

Evaluation of Digital Twin Technologies for In-Situ Ballast Tank Inspection

SOUTHWEST RESEARCH INSTITUTE®

September 23, 2026
John Reyes



INTELLIGENT SYSTEMS

Southwest Research Institute's Background

From Deep Sea to Deep Space and Everything in Between



- ~3,000 employees
- ~2.3 million ft² labs/offices
- Over 1,500 patents
- 54 R&D 100 Awards
- Nonprofit 501(c)(3)
- Commercial & Government
- Broad Technological Base
- Services:
 - Advanced Science
 - Applied Research
 - Engineering Development
 - Testing & Evaluation

Benefiting government, industry and the public through innovative science and technology



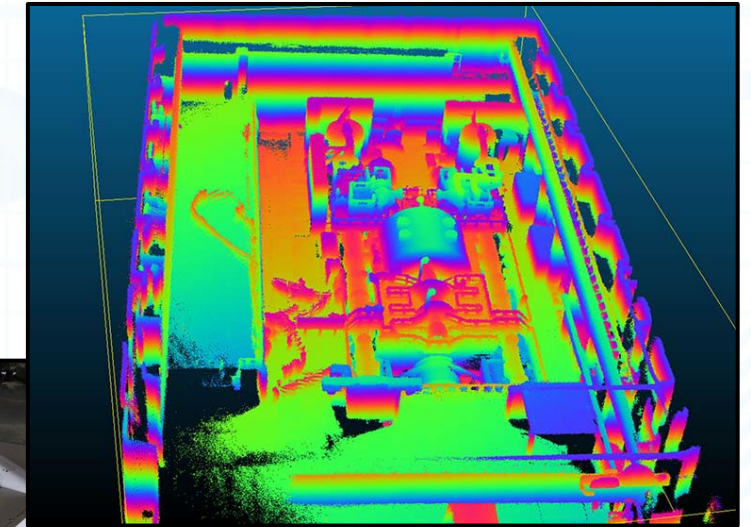
INTELLIGENT SYSTEMS

Robotics at SwRI

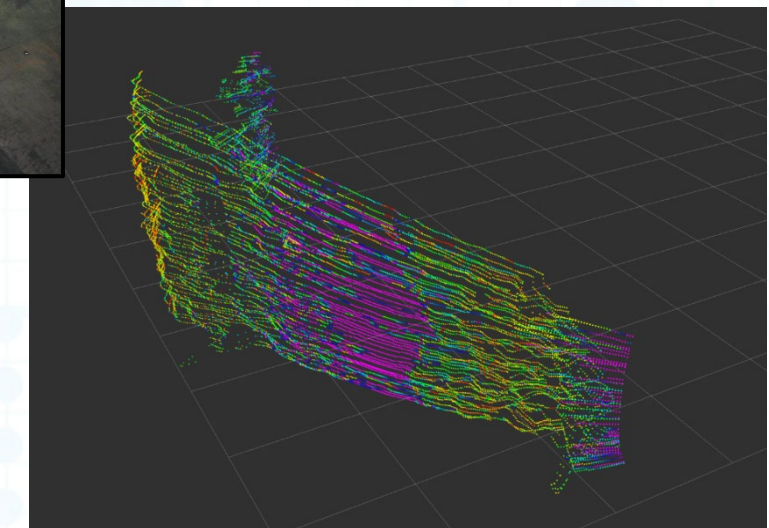
- Work across a wide range of industries to integrate first-of-its-kind automation, autonomy, and robotic systems into industry
 - Autonomous ground and aerial platforms, manipulator robotics, novel automation, AI, etc.
- Develop advanced perception systems
 - Cameras, lidar, stereo, & multispectral
- Conducted several internally-funded research projects assessing sonar and stereo cameras for generating 3D maps of underwater environments with an ROV



