

Konrad Wolsing, Antoine Saillard, Elmar Padilla, Jan Bauer

XLab-UUV – A virtual Testbed for Extra-Large Uncrewed Underwater Vehicles

Motivation

Maritime Industrialization: The Emergence of Underwater Applications

- Inspection, maintenance, and repair (IMR) of offshore infrastructures
- Deep sea exploration and exploitation of underwater resources
- Surveillance and reconnaissance



Motivation

XLUUVs: A new Breed of UUVs

Extra-Large Uncrewed Underwater Vehicle (XLUUV)

- Remote-controlled, semi-autonomous
- Long-term operations, large distances
- Military stakeholders



Orca XLUUV (Boeing / US Navy)

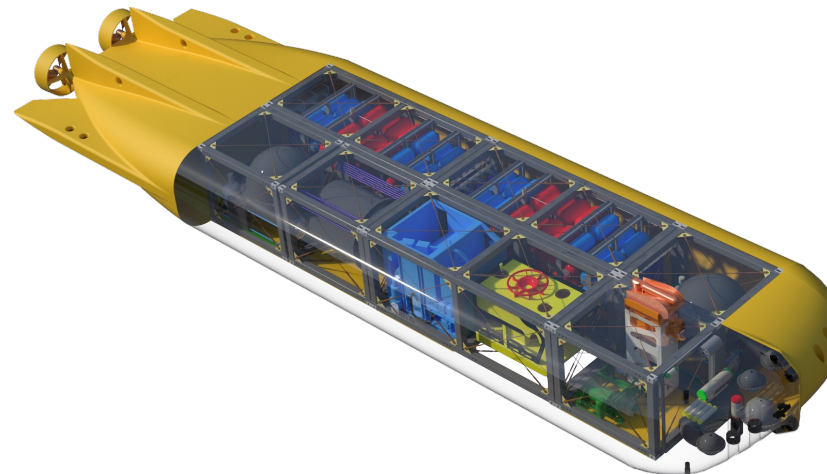


MUM

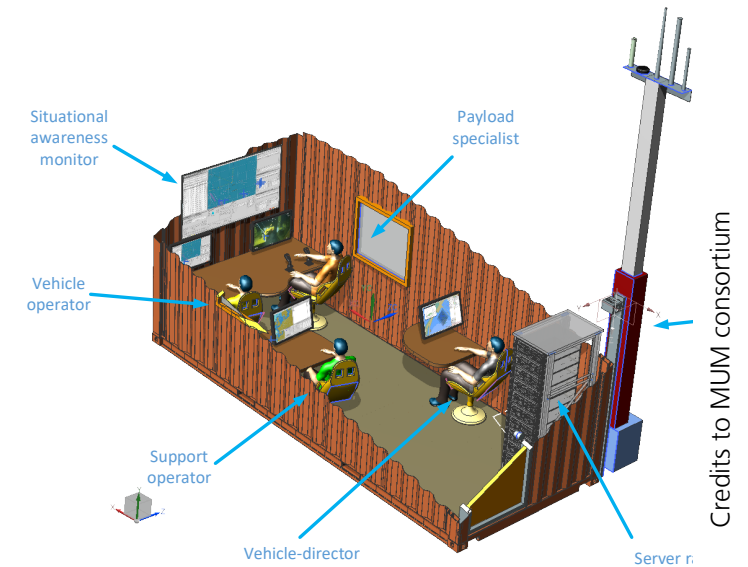
Modifiable Underwater Mothership

MUM is not the same

- Civil project with German partners around thyssenkrupp Maritime Systems (tk MS)
- Goal: XLUUV with unique features
 - modular and multi-purpose
 - carrying of payloads (e.g., ROVs)
 - green techs (hydrogen fuel cells)



