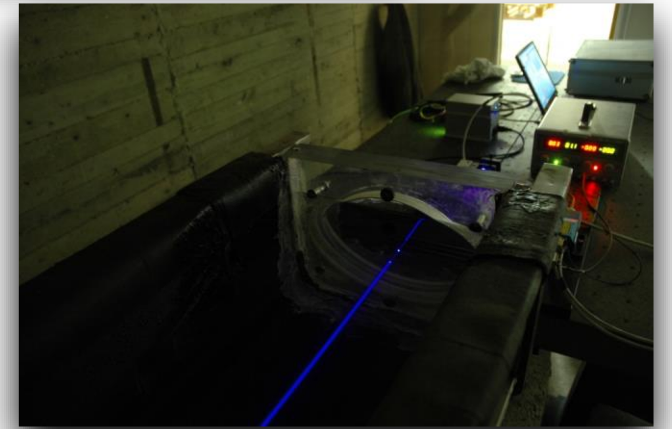
k=water attenuation coefficient (increases with water turbidity)

If the system operates at modulation frequency larger that the cut off frequency the contribution of the optical noise originating from water backscattered laser is minimized.

EXPERIMENTAL VERIFICATION OF THE LOW PASS FILTER BEHAVIOR

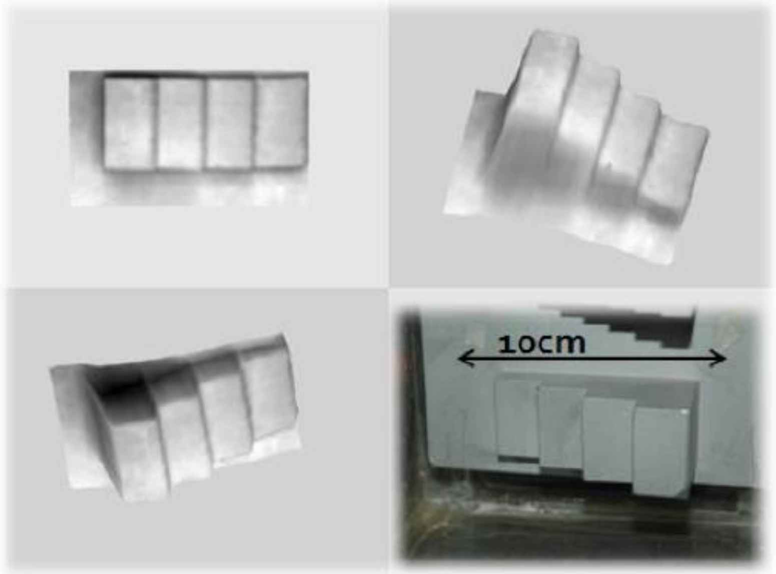


25m long test tank facility



The cut off frequency for typical values of k for coastal and open seawaters is within the range 30-100 MHz.
COTS diode laser have modulability up to 200MHz.

EXPERIMENTAL RESULTS



Cut-off frequency 20MHz

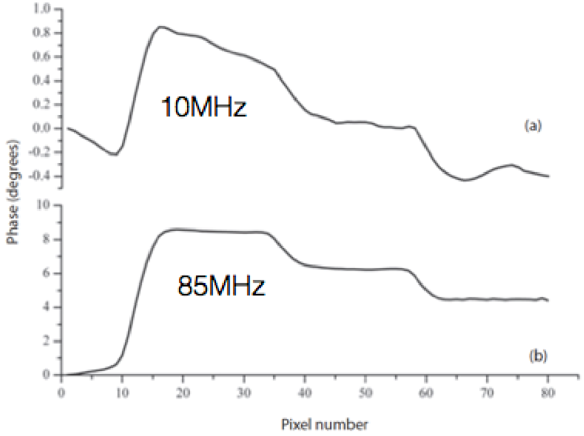


FIG. 5 Linear scan of the target profile for (a) $f_m = 10$ MHz and (b) $f_m = 85$ MHz.

Distance from the sensor 10m.
Modulation frequency 85 MHz
water attenuation coefficient k = 0.3m-1
80x40 pixels
Acquisition time 5sec.

