MARINE & MARITIME INTELLIGENT ROBOTICS

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Sensor Fusion for Robust Underwater Navigation: A Monocular Camera-based SLAM System with ORB-SLAM3

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Context and motivation

Unexplored Depths
95% of the Earth's oceans remain unexplored, largely due to the immense challenges of underwater navigation:

- Environmental Challenges: Traditional sensors struggle with limited visibility, harsh currents, and varying underwater terrain.
- GPS Reliance: The absence of readily available GPS underwater significantly hinders navigation accuracy and ease of use.
- Localization Drift: Traditional methods accumulate errors over extended operation times, compromising precision.

SLAM: A Promising Approach
Simultaneous Localization and Mapping (SLAM) is a cost-effective and efficient solution for creating underwater maps while simultaneously determining vehicle location. The sensors used for this purpose can be divided into two mean areas:

- **Acoustic Sensors** have been the dominant approach for over 30 years, they perform well in low-light conditions but can generate data with limited resolution and potential inaccuracies.
- **Visual Sensors** provide high-resolution detail but are susceptible to poor lighting and reduced visibility in turbid water.

Sensor Fusion: Unlocking Potential
By strategically combining data from multiple sensors, a more robust and accurate SLAM system can be developed.

State-of-the-art

Acoustic-based SLAM[1]

- Extended Kalman Filters (EKF): A classic and reliable method, but can struggle in highly dynamic environments.
- Particle Filters (FastSLAM): More robust to non-linearities but can be computationally expensive.
- GraphSLAM: Efficiently handles non-linear environments using seamark information from Side-Scan Sonar (SSS), but may struggle with sparse features.

Visual-based SLAM[2]

- ORB-SLAM: A popular solution using keypoint features, but performance degrades significantly in low-light conditions.

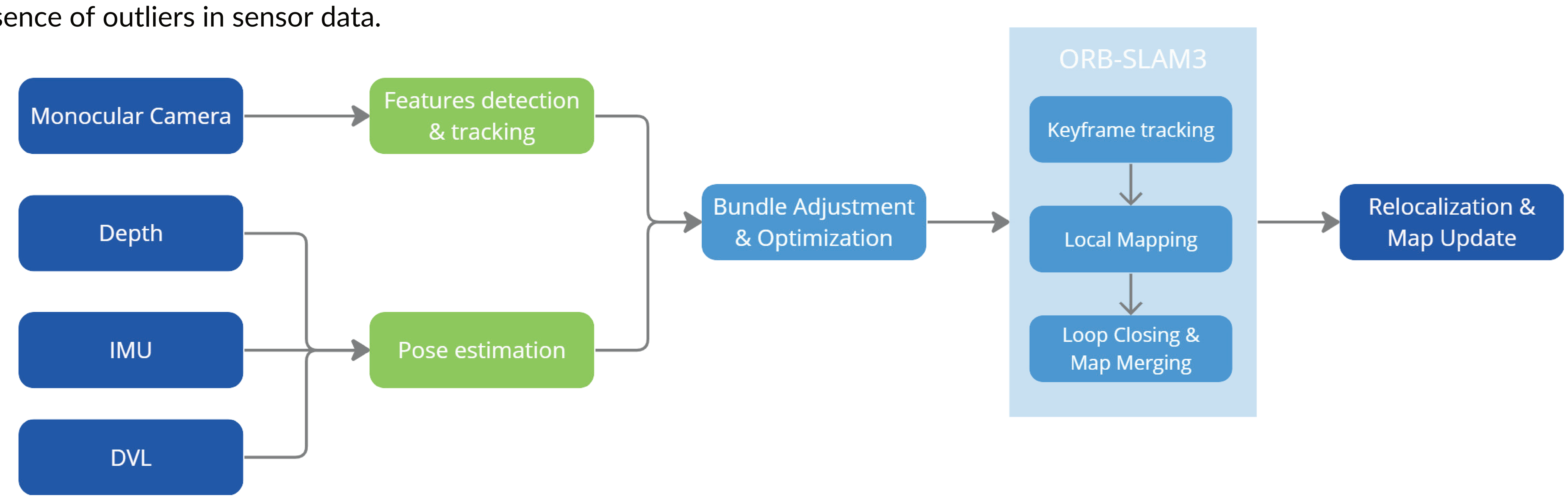
Combined Sensor SLAM

- SVIN[3]: Uses sensor fusion by combining visual sensors, IMU, depth meters, and sonar. It utilizes a bag-of-words (BoW) library for loop-closure detection and relocalization, significantly improving system performance.
- Vargas et Al.[4] extended ORB-SLAM2 using motion priors calculated via acoustic odometry by fusing data from a DVL, a gyroscope and an altimeter/depth sensor.

Contribution

Building upon the work of Vargas et al. (2023) which utilizes ORB-SLAM2 with a stereo camera setup, this research proposes a novel underwater SLAM system with the following key contributions:

- **Cost-Effective Monocular Camera Configuration** Replacing the stereo camera with a monocular camera, significantly reducing system cost and promoting wider accessibility.
- **Pioneering ORB-SLAM3 Implementation** This research aims to be among the first to implement the state-of-the-art ORB-SLAM3 framework for underwater SLAM. This integration unlocks the benefits of multi-map functionality, enabling navigation in larger and more intricate underwater environments.
- **Sensor Fusion with Acoustic Odometry** Incorporating sensor fusion with acoustic odometry.
- **Comprehensive Performance Evaluation** The proposed system will undergo rigorous evaluation in increasingly complex underwater environments. This evaluation will include:
  - Comparison to Existing Methods: The system's performance will be compared against established ORB-SLAM methods and benchmarks.
  - Robustness Analysis: We will analyze the system's behaviour under challenging scenarios, such as the absence of DVL bottom lock or the presence of outliers in sensor data.



Integration of ORB-SLAM3 with acoustic odometry.

References

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