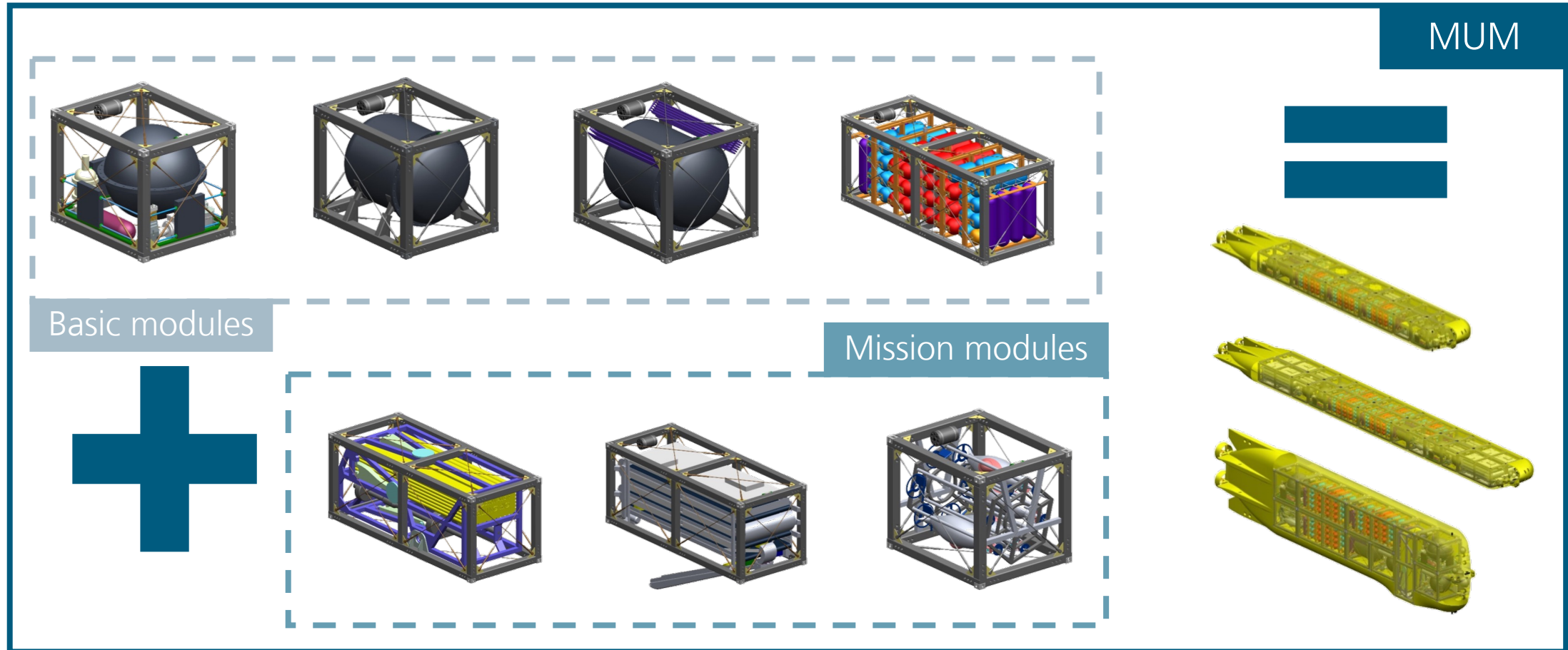
MUM XLUUV



Remote Control Center (RCC)

MUM's Modularity

Composing an Application-tailored XLUUV



Credits to MUM consortium

MUM Development Process

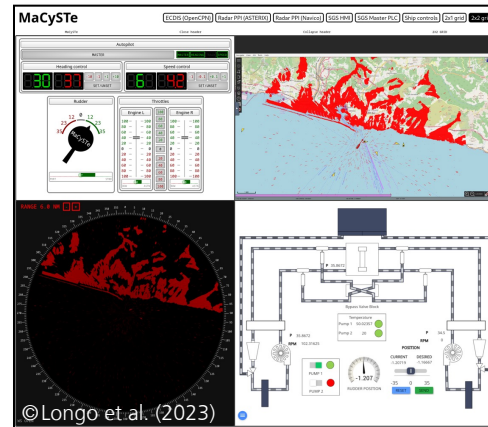
XLUUV Simulation

Researchers need development environments

- Other disciplines use simulation: driving physics, hull hydrodynamics, control system
- IT / OT simulation