EXPERIMENTAL RESULTS

3D model of a spool piece acquired immersing the version 2 of the device in a test pool.

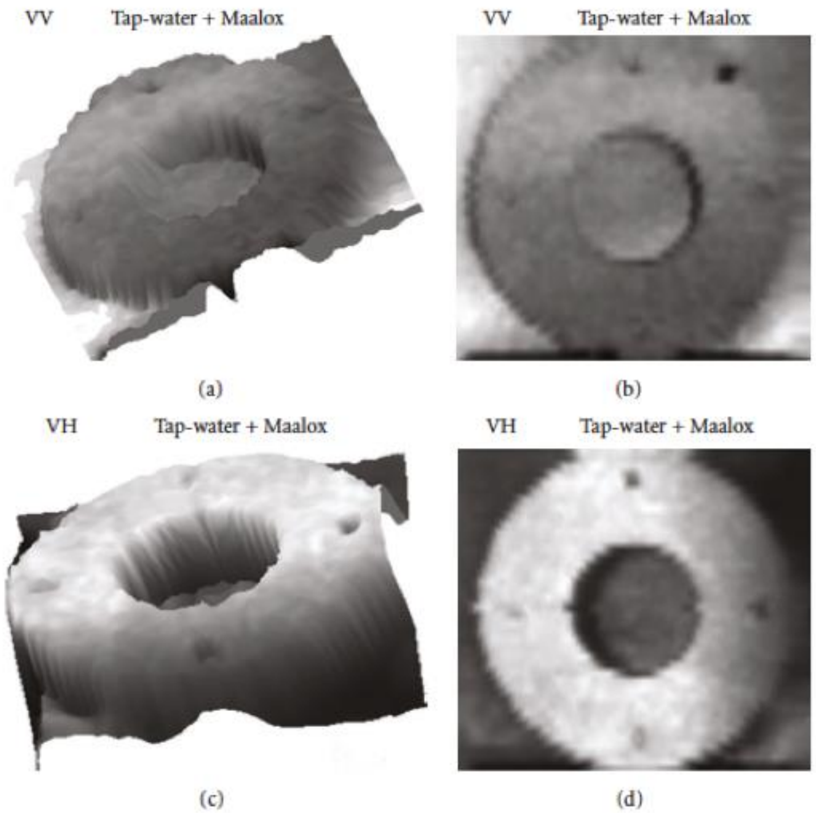
Water depth 5m

Distance of the target form the sensor: 10m

Modulation frequency 85MHz

Digital model with accuracy of 4%

THE RESOLUTION OF THE 3D MODELS ACQUIRED CAN BE FURTHER IMPROVED BY ADOPTING A CROSS POLARIZED CONFIGURATION FOR THE LASER AND THE RECEIVING OPTICS. IN FACT MOST OF THE TARGET DEPOLARIZES THE REFLECTED LASER BEAM.



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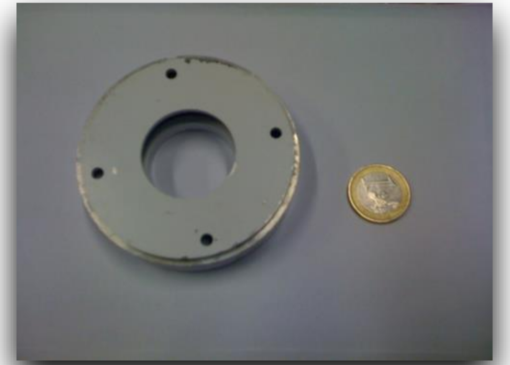
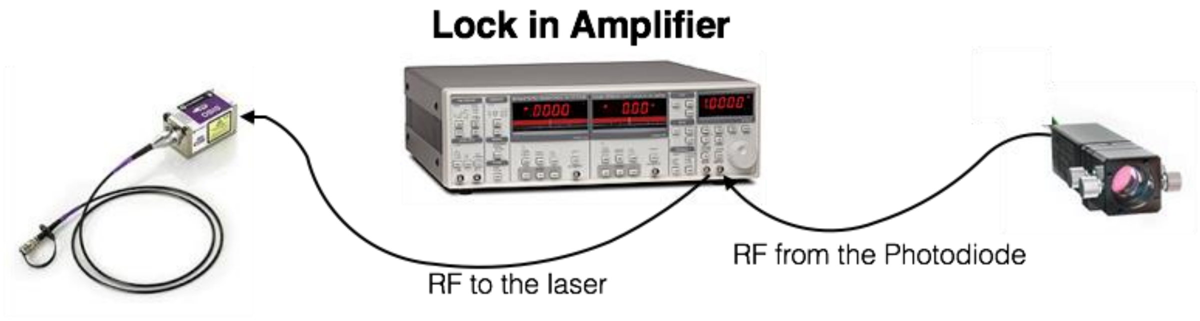
Acquisition time 5sec.



