Real-time Laser Scanner for Autonomous IMR Applications

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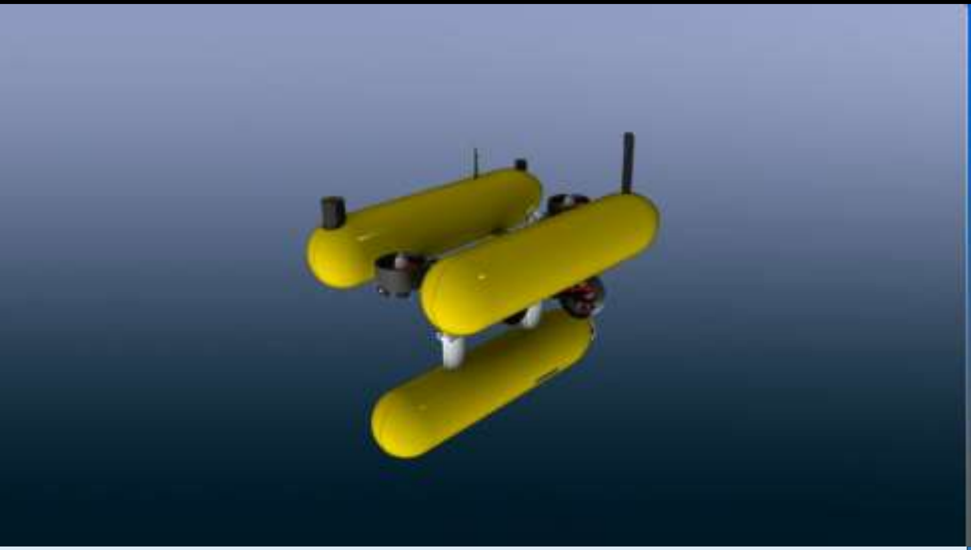
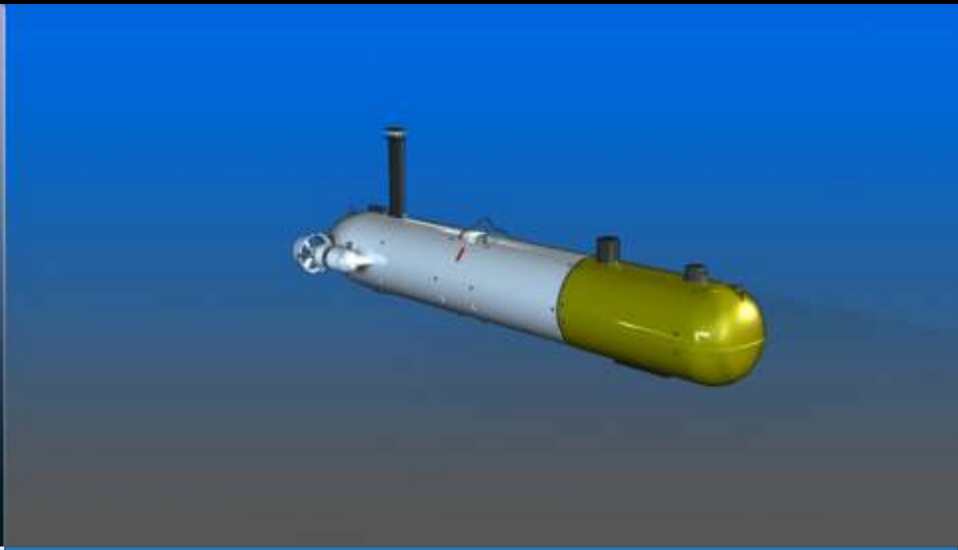
GIRONA **UNDERWATER VISION AND ROBOTICS** LAB

Underwater Robotics Perception – ICRA'19 Workshop

GIRONA 500 & SPARUS II AUVs





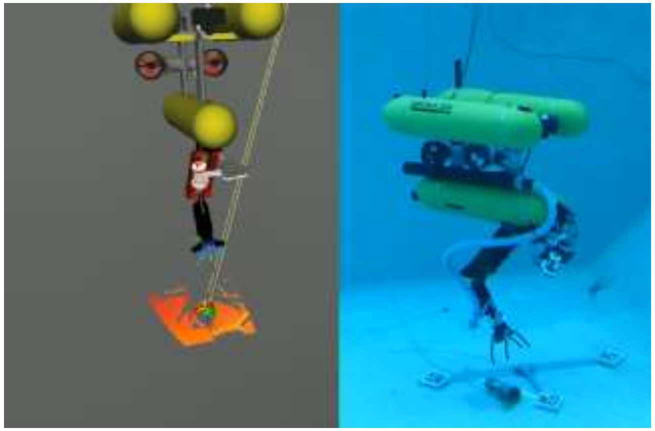
KEY POINTS

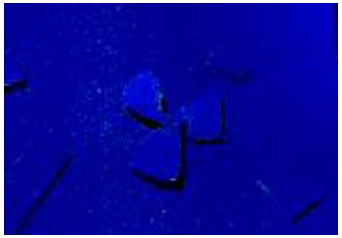
- 500 m Rated
- Hovering
- Light Weight (140 Kg)
- Open Payload
- Open Software (ROS)
- Affordable
- DGPS/USBL/DVL/IMU
- Wifi/Acoustic Modem
- Wifi buoy
- Flasher Light
- Central hooks
- GUI

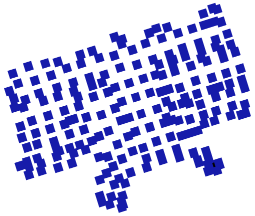
KEY POINTS

- Efficient hydrodynamics
- Hovering
- Man Portable AUV (52 Kg)
- Open Payload
- Open Software (ROS)
- Affordable
- DGPS/USBL/DVL/IMU
- Wifi/Acoustic Modem
- Wifi buoy
- Flasher Light
- 3 deployment hooks
- 200 m rated

Goal: Develop a real time laser scanner for IMR applications

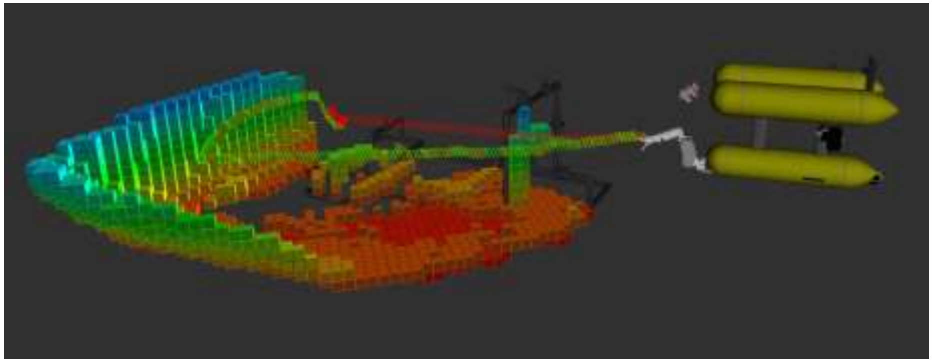


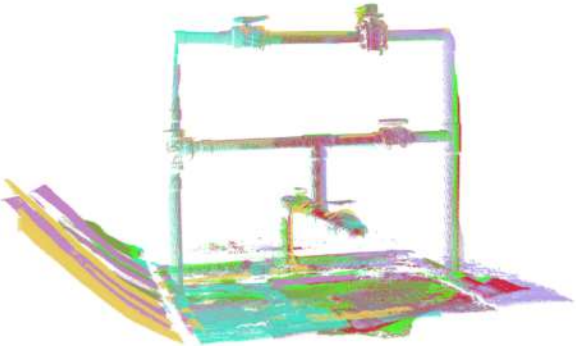




To be used for:

- Object detection
- Planning
- Exploration
- Inspection
- Localization
- Mapping
- …

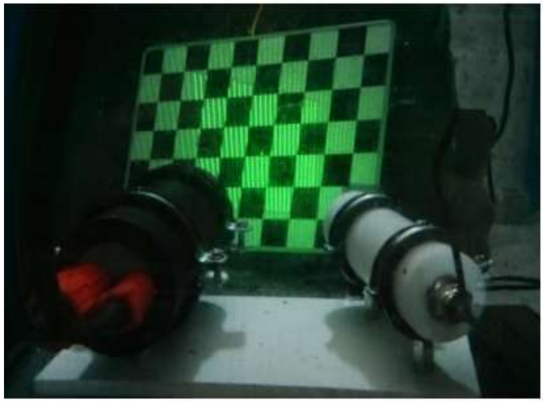




Underwater laser scanner: State of the art

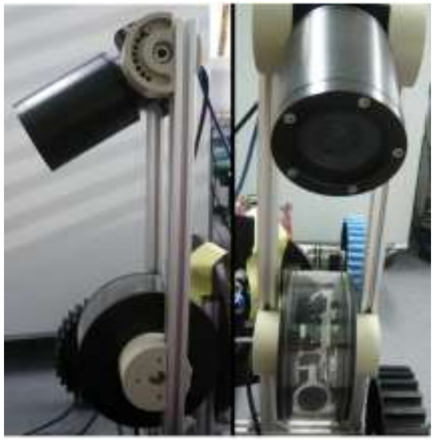
	Variable resolution	High scan speed	Flat viewport	Laser deformation model
[2G Robotics]	✓	✗	✓	✗
[Inglis et al., 2012]	✓	✗	✓	✗
[Massot and Oliver 2014]	✗	✓	✓	✗
[Prats et al., 2012]	✓	✗	✓	✗
[Bleier and Nuchter 2017]	✓	✗	✓	✗
[Hildebrandt et al., 2008]	✓	✗	✗	✗
[Nakatani et al., 2011]	✓	✗	✗	✗
[Chantler et al., 1997]	✓	✓	✓	✗
[Chi et al., 2016]	✓	✓	✓	✗
[Kocak et al., 1999]	✓	✓	✗	✗

[2G Robotics]

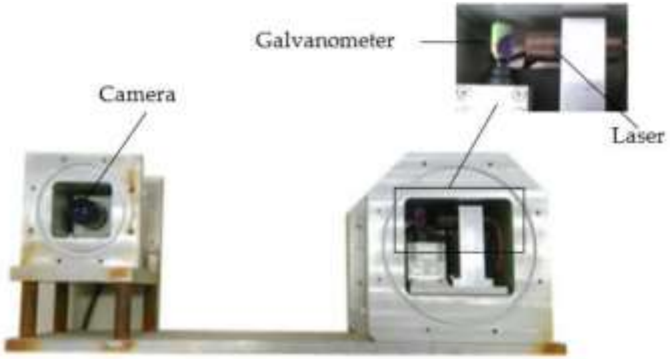


[Massot-Campos and Oliver-Codina 2014]

[Bleier and Nuchter



[Hildebrandt et al., 2008]



[Chi et al., 2016]

Underwater laser scanner: Our approach

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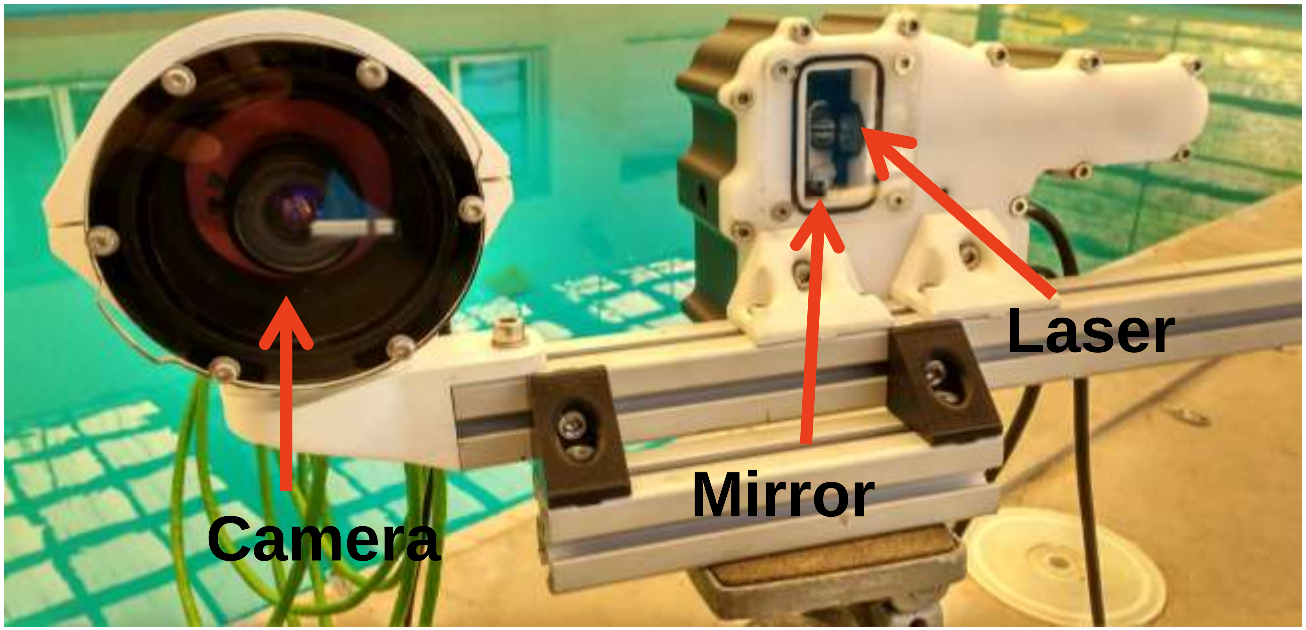
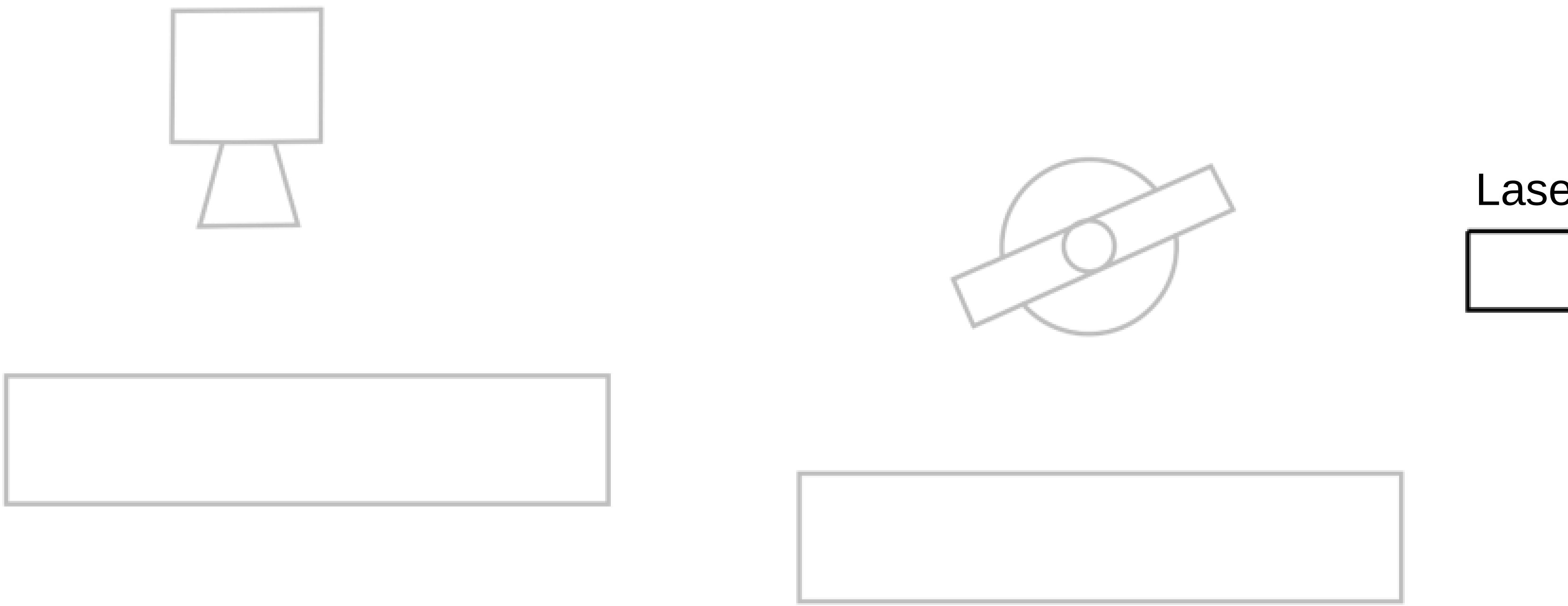


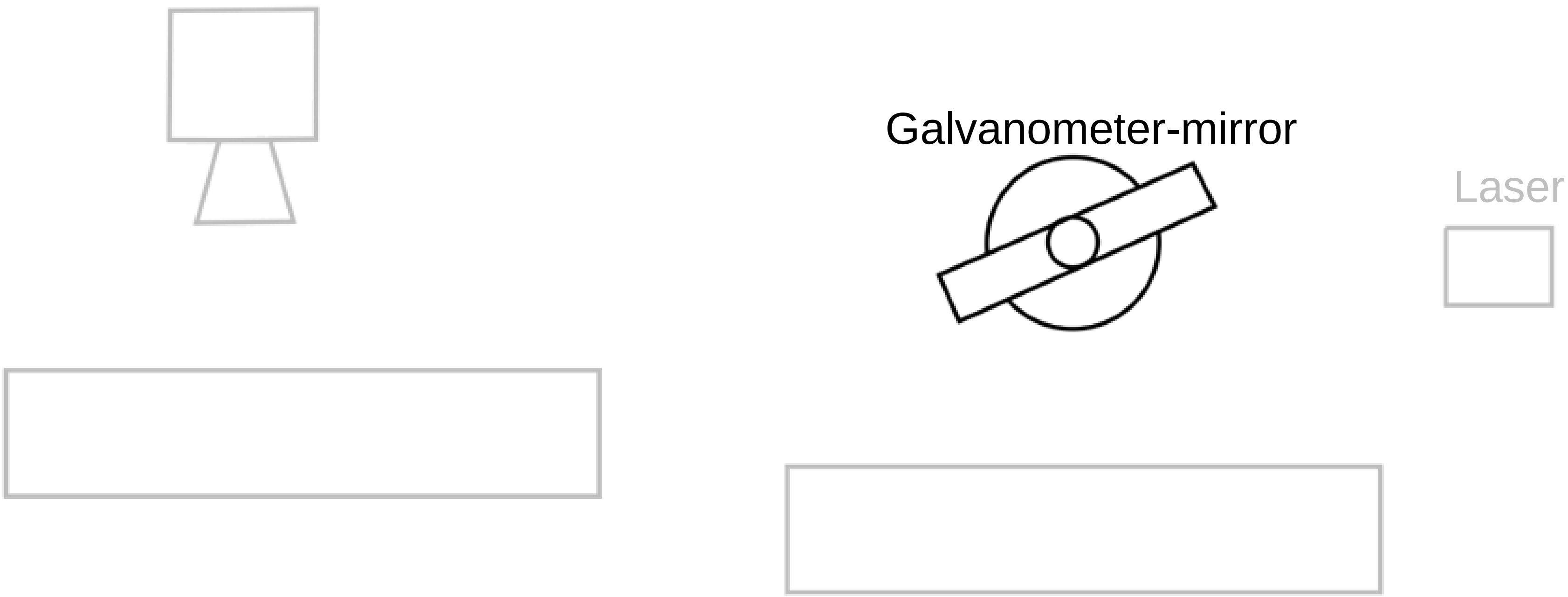
- Steering laser (camera fixed)
- Scan time 0.1-2s
- Laser scanning angle 80º

	Variable resolution	High scan speed	Flat viewport	Laser deformation model
Our approach	✔	✔	✔	✔