Cyber-SHIP @ Univ. of Plymouth



MaCySte @ Univ. of Genoa



Grace Modules @ FATHOM5

MUM Development Process

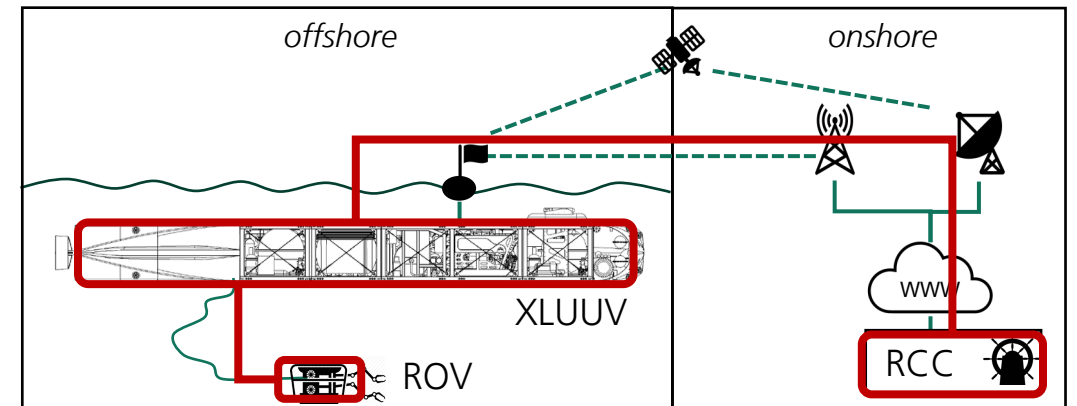
XLUUV Simulation

Researchers need development environments

- Other disciplines use simulation: driving physics, hull hydrodynamics, control system
- IT / OT simulation: **Lack of testbeds for XLUUVs!**

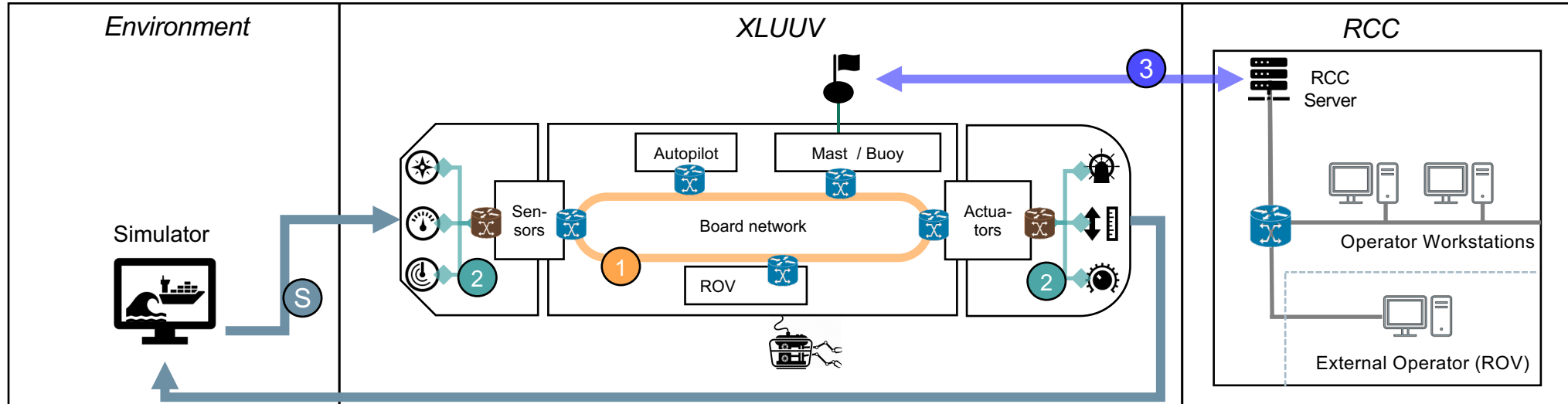
Testbed requirements

- Holistic system with meaningful level of abstraction
- State-of-the-art, practice-oriented technologies and protocols
- Generic and flexible (modularity and tech comparison)
- Real-time capable



