Constructing Communication-Constrained Underwater Multi-Robot SLAM Datasets from an Ensemble of Single-Robot Data

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Introduction

Robots, to successfully coordinate, must know the states of their team members in addition to themselves. Therefore, it is of great interest to develop robust algorithms for multi-robot SLAM that address the communication constraints of the underwater environment. To support this endeavor, we have developed a methodology for generating multi-robot SLAM datasets from data collected with a single robot.

Hardware

We use a customized BlueROV2-Heavy. The vehicle has been outfitted with a custom sensor payload. Sensors include:

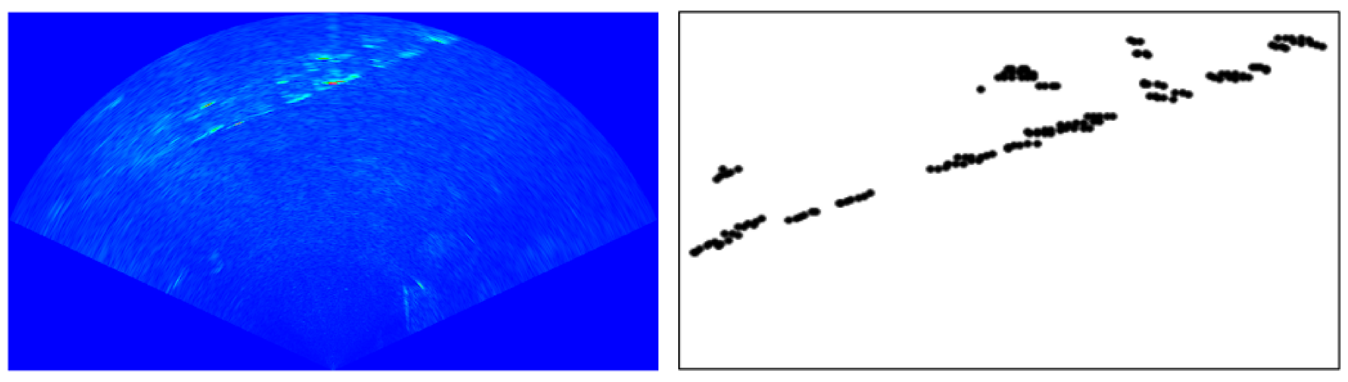
- Blueprint Subsea Oculus M750d sonar
- KVH DSP-1760 Fiber Optic Gyro (FOG)
- VectorNav VN100 inertial measurement unit (IMU)
- Rowe SeaPilot Doppler velocity log (DVL)
- Bar30 pressure sensor

Figure 1: Field setup for data-gathering with our BlueROV2-Heavy

Sonar Examples

Given bandwidth limitations, we may only be able to send raw perceptual data to team members at some time steps. Acoustic modems often operate on the order of 5,400-100,000 **bits**/second. Below are perceptual data transmission costs:

- Sonar image (512 x 464): 1,900,544 bits
- Average point cloud: 9,140 bits
- Scene descriptor: 128 bits



(a) Raw sonar image **(b)** Point cloud from (a)

