Modelling and Simulation Tools for Verification and Validation (V&V) of Autonomous Maritime Systems

Abstract — The use of autonomous systems in military operations, in particular in the underwater domain, requires preliminary phases of testing (does it work?) as well as experimentation and analysis (how well does it work?) using accurate and realistic scenarios. The Modelling and Simulation (M&S) team at NATO STO CMRE (North Atlantic Treaty Organization Science and Technology Organization Centre for Maritime Research and Experimentation) is addressing these questions using an interoperable simulation approach: a multi-layer interoperable HLA (High-Level Architecture) federation has been developed to support the performance evaluation of algorithms and inter-agent collaboration frameworks for underwater autonomous systems.

1 Introduction

Autonomous systems hold the promise to augment future military maritime operations. They are designed to keep the military operator out of harm's way, and to aid the operator in performing dirty, dull and difficult tasks. The latter tasks are more and more frequently solved by using machine-learning algorithms. Although it is believed that maritime autonomy – functions and systems – are at the tipping point, there are still quite some barriers to be overcome: S&T (perception, decision, control and collaboration), communication, architecture and interoperability (standards), mission assurance, cyber resilience, doctrine, training, and verification & validation (V&V). NATO STO CMRE has developed a research programme that addresses some of these barriers, and this paper focuses on a subset of that programme: V&V. Does the system or function meet the specifications (verification) and is it fit for purpose (validation)? Many methods and tools are available from experience (conventional military systems, mission critical systems) and can be found in literature; these can be leveraged, at least for part of the problem space that the autonomous system community is currently facing. Conventional tools focus on formal methods, which are not suited to deal with machine learning based autonomy. It is in this field that modelling & simulation (M&S) may provide additional tools. The focus of the paper will be on the M&S capability that has been set up at CMRE, a capability that is modular and based on a standardised approach.

2 Objectives and Approach

The Persistent Autonomous Reconfigurable Capability (PARC) project aims to address technology and engineering requirements that enable future unmanned systems of systems to reach their full potential in the maritime domain. PARC, a NATO STO Centre for Maritime Research and Experimentation (CMRE) project that started in 2014, is focused on increasing autonomous robotic system capabilities, persistence, interoperability, and scalability whilst addressing standardisation and information assurance considerations. To achieve this, Modelling & Simulation (M&S) has been identified as a methodology that can extensively support the testing, experimentation and analysis of the Autonomous Underwater Vehicles' (AUVs). Furthermore, M&S capabilities provide an opportunity to improve the training of both humans and autonomous systems. The M&S capability is also used as a tool for autonomous/unmanned systems' Verification and Validation (V&V), i.e. by complementing formal methods.

V&V of autonomous and unmanned systems has been identified as a key topic in the robotic domain. In the community, a start has been made with assembling the various tools available into a coherent process to verify Autonomous Systems (AS), while identifying possible missing tools in the different parts of the process. For V&V, a mixed strategy is foreseen, in part formal (architecture/software analysis using formal methods), and M&S based where necessary. Since formal methods and machine-learning do not easily go hand-in-hand, M&S will be required as a tool for V&V. A probable way ahead is the combination of formal methods and M&S based techniques into a risk-based assessment and a licensing scheme for autonomous and unmanned systems to operate. Mission assurance should be an integral part of this. CMRE's near future goals for V&V include:

- decomposition of the V&V process into parts, identifying those that will have to be addressed using M&S,
- reduction of the number of scenarios to be simulated (since the state space is expected to be very large) by using smart, e.g. adaptive sampling, techniques,
- definition of the appropriate metrics,
- design and analysis of an appropriate use case.

3 M&S Architecture

The M&S architecture for supporting V&V has been designed for the integration of HW and in-the-loop simulation with a set of building blocks (federates), which provide a link between Robotics and C2 and Communication [1].

In the following section information are provided about the core High Level Architecture federation, with both HW and SW -in-the-loop simulation capabilities, see Figure 1.