XLab-UUV Testbed

System Architecture, Tools, and Technologies

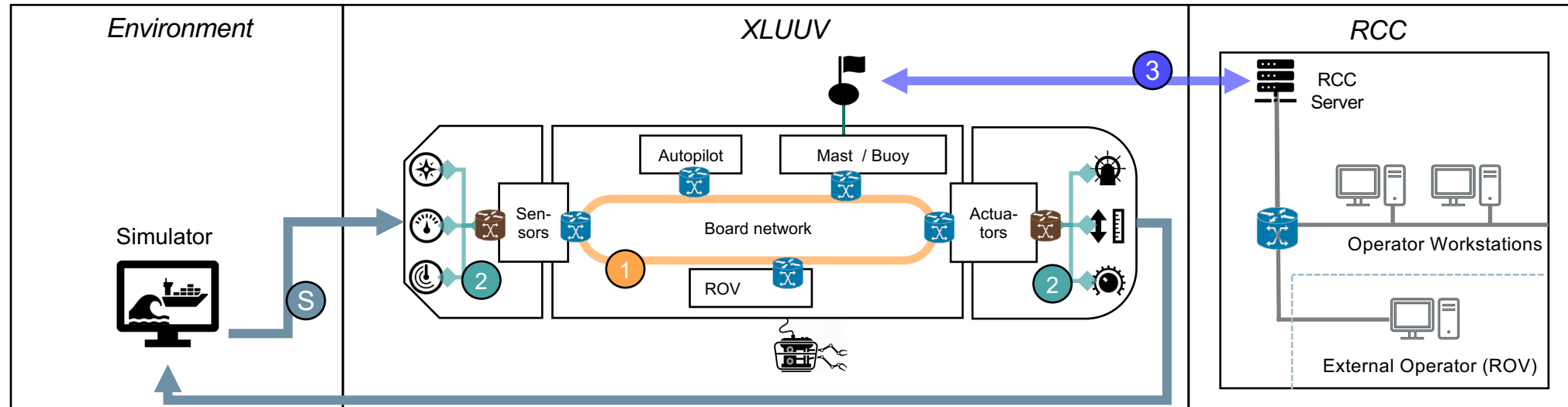


1 IT Communication

- Mininet (virtual network emulator with Linux kernel)
- High-availability Seamless Redundancy (HSR) network protocol (IEC 62439)
 - Ring topology
- Data Distribution Service (DDS) for pub-sub (OMG standard)

