# Senses for Submarines: Concepts for Optical- and Acoustic-Based Odometry and SLAM for Underwater Navigation

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**SUMMARY**

Autonomous underwater vehicles (AUV) offer a great potential for hydrography and exploration of the deep sea. In the CIAM research project (Comprehensive integrated and fully autonomous subsea monitoring), funded by the German Ministry of Economy, various AUVs are developed to monitor critical infrastructure, especially pipelines, in the deep sea. They are equipped with a variety of acoustic, electromagnetic, and optical sensors recording the condition of the pipeline and thus make damage and leaks detectable. The autonomous deployment allows for savings in personnel, an improved data basis, and a reduction in costs. Applying a port-to-port concept, further costs can be saved by following the pipeline and omitting the mothership. Conventionally, the navigation of AUVs has been based on inertial navigation. To ensure the reliability it can be coupled with updates from a surface mothership via an Ultashort Base Length modem (USBL) or an array of installed underwater antennas that provide extrinsic pose estimation via Long Base Length (LBL). This methodology can be considered expensive and not robust due to the high value inertial sensor technology and the challenging and error-prone acoustic communication technique. To address this issue the objective of this paper is developing an improved navigation concept with extrinsic sensors to ensure the collected data to be geo-referenced and a robust control of the AUV. For monitoring the pipelines, the versatile sensors are used to generate 3D models of the pipeline. In addition to the actual data evaluation and damage recognition in postprocessing, the methods for mapping the environment are also applicable for odometry, SLAM-based navigation and mission planning control. Hence, in the context of this paper, alternative concepts for navigation solutions are elaborated that use the detection of features in the AUVs operational environment to ensure simultaneous localisation and mapping. For this purpose, methods of environment representation are used by evaluating sensor data via artificial intelligence, machine learning and deterministic analysis to detect features. The use of a Madgwick filter offers promising results, if the course change of the pipeline determined by the forward-looking sonar is integrated as control input.

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Possibly, this algorithmic improvement facilitates the replacement of the common and high-quality FOG inertial systems with low-cost MEMS inertial systems. However, the real-time fusion of the sensor data into a feature map, apart from the high computational cost for the embedded computers, offers the potential for a robust navigation estimation that enables safe navigation of the AUV during autonomous tracking of the pipelines.