

# 7 Concluding Remarks and the Way Forward

## 7.1 Conclusions

This book has presented the fundamental aspects of service-oriented agents that are the core of an Intelligent Control Architecture (ICA) for autonomous marine vehicles. The ICA is generic in nature but aimed at a case study where a marine surface craft and an underwater vehicle are required to work cooperatively. Nevertheless, this fact does not invalidate the architectural approach proposed since the ICA principles of flexibility and adaptability are based on service orientation and agent technology which have been successful in many application domains by providing flexible and adaptable solutions.

The ICA foundation lies on the basic service infrastructure of service-oriented computing, i.e. discovery of system capabilities, dynamic system reconfiguration, and decoupled interaction among applications. The approach also improves the SA of the above vehicles by relying on Observe-Orient-Decide-Act (OODA) loops performed by agents that combine their knowledge and skills with the information acquired during missions. The above architectural elements make it possible to achieve adaptive and reflective mission planning based on a dynamic reconfiguration of plans according to given mission.

The ICA was implemented in the pervasive Robot Operating System (ROS) middleware. Computer simulations and trials of the ICA implementation show the system performance (including the advertisement and discovery mechanisms for services as well as the resource management) were successfully carried out. An experiment of the ICA performance in scenario including faults has also been presented. It shows the greatest potential of the research contribution since maritime vehicles are able to make in-mission decisions without contacting or getting back to the human operator for advice on what to do.

The promising ICA approach is a general solution for maritime autonomy that opens opportunities to be applied to other maritime missions, and Unmanned Marine Vehicles (UMVs). In fact, the knowledge of different missions has to be added to the ontological database and the reasoner has to include updated rules needed to deal with the new operational situations. Additionally, the ICA is platform-independent from the software point of view. Thus, only high-level changes are required in the ICA implementation. The software library provides means to help implementing and integrating any new capability added to the system (no matter whether it is a new AMR system or an existing one).

The autonomous characteristics of the ICA pave the way for a reduction in the expensive deployment and operation of Remotely Operated Vehicles (ROVs), and bring within reach complex multi-vehicle collaborative missions that were previously too costly or logistically infeasible.

## 7.2 Future Work

There is still investigation to be made into this promising architectural approach. The main aspect to be dealing with in order to optimize the ICA are: knowledge representation and reasoning, and diverse application cases with a strong emphasis on faults (including errors and failures) and marine missions (including a broad set of environmental situations).

The knowledge representation is critical for any decision-making process. Knowledge is a cognitive system property. Data with meaning is information which in turn becomes knowledge when a purpose and the potential to generate action are added. Knowledge is the intellectual machinery used to achieve goals (carrying out actions), and create new information. Artificially-intelligent systems such the ICA-based ones are able to accurately determine what activity will maximize the likelihood of achieving a goal successfully. The ICA has knowledge-based intelligence that relies on ontological reasoners. Semantic dependencies in ontology as well as reasoning rules for ontological inference are essential to have a developmental ICA intellect. Therefore, future steps of this research would be to increase the autonomous maritime capabilities of the AMR systems by the improving ontological database, and the reasoner.

New research directions will also take into account more complex evaluation scenarios by including other potential faults and unexpected situations in order to deal with some faults to be handled through self-repairing capabilities. There are different types of faults to be considered that can arise at the deliberative control layer and from (1) vehicle problems or (2) environmental conditions; or at the reactive control layer, and from (3) vehicle problems or (4) environmental conditions. Considering different faults will allow an updated ICA approach to be able to cope with more realistic operation scenarios, involving software and hardware problems as well as environment changes.

## 7.3 Exploitation

Opportunities to exploit the outcomes from this book are within the following sectors: research, academics, and industry.

**Scientific Sector.** Contributions to scientific research can be divided into two main branches: state of the art, and research applications. The former represent the current pool of robotic control architectures (including those for any domain). A potential impact can be on competitions of robots such as EURATHLON [32]

(a robot competition supported by the European Commission in the FP7), and the DARPA Robotics Challenge [34]. The latter involves tasks from activities related to oceanographic monitoring systems, and marine biology studies so it could take into account the ICA for measuring UMV performance (back-end technology based on the ICA approach).

**Academic Sector.** Practical work in laboratory classes can implement the ICA as a development platform for student projects. Also, appropriate lectures can include the ICA approach as an application example of adaptive solution for robotics control architectures. The ICA applicability can be expanded in order to cope with other application domain so it can be taken into account in academic activities from other engineering field such as software and systems engineering as well as sciences such as computer science. The Student Autonomous Underwater Competition – Europe (SAUC-E) [33] can also benefit from the ICA. It is always looking for novel robot architectures to get high levels of adaptability for missions (in particular, different environments).

**Industrial Sector.** Defence industries and UK Ministry of Defence initiatives can also be interested in the ICA and its potential use for ocean/sea mission such as mine countermeasures. On one hand, there is an increasing concern for autonomy metrics from cooperative solutions for intelligent searches. On the other hand, heterogeneous robot teams (including water, land, and air) are in the thick of defence priorities. Thus, a technology that allows stakeholders to carry out collaborative operations based on an on-demand capability approach are becoming essential for missions such as recce, and rescue of people.