Laser ablation (depaint) robot used for large-scale industrial contexts



Autonomous Drone Mapping



Sonar pointcloud imaging from previous project work
INTELLIGENT SYSTEMS

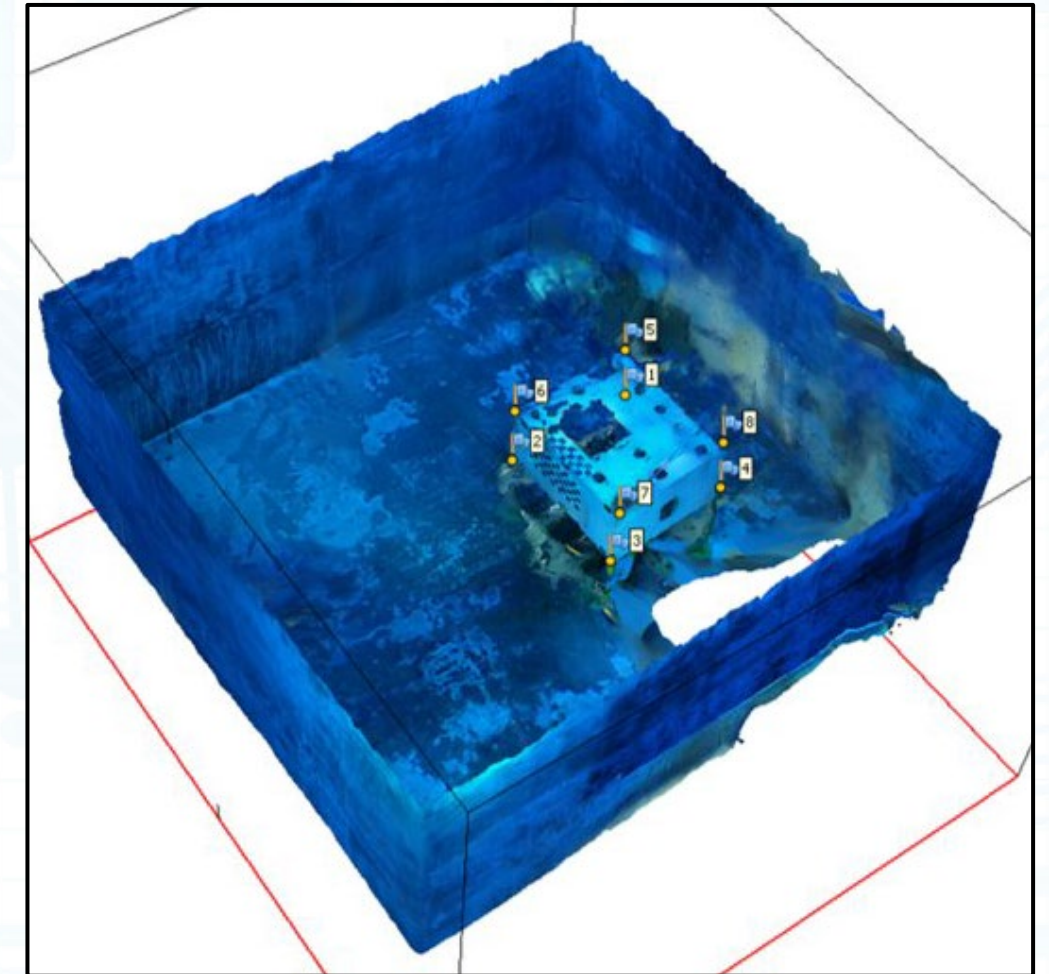
Problem Statement

Context:

- Inspection is a key component in the ship maintenance process
- Submerged structures are difficult to inspect manually
- Manual inspections are imprecise
 - Lack rigor and consistency to carry information over between inspections

Needs:

- Nimble and compact platform
- Precise reconstruction of visual information
- Safe and easy to operate



Example of SwRI-produced 3D structural inspection map created via photogrammetry

Project Goals

- Examine the viability of using current 3D mapping software and commercial-off-the-shelf (COTS) underwater inspection robots to visually inspect corrosion of ballast tanks.



Example corroded ballast tank



DeepTrekker Photon COTS
Remote Operated Vehicle (ROV)



WaterLinked 3D-15 sonar

Project Approach

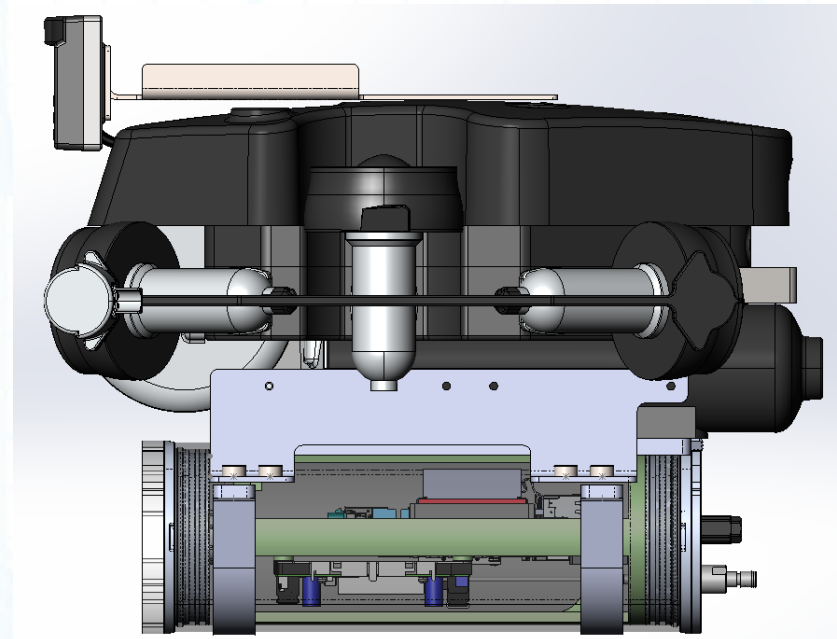
- Outfit existing ROV with new sensing technology
- Combine previously separate data inputs (sonar, camera) for more comprehensive results
 - Combining inputs accounts for the potential shortcomings of each type
- Utilize SLAM algorithms to produce high resolution maps for reference



