Virtual Framework for Testing/Experiencing Potential of Collaborative Autonomous Systems

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ABSTRACT

This paper proposes a simulation architecture as virtual framework for experimenting solutions, policies and technologies related to the interoperability among different unmanned vehicles (Unmanned Ground Vehicle UGV, Autonomous Underwater Vehicle AUV, Unmanned Surface Vehicle USV, Unmanned Aerial Vehicle UAV). Indeed, this research aims to develop an interoperable simulation for experiencing collaboration among autonomous and intelligent systems able to investigate new emerging concepts and requirements for innovative technologies.

The authors propose an approach to interoperate among different systems within a simulation framework; indeed the paper benefits of the long experience of Simulation Team in Interoperable Simulation over joint Scenarios and the expertise from CMRE (Center for Maritime Research and Experimentation) in developing innovative AUV solutions; in addition, the proposed architecture includes results from NATO M&S COE (Modeling & Simulation Center of Excellence) researches in adopting an Hybrid Validation Test-bench (HVT).

So this study presents the approach for developing an innovative architecture and to start testing these assets structured in collaborative robotic teams. Indeed, due to the complexity of the joint mission environments, the Intelligent Agents developed by Simulation Team allows creation of complex multidimensional scenarios where different assets interoperate in collaborative task assignments. In addition a specific focus in this paper is devoted to the data-centric system architecture which is based upon the Real-Time Data Distribution Services, a standard integration middleware adopted for both the MRS and the HVT.

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INTRODUCTION

Research and Development (R&D) of robotic systems able to communicate with humans and with each other is a new frontier destined to overtake the limitations of single systems. In fact, from this point of view, the introduction of autonomy within collaborative systems allows one to address more complex operative tasks. In order to succeed in this sector, it is critical to involve different disciplines, such as mechatronics, computing science, artificial intelligence, etc.; therefore, it is also important to address aspects related to interactions among robots and humans both in terms of man-machine interface as well as in terms of interaction with humans while performing the operations (Cooke et al.2006). From this point of view, the research in robotics should aim to develop robotic devices able to emulate some kind of human-like intelligence, interacting among themselves over complex environments in a socially acceptable way (Fernandez et al. 2013). The strategies of interaction encompass theories from such diverse disciplines as intelligent agents, game theory/economics, theoretical biology, distributed computing/control, and artificial life.

Unmanned systems are nowadays successfully used in different kinds of operations, such as area clearing, area patrolling, intelligence, situational awareness, geographical exploration, while the use of robots in surveillance and exploration have been widely demonstrated and accepted in recent years. Typical applications include air and ground-based mapping of predetermined areas for tasks such as target detection, tracking, and search and rescue operations. In this setting, it is highly desired to fuse information from all available sources. The development and acquisition of Multi-Robot Systems (MRS) is identified as a mainstream element in the future of military and security operations. Examples include formation following, localization of chemical or radioactive sources, target assignments, autonomous driving in dangerous areas, perimeter control, surveillance, and search and rescue missions.

The use of autonomous systems is more and more popular over a wide spectrum of applications. The evolution of related technologies is improving their performance and reliability, while considerable experience has been achieved using drones in real scenarios. Indeed, autonomous systems provided very significant benefits in terms of reducing human exposure to risk in both natural disasters and military operations, while their operative capabilities continue to extend and grow. Today, Unmanned Autonomous Systems (UAS) currently cover all of the operative domains including air (i.e. Unmanned Aerial Vehicles, UAV), land (i.e. Unmanned Ground Vehicles, UGV), sea surface (i.e. Unmanned Surface Vehicles, USV) as well as space (i.e. Unmanned Spacecrafts and Space Probes).

In addition to the extension of capabilities, missions and operative domains, the autonomy of these systems likewise increased; the opportunity to assign autonomous systems more and more sophisticated tasks also emerged. As a result, it becomes important to evolve from single system operations to multi system cooperation, and to investigate collaborative approaches. Current mission environments are evolving into more integrated contexts over different domains, which further affects the requirements and expectations for UAS and MRS. Joint scenarios involving air, ground and sea are a great example: they are very challenging, but at the same time they represent the more explicit need to introduce cooperative and collaborative uses of different kinds of autonomous systems.

Due to the complexity of articulated mission environments, specific UAS characteristics, and associated heterogeneous networks, the use of Modeling and Simulation to support R&D in this sector is important. Simulation, in fact, could address specific issues related to training on future scenarios, as well as on capability assessments related to new features from emerging technologies and challenges.

FROM SINGLE UAS TO MRS

Due to the above mentioned reasons, UAS are evolving from single autonomous systems to cooperative groups, and in the future, they are expected to turn into collaborative fleets and eventually become an integrated joint swarm, passing over different possible configurations as proposed in examples reported in figure 1.

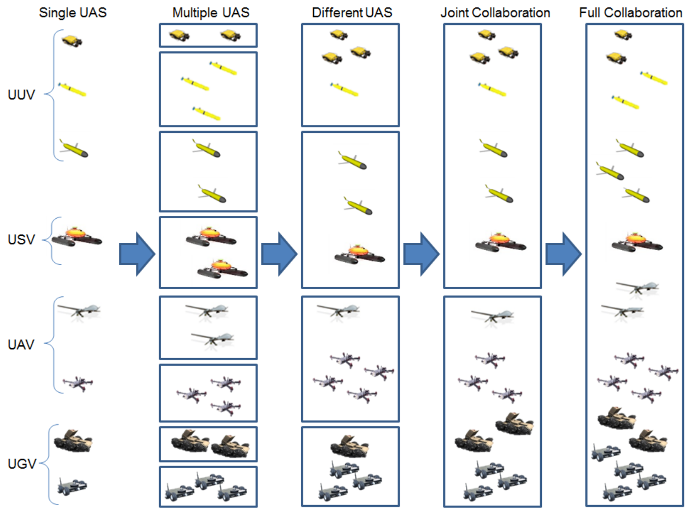

Figure 1: Different Paradigms

Obviously this requires one to investigate different aspects and services related to UAS in order to face all level of challenges in terms of complexity paradigm; the graph proposed in figure 2 clarifies the concept extracted by reports in this field (Ross et al. 2006; Tether 2009; DARPA 2012; Lundquist, 2013) addressing a series of projects and examples on the wide spectrum of UAS / MRS applications involving different levels of complexity over the different paradigms.

The use of interoperable simulation is a strategic advantage to check a priori the interaction among the different systems and to test prototypes in a virtual scenario; in fact simulation is able to explore all the aspects of the life cycle related to these aggregated systems, as proposed in figure 3 (Zini, 2012). The potential of simulation in addressing a wide spectrum of issues such as requirement re-engineering, virtual testing, operational effectiveness analysis cannot be understated.

