A semantic layer to improve AUV autonomy

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I. Introduction

We present an ontology-based architecture intended to improve autonomy and cognitive capabilities of marine robotics systems. With the increase of marine operations, also signalled by the growth of the so-called *blue economy*, reliable and robust marine systems are becoming more and more needed. A robotics system that can store and reason with world information is a key enabler to accomplish complex missions in long-term autonomy. This abstract outlines a proposed AUV architecture, based on the central role of the knowledge base and its relations with the other vehicle subsystems. A discussion of the experimental in-water trials will highlight the current level of integration and the are still under development.

II. The role of the knowledge base

This section gives an overview of the central role of the knowledge base, which functions not only as repository for world information, but actively links other subsystems together. Figure 1 shows these connections. Three subsystems are highlighted for clarity of presentation:

- subsystem A: external knowledge
- subsystem B: internal knowledge
- subsystem C: planner interaction

The *subsystem A* deals with representing the external world, and handles the full flow from signal to symbol. The subsystem consists of sensors, which output data into an ATR System (Autonomous Target Recognition), which interacts with the knowledge base to add new instances and update the uncertainty. However, the knowledge base is not only receiving data, but can be used to actively insert new waypoints, linked to the inserted instances. The semantic analysis associated to sensor measurements can help to trigger a new *smart* inspection in order to reduce the ambiguity and correctly classify the object. Instead of considering the classification problem as passively processing sensor data, this allows to intervene in the vehicle planning and control, aiming at a more accurate result.

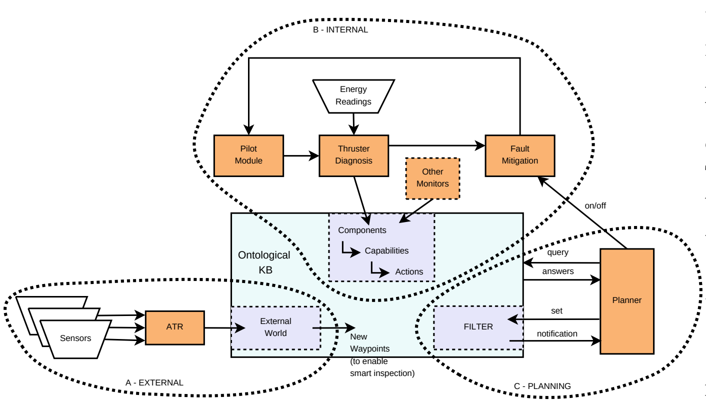

Fig. 1. The role of the knowledge base in the vehicle's architecture, and its relations with other components of the vehicle.

The *subsystem B* deals with the internal knowledge of the vehicle. For the knowledge base, this is represented mainly by the relation *components* $\rightarrow$ *capabilities* $\rightarrow$ *actions*. Each possible action of the vehicle can be performed only in presence of predefined capabilities. Those capabilities are dependent on the availability of specific components. The fault management subsystem, implemented for the case of a thruster failure, interacts with the knowledge base to signal specific components which are out of order. The system can be easily generalised and extended for other components.

The *subsystem C* encompasses the planning system. The knowledge base is an essential tool for the planning system as a way to represent symbolic information that can be used by a planner. Under this subsystem there are all the usual communications with the planning system querying the ontology to get information about the world, in order to be able to plan, and the ontology replying to the queries of the planner. However, the proposed system also deals with the necessity to replan when the world changes and invalidates the current plan. This is done through a structure in the knowledge base, named *Filter*, which *filters* the operations happening in the knowledge base and sends notification to the planner system only if any operation is considered *of interest* for the planning system. The planning system therefore interacts with the knowledge base to set / clear the filter, and receives notifications from the knowledge base about its topics of interest. The planner system can fetch the waypoints generated in the *subsystem A* with this structure.

This has briefly shown a high-level overview of the central role of the knowledge base in the system and its important role not only as a storage of information, but also to actively link different aspects of the overall system, increasing therefore the level of autonomy of the robot.

III. Preliminary Results

The knowledge framework has been integrated in the *Nessie VIII* AUV of the Ocean Systems Laboratory, in the framework of the Pandora project [2]. This section shows tank trials where the knowledge framework plays a central role in all three subsystems described.

The mission to be completed is to inspect an area of interest and, in case a pillar is recognised, the vehicle would perform a helix inspection. Initial waypoints are given to the vehicle. The role of the knowledge base is:

- to store information acquired by the environment
- to suggest new waypoints to properly classify a potential object
- to get updates by the diagnostic system about vehicle's capabilities
- to communicate with the planning system about the world information, to instantiate the problem, about the new items discovered in the environment and about vehicle capabilities.

Figure 2 shows the trajectory of the vehicle, visualised through RViz. The data comes from the navigation module of the vehicle, which integrates DVL measurements with gyroscope, compass and depth measurements. Given the dimensions of the OSL wave tank, a pillar has been simulated with a cylindrical pipe, with two pipes and one buoy in the environment.