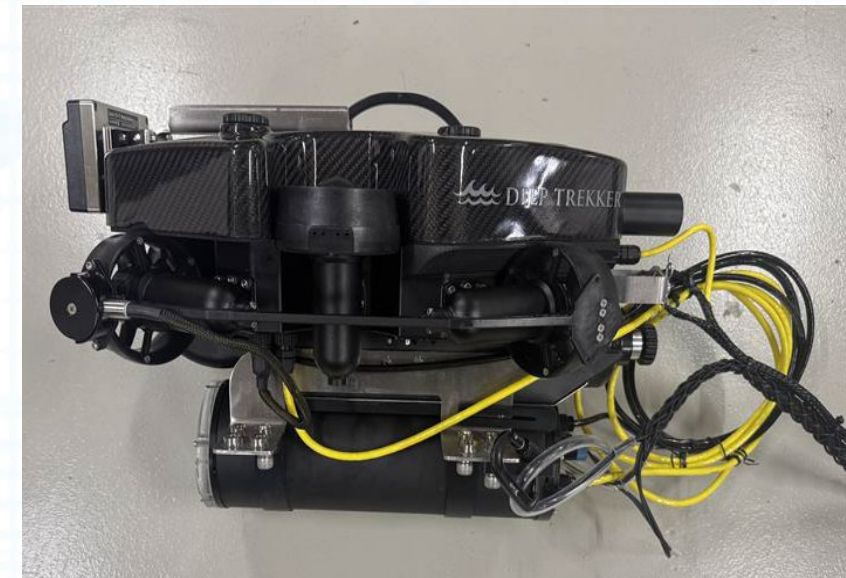
SwRI engineers test current
ROV capabilities

Platform Design

- Base Vehicle: DeepTrekker Photon ROV
- Waterlinked 3D-I5 imaging sonar
- Sensing Payload
 - Zed 2i Mini Stereo Camera
 - Nvidia Jetson Orin NX w/ 16GB Ampere GPU
 - Microstrain IMU
 - 100 m fiber tether
- Custom mounting brackets



CAD render of the ROV platform



Physical ROV platform

Platform Specifications



Operating Life: ~2 hours



Charge Time: ~2.5 hour battery charge time



Sensor Field of View: 90° (H) x 40° (V)



Weight: ~45 lbs



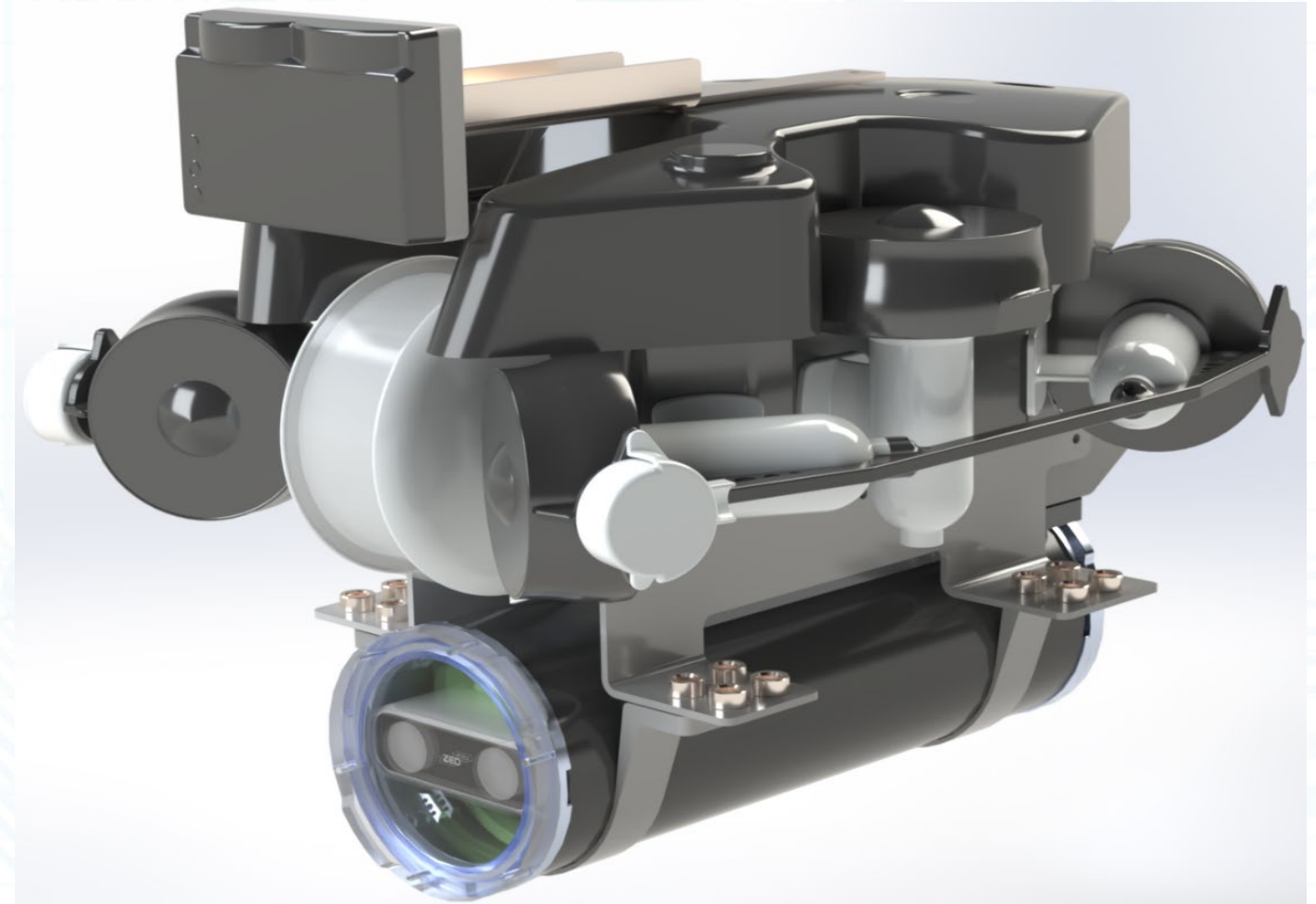
Size: 12.5" x 13.25" x18.5"