THE MAIN BOTTLENECK FOR DEVELOPING AN AMPLITUDE MODULATED 3D LASER IMAGING SYSTEM FOR SUBSEA APPLICATIONS IS THE GENERATOR AND ANALYZER OF RADIO FREQUENCY



- ❑ RF electrical signals cannot be transmitted efficiently over long distances due to dispersion effects.
- ❑ Commercially available Lock-In Amplifiers (LIA) are bulky

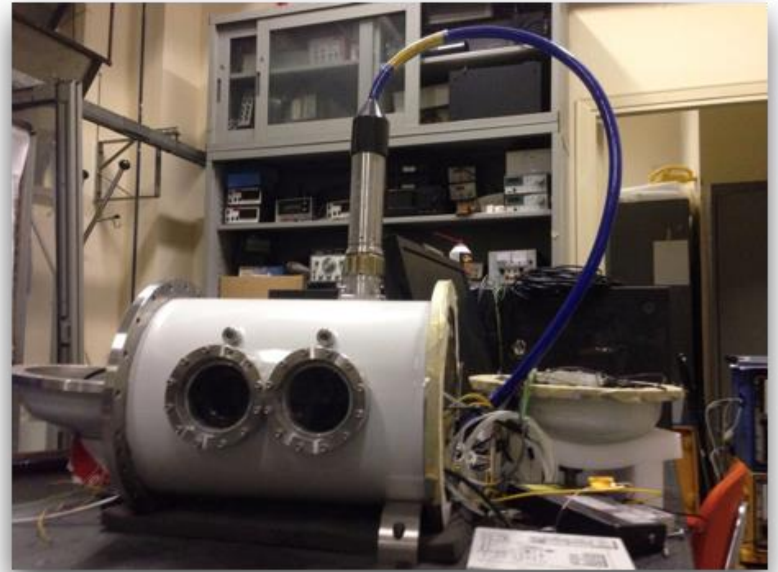
THE ENEA LASER 3D IMAGING SYSTEM FOR SUBSEA APPLICATIONS

Version 1 - 2013

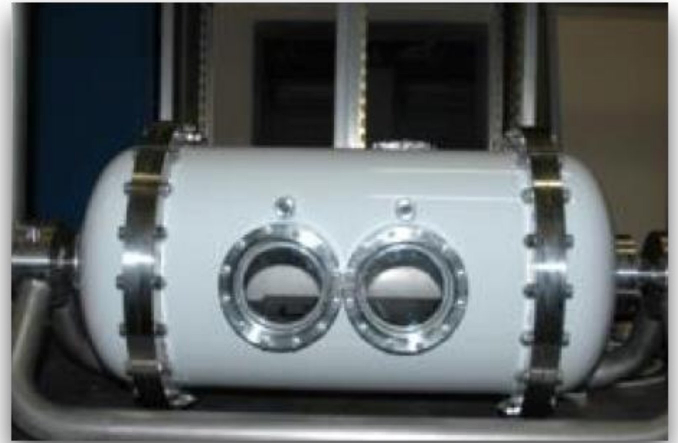
The small cylinder contains the laser source, the scanning system and the receiving stage (lens and fast photomultiplier). The big cylinder allocates the electronic modules (e.g., lock-in amplifier)