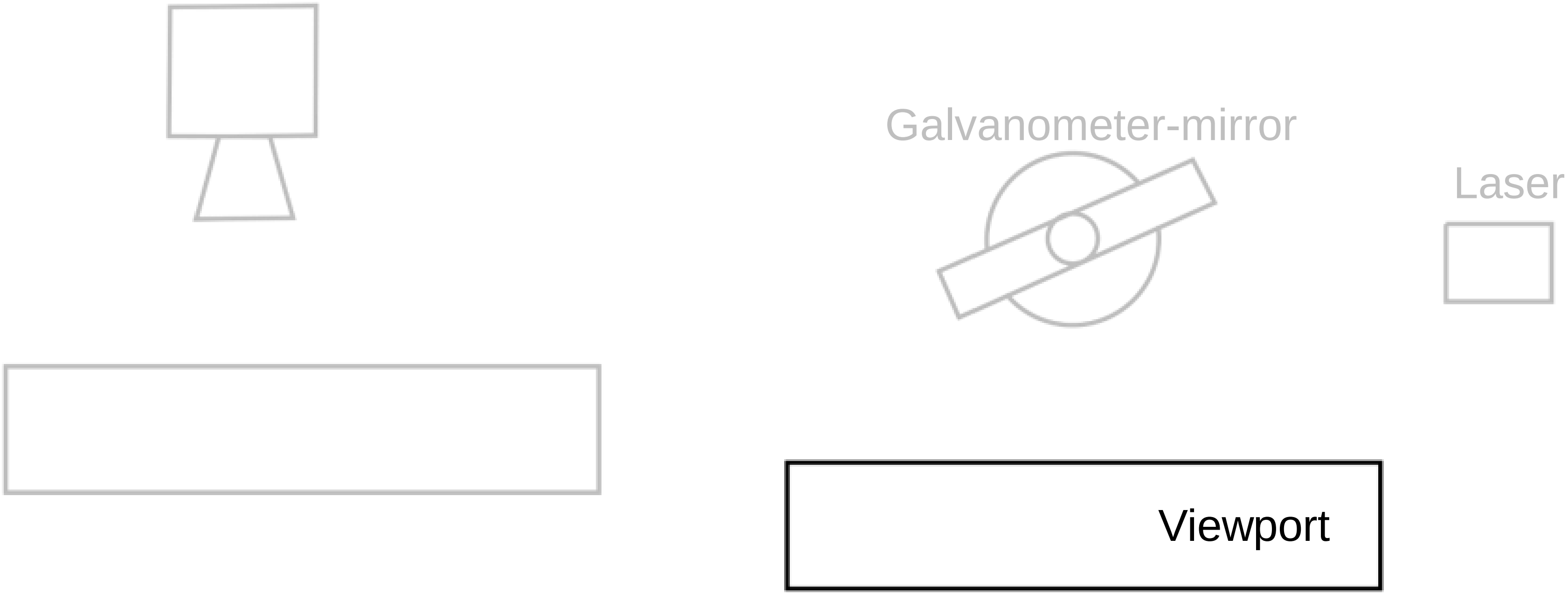
Underwater laser scanner: Sensor model



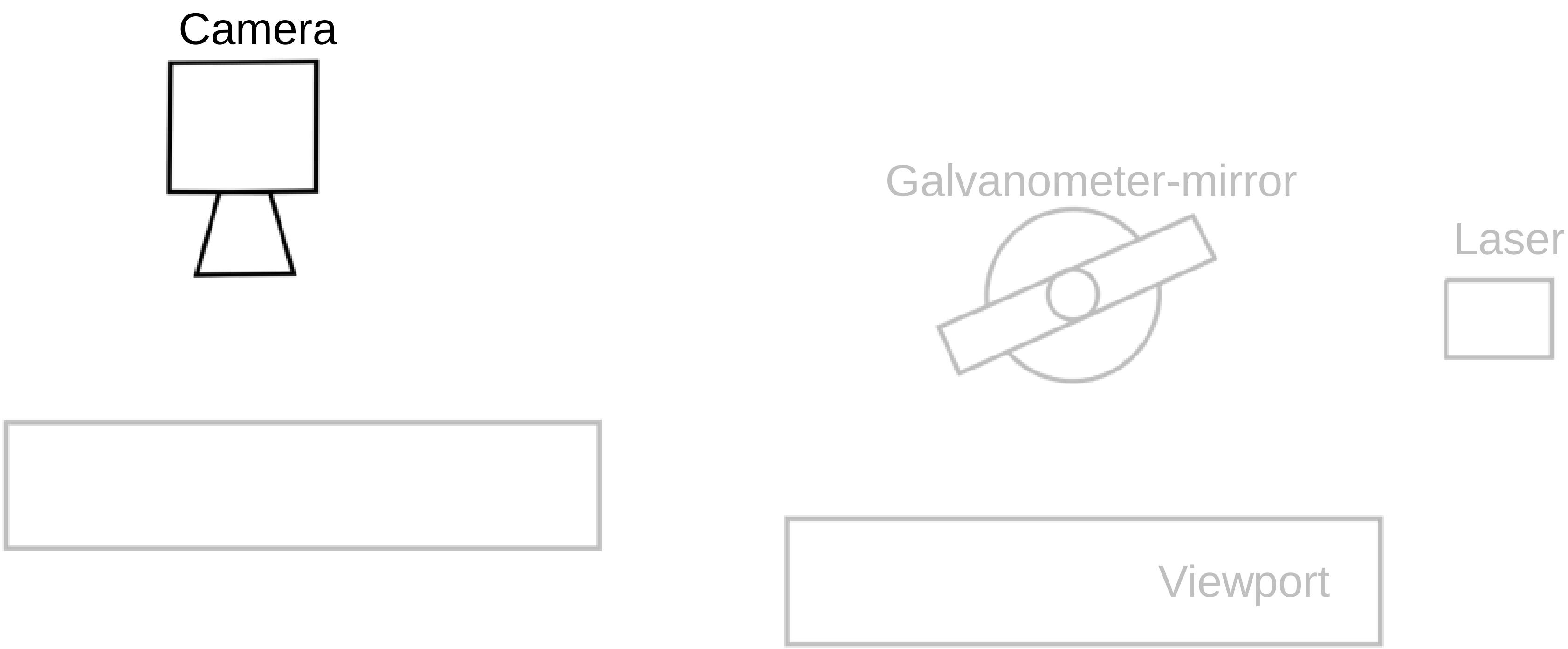
Underwater laser scanner: Sensor model



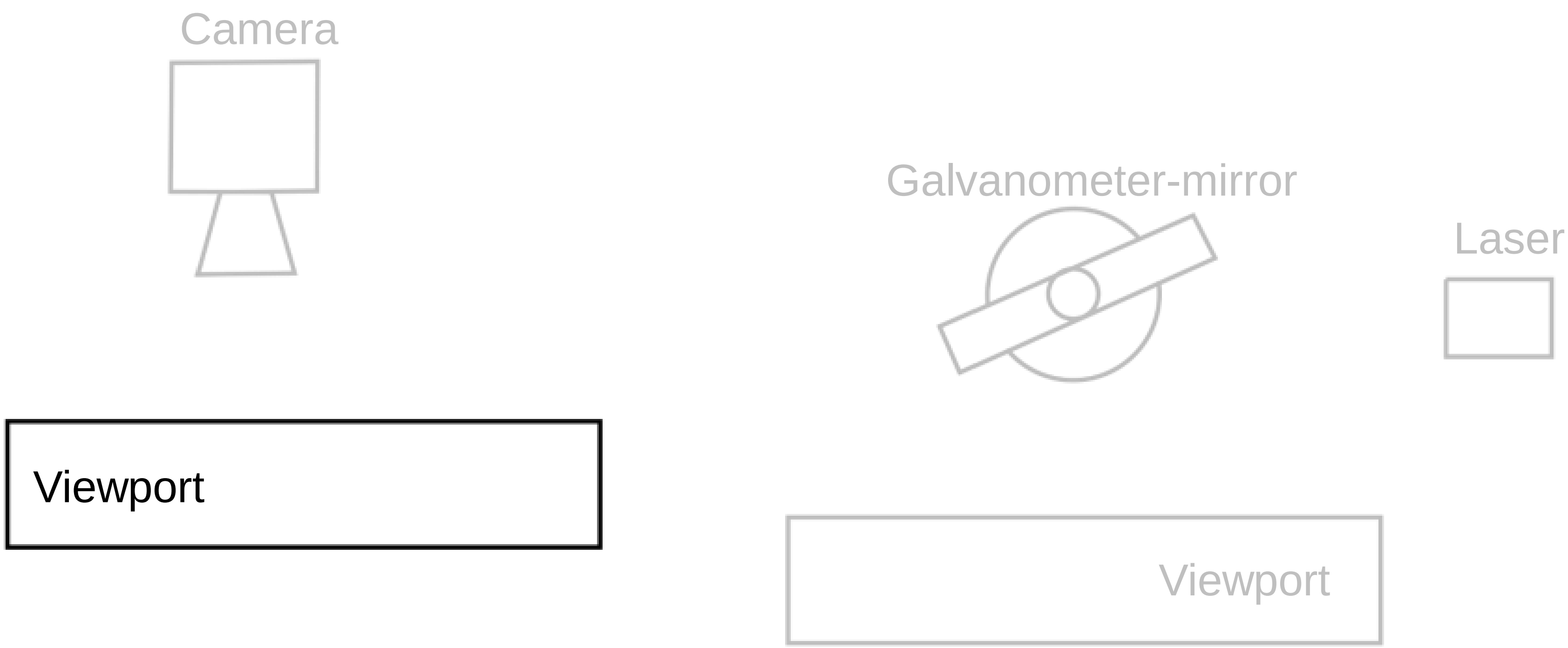
Underwater laser scanner: Sensor model



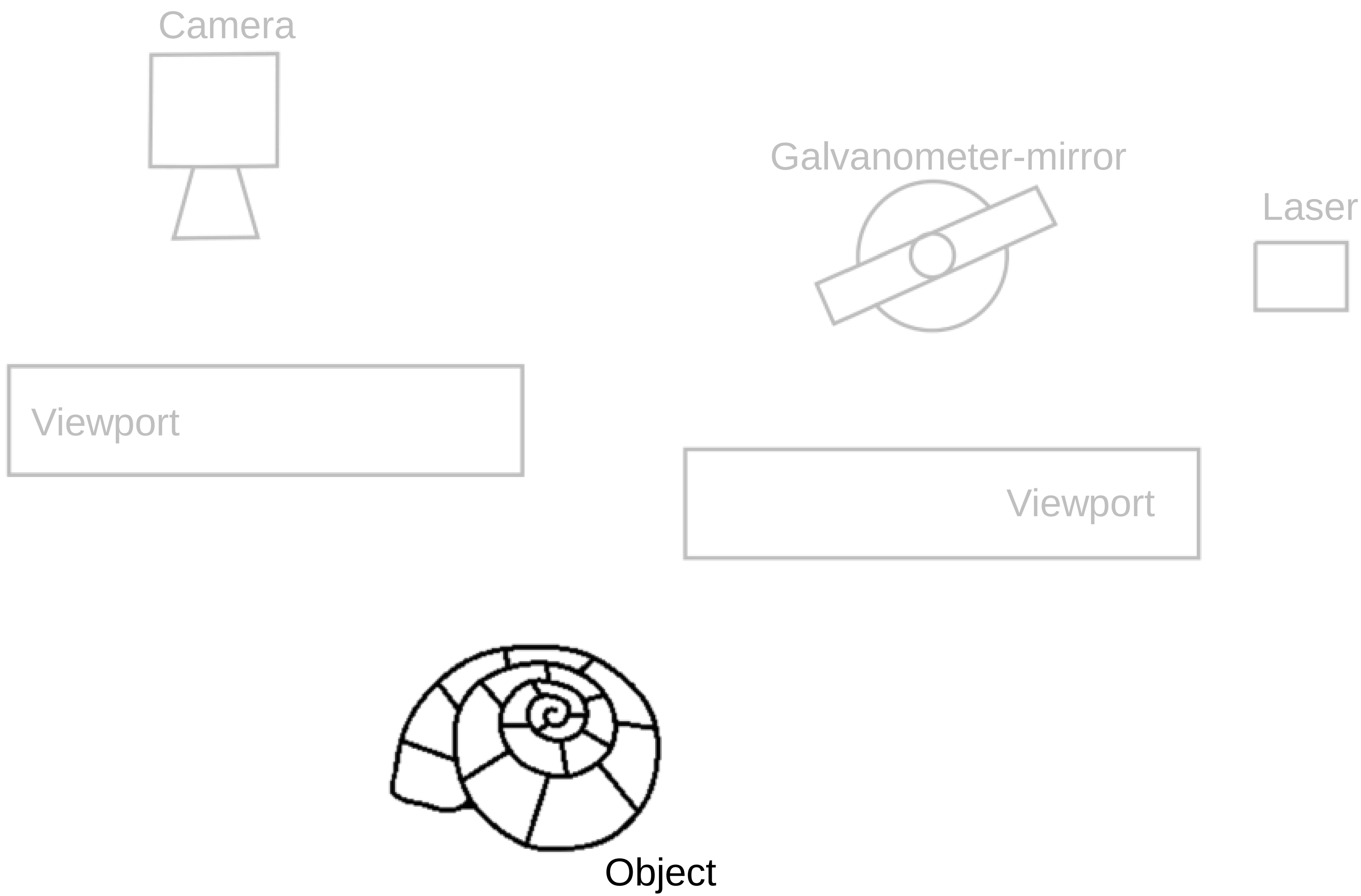
Underwater laser scanner: Sensor model



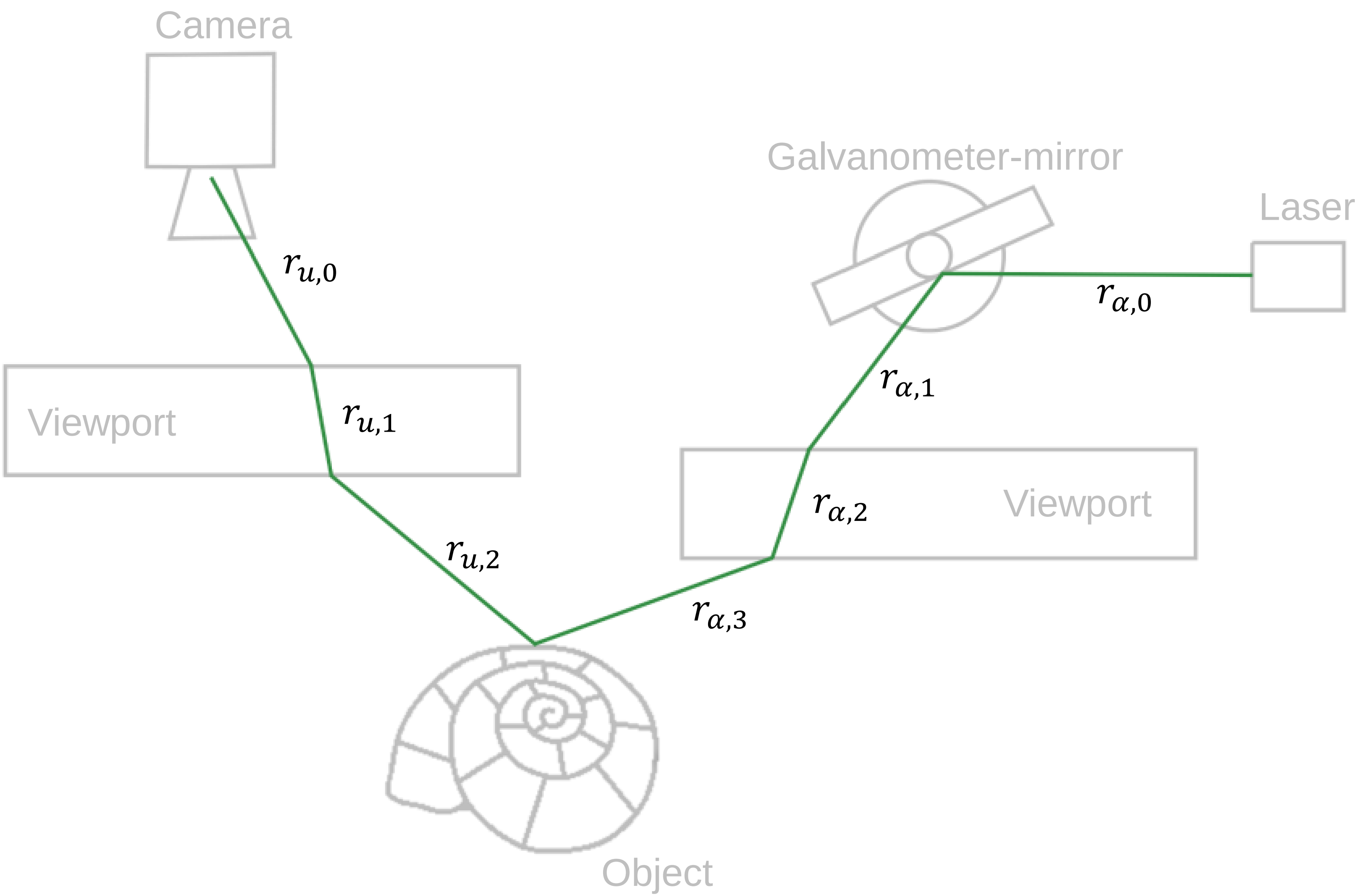
Underwater laser scanner: Sensor model



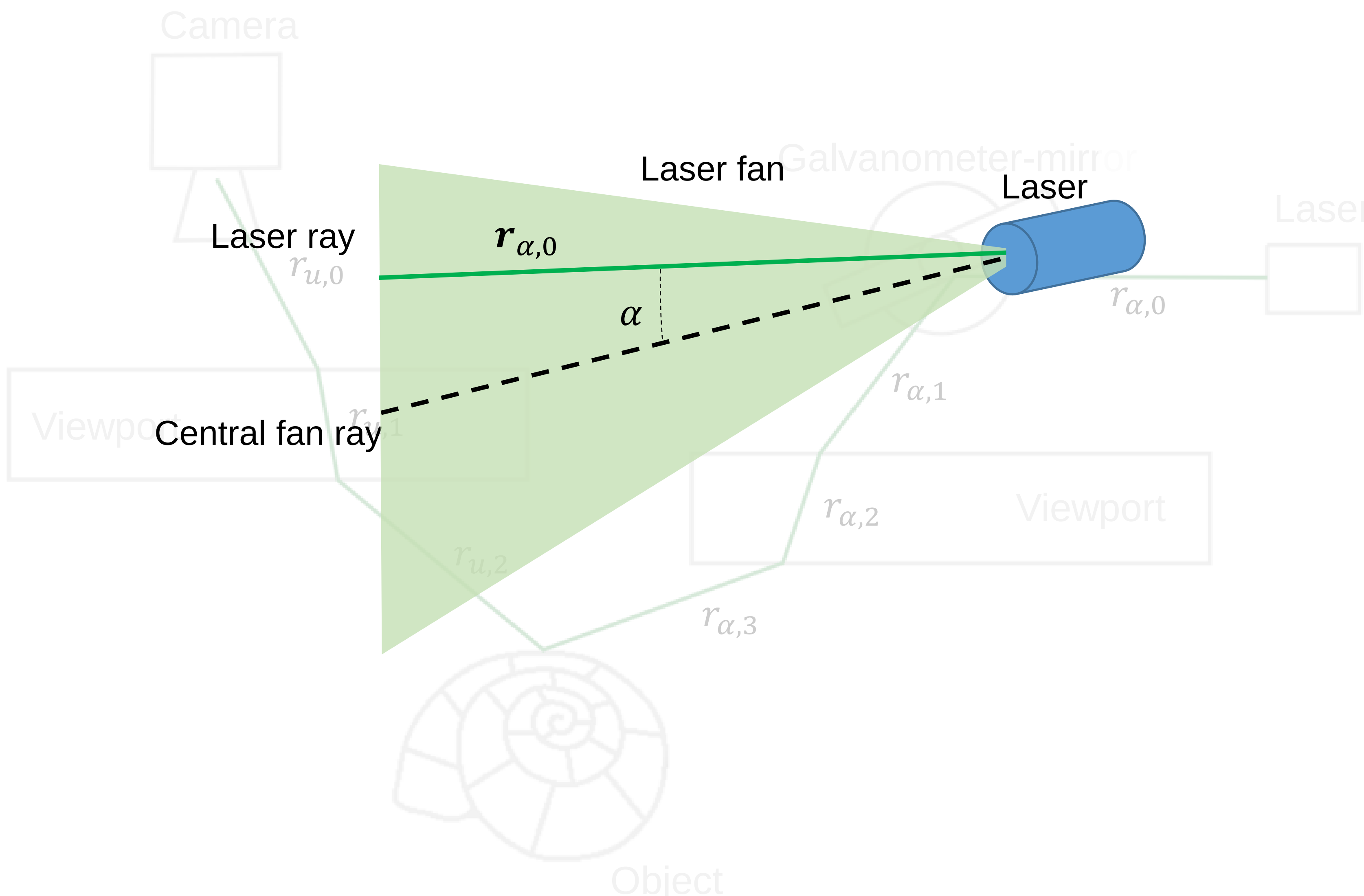
Underwater laser scanner: Sensor model



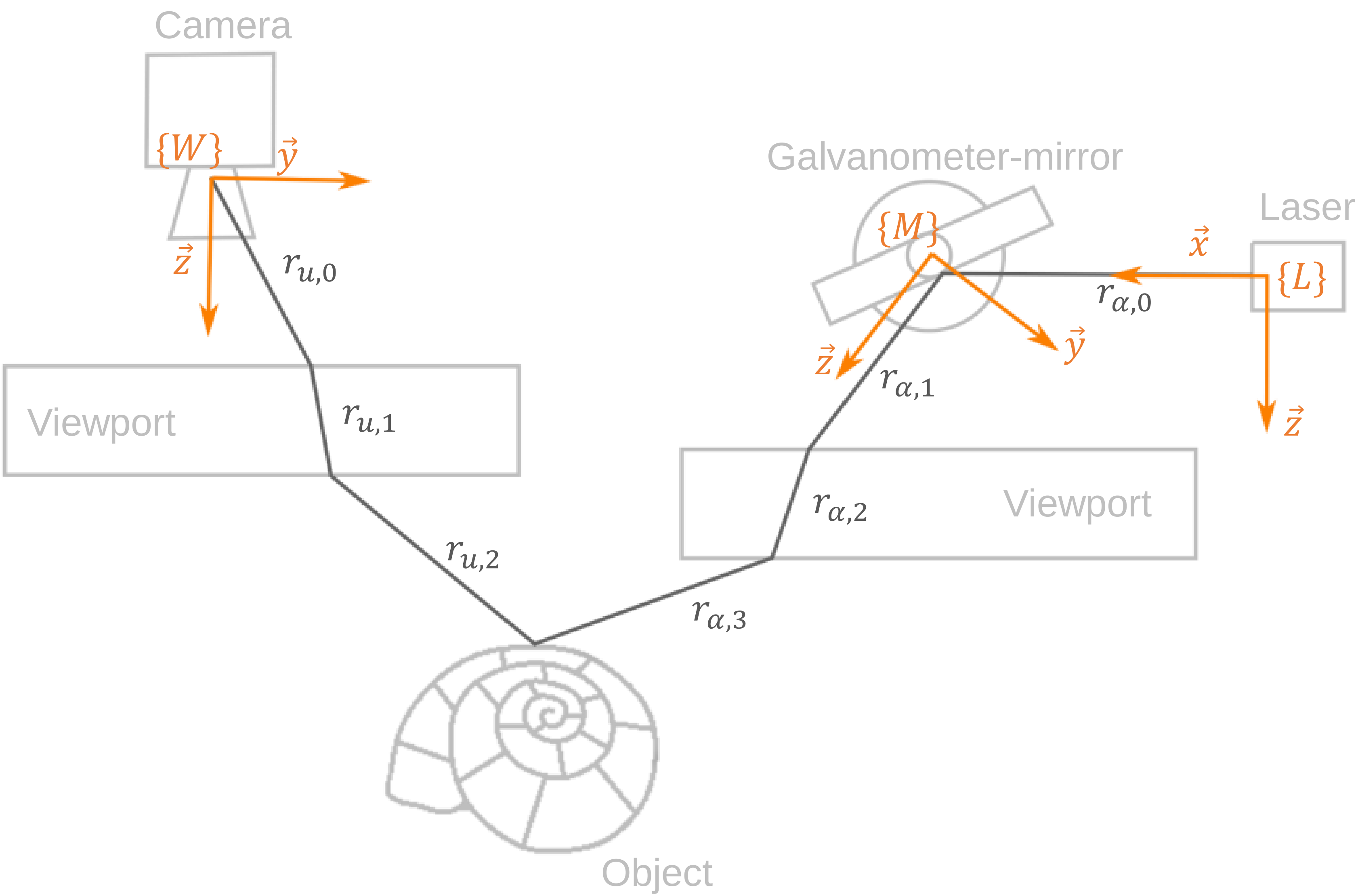
Underwater laser scanner: Sensor model



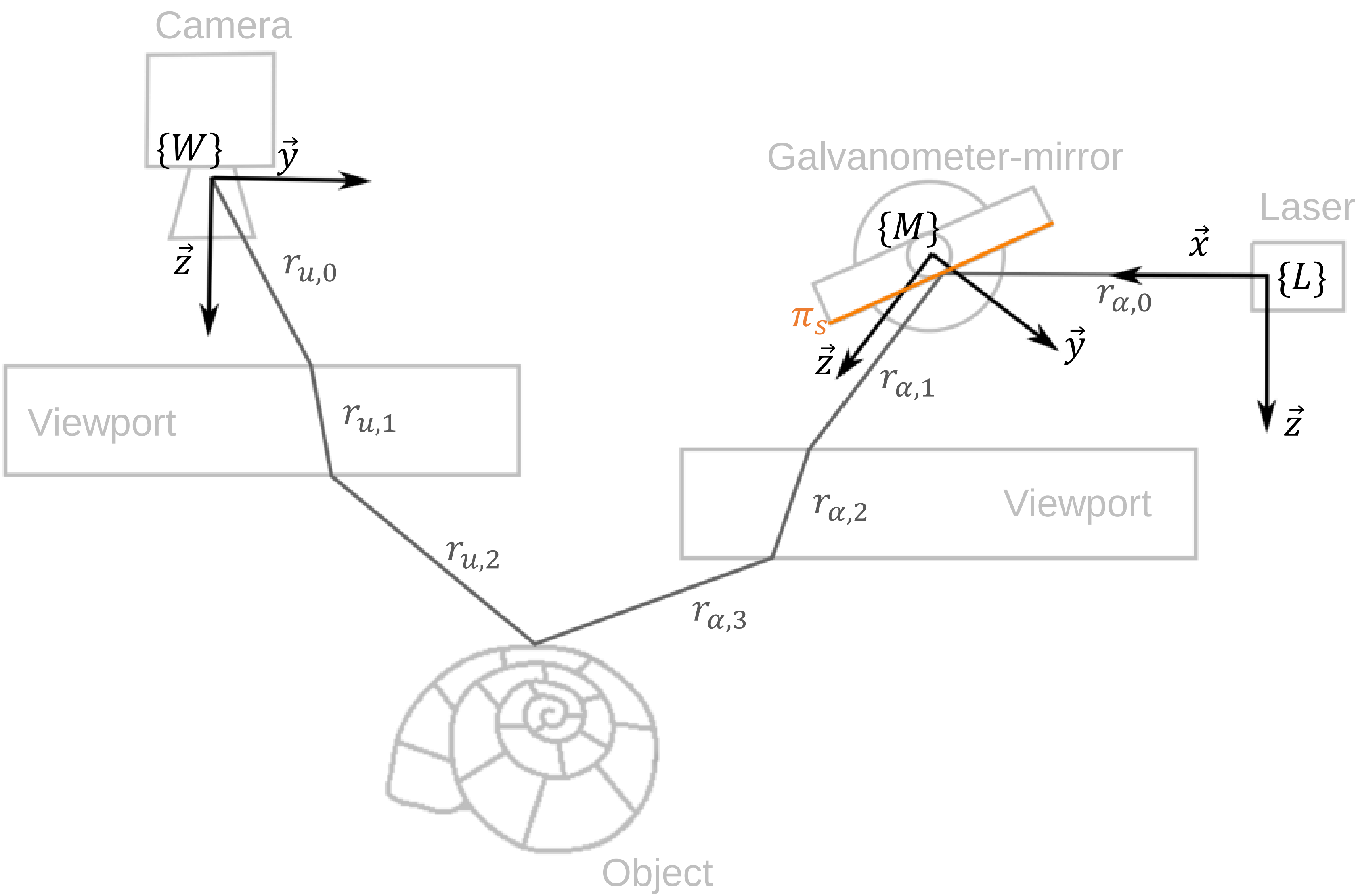
Underwater laser scanner: Sensor model



Underwater laser scanner: Sensor model



Underwater laser scanner: Sensor model



Underwater laser scanner: Sensor model

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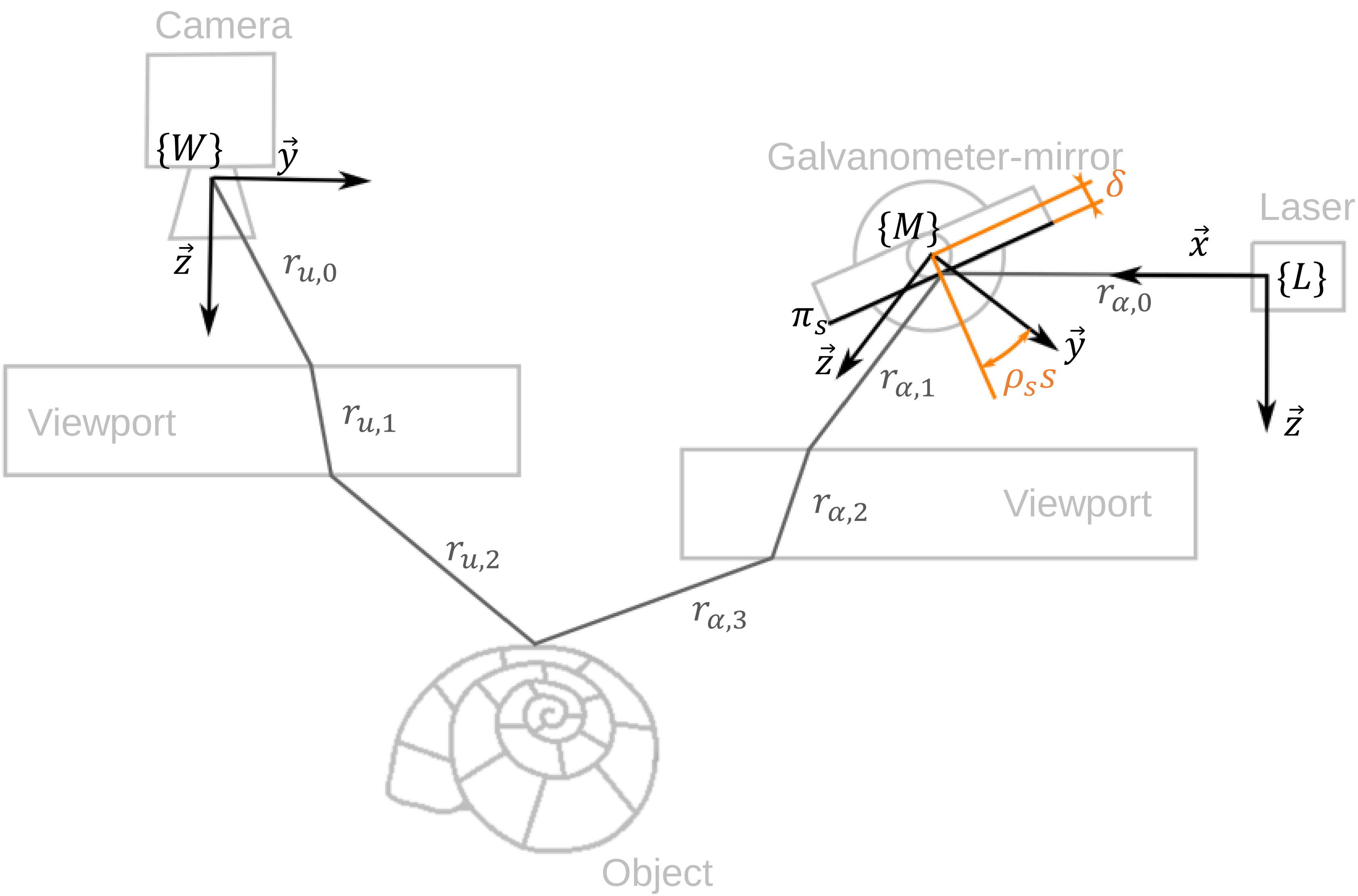
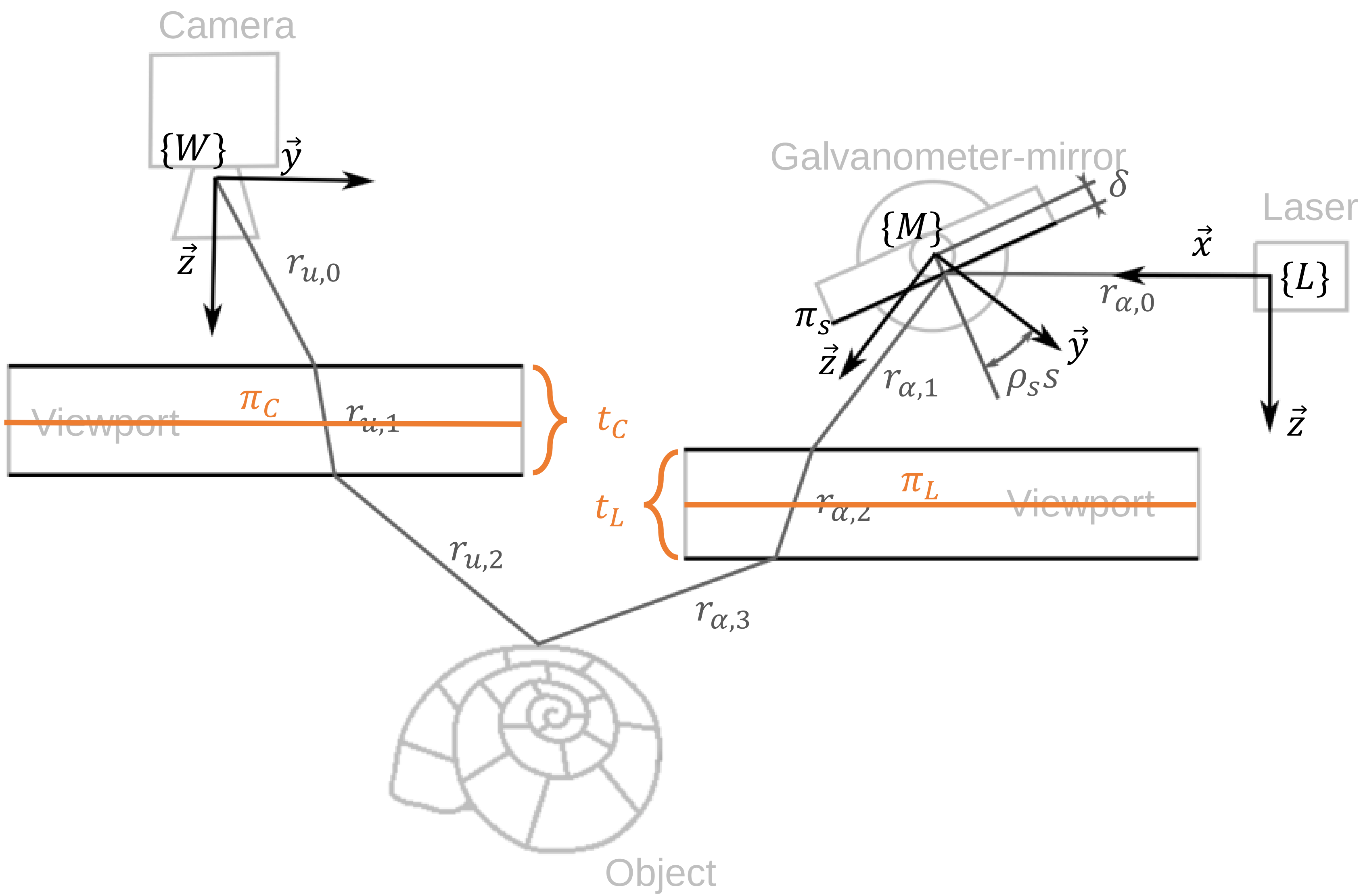
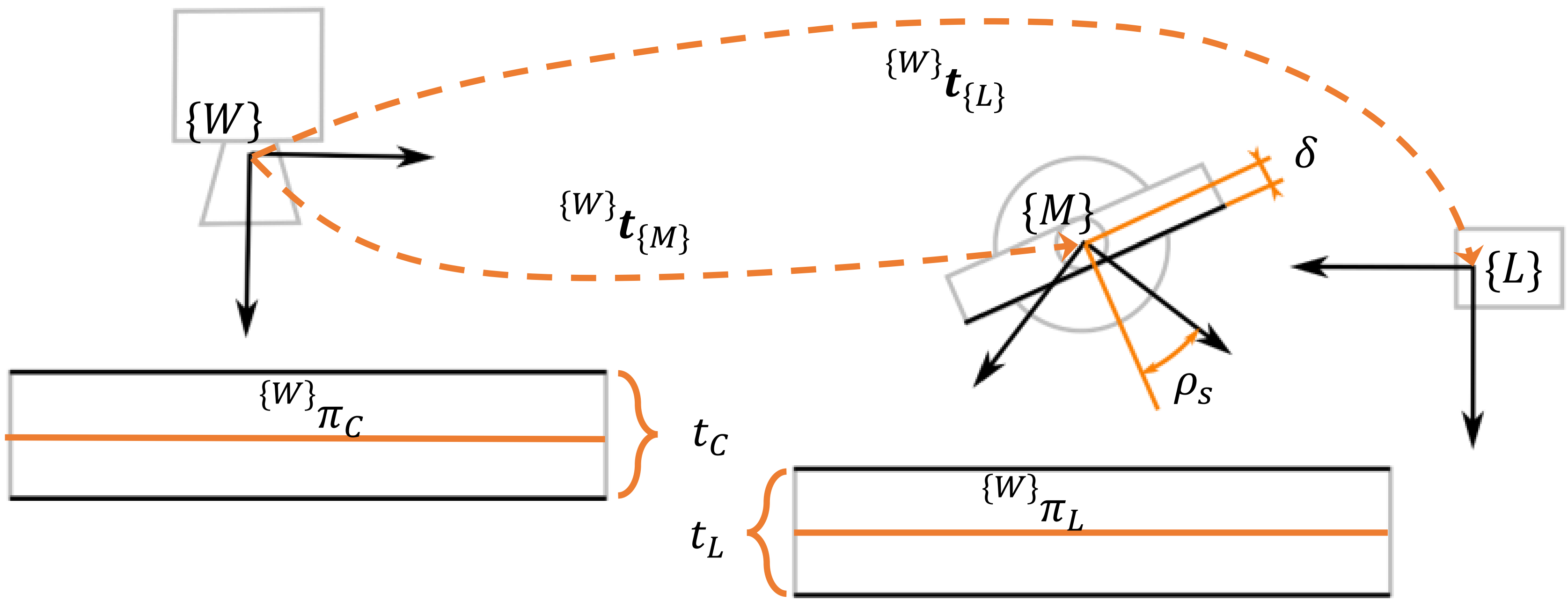


Underwater laser scanner: Sensor model

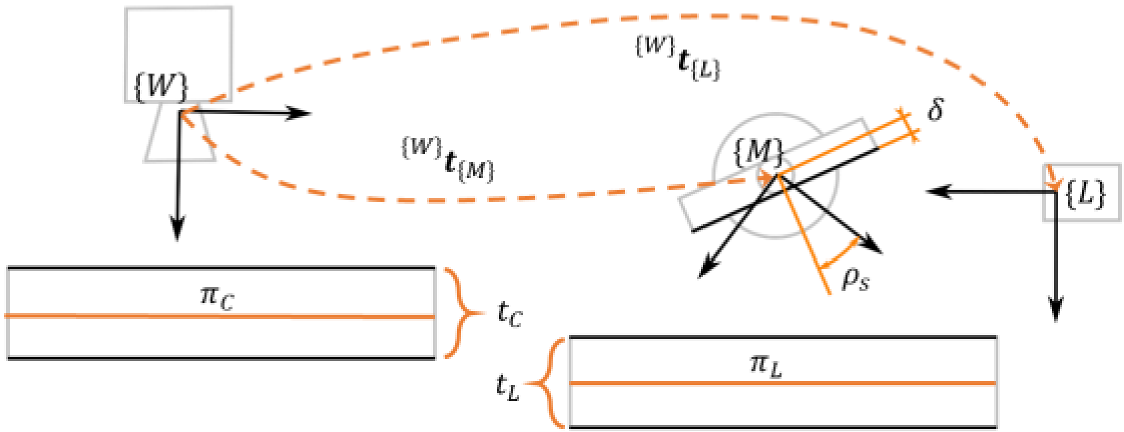


Underwater laser scanner: Sensor model



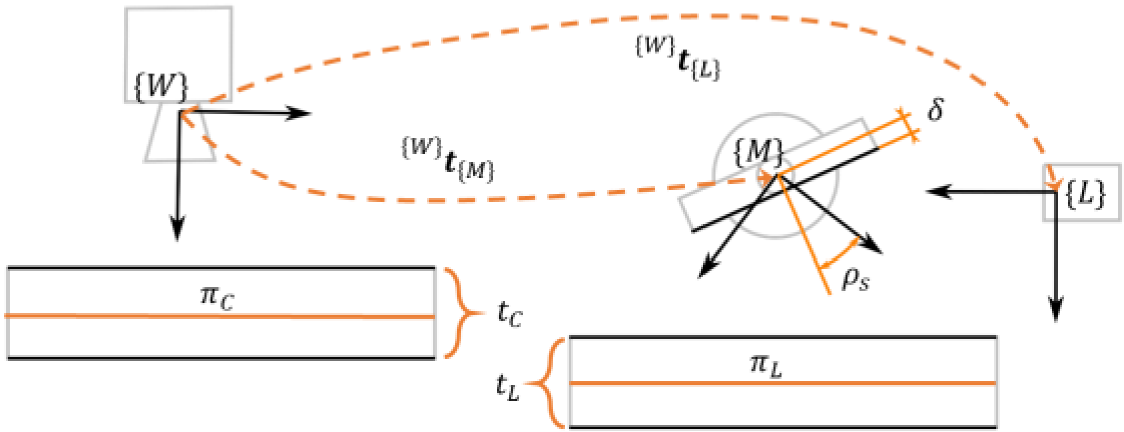
- Camera intrinsic parameters
- Laser model: ${}^{\{W\}}\boldsymbol{t}_{\{L\}}$
- Mirror-galvanometer model: $\Pi = \begin{bmatrix}\rho_s & \delta & {}^{\{W\}}\boldsymbol{t}_{\{M\}}\end{bmatrix}$
- Camera viewport: $\Omega_C = \begin{bmatrix}{}^{\{W\}}\pi_C & t_C\end{bmatrix}$
- Laser viewport: $\Omega_L = \begin{bmatrix}{}^{\{W\}}\pi_L & t_L\end{bmatrix}$

