CSF Project:
Robust Structured Light Coding for 3D Imaging in Difficult Conditions

On Underwater Structured Light Scanning

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- Webpage: https://www.fer.unizg.hr/3dcoding/en

Project team

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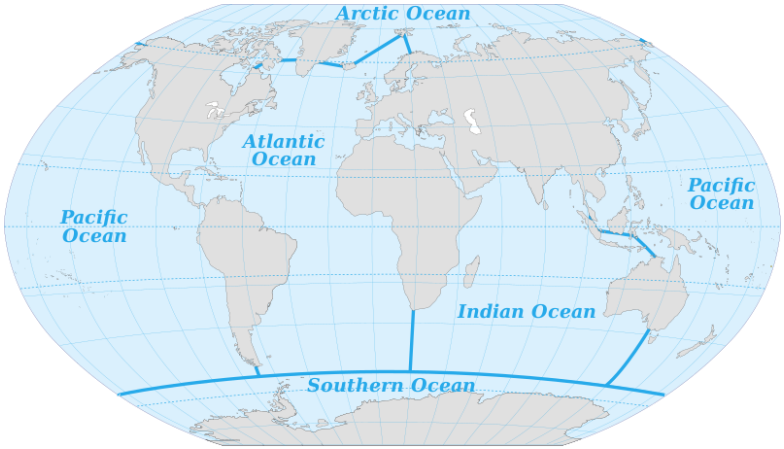
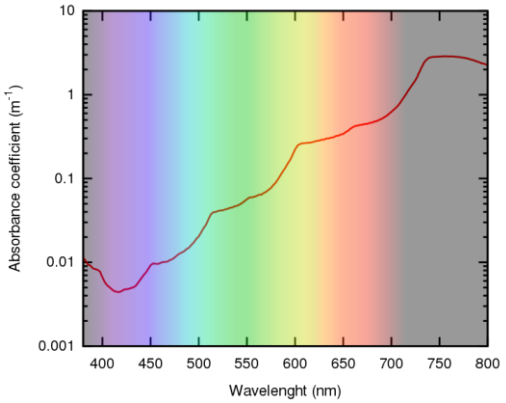
Motivation for underwater imaging

- About 71% of Earth's surface is covered by liquid water
- The sea is mostly unexplored
- There is a strong interest for underwater imaging with many applications
  - marine robotics
  - oceanography
  - archaeology
  - marine biology



(source of image: Wikipedia)

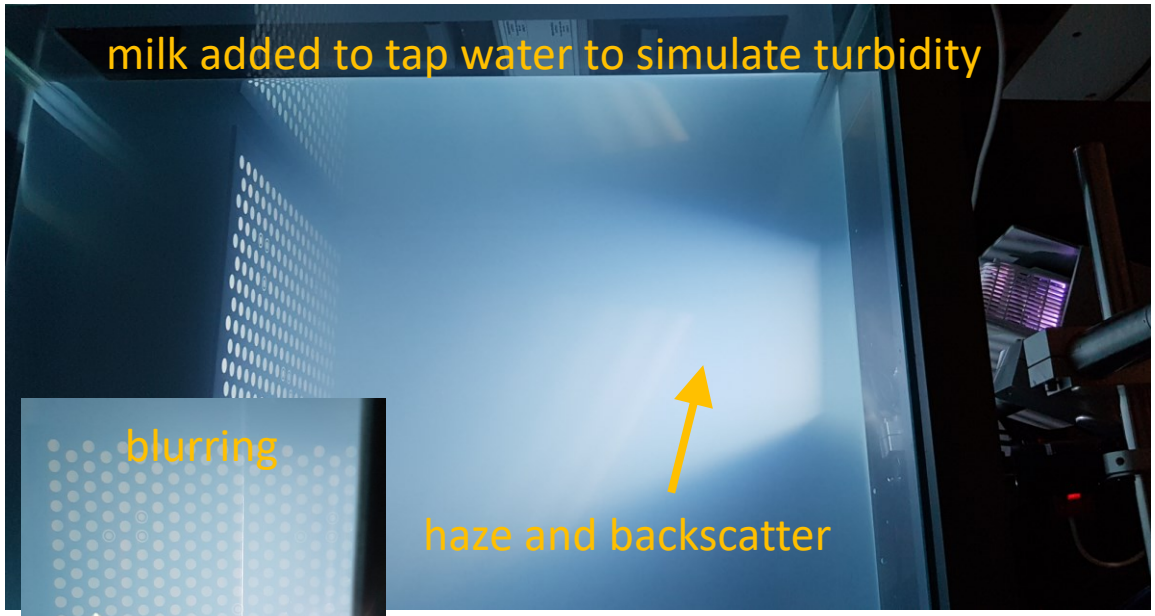
Underwater imaging and physical properties of water



