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Underwater Perception using Continuous System Integration & Human in the Loop

Study cases: Deep-sea Perception and Diver Interaction

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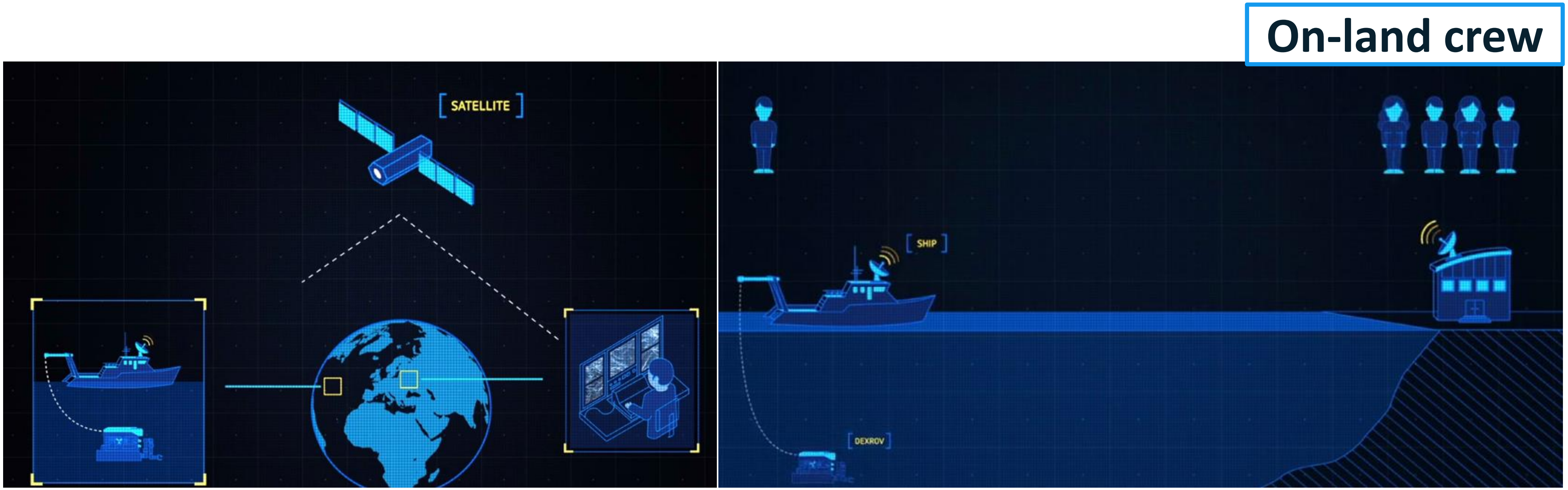
Continuous system integration for deep-sea perception

Motivation

- Field-trials for underwater robotics are very costly and pose high-risk for the crew and equipment.
- EU H2020 DexROV project → 60K euros for each trial day approx.
- Too costly for research purposes, even for industry.

DexROV Solution

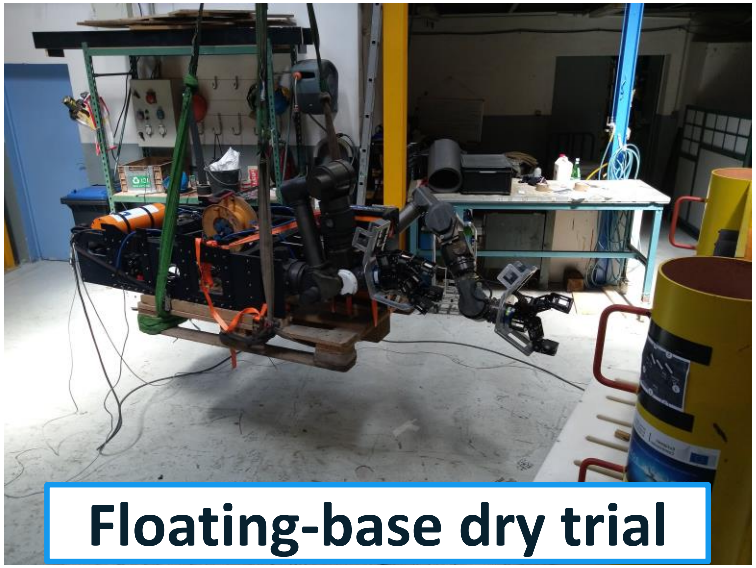
- **EU H2020 DexROV project (www.dexrov.eu/)**
  - **On-shore teleoperation of ROV to reduce ship crew.**
  - **Account for communication latencies for exploration and manipulation tasks.**



Watch DexROV concept video at: *https://www.youtube.com/watch?v=ONAyE1H3iC0*

Development challenges

- **For development purposes this is still a problem because researchers must investigate thoroughly proposed methods.**
  - **Only one sea trial per year.**
  - **Reproduce scenarios on-land as similar as possible as the underwater counterpart.**
  - **Very hard to mimic all variables for manipulation (floating-base), lightning, extrinsic calibration, etc.**



Floating-base dry trial

Extrinsic calibration test

Proposed solution

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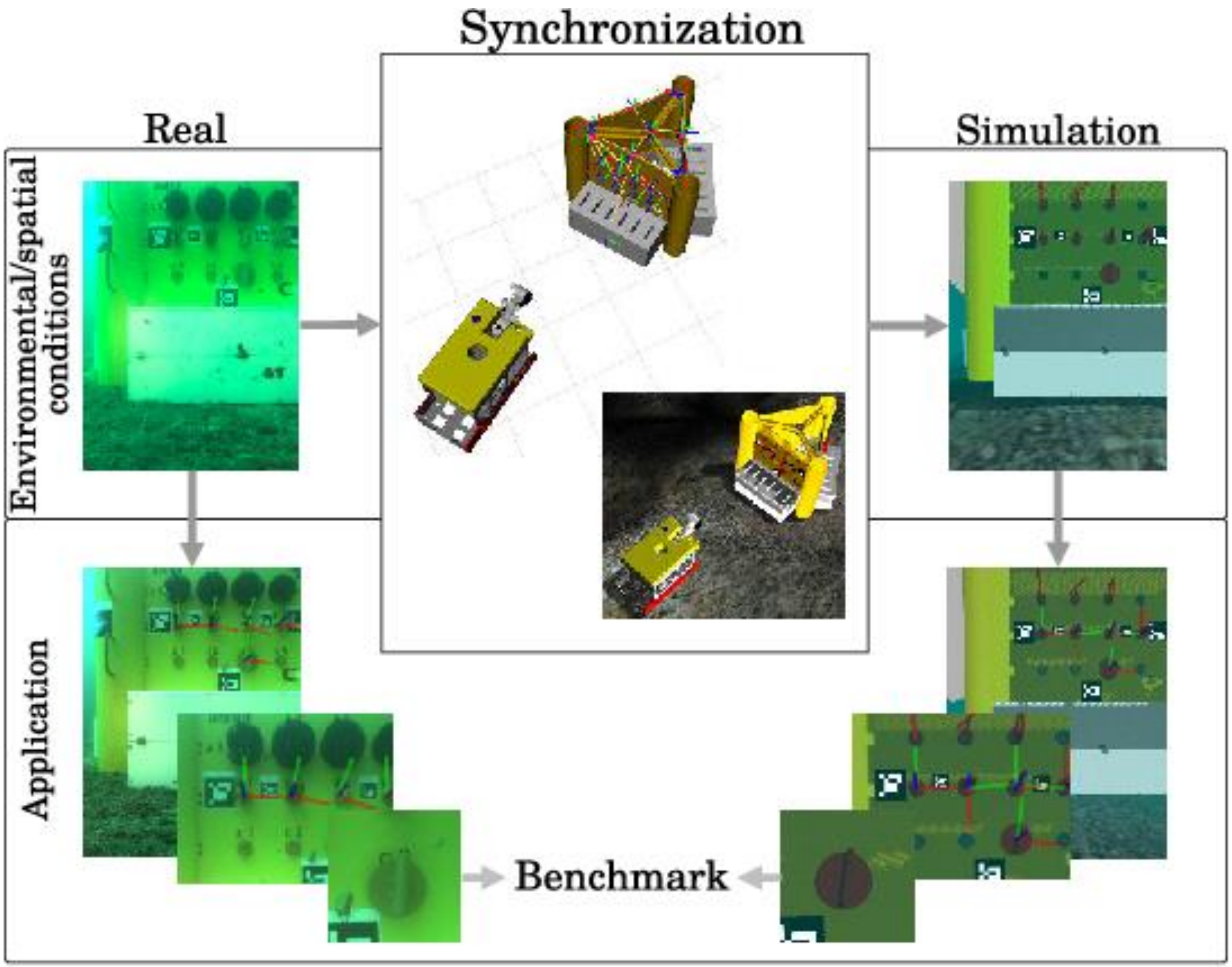
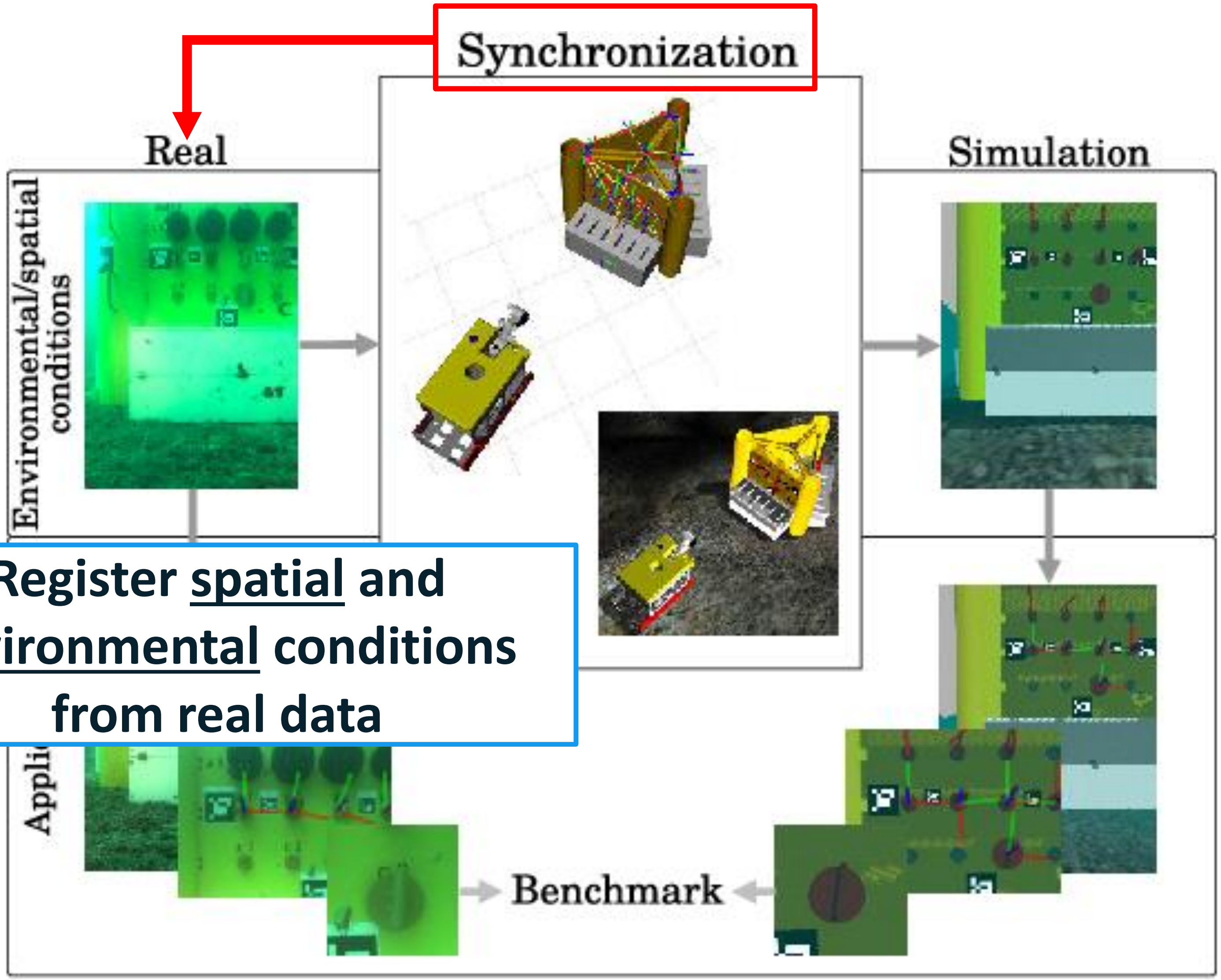
- **CONTINUOUS SYSTEM INTEGRATION**
- **Close discrepancy between simulated and real world-data.**
  - **Synchronize** simulated and real-world data through environmental and spatial references from previous field trials.
  - **Provide** an augmented virtual environment reflecting conditions experienced in real missions to benchmark and enhance system modules.
  - **Allow** the use of simulated and real system components during pipeline tests and their easy interchange.
  - **Perform** tests on distributed software deployment (modules running on ship and ROV), interfaces, data degradation, and fault/recovery methods.

