Université de Toulon
MIR – EMJMD in Marine and Maritime Intelligent Robotics

Autonomy in Subsea Operations

Project Work:
NTNU Study Track

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1 Project Work: Adaptive missions for underwater vehicles

Oceans are vast and cover 71% of Earth's surface, playing a significant role in shaping our climate. As a result, understanding marine environments is essential for gaining insights into climate dynamics. However, limited prior knowledge of underwater environments poses challenges for mission planning. This underlines the need for systems that are adaptive and robust, to be able to change their behavior according to current conditions. Adaptivity for Autonomous Underwater Vehicles (AUVs) is especially crucial for the autonomous execution of missions, due to the high cost of sea-trials and the big amount of unknown factors regarding the objects of interest. In this abstract, we explore various approaches to adaptive missions, with a particular focus on behavior-based systems. Next, the approach of two scientific papers implementing adaptive control is analyzed, alongside their weaknesses and strengths.

The first manuscript [1] describes different approaches to robot control. Deliberate control uses sensory information to plan for the next action to be taken. This allows system to perform complex operations. However an accurate internal model of the world must be built and computationally costly operations must be made during run-time. Reactive systems couple system inputs to specific responses, allowing a robot to react quickly to its environment. It requires a minimal amount of computation, however fails in complex environments due to the simplicity of its world model. In behavior-based systems the control of the system emerges from the interplay between multiple behaviors, i.e., modules that pass on information to actuators and other modules, after having received sensory information. In this way they are like reactive systems, however they store representations and can therefore consider past and future information. In a bottom-up construction multiple behaviors, such as collision avoidance or target-chasing, result in emergent intelligent behavior of the system. According to their level of importance, they are chosen using a process known as action selection. During the operation of e.g., an AUV, its behaviors or their representations can be modified during a mission, leading to an improved adaptation of the agent in a fast-changing environment. This work offers an intuitive introduction into the topic, while still diving into the details. Common misconceptions are confronted and many theoretical examples, as well as current research examples are given. As such, it can be recommended as a textbook for a first introductory dive into the topic.

In [2] an AUV samples in situ data on Arctic surface fronts, i.e., regions of differing temperature. First a front is tracked automatically, after which the sampling resolution is increased for more accurate measurements. Due to a large variability in time and space of the sea-water's parameters, using adaptive systems is crucial: Adapting the search pattern according to the current measurements enables a faster sampling, as well as higher spatial resolution. The behavior of the vehicle is encoded in a Finite State Machine (FSM), leading to a subsumption-based approach. The two main maneuvers consisted in a vertical zigzag motion and a regain maneuver, backtracking to the last seen point of the front. Search, Track and Recover behaviors are used to obtain a full mapping of the front. Various trials at Trondheimsfjord and Svalbard showed the real-life application of the system, resulting in high resolution volumetric temperature distributions. In this case there was no need for a complex internalized model, due to the nature of the task. Possible future research entails the sampling of the column using multiple AUVs or gliders, to link the high-resolution observations to external forcing. The paper is well structured and provides a detailed explanation not only on the implementation, but also on the challenges related to the harsh environment. Not only is the system shown to function in a simulated environment, but also during sea-trials in production. As such, the process of the development cycle of these kinds of systems is explained, and links between algorithmic implementation and the physical intricacies of an AUV are given.

The paper [3] presents an adaptive method for feature detection and following applied to the example of an AUV scanning bathymetric contours. Planning and mapping capabilities are included into the behavior-based model to allow for an adaptive search of the object of interest according to new sensor readings. It is essential for the behaviour to be adaptive in a way that unforeseen mission states can be confronted during the mission, instead of relying solely on planning before the mission in the case of contingencies. Instead of incorporating this behavior into a higher layer of the subsumption architecture, it's embedded in the lower levels, resulting in an increase in vehicle capability without resulting in penalties to due scaling of the layers. Especially the incorporation of a grid-based map and waypoint generation presented a key step in the simulation-based verification of the results: The *trench_finder* behavior keeps track of the visitation map, which tracks all locations that have been visited, as well as the feature map, a subset of this map where features where detected. In a planning phase, candidate cells are found and ranked according to the cost of visiting and distance and visited. Should no feature be found, a spiraling motion around the region of interest is started. This way the considering of the mission history results in adaptive behavior, which had not been possible using “traditional” behaviors, which failed due to the revisiting of already visited features. The paper itself is structured very clearly, providing illustrative visuals of the process, along with diagrams explaining the FSM. Future improvements include the mapping of dynamic water column features, which would require accurate sampling at the current time, as well as predicting the future position of that feature. Also, contour feature could be used as navigational aid, to improve relocalisation, given the current map of contour features.

In summary, the use of behavior-based systems in adaptive AUV missions is a promising approach, allowing for improved performance and adaptation to changing environments. The analyzed textbooks and papers demonstrate successful implementation of such systems in real-life applications, emphasizing the importance of adaptive control in autonomous underwater vehicles. Especially the use of behaviour-based systems is shown, along with the advantages of the subsumption architecture.

References

[1] B. Siciliano, O. Khatib and T. Kröger, *Springer handbook of robotics*. Springer, 2008, vol. 200.

[2] T. O. Fossum, P. Norgren, I. Fer, F. Nilsen, Z. C. Koenig and M. Ludvigsen, ‘Adaptive sampling of surface fronts in the arctic using an autonomous underwater vehicle’, *IEEE Journal of Oceanic Engineering*, vol. 46, no. 4, pp. 1155–1164, 2021.

[3] A. Bennett and J. Leonard, ‘A behavior-based approach to adaptive feature detection and following with autonomous underwater vehicles’, *IEEE Journal of Oceanic Engineering*, vol. 25, no. 2, pp. 213–226, 2000. DOI: 10.1109/48.838985.