(source of images: Wikipedia)

- Liquid water strongly absorbs electromagnetic radiation
- There is a narrow window of weak absorption
  - it includes the visible spectrum
  - the lowest absorption is for the blue light (at 418 nm for water at 22°C)
- Underwater imaging using the visible spectrum is of particular interest
- Compared to ultrasound imaging
  - spatial resolution is much better when using visible light
  - imaging range/distance is much better when using sound

Challenges of underwater imaging



- Compared to in-the-air imaging
  - the absorption coefficient of liquid water is much higher
  - turbidity of water causes blurring, haze, and backscatter
  - air-to-water interface causes refractions

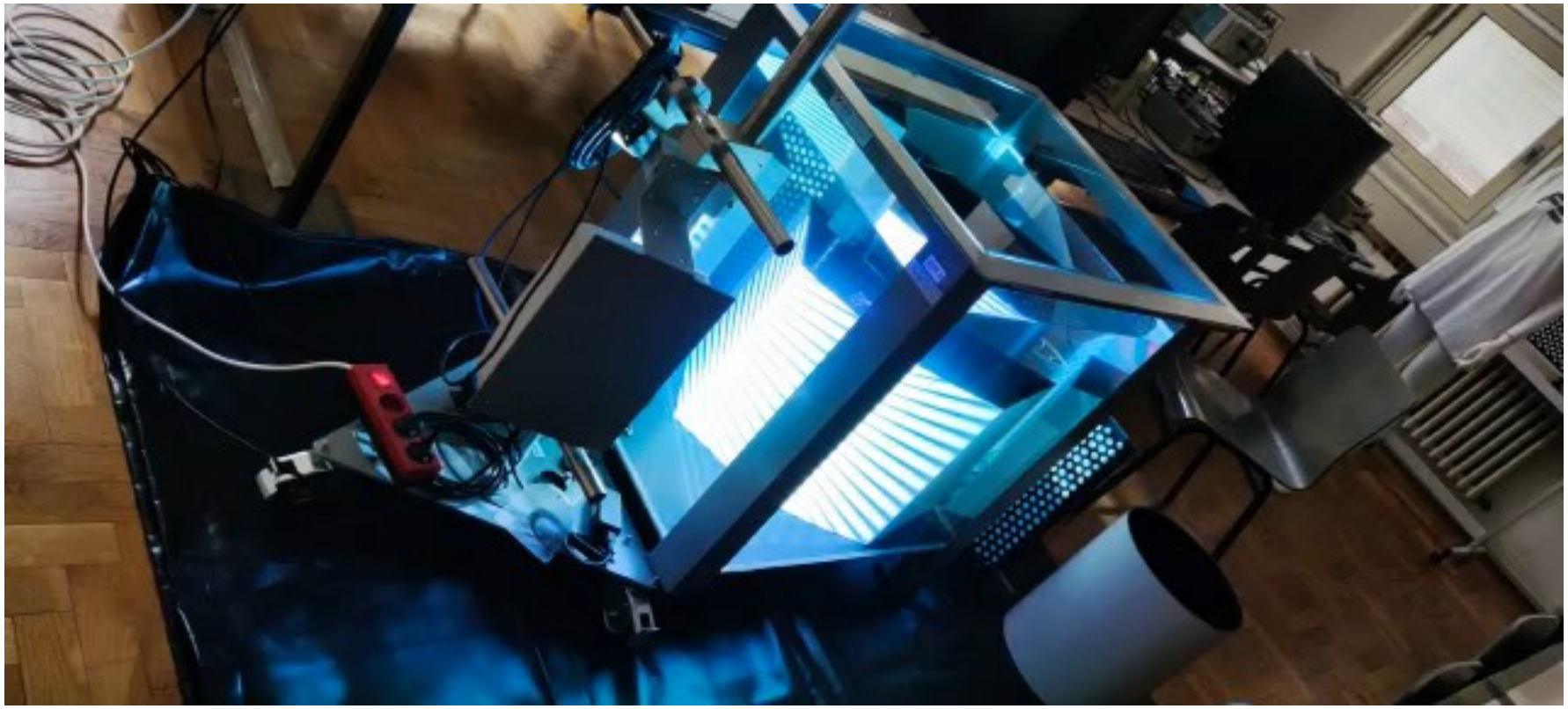
Underwater structured light imaging

- In structured light imaging an artificial controllable light source is used to illuminate a scene
- Multiple measurements are made for various projected patterns
- Computational imaging is used to extract the data of interest from measurements such as
  - 3D surface of the observed object
  - true color of the observed object
  - light transport matrix of the observed scene
- The key issue is the design of the structured light patterns