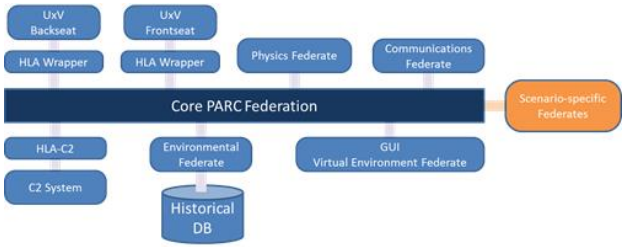

Fig. 1. Sample of the generic HLA federation developed

The federation includes the following federates:

- AUV Front-seat: it integrates the low-level software in charge of controlling the AUV. This federate receives the requests of the backseat and transforms them in commands for the sensors and actuators. Moreover, this federate may contain the real asset in the case of HW-in-the-loop simulation.
- AUV Back-seat: it integrates the high-level software modules in charge of defining the behaviours of the AUV. This federate receives the mission requirements and commands from the C2 system and transforms them into commands for the AUV according to the environmental conditions. Back seat is where typically the autonomous behaviour sits.
- C2 System: it emulates the capabilities of a C2 system. This federate is integrated by using a Service Orientated Architecture (SOA) approach.
- Underwater Communication Simulator: it simulates the communication channels between the different assets, including noise, transmission time, and possible interferences.
- Physics and Environmental Simulators: are in in charge of simulating all the movements and interactions of the simulated assets within realistic environmental conditions
- Virtual Environment: it provides a graphical and 3D representation of the overall scenario simulated by the federation.

Currently the autonomous systems integrated are all ROS (Robotic Operating System) based. Other platforms will be integrated and tested later in 2019.

The federate conceptual models have been developed in close collaboration with engineers and scientists from different CMRE departments, each one covering specific domain: autonomous systems, environment, and underwater communications.

4 Preliminary Results

The current federation is a result in itself, allowing a scalable and modular approach for supporting V&V of autonomous systems. It is also possible to run over-the-internet distributed experiment with partners and third party software included in the simulation.

Autonomous behaviours can be deterministic (state-machine-like), or stochastic (machine-learning): machine-learning algorithms are trained using either off-line date (supervised-learning with limited data-set) or in a continuous way, during field operations (self-learning). The work of the CMRE M&S team is focusing on supporting supervised-learning algorithms.

A sample of preliminary experimental results has been provided by recent analysis on an adaptive path planning algorithm for the MCM (Mine-Counter Measures) mission detection stage. Twelve simulated trials, carried out between mid-September to mid-October 2018, have generated the necessary data to quantitatively assess the performance of this algorithm [2].

Another MCM federation has been created to test a framework for distributed collaborative autonomous missions. This experimentation is currently ongoing.

4 Way Ahead and Conclusions

The CMRE M&S team is exploring new opportunities to enrich the M&S testbed capability according to the goal of de-risking sea-going activities, V&V, concept development and experimentation, and training. Some of the steps planned can be summarized as follows:

- consolidation of the MCM and development of new Anti-Submarine Warfare (ASW) scenarios

- investigation of Augmented/Virtual Reality applications in the underwater domain

- investigation on the usage of serious games for the analysis of the human decision making process to support machine-learning algorithms.

This study reveals the potential of adopting M&S for safe-to-fail and cost effective experimental campaigns for verification, validation and testing for autonomous vehicles.

The autonomous behaviour part(s) of the federation, concentrated in the unmanned system's back-seat, lend themselves to an M&S approach to V&V. The state-space of machine learning techniques are typically large and M&S is proving to be an effective methodology for limiting such space, in order to keep the V&V of autonomous and unmanned systems tractable.

References

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[2] A. Carrera et al. (NU) "CMRE Memorandum Report on ANMCM experimentation" (2018)

[3] IEEE 1516-2010 and STANAG 4603, (2010).

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List 50-word author/speaker biographies for each author or speaker if your extended abstract describes a panel presentation. List each author's name in bold type followed by the short biography and a space between each biography.