Buoyancy: Neutrally buoyant



Operating Range: ~330' tether



Initial Testing of the Platform

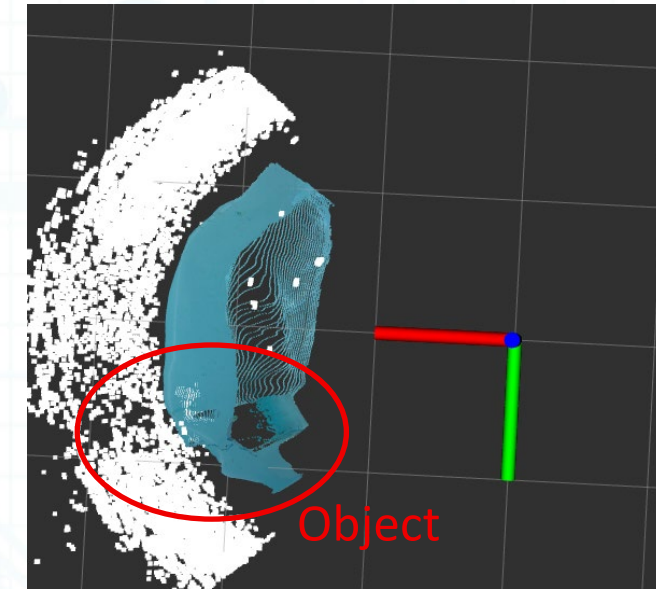
- Conducted the initial system checkout in March 2026
- Used a 12 ft diameter, 6 ft tall tank
- Served as initial platform checkout and basic data validation
- Not meant to simulate the ballast tank's conditions



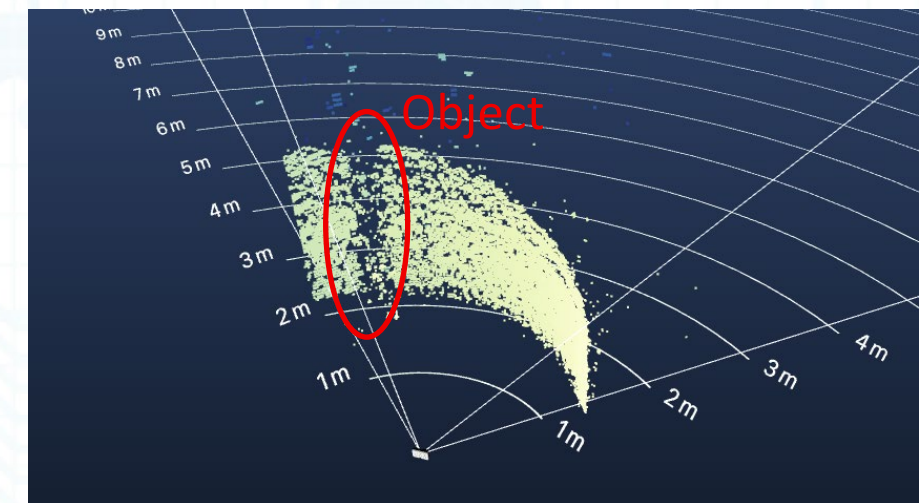
Overhead view of test tank area

Initial Results – Raw Data

- Able to see both sonar and image data in real time
- Fairly featureless tank
- Inserted a small steel object in the tank to evaluate some form of a feature