Key prerequisites for successful imaging

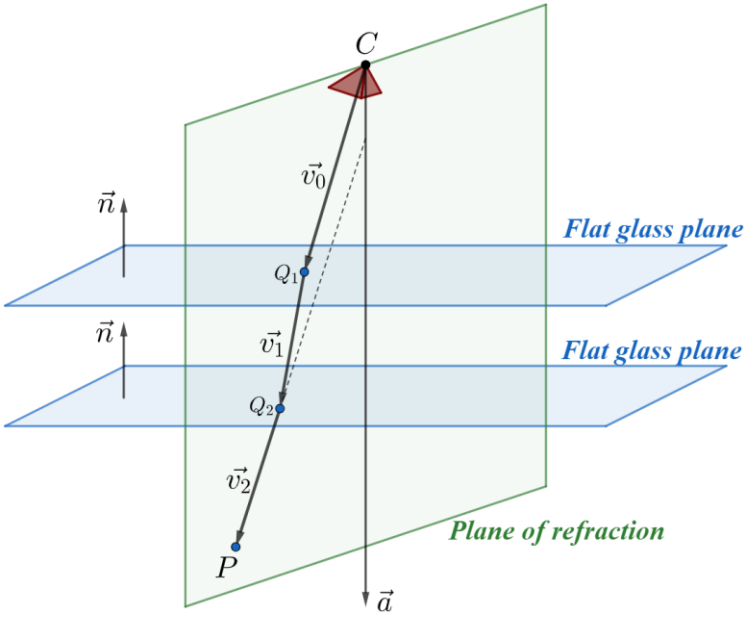
- Well designed structured light patterns to be projected
  - most often a set of moving sinusoidal fringes, selection of spatial shape is difficult
- A comprehensive image formation model
  - should account for refractions, backscatter and blurring
- A robust and easy to use calibration procedure
  - calibrate on land/in the laboratory, minimal adjustments in the field
- A practical underwater enclosure for imaging equipment
  - allows adjustments to set the baseline and overlapping fields of view

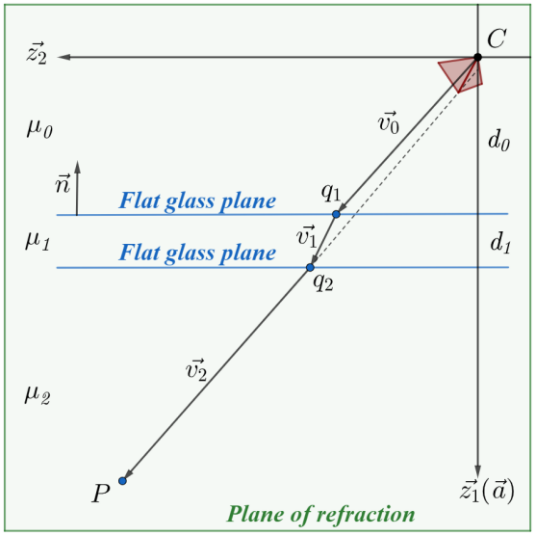
Structured light patterns

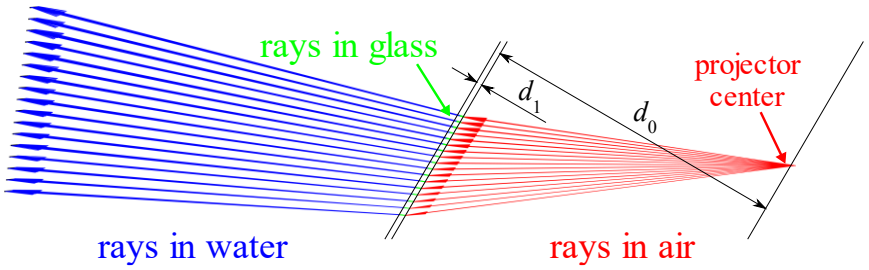


- A sinusoidal fringe with varying phase shifts, spatial frequencies and orientations is projected.