This paper focuses on the development of an interoperable simulation framework to support capability assessment and training for UAS operating in integrated scenarios over different domains.

OPERATIONAL ENVIRONMENT AS VALIDATION PROCEDURES FOR MRS

A key element of mission success is the effective and reliable coordination across all the operational domains: land, maritime, air, space, cyber. Therefore this aspect is crucial for manned forces and even more for unmanned forces. In the future the warfighter and the autonomous systems will have to intensively interact and cooperate for the success of the mission. In fact, while unmanned systems have shown their value in military operations over the past decades, in recent years these systems have achieved an additional evolution with the introduction of new autonomous functions. The remarkable increment in UxS (Unmanned Systems - x referring to the different Operational Domain) on the battlefield and the evolution from UxS to AxS (Autonomous Systems - x referring to the Operational Domain) is due to their ability to persistently work in unfamiliar, hazardous and austere environments, avoiding human friendly forces to operate in these areas.

The next evolution could be a Multi-Robot System (MRS) as a result of cooperation among single intelligent elements; these elements should be coordinated for mission success and devoted to guarantee high effectiveness and reliability.

In the future, it could be also possible to envision Autonomous Coalition Forces (ACFs) combining a swarm of expendable AxSs coordinated by more capable and expensive AxSs, as well as by war fighters. These ACFs may achieve a very high level of complexity; in this complex system the nonlinear components and the high degree of interactions among the different elements and different policies for coordination (i.e. Centralized Coordination, Behavior Based Control, Hybrid Control) could reveal unexpected behaviors that have to be carefully investigated and managed. From this point of view the use of M&S is critical: on a per-mission basis, through intensive simulation campaigns, MRS could be validated as a foundation for Future Autonomous Coalition Forces. For instance, it could be mentioned that the Hybrid Validation Test-bench (HVT) adopted by M&S COE was able to accelerate the understanding of emerging behaviors in the battlefield due to the complex interactions between AxS.

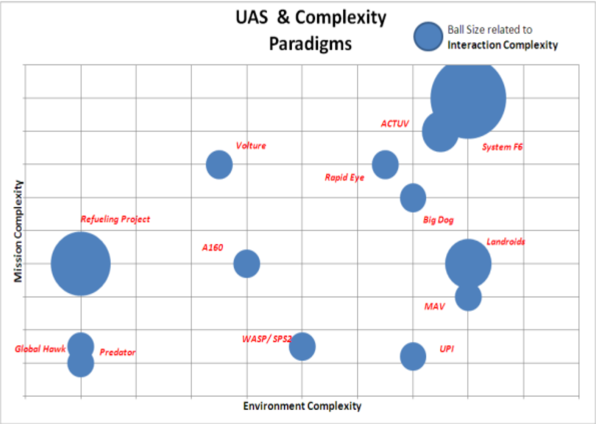

Figure 2: Overview of Complexity Paradigms over different R&D Projects related to UAS/MRS

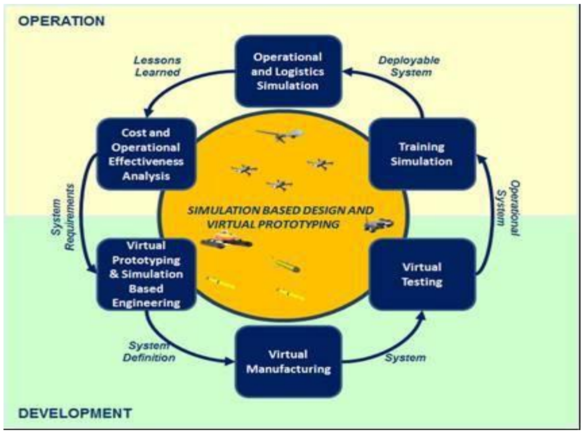

Figure 3: Using Modeling and Simualtion

STATE OF ART ON AUTONOMOUS SYSTEM COORDINATED AND JOINT OPERATIONS

Reported works in scientific literature on interaction of heterogeneous teams of multiple agents over all domains, such as fleet of UAVs, UGVs, AUVs and SUVs, are fairly limited. Therefore, many authors have addressed the problem of developing frameworks for the coordination of a single class of vehicles; for instance, multiple UAVs (Vail 2003) and multiple AUVs (Richards et al. 2002; Stilwell et al.2004). In terms of joint operations, a coordination mechanism for multiple AUVs and a single unmanned aerial vehicle cooperatively performing an ocean exploration mission has been studied in order to identify an effective working-together method (Sujit et al. 2009).

Combine heterogeneous systems and remote human controllers is another important issue due to the implications on aspects such as engineering, use modes and training. For this purpose there are studies devoted to understand how scientists should assist autonomous system in environmental monitoring and inspection within marine domain in a consistent, efficient, and comprehensive manner using robots; for instance, a heterogeneous multi-robot system interacting with off-site scientists and operating within a hierarchical structure was designed in order to collect visual footage autonomously (Shkurti et al. 2012). This study evaluated how high - level commands could be issued to a robot team composed of three disparate vehicles, namely an aerial (UAV), a surface (ASV) and an underwater vehicle (AUV).

In a different mission environment there are interesting examples of a MRS in which an AUV and an autonomous kayak (USV) collaborating in search and coverage tasks such as underwater mine clearance (Shafer et al. 2008); the heterogeneity of these autonomous vehicles is exploited to optimize energy and time resources. In intelligence, surveillance and reconnaissance (ISR) missions are envisioned to utilize a variety of unmanned vehicles closely cooperating to obtain situational awareness, not only for providing information to remote assisting scientists, but also for the robotic team performing the task.

Novel methods to network and control the robotic vehicles need to be explored and tested. For example switch cooperative control schemes have been studied to coordinate ground and aerial unmanned vehicles for the purpose of locating a moving target in hostile environments (Tanner 2007). A major thrust within this area is the optimal control and use of robotic resources and coordinated deployment of robotic sensor platforms. Scalable and flexible solutions involving air and ground domains have been analyzed (Grocholsky et al. 2006), with special attention to the task of improving reliability in the detection and localization of unknown number of entities within a prescribed search area, deploying UAVs and UGVs and inexpensive off the-shelf sensors for target detection.

Another example of two heterogeneous groups of mobile agents coordinated in discrete time (a group of UGVs and a group of AUVs) was studied in terms of potential applications to cooperative intelligence surveillance and reconnaissance (ISR) missions (Tanner et al.2007). In these simulated ISR missions, joint efforts between teams of mobile agents are required: teams can have different goals, but all should support the common objective. The ground units synchronize their velocities and maintain a cohesion and separation behavior on the basis of their formation's centroid.