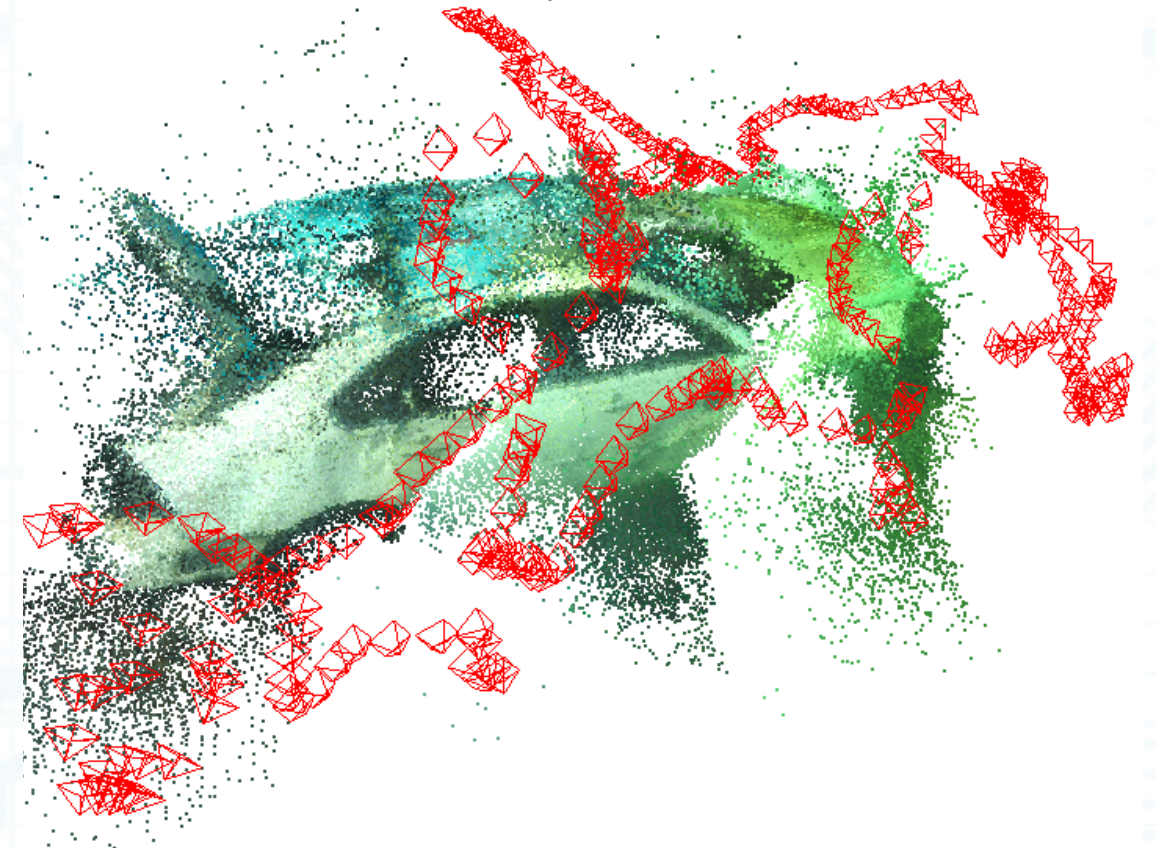
Superimposed point clouds from sonar (white) and stereo camera (blue)



Sonar pointcloud in OEM's interface

SLAM - Simultaneous Localization and Mapping

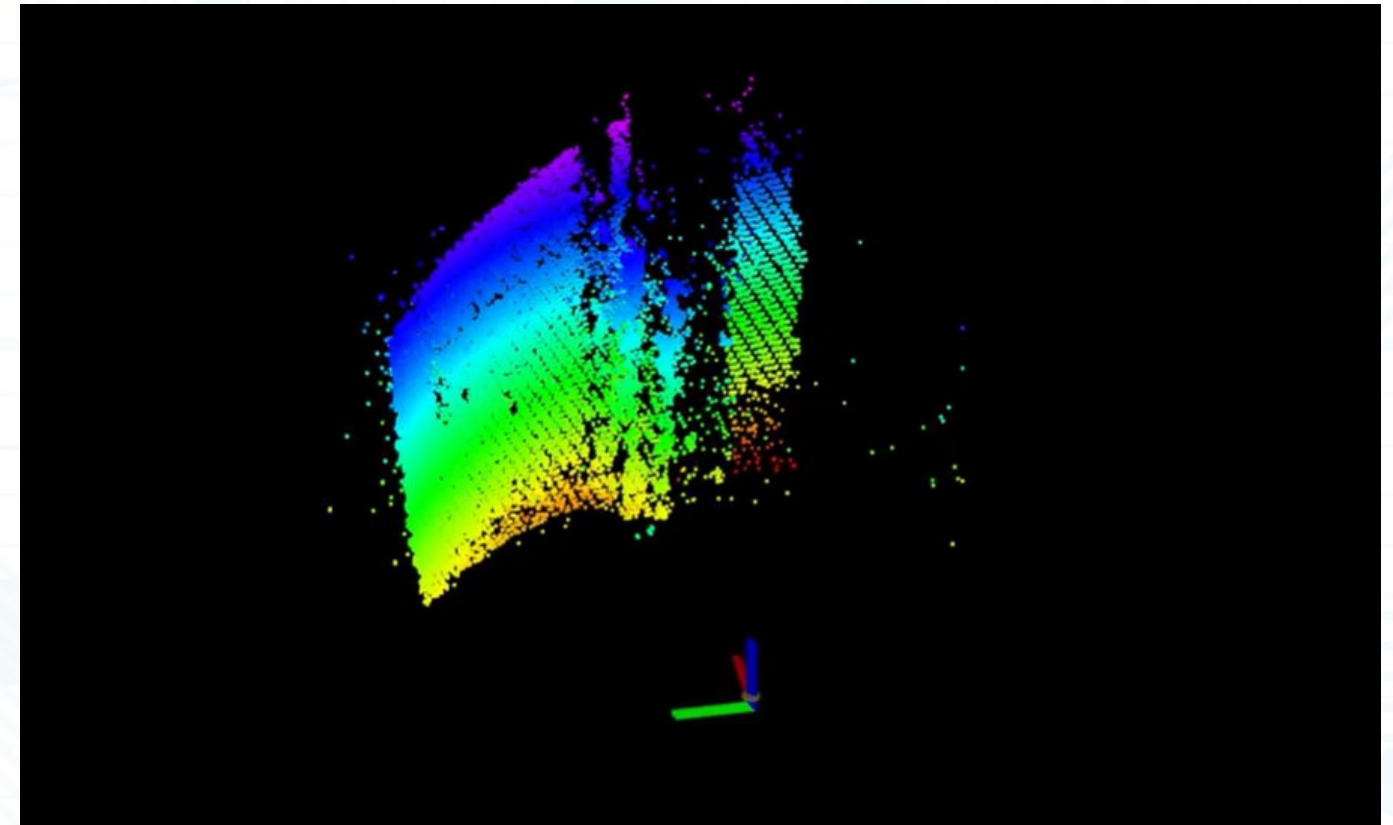
- Process of building a map of an unknown environment while also keeping track of exact vehicle position
- Mapping requires knowing where the robot is located and localization requires a map to localize
 - SLAM algorithms solve this challenge
- Evaluated two SLAM algorithms for this project



