2 Existing Robotic Control Architectures

2.1 Single and Multiple Agents per Vehicles

The state of the art of robotic control architectures presented in this Chapter focuses on the ocean engineering and robotics areas. In particular, it only involves mobile agent systems for marine vehicles since this book proposes to apply the agent technology to an ARM system where each Autonomous Marine Vehicle (AMV) is considered a mobile agent.

Addressing the above context, two main classifications can be made. The first is according to the amount of agents implemented per vehicle. The second is according to those approaches that rigorously follow the basic agent architecture and in particular, those which really propose approaches of intelligent agent architecture.

There are many proposals implementing several agents per individual mobile platform. These approaches generally assign an agent to a functional system module (navigator, pilot, vision processor, etc.). Thus, the agents are defined as key components of the infrastructure that supports the system [3]–[9]. An alternative approach some researchers have taken is to implement only one agent per mobile platform [10]–[14], [27]. Many-agent solutions can be computationally distributed within a vehicle so simpler agents can be implemented but the interaction among agents is increased which involves additional communication tasks. One-agent solutions increase the need for computational resources to implement the agent but simply the agency (community of agents), i.e. external communication among agents.

2.2 Intelligent Agents

Researchers at the Center for Intelligent Systems Research (CISR), George Washington University are working on decentralized control for multiple Autonomous Underwater Vehicles (AUVs). They proposed an ontological approach for collective behaviour of intelligent agents that can be applied to AUV fleets [14]. Their proposal is based on collective intentionality in agents. It is an alternative to the traditional Beliefs-Desires-Intentions (BDI) model of individual agents that capitalized on the commitments agents have to one another rather than the commitments the agents have to maximize their own individual utility functions [15].

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This collective way to manage agent commitments is good for lowering the number of tasks per agent (less busy agents) but it consequently makes agent more sophisticated to achieve effective interactions.

The Ocean Systems Lab at Heriot-Watt University has started working on situation awareness (SA) in service-oriented agents for AUVs. SA is an agent ability to be conscious to realize about internal and external states (see page 23). The information provided by SA is essential to make decisions. Better decisions can be made based on higher SA. The research mainly focuses on semantic knowledge-based representation for improving SA [9], distributed ontological world model [17], and adapting mission planning [18]. The above approaches pave the way towards reconfigurable control architectures for autonomous maritime vehicles based on service-oriented agents. They provide AUVs with flexible adaptation to mission requirements (e.g. self-repairing capabilities for planning, the ability to autonomously re-plan or repair a plan (totally or partially) without the operator intervention is invaluable and save time during AUV missions).

There are successful stories of underwater operations such as field measurements of scalar temperature, salinity, or pollutant concentration fields in environmental tracking applications of formation control of AUVs [19]. Defence systems are also demanding autonomous air and marine vehicles for networked multi-vehicle systems for an ocean platform control for the mobile offshore base which includes coordinated operations of several AUVs, and unmanned combat air vehicles [20]. It shows some current issues common to the above systems regarding hardware-software co-design, coordinated control strategies, manoeuvres, communication, and real-time constraints.

2.3 Comparison of Agent-Based Approaches

The main contribution of this book is a generic architectural solution for autonomous marine vehicles. The ICA proposed is a solution that goes beyond existing approaches by combining and extending the characteristics mentioned above in Subsection 0, i.e. autonomy mainly based on adaptive planning of tasks to tackle missions for single and multiple AMV(s) and AMV behaviours generated by means of autonomous on-board decision-making capabilities. Whilst some approaches [15], [16] do propose agents to deal with the coordination of marine vehicles, the ICA additionally proposes a mechanism for dynamic discovery of platform capabilities, and a knowledge database [17] in order to support adaptive planning of missions [18]. None of the approaches presented in this Section has an integrated ability to (1) advertise, (2) discover, (3) (re-)plan based on, (4) monitor health of, and (5) execute system capabilities while dealing with maritime missions in a fault-tolerant manner.

The advertisement and discovery of system capabilities as well as a semantic knowledge database with on-board decision-making to build action plans make the main difference from the current approaches. They are essential elements to endow UMVs with intelligent autonomy. These two essential human-like mechanisms allows operators to fully delegate control to the autonomous maritime system (the ASC, and the IAUV) to autonomously carry out maritime activities that are currently assisted and pre-programmed by human operators in other approaches. This is a clear increase in the degree of maritime autonomy, aiming to reduce the expensive deployment and operation of ROVs. Thus, it also brings within reach complex multi-vehicle collaborative missions that are too costly or logistically infeasible with current approaches (i.e. MUVs, ROVs, and most AUVs) due to the low degree of autonomy they have to deal with underwater missions. This is ultimately limited by the computational and mechanical capabilities they have integrated on board.

Table 2.1 shows the criterion to compare existing approaches with the ICA proposed in this book. What is being assessed is the ability of each architecture to deal with faults (how much can be coped with), make decisions on board and on the fly, dynamically recognize services available in the system, and compute data.

Table 2.1 Comparison of most relevant approaches of intelligent control architectures applied to maritime robots

Architectural Approaches	Faults Diagnosis & Mitigation	Planning & Re-planning	Advertise & discovery of capabilities	In-vehicle Computing Paradigm
PN-MAS [14]	Partially supported	Only for obstacle detection	No	Agent
SKR [9], [17], [18]	Some cases supported	Off-board decision-making	No	Object
MARIOUS [7]	Few cases supported	On-board decision-making	No	Multi-agent
MAA [10]	Not supported	Off-board decision-making	No	Multi-agent
DVMA [13]	Not supported	Off-board decision-making	No	Sequential
T-REX [27]	Not supported	Constraint-based reasoning decision-making	No	Agent
JAUS [22]	Not defined	Open platform decision-making	No	Service-based component
REMORAS [28]	Not supported	On-board decision-making	Pre-known functions as agent roles	Multi-agent
Proposed ICA	Supported	On-board decision-making	Supported	Multi-agent based on services