Underwater laser scanner: Calibration



- Camera calibration
  - Camera parameters
    $f_x \quad f_y \quad c_x \quad c_y$
  - Camera distortion
    k_1, k_2, p_1, p_2, k_3 …
- Laser calibration
  $^{\{W\}}\boldsymbol{t}_{\{M\}}, {}^{\{W\}}\boldsymbol{t}_{\{L\}}, \delta, \rho_s$
- Camera viewport calibration
  $\pi_C,\ t_c$
- Laser viewport calibration
  $\pi_L,\ t_L$

Underwater laser scanner: Calibration



In air (no viewport)

- Camera calibration
  - Camera parameters

    $f_x \quad f_y \quad c_x \quad c_y$
  - Camera distortion

    k_1, k_2, p_1, p_2, k_3 ...
- Laser calibration

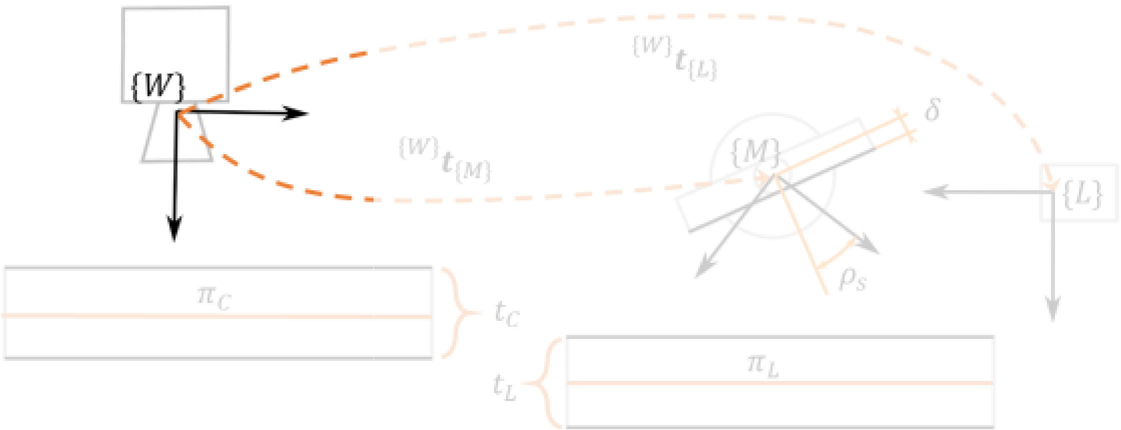
  $^{\{W\}}\boldsymbol{t}_{\{M\}}, {}^{\{W\}}\boldsymbol{t}_{\{L\}}, \delta, \rho_s$
- Camera viewport calibration

  π_C, t_c
- Laser viewport calibration

  π_L, t_L

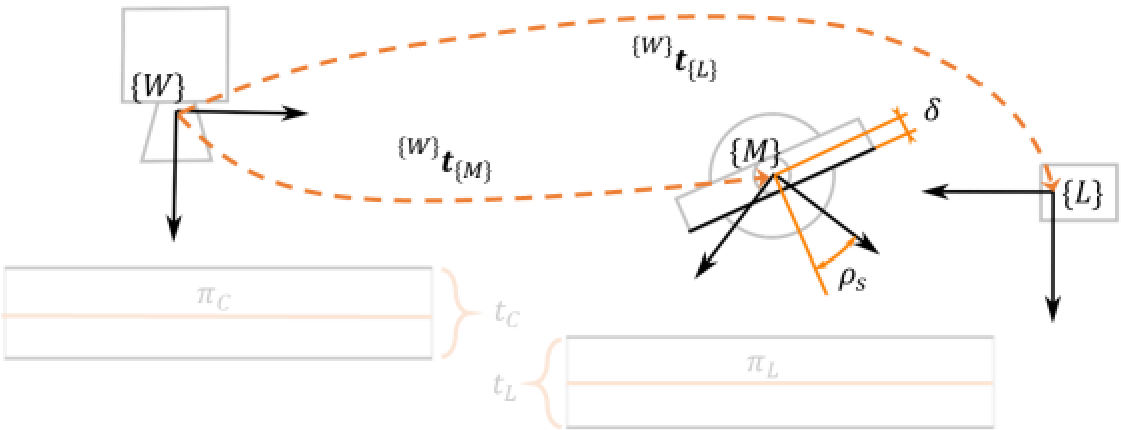
Underwater (with viewport)

Underwater laser scanner: Calibration



- Camera calibration
  - Camera parameters
    $f_x \quad f_y \quad c_x \quad c_y$
  - Camera distortion
    k_1, k_2, p_1, p_2, k_3 …
- Laser calibration
  ${}^{\{W\}}\boldsymbol{t}_{\{M\}}, {}^{\{W\}}\boldsymbol{t}_{\{L\}}, \delta, \rho_s$
- Camera viewport calibration
  π_C, t_C
- Laser viewport calibration
  π_L, t_L

Underwater laser scanner: Calibration



- Camera calibration
  - Camera parameters

    $f_x \quad f_y \quad c_x \quad c_y$
  - Camera distortion

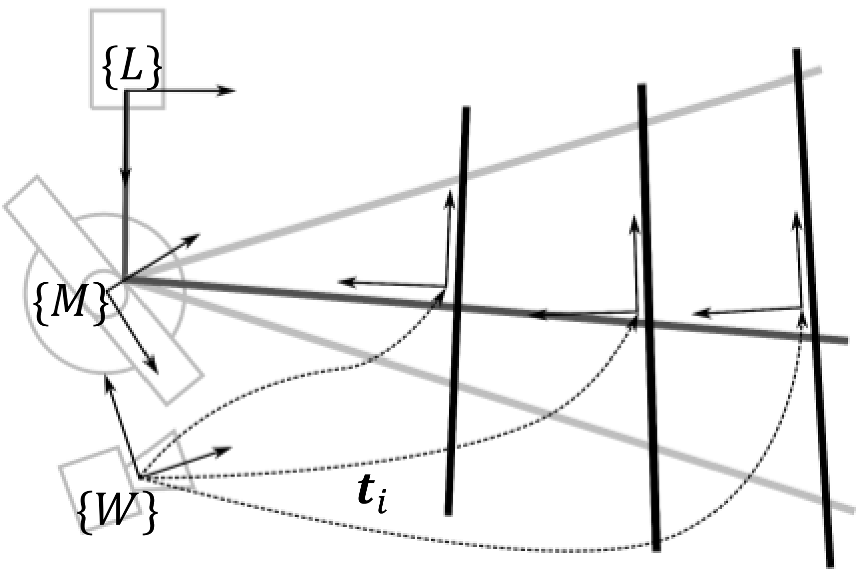
    $k_1, k_2, p_1, p_2, k_3 \ldots$
- Laser calibration

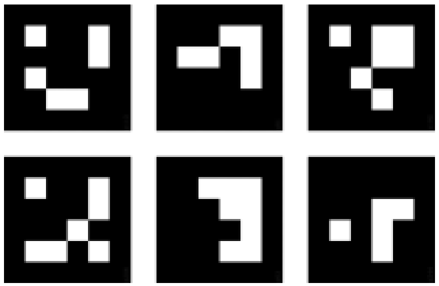
  ${}^{\{W\}}\boldsymbol{t}_{\{M\}}, {}^{\{W\}}\boldsymbol{t}_{\{L\}}, \delta, \rho_s$
- Camera viewport calibration

  π_C, t_C
- Laser viewport calibration

  π_L, t_L

Underwater laser scanner: Calibration

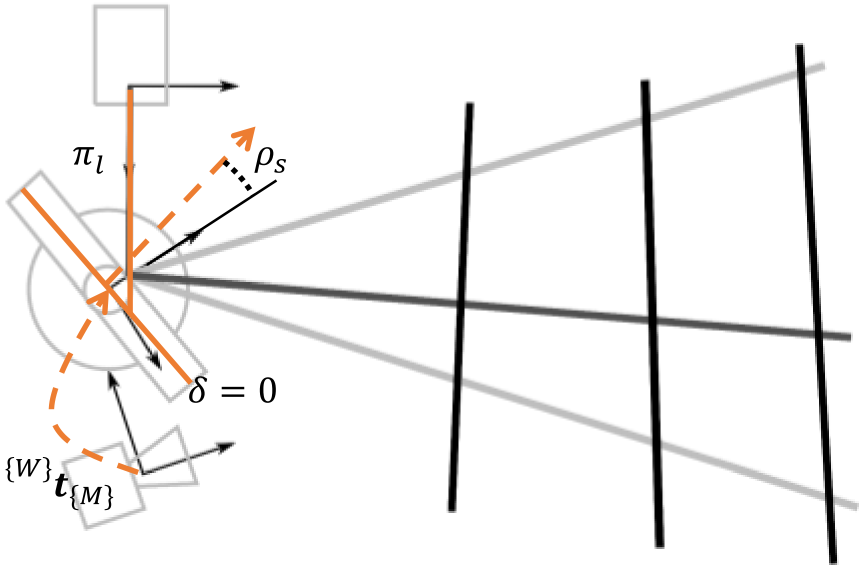




Laser calibration data generation

- Project the laser onto different projection planes: $1 \ldots i \ldots m$
- Project the laser for different mirror angles: $1 \ldots j \ldots n$
- For each projection plane-mirror angle save the laser pixels $\boldsymbol{u}_{i,j,k}$: $1 \ldots k \ldots o$
- Add reference frame $\boldsymbol{t}_i$ to each projection plane
- Compute projection planes π_{p_i}
- Compute calibration points $\boldsymbol{p}_{i,j,k}$ intersecting each $\boldsymbol{u}_{i,j,k}$ with its projection plane π_{p_i}

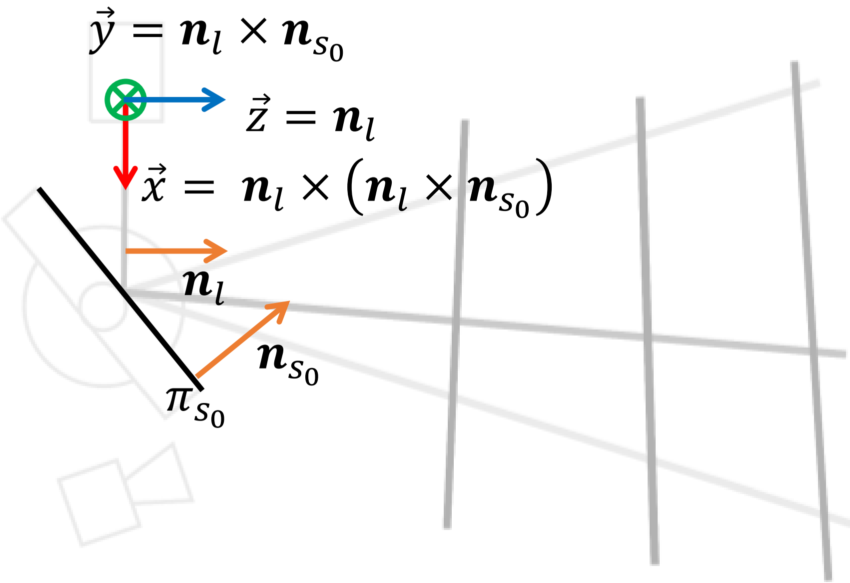
Underwater laser scanner: Calibration



Laser calibration: Simplified model

- Laser plane π_l
- Mirror pose ${}^{\{W\}}\boldsymbol{t}_{\{M\}}$
- Mirror step ρ_s
- Rotation distance $\delta = 0$

Underwater laser scanner: Calibration

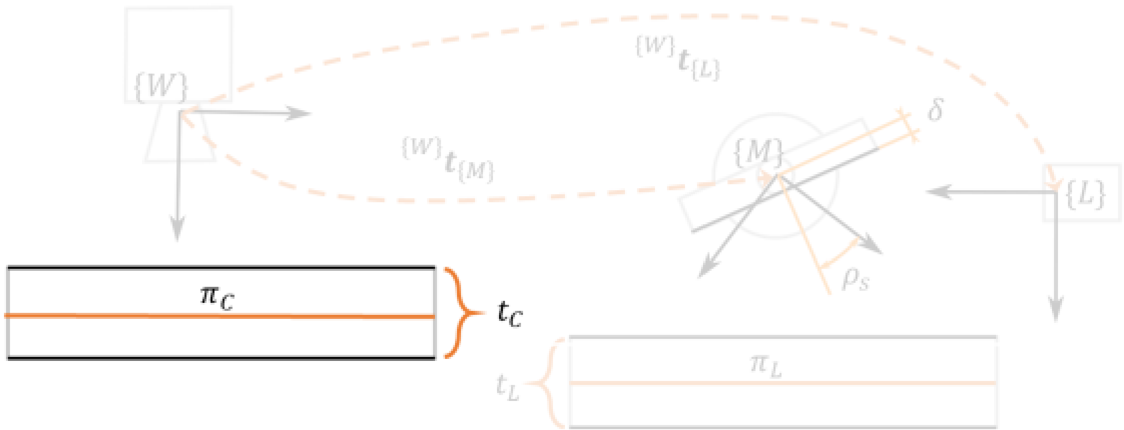


Laser pose

- For each $\boldsymbol{P}^{\uparrow}_{s_j}$ and $\boldsymbol{P}^{\downarrow}_{s_j}$ compute the laser ray $\boldsymbol{r}^{\uparrow}_{s_j}$ and $\boldsymbol{r}^{\downarrow}_{s_j}$
- Reflect each $\boldsymbol{r}^{\uparrow}_{s_j}$ and $\boldsymbol{r}^{\downarrow}_{s_j}$ onto its corresponding mirror plane π_{s_j} to obtain $\boldsymbol{r}^{\uparrow -}_{s_j}$ and $\boldsymbol{r}^{\downarrow -}_{s_j}$
- Estimate the translation part of ${}^{\{W\}}\boldsymbol{t}_{\{L\}}$ by finding the closest to all $\boldsymbol{r}^{\uparrow -}_{s_j}$ and $\boldsymbol{r}^{\downarrow -}_{s_j}$ on π_l
- Set the rotation part of ${}^{\{W\}}\boldsymbol{t}_{\{L\}}$ aligning $\vec{z}$ to $\boldsymbol{n}_l$ and $\vec{y}$ to the direction of the intersection of π_l and π_{s_0}

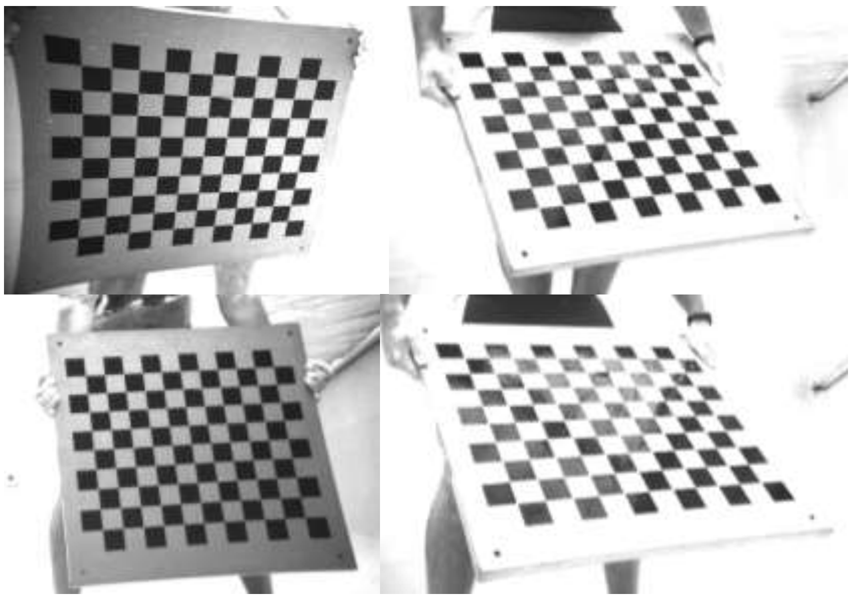
$$ {}^{\{W\}}\boldsymbol{R}_{\{M\}} = \left[\boldsymbol{n}_l \times (\boldsymbol{n}_l \times \boldsymbol{n}_{s_0}) \quad \boldsymbol{n}_l \times \boldsymbol{n}_{s_0} \quad \boldsymbol{n}_l\right] $$

Underwater laser scanner: Calibration



- Camera calibration
  - Camera parameters
    $f_x \quad f_y \quad c_x \quad c_y$
  - Camera distortion
    $k_1, k_2, p_1, p_2, k_3 \ldots$
- Laser calibration
  ${}^{\{W\}}\boldsymbol{t}_{\{M\}}, {}^{\{W\}}\boldsymbol{t}_{\{L\}}, \delta, \rho_s$
- Camera viewport calibration
  $\pi_C,\ t_c$
- Laser viewport calibration
  $\pi_L,\ t_L$

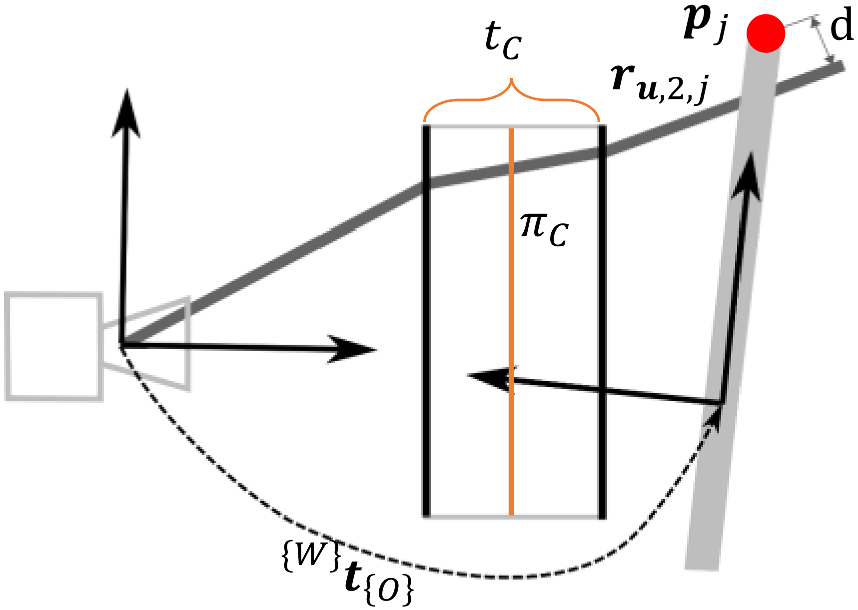
Underwater laser scanner: Calibration



Camera viewport $\Omega_C = [\pi_C \quad t_C]$

- Multiple underwater view of a calibration pattern

Underwater laser scanner: Calibration

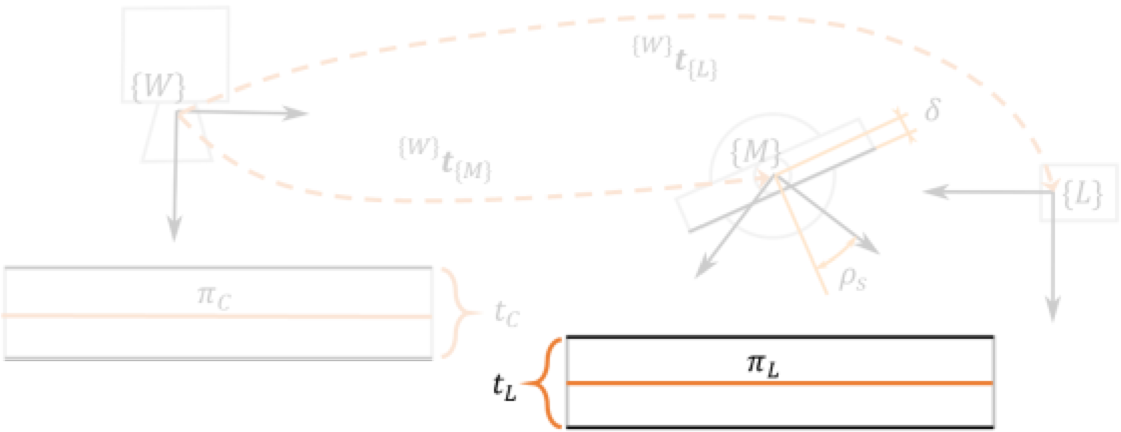


Camera viewport $\Omega_C = [\pi_C \quad t_C]$

- Multiple underwater view of a calibration pattern
- Pattern initial guess: Solve PnP
- Viewport initial guess: CAD design
- Compute error for each point of the calibration pattern $j = 1..n$
- Refine viewport Ω_C and calibration pattern positions $\boldsymbol{T}$ using all images of the calibration pattern $i = 1..m$

$$[\Omega_C \quad \boldsymbol{T}] = \underset{[\Omega_C \quad \boldsymbol{T}]}{\operatorname{argmin}} \sum_{i=1}^{m} \sum_{j=1}^{n} \mathrm{d}\left({}^{\{W\}}\boldsymbol{t}_{\{O\},i} \oplus \boldsymbol{p}_j,\ \boldsymbol{r}_{\boldsymbol{u},2,i,j}\right)$$

Underwater laser scanner: Calibration



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  - Camera parameters
    $f_x \quad f_y \quad c_x \quad c_y$
  - Camera distortion
    $k_1, k_2, p_1, p_2, k_3 \ldots$
- Laser calibration
  $^{\{W\}}\boldsymbol{t}_{\{M\}}, {}^{\{W\}}\boldsymbol{t}_{\{L\}}, \delta, \rho_s$
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  π_C, t_C
- Laser viewport calibration
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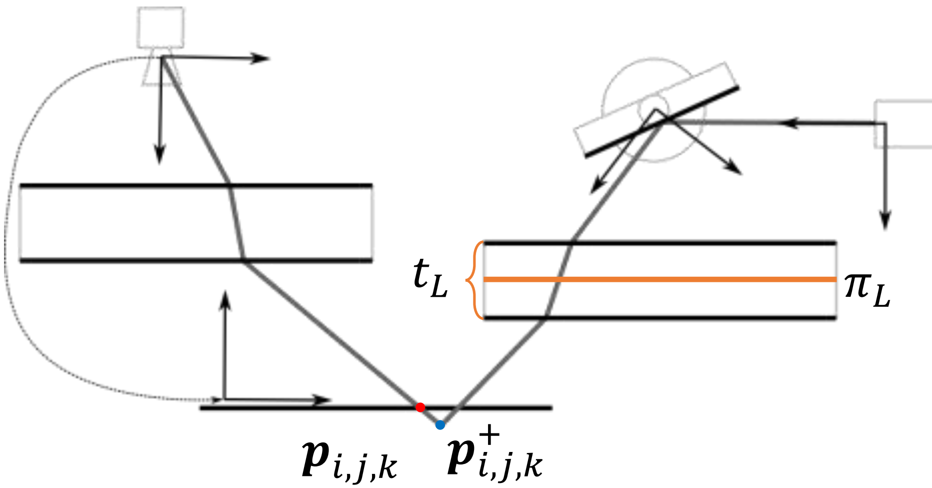
Underwater laser scanner: Calibration

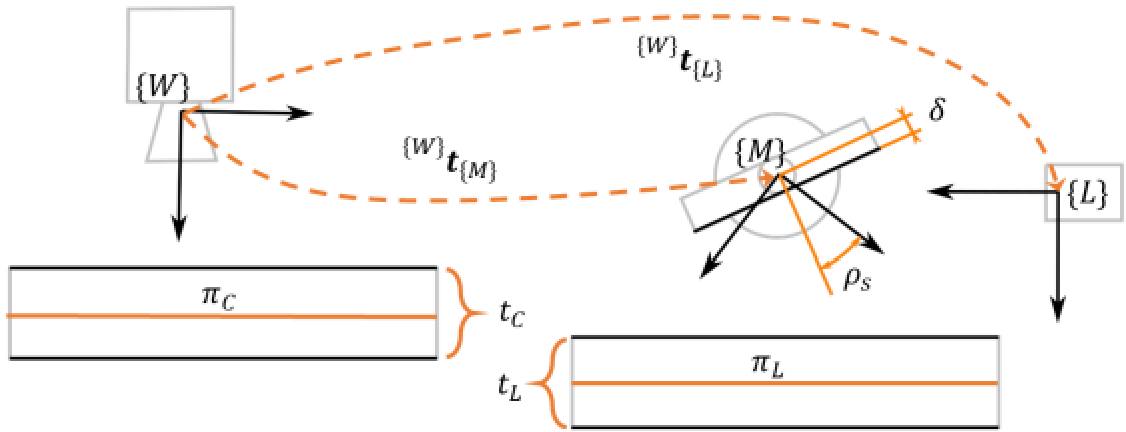


Laser viewport $\Omega_L = [\pi_L \quad t_L]$

- Same type of dataset as in air laser calibration
- Laser viewport initial guess: CAD design
- Estimate position of projection
- Compute calibration point $\boldsymbol{p}_{i,j,k}$
- Compute point using ray-ray triangulation $\boldsymbol{p}^{+}_{i,j,k}$
- Refine the laser viewport

$$\Omega_L = \underset{\Omega_L}{\operatorname{argmin}} \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{o} \boldsymbol{p}^{+}_{i,j,k} - \boldsymbol{p}_{i,j,k}$$

Underwater laser scanner: Calibration



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Underwater laser scanner: Deformation model

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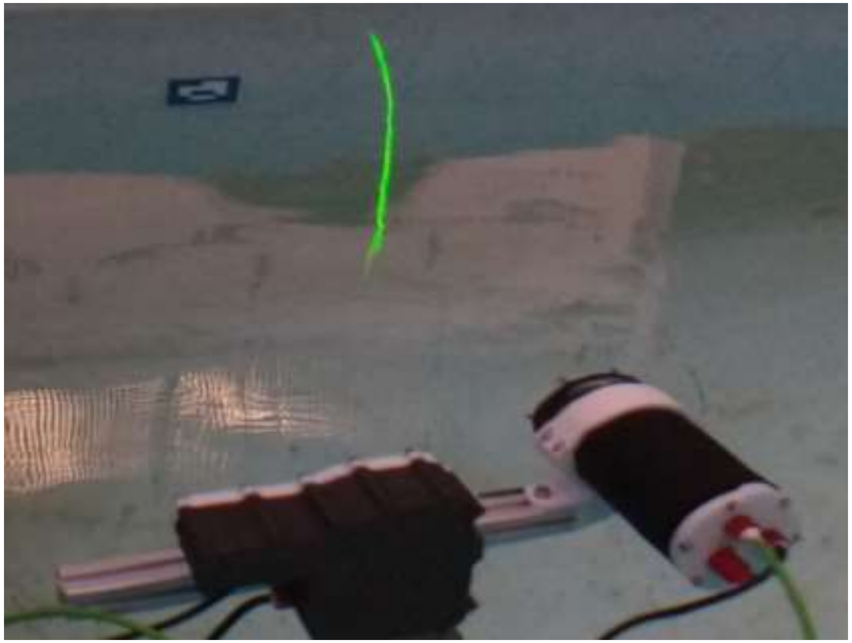
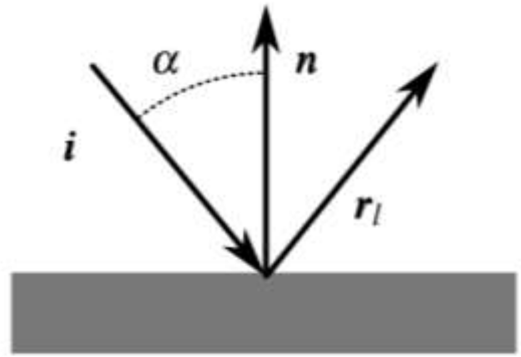
How to model the laser deformation?