Reconstruction of an environment highlighting robot position relative to the map (red)

Preliminary Results – FastLIO2

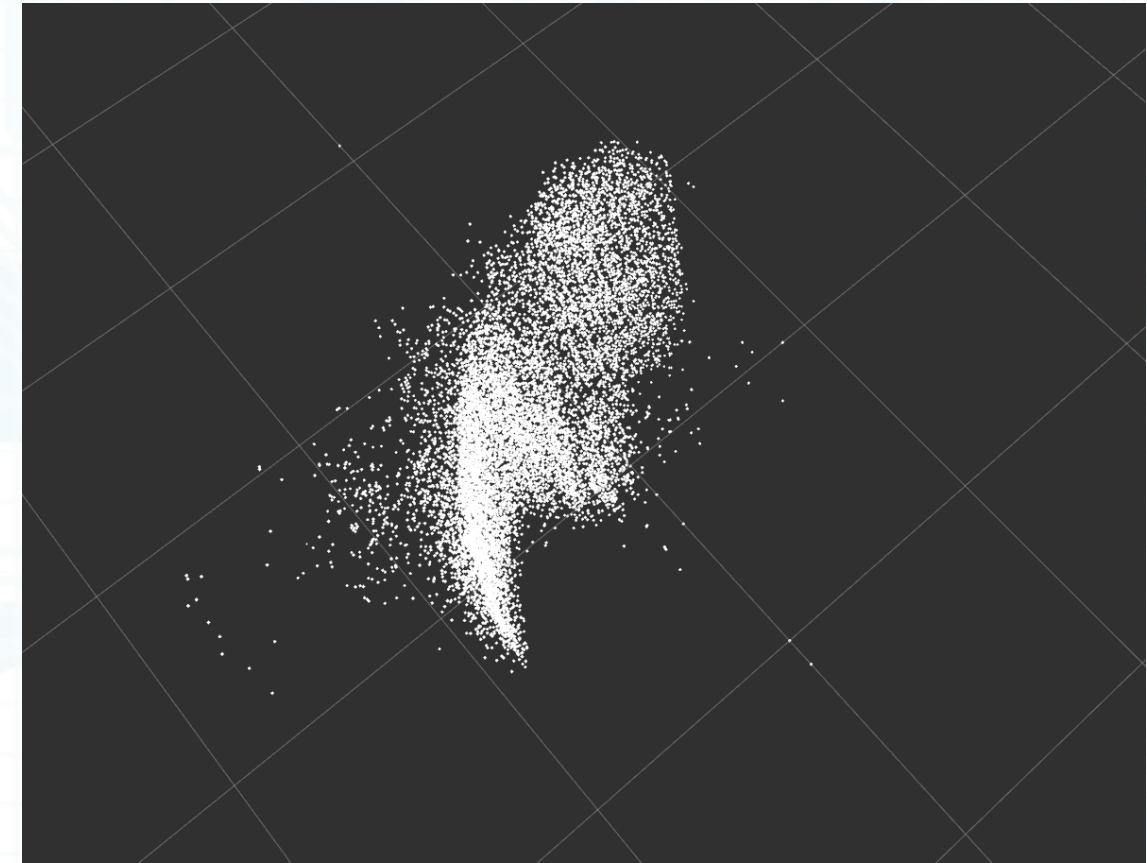
- FastLIO2 – Fast Direct lidar-Inertial Odometry
 - Pointcloud-based SLAM algorithm
- Overall strong reconstruction of wall structures
- Difficulty in feature matching with fast rotations