The initial knowledge of the vehicle was only represented by three points of interest, and the goal was set to inspect all pipes.

When the vehicle arrives to inspect the first point (Figure 2 left), the interaction with the knowledge base states that a possible pillar is detected, but a new observation is needed from a different viewpoint and depth. Therefore the vehicle moves to the newly generated waypoint. The ATR module, together with interaction with the knowledge base and domain-specific rules, is able to detect that it is a pillar and therefore the planner launches the inspection action.

Same decision making to inspect the second point (Figure 2 center): after detecting a potential pillar, a new waypoint is actively issued to confirm the classification. In this case, however, a pillar is not recognised and the object is therefore ignored.

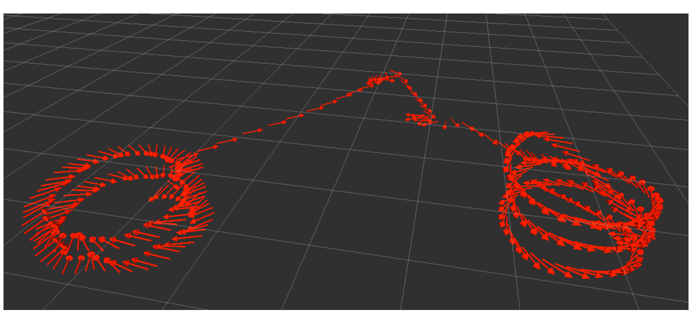

Fig. 2. The full path of the robot *Nessie* in RViz, the ROS visualisation system. Each square of the grid is 1m long. The recorded path starts on the left, when the robot perform an inspect of the pillar, then moves to inspect a second location, finding out that it was not of interest, to finally arrive to the third location, recognise a pillar and perform an inspection. Note that the last inspection follows a different path, due to a fault injected in the system on a lateral thruster.

Then, the vehicle moves to inspect its final point (Figure 2 right). At this moment, a fault is (manually) injected during the transit to significantly reduce the functionality of one of the lateral thrusters. The vehicle diagnostic system, as explained in Figure 1 (subsystem B) exchanges information with the knowledge base updating the relations components / capabilities / actions. The knowledge base therefore communicates with the planning system and a different inspection pattern is chosen, in order to accomplish the mission. Whilst in the first inspection, the vehicle was always facing the target with both forward-looking sonar and pan-tilt sonar mounted underneath the vehicle collecting data about the target, in the second inspection, due to the inability of lateral movement, the vehicle uses only the forward thrusters (and the depth ones), the pan-tilt rotates the sonar of 90DEG, and the target is still inspected by one sensor. It is to be noted that without a fault management system the vehicle would not have been able to accomplish its mission, whilst with this system it managed to collect data. Additionally, safety aspects would have arisen, both for the structure integrity and for the vehicle itself. The current knowledge framework, integrated with a fault detection system and communicating with the planning system provides the possibility to efficiently accomplish the mission, maintain an up-to-date state of the world, with the ability to cope with unexpected events.

IV. Current Work

Based on these promising results, the current efforts are devoted towards a semantic-aided localisation system. This goes further towards enabling efficient and effective robustness in the AUV system. Geometric localisation approaches have been described in previous work, both only processing the sensor data [3], and in an *active* system with vehicle planning and control in the loop [1]. Our hypotheses are that adding semantic information in the localisation process, the geometric localisation results will be more accurate and the process computationally more efficient, dealing with few symbolic information, rather than with many geometric ones. Our initial work is focused on defining the *likelihood* function (which is at the base of any particle filter approach), based on semantic data.

V. Conclusions

In this work an ontology-based AUV architecture has been developed as pivotal for AUV persistent autonomy. Experimental results have shown the potential for correctly identify the surrounding environment, cope dynamically with faults and interface with the planning system. The current work is now focused on semantic localisation, to aid robust AUV navigation.

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REFERENCES

[1] Francesco Maurelli and Yvan Petillot. *Particle diversity reduction for AUV's active localisation*. 2010. ISBN 9781424452217. doi: 10.1109/OCEANSSYD.2010.5603648.

[2] Francesco Maurelli, Marc Carreras, Joaquim Salvi, David Michael Lane, Kostas Kyriakopoulos, George Karras, Maria Fox, Derek Long, Petar Kormushev, and Darwin Caldwell. *The PANDORA project: A success story in AUV autonomy*. IEEE, United States, 2016. ISBN 9781467397247. doi: 10.1109/OCEANSAP.2016.7485618.

[3] Y. Petillot, F. Maurelli, N. Valeyrie, A. Mallios, P. Ridao, J. Aulinas, and J. Salvi. Acoustic-based techniques for autonomous underwater vehicle localization. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, 224(4):293–307, 11 2010. ISSN 1475-0902. doi: 10.1243/14750902JEME197.