Weight:150 KG **Volume**:400L **Support**: Heavy work class ROV

THE ENEA LASER 3D IMAGING SYSTEM FOR SUBSEA APPLICATIONS



Version 2 - 2015



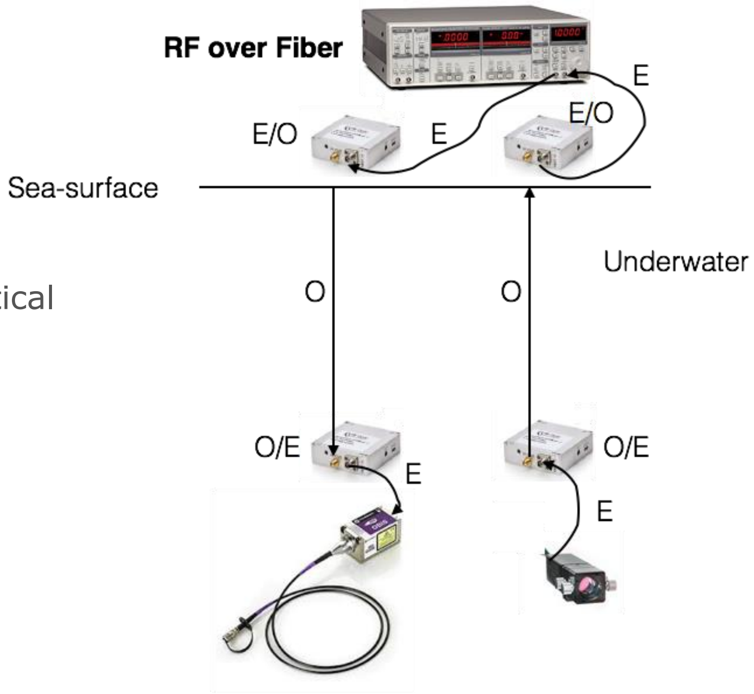
Only one cylinder with the laser source, the scanning system and the receiving stage. The lock amplifier is onboard the controlling vessel and the RF frequency is transmitted over fibers by means of Electrical/Optical RF converters.

Weight: 30KG **Volume**: 50L **Support**: Observation/light work Class ROV

THE COMMAND AND CONTROL PART OF THE DEVICE IS ONBOARD THE VESSEL AND ONLY THE OPTICAL HEAD OPERATES UNDERWATER.

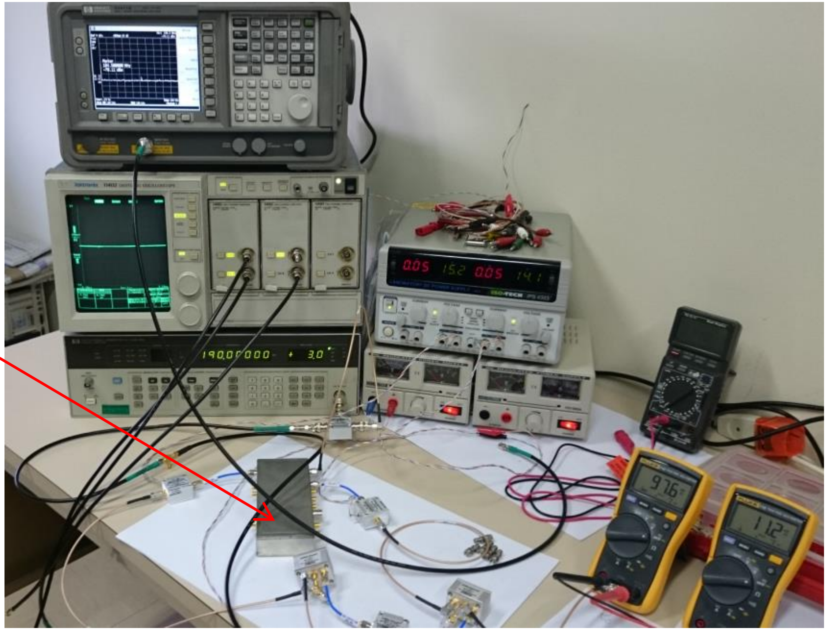
Command & Control

The tether transmits through single mode optical fiber the optically RF modulated signal



TO OVERCOME THE LIMITATIONS IMPOSED BY COMMERCIAL LOCK-IN AMPLIFIERS (LIA) ENEA HAS DEVELOPED IN ITS LABORATORIES A FIT FOR PURPOSE COMPACT LIA.