Studies related to the cooperation among different kinds of UAV and AUV over a port environment for security were investigated by using interoperable HLA Simulation. An effective approach has been followed by Simulation Team; namely a stochastic simulator of joint operations involving UAV and other assets such as ground units, attack helicopters and planes, called IA-CGF U-COIN (Intelligence Agent Computer Generated Forces UAV and Counter-Insurgency) (Bruzzone et al. 2010).

In the simulated scenario, the UAV system can be directed with high level assignments such as area of operations, sectors to be avoided, base to be used, rules of engagement (i.e. detection, targeting, engagement, etc.). UAVs interact with ground units in order to observe caravans moving in the area, to detect insurgents position and to reduce their capabilities in the area. Civil caravans and insurgents controlled by intelligent agents could adopt different behaviors, such as hiding in the caravan, attacking coalition assets, avoiding contacts and getting protection from civil infrastructures. Also the behavior of the civilians is modeled thanks to the Human Behavior Modeling of the intelligent agents: for instance, the caravan could adopt the attitude to avoid contact with insurgents fearing it will be attacked, or to avoid contact with coalition forces, or even both.

PORT SCENARIO AS EXAMPLE OF MISSION ENVIRONMENT

Port and Maritime operations and their associated facilities and infrastructure represent a challenging and varied environment to test the concepts proposed in this paper; for this reason the authors are using the port scenario as an example for investigating the architecture to be adopted and the elements to include in the simulation. Ports are not only a crucial spot for the security of nations, but the global economy relies on them: global trade is dependent mainly on maritime transport and any delay (whether or not related to security) affects all operations.

Ports and shipping remain attractive targets for criminals and organized crime because of the concentration of goods, vulnerable to theft, smuggling and vandalism. Terrorism is another important concern, particularly with respect to the movement and identification of containers and contents; furthermore any attack to a large port facility could affect a nation’s economy and markets, cause casualties and damage irreversibly the local environmental damage. The detection identification, classification and verification of all vessels, aircraft, and objects approaching from the land, air, and above or below the surface of the water is of crucial importance in order to recognize in advance any potential threat; in addition it is necessary to further investigate alerts and suspect behaviors or situations.

Ports with both commercial and military activities involve a set of different institutions, agencies and entities (i.e. Coast Guard, Custom Organization, Port Authority, Private Port Terminal, Homeland Security Department, Navy, Ship Yard Constructions, Private Contractors, etc.) interacting for the protection of the infrastructure and related assets. Actors involved in port protection need to consider an integrated joint approach, a comprehensive strategy to address the security. In particular a MRS covering all the different domains which integrate with existing port security systems could be the best solution to monitor port activities without additional manpower that may be costly and not sustainable.

GENERAL ARCHITECTURE AND SIMULATION ENVIRONMENT

The purpose of paper is to recommend an innovative virtual framework to support unmanned and autonomous vehicles computer simulations. The proposed approach is based on multiple layers using different standards and technologies in order to have a flexible architecture enhancing system capabilities. The High Level Architecture (HLA) is the suitable architecture to integrate the systems and simulators, whose interactions and objects will interoperate by a Run-Time Infrastructure (RTI).

The idea to use multiple layers is motivated by the need to guarantee an open architecture with the possibility to integrate commercial applications and compact drones by using standard communication protocols. This approach requires additional efforts in terms of development time with respect to single layer architecture, but it could guarantee more flexibility in integrating standard modules and proprietary convenient systems.

The above described port scenario greatly benefits from an interoperable simulation: the environment, the entities, the activities, operations and threats could be modeled and federated within the same simulation. The federation architecture could integrate basic drone emulators within collaborative supervision solutions. In this case the human interaction with agents is proposed as an element of the architecture; in fact this scenario could include ST_VIV (Simulation Team Virtual Intelligent UAV & AUV), an HLA interoperable federate, able to provide an interactive framework among a human supervisor and agents within a virtual immersive environment (see figure 8). In this framework the operator acts as a general director and the drones are controlled through the proposed architecture.

The scenario entities could be modeled as Intelligent Agents (i.e. IA-CGF presented over a marine scenario in figure 7) coordinating the operations and supporting AxS collaboration. Drones and robots that have embedded software and/or simulators devoted to emulate in details specific configurations could have problems into being federated. These systems are expected to interoperate at a low level based on their operating systems (by using ROS and DDS), and connected to others through an HLA gateway.

Indeed this approach could be able to address the innovative concept of human on the loop: the human operators are required to interact with IAs (Intelligent Agents) and assign tasks and goals while the drone control is responsibility of the different IA (Magrassi 2013). It is expected that future scenarios, due to the high number of entities, high density and task complexity, could overpass the human control capabilities in terms of reaction speed and precision. In these cases, the agents will be in charge of low level activities (i.e. driving drones or engaging targets) taking care of de-conflicting and coordinating actions among the drones, while humans will keep the leading role in terms of high level task assignments and collaboration directives to the IAs. The different layers of the simulator architecture are devoted to guarantee the possibility of addressing these operative modes and face the above mentioned challenges over complex scenarios.

In order to validate these concepts, a set of preliminary experiments, conducted by the authors are presented. These experiments represent a first set of tests for evaluating the layers proposed in this architecture in terms of their capabilities to simulate complex scenarios. It will be necessary to define the Federation Object Model (FOM) to integrate different components in the port scenario including both man-in-the-loop simulators (i.e. UAV flight simulator), man on the loop simulators (UAS Supervisor) and autonomous entities directed by intelligent agents (Bruzzone 2013; Magrassi 2013).

The port scenario federation will include:

UAV Federate:	Simulator of Unmanned Air Vehicles
USV Federate:	Simulator of Unmanned Surface Vehicles
UGV Federate:	Simulator of Unmanned Ground Vehicles
AUV Federate:	Simulator of Autonomous Underwater Vehicles
Environment Federate:	Simulator of the Environmental Conditions
Intelligent Agents:	Federate managing the Intelligent Agents driving the UAS in collaborative approach over the scenario and directing the Computer Generated Forces
Centralized MRS:	A Centralized Control System for a Sub Set of AUS
Supervisor System:	Supervision System directed by Humans assigning tasks/missions to the MRS/AUS Port Federate:
Port federate:	Simulating the general cargo, commercial and private traffic
Traffic Federate:	Model and Simulator of the Threats within them mission environment
Threat Federate:	Other EntitiesAny Other Simulation Model of entities in the port (i.e. boats, Port ranes,etc.)
Other Entities:	Simulators of Unmanned Air Vehicle

This architecture affords further integration of simulators (i.e. LVC Simulators, Sensors) and extend the capabilities of this Federation.

Figure 4 below is the general architecture of the federation proposed:

Figure 4: Port Scenario Architecture

Therefore in order to guarantee the possibility of testing the C2 (Command and Control) of a MRS, it becomes necessary to reproduce exactly the Information and Communication Technology infrastructure (ICT); hence particular attention will be given to modeling these elements.