- T. Fromm, et.al., "**Efficient continuous system integration and validation for deep-sea robotics applications**," *OCEANS 2017 – Aberdeen.,* 2017.
- C. A. Mueller, et. al., "**Robust Continuous System Integration for Critical Deep-Sea Robot Operations Using Knowledge-Enabled Simulation in the Loop**," *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2018.

Proposed solution

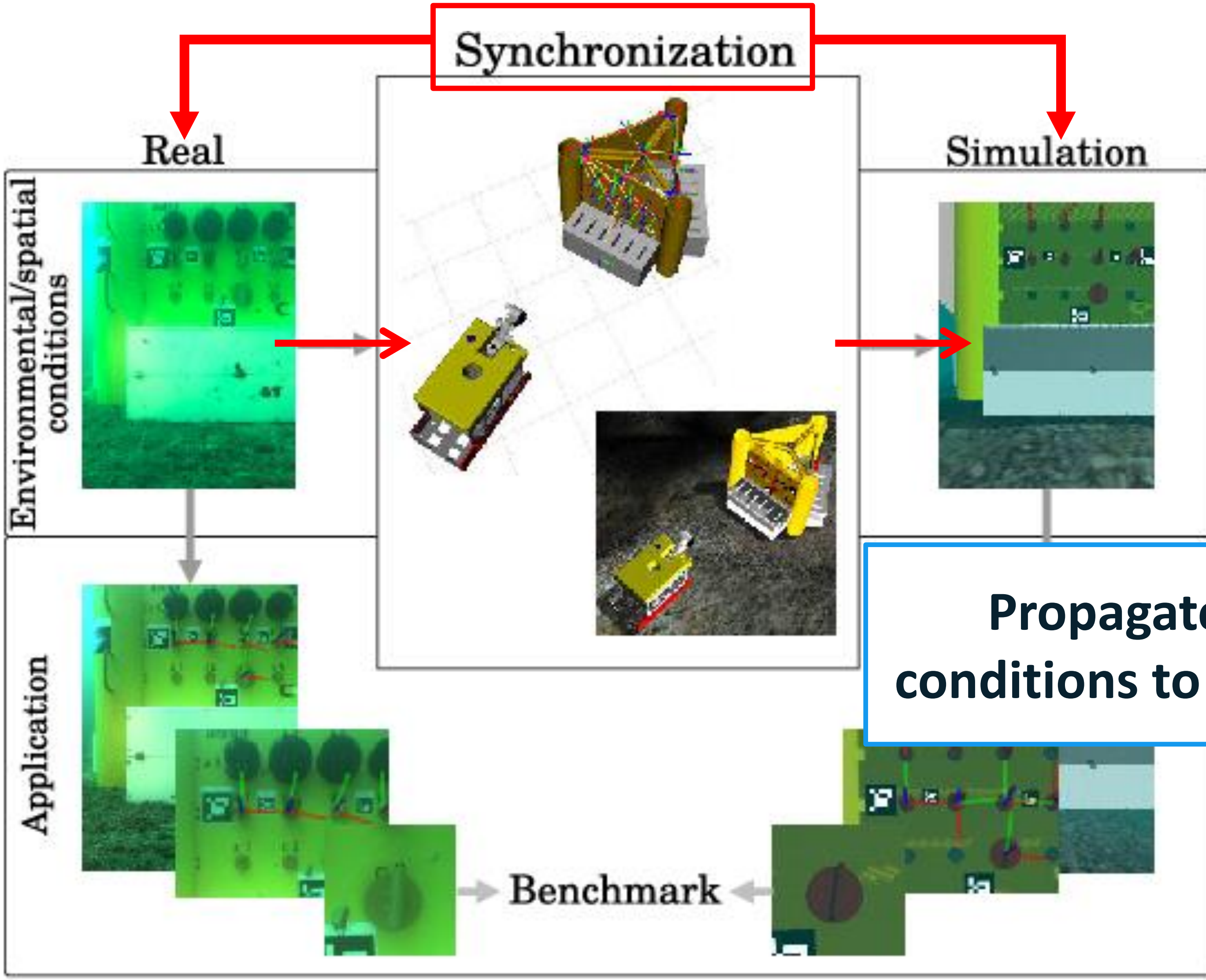


Proposed solution



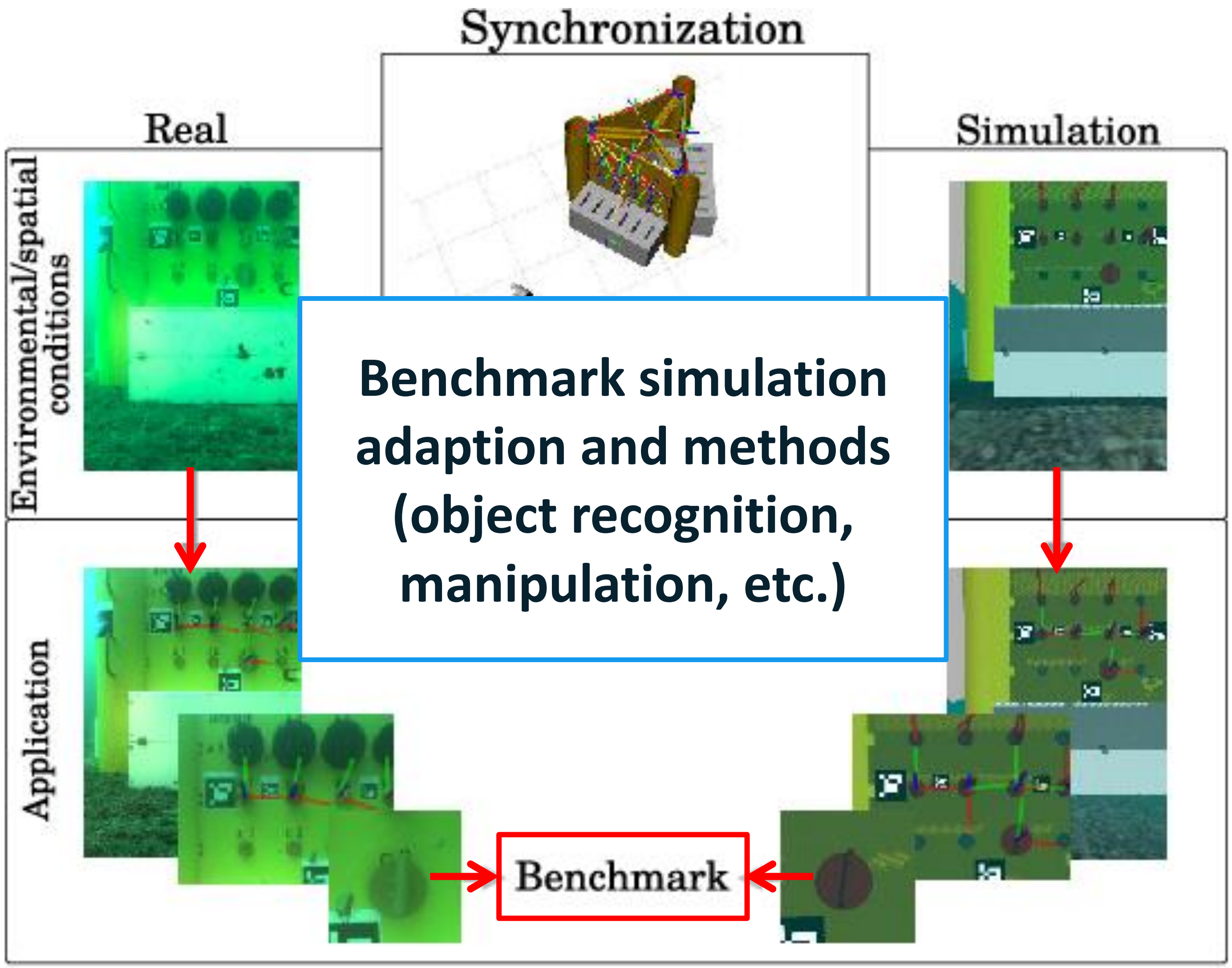
Register spatial and environmental conditions from real data

Proposed solution



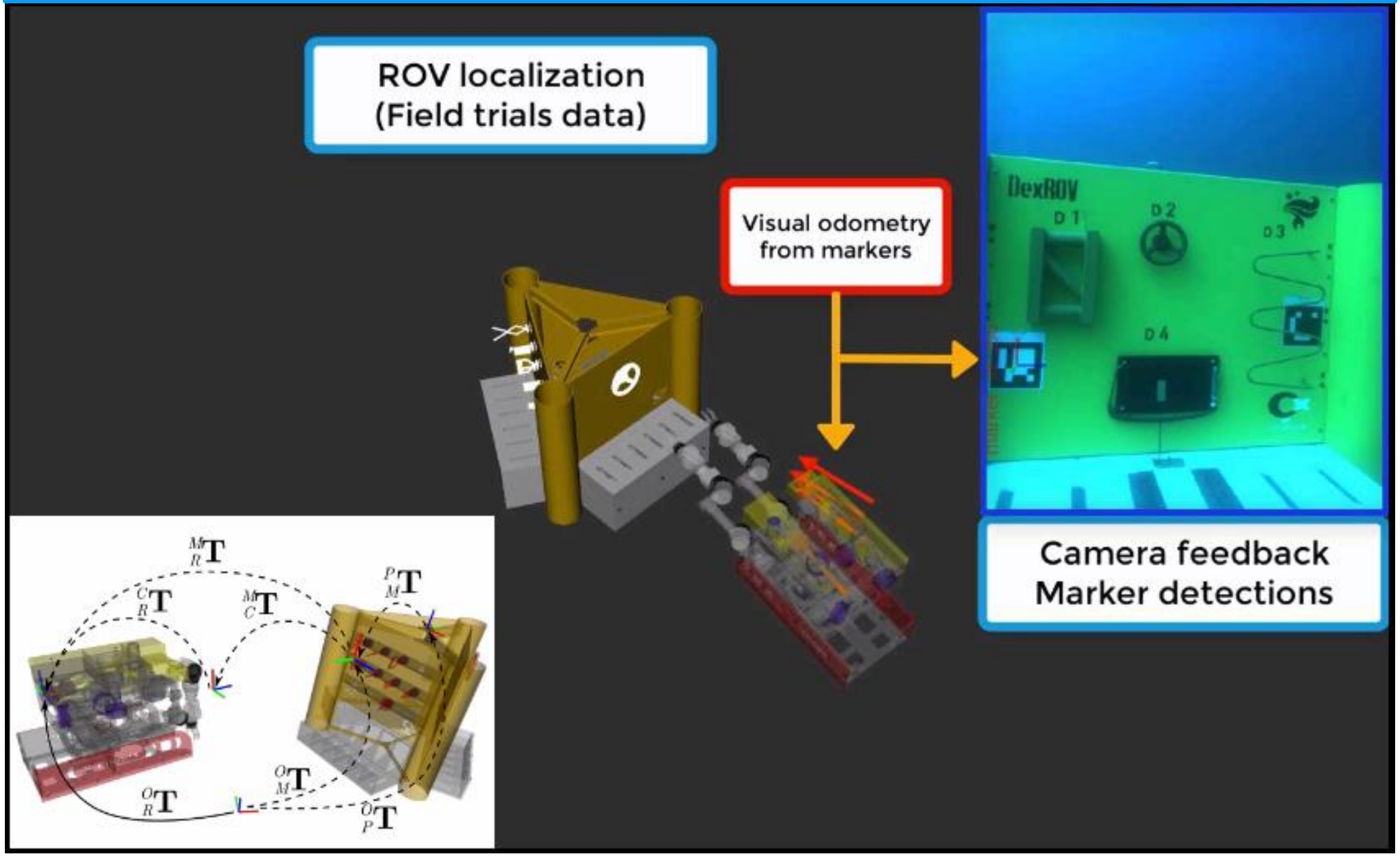
Propagate these conditions to simulation