Fast LIO2 reconstruction from initial tests with 3D scanning sonar

Preliminary Results - GLIM

- GLIM – Direct multi-scan registration method
 - Pointcloud-based SLAM algorithm
- SwRI has found success with this method in ground robotics
- Found overall worse performance than FastLIO2
 - Higher level of noise
 - Sparser mapping of solid features



GLIM LIO2 reconstruction from initial tests with 3D scanning sonar

Preliminary Conclusions

Algorithmic improvement suggestions:

- Intelligent filtering for noise and “multipath” errors
 - Addresses bouncing returns that are expected in confined spaces
- Adjust feature extraction to target sparse, enclosed environments
- Add camera data to supplement sonar-based mapping
 - Currently looking into suggested approaches for this
- Data collection in accurate tank environments
 - Evaluates closer approximation to use-cases and higher feature density

Project Challenges

- Material Delays – Sonar
 - 3-month delivery delay
 - Final platform standup completed in January 2026
 - 3 months behind schedule
- Shipyard visits and demonstrations
 - No data collection completed with a mockup tank due to CUI/contractual challenges

Short Term Development Goals

Planning a follow-up panel project to address the following tasks:

- Conduct additional data collections within the ballast tank environment
- Further tuning of 3D SLAM algorithms once more data has been collected
- Implement at least one more method of map generation for more robust reconstruction
 - Will incorporate color data from the stereo image
 - Currently investigating FAST LIVO – lidar Inertial Visual Odometry
- Improve usability and inspection workflow to ease user adoption and training

Long-Term Future Development Goals

- Integrate SLAM processing and map generation into RealTime operation
- Add autonomous routing and station keeping protocols for larger scale structural exploration
- Integrate swarming and multi-platform capabilities
 - Improves potential inspection speed
- Incorporate maintenance tooling into inspection platform
 - Enables immediate ability to address discovered anomalies