XLab-UUV Testbed

System Architecture, Tools, and Technologies

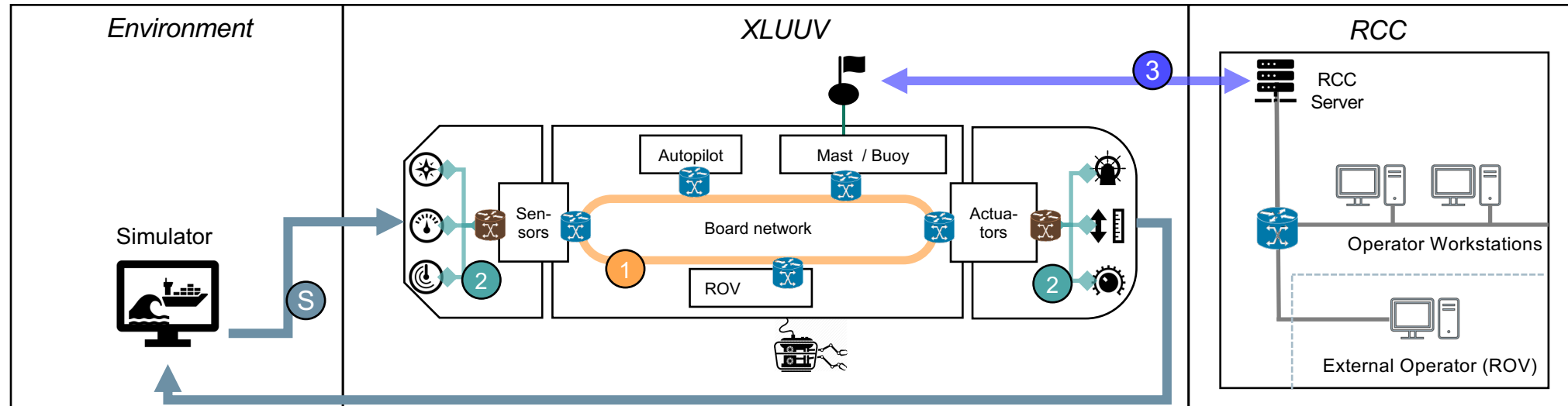


- ① IT Communication
- ② OT Communication

- simple IT-OT proxy

XLab-UUV Testbed

System Architecture, Tools, and Technologies

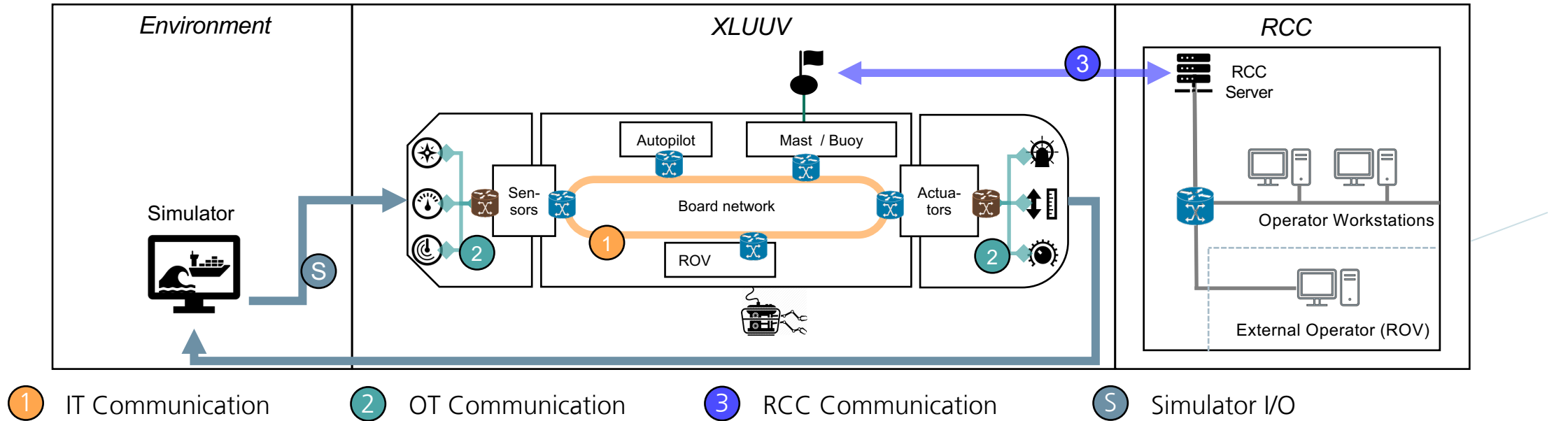


- ① IT Communication
- ② OT Communication
- ③ RCC Communication

- netem (link quality modulation)
- Google Remote Procedure Calls (gRPC)