Two different approaches of controlling of a multi-robot system have been identified. In the centralized approach, the global information about the state of the whole system is maintained; the System gathers information from all robots, which are coordinated by a common control unit which has full decision making capability. The common control unit may be a ground based computer or one of the agents. In this case all the tasks to be performed by the centralized approach are collected, decomposed, assigned to robots with respect to their capabilities, work, load and location. Relatively easy to be implemented, this approach tends to decompose a large complex problem into simpler ones. Centralized systems are highly deterministic structures, in which a single error in a single subsystem totally disorients the system. As the robot system interacts with a real environment from which it is difficult to extract good information, this approach makes the robot extremely unreliable.

The second approach is based on the concept of distributed robotic systems; the decision making function results from the cooperation between the agents, and each agent possessing its own decision making autonomy based on the sensing information and its internal states. Intelligence and sensing capabilities are explicitly distributed. Also, each agent consists of processing and storage facilities as well as subsystem that support communication; no central control unit is required. Agents negotiate one with other to make the best of potential interactions and solve conflicts; so, the agents may be cooperating to accomplish a single global task or to accomplish separate individual goals that interact. The motivation of such systems is to increase flexibility, reliability, potential parallelism, and hence to have a robust system. In the proposed architecture, both approaches could be covered, while the Supervisor System could address multiple and single systems through the agents, directing distributed robotic systems or single centralized units.

AN EXAMPLE OF ROBOT OPERATING SYSTEM

The Robot Operating System (ROS), proposed in this paper, originally called switchyard, is a result of the STAIR (Stanford Artificial Intelligence Robot) Project of the Stanford Artificial Intelligence Laboratory and Willow Garage is now maintaining the related code. Indeed ROS is a widely adopted framework providing libraries and tools in order to help Robot Software Development and it suggests standard operating system services such as hardware abstraction, low-level device control, commonly-used functionality, and message-passing between processes. Figure 5 shows an example of a Function State Diagram of the Robot Operating System.

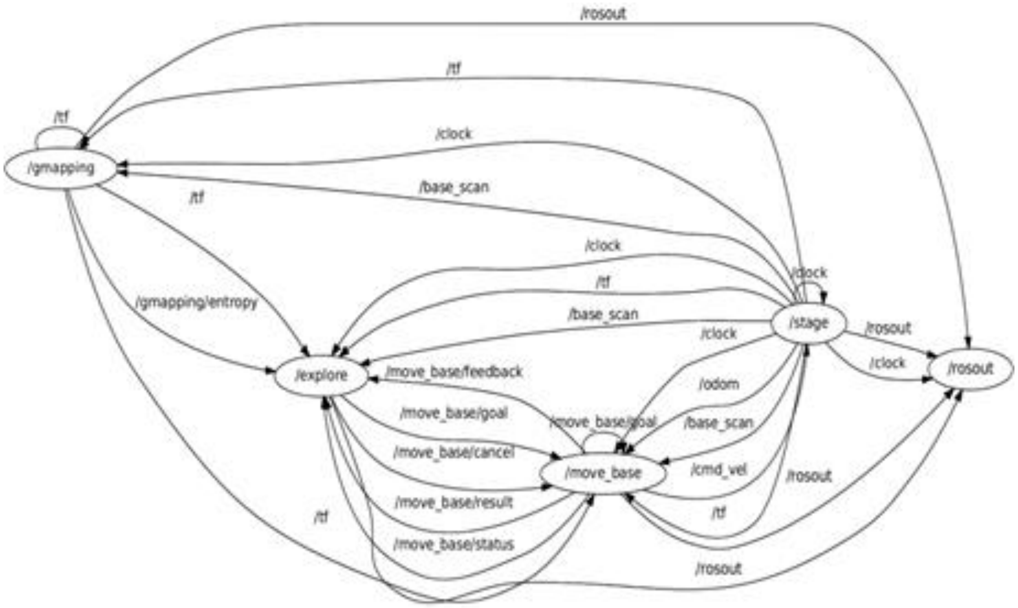

Figure 5: Example of Function State Diagram

A ROS provides high level capabilities such as simultaneous localization and mapping (Figure 6), path planning & control, sensor control. The abstraction layer of ROS coupled with its wide spread adoption permits an effective testing of target code for real robots in a virtualized environment, cutting down the cost for the porting of the software in the target ROS compliant platform.

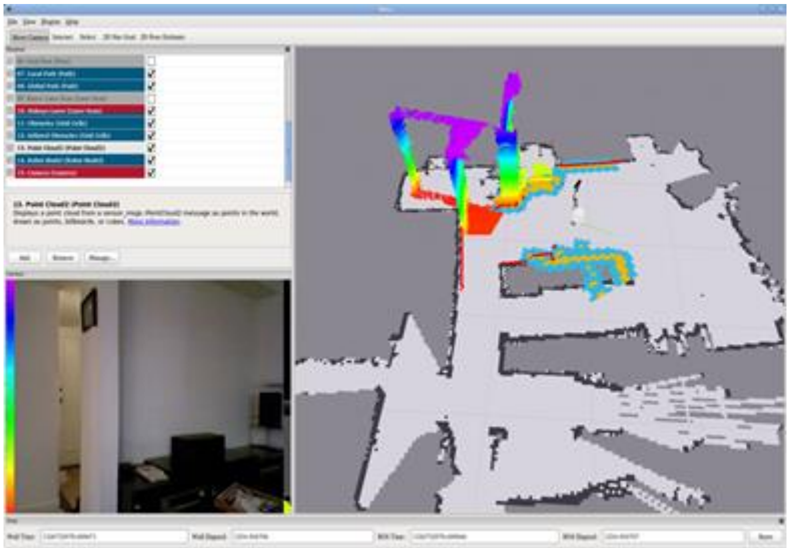

Figure 6: Examples of Path Planning and Mapping Capabilities

The Data Distribution Service (DDS)

While the virtualization of a single robot is obtained through the use of ROS, a standard communication protocol allowing agents to exchange information should be needed. Indeed the Service-oriented Architecture (SOA) protocols, based on services, are able to guarantee the interoperability among different systems; these protocols are widely used in many applications (i.e. C2 interacting in a battlefield by SOA) and represent a suitable communication method to connect different robotic agents. A specific SOA based framework, the Data Distribution Service (DDS), has been identified as the best publish-subscribe protocol to be adopted in the Hybrid World Simulator developed as testbed for MRS in NATO M&S COE. The original Data Distribution Service for Real-time Systems was designed by the Object Management Group (OMG) to address the need for real -time data centric architectures.