Figure 2: Example perceptual data

Code, Data and Acknowledgements

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System Architecture

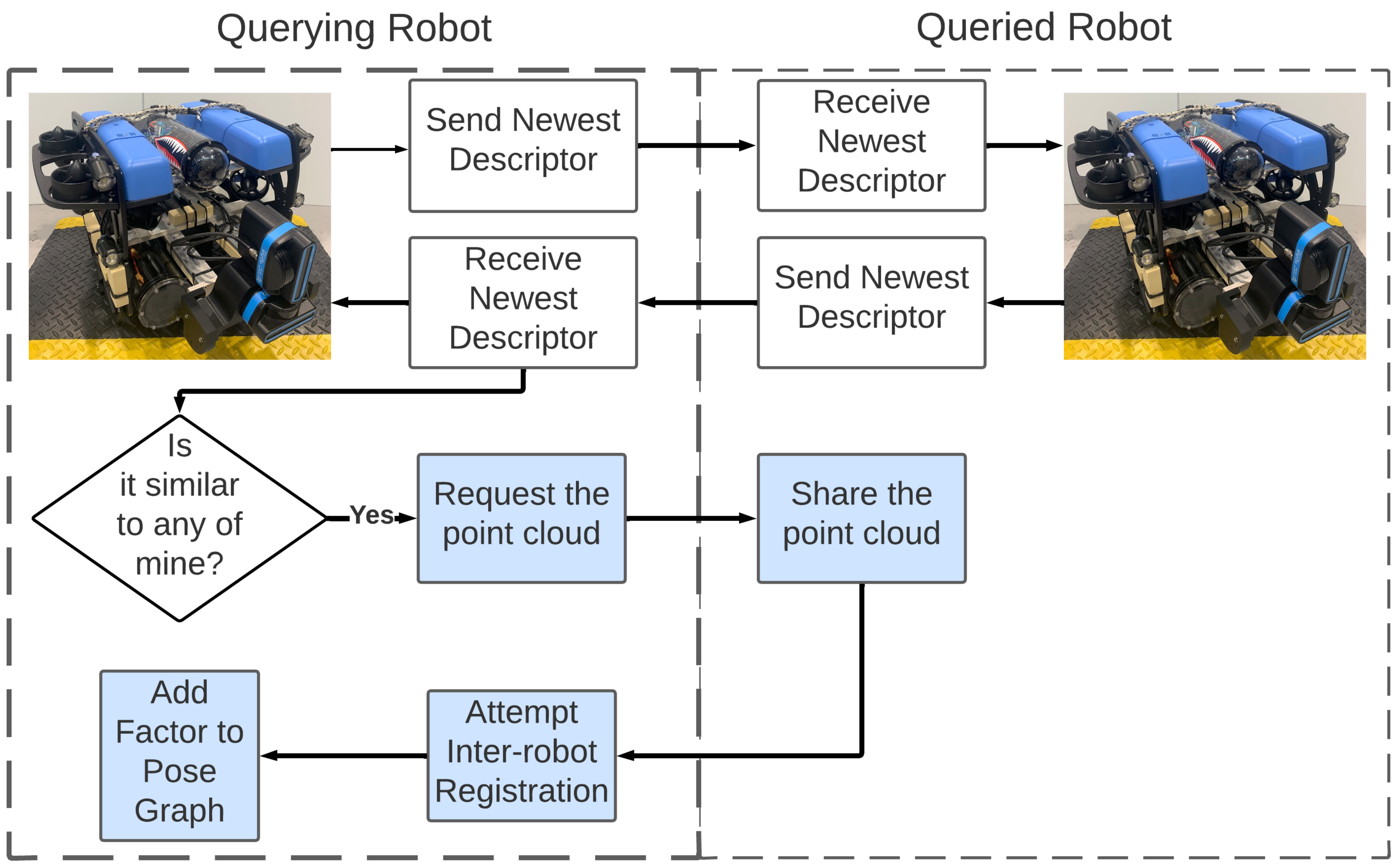


Figure 3: System architecture for information exchange between a pair of robots (derived from data collected with a single robot). The steps highlighted in white occur with a fixed time-step, while the steps in blue only occur when a robot decides to request a point cloud from another robot. Our system can handle any number of robots - descriptors are broadcast to all robots within communication range.

Our system works by taking the following steps:

- Each (simulated) robot shares low-cost scene descriptors at each time step
- Robots compare scene descriptors; only if they are similar do we exchange raw sensor data
- Optionally, we compress the raw sensor data using a voxel-based compression
- Once sensor data is exchanged, we attempt registration
- Loop closures not rejected are added to the factor graph and shared with the team
- Our system supports N robots, with experiments showing **two and three robot cases**