XLab-UUV Testbed

System Architecture, Tools, and Technologies



- Ship simulator
- Incl. other vessels and environment

XLab-UUV Visualization

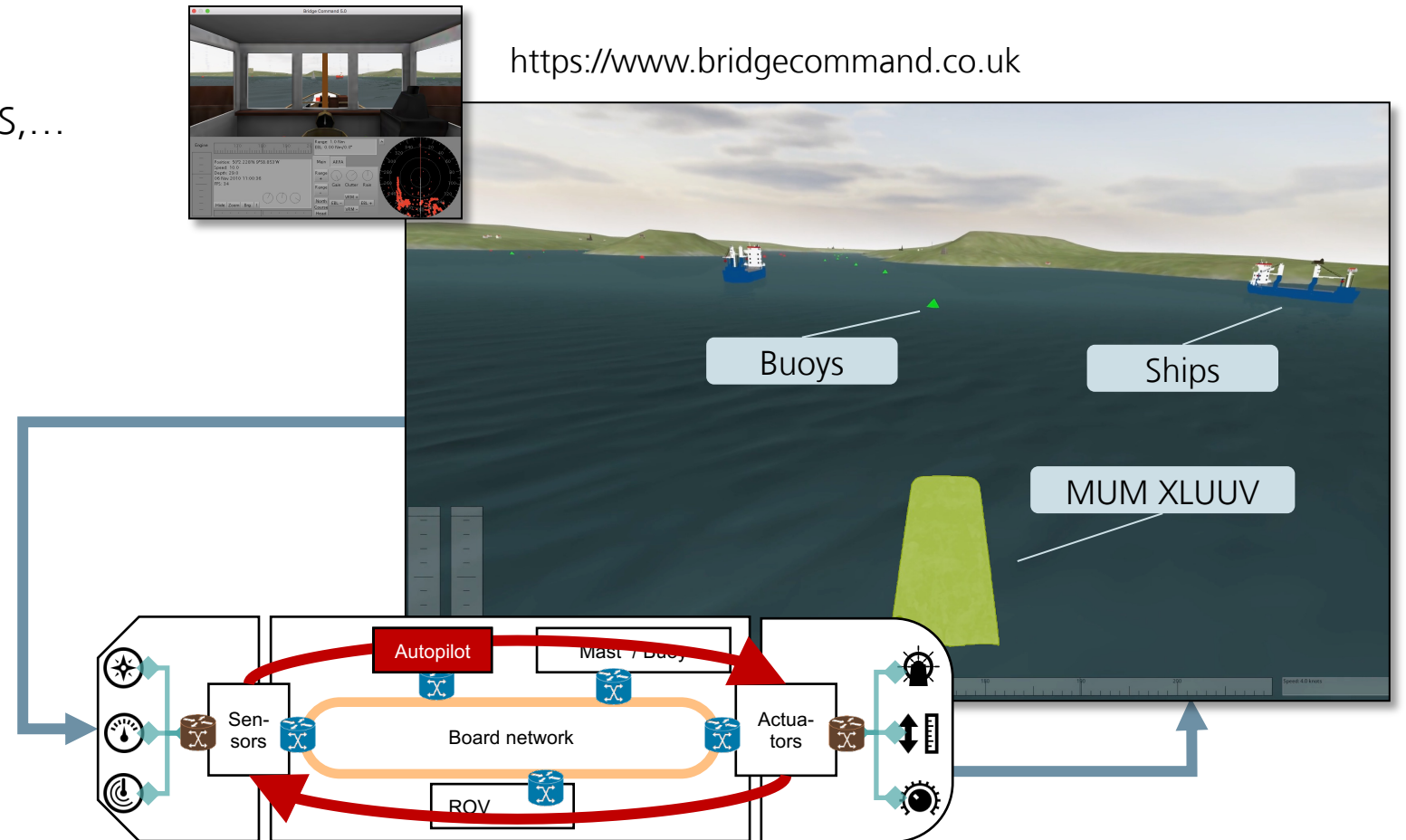
MUM Simulation

Leveraging Bridge Command

- Output: course, navigation, mechanics, AIS,...
- Input: steering commands
- Further modifications: MUM 3D-model, maps/scenarios, ...

Guidance, navigation, and control

- (basic) autopilot as MUM basic module



XLab-UUV User Interface

RCC Human-Machine Interfaces (HMIs)

Extending OpenCPN

- Chart Plotter Navigation software
 - Situation picture and route planning
- HMI for status monitoring
- Autopilot interface
 - Creation of mission plans, i.e., waypoints, loitering points, diving commands, etc.



<https://opencpn.org>

The screenshot displays the XLab-UUV User Interface, which is an extension of OpenCPN. It features a central chart plotter showing a mission route in a harbor area. The interface is divided into several panels:

- Status Panel (Left):** Displays mission status (ENABLED), autopilot status (ENABLED), and current route ('rostock_dev' at Waypoint 2/17). It also shows sensor values (GNSS, COG, Rudder, SOG, RPM) and actuator commands (Wheel, ENG, THR).
- Mission Controls (Right):** Includes buttons for Skip, Start, Stop, Res., and Susp. for the mission, and similar controls for the autopilot. A prominent red 'Emergency Stop' button is visible.
- Send Procedures (Bottom Right):** A table for sending mission-related commands.

