Oceanographic observatories, year-round energy industry subsea field inspections and continuous homeland security coast patrolling now all require the routine and permanent presence of underwater sensing tools.

These applications require underwater networks of fixed sensors that collaborate with fleets of autonomous underwater vehicles and gliders. Technological challenges related to the underwater domain, such as power source limitations, communication and perception noise, navigation uncertainties and lack of user delegation, are limiting their current development and establishment. In order to overcome these problems, more evolved embedded tools are needed that can raise the platform’s autonomy levels while maintaining the trust of the operator.

Embedded decision-making agents that contain reasoning and planning algorithms can optimize the long-term management of heterogeneous assets and provide fast, dynamic response to events by autonomously coupling global mission requirements and resource capabilities in real time. The problem, however, is that at present, applications are mono-domain; Mission targets are simply mono-platform, and missions are generally static. Pre-composed lists of commands described a priori by the operator. All this, therefore, leaves the platforms in isolation and limits the potential of multiple coordinated actions between adaptive collaborative agents.

In a standard workflow, operators describe the mission to each specific platform, data are collected during the mission and they are then post-processed off-line. Consequently, the current main use for underwater platforms is to gather information from sensor data on missions that are static and incapable of coping with long-term environmental changes or resource changes.

In order for embedded service agents to make decisions and cooperate, it is necessary that they have the capability of dealing with and understanding the highly dynamic and complex environments where these networks are going to operate. These decision-making tools are constrained to the quantity and scope of the available information.

Shared knowledge representation between embedded service-oriented agents is therefore necessary to provide the networks with the required common situation awareness. Two sources can provide this type of information: the domain knowledge extracted from the expert (orientation) and the retrieved knowledge from the processed sensor data (observation). In both cases, it is necessary for the information to be stored, accessed and shared efficiently by the collaborative agents while performing a mission. These agents, providing different capabilities and working in collaboration, might even be distributed among the different platforms or have some limited resources.

Semantic frameworks, such as the one being developed at the Ocean Systems Laboratory, have recently raised interest by providing a solution for hierarchical distributed representation of shared knowledge for multi-disciplinary agents interaction. These frameworks use a pool of hierarchically structured ontologies to represent the extracted knowledge and processed sensor data. They provide a common machine-understanding representation between embedded agents that is generic and extensible. They also include a reasoning interface for inferring new knowledge from the observed data and guarantee knowledge scalability by checking for inconsistencies.

These frameworks improve local (machine level) and global (system level) situational awareness at all levels of service capabilities, from adaptive mission planning and autonomous target recognition to deliberative collision avoidance and escape.

They act as enablers for autonomy and onboard decision making.

There are currently several institutions and consortia developing standards that extend the knowledge scope under these frameworks. Based on their capabilities, service-oriented agents can gain access to the different levels of information and contribute to the enrichment of the knowledge. If the required information is unavailable, these frameworks provide a facility for requesting that information be generated by other agents with the necessary capabilities.

Once the knowledge is available, autonomous adaptation algorithms can release the operator from decision-making tasks. These, in consequence, require less communication with the operator and, therefore, save power.

Adaptation plays an important role in providing long-term autonomy. The aim is to be effective and efficient, but a plan takes time to prepare. Once the initial plan has been made, it might be more efficient to try to reuse previous efforts by making repairs when changes occur. Also, commitments might have been made to the current plan. Adapting by repairing an existing plan ensures that as few commitments as possible are invalidated. Adaptive incremental search methods for trajectory planning and adaptive mission plan repair algorithms have been found to maintain stability with the original plans while maximizing time response. Finally, several planners (usually autonomous and human planners combined) could perform together to achieve the mission goals. In such cases, it is more likely that a similar plan will be accepted and trusted by the operator than one that is potentially completely different.

In the short term, we will see how decision-making algorithms and shared knowledge representation are able to provide the required interoperability between embedded service-oriented agents to achieve high-level mission goals, deflect the operator from routine mission decision making and, ultimately, enable the permanent presence of underwater dynamic sensing networks.

Pedro Fabrín is a research associate at the Ocean Systems Laboratory at Heriot-Watt University and a senior engineer at SeaByte Ltd.