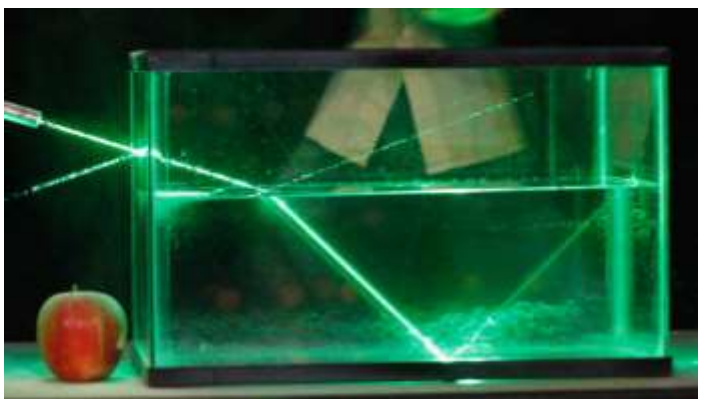
Underwater laser scanner: Deformation model

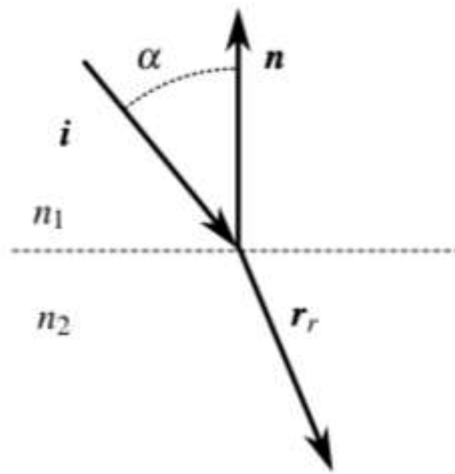
Reflection



$$\boldsymbol{r}_l = \boldsymbol{i} - 2(\boldsymbol{i} \cdot \boldsymbol{n})\boldsymbol{n}$$

Refraction

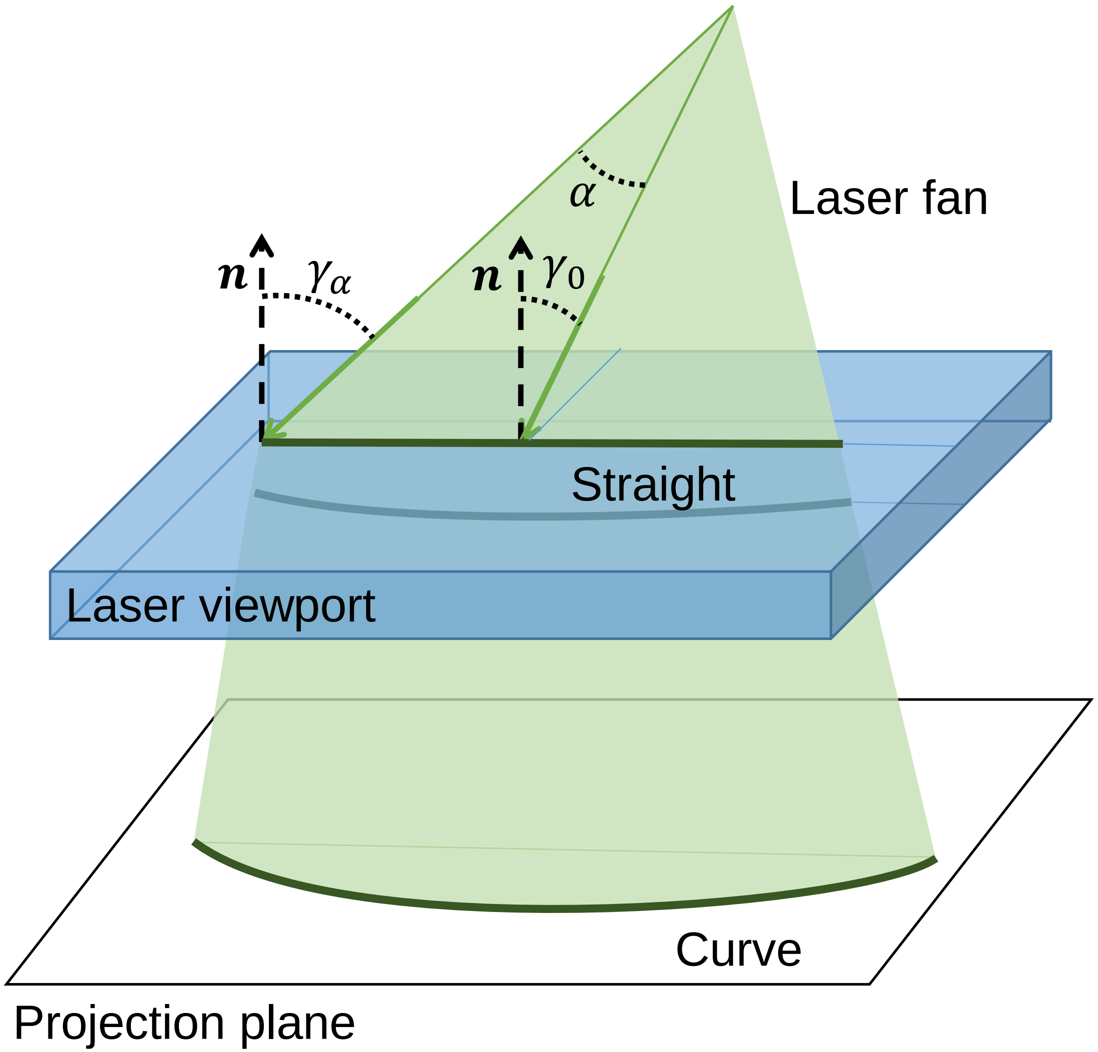


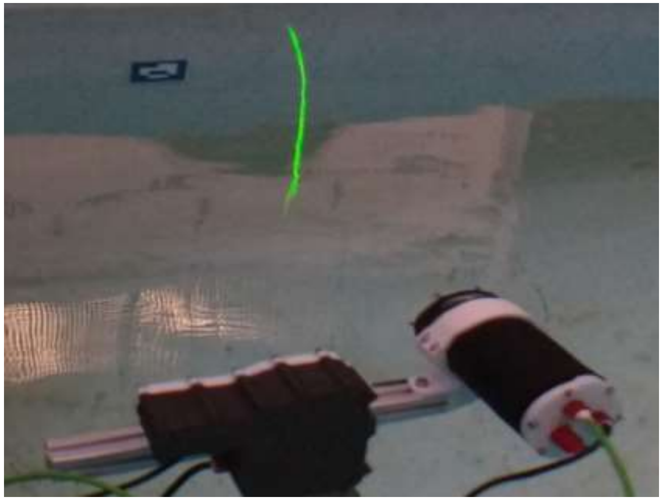


$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

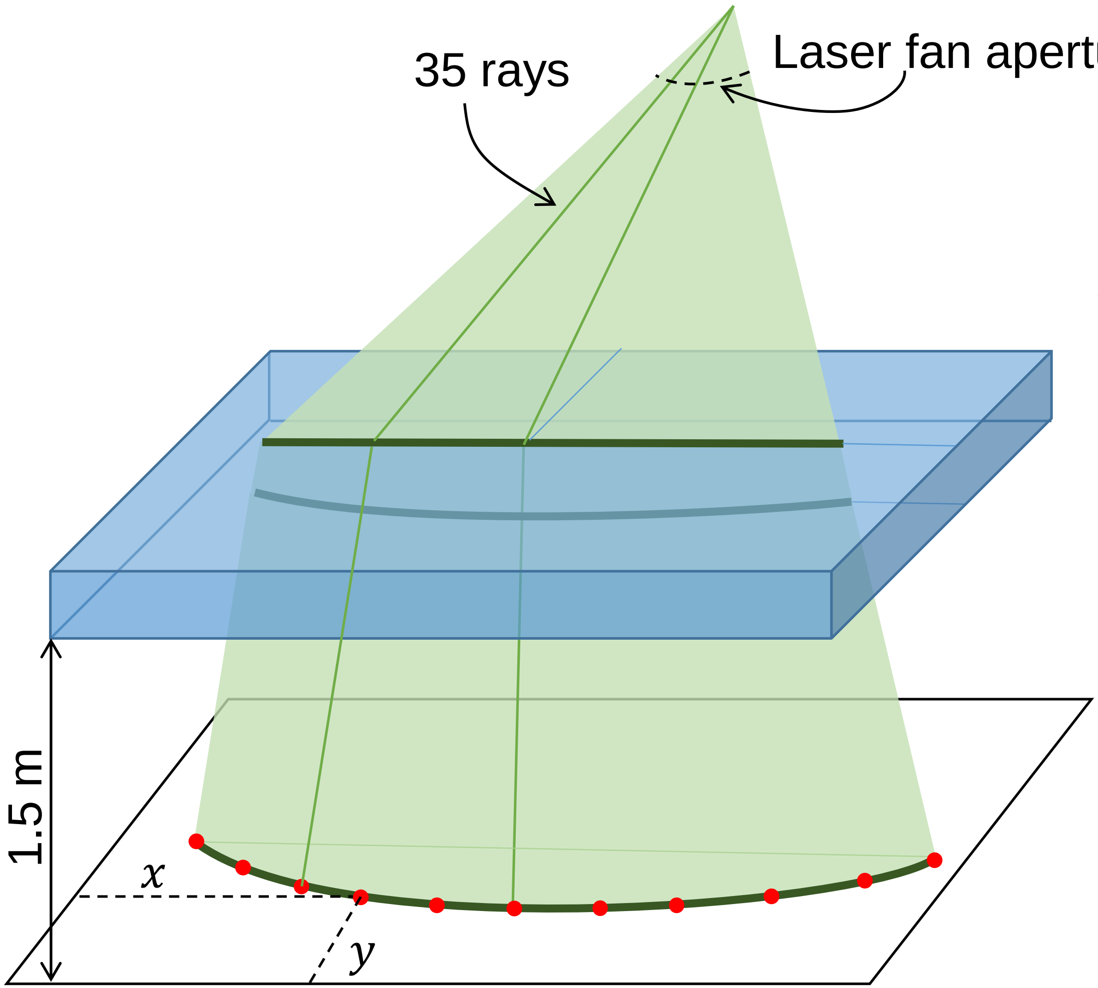
$$\boldsymbol{r}_r = \frac{n_1}{n_2}\big(\boldsymbol{n} \times (-\boldsymbol{n} \times \boldsymbol{i})\big) - \boldsymbol{n}\sqrt{1 - \left(\frac{n_1}{n_2}\right)^2 (\boldsymbol{n} \times \boldsymbol{i}) \cdot (\boldsymbol{n} \times \boldsymbol{i})}$$

Underwater laser scanner: Deformation model





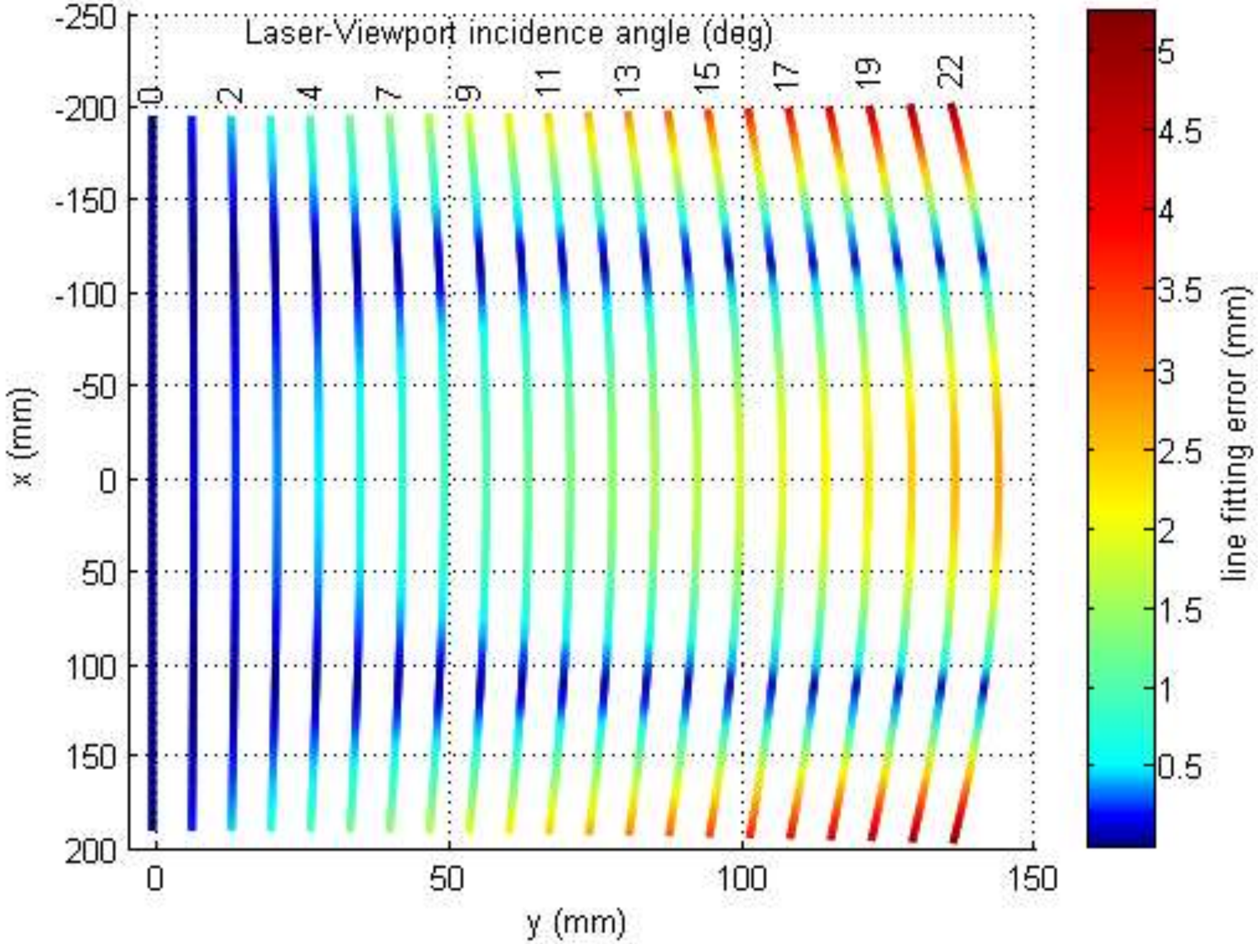
Underwater laser scanner: Deformation model



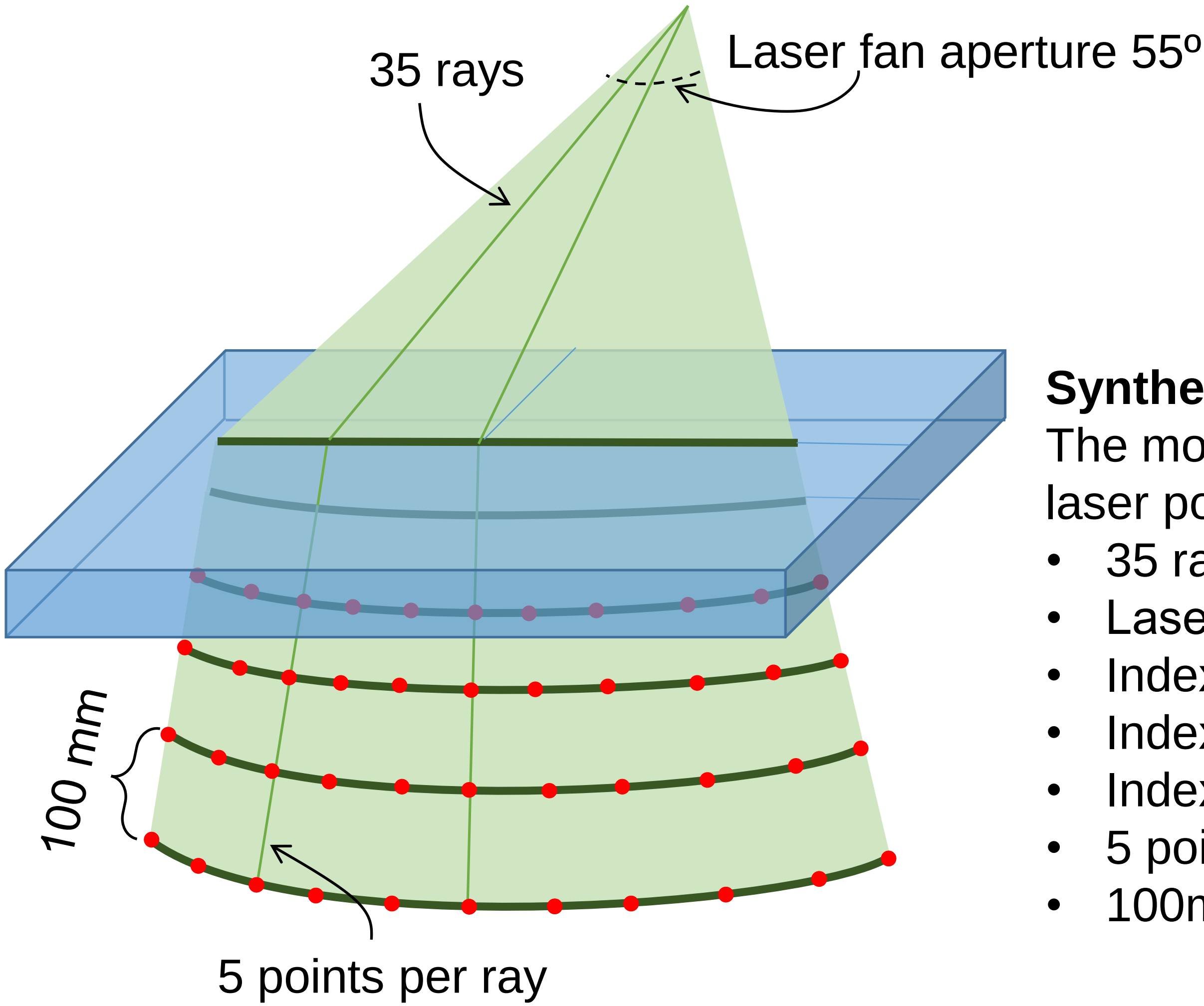
Synthetically generate points on projection plane

- 35 model rays
- Laser aperture: 55º
- 21 different laser-viewport incidence angle from 0 to 22º
- Projection plane at 1.5 m distance from the outer part of the viewport

Underwater laser scanner: Deformation model



Underwater laser scanner: Deformation model

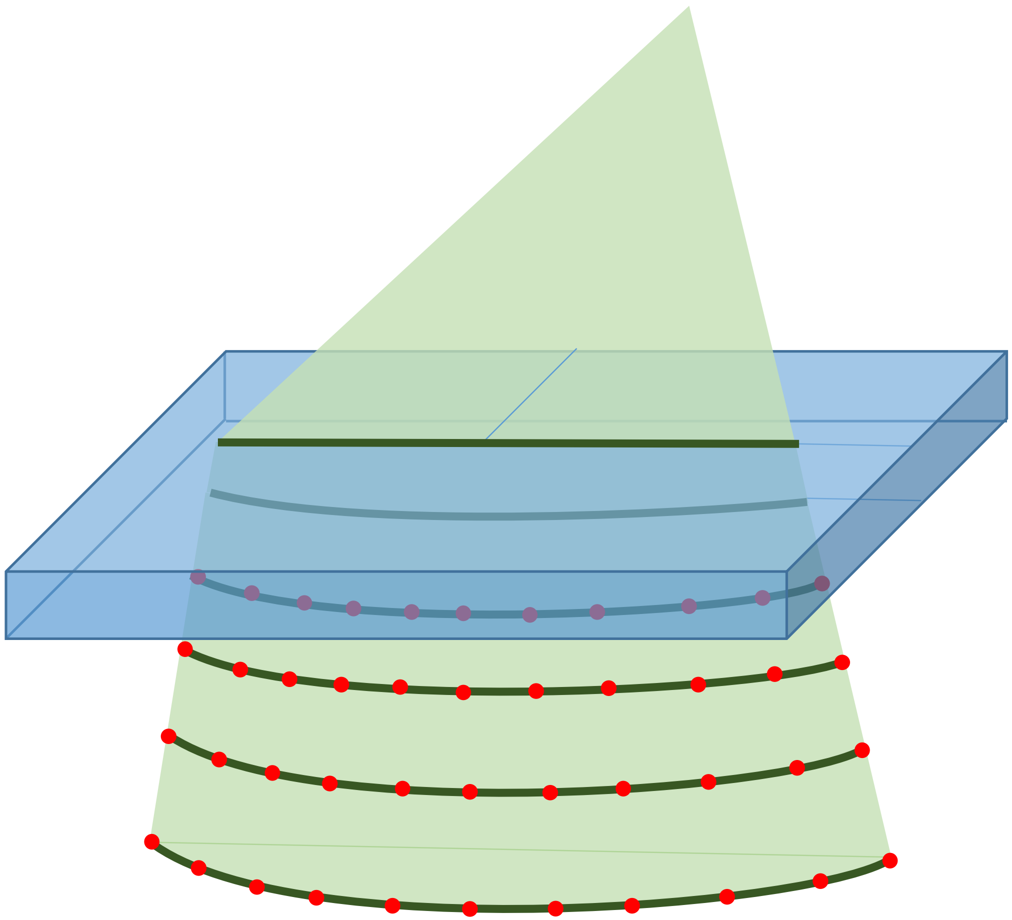


Synthetic experiment

The model was used to generate laser points:

- 35 rays
- Laser aperture 55°
- Index of refraction air: 1
- Index of refraction viewport: 1.49
- Index of refraction water: 1.33
- 5 points per ray
- 100mm intervals

Underwater laser scanner: Deformation model



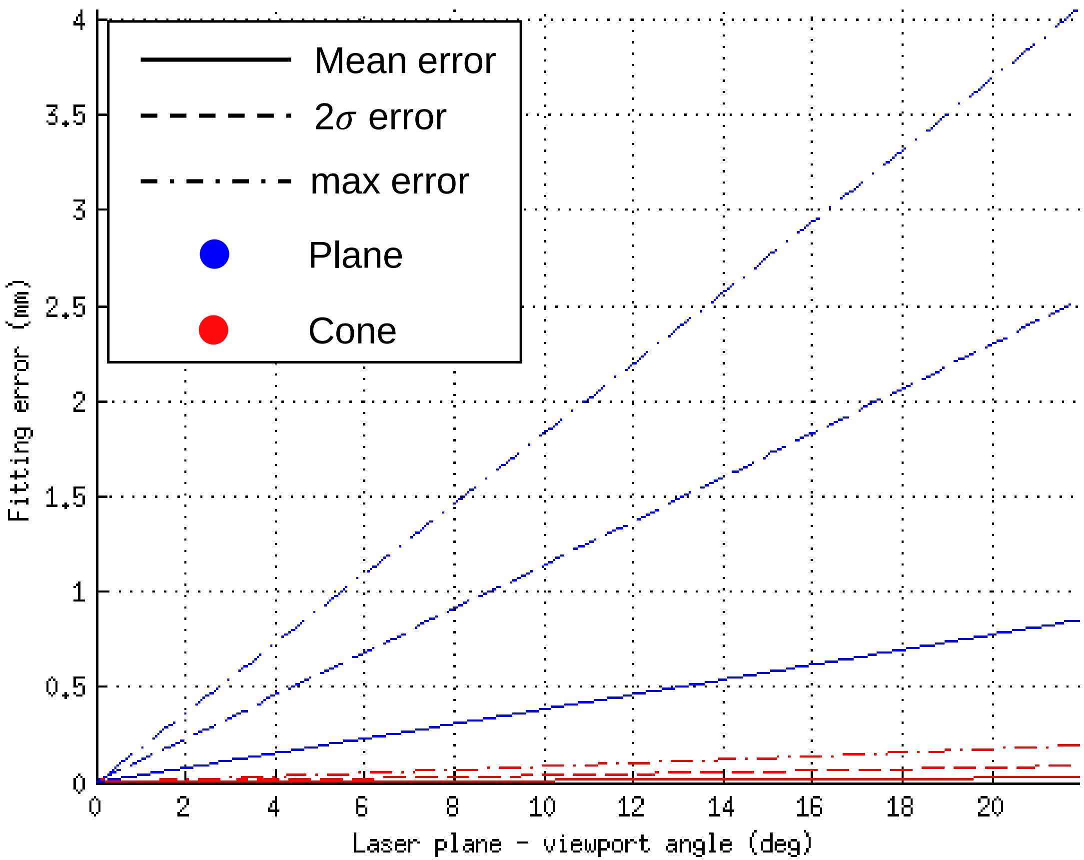
Elliptic cone:

- Closed form solution for ray-cone intersection
- Can also be a plane

$$\boldsymbol{c}(h,\beta)=\begin{bmatrix} a\,h\ \cos(\beta) \\ b\,h\ \sin(\beta) \\ h \end{bmatrix}$$

$$\boldsymbol{g}(\boldsymbol{c},\boldsymbol{t})=\boldsymbol{t}\oplus\boldsymbol{c}(h,\beta)$$

Underwater laser scanner: Deformation model



Cone fitting error < plane fitting error

Experiment:

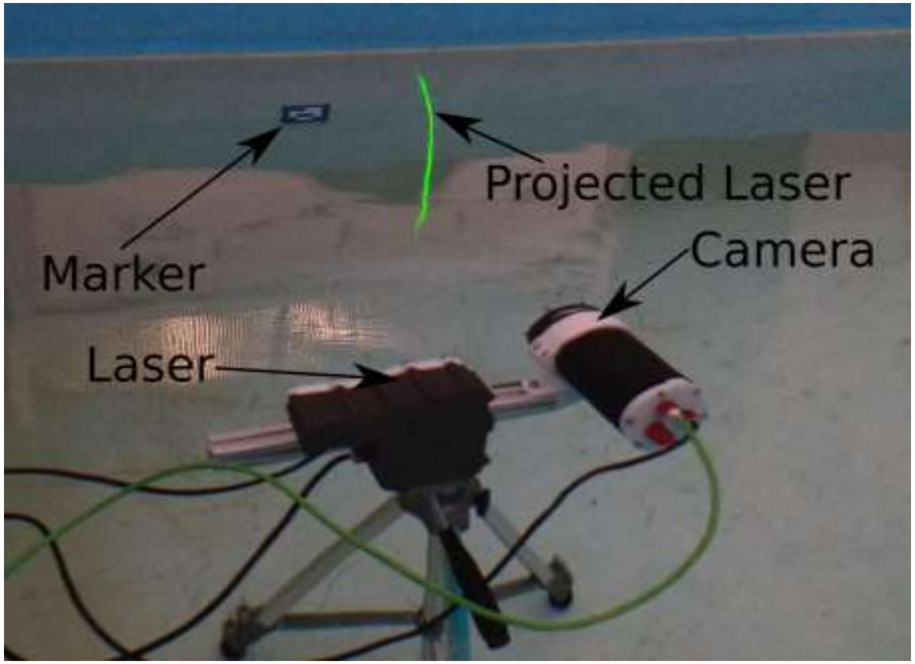
- Sample points from the laser fan
- Fit plane to dataset
- Fit cone to dataset
- Plot fitting error vs incidence angle

Underwater laser scanner: Deformation model

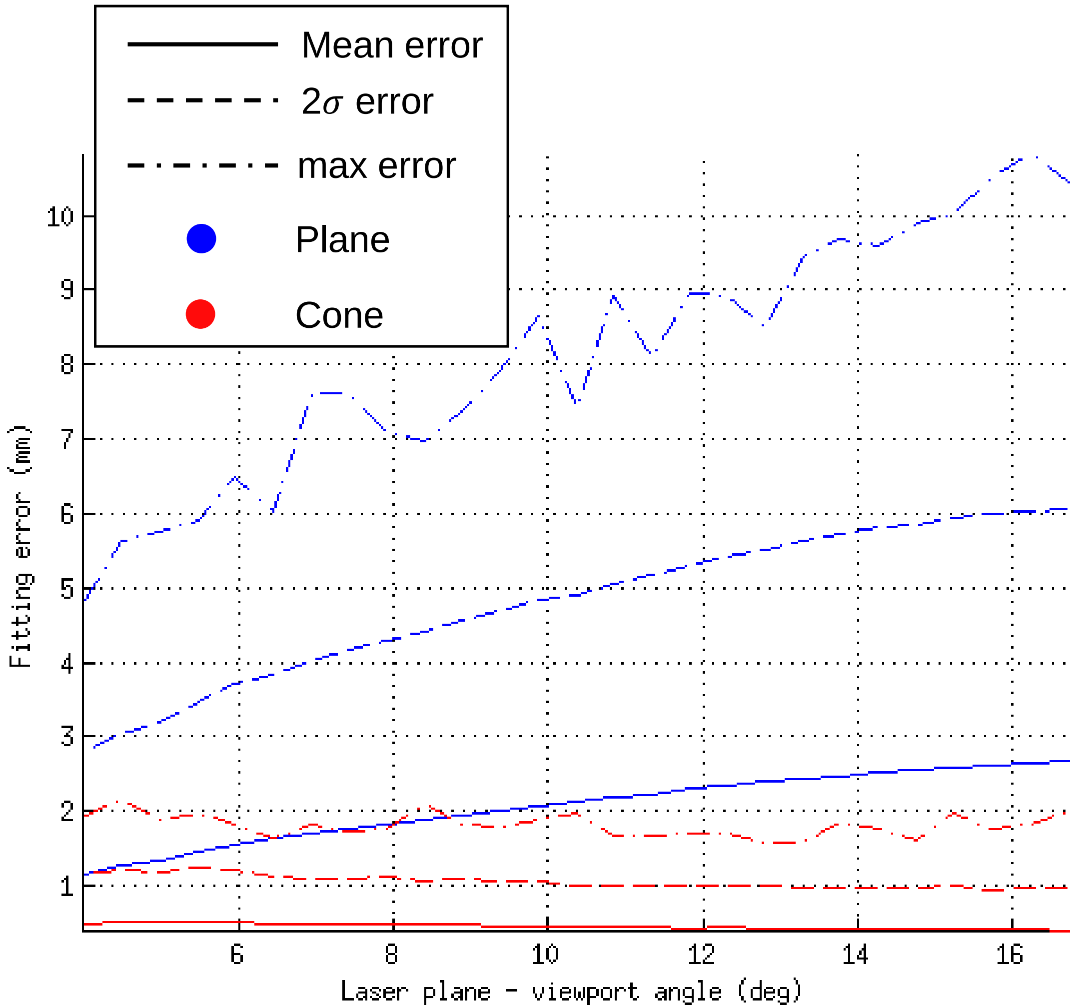
Real experiment

Use scanner to generate data points

- Use computer vision to estimate projection plane pose
- Intersect camera ray with projection plane to compute points



Underwater laser scanner: Deformation model



Cone fitting error < plane fitting error

Underwater laser scanner: Triangulation

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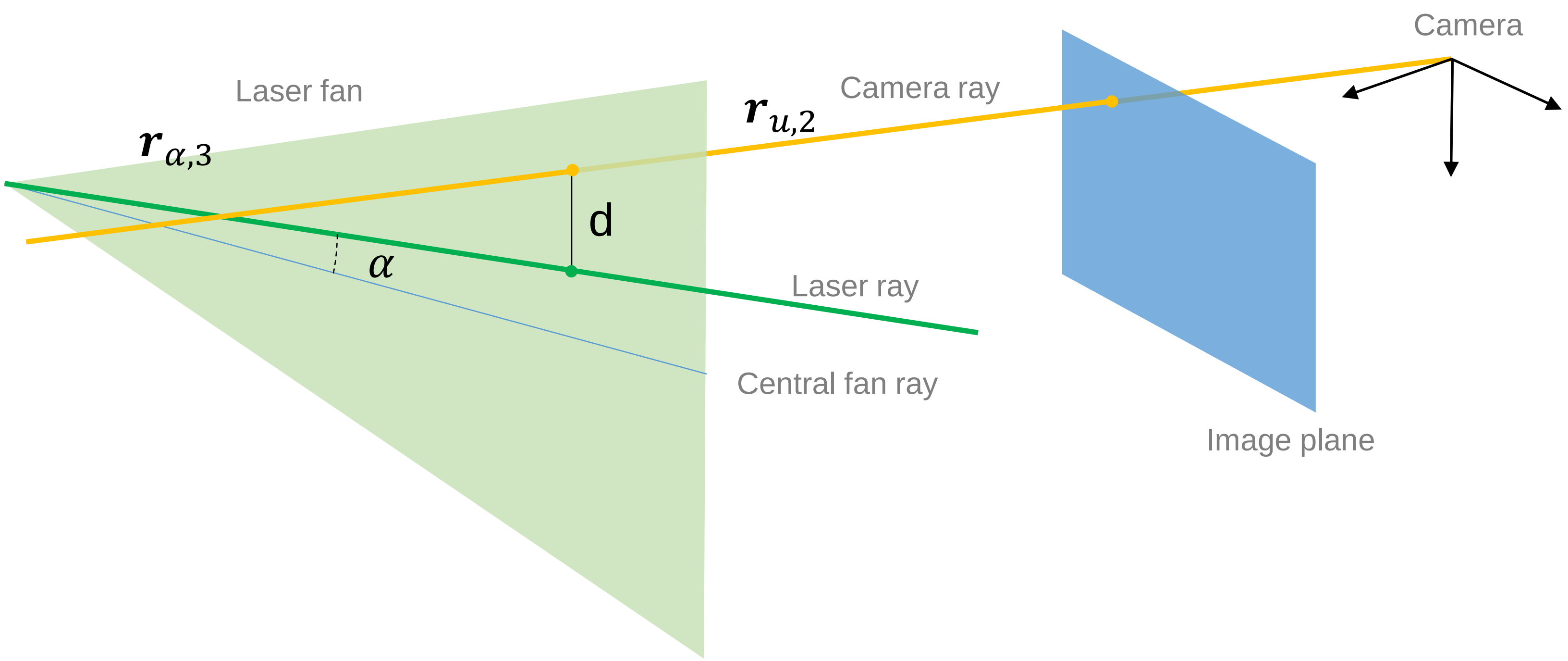
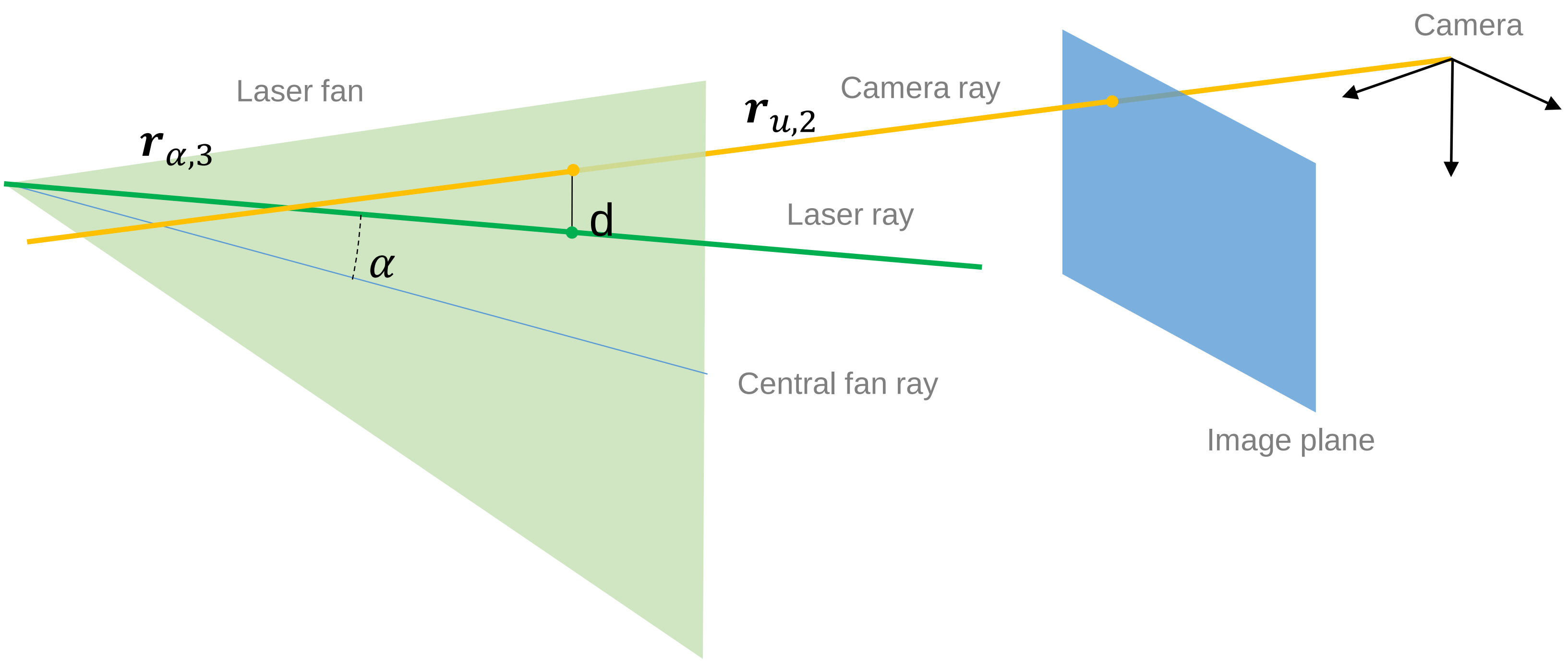
Ray-ray triangulation