Proposed solution



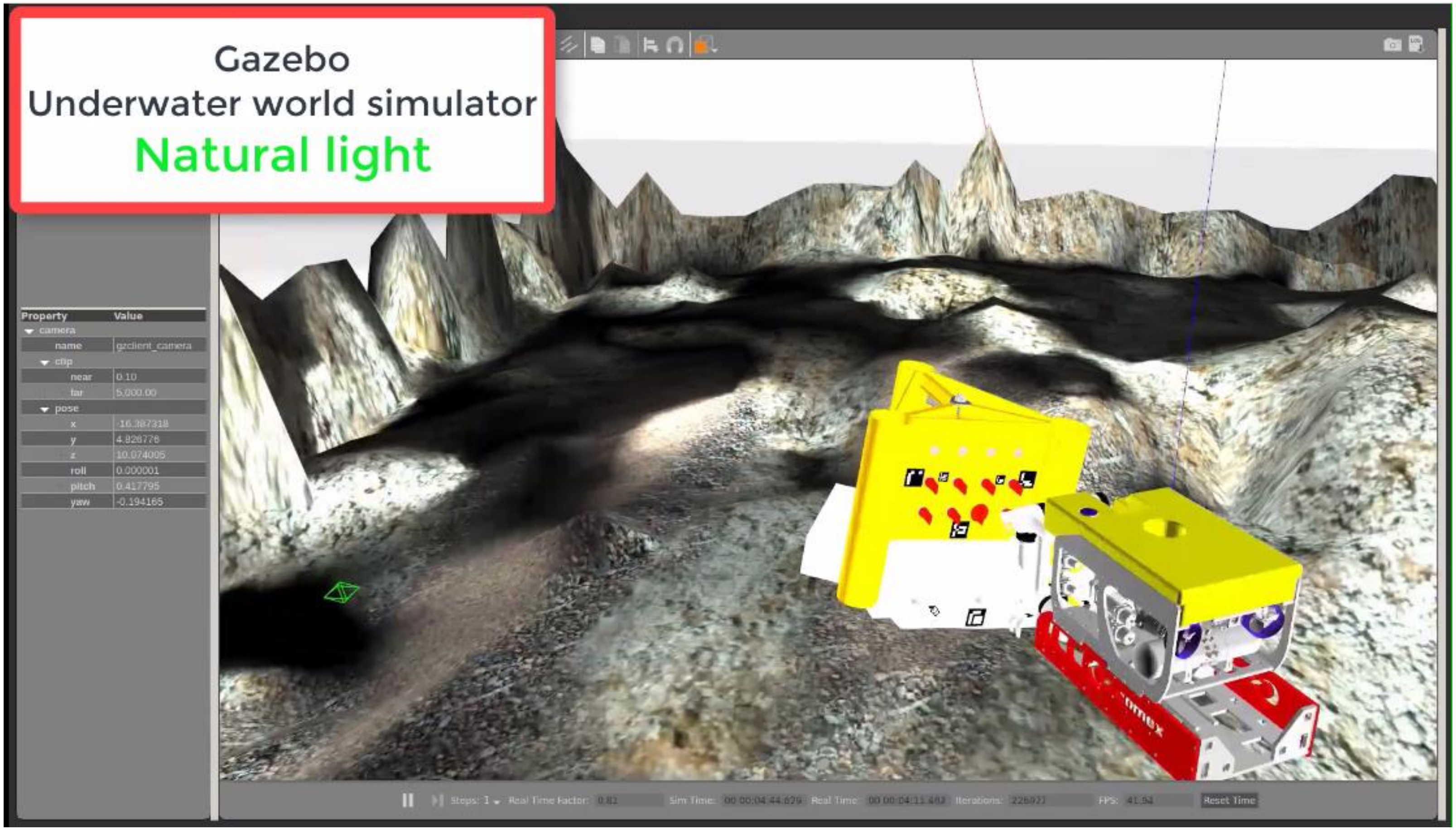
Deep sea – Oil & gas panel

SPATIAL SYNCHRONIZATION: Markers used as landmarks



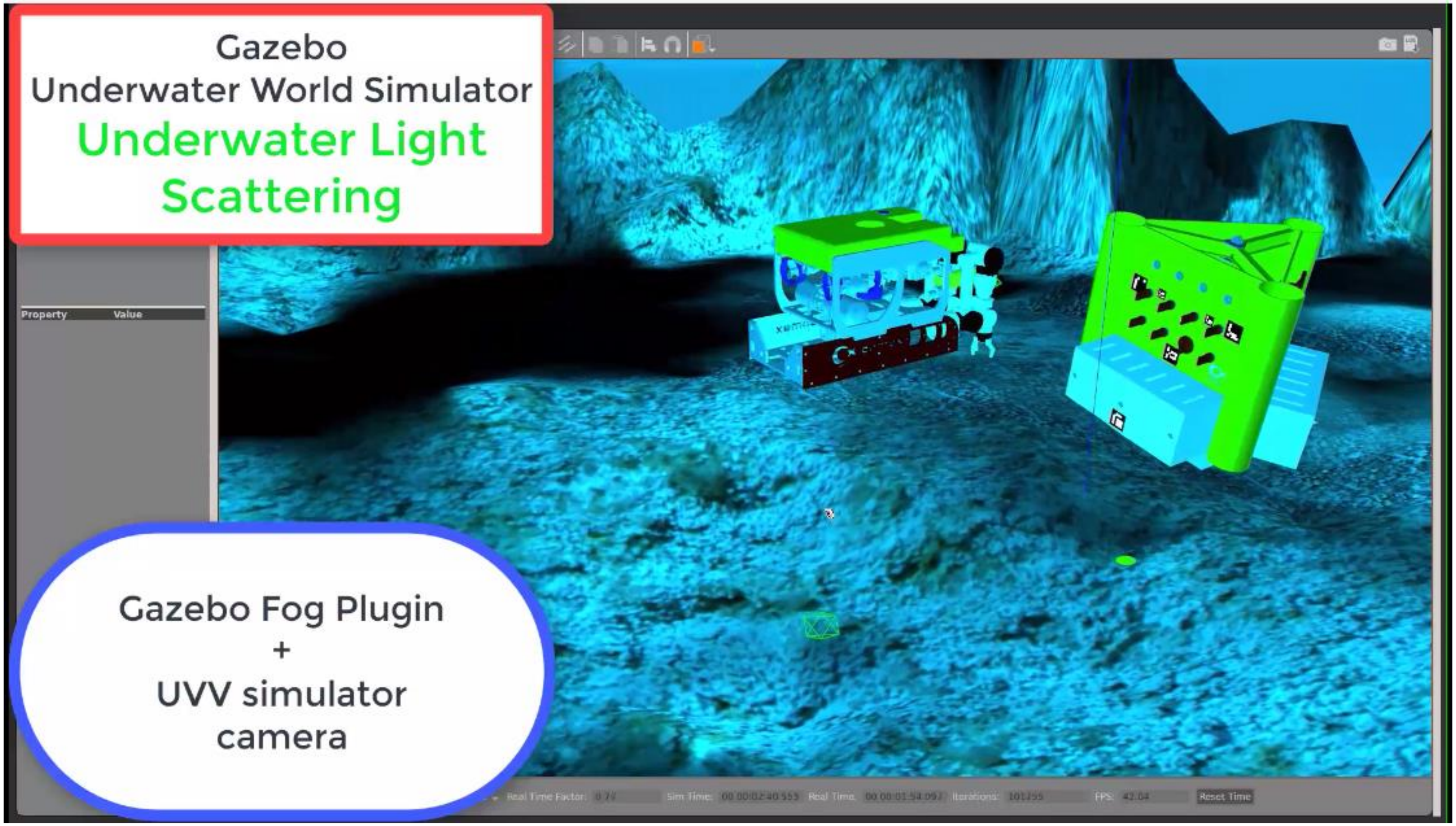
Deep sea – Oil & gas panel

ENVIRONMENTAL SYNCHRONIZATION: Light degradation



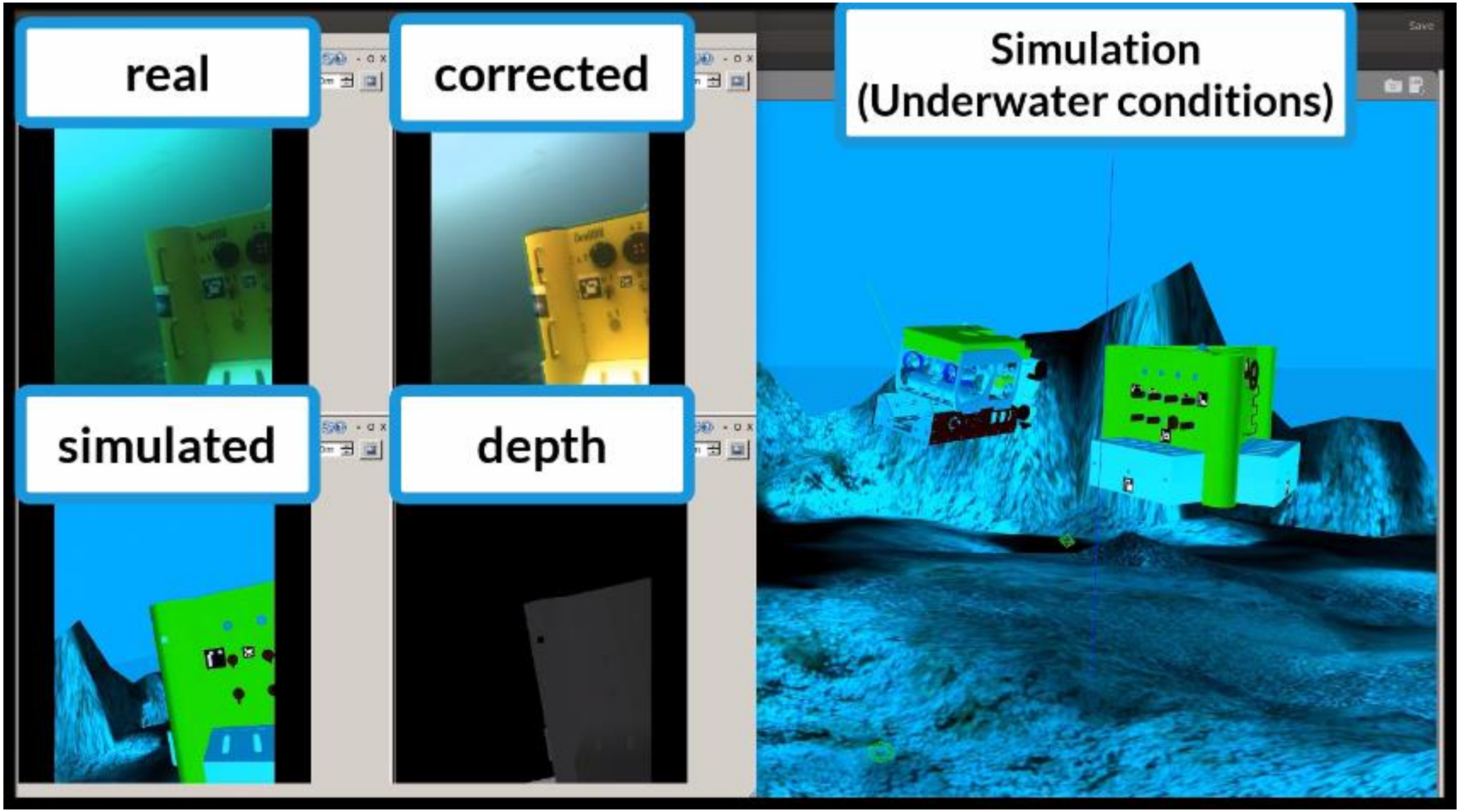
Deep sea – Oil & gas panel

ENVIRONMENTAL SYNCHRONIZATION: Light degradation



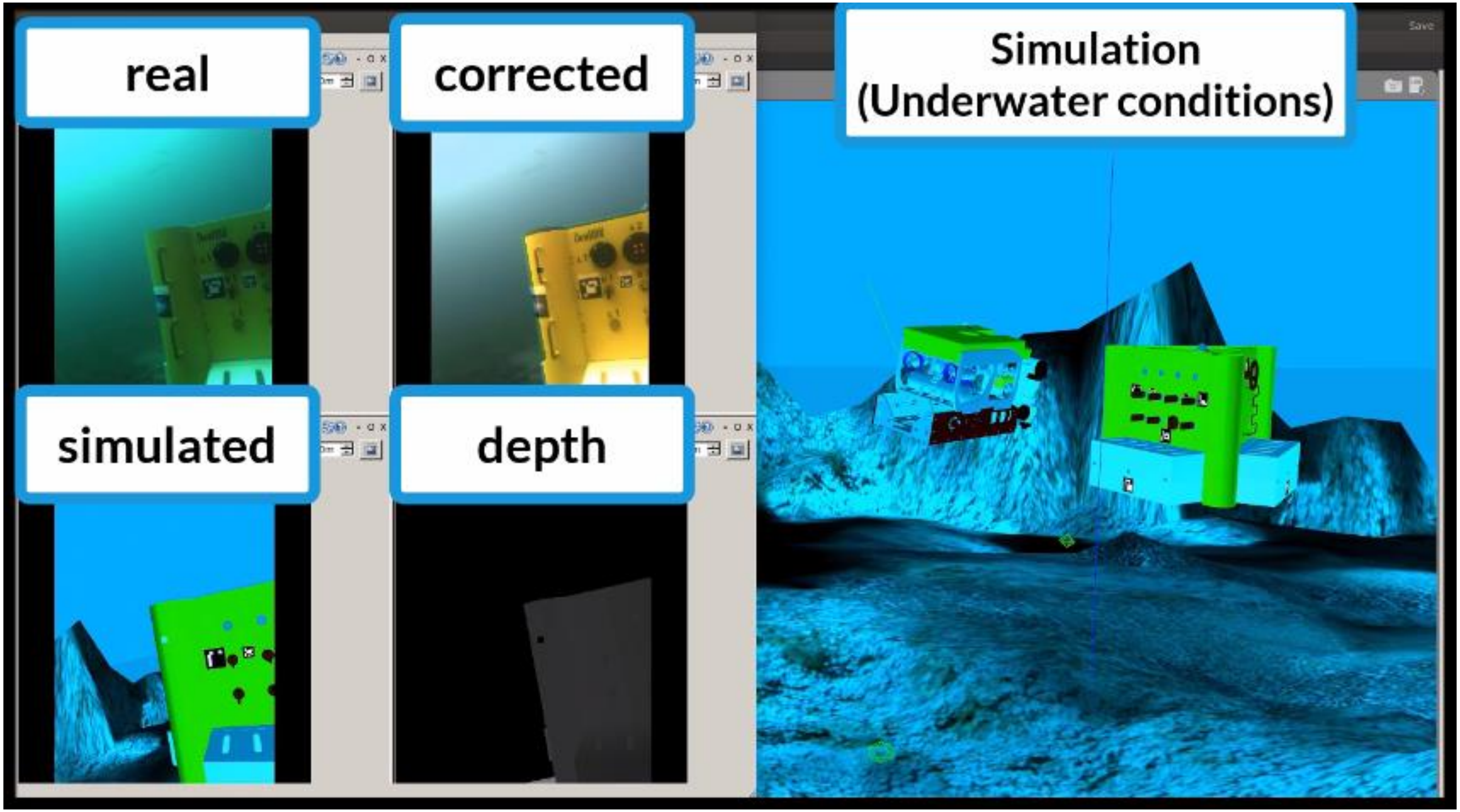
Benchmark: Image dehazing

- **CAD model provides ground-truth depth which can be used to estimate light attenuation.**