Since DDS is designed for Real-Time Systems with critical wireless applications, DDS is therefore suitable to manage communication and data exchange between AxS. The DDS v1.0 was released in December 2004 and the standardization process is continuing (DDS-XTopics 2010, DDS-TCP-IP 2012, …). DDS is adopted in many commercial applications (Smart Cities, Large Scale SCADA Systems, Train Control Systems, High Frequency Auto-Trading Systems, Complex Medical Devices) as well as within Defense (Naval Combat Systems, Unmanned Air Vehicle, Air Traffic and Control Management, and Aerospace Systems). This means that DDS is spreading in the context of military training systems too. However the main goal of DDS is to facilitate the efficient distribution of data in a distributed system; indeed it has a publish/subscribe communication architecture, supports object modeling and notion disseminating update to the object instance, a rich set of Quality of Services (QoS) policies, a strongly typed data model and support for state propagation including coherent and ordered data distribution (Joshi, 2006).

DDS introduces a virtual Global Data Space where applications can share information by simply reading and writing data-objects addressed by means of an application-defined name (Topic) and a key. A topic associates a unique name a data-type, and QoS related to the data itself. The type-definition provides enough information to the service to manipulate the data, and the coupling with QoS settings enables implementation optimizations. DDS has a notion of Partition QoS policy which could be used effectively to introduce a logical partition among the topics visible by a Publisher and a Subscriber; a Publisher and a Subscriber communicate only if they have a common partition name. DDS middleware distributes the data so that each reading participant can access “the most current values”, allowing also the propagation of the state information. In this way, the state propagation provides a compact way for an application to model a remote system, as well as allowing a late joining participant to behave as if it had seen the complete history of the system.

The DDS purpose is to provide a common application-level interface, a platform independent model that can be mapped into a variety of concrete platforms and programming languages. This makes DDS a suitable architecture to be used in various environments and easily applied to different configurations as the ones where AxS operate.

Real Time Robotics Interoperation – Case Study

Currently the NATO Modeling and Simulation Centre of Excellence (M&S COE) in Rome, is working on a case study of robotic interaction that involves real and virtual robots. Currently each robot runs the Robot Operating System and interacts with the other robots using the Data Distribution Services. The AxS used in M&S COE HVT communicates through a C-OFDM (Coded Orthogonal Frequency-Division Multiplexing) Wireless link underlying the DDS Domain.

An UGV (Unmanned Ground Vehicle) equipped with a Laser Scanner was guided in the Arena to get, real time, a 2D map of the environment. Subsequently a 3D Laser scanner and a High Definition Camera collect Data to create a Cloud of Points and a 3D scenario of the Arena. After map data acquisition, the UGVs are made autonomous and a mission starts. A virtual threat is placed on a specific location of the map, and three robots (one real and two virtual) are sent through the game area, to reach and deactivate the threat. The robot simulator, equipped with DDS interface, provides a 3D visualization of the scenario, showing the physical & virtual nodes cooperating together and moving around the map.

INTELLIGENT AGENTS FOR CREATING THE VIRTUAL EXPERIENCE

The Simulation Team developed over the years the IA-CGF (Intelligent Agents – Computer Generated Forces) that represent a set of units, libraries and Non Conventional Frameworks (NCF) devoted to control entities within synthetic environments. The IA-CGF are designed as federates to be integrated in HLA simulation and they were successfully applied in a wide spectrum of applications. For example IA have been successfully used to control both insurgents and terrorists (i.e. CAPRICORN and SIBILLA Simulators) and paramilitary units. IA-CGF have already been used in modeling and directing different kind of Autonomous Systems: they have been integrated in different federations such as ST_VP (containerized real-time distributed HLA port simulator operators training), ST_VIV(real-time agent driven simulation of autonomous vehicles that operates as swarms of AUV or UAV), and IA-CGF U-COIN (a stochastic simulator of joint operations involving UAV and other assets such as ground units, attack helicopters, planes)(Massei & Tremori, 2010; Bruzzone, A.G., Tremori, A., Massei, M., 2011; Bruzzone 2013).

In the proposed port federation IA-CGF will direct different entities (i.e. tugs, neutral units, military and paramilitary forces) as well as the autonomous systems; from this point of view the task execution and their evolution in single orders to a single vehicle could be organized in order to face the different management strategies.

IA-CGF entities have the capability to aggregate and desegregate based on external orders or on autonomous decisions; each agent perceives the situation based on its available resources and develop its own scenario awareness. This awareness could be a single UAS perception as well as the one of the MRS or of the Human Operation Supervisor.

Furthermore IA-CGF allow to model communications through heterogeneous networks. The IA-CGF operate as stochastic discrete event models and their perception of the scenario is based on fuzzy allocation matrices that allow the combination of the quantitative information with the qualitative importance and relevance of tasks or threats information. In past projects Simulation Team tested the capabilities of IA-CGF to direct actions in a collaborative way (ie, by requesting support to other entities in order to achieve the desired effects).

Based on the general requirements identified in this paper, the authors have introduced original IA-CGF Drones into a HLA federation (IA-CGF Drones Demonstrator) that reproduces a coast located scenario populated with several entities belonging to different parties (friend, foes, neutral, civil entities). This scenario currently includes assets such as surface vessels (i.e. a frigate, several USV, yachts, cargos, boats), aircrafts (i.e. helicopters and UAVs), underwater (i.e. UAV and gliders) and ground entities (i.e. caravans and UGV).

JOINT SUPERVISION AND COORDINATION FOR COLLABORATIVE AUTONOMOUS SYSTEMS

A proposed graphic interface for IA-CGF Drones Demonstrator (figures 7&8), reproduces the Intelligent Agents and is open to be integrated in the HLA Federation. The control of the Agents in terms of high level logic provides an interesting opportunity to develop new solutions for assigning high level task to MRS and UAS as well as to control their behavior. The concept here proposed refers to a supervisor system where humans could assign tasks, missions, high level orders and, at the same time, they can supervise the whole scenario and all of the drones' activities. Since these systems are becoming more collaborative and autonomous, some kind of evolved C2

(Command and Control) is required, therefore it is expected that, in the future, direct orders could be assigned to UAS and/or MRS using existing standards, but some specific frameworks to address their specific logic and controls are required. These systems will become an intermediate control between a single UAS driving device and Operation Command; during the test it emerged that the assignment of high level orders to multiple robotic systems required the definition of new specific functions, as well as a cockpit for controlling the actions.