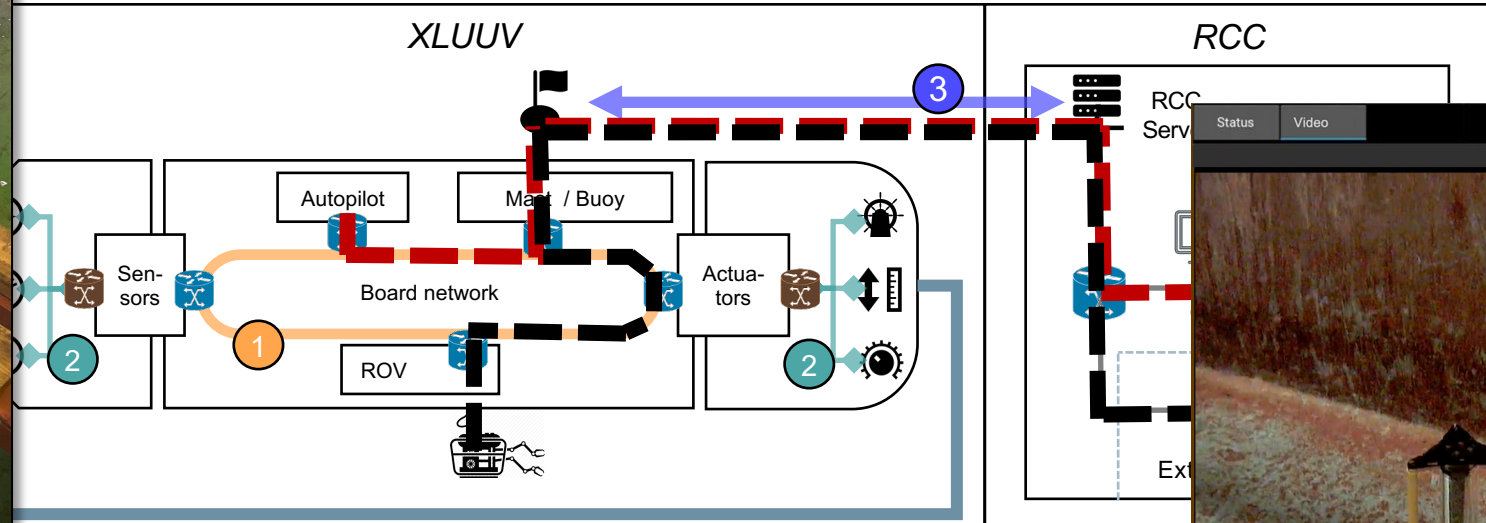
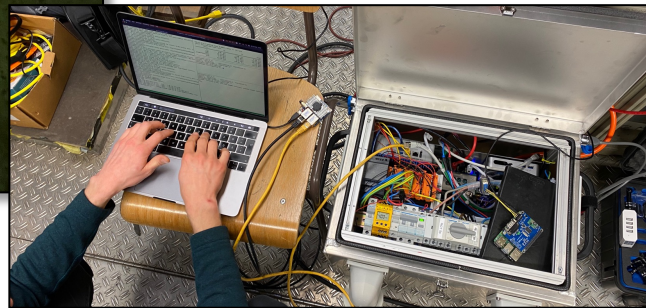
Send Procedures		
Mission ZIP	Load	Send
Mission	Load	Edit Send
Route	Load	Edit Send
Loiter Pos.	Load	Edit Send
Dive Proc.	Load	Edit Send

XLab-UUV Testbed

Communication Example: Command & Control



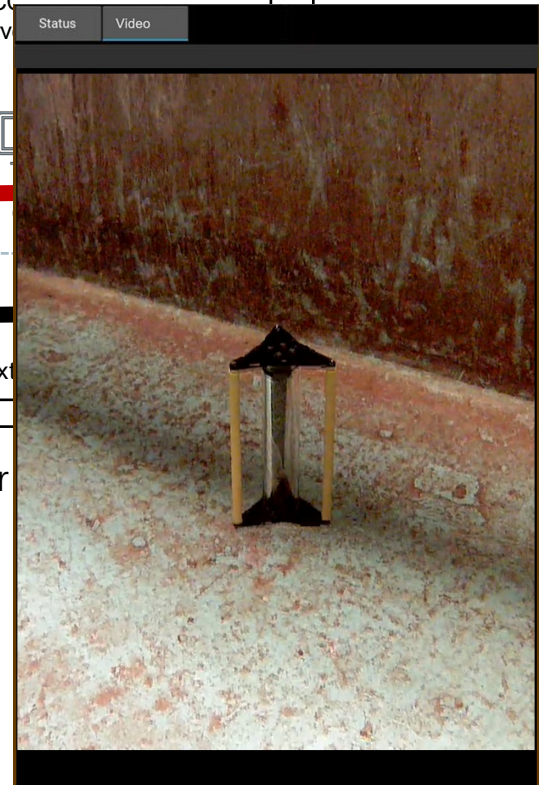
BlueROV2 (Blue Robotics) data capturing



Communication

Ⓢ Simulator

— ROV Video



Potential Use-Cases of XLab-UUV

Outlook for Future Research



Communication

- Performance analyses (latency, reliability, overhead, ...)
- Quality of Experience (QoE), e.g., for ROV control during remote operations



Security

- Threat analyses and attack modelling
- Cyber risk assessments
- Evaluation of countermeasures
 - Prevention (e.g., network segmentation or authenticated encryption)
- Intrusion Detection Systems