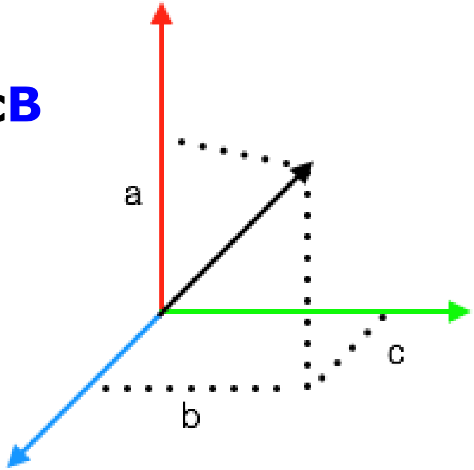
ENEA Lock In Amplifier



This achievement is the starting point for the **Version 3** of the ENEA subsea 3D laser imaging system

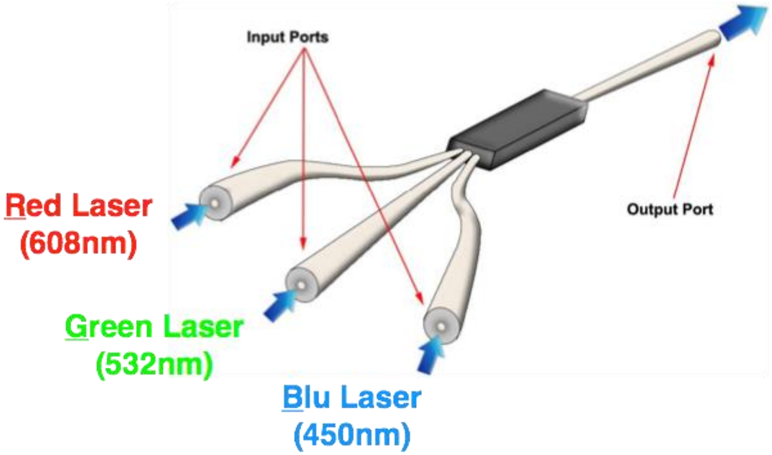
Weight:15 KG **Volume**:30L **Support**: Mini observation Class ROV and AUV

Color= a$\color{red}{R}$+b$\color{green}{G}$+c$\color{blue}{B}$

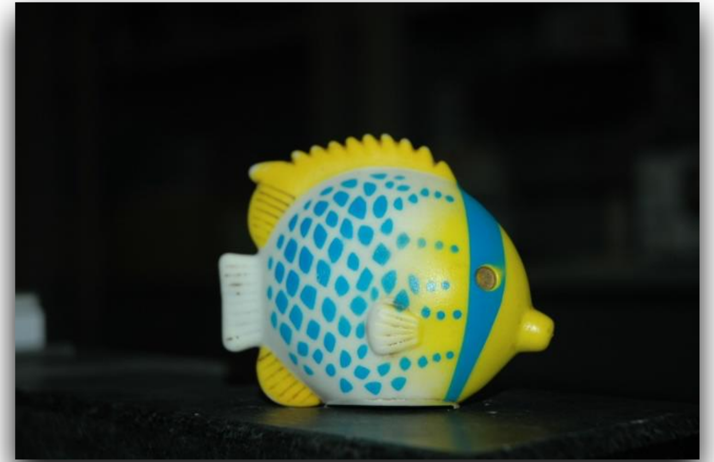


Color is a vector in a three dimensional space where a basis has been chosen.
The coordinates (a,b,c) of the vector are proportional to the reflectivity at the colors of the basis.