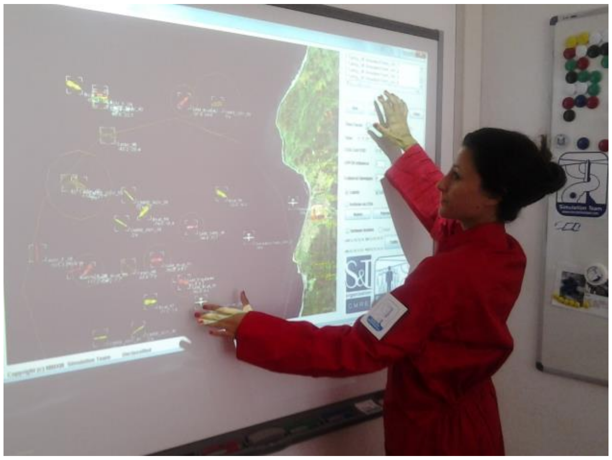

Figure 7: Experimentation on Interactive Whiteboard

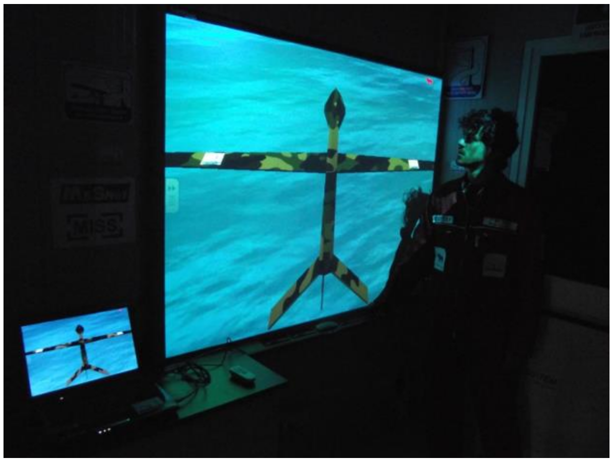

Figure 8: IA-CGF Drones during Demonstration

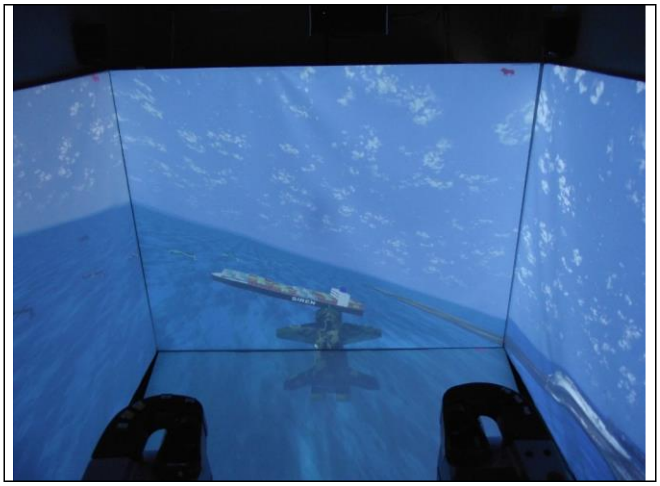

Figure 9: Experimentation on Interactive Whiteboard and Cube™ Solution to control UAV Swarms

This research addresses the requirements for such supervision systems as well as the implementation of tests for alternative solutions. The authors are currently investigating different solutions to develop these kinds of new systems with alternative interface solutions. Among the others, they are specifically considering an immersive interactive cave composed by an interactive whiteboard and a cube solution. A cave of this kind has already been developed by Simulation Team; the experience with the cube on Unmanned Virtual Control of two swarm of 12 UAV each was effectively tested within a small Cube™ (1.5m x 1.5m x 1.5) covering 270 Horizontal Degrees and 160 Vertical Degrees and including motion, sounds and ergonomics controls (see figure 9).

In the future, the authors will conduct tests on voice commands and specific man -machine interfaces based on movements and interactions (i.e. Kinetic™) in order to improve the immersive characteristics of the proposed solutions. In this paper preliminary experimentations are carried out in a complex scenario where one UAV, three AUVs and two UGV operate in a joint mission to control the area and to detect suspects that adopt camouflage, cover, concealment and deception techniques (*CCD*) to approach the port. In order to correctly define these behaviors, the following target functions have been defined:

- Insurgent Control Area (*ICA*) expressed as percentage of terrain under control of insurgents with respect to the whole area at *t* time; this measure is computed during the simulation and it is unknown to the coalition player, considering that the position and possibility of identification of insurgent in the area are partially known due to the fog of war and to their *CCD*

- Coalition Safe Area (*CSA*) expressed as percentage of terrain, is supposed to be under coalition control at *t* time

$$ICA(t) = \frac{\int_A D(X,t)dX}{A}$$

$$I\_PX(X,t) = \sum_{i=1}^{n_i} \left[I\_WP_i(t) \cdot H\left(\left| X - I\_UX_i(t) \right|_2 - I\_WR_i(t) \right) \cdot I\_Sts_i(t) \right]$$

$$C\_PX(X,t) = \sum_{i=1}^{n_c} \left[C\_WP_i(t) \cdot H\left(\left| X - C\_UX_i(t) \right|_2 - C\_WR_i(t) \right) \cdot C\_Sts_i(t) \right]$$

$$D(X,t) = H\left(I\_PX(X,t) - C\_PX(X,t) \right)$$

$$CSA(t) = \frac{\int_{t-\delta}^{t} \int_A S(X,v) \cdot FoW(X,v) \cdot \frac{\delta + v - t}{\delta} dXdv}{A}$$

$$I\_PXa(X,t) = \sum_{i=1}^{n_i} \left[I\_WP_i(t) \cdot H\left(\left| X - I\_UX_i(t) \right|_2 - I\_WR_i(t) \right) \cdot I\_Sts_i(t) \cdot I\_Dtc_i \right]$$

$$FoW(X,v) = \sum_{i=1}^{n_c} \left[H\left(\left| X - C\_UX_i(t) \right|_2 - C\_DR_i(t) \right) \right]$$

$$S(X) = H\left(C\_PX(X,t) - I\_PXa(X,t) \right)$$

$$H(y) = \begin{cases} y < 0 & 0 \\ y \geq 0 & 1 \end{cases}$$

ICA(t)	Insurgent Controlled Area at *t* time [0-100%]
CSA(t)	Coalition Safe Area at *t* time [0-100%]
X	Position on the Terrain (i.e. Latitude and Longitude)
A	Considered Area
δ	Time interval considered to be reliable for considering a part of the area safe after being checked
n_i	Number of Insurgent Entities on the Area
n_c	Number of Coalition Entities on the Area
H(y)	Heavyside Function
D(X,t)	Theoretical Predominance of Insurgents in position *X* at *t* time
I_PX(X,t)	Theoretical Force of Insurgents in position *X* at *t* time
I_PXa(X,t)	Perceived Force of Insurgents in position *X* at *t* time
$I\_UX_i(t)$	Position of the *i*-th insurgent at *t* time
$I\_WP_i(t)$	Weapon Power of the *i*-th insurgent at *t* time
$I\_WR_i(t)$	Weapon Active Range of the *i*-th insurgent at *t* time
$I\_Sts_i(t)$	Status in terms of operational effectiveness (0-100%) of the *i*-th insurgent at *t* time
$I\_Dtc_i\ (t)$	Detection Status of *i*-th Insurgents at *t* time (0 Undetected, 1 detected)
C_PX(X,t)	Theoretical Force of coalition unit in position *X* at *t* time
$C\_UX_i(t)$	Position of the *i*-th coalition unit at *t* time
$C\_WP_i(t)$	Weapon Power of the *i*-th coalition unit at *t* time
$C\_WR_i(t)$	Weapon Active Range of the *i*-th coalition unit at *t* time
$C\_DR_i(t)$	Sensor Active Range for detection of the *i*-th coalition unit at *t* time
$C\_Sts_i(t)$	Status in terms of operational effectiveness (0-100%) of the *i*-th coalition unit at *t* time
FoW(X,t)	Fog of war for the coalition in the point *X* at *t* time (1 known, 0 unknown)