Ray-ray intersection: $\alpha = \underset{\alpha}{\operatorname{argmin}}\, \mathrm{d}(\boldsymbol{r}_{\alpha,3}, \boldsymbol{r}_{u,2})$

Underwater laser scanner: Triangulation

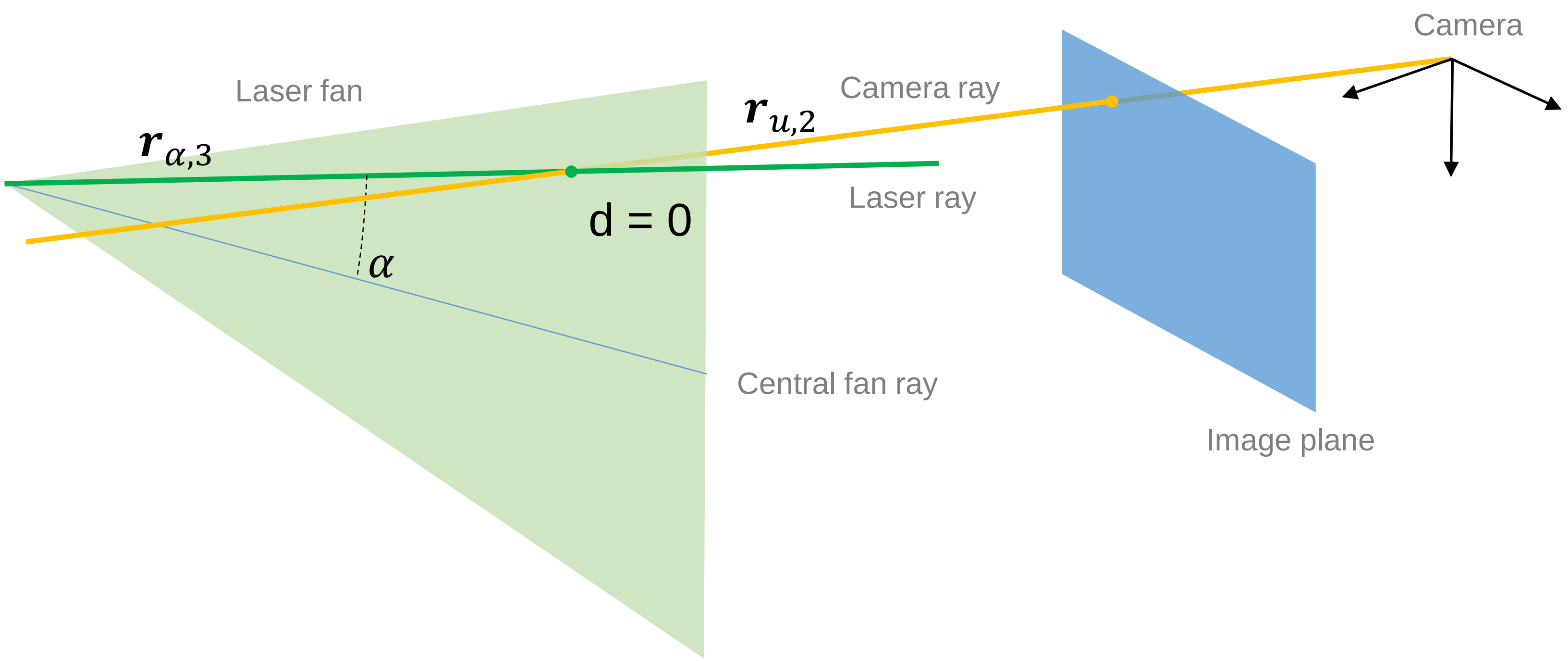
Ray-ray triangulation



Ray-ray intersection: $\alpha = \underset{\alpha}{\operatorname{argmin}}\, \mathrm{d}(\boldsymbol{r}_{\alpha,3}, \boldsymbol{r}_{u,2})$

Underwater laser scanner: Triangulation

Ray-ray triangulation



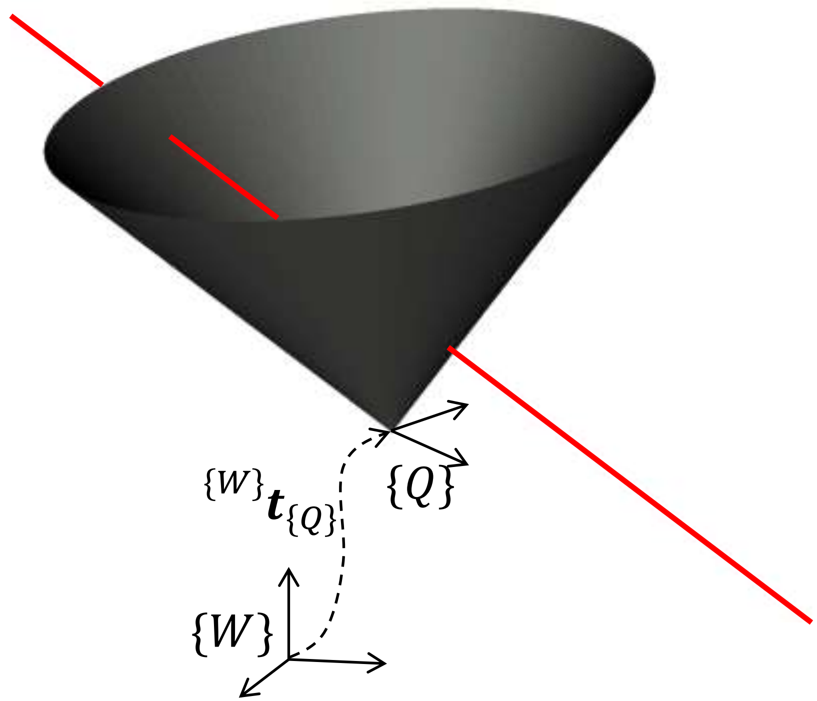
Ray-ray intersection: $\alpha = \underset{\alpha}{\operatorname{argmin}}\, \mathrm{d}(\boldsymbol{r}_{\alpha,3}, \boldsymbol{r}_{u,2})$

Ray-cone triangulation

Cone equation

$$^{\{Q\}}\boldsymbol{c}(h,\beta) = \begin{bmatrix} a\,h\ \cos(\beta) \\ b\,h\ \sin(\beta) \\ h \end{bmatrix}$$

$$\boldsymbol{g}(h,\beta,\boldsymbol{t}) = {}^{\{W\}}\boldsymbol{t}_{\{Q\}} \oplus {}^{\{Q\}}\boldsymbol{c}(h,\beta)$$



Ray-cone triangulation

Cone equation

$$^{\{Q\}}\boldsymbol{c}(h,\beta) = \begin{bmatrix} a\,h\ \cos(\beta) \\ b\,h\ \sin(\beta) \\ h \end{bmatrix}$$

$$\boldsymbol{g}(h,\beta,\boldsymbol{t}) = {}^{\{W\}}\boldsymbol{t}_{\{Q\}} \oplus {}^{\{Q\}}\boldsymbol{c}(h,\beta)$$

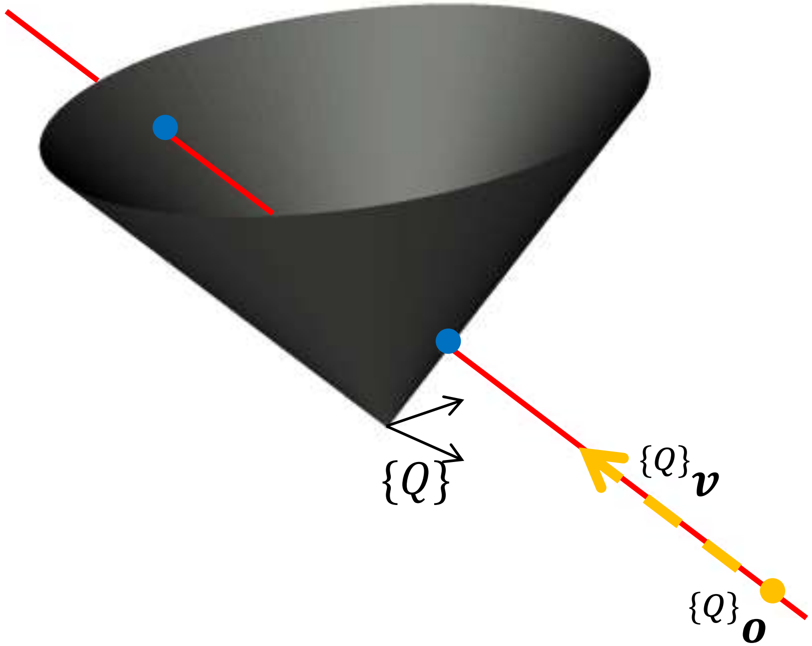
Ray in cone space

$$^{\{W\}}\boldsymbol{r}(\lambda) = \lambda\,^{\{W\}}\boldsymbol{v} + {}^{\{W\}}\boldsymbol{o}$$

$$^{\{Q\}}\boldsymbol{r}(\lambda) = {}^{\{W\}}\boldsymbol{R}_{\{Q\}}^{-1}\left(\lambda\,^{\{W\}}\boldsymbol{v} + {}^{\{W\}}\boldsymbol{o} - [t_x \quad t_y \quad t_z]^T\right)$$

Ray-cone intersection

$$^{\{Q\}}\boldsymbol{r}(\lambda) = {}^{\{Q\}}\boldsymbol{c}(h,\beta) \rightarrow \lambda\,^{\{Q\}}\boldsymbol{v} + {}^{\{Q\}}\boldsymbol{o} = \begin{bmatrix} a\,h\ \cos(\beta) \\ b\,h\ \sin(\beta) \\ h \end{bmatrix}$$



$$\begin{aligned} &\lambda^2\left(b^2 v_x^2 + a^2 v_y^2 - a^2 b^2 v_z^2\right) \\ &+ 2\lambda\left(b^2 v_x o_x + a^2 v_y o_y - a^2 b^2 v_z o_z\right) \\ &+ \left(b^2 o_x^2 + a^2 o_y^2 - a^2 b^2 o_z^2\right) = 0 \end{aligned}$$

- 2^{nd} degree equation λ
- Closed form solution

Underwater laser scanner: Results

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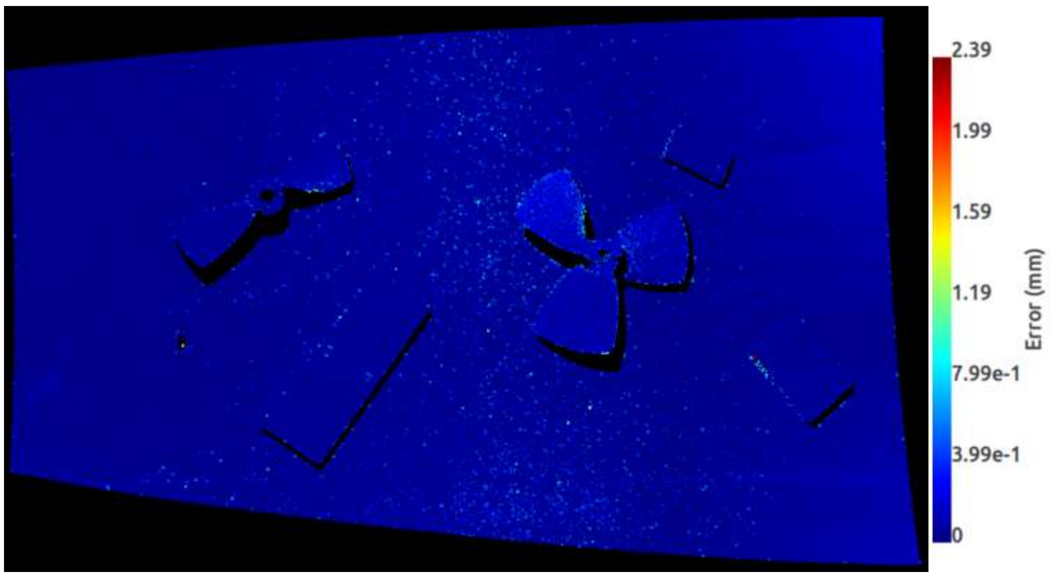
Triangulation method comparison



- Reconstruct scene with ray-ray triangulation
- Reconstruct scene with ray-cone triangulation
- Compute distance between each point of each triangulation type

Error

$\mu = 0.05$ mm

$\sigma = 0.062$ mm

	Ray-ray	Ray-cone
Time	≈21 s	≈5 s

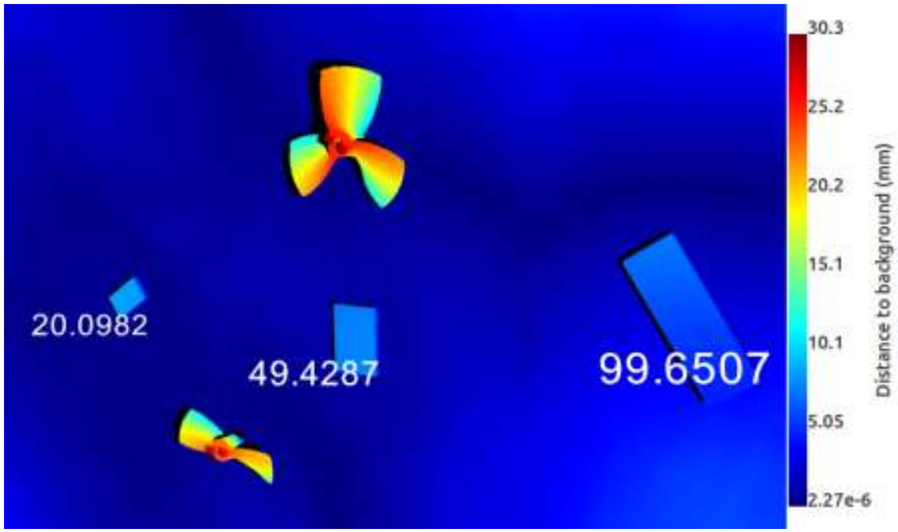
Ray-cone triangulation is **faster** than ray-ray triangulation at the same **accuracy**.

Underwater laser scanner: Results

3D reconstruction results

Underwater laser scanner: Results

3D reconstruction



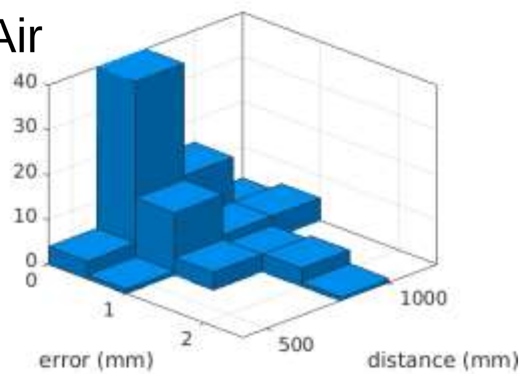
- Measure 3 ceramic gauges of 20, 50 and 100 mm length in 29 different positions from 0.5 m to 1.2 m
- Air error:

$$\mu = 0.44 \text{ mm}$$
$$\sigma = 0.35 \text{ mm}$$

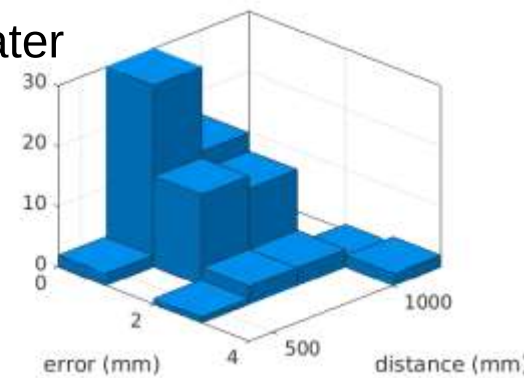
- Underwater error:

$$\mu = 0.98 \text{ mm}$$
$$\sigma = 0.72 \text{ mm}$$

Air



Underwater

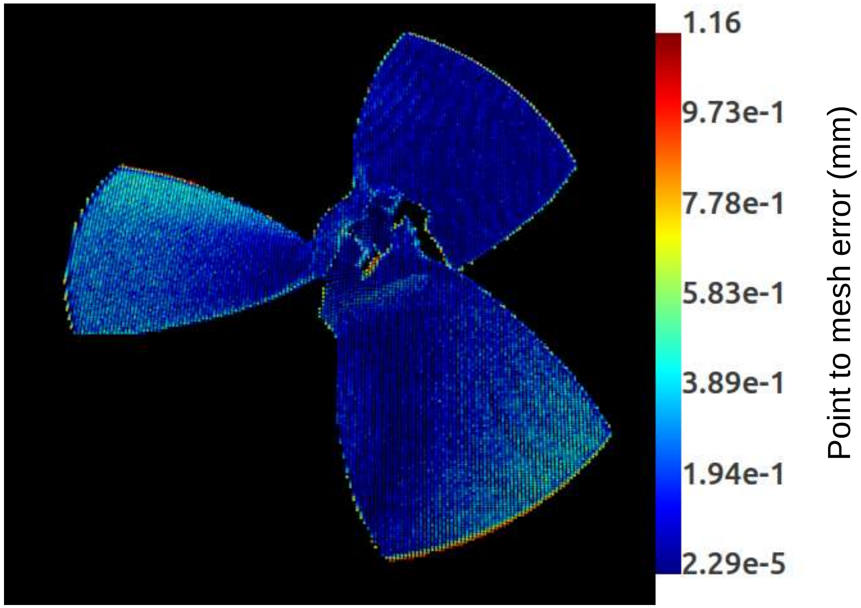


Same order of magnitude in error with bigger errors underwater.

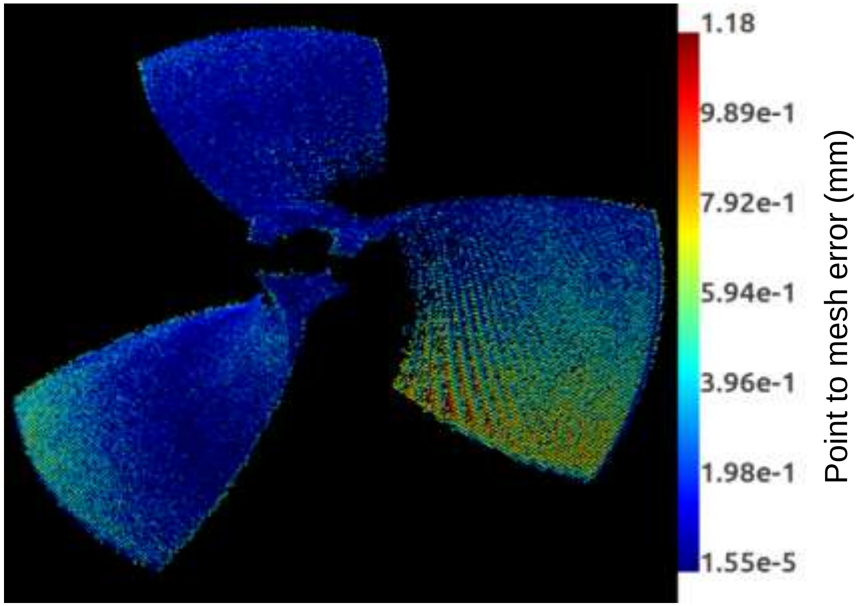
Underwater laser scanner: Results

3D reconstruction

Air

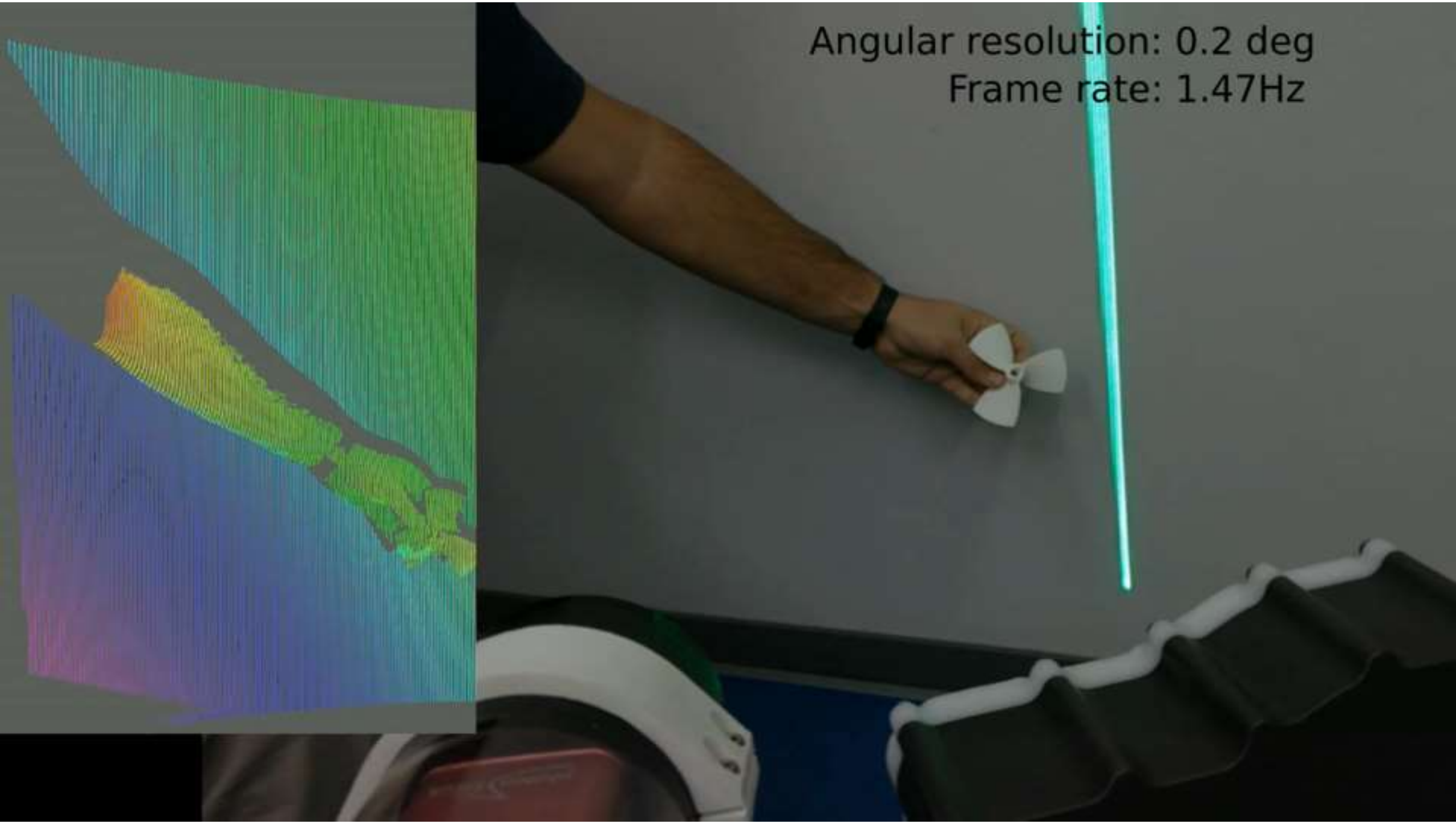


Underwater

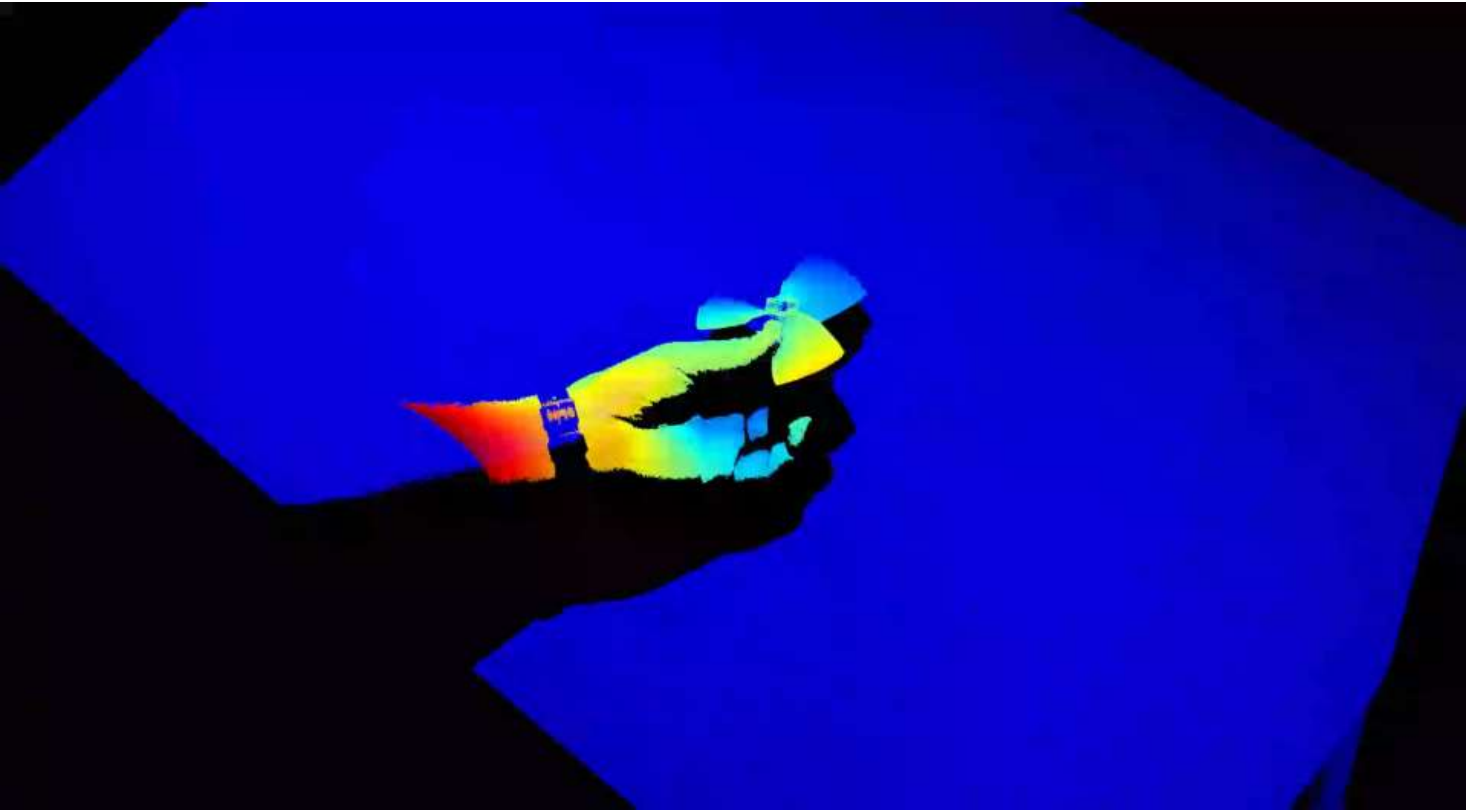


Same order of magnitude in error with bigger errors underwater.