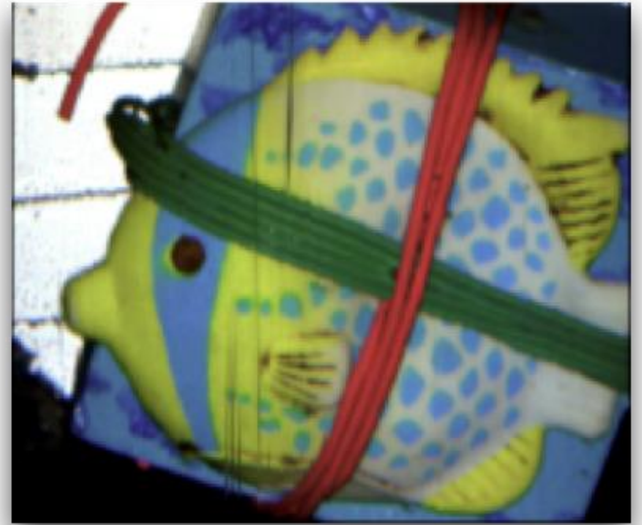
In the subsea 3D laser imaging system
this is realized by using three laser beams.
They are mixed to generate a single laser beams
which scan the target acquiring at the same
time the 3D shape and color of the target



THE FIRST 3D MODEL WITH COLORS OF AN OBJECT IMMERSED IN WATER



Real Object



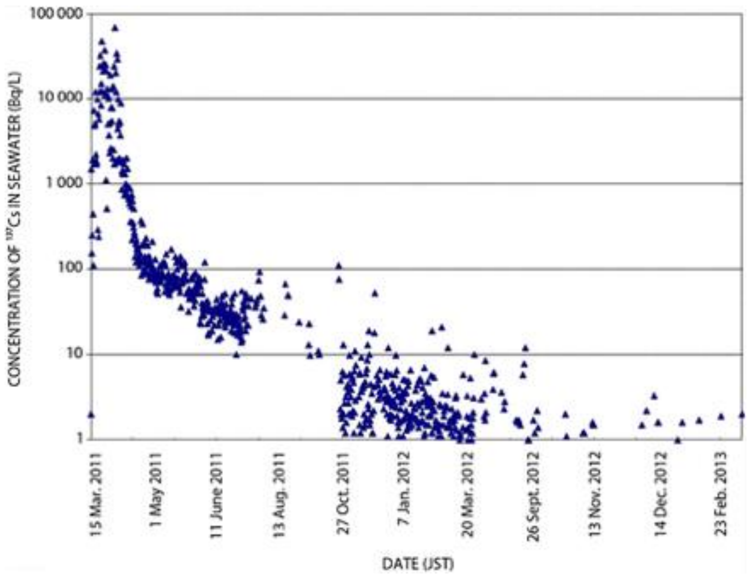
3D model

- The RGB mixed laser beam propagates 5m in water before to scan the target
- Monostatic configuration

3D model of a sea sponge

Immersed in water
5m of distance from the laser sensor
Simultaneous acquisition of 3D shape and colors
High resolution (details of 1mm resolved)

WHAT IF THE SEAWATER IS RADIOACTIVELY CONTAMINATED?

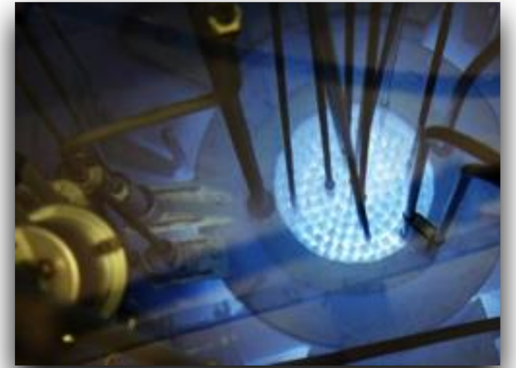


If the 3D laser imaging system is immersed in seawater with this level of contamination a value of absorbed dose of the order of 105 Gy is easily achieved.
At this level of absorbed dose electronic devices do not work properly and optical components degrade.