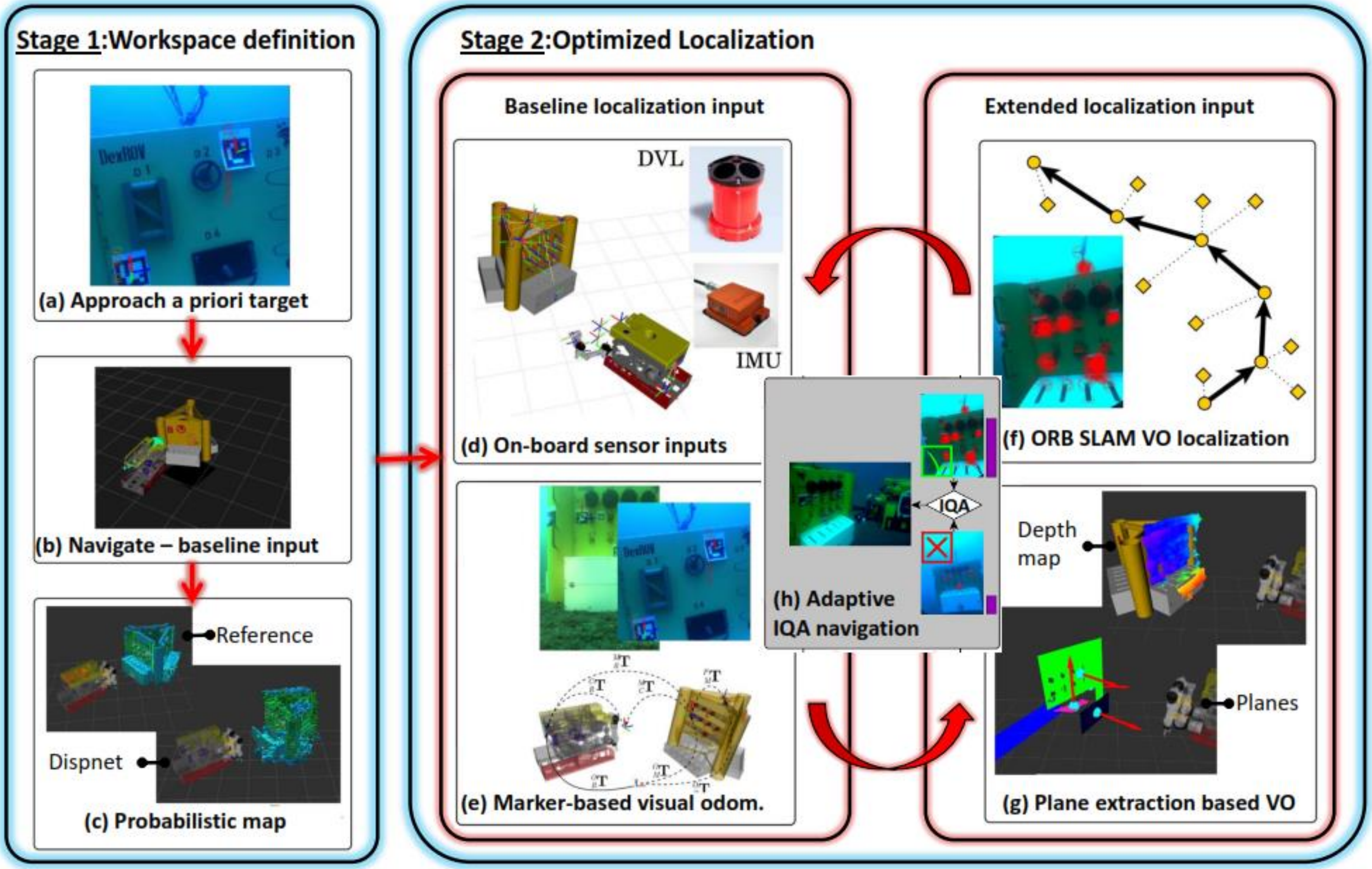
Benchmark: Image dehazing

- T. Doernbach, A. Gomez Chavez, C. A. Mueller, A. Birk, “**High-Fidelity Deep-Sea Perception Using Simulation in the Loop**”, *IFAC-PapersOnLine*, 2018.

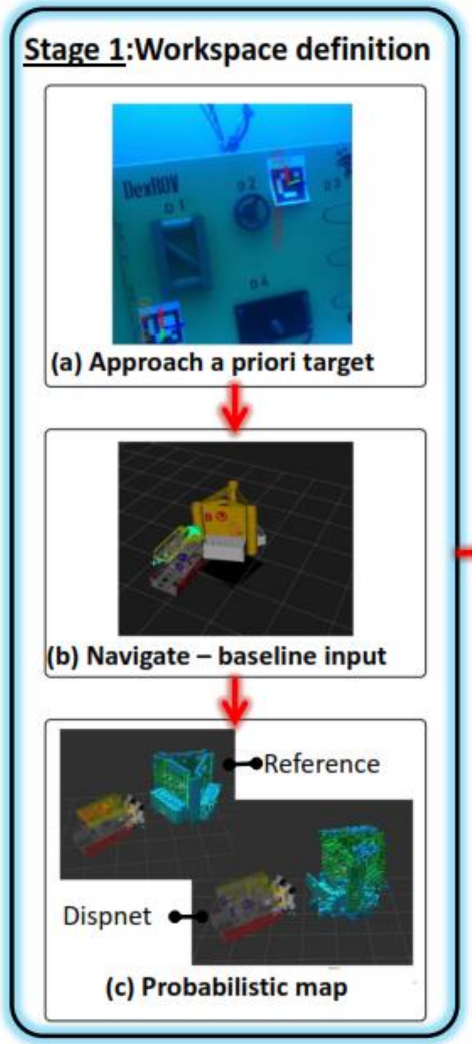


Benchmark: Localization

- **Benchmark and interchange localization modules to find best sensor input combination and fine-tune parameters.**



Benchmark: Localization



Stage 1 – Workspace definition

(a) Approach target until an priori known landmark is recognized (global 3D pose).