Image formation model

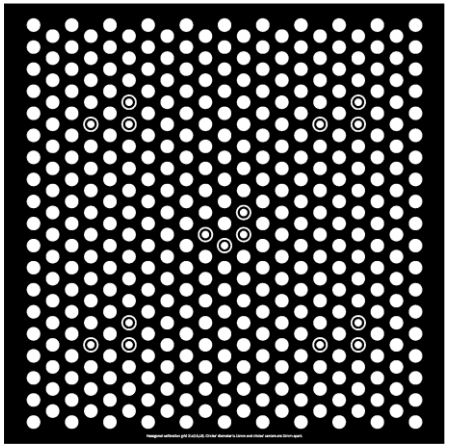




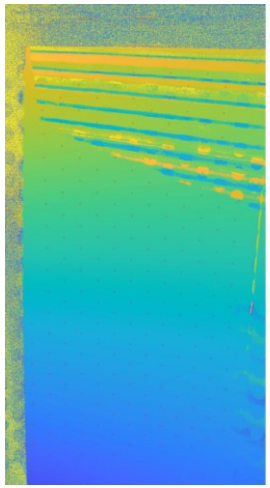


- Developed for flat refractive interfaces
  - a flat acrylic sheet is a viewport for camera to image and for projector to illuminate
  - a key concept is plane-of-refraction
  - it is similar to an axial camera model