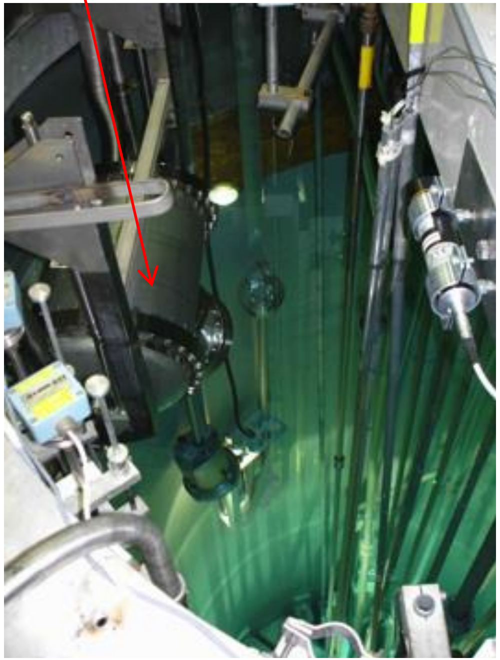
Developing a 3D laser imaging system qualified to operate in contaminated seawater demands the use of radiation hardened components.

ENEA HAS DEVELOPED A 3D LASER IMAGING SYSTEM QUALIFIED TO OPERATE IN WATER CONTAMINATED UP TO 1MGY.

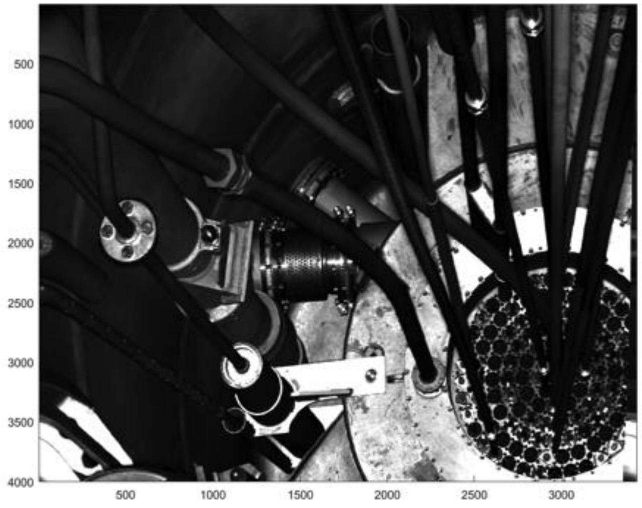
The device has been tested in a nuclear reactor at ENEA



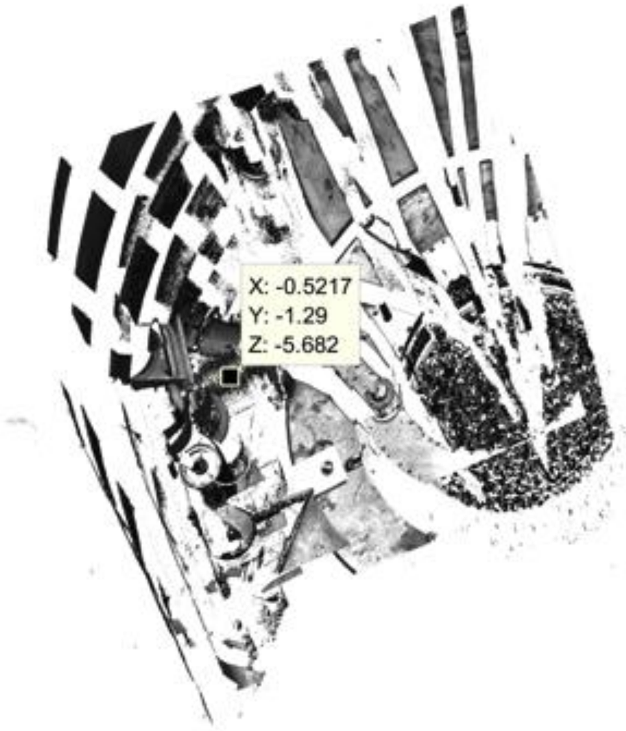
The device has been immersed in the reactor vessel with cooling water contaminated at 1MGy



EXPERIMENTAL RESULTS



3D models acquired at 7m of distance



Concluding Remarks

- Subsea 3D laser Imaging has seen promising advances during the last five years
- Most of the practical applications and R&D are carried out by SMEs and Research Centers
- The interest and active involvement of large companies is still limited
- Further improvements in performances and reduction of the costs for a survey mission could be the drivers to overcome the market barriers.

Thank you for your attention!

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www.strongmar.eu

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