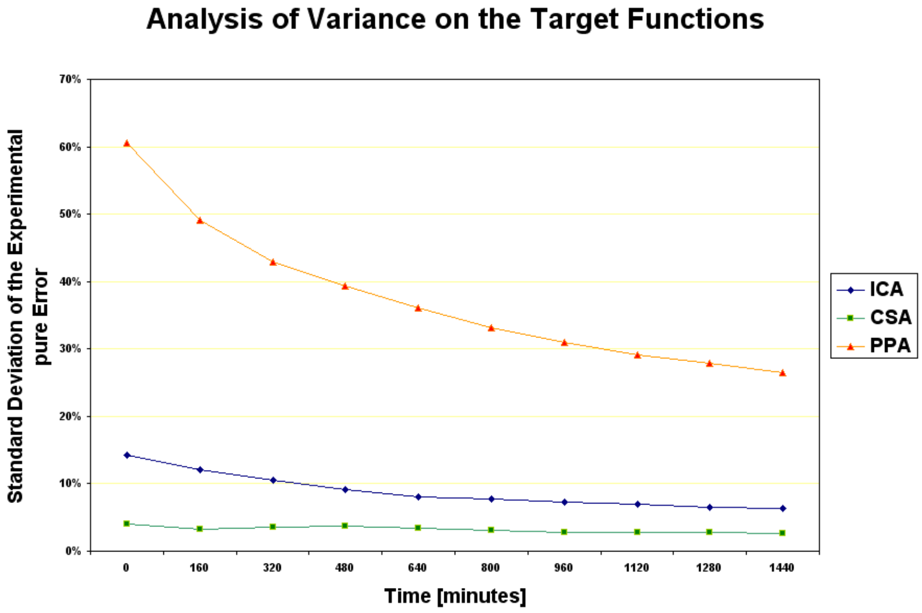

Figure 10. ANOVA in the Simulation Runs

These functions allow one to define metrics to evaluate the evolution of the scenario as well as the knowledge of the supervisor in the real situation; in the absence of fog of war, correct information, full coverage of the area, complete detection and estimation of insurgent forces the following relations should be correct:

$$ICA(t)=CSA(t)-1$$

Unfortunately this relation is not accurate in most of the cases; in fact, due to the above mentioned elements that affect both correctness and completeness related to scenario awareness, it is necessary to define a measure of Proper Perception over the Area (*PPA*) such as:

$$PPA(t) = 1 + CSA(t) - ICA(t)$$

The use of these metrics during a training session where Humans control the Supervisor System to direct multiple UAS and MRS allows one to estimate their capabilities in terms of skills as well as performances of their operative procedures. The result is obviously affected by effectiveness algorithms driving the intelligent agents of the autonomous systems. Some preliminary results of these indicators is proposed in figure 10 with respect to the current scenario. The plotted data represent the results of an Analysis of Variance (ANOVA) which allows one to estimate over time the tolerance on each target function in terms of the pure error; the pure error is the one affected just by the stochastic components of the simulations.

CONCLUSIONS

This paper represents a focused investigation about the possibility of creating an interoperable simulation framework to address the complex joint scenarios in which AxS interact and collaborate as entities or MRS. The proposed approach addresses some of the critical issues and identifies the general architecture to face the associated problems and to develop new simulators. The proposed federation of simulators enhances the possibility to experience new solutions to supervise swarms of drones and to direct their collaborative actions considering an extended autonomous paradigm.

In order to deal with these challenges, the importance of properly defining the technological solutions and the general architecture as well as the specific approaches to model the drones and their ICT emerges. Special attention must be paid to the soft computing aspects related to the intelligent behaviors that are crucial not only for the development of new agents but especially for the evolution of the human role from Human in the Loop to Human on the Loop. This concept changing requires the identification of new scenarios and the development of a new generation of training equipment based on open architecture and updated existing standards. The use of interoperable simulation is considered a very promising and decisive tool to test new solutions and, more importantly, to develop effective training to direct multiple robots collaborating over different scenarios. The authors are actively involved in deepening these visions and developing new projects taking into account specific mission environments and operative tasks.

REFERENCES

Bhatta P., E. Fiorelli, F. Lekien, N. E. Leonard, D. A. Paley, F. Zhang, R. Bachmayer, R. E. Davis, D. Fratantoni and R. Sepulchre: Coordination of an underwater glider feet for adaptive sampling, International Workshop on Underwater Robotics, Genova, Italy, pp 61-69, 2005.

Bruzzone, A.G.; Mosca, R.; Orsoni, A.; Revetria, R., "Simulation -based VV&A methodology for HLA federations: an example from the Aerospace industry,"Simulation Symposium, 2002. Proceedings. 35th Annual, vol., no. , pp.80,85, 14-18 April 2002

Bruzzone A.G., Massei M. (2007) "Polyfunctional Intelligent Operational Virtual Reality Agent: PIOVRA Final Report", EDA Technical Report

Bruzzone A.G. (2008) "Intelligent Agents for Computer Generated Forces", Invited Speech at Gesi User Workshop, Wien, Italy, October 16-17

Bruzzone A.G., Tremori A., Bocca E., (2010) "Security & Safety Training and Assessment in Ports based on Interoperable Simulation", Proceedings of HMS2010, Fes, Morocco, October 13-15

Bruzzone A.G., Massei M., Tarone F., Madeo F. (2011) "Integrating Intelligent Agents & AHP in a Complex System Simulation", Proceedings of the international Symposium on the AHP, Sorrento, Italy, June.

Bruzzone, A.G., Massei, M., Tremori, A., Longo, F., Madeo, F., Tarone, F., 2011. “Maritime security: emerging technologies for asymmetric threats.” In Proceedings of the European Modeling and Simulation Symposium, EMSS2011 (Rome, Italy, September 12-14).