Underwater laser scanner: Results



Underwater laser scanner: Results



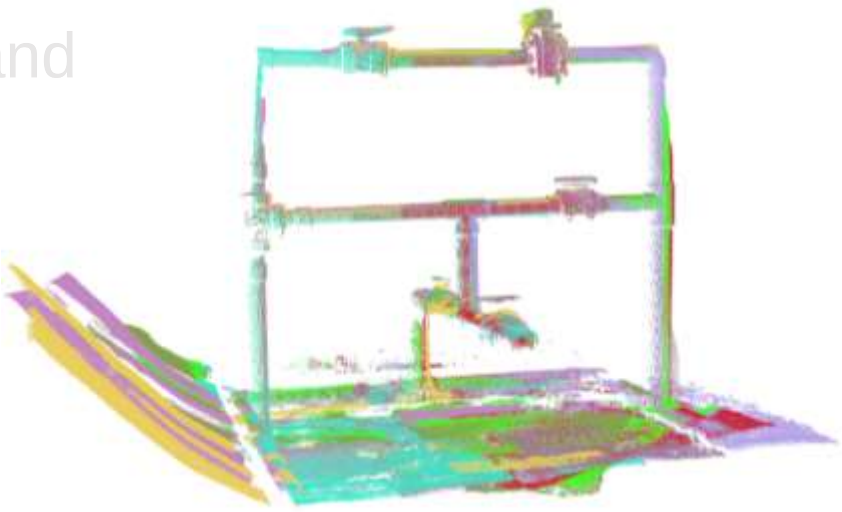
Underwater laser scanner

Summary

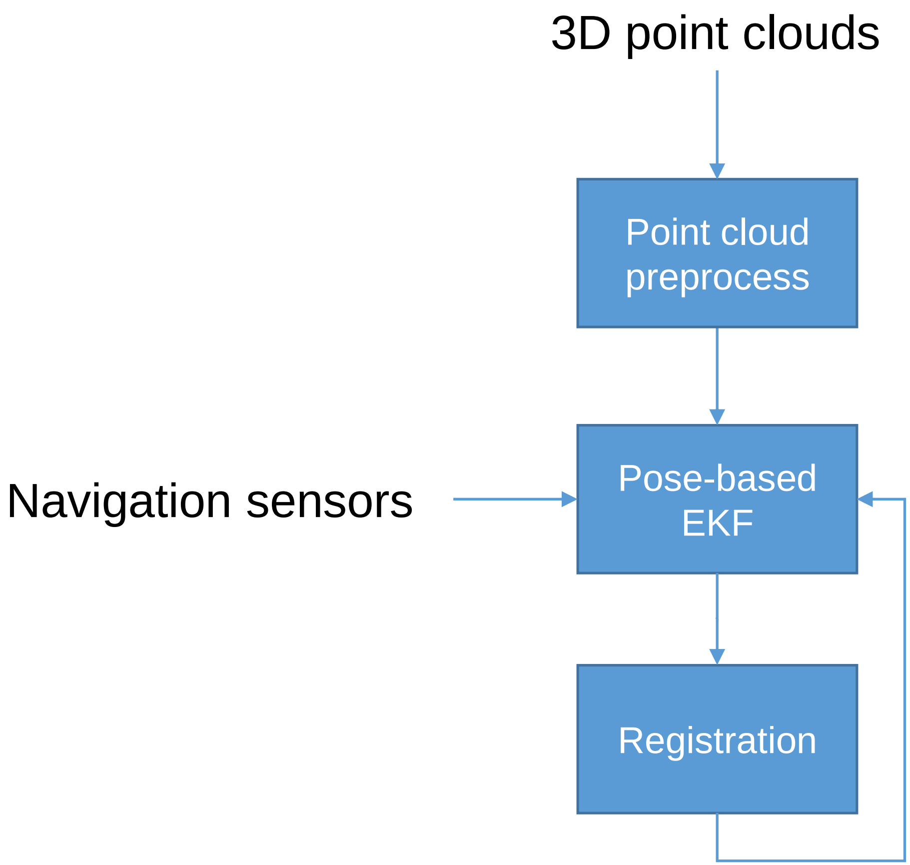
- New underwater laser scanner
- Variable speed and resolution
- A calibration procedure has been established
- Sensor deformation model
- Elliptical cone representation of the light surface
- Ray-cone triangulation is a better approach to triangulate 3D points for steering lasers with flat viewports
- Submillimetric accuracy within calibrated range (0.5-1.5m)

IMR Applications:

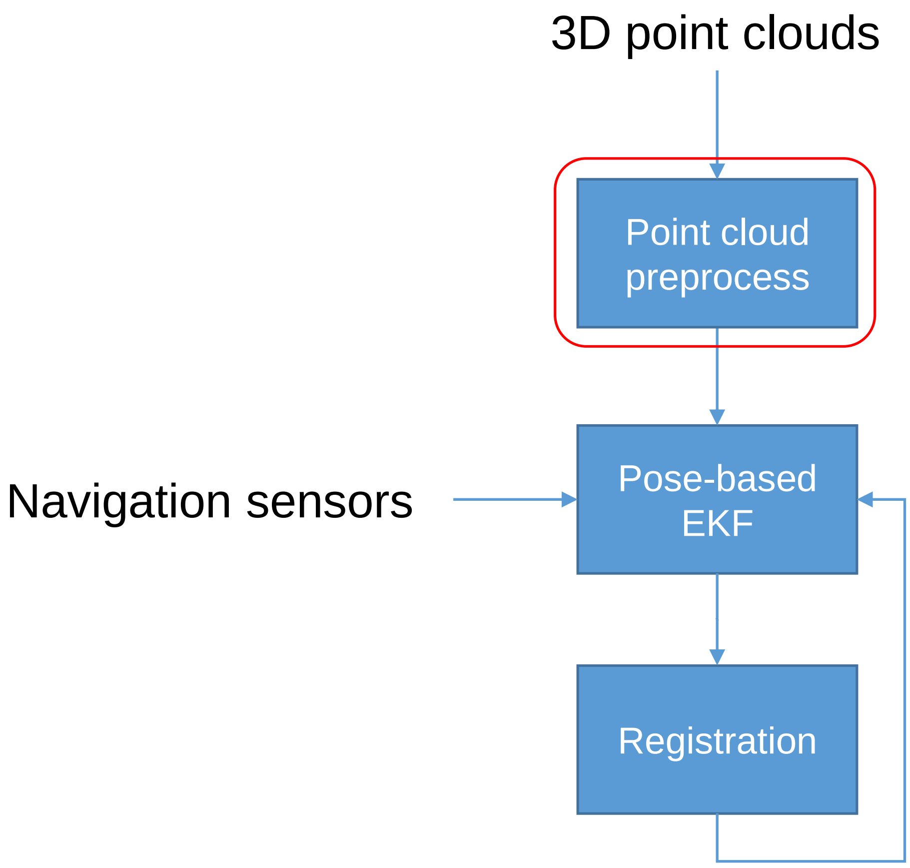
- Structure inspection
- Underwater manipulation and motion planning
- Object detection
- Exploration



Structure inspection using underwater laser scanner



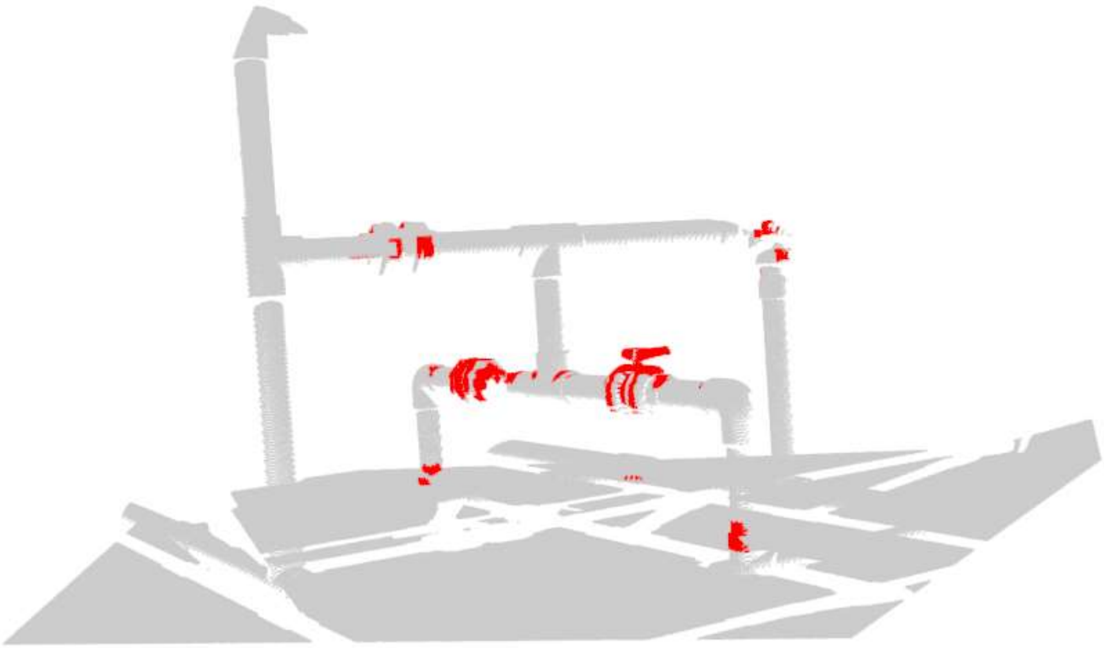
Structure inspection using underwater laser scanner



Structure inspection using underwater laser scanner

Point cloud preprocess

- Key points extraction
  - Remove planar surfaces (RANSAC, Fischler et al. 1981)
  - Remove points with curvature (Pauly et al., 2002) below threshold

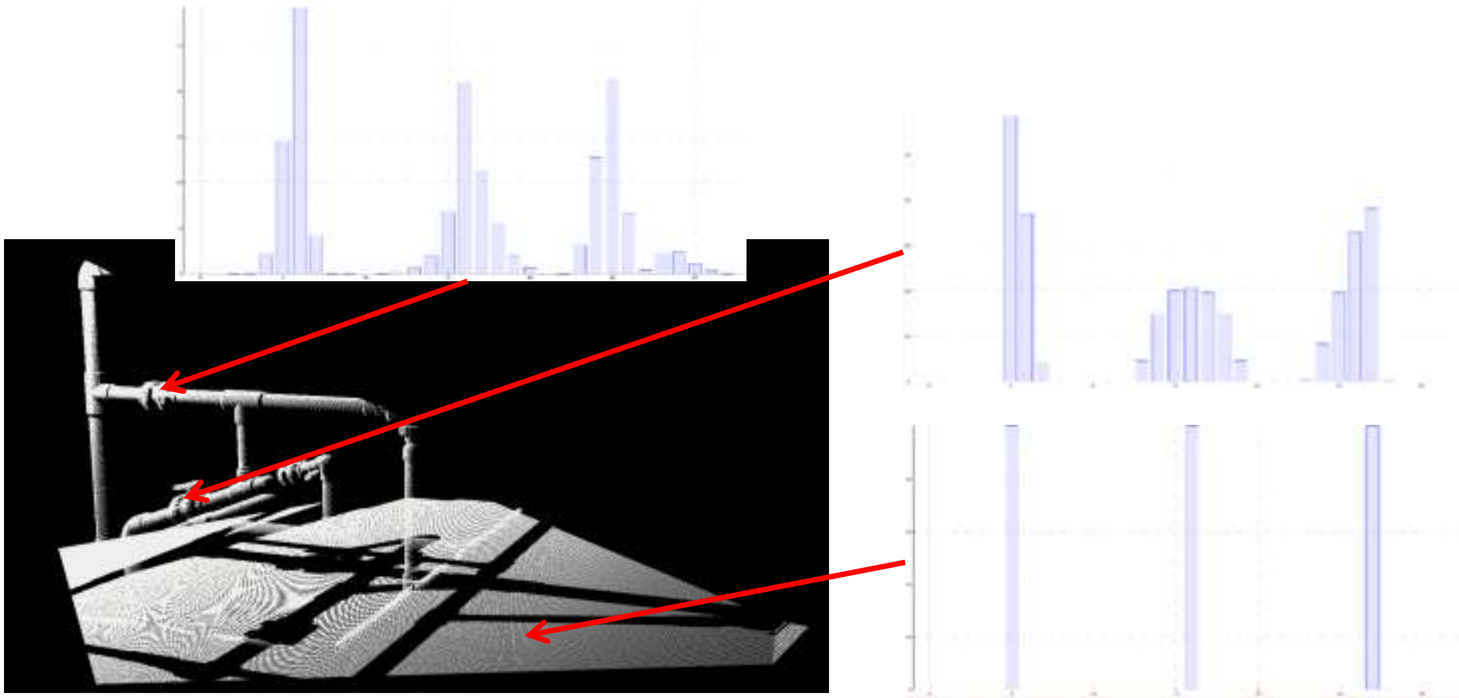


Structure inspection using underwater laser scanner

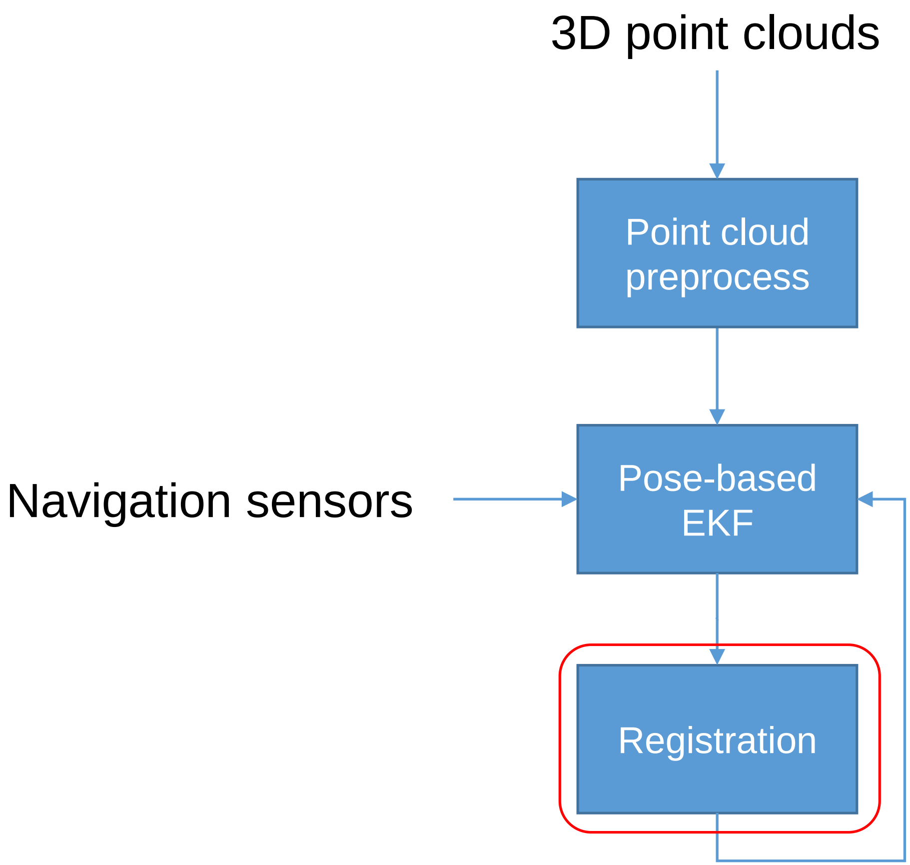
Point cloud preprocess

- Key points extraction
  - Remove planar surfaces (RANSAC, Fischler et al. 1981)
  - Remove points with curvature (Pauly et al., 2002) below threshold

- Feature extraction: Fast point feature histogram (Rusu et al., 2009)



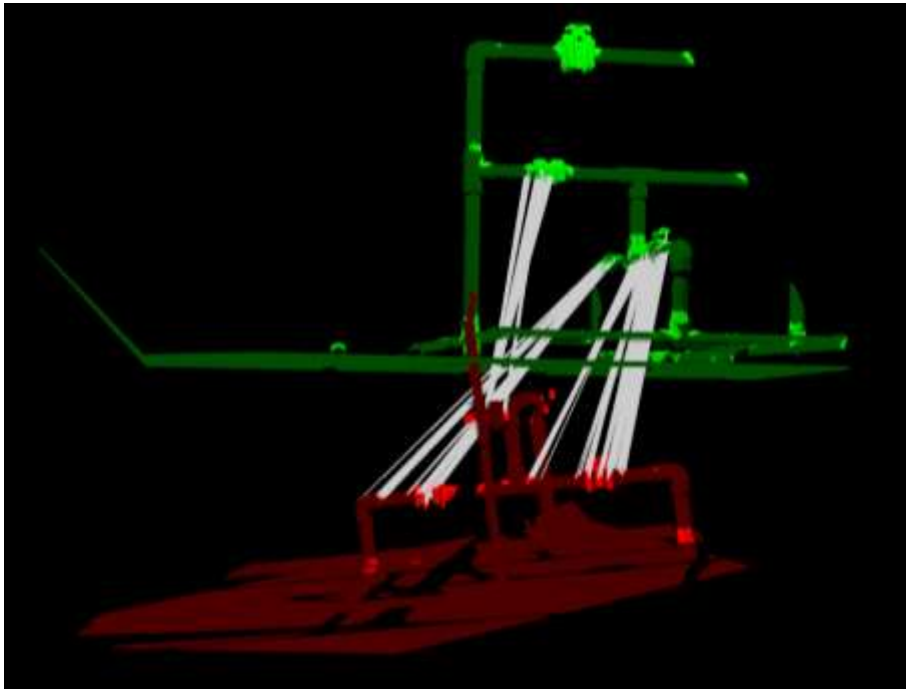
Structure inspection using underwater laser scanner



Structure inspection using underwater laser scanner

Registration algorithm

- Coarse registration
  - Feature association
  - Roto-translation using Singular Value Decomposition (J. Besl and McKay, 1992)



Structure inspection using underwater laser scanner

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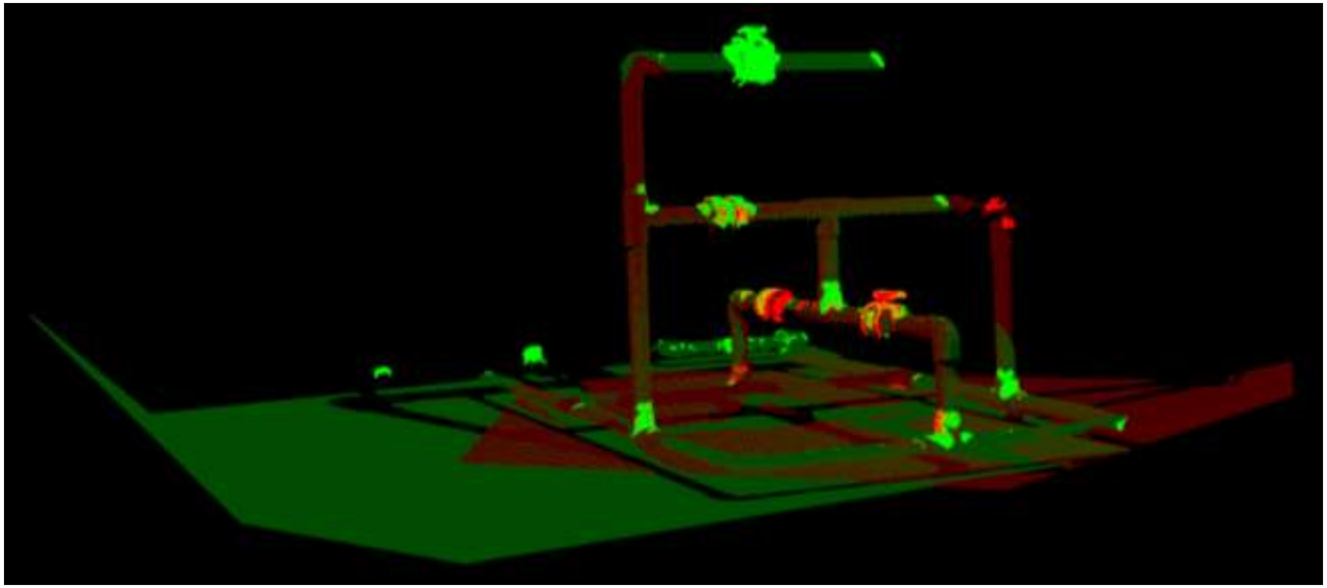
Registration algorithm

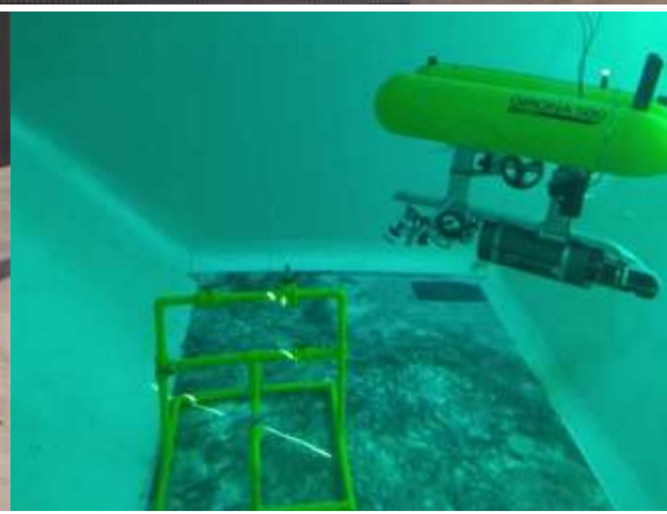
- Coarse registration
  - Feature association
  - Roto-translation using Singular Value Decomposition (J. Besl and McKay, 1992)

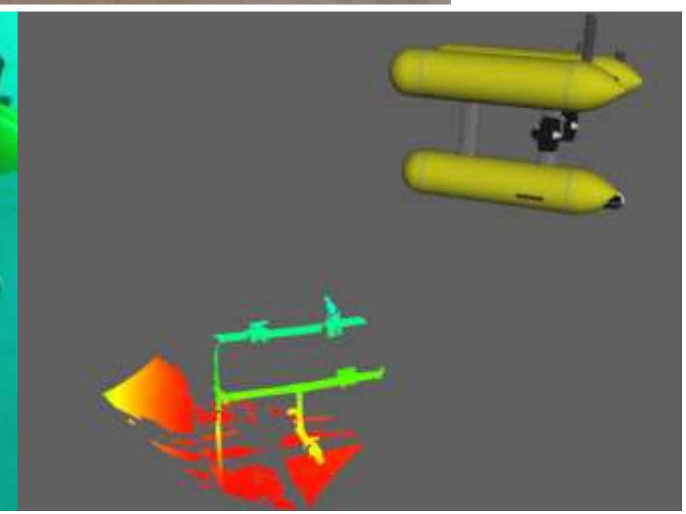
- Fine registration: Point to point ICP



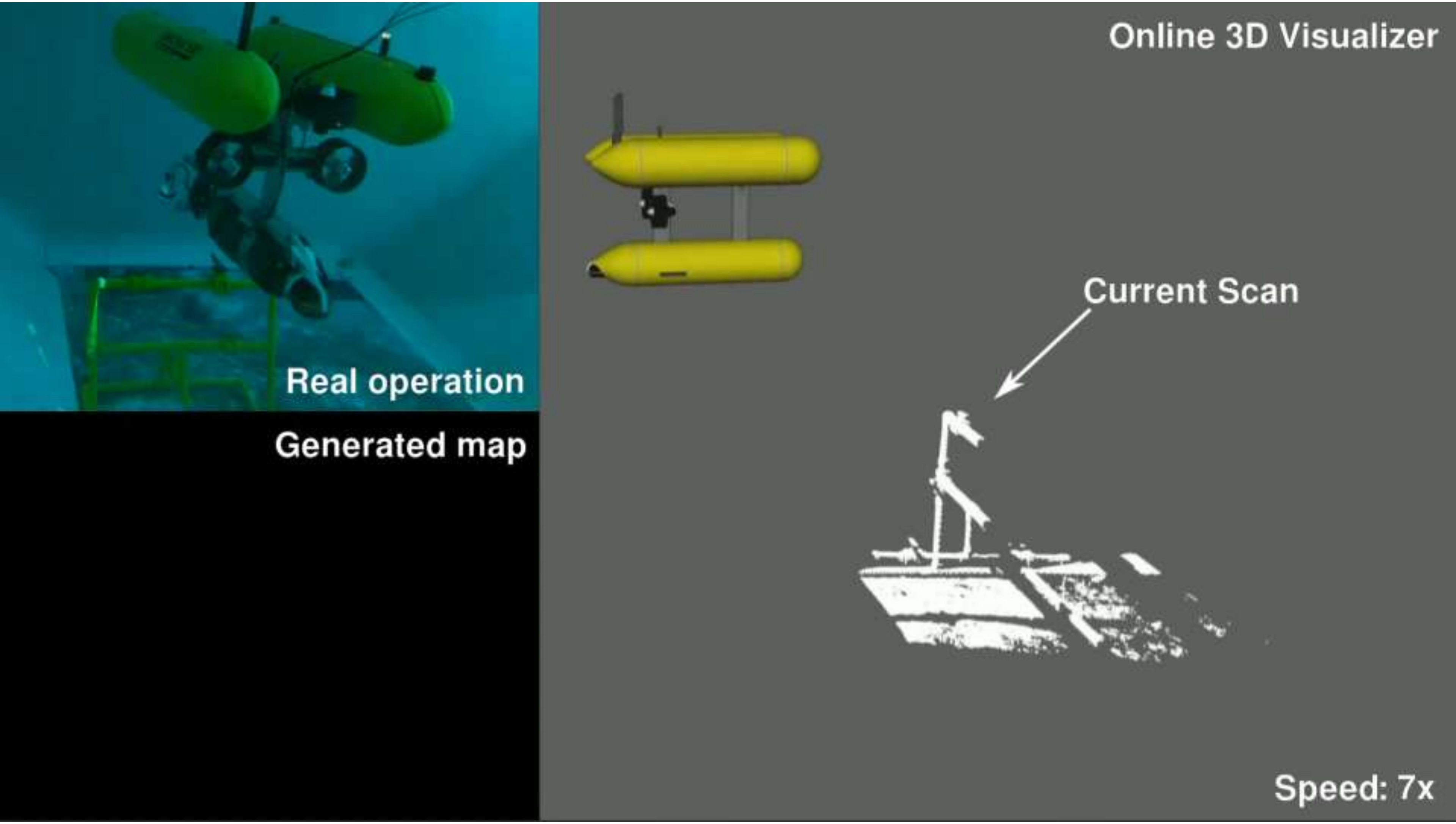
Structure inspection using underwater laser scanner