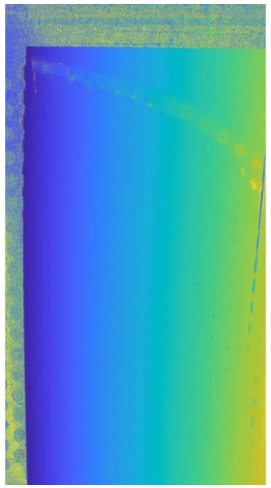
Calibration procedure



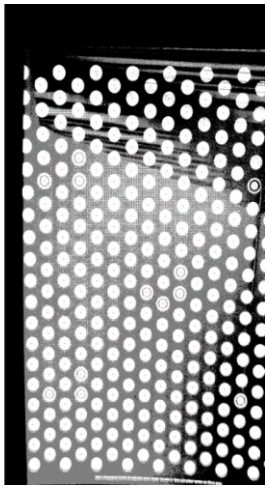
flat calibration board



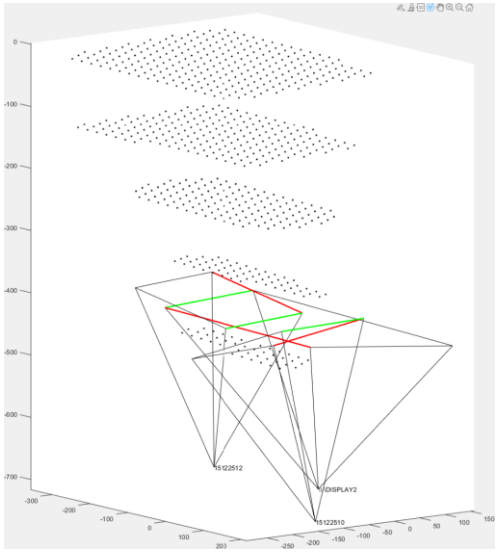
projector columns



projector rows



illuminated area



imaging geometry

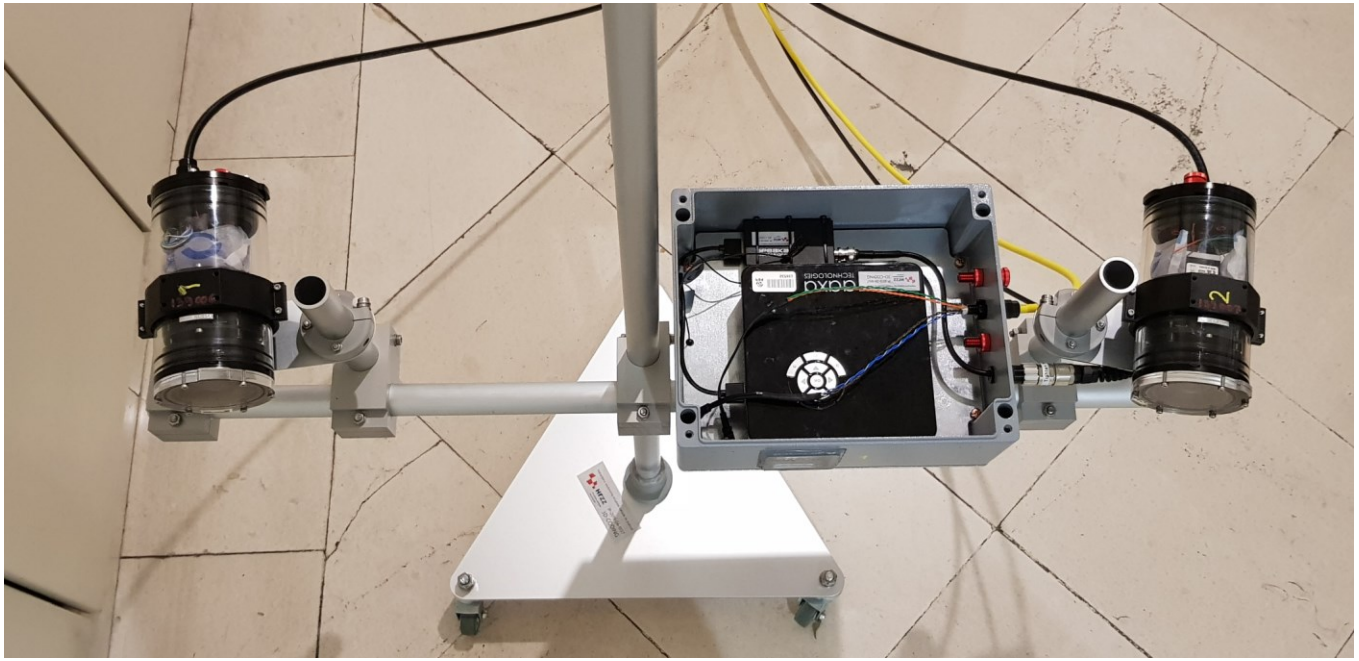
- Calibration can be performed in the laboratory
- Imaging is possible both in air and underwater simply by changing the refraction index of the last medium

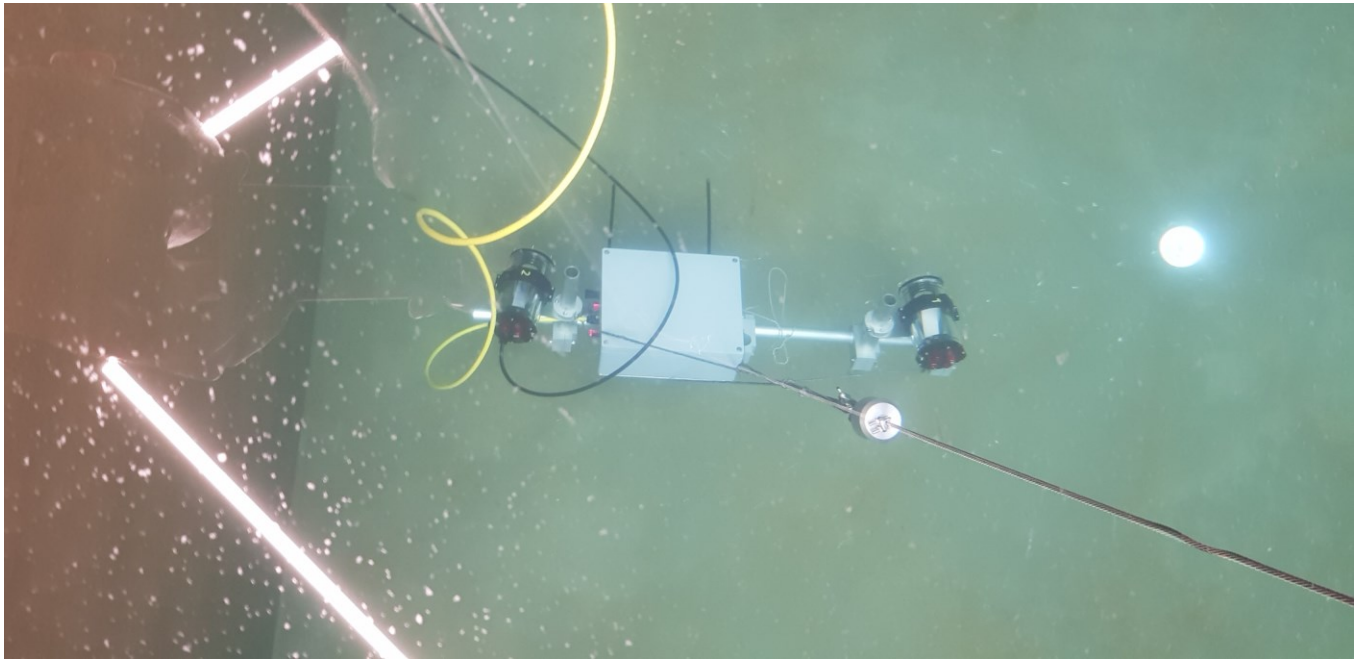
Prototype of an underwater SL scanner

two cameras (image acquisition)