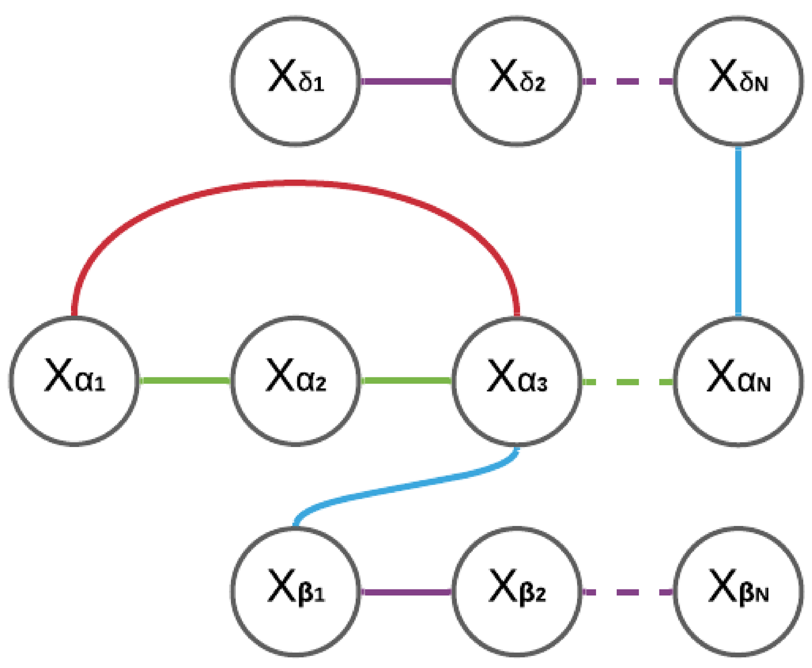
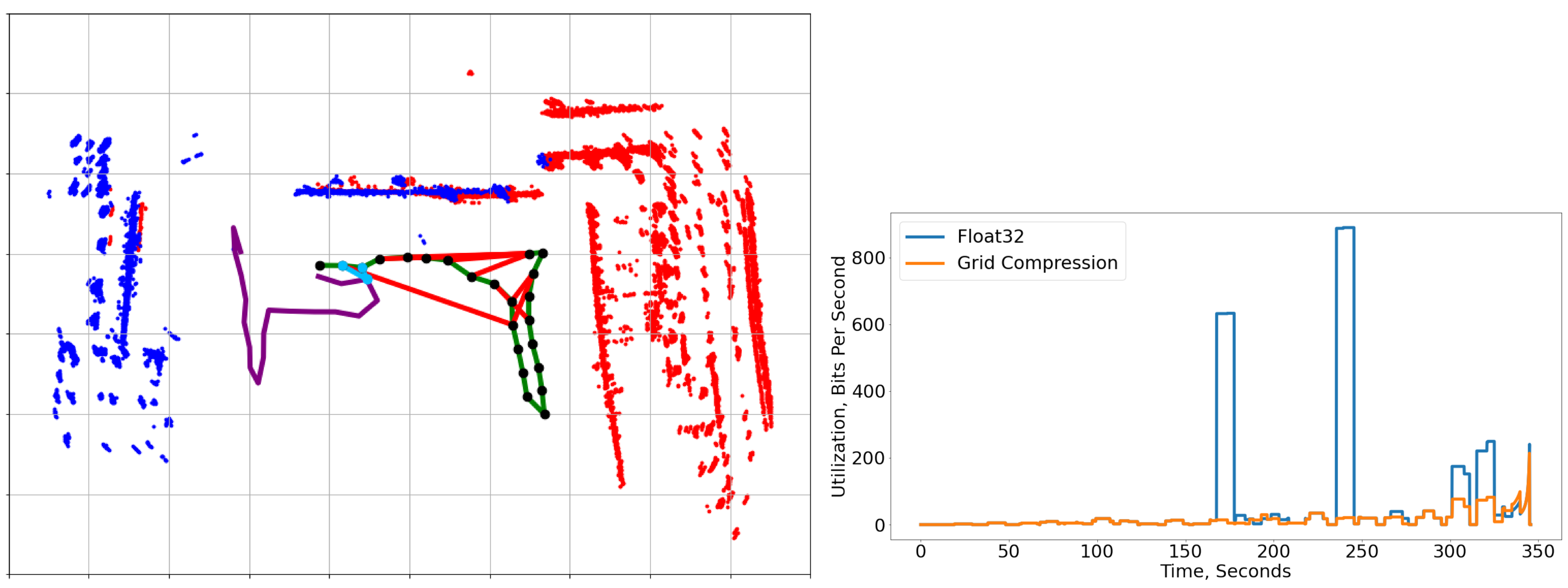


Figure 4: SLAM Factor Graph. Robot poses $\mathbf{x}$ for three robots, α, β, δ are considered with several factors: sequential scan matching factors (SSM) in green, non-sequential scan matching factors (NSSM, intra-robot loop closures) shown in red, inter-robot (IR) loop closures in blue and partner robot (PR) factors in purple.

Results



(a) Example two robot mission **(b)** Bandwidth usage during the mission

Figure 5: (a) shows an example multi-robot SLAM run from the environment in Figure 1, from the perspective of one robot. This robot's poses are shown as black dots connected by the factors in Figure 4. This robot's map is shown in red with blue points merged from the other robot in the mission. (b) shows the time history of bandwidth usage during this mission, with the proposed framework shown in orange.