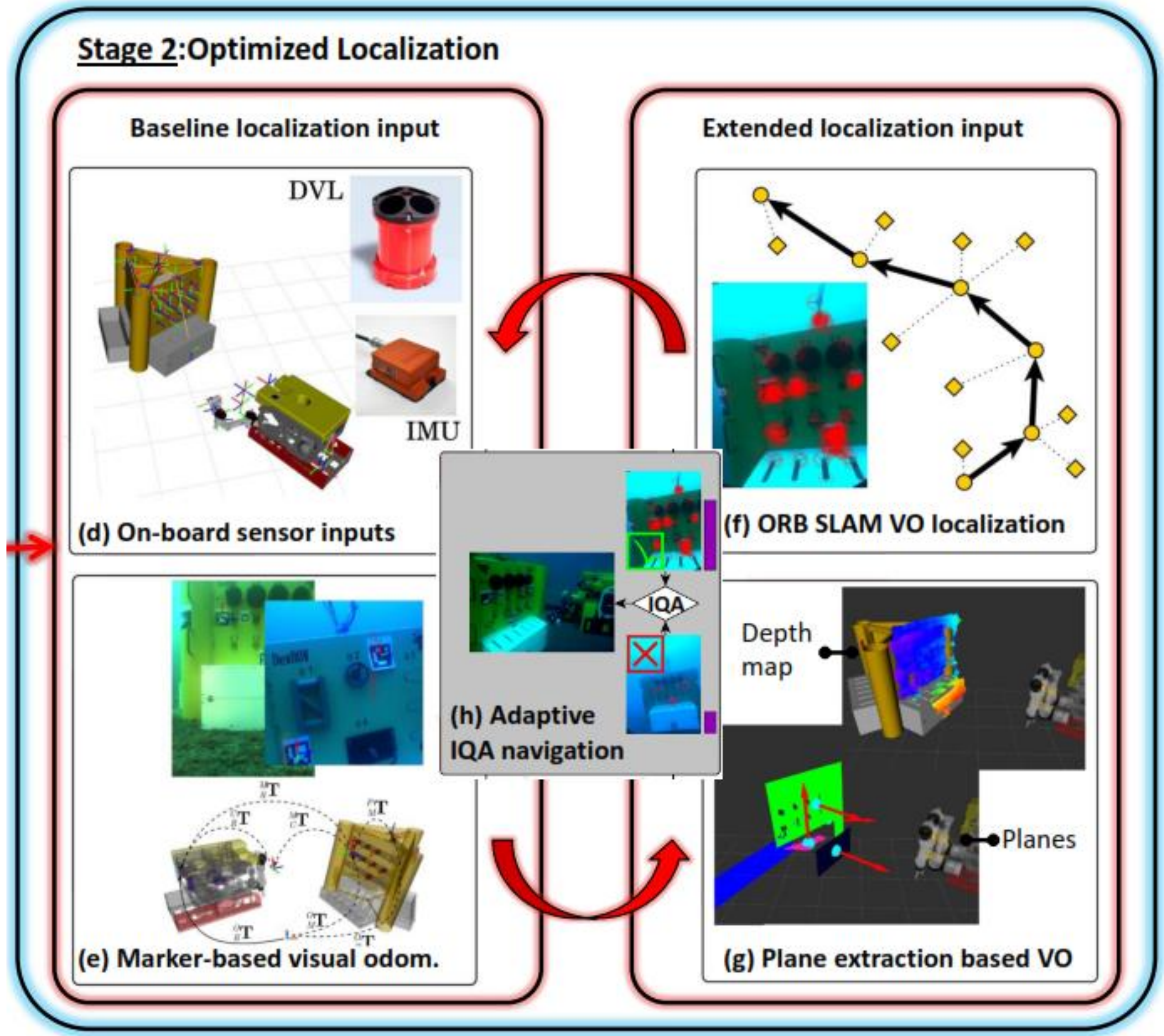
(b) Navigate with baseline odometry (IMU + DVL).

(c) Define workspace with a probabilistic map derived from stereo input.

Benchmark: Localization

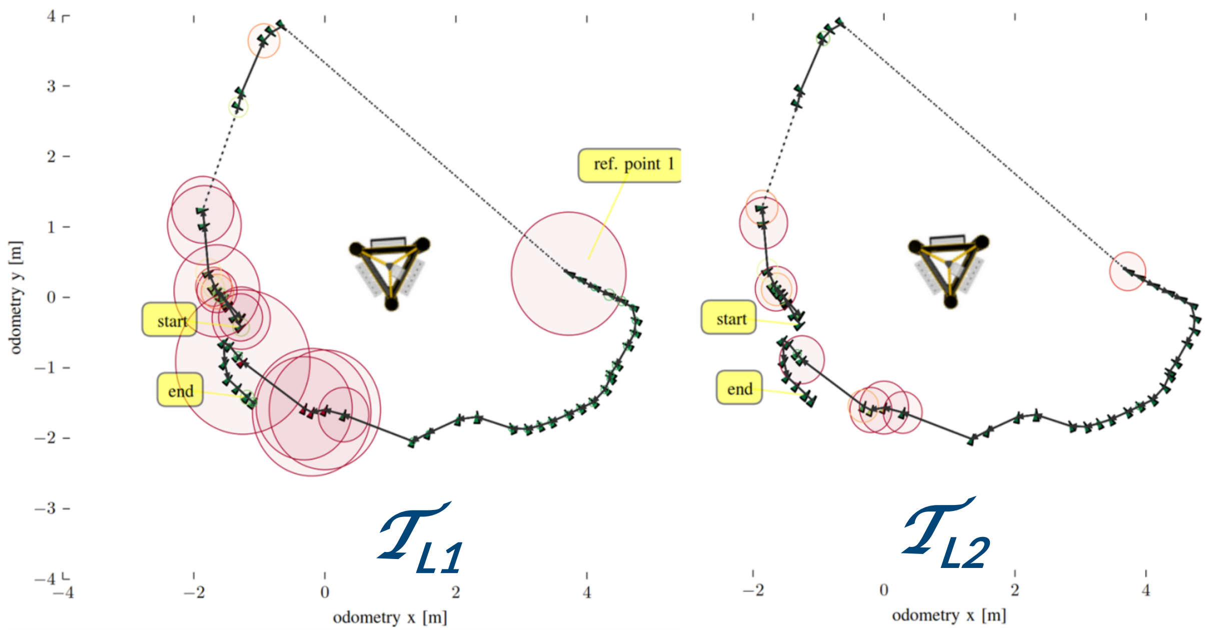
Stage 2 – Optimized localization

(d-e) Continue task with baseline input.
(f) Extract and track 2D features (ORB) from imagery to enable loop-closures.
(g) Extract planes from dense point clouds, filtered with probabilistic map, then register.
(h) Evaluate quality and reliability of stereo imagery (IQA), select best visual VO method and integrate it in the localization filter.



Benchmark: Localization

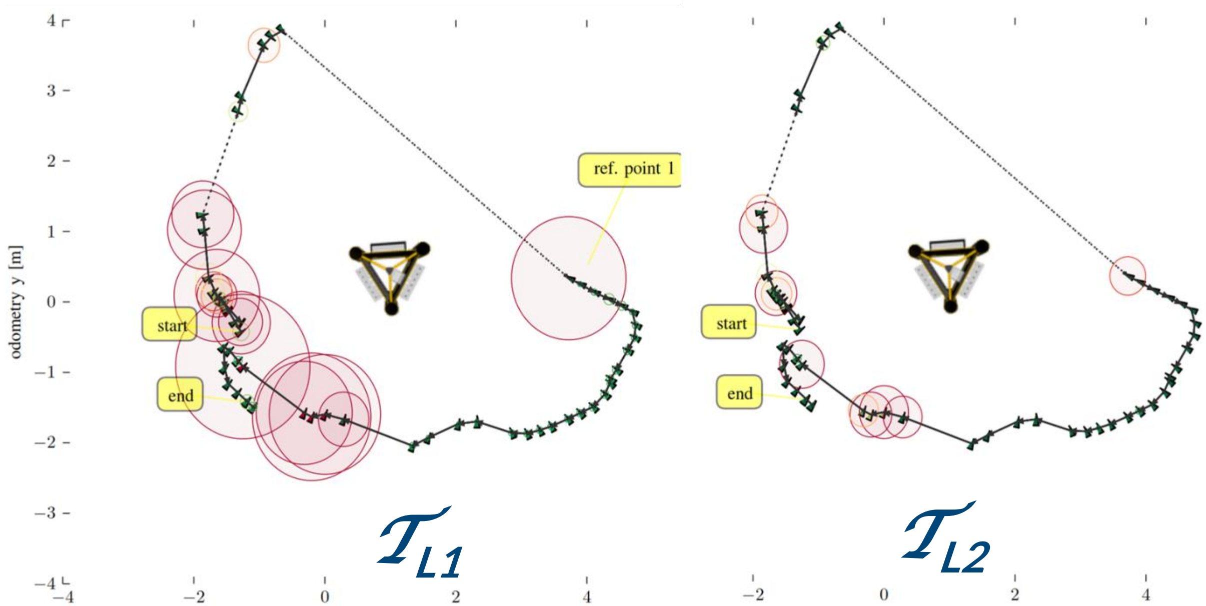
- **Baseline localization ($\mathcal{T}_{L1}$ -all sensors) vs localization based on image-quality ($\mathcal{T}_{L2}$).**



		$\mathcal{T}_{L1}$	$\mathcal{T}_{L2}$
Position error --	$\bar{m}_{M,F}(\mathcal{T}_{Li}\langle\bar{\mathrm{p}}\rangle)$[m]	0.65 ± 0.58	0.31 ± 0.11
Orientation error --	$\bar{m}_{M,F}(\mathcal{T}_{Li}\langle\bar{\mathrm{q}}\rangle)$[deg]	14.65 ± 8.42	7.21 ± 2.10
Autocorrelation --	$m_A(\mathcal{T}_{Li})$	0.88	0.94

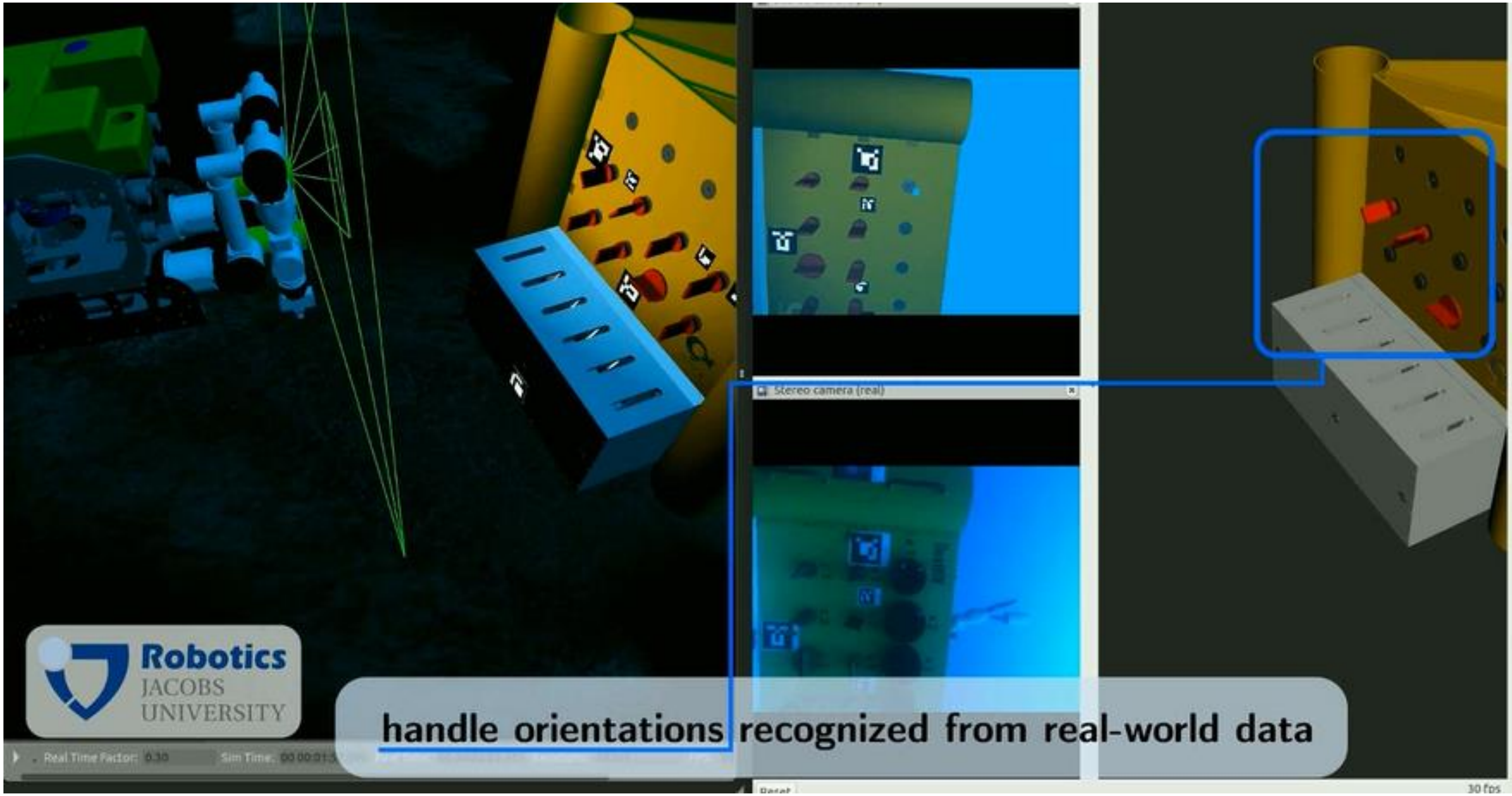
Benchmark: Localization

- **Baseline localization ($\mathcal{T}_{L1}$ -all sensors) vs localization based on image-quality ($\mathcal{T}_{L2}$).**



- A. Gomez Chavez, Q. Xu, C. A. Mueller, S. Schwertfeger, A. Birk, "**Adaptive Navigation Scheme for Optimal Deep-Sea Localization Using Multimodal Perception Cues**", *arXiv e-prints*, arXiv:1906.04888, 2019.

Benchmark: Manipulation



Watch more videos about the DexROV system at:
https://vimeo.com/jacobsrobotics

Human in the Loop for Diver Exploratory Missions

Motivation – UW Robots

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- Rapid progress in the development of ROVs and AUVs has been made in the past years (*EU FP7 MORPH, CADDY, H2020 DexROV*, etc)
- Enable rapid 3D mapping for exploration and diver assistance in hazardous environments.

Girona 500

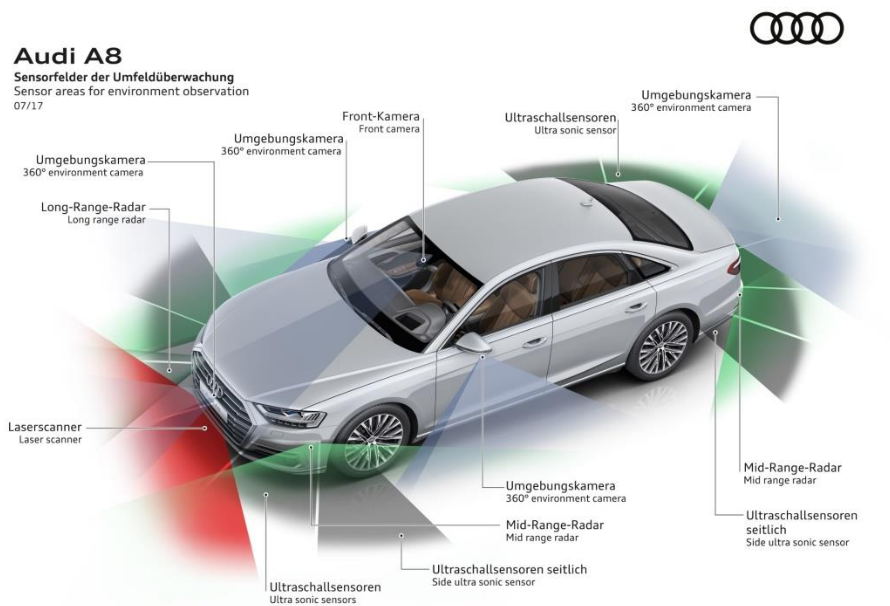
Medusa IST

BUDYY UniFER

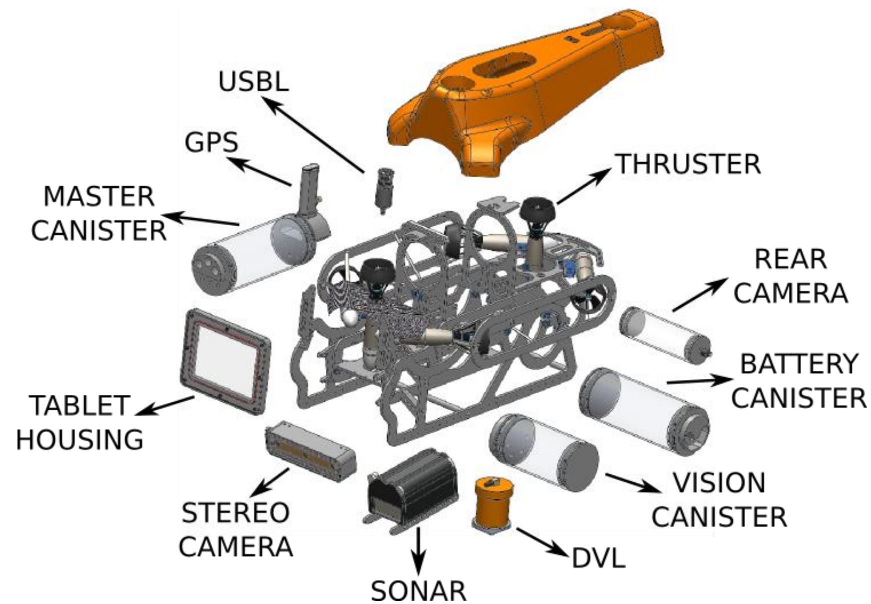
OceanOne

Motivation – UW Robots

- **Field robotics – Analogous to Autonomous driving (not the same scale)**
- **Great variety of sensors available for redundancy, BUT …**



Audi A8



BUDYY UniFER

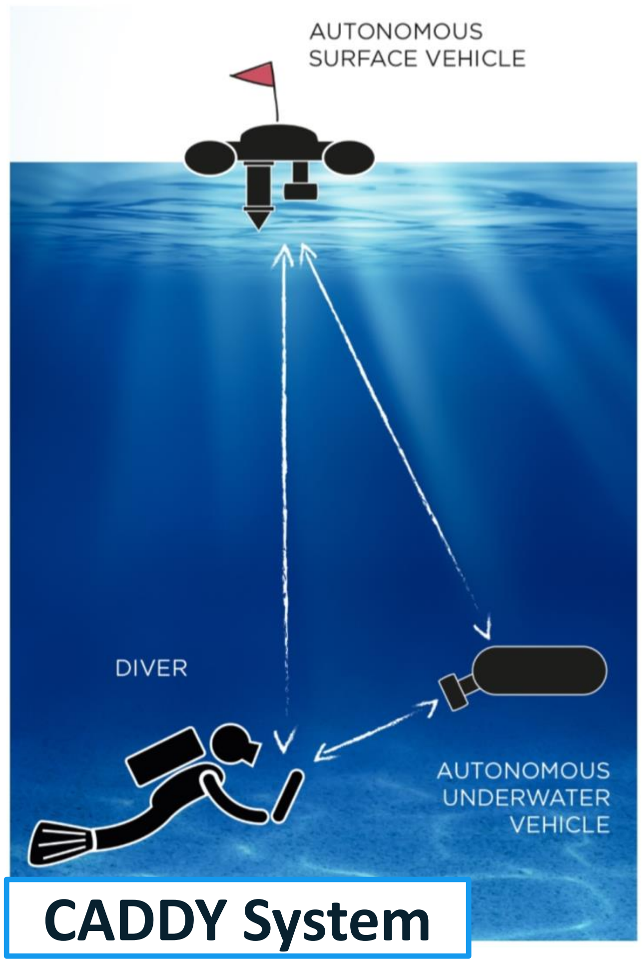
What have we learned ?

- **Human intervention is still indispensable, environment and missions too complex to have a fully autonomous vehicle.**
- **Investment in camera setups (lower energy, faster processing, closer to diver – same as Autonomous cars).**

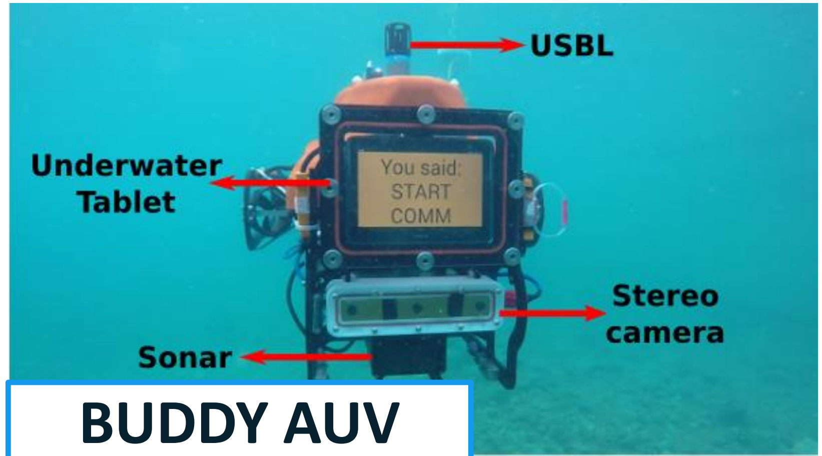
Source: Ministry of Culture of Croatia, UNESCO

Solution – Diver assistant

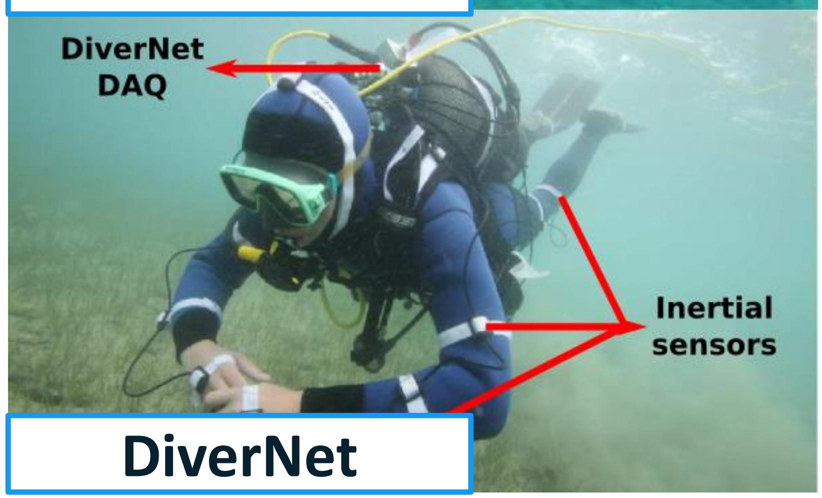
- EU FP7 Cognitive Autonomous Diving Buddy (CADDY) - http://caddy-fp7.eu/



CADDY System



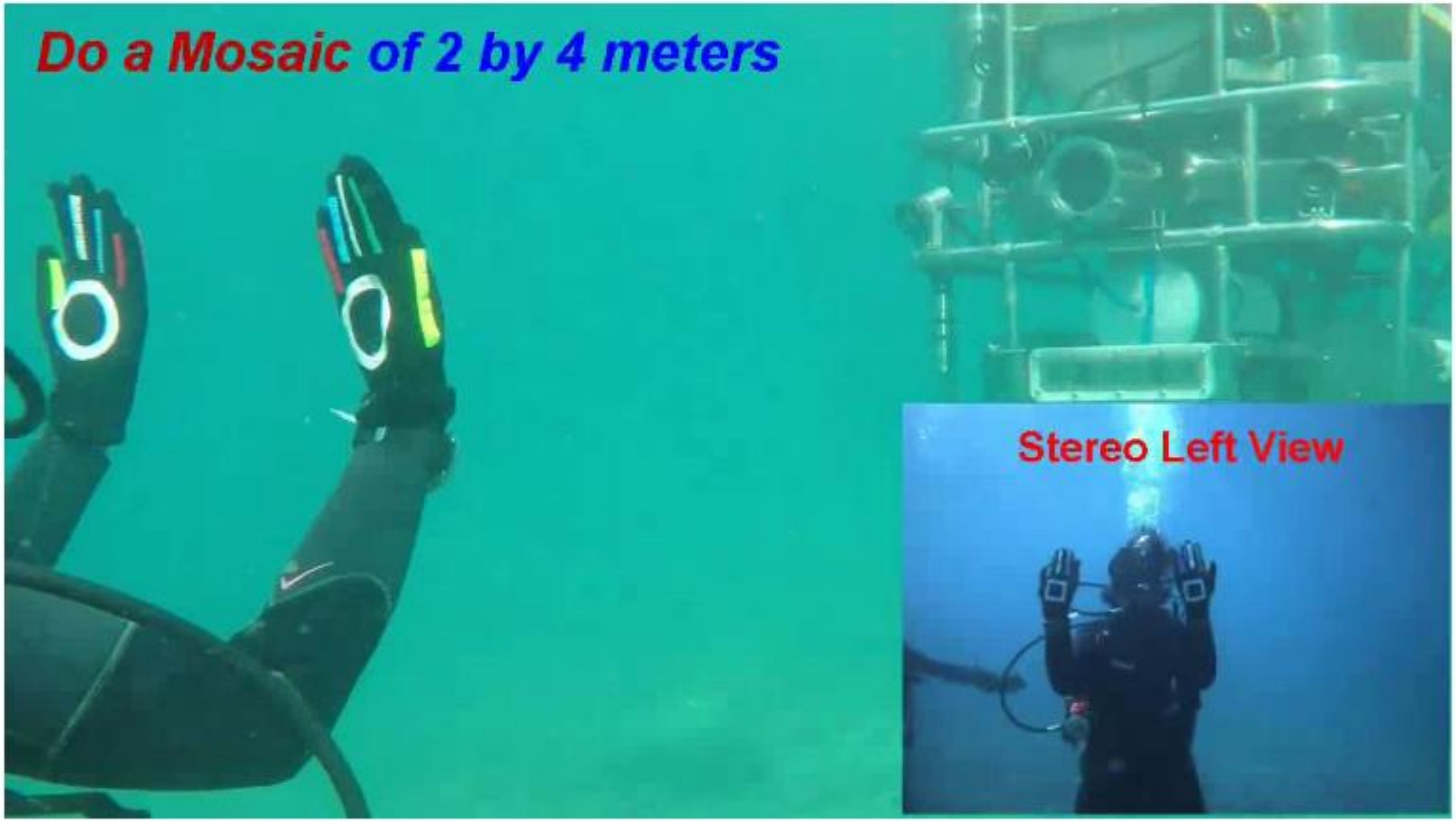
BUDDY AUV



DiverNet

Hand gesture recognition

- EU FP7 Cognitive Autonomous Diving Buddy (CADDY).



Hand gesture recognition

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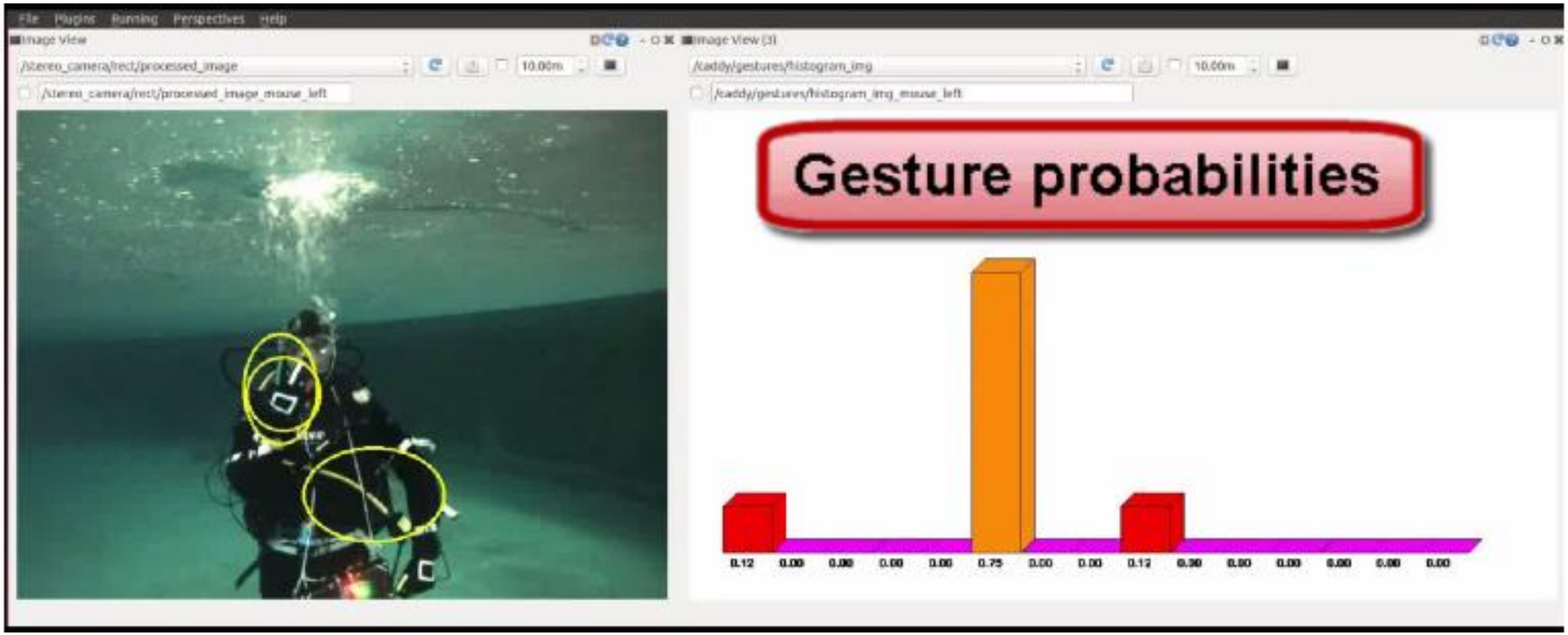
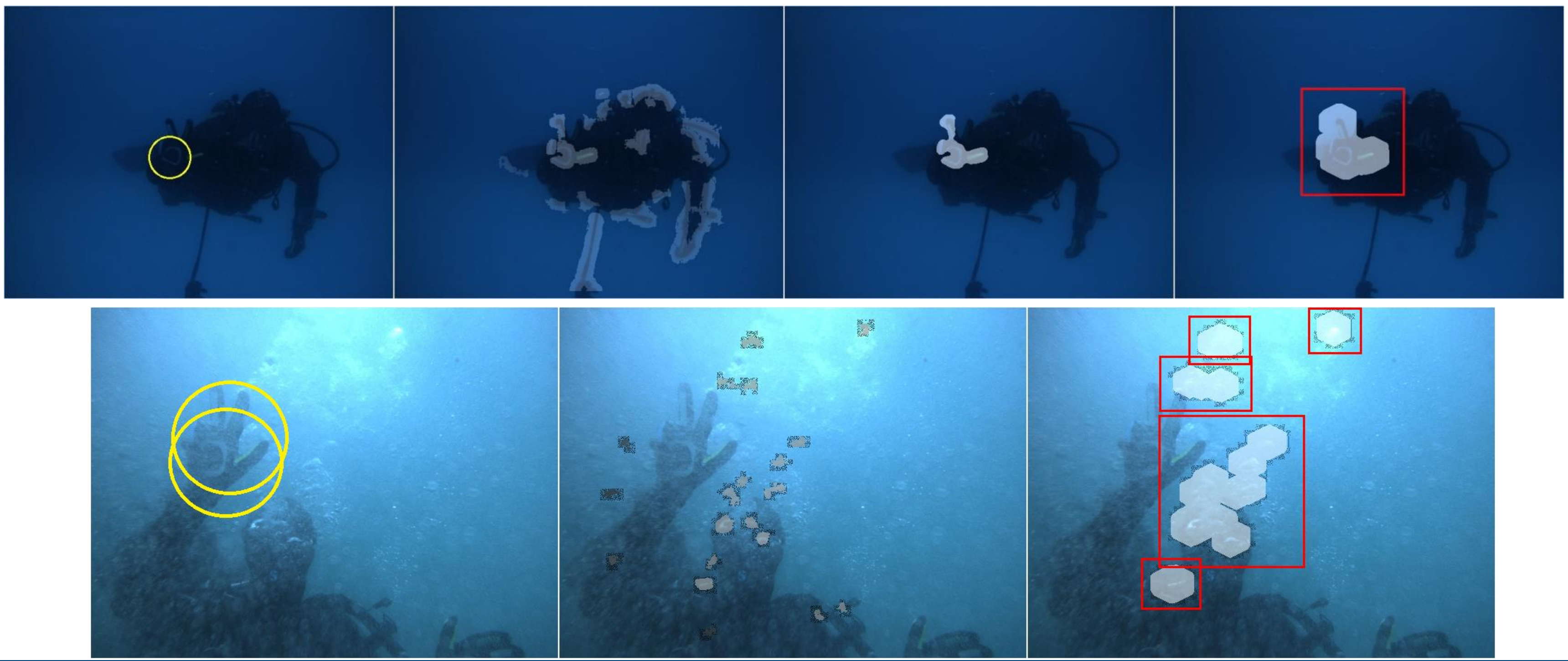
- EU FP7 Cognitive Autonomous Diving Buddy (CADDY).



- A. Gomez Chavez, et.al., "**Robust Gesture-Based Communication for Underwater Human-Robot Interaction in the context of Search and Rescue Diver Missions**", *arXiv e-prints*, arXiv:1810.07122, presented at IROS 2018 Workshop on Human-Aided Robotics.

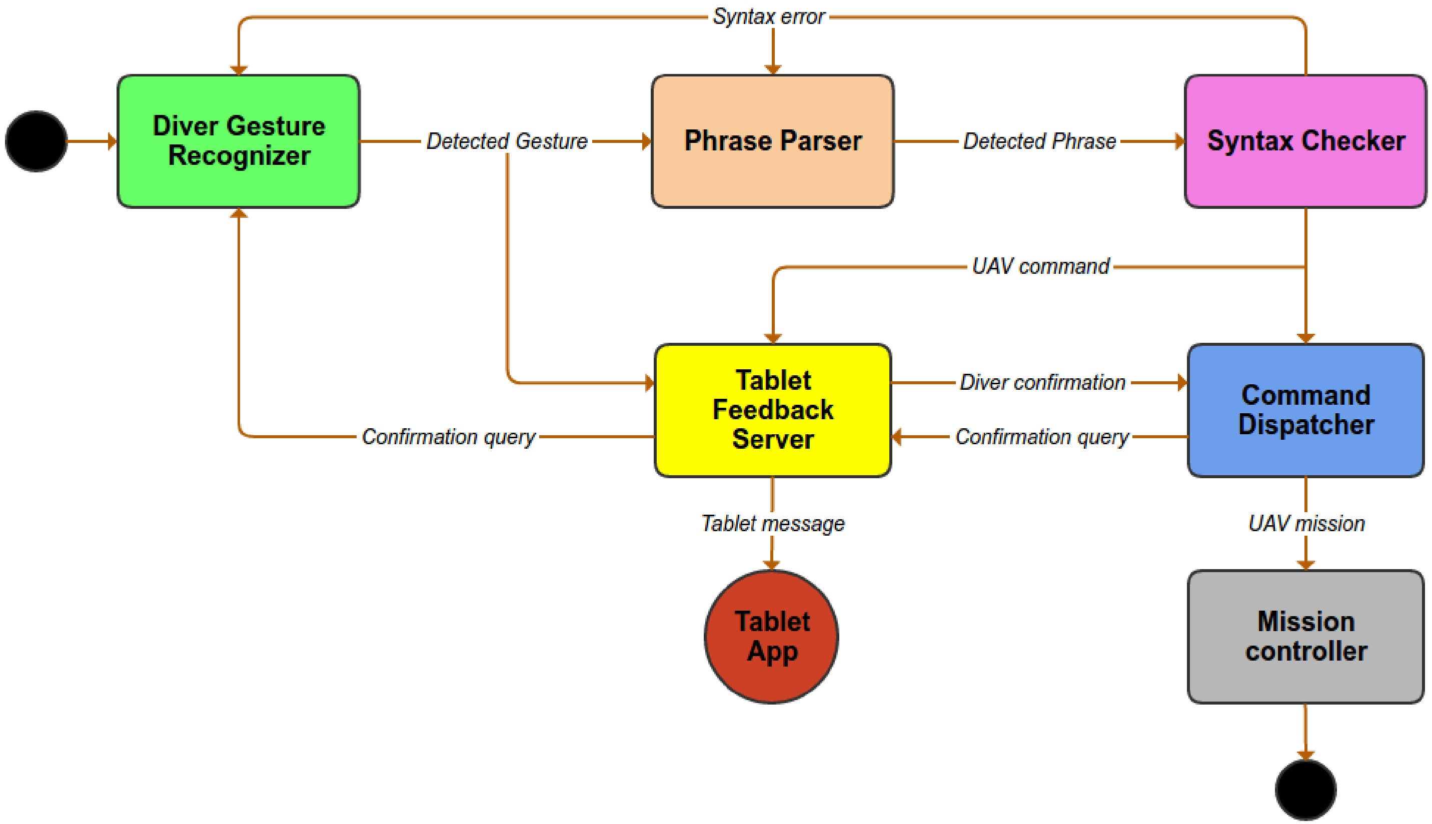
Sensor fusion

- **Several false positives from 2D recognition, less robust to image degradation.**
- **Combine with disparity maps to create saliency regions.**
- **2D compensates false positives from disparity as well (bubbles) → cross-validation.**



Human in the loop

- **Full integration of CADDIAN language and feedback.**

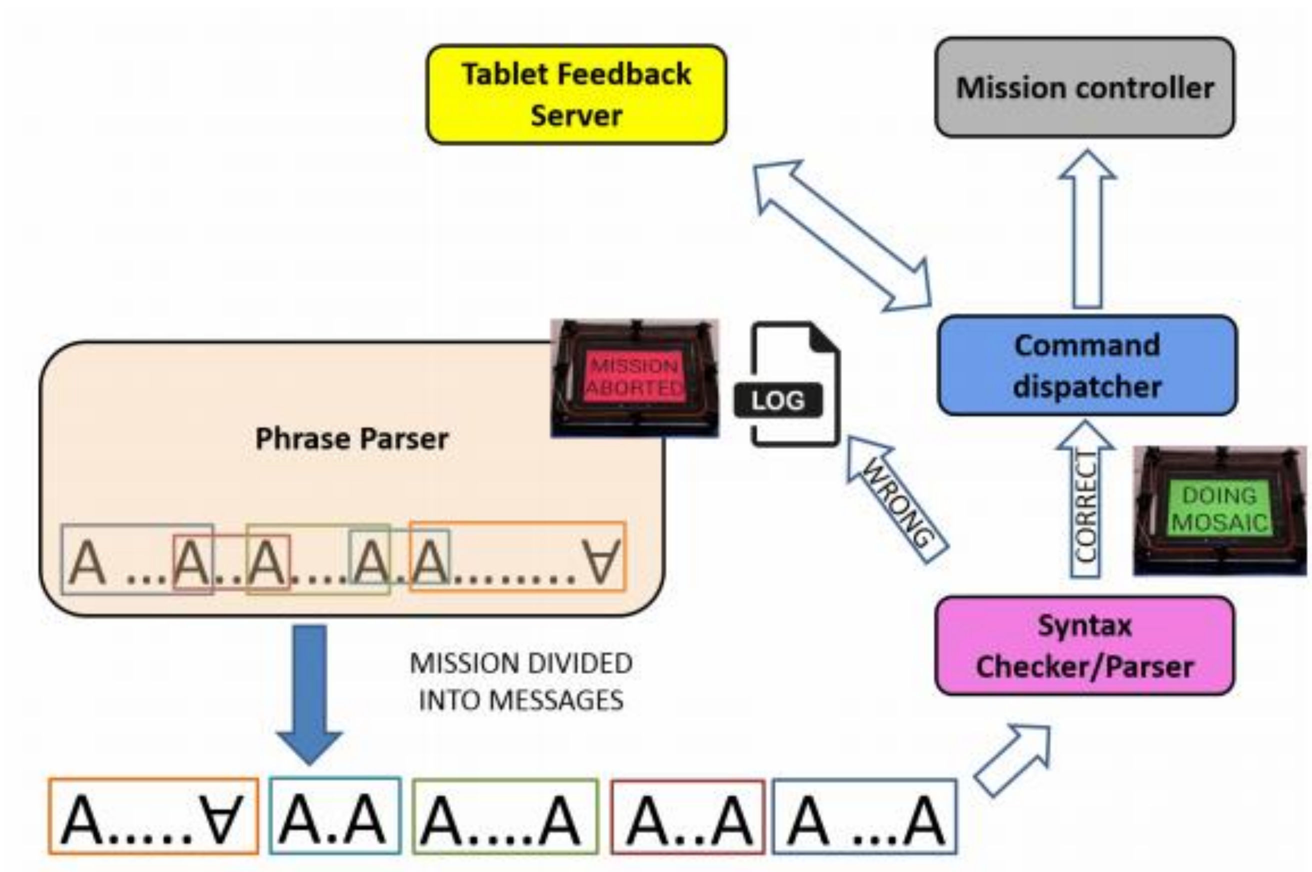


Human in the loop

- **Feedback with underwater tablet → Full integration of CADDIAN language.**

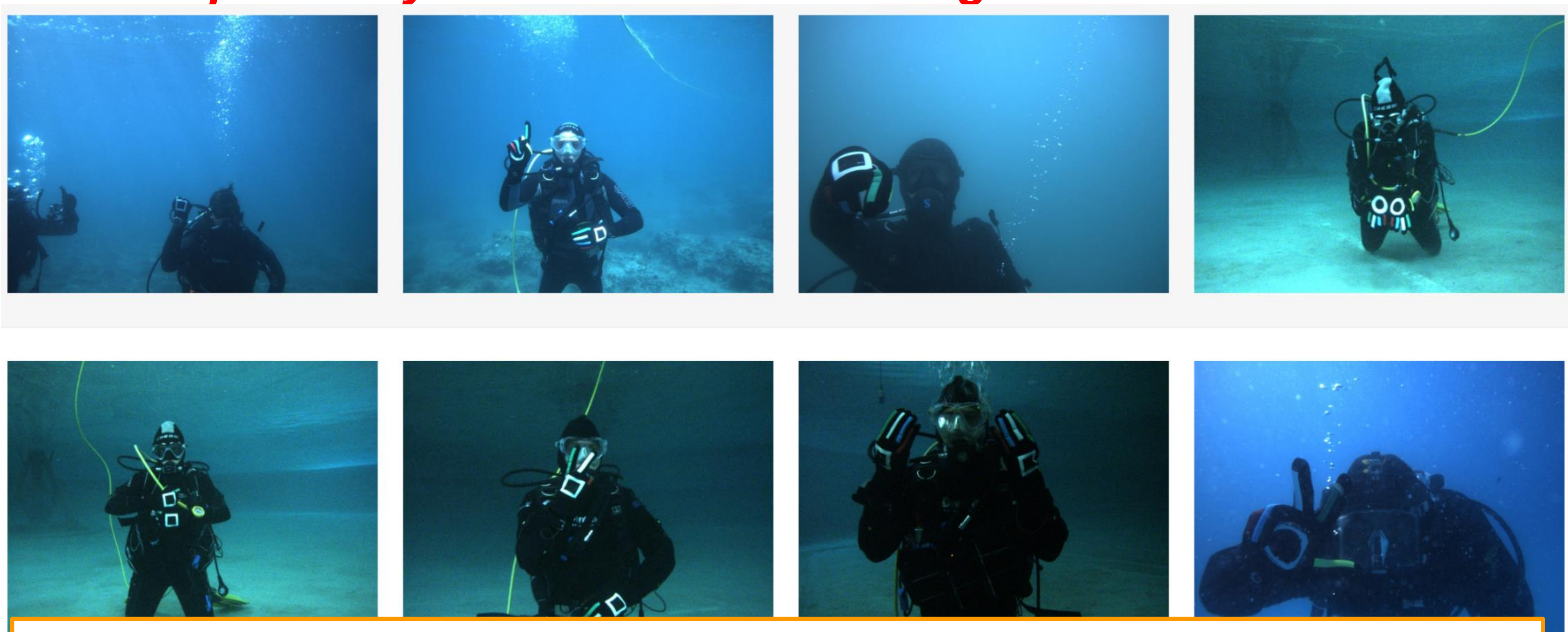
Human in the loop

- **Phrase parser→ Full integration of CADDIAN language.**



Dataset collection

- **Towards data-driven methods.**
  - ***http://caddy-underwater-datasets.ge.issia.cnr.it/***



- A. Gomez Chavez, et. al., "**CADDY Underwater Stereo-Vision Dataset for Human–Robot Interaction (HRI) in the Context of Diver Activities**", *Journal of Marine Science and Engineering*, 2019.

Questions