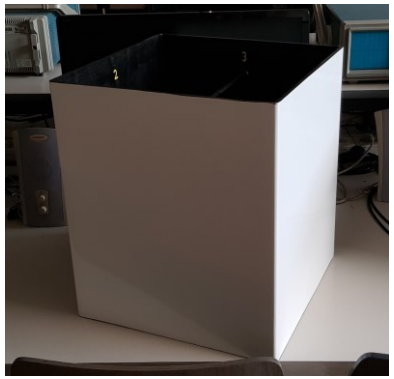
one projector (illumination)

three watertight enclosures and support structure

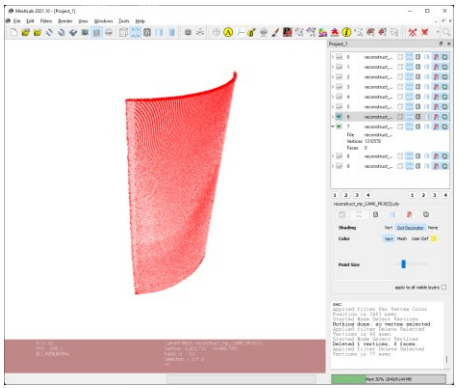


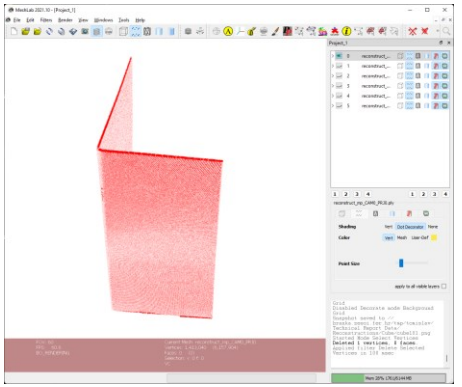


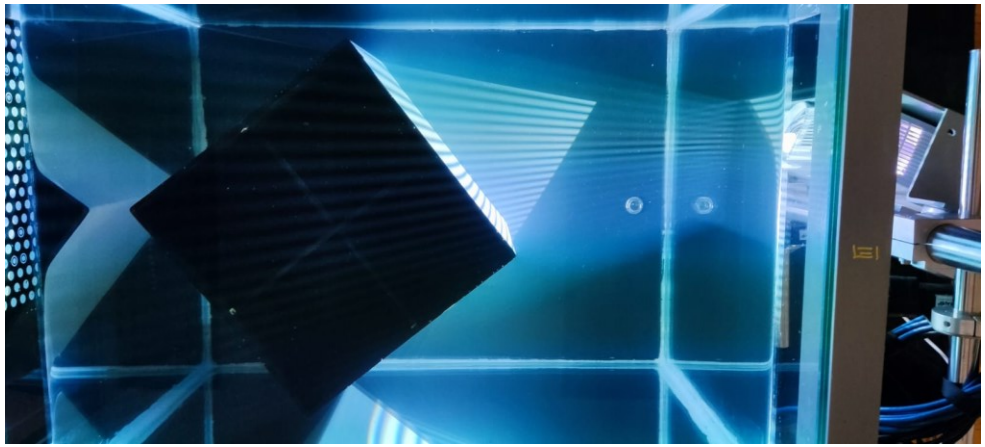
Verification via known objects



Two verification objects are a cube and a cylinder of known dimensions.







3D scanning in clear water

3D reconstruction

Conclusion

- Underwater structured light imaging is an interesting and propulsive research topic with many possible applications
- Future work
  - designing spatially pre-warped structured light patterns which are insensitive to flat refractive interface
  - research Fourier imaging to measure the light transportation matrix and enable imaging under very high turbidity
  - investigate possibilities of spatio-temporal processing to enable imaging dynamic scenes
- Please send any questions (and research and collaboration ideas) to tomislav.petkovic.jr@fer.hr
- Thank you for your attention