Experiments and results



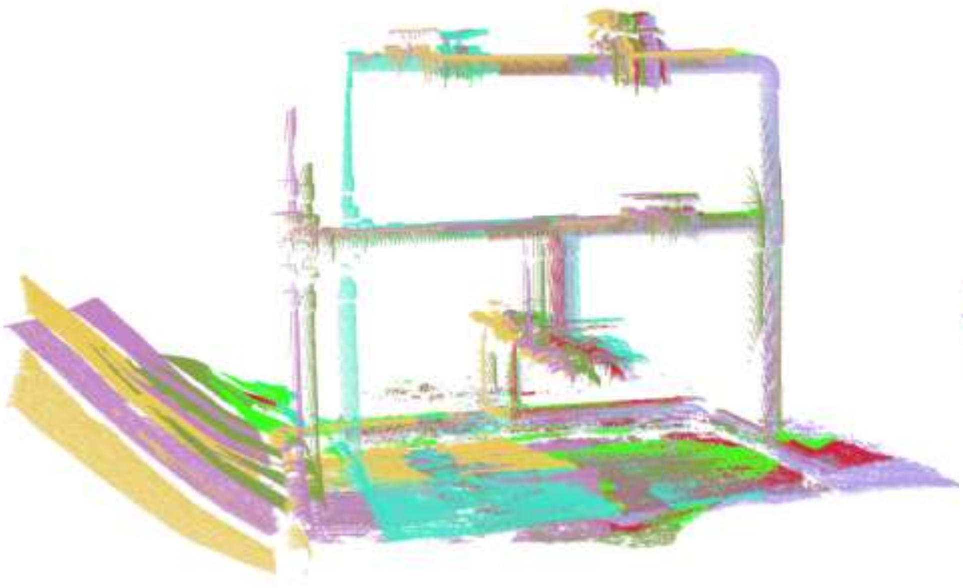


Structure inspection using underwater laser scanner

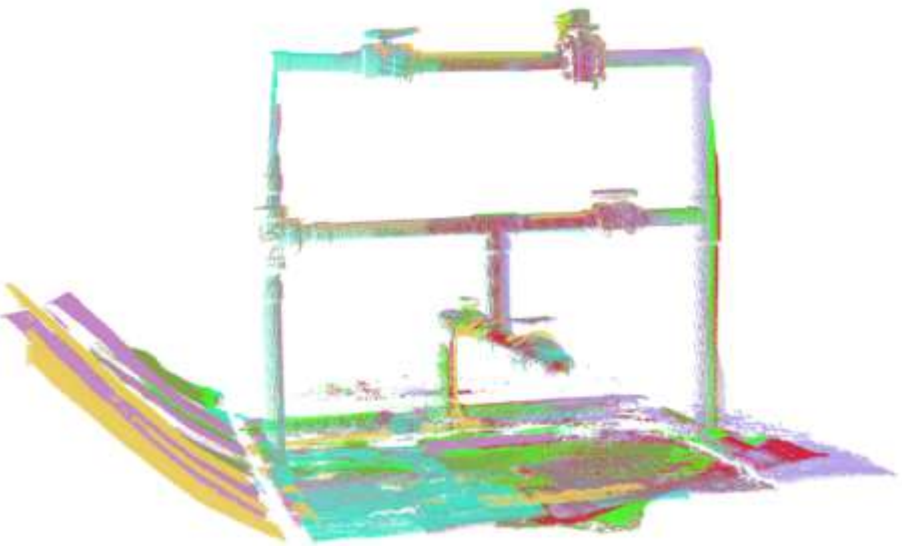


Experiments and results

Dead reckoning

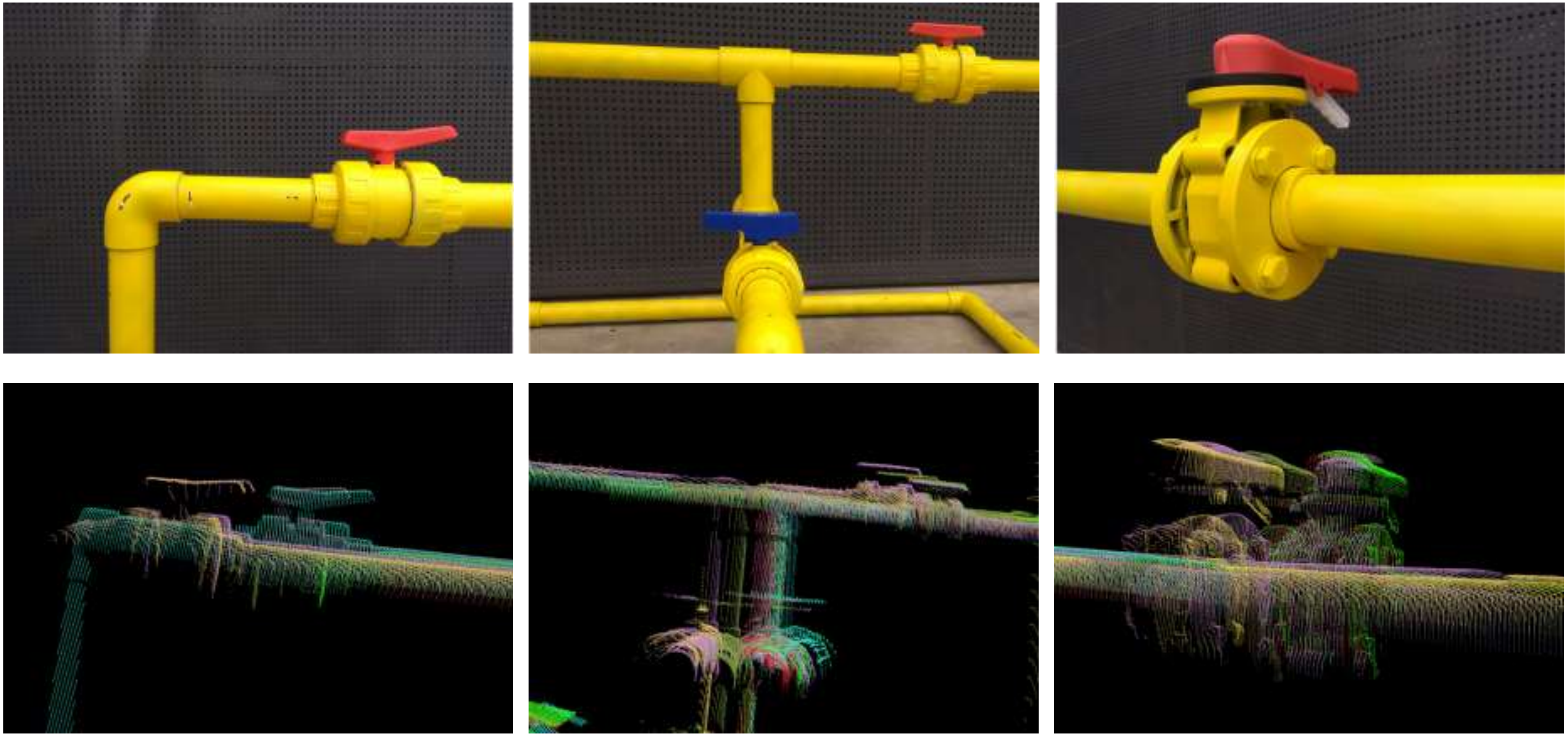


SLAM



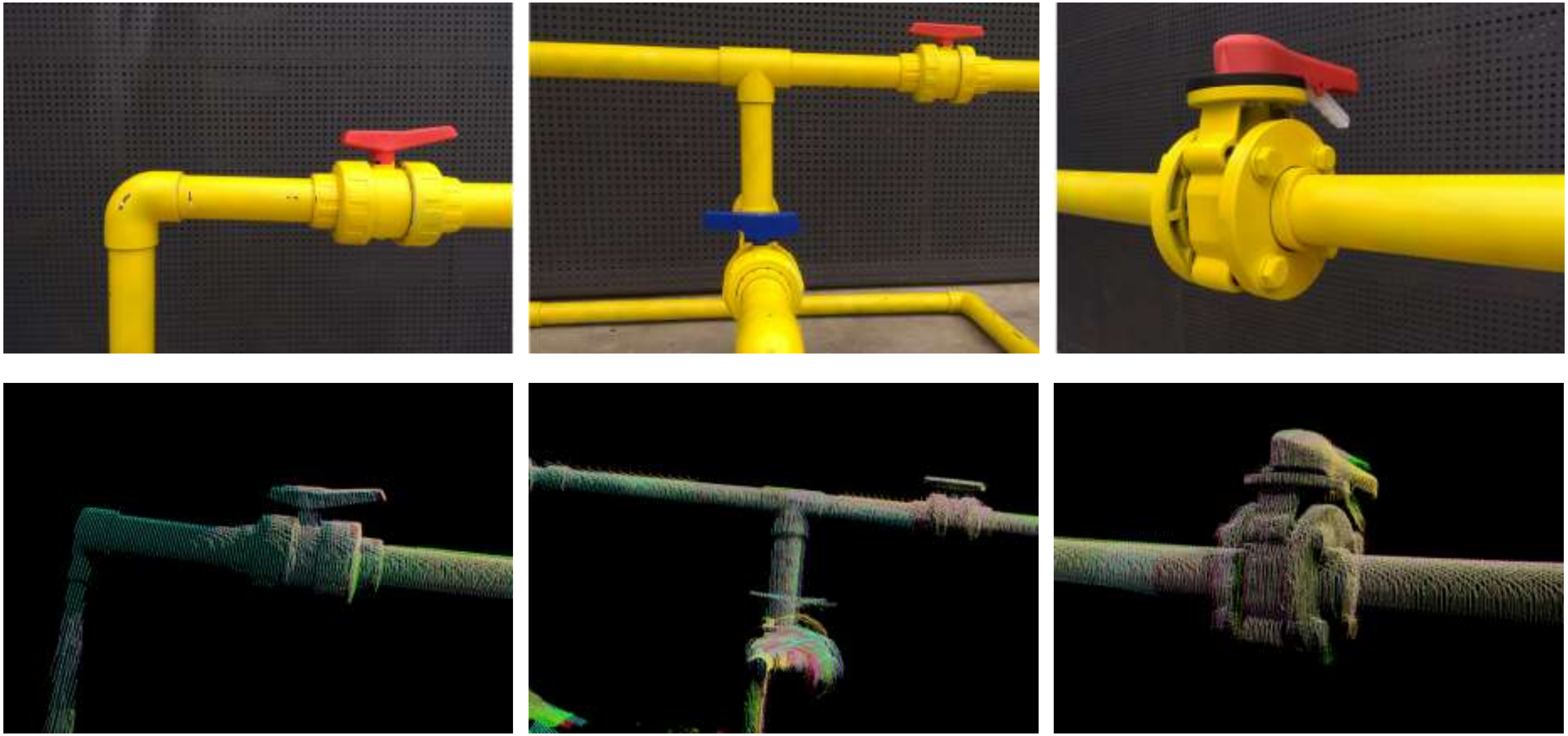
Experiments and results

Structure details: dead reckoning navigation



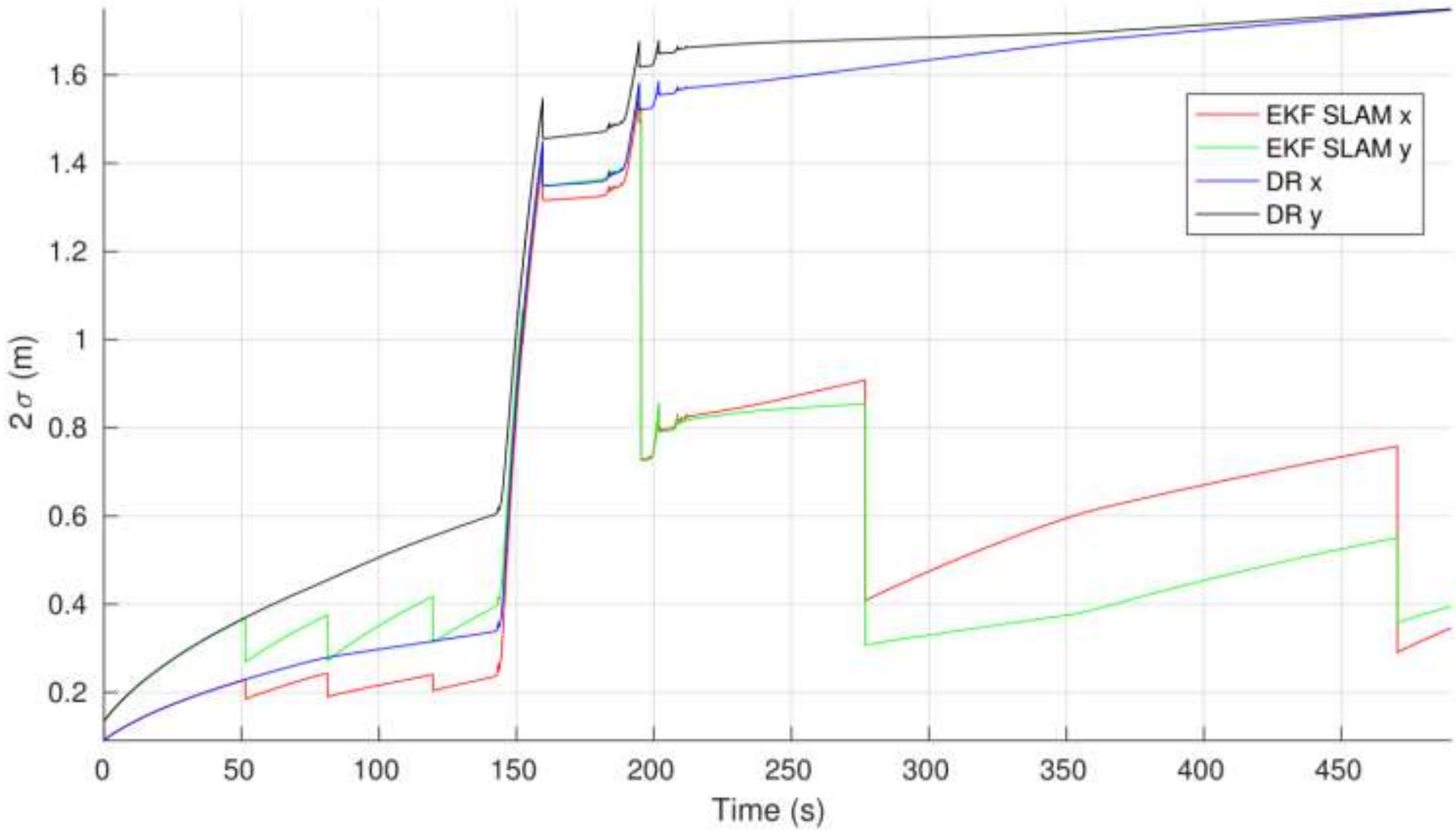
Experiments and results

Structure details: SLAM



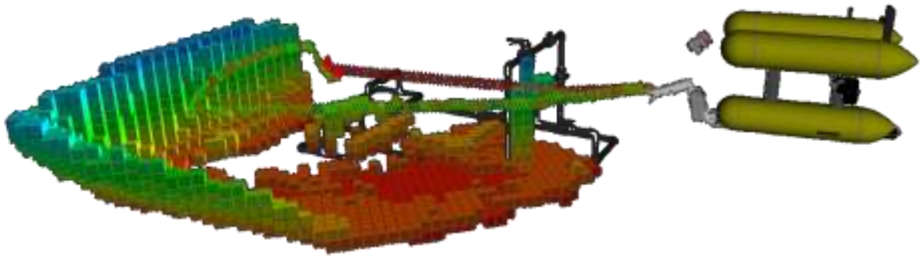
Experiments and results

Robot uncertainty



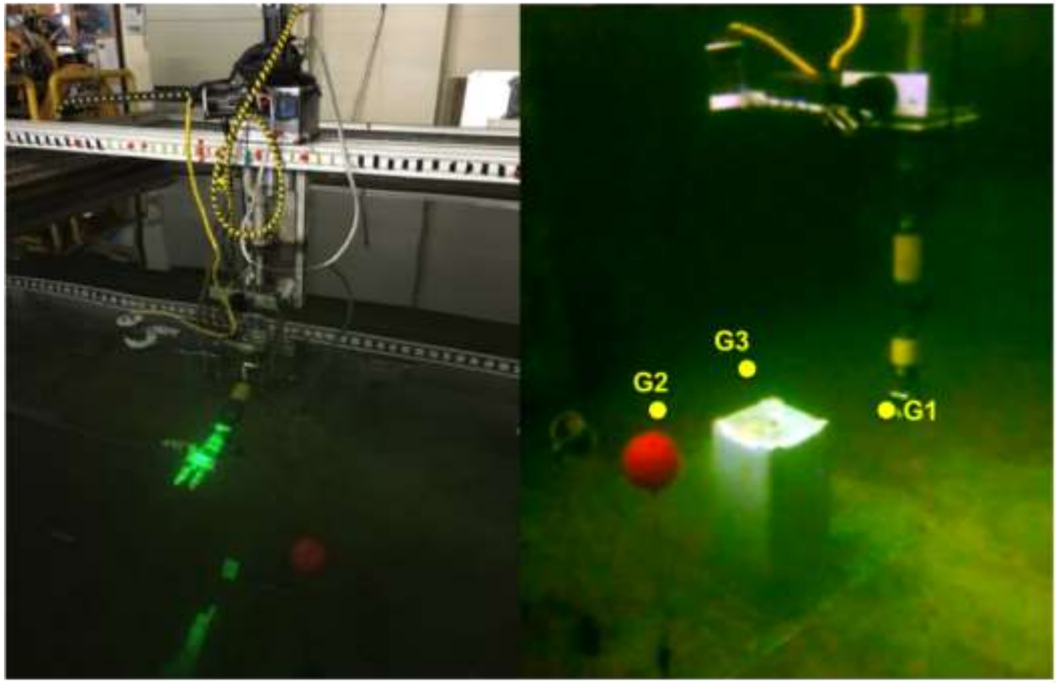
IMR Applications:

- Structure inspection
- Underwater manipulation and motion planning
- Object detection
- Exploration



Underwater manipulation using laser scanner

Fixed-based underwater manipulation system



- Cartesian manipulator
- 6 degrees of freedom robotic arm
- Motion planning in unknown environment

Underwater manipulation using laser scanner

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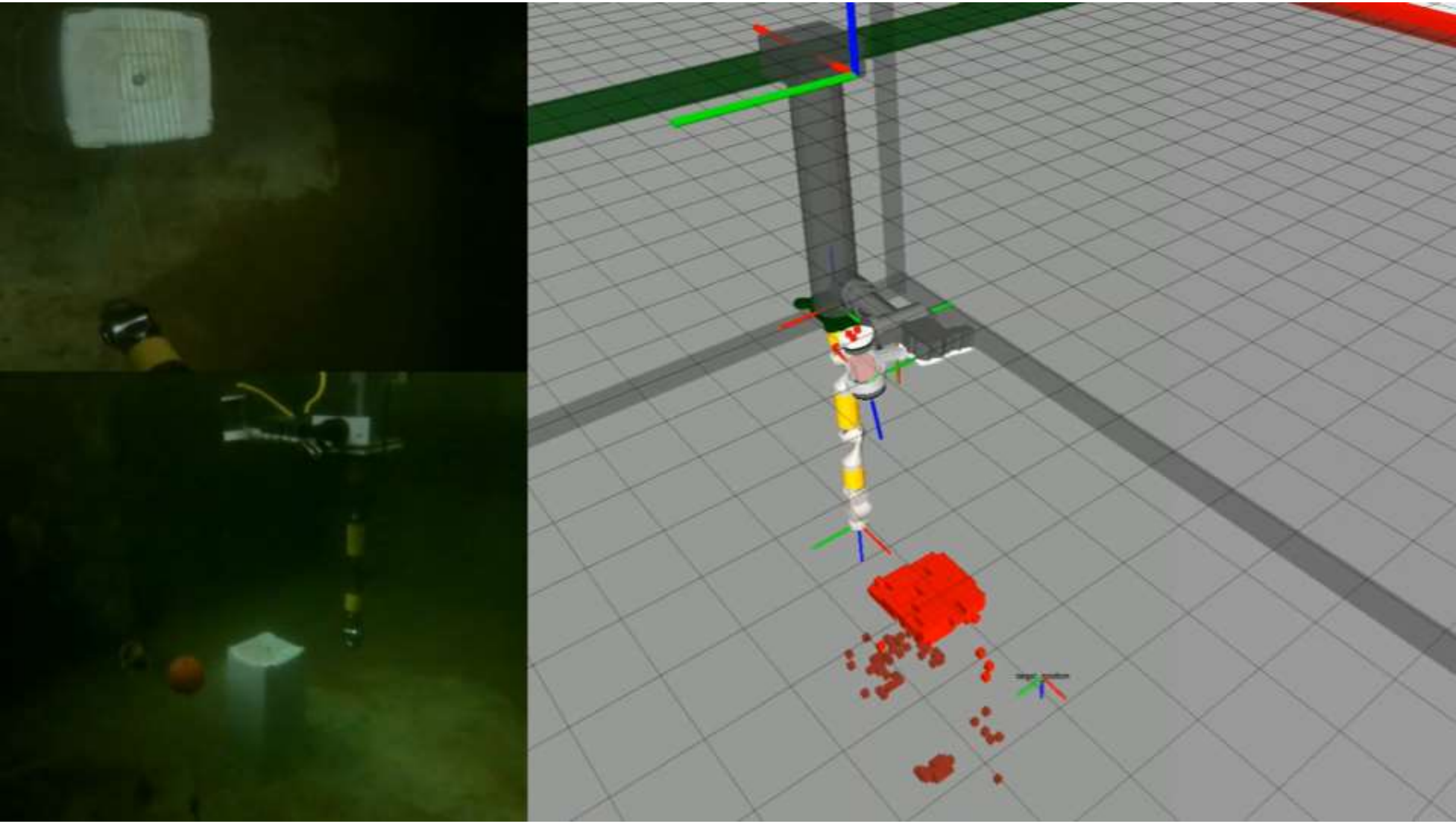


Motion Planning for Autonomous Intervention

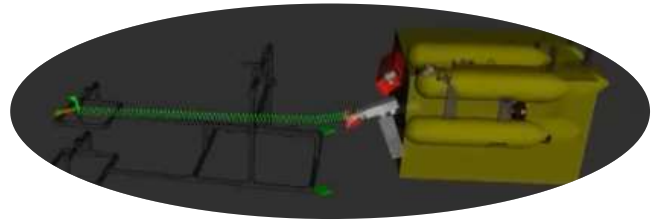
1. Localize

Locate pipe corner markers

2. Homing

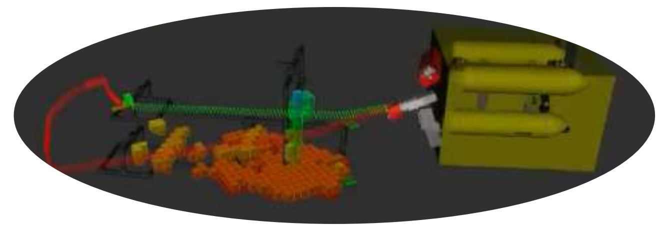
Moving in front of the pipe

3. Approach



Plan before perceiving

Plan after perceiving

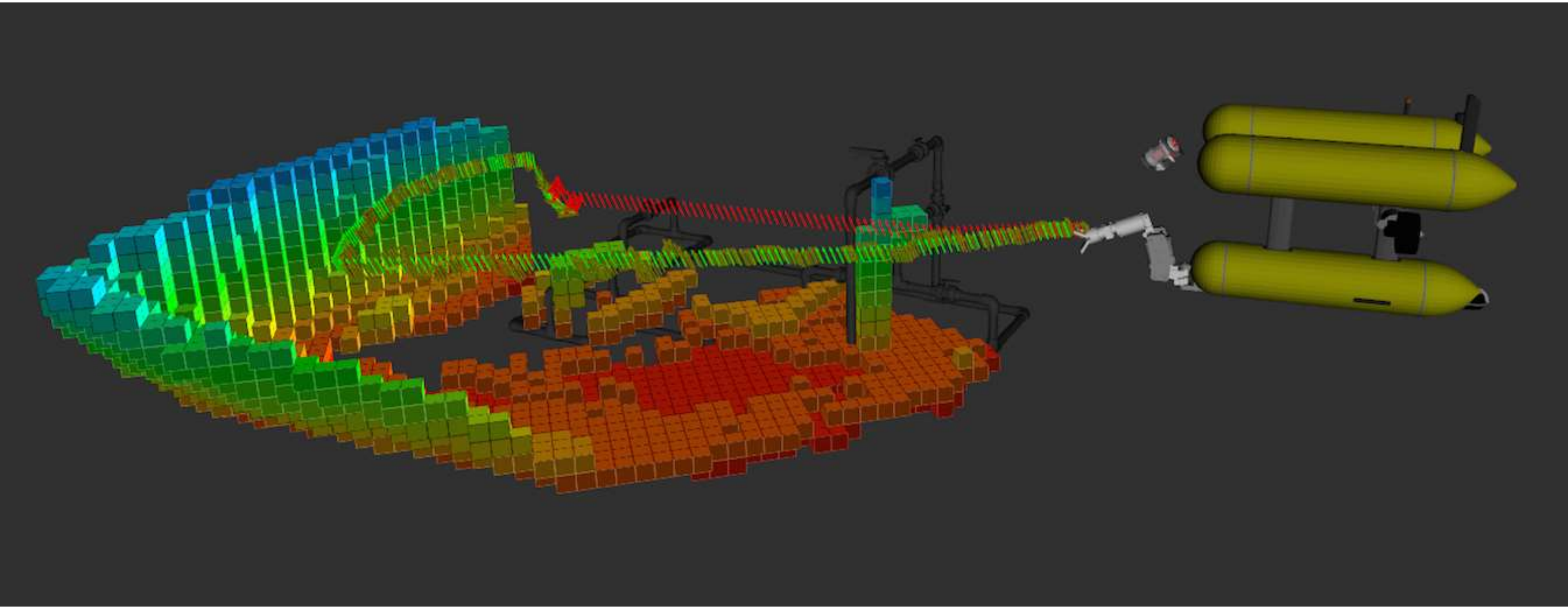


4. Visual Servoing

Detect & Turn Valve

- ***Visual Navigation using poster features during the whole test.***
- ***Laser was on after first approach planning.***

Motion Planning for Autonomous Intervention



Motion Planning for Autonomous Intervention

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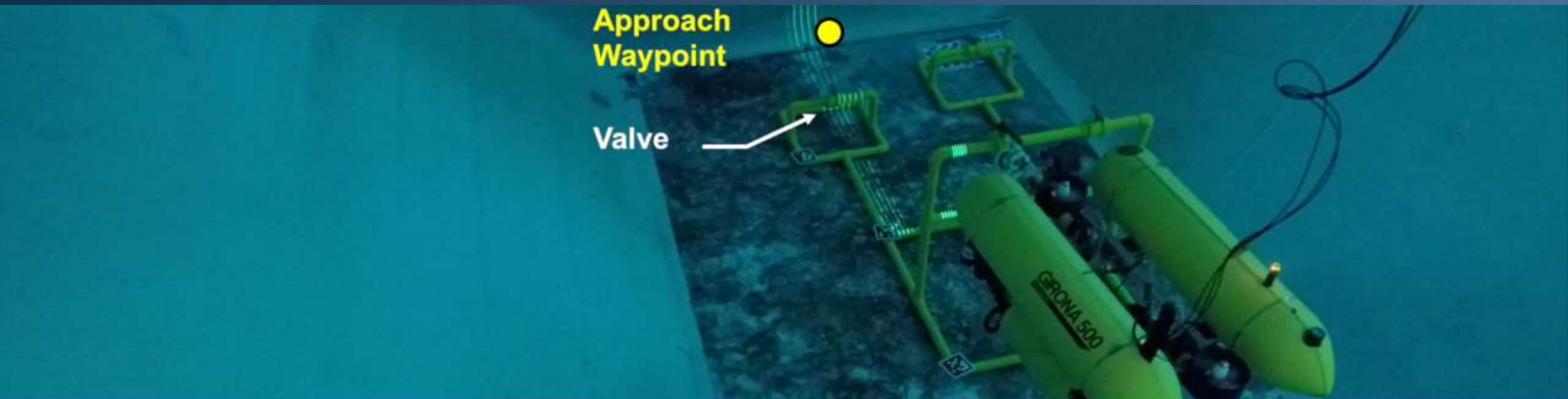
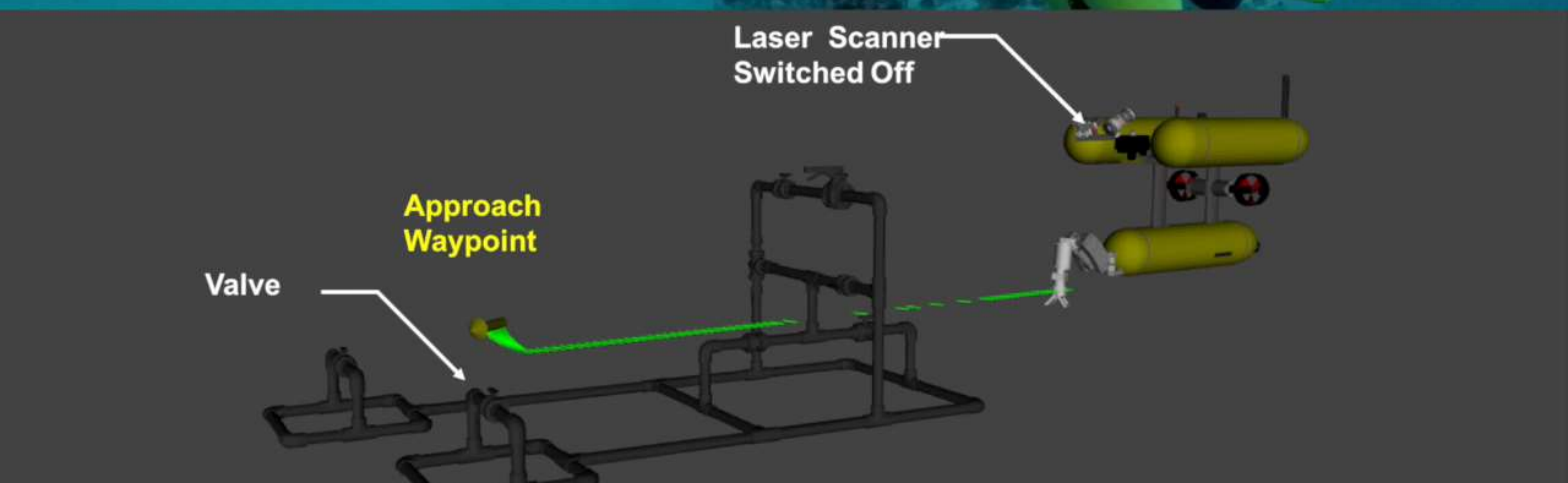




- **Unknown Static Obstacles**
- **SBPL Motion Planning**
- **Connector Plugging**

IMR Applications:

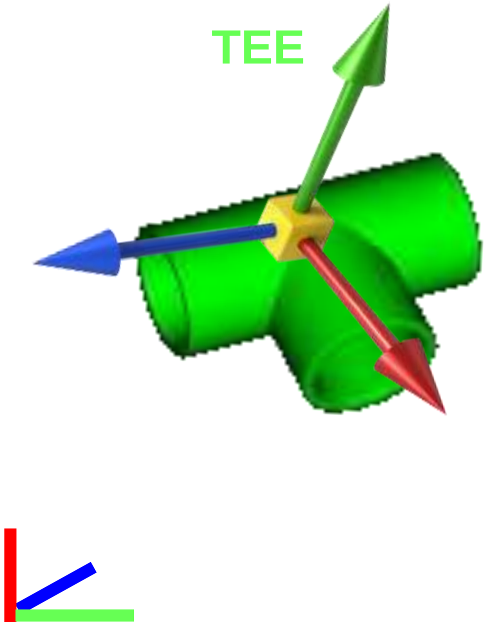
- Structure inspection
- Underwater manipulation and motion planning
- Object detection
- Exploration

3D object recognition pipeline

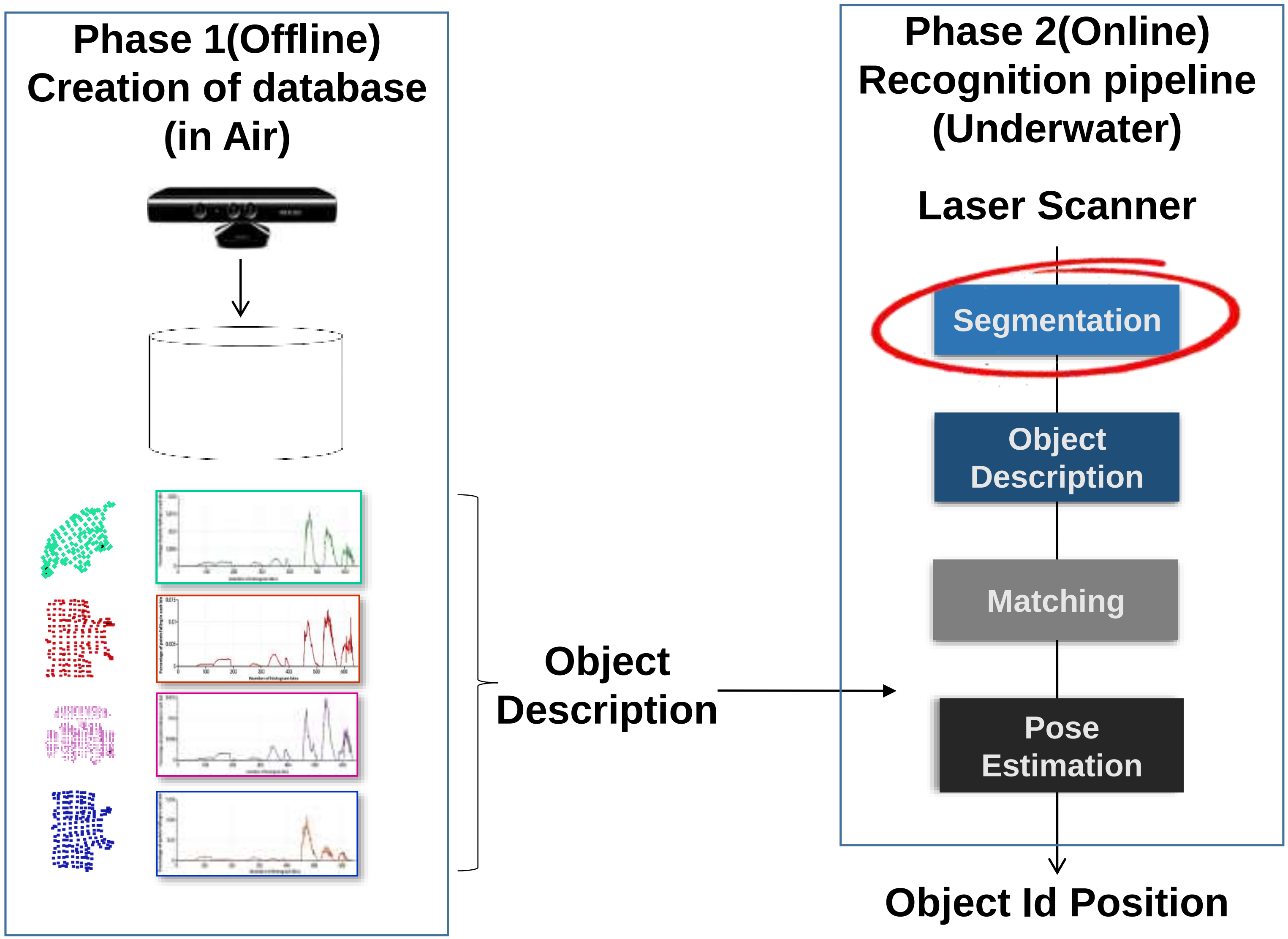
Goal 1: Automatically recognize and locate objects from colourless 3D point clouds.

Girona 500 AUV with the laser scanner.