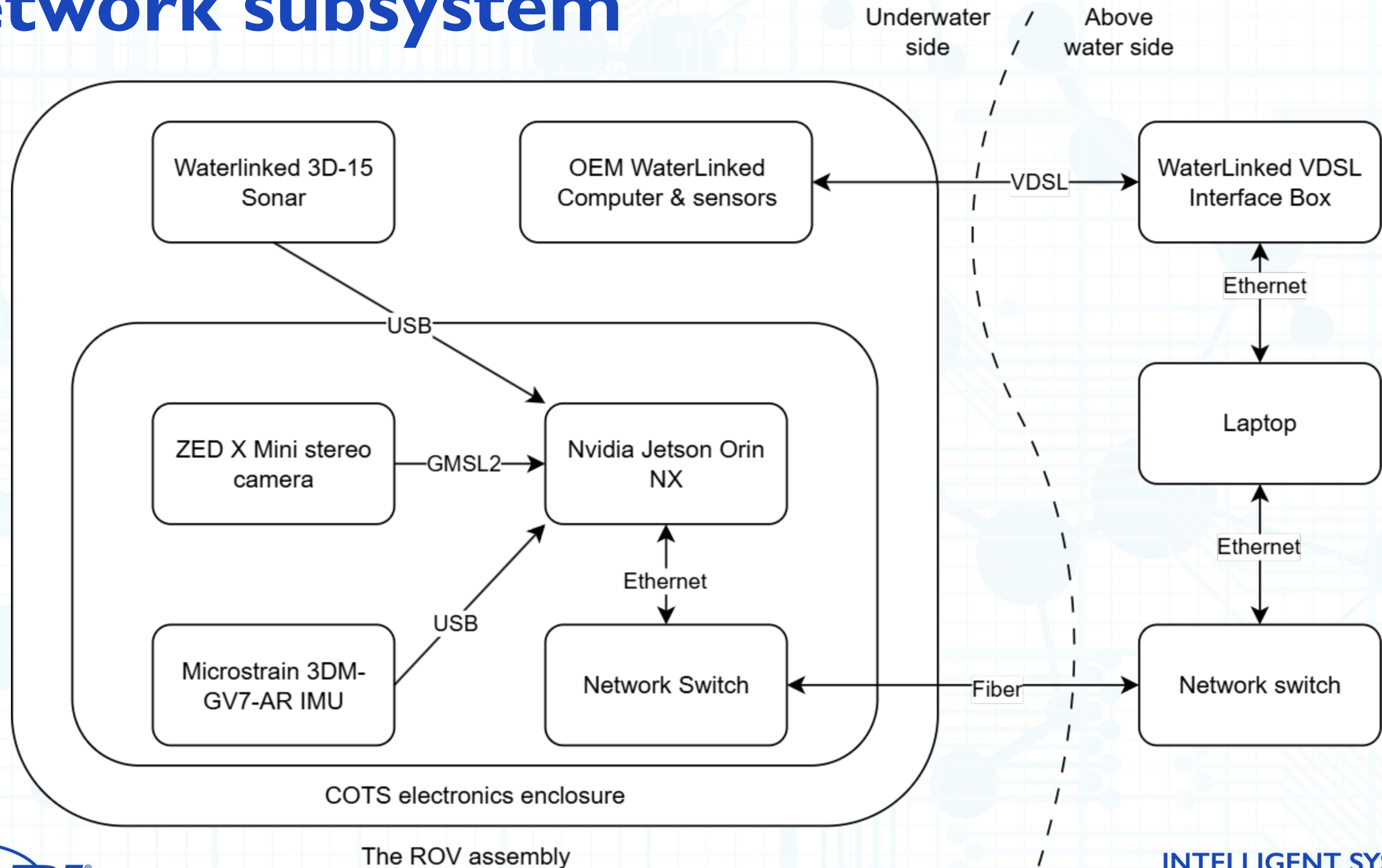


Deployment of SwRI ROV in test tank

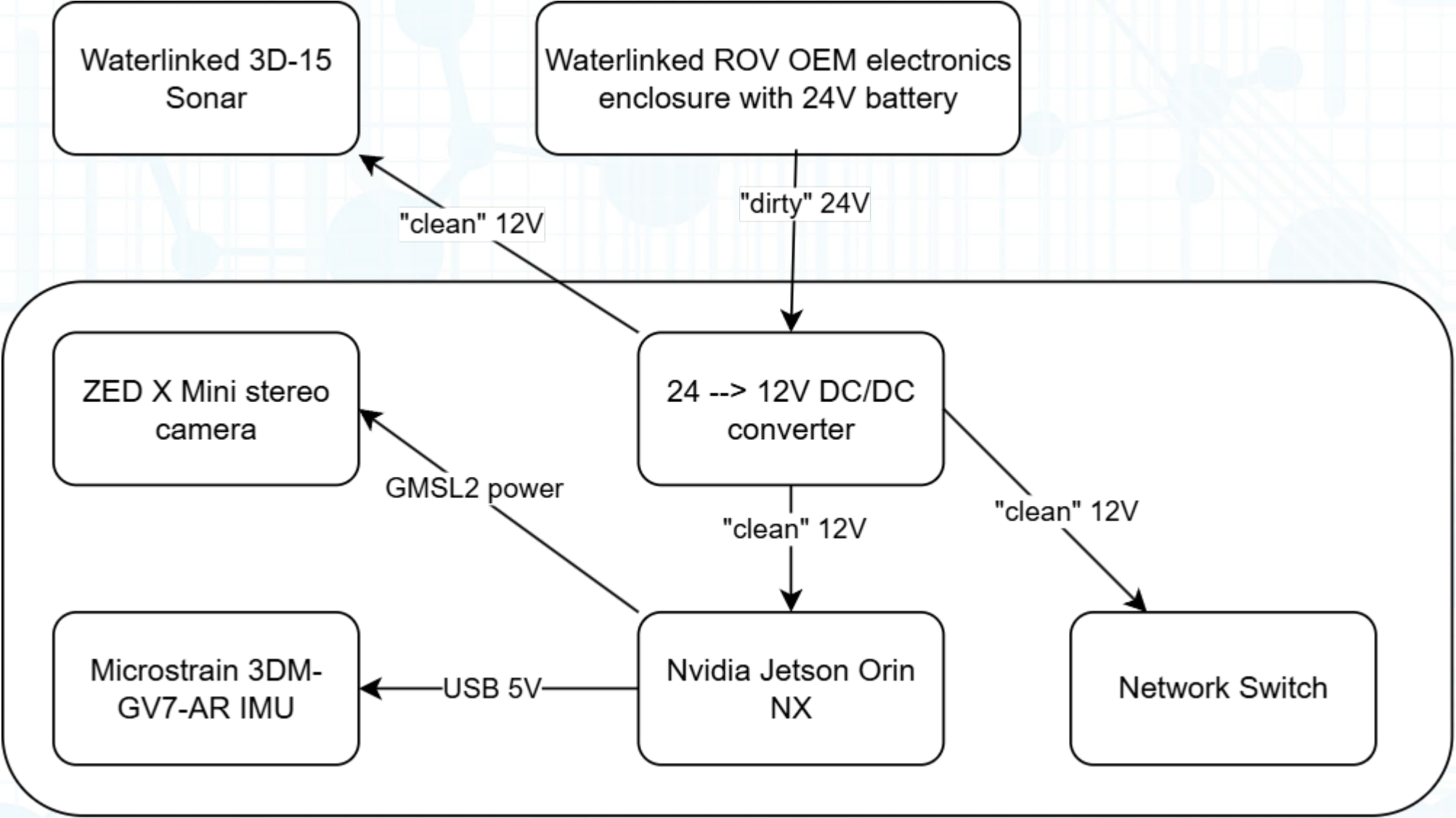
Questions?

Appendix – Technical Details

Network subsystem



Power Subsystem



Power consumption	Item
10-40 W configurable	Computer
0.3 W	IMU
1.5 W	Camera
20 W	Sonar
4.5 W	Network Switch
36.3-66.3 W	Subtotal
8%	Power supply
39.5-72 W	Total