Bruzzone, A.G., Tremori, A., Massei, M., 2011. “Adding Smart to the Mix,” Modeling, Simulation & Training: the International Defence Training Journal, 3, 25-27.

Bruzzone A.G. (2013) “New Challenges for Modelling & Simulation in Maritime Domain”, Keynote Speech at SpringSim2013, San Diego, CA, April

Calfee, S.H., Rowe, N.C., 2004. “Multi-agent simulation of human behavior in naval air defense,” Naval Engineers Journal, 116, no.4, 53-64.

Cooke N.J., Pringle H.L., Pedersen H.K., Connor O. (2006) "Human Factors of Remotely Operated Vehicles", JAI Press, NY

DARPA (2012) "Making Connections At 45,000 Feet: Future UAVs May Fuel Up In Flight", DARPA Information, October 05

Dogan A., U. Zengin, Unmanned aerial vehicle dynamic-target pursuit by using a probabilistic threat exposure map, AIAA Journal of Guidance, Control and Dynamics 29 (4) (2006) 944–954.

Feddema, J.T.; Lewis, C.; Schoenwald, D.A., "Decentralized control of cooperative robotic vehicles: theory and application, "Robotics and Automation, IEEE Transactions on, vol.18, no.5, pp.852,864, Oct 2002

Ferrandez J.M., De Lope H., De la Paz, F. (2013) “Social and Collaborative Robotics”, International Journal Robotics and Autonomous Systems, 61, 659-660

Grocholsky, B.; Keller, J.; Kumar, V.; Pappas, G., "Cooperative air and ground surveillance, "Robotics & Automation Magazine, IEEE, vol.13, no.3, pp.16,25, Sept. 2006

Joshi R., Castellote G.P., “A Comparison and Mapping of Data Distribution Service and High -Level Architecture”, Real Time Innovations, 2006 1-5.

Kalra N., D. Ferguson and A. Stentz: A generalized framework for solving tightly-coupled multirobot planning problems, Proc. of the IEEE International Conference on Robotics and Automation, April 2007, pp.3359-3364.

Kennedy, K.P., 2010. “Training: the key to keeping your head in a crisis situation,” Naval Engineers Journal, 122, no.3, 73-85.

Kracke, R., Hauge, J.B., Duin, H., 2006. “Training of strategic decisions in collaborative networks through serious games,” Network-Centric Collaboration and Supporting Frameworks Book Series, International Federation for Information Processing, 224, 305-312.

Kuhl, F., Weatherly, R., Dahmann, J., 1999. Creating Computer Simulation Systems: An Introduction to the High Level Architecture. Prentice Hall, Upper Saddle River, USA.

Lundquist, E.H (2013) "Navy Currents", Sea Technology, February, Vol 54, Issue 2, p77

Magrassi C. (2013) “Education and Training: Delivering Cost Effective Readiness for Tomorrow's Operations“, Keynote Speech at ITEC2013, Rome, May 22-24

Maravall D., J. de Lopea,b, R. Domíngueza, Coordination of communication in robot teams by reinforcement learning, Robotics and Autonomous Systems 61 (2013) 661–666

Martins, R.; de Sousa, J.B.; Afonso, C.C.; Incze, M.L., "REP10 AUV: Shallow water operations with heterogeneous autonomous vehicles," OCEANS, 2011 IEEE - Spain, vol., no., pp.1,6, 6-9 June 2011

Massei, M., Tremori, A., 2010. “Mobile training solutions based on ST_VP: an HLA virtual simulation for training and virtual prototyping within ports.” In Proceedings of the 2010 International Workshop on Applied Modeling and Simulation, WAMS2010 (Buzios, Brazil, May 5-7).

Michael N., J. Fink and V. Kumar (2007) “Controlling a team of ground robots via an aerial robot", Proc. of the IEEE International Conference on Intelligent Robots and Systems, San Diego, CA, Oct 2007.

Ören, T.I. and L. Yilmaz (2009) "On the Synergy of Simulation and Agents: An Innovation Paradigm Perspective", Special Issue on Agent-Directed Simulation. The International Journal of Intelligent Control and Systems (IJICS), Vol. 14, Nb. 1, March, 4-19.
Richards A., J. Bellingham, M. Tillerson, and J. P. How: Co-ordination and control of multiple UAVs, Proc. of the AIAA Guidance, Navigation, and Control Conference, Monterey, CA, Aug. 2002, AIAA-2002-4588.
Ross, S., D. Jacques, M. Pachter, and J. Raquet, (2006) "A Close Formation Flight Test for Automated Air Refueling," Proceedings of ION GNSS-2006, Fort Worth, TX, Sep
Shafer, A.J.; Benjamin, M.R.; Leonard, J.J.; Curcio, J., "Autonomous cooperation of heterogeneous platforms for sea-based search tasks," OCEANS 2008 , vol., no., pp.1,10, 15-18 Sept. 2008
Stilwell D. J., A. S. Gadre, C. A. Sylvester and C. J. Cannell: Design elements of a small low-cost autonomous underwater vehicle for field experiments in multi-vehicle coordination, Proc. of the IEEE/OES Au-tonomous Underwater Vehicles, June 2004, pp. 1-6.
Shkurti, F.; Anqi Xu; Meghjani, M.; Gamboa Higuera, J.C.; Girdhar, Y.; Giguere, P.; Dey, B.B.; Li, J.; Kalmbach, A.; Prahacs, C.; Turgeon, K.; Rekleitis, I.; Dudek, G., "Multi-domain monitoring of marine environments using a heterogeneous robot team,"Intelligent Robots and Systems (IROS), 2012 IEEE/RSJ International Conference on, vol., no., pp.1747,1753, 7-12 Oct. 2012
Sujit, P. B.; Sousa, J.; Pereira, F.L., "UAV and AUVs coordination for ocean exploration,"OCEANS 2009 - EUROPE, vol., no., pp.1,7, 11-14 May 2009
Tanner H. G. (2007) "Switched UAV-UGV cooperation scheme for target detection", IEEE International Conference on Robotics and Automation, Roma, Italy, April 2007, pp. 3457-3462.
Tanner H.G., D.K. Christodoulakis, Decentralized cooperative control of heterogeneous vehicle groups, Robotics and Autonomous Systems 55 (2007) 811–823
Tether, T. (2009) "Darpa Strategic Plan", Technical Report DARPA, May
Vail D. and M. Veloso: Dynamic multi-robot coordination, In Multi-Robot Systems: From Swarms to Intelligent Automata, Vol II, 2003, pp. 87-100.
Zini A. (2012) "Virtual Ship: Dream or Reality", Keynote Speech at Summersim 2012, Genoa, July

WEB REFERENCES

http://portals.omg.org/dds
http://www.playerstage.sourceforge.net
http://www.willowgarage.com