Recognized 3D Model



3D object recognition pipeline



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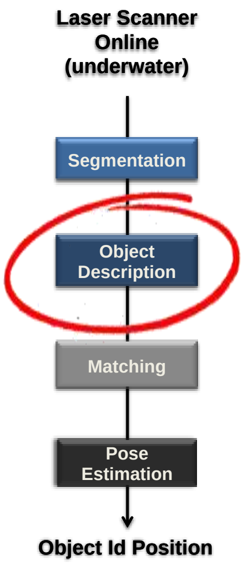
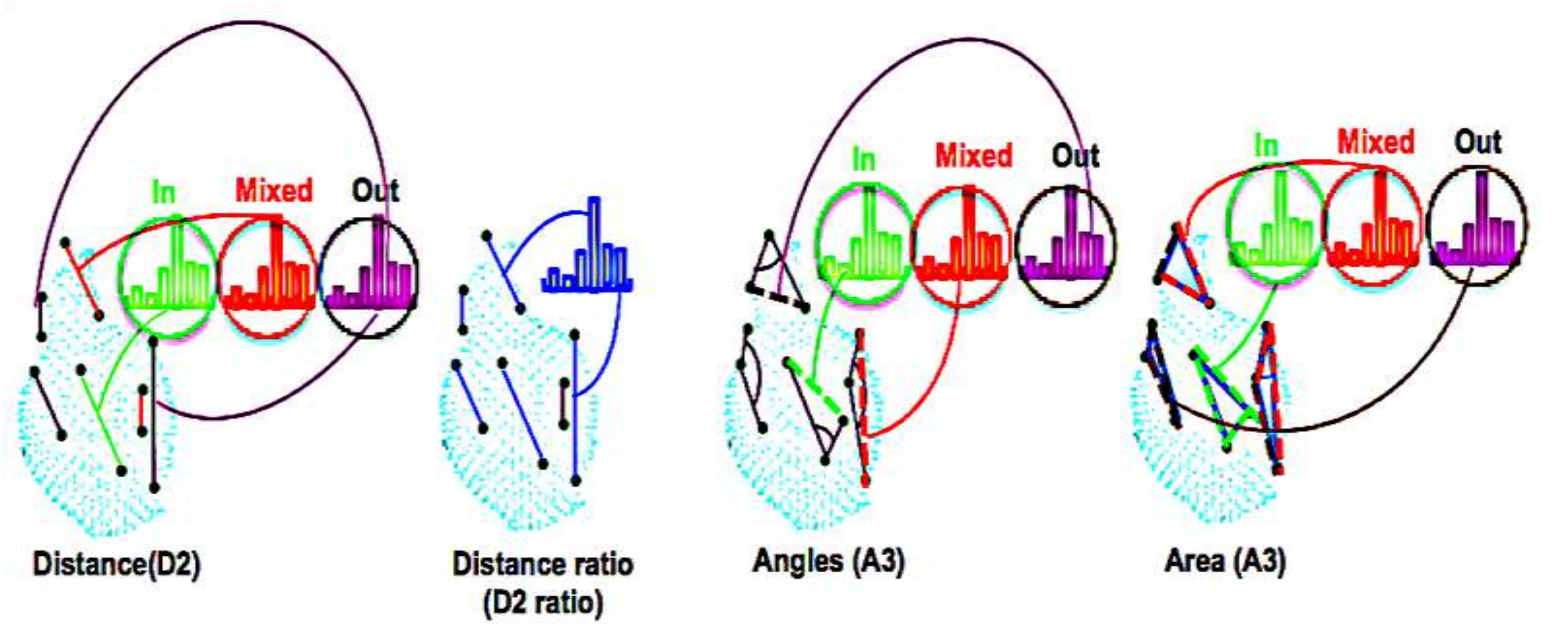


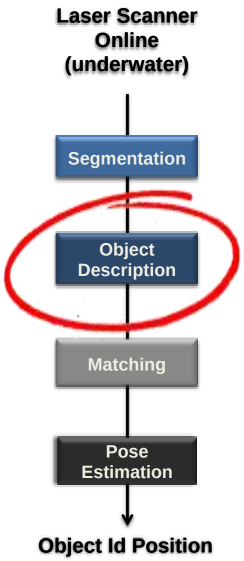
The proposed pipeline: Features Description

- **Ensemble of Shape Functions (ESF).**



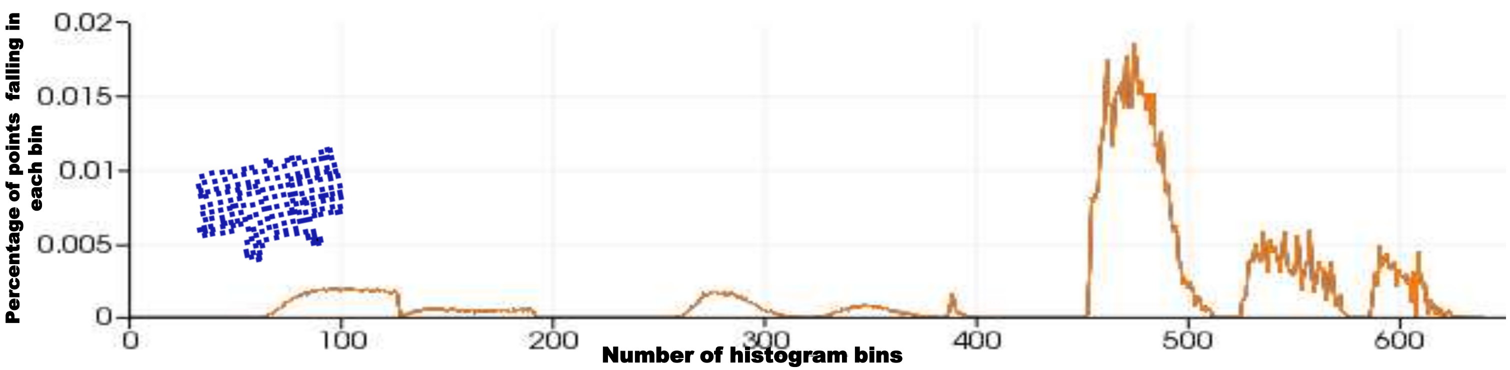
- Introduced by Wohlkinger [Wohlkinger 11].
- Building on the shape function [Osada 01].

3D object recognition pipeline

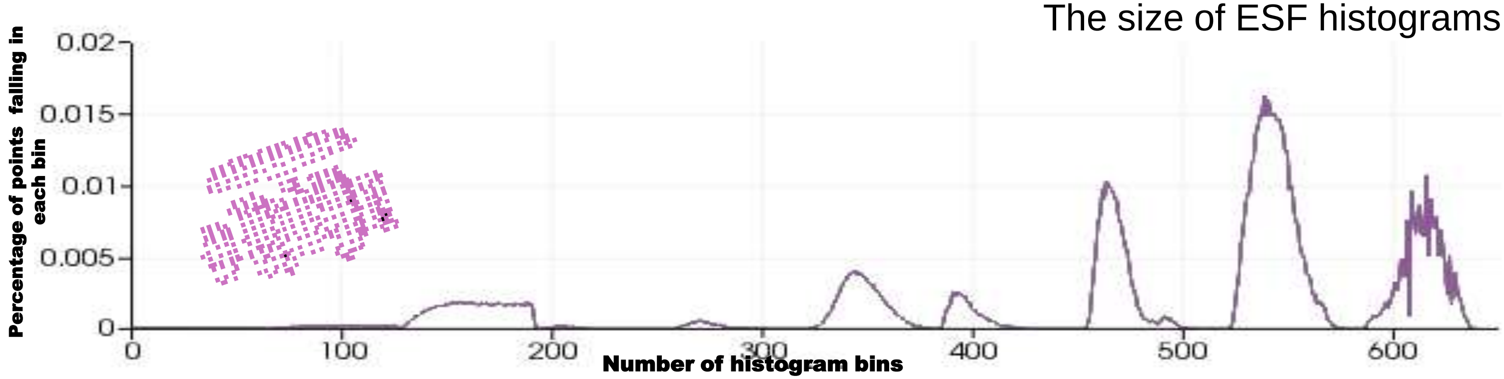


The proposed pipeline: Features Description

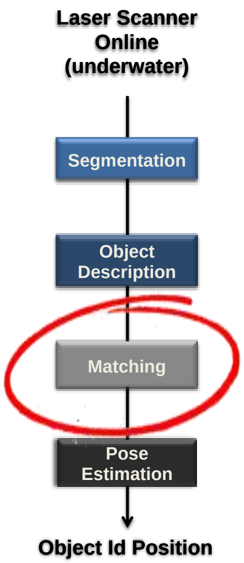
- **Ensemble of Shape Functions (ESF).**



The size of ESF histograms **= 640**

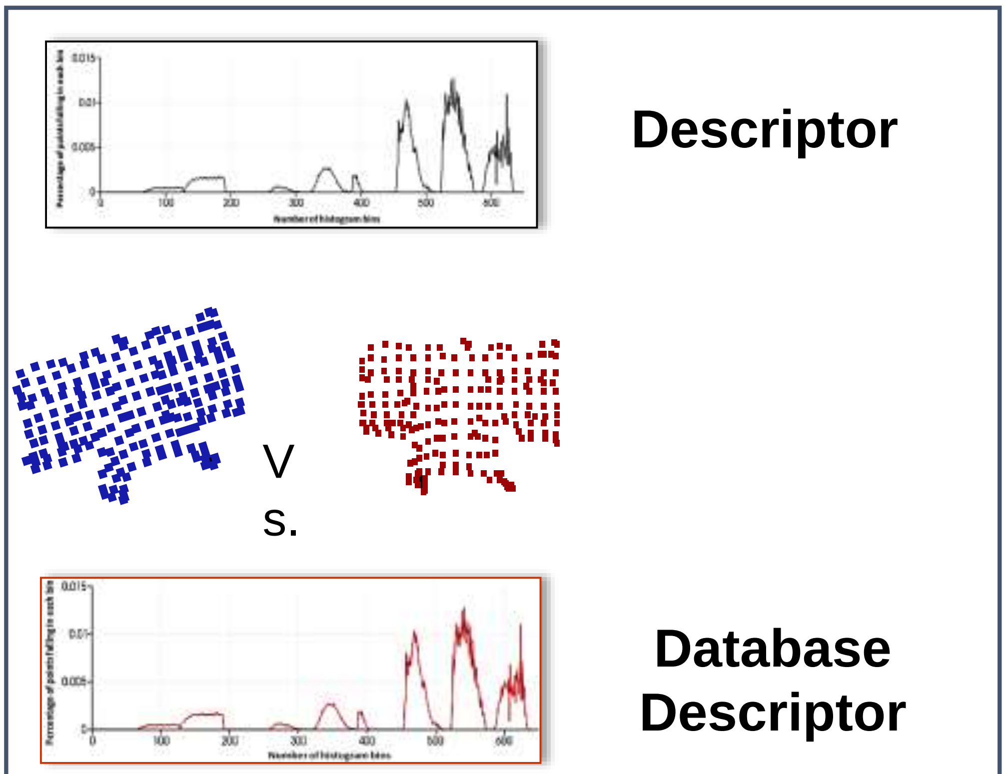


3D object recognition pipeline

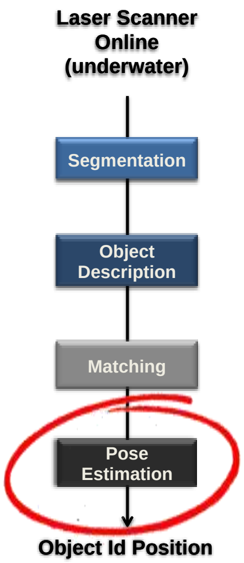


The proposed pipeline: Matching

- **Matching based on Chi-square distance**
  Based on minimum Chi-square distance between scan object and all objects views in the database [Rusu 08] [Hetzel 01].



3D object recognition pipeline

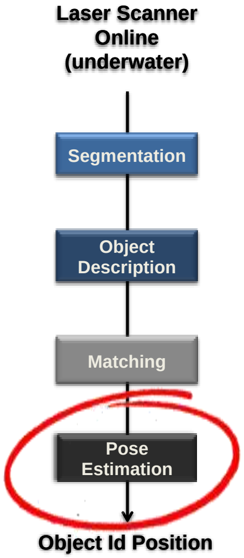


The proposed pipeline: Pose Estimation

1. **Coarse alignment** :
   - ❑ Features based registration algorithm. The Fast Points Features Histogram (FPFH) [holz 15].

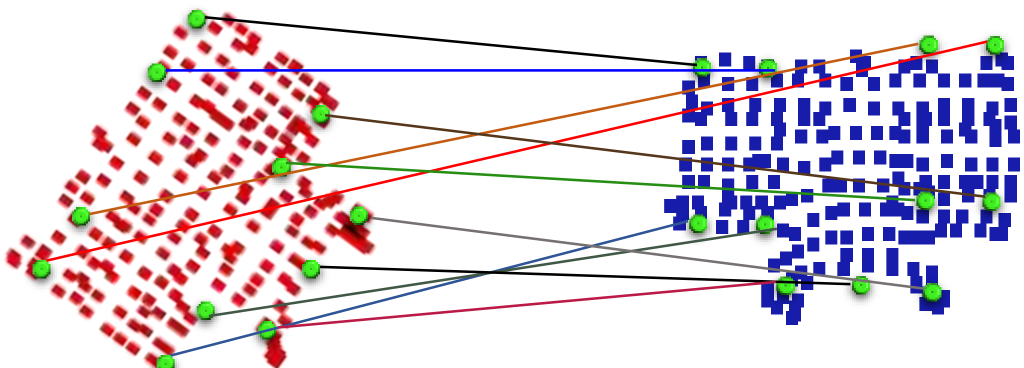
2. **Fine alignment**:
   - ❑ Iterative registration algorithm (ICP) [besl 92].

3D object recognition pipeline



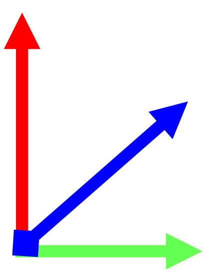
The proposed pipeline: Pose Estimation

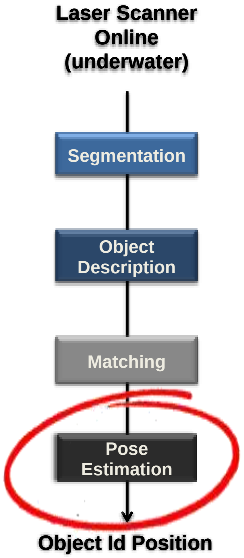
1. Coarse alignment :



Matched segmented Cloud

Scanned segmented Cloud

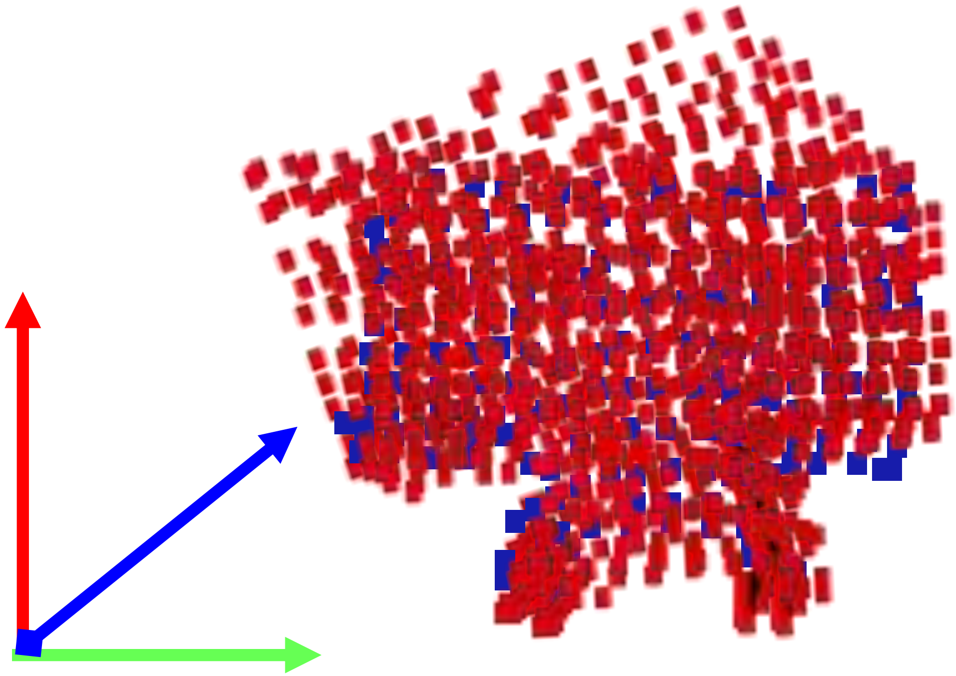




The proposed pipeline: Pose Estimation

2. Fine alignment:

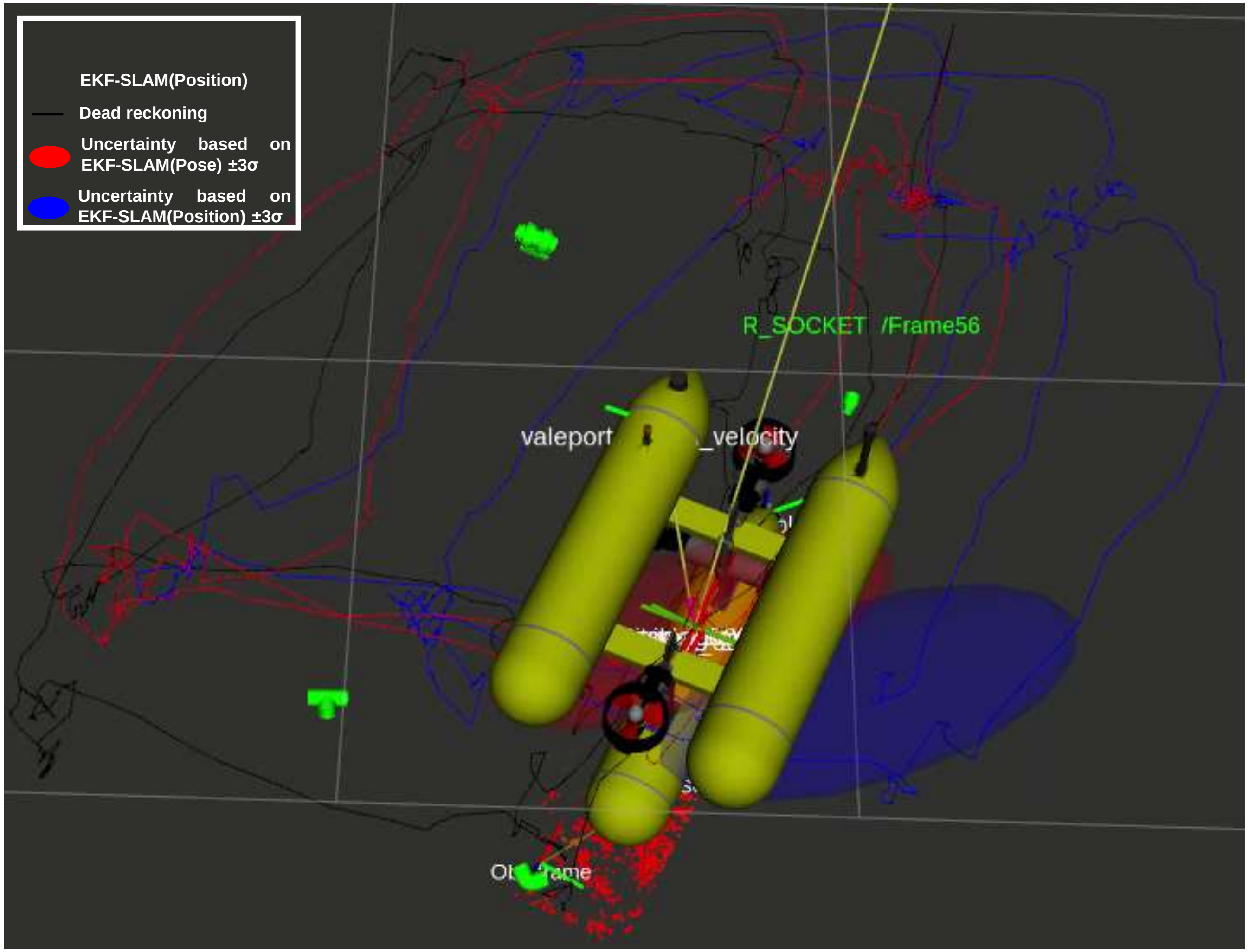
- ❑ Iterative Closest Point algorithm (ICP) [besl 92].



IMR Applications:

- Structure inspection
- Underwater manipulation and motion planning
- Object detection:
  - Localization
  - Manipulation
- Exploration

3D object recognition: Localization



3D object recognition: Manipulation

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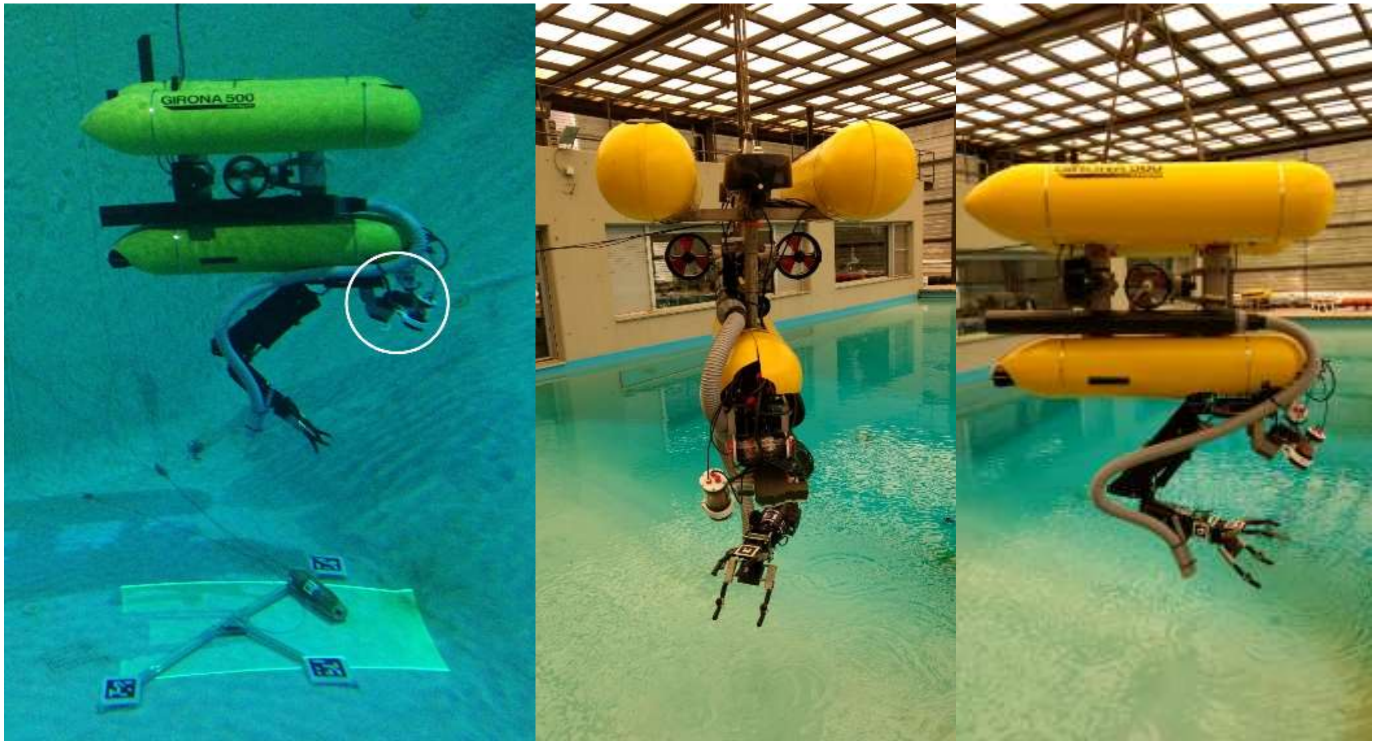
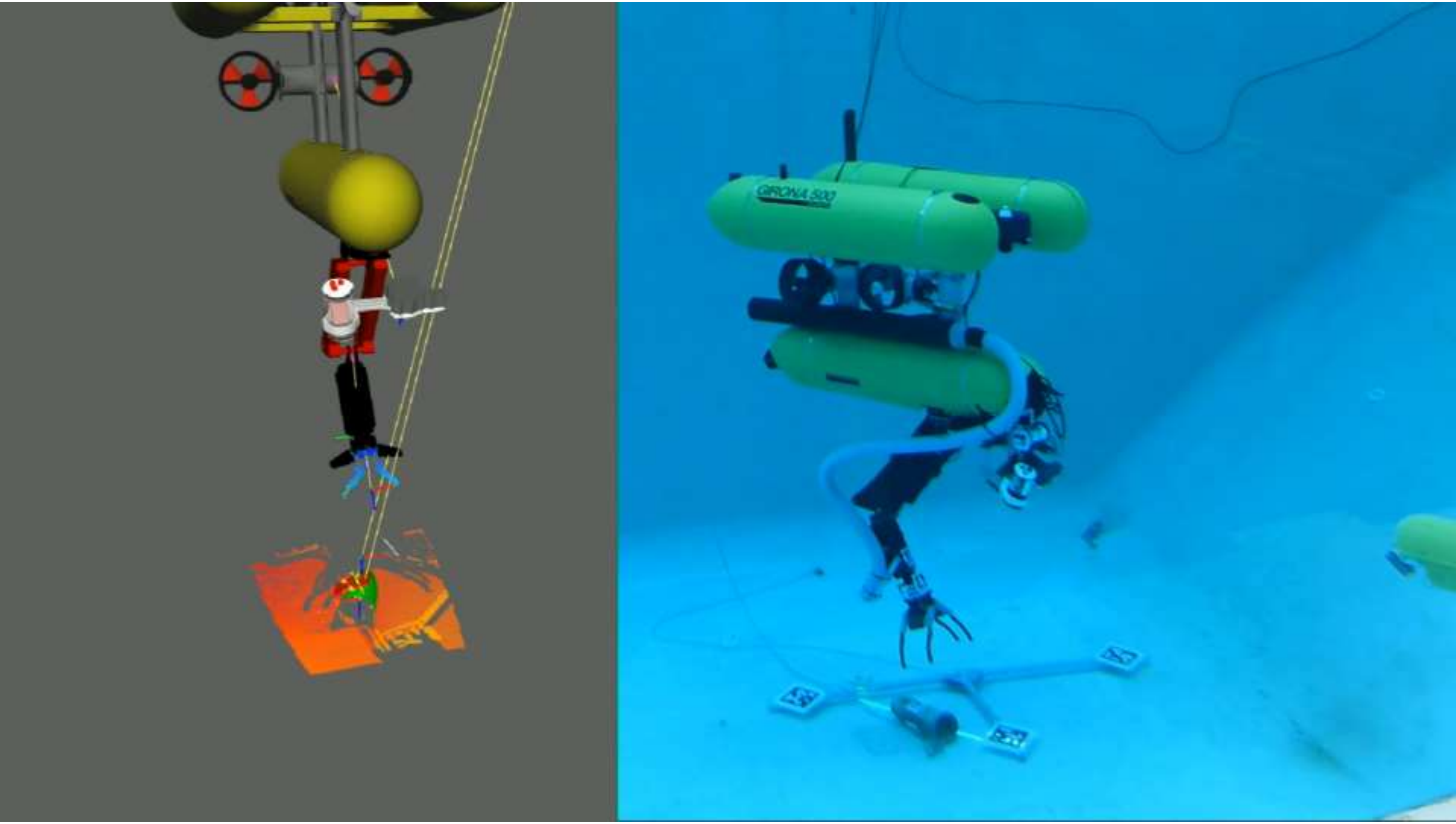
Underwater vehicle manipulation system



- Girona 500 AUV
- 4 degrees of freedom robotic arm
- Object grasping

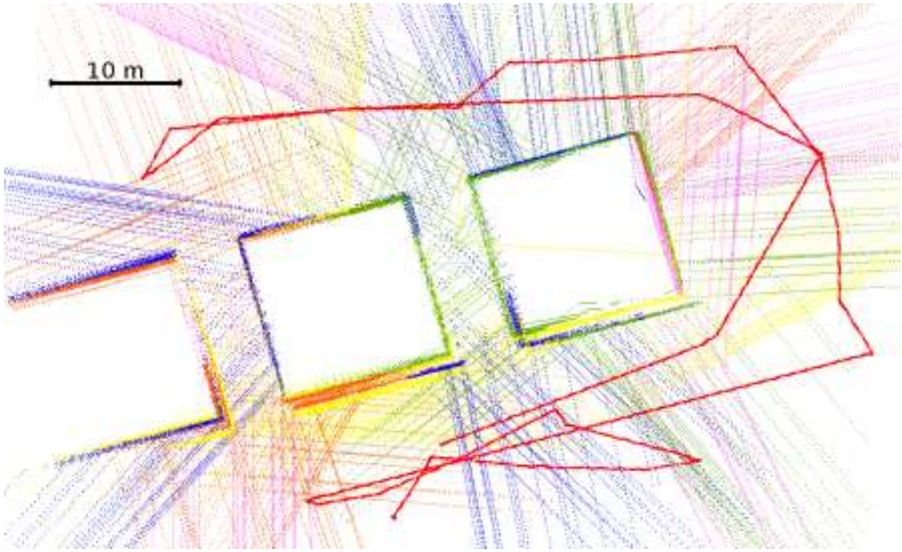
3D object recognition: Manipulation



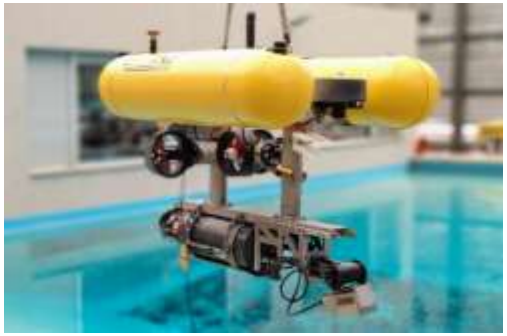
IMR Applications

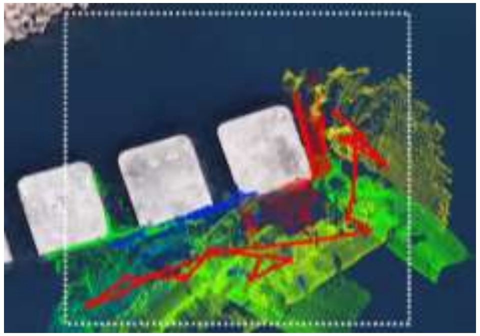
IMR Applications:

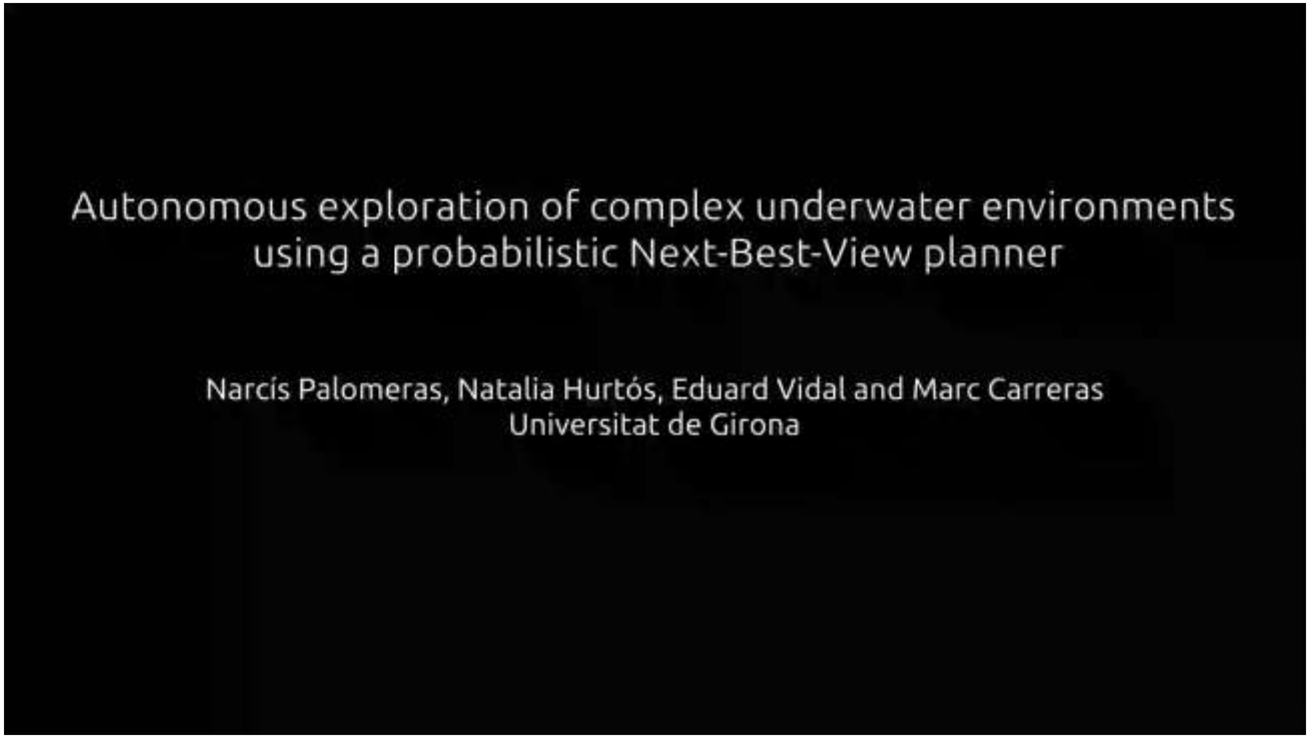
- Structure inspection
- Underwater manipulation and motion planning
- Object detection:
- Exploration



Underwater autonomous exploration







Autonomous exploration of complex underwater structures. Nowadays carried out using a multibeam sonar and a pan&tilt but carried out using a laser scanner in a near future.

L3S: Licensed to IQUA Robotics

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ViCOROB
Computer Vision and Robotics Research Institute

Girona Underwater Vision and Robotics

Real-time Laser Scanner for Autonomous IMR Applications

May 24, 2019

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