Navigation & Safety

- Development and testing of safety algorithms and error handling
- Failure Mode and Effects Analysis (FMEA)
- Hazard identification (HAZID)

Conclusion

Well, it's still work-in-progress

- **XLUUV-Testbed oriented at MUM**

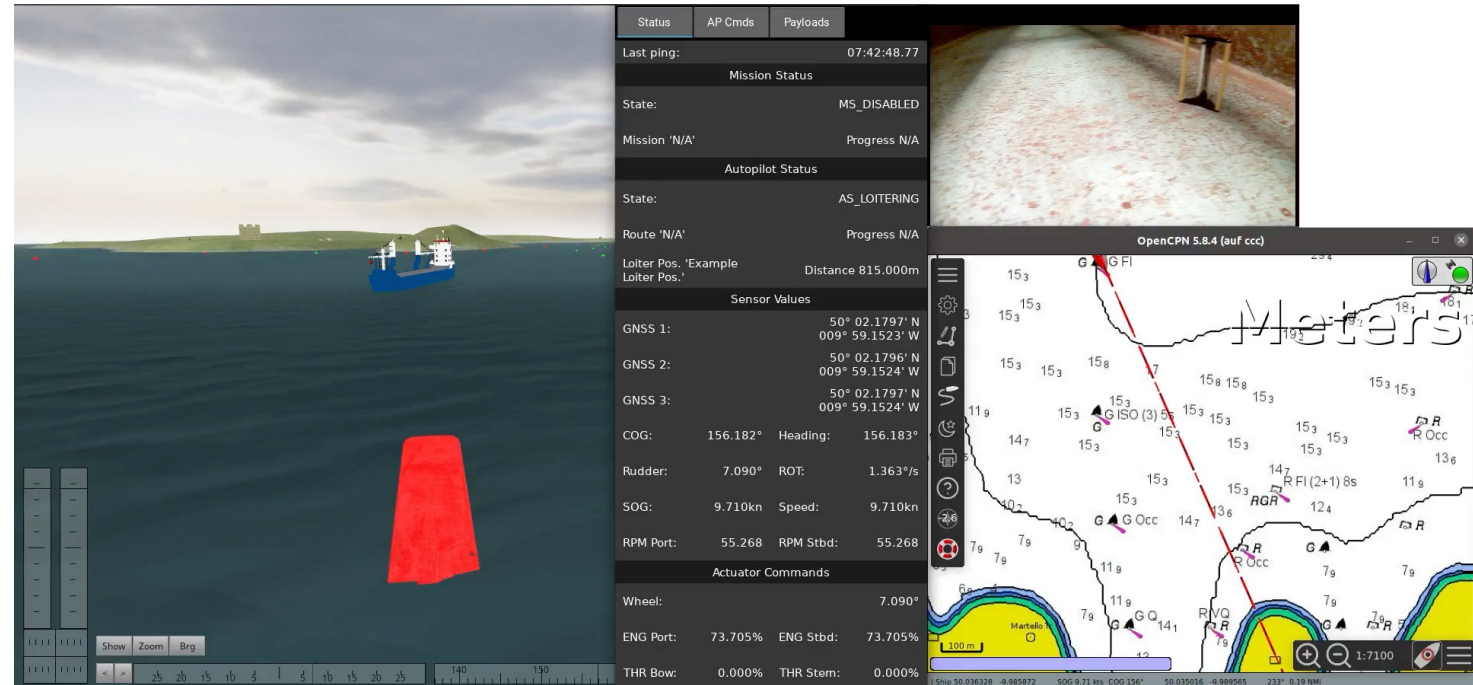
- Generic: XLUUV + RCC + Payloads

- **Emulation with real protocols**

- Credible testing and development
- Decision support for XLUUV design (final IT/OT of MUM will differ!)

- **Future Work on XLab-UUV**

- RCC multi-link (e.g., VHF, WLAN, 4G, VSAT)
- Diving mode → disruption of comm. / radar



Available soon at:
<https://github.com/fkie-cad/XLab-UUV>

Thank you!



Jan Bauer

Fraunhofer FKIE – Cyber Analysis & Defense

Research Group: Maritime Cyber Security

jan.bauer@fkie.fraunhofer.de

www.mum-project.com

Supported by:

