Synthetic Environment for Robotics and Autonomous Systems

LTC Marco Biagini
NATO Modelling and Simulation COE
Rome
ITALY

mscoe.cde01@smd.difesa.it

Cap. Salvatore De Mattia
NATO Modelling and Simulation COE
Rome
ITALY

mscoe.cde04@smd.difesa.it

Massimo Pizzi
NATO Modelling and Simulation COE
Rome
ITALY

pizmasio@gmail.com

Col. Michele Turi
NATO Modelling and Simulation COE
Rome
ITALY

mscoe.director@smd.difesa.it

LTC Bradley Koerner
NATO Modelling and Simulation COE
Rome
ITALY

mscoe.dir02@smd.difesa.it

Marco Picollo
Leonardo
Genova
ITALY

marco.picollo@leonardocompany.com

ABSTRACT

The employment of Robotic Autonomous Systems (RAS) and robotic swarms in the future military operational environment is going to be one of the main challenges to modern warfare. NATO Modelling and Simulation Centre of Excellence (M&S COE) has been developing the Research on Robotics for Concepts and Capability Development (R2CD2) project since 2016 to deliver in three annual phases an open, scalable, modular, standard-based prototypical architecture of M&S tools for experimentation on RAS and Robotic Swarms. In detail, it focused on experimentation of the extension of the C2SIM standard to Unmanned Autonomous Systems (UAxS) for the exchange of orders and reports between Command & Control (C2) and simulation systems. The R2CD2 2nd generation architecture implemented a tactical network simulation and cyber effects capabilities, to support the experimentation and proof of concept for a recognized cyber picture layer in a military Common Operational Picture (COP) representation, to extend and improve the RAS and swarm Situational Awareness at Tactical and Operational levels. The experimentation, conducted in 2020, proved the feasibility of complex interactions among different systems in three different locations through several interoperability standards.

The last generation of this architecture, named R2CD2 EVO, introduces virtual simulation, a real Ground Control Station (GCS) for real and simulated Unmanned Aerial Systems (UAS) and a C2 system to provide a RAS/Swarm COP that includes the cyber layer. The platform allows us to study, analyse and counter-measure RAS systems and swarms, highlighting a behavioural script describing the process reacting to external stimulus from modelled sensors, according to mission tasks and dynamics attitude of the simulated system. The platform data setting scenario was developed implementing an urban environment based on a future mega-city model (WISDOM) and extends the wargaming concepts to RAS, acting as a training test arena, not only for standard training of personnel employing RAS systems during a military mission, but also as attitudinal training algorithms projected to capability development. As a result of the research and development activities, the R2CD2 EVO was proposed as the cornerstone for the development of a Synthetic

Environment for RAS to support Concept Development, Experimentation, Training and Exercise activities on multi-domain UAxS both for NATO and nations.

1.0 INTRODUCTION

Modelling and Simulation (M&S) enables support to Concept Development and Experimentation (CD&E) activities to investigate new technologies (such as autonomous robotic capabilities) and to define human-machine interactions linked to Command and Control (C2) of robots. In this field, it is also important to examine and study artificial intelligence applications for planning and execution of missions, and moreover, to support robotics system's decision making and self-learning capability. The NATO M&S COE has been developing the Research on Robotics for Concepts and Capability Development (R2CD2) project since 2016. Initially designed to support CD&E activities, the platform provides an open, scalable, modular and standards-based prototype architecture, for testing simulated robotic platforms in military operational environments with related countermeasures.

This capability was also designed to contribute to the testing of the C2SIM interoperability language within the MSG-145 (Modelling and Simulation Group). In detail, the Centre focused on the aspects concerning the extension of the C2SIM standard to Unmanned Autonomous Systems (UAxS), to obtain an exchange of orders and reports between C2 and simulation systems.

R2CD2 is based on a federated simulation architecture designed to make interoperable different tools, using the HLA (High Level Architecture – IEEE 1516) and Distributed Interactive Simulation (DIS) protocols, to combine the functional features of each simulator (Figure 1-1).

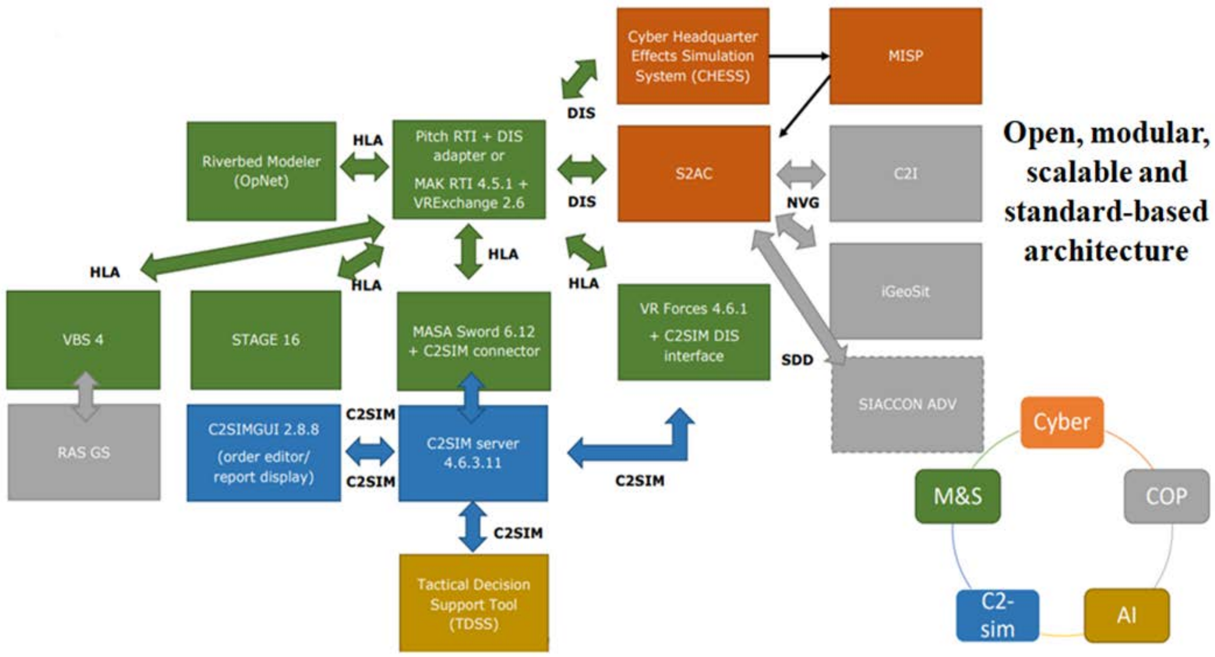

Figure 1-1: Complete architecture of R2CD2-EVO project.

The evolution of this project (R2CD2-EVO) was addressed in a study aimed to support the capability development of RAS platforms, proposing a synthetic environment architecture to carry out experimentation on autonomous robotic systems to be used in military operations. In addition, performing different simulations of the scenario, with the aim of adopting analytical considerations in relation to the stochastic results. The complete architecture includes, in addition to the mentioned tools, the integration of cyber effects services to conceptualize both the use of autonomous robotic systems in the cyber layer and the wargaming capability applied in the robotic field with specific applications (i.e., MASA SWORD) for the analysis of multiple Courses of Action (CoA).

M&S techniques were used to allow the development of behavioural codes for the unmanned platforms modelled within the simulators and to structure specific attitudes linked to a particular mission execution. Behavioural codes provide autonomy to unmanned systems, which must be able to adapt, with different reactive actions, to the surrounding conditions of the scenario. The triggers for the attitude engine consist of data detected by sensors modelled and placed on board each platform, with different functional performances, to correlate the individual operational actions at the technological level defined for each entity within the synthetic environment.

This project improvement further aimed to verify and validate the attitude of models implemented on the simulated platforms. M&S, creating a cyclical synergy between the simulated and the real world, would allow the ability to outline the peculiar and doctrinal aspects to adapt the autonomous actions of the platforms in diversified technical, operational and informational contexts. In this way is it possible to quantify the impact of autonomous systems on military operations and, subsequently, to study and implement technological countermeasures harmonized with Tactics, Techniques and Procedures (TTPs).

The NATO M&S COE, to support the Italian Army RAS CD&E Campaign, demonstrated to the Army General Staff the potential of implementing a RAS-SE architecture to support the ongoing and future CD&E activities related to Robotic Forces. Additionally, the Centre highlighted the aspects strictly connected to the development of behavioural codes dedicated to autonomous robotic platforms for the simulated entities. This architecture, in its first implementation, will be available to provide Computer Assisted Wargaming (CAW) capabilities at team, squad and platoon levels, and a Virtual Constructive federated Simulation. The latter includes humans in the loop to support experimentation activities, training and mission rehearsal, and to provide additional experimentation verification and validation activities regarding the robotic simulated entities and their modelled attitudes and characteristics.

2.0 ROBOTICS AND AUTONOMOUS SYSTEMS SYNTHETIC ENVIRONMENT

The idea to design and implement a Robotics and Autonomous Systems Synthetic Environment (RAS-SE) was born from the need to create a homogeneous environment made of several M&S tools and expert systems, federated and interconnected together, to provide a Virtual Constructive simulation capability adding to the architecture expert tools (AI driven application like TDSS – Tactical Decision Support System) and C2 Systems. Furthermore, the challenge was to make them available through a Modelling and Simulation as a Service (MSaaS) architecture.

The proposed platform represents a synthetic environment able to verify, validate and test the use of RAS in military operations of different types. The RAS-SE, in its full implementation, would allow, not only to develop and proof innovative concepts related to innovative and emerging disruptive technological, but also to define, develop, experiment and test peculiar doctrinal elements (TTPs) concerning the use of RAS, to support autonomous tasks related to accomplishing a mission while also taking into account the human-machine interaction.

2.1 Core Architecture

The RAS-SE architecture developed to support the early phases of the Italian Army RAS CD&E campaign is based on the R2CD2 EVO architecture, extending the simulation capabilities to the Virtual Simulation federating a Virtual Simulator, to the architecture selecting other core M&S tools, according to their specific features.

The HLA federation takes place through the activation of a middleware, called Run Time Infrastructure (RTI), which essentially acts as a communications bus to each simulator connected to share the main parameters. To configure the simulators for connection to RTI, it is necessary to set the main parameters characterizing the network within configuration files defining HLA standard.

The core architecture to support the RAS-SE project implements the following federated simulators, as listed (Figure 2-1):

- VT MAK - VR Forces.
- C2SIM client-server communication for emulating communication with a SISO-compliant protocol.
- Presagis - STAGE.
- Bohemia Interactive Simulations - VBS4.

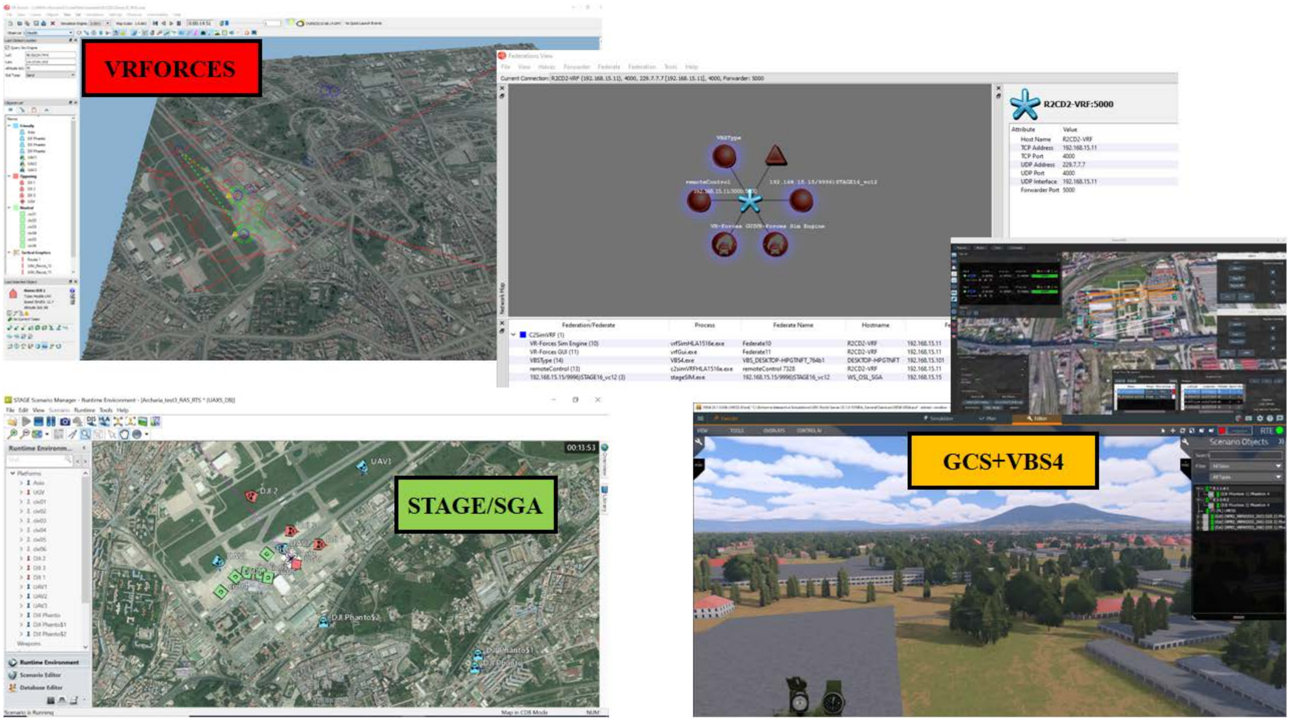

Figure 2-1: HLA federated simulation in the R2CD2-EVO project.

The simulators publish and subscribe entities and events according to the HLA standard: the sharing of information, in addition to a corresponding Federate Object Model (FOM) to define the structure of the incoming and outgoing information on each simulator. This also requires a mapping activity to allow a consistent representation of the events that occur on all the entities of the federation.

In this operational scenario, different RAS simulated entities with different levels of autonomy have been described. The attitudinal autonomy modelled within the synthetic environment is implemented in the form of a functional algorithm, or the development of a code (LUA), aimed at describing the processes constituting the behavioural mission of each system.

3.0 CYBER EFFECT SERVICES AND RAS SITUATIONAL AWARENESS

A first additional extension to the RAS-SE core architecture to enhance Robotic Situational Awareness is achievable augmenting robotic platforms with a cyber recognized picture informative layer by a MSaaS architecture, considering the impact in multidomain operations and the needs for a comprehensive Common Operational Picture at tactical and operational levels.

This add-on architecture (Figure 3-1) implements and improves the Cyber Effects R2CD2 EVO architecture with the spin-off application of M&S Services from another project developed by the M&S COE, namely the Virtual Security Operation Centre and Cyber Operational Cell.

In particular, the application of the MSaaS paradigm to the RAS-SE project completes and fully enables the concept for a real synthetic environment where applications and services could be made available 24/7 through a cloud-based infrastructure.

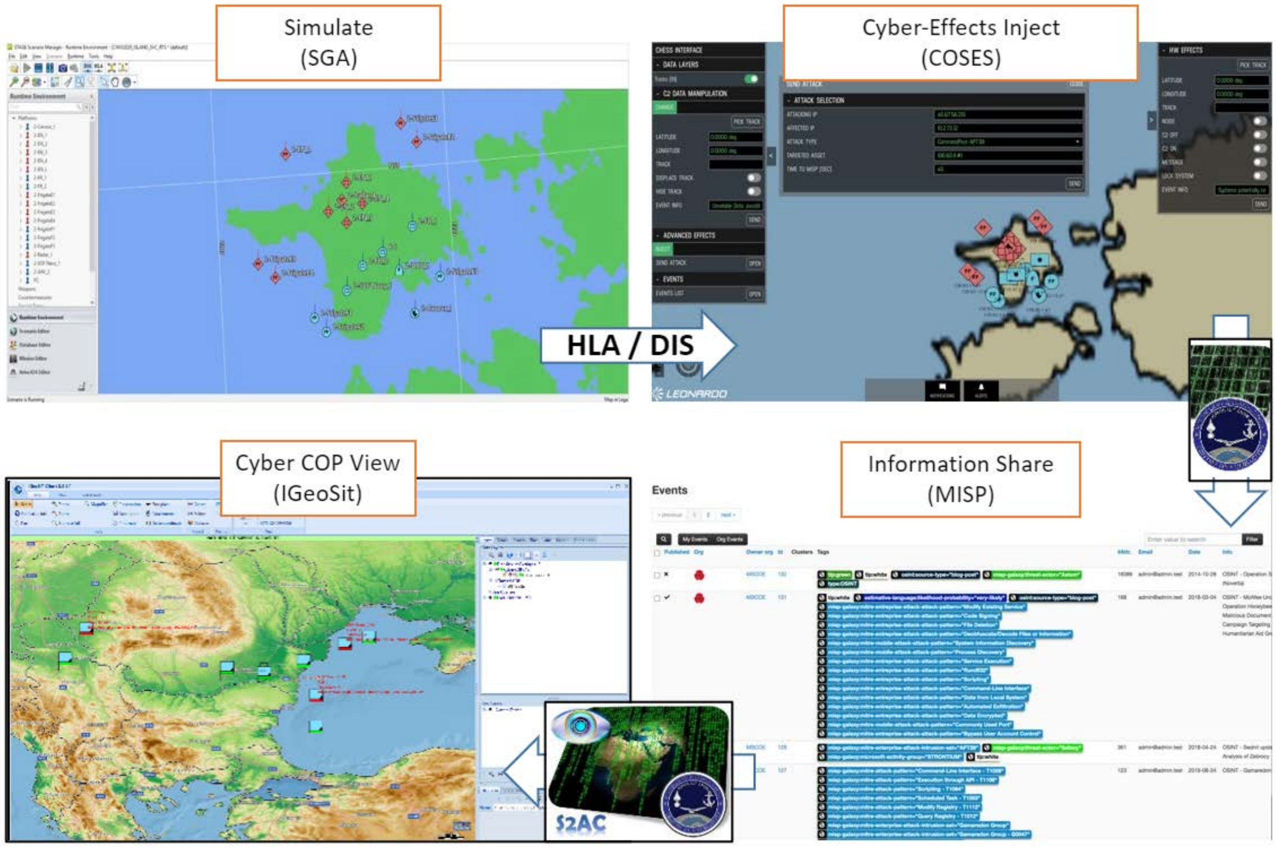

Figure 3-1: Schematic steps from Simulation to Cyber COP in RAS-SE architecture.

The cyber effects services architecture allows, through the available tools for experimentation, to proof the concept regarding possible effects that could be achieved in the cyber electromagnetic domain (CEMA), to protect friendly robotic forces and, eventually, to attack hostile unmanned robots. It does this by focusing on the electromagnetic space and the effects of possible cyber activities against the robotic platforms, the possible countermeasure and autonomous robotic behaviours, and in this case, focusing on the cyber TTPs to achieve such effects. The representation of the tracks of the simulated robotic entities on the battlefield, and their cyber status informative layer, are then visualized on military C2 Systems and COP viewers, adopting the NATO Federated Mission Networking (FMN) specifications and implementing the NATO Vector Graphic Protocol (NVG), and the military map symbols standard (MIL-STD-2525D change 1 and the NATO APP 6).

4.0 COMPUTER ASSISTED WARGAMING FOR RAS

One of the M&S tools leveraged with the RAS-SE project implementation is the constructive simulator MASA SWORD. The scope was to demonstrate and experiment the capability of this tool to be used in support of CAW activities, thus benefiting from the built-in analysis features. These features were evaluated to proof the concept for the future deployment of autonomous robotic platforms in operational environments operating with military land units in combat, combat support and combat service support activities, taking into consideration, hypothetical future operating environments in 2035 and beyond.

From a technical point of view, a RAS computer assisted wargame, as an alternative to a tabletop wargame, could be carried out with different teams operating with different simulators (human in the loop), or by taking advantage of using a platform (i.e., constructive simulator) where it is possible to plan the operation by teams and then to execute the CAW. The adjudication phase, in this case, will be devolved to the simulation that will provide the results of different alternatives based on their "quantitative" analysis.

In the CAW planning phase, Subject Matter Experts (SMEs) should be provided conceptual models of the expected RAS behaviours that should be designed and coded in attitudinal algorithms to be implemented on a specific simulated entity RAS model. This will allow the possibility for the Simulation system to analyse different courses of action in the use of autonomous robotic systems and to improve the attitudinal logic within the systems (Robotic Wargaming). The multiple simulations would allow the ability to acquire multiple operational cases to train the RAS platform modelled on a wide spectrum of causality, thus reducing the behavioural error differentials that can be verified in a process algorithm.

5.0 DESIGN, MODEL AND IMPLEMENT RAS BEHAVIOURS

The engineering skills applied to the M&S field, (e.g., the characterization and design in behavioural code), would provide a valid and essential aid for real prototype development. M&S activity for developing technological capabilities is a significantly important process in the context of the transformation of military forces within increasingly complex and multi-factorial scenarios.

The implemented synthetic environment could also allow the development of concepts and related behavioural models, and relevant elements, which could also be ported to upgrade a real RAS platform. The development of a real physical object (prototype) could follow a process based on the following steps:

- Identification of an unmanned system based on an "open" platform to connect different sensors (e.g., optical, infrared, radio frequency, radar, acoustic, lidar) to provide greater versatility of use to the platform.
- Modelling of the unmanned platform in terms of the main physical parameters to derive the complete dynamics of the simulated entity and achieve maximum correspondence with the real platform.
- Modelling of all sensors on unmanned platforms to verify their performance effectiveness in cases recreated within the constructive environment.
- Design of behavioural algorithms (e.g., via LUA programming language) with definition of execution priorities, with reference to the level of autonomy to be achieved on the platform. The designed algorithms are gradually tested within multiple simulations, carrying out a technical validation of what is present in the technical-operational requirements.
- Transposition of the algorithms within an electronic board (e.g., Field Programmable Gate Array and/or microcontroller) adaptable and consistent with the unmanned platform to provide it with different RAS capabilities, in terms of attitude processes to be performed. In this context, what is modelled and simulated in a synthetic environment is tested under realistic conditions by carrying out an operational validation of the system.

The multiple passages from the real world to the simulated one are essential for creating a reliable RAS system operating in diversified operating contexts, with the use of feedback for the development, verification and testing of the autonomous behavioural engine of the system.

Sensors are the components that allow the autonomous platform to make the changes from one behavioural state to another. Therefore, their modelling is a fundamental and necessary operation to perform the testing on the attitudinal algorithms of the autonomous system.

The diagram reports the proposed process using the M&S tools for capability development (Figure 5-1), highlighting the main processes concerning each phase and the related transitions. In this schematic diagram it is possible to underline the technical validation and the operational validation of autonomous attitude in a cyclic implementation.

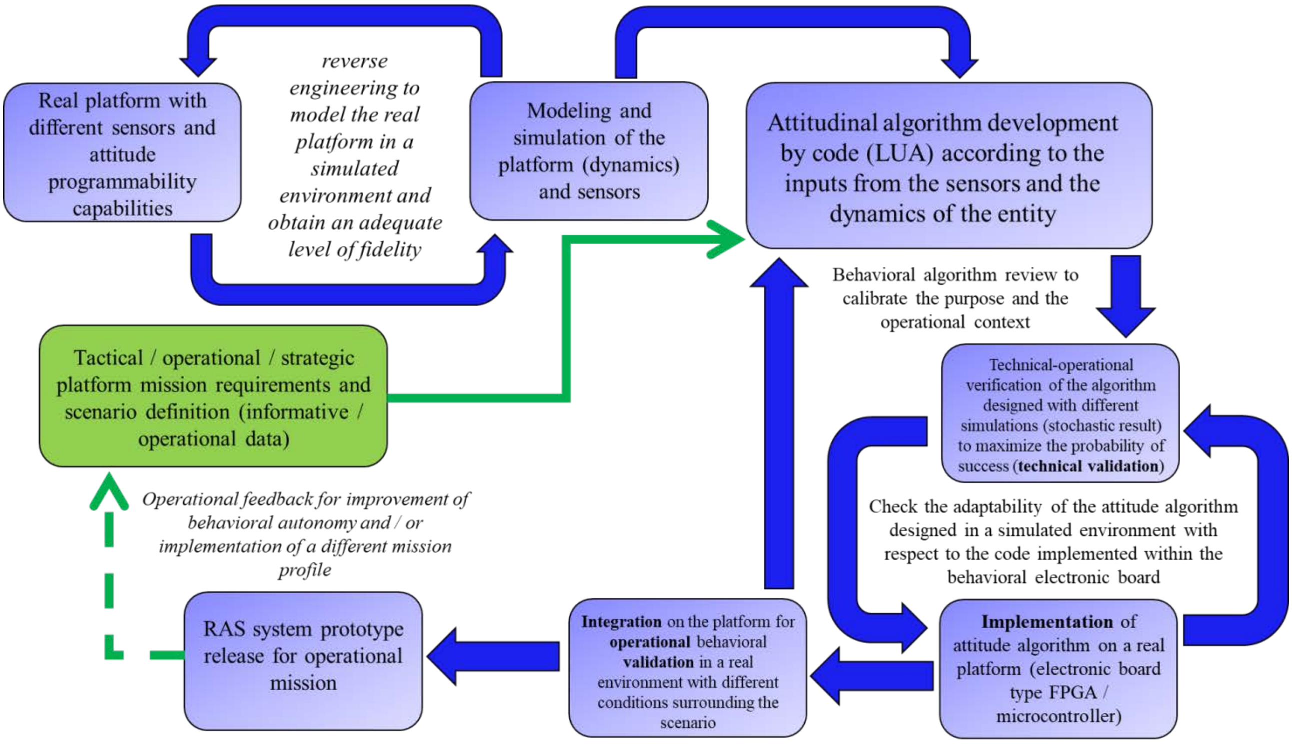

Figure 5-1: Schematic diagram of RAS capability development process using M&S tools.

5.1 Technical development of RAS capability

The platform presented and developed in the RAS context allows the adoption and endorsement of certain procedures of primary importance for the development of a complex capacity, where M&S can develop the primary design cornerstones and technical-operational verification/validation.

Through a scenario developed to show the use of RAS systems in military operations, the main points of interest can be defined, aimed at the study and implementation of a technological capability that can be used in the complex scenarios of the future. The elements of interest and the perspectives of the RAS project are listed below:

- The modelling of the complex scenario of the future (e.g., WISDOM) could facilitate the formulation of adequate technical-operational requirements for the development of a RAS platform. The scenario must be expressed under multiple and diversified layers (tactical, operational, strategic, electromagnetic, cybernetic, social, etc...), with the aim of developing a synthetic environment, where the simulation of the RAS platforms would allow the analysis of more realistic behavioural responses.

- A training platform for RAS systems would allow the concept of wargaming to be extended to autonomous systems, to study and analyse different courses of action.
- The modelling and simulation of the dynamics and of the peculiar components of the RAS platform is a complex operation from a technical point of view, due to the high engineering eclecticism required, at different levels of abstraction, in the knowledge of the subsystems suitable for the accomplishment of missions. In particular, the fundamental components to be modelled and simulated include the platform sensors, which will act as the main element of generation and processing of the data characterizing the surrounding environment. The values provided by the sensors constitute the process stimuli for the behavioural engine of the RAS system and to provide adequate attitudinal decision-making.
- The behavioural algorithms developed must constitute simple integration operations within an electronic board to be connected to the RAS system. The translation of the algorithms from the simulated environment to the real one, is a fundamental operation for carrying out the verifications/validations of the project and to fully exploit the results obtained during the behavioural analysis of the autonomous system. In this step, it would be better to correlate the development of the behavioural code within an algorithm based and compliant with ROS (Robotics Operating System) operations.
- The flexibility inherent in the use of a simulation for capacitive development favours the technical-operational feedback process, which is essential for the creation of a system that is fully suited to complex military needs. In this way, the attitude of the platform could be customized according to guidelines provided by the operational team of the Armed Forces, at the same time as multi-factorial parameters of an informative, operational and logistic type. The mentioned activity would allow a preparatory drafting of a doctrine on the use of RAS systems in the operational environments of the future to support military missions.
- The development of code within the simulators to structure a behavioural algorithm of the RAS system constitutes the basic technical activity of the autonomous platform. This step is closely related to the previous ones and should be contextualized with the level of autonomy to be given to the platform and the type of mission to be summarized within the decision-making processes.
- With the use of artificial intelligence, the attitudinal algorithms would reach a greater level of versatility and functionality, giving a significant and greater impact to the M&S tool to train autonomous platforms within a synthetic environment. In this way, the RAS platform, depending on the different conditions surrounding the scenario, could improve the behavioural responses in multiple external causalities and minimize the percentage of error, with the progressive mitigation of any decision gaps not calculated in the design phase.
- The platform for the simulation of RAS systems would allow to test and adopt countermeasures to robotic systems, through the implementation of complex models for the adoption of kinetic activities and not for the inhibition of autonomous targets. In this context, the decision-making implemented inside the platforms would require the integration of countermeasure systems within certain attitudinal processes, to obtain maximum effectiveness and allow the capabilities of autonomous systems to be extended to a remote and automated way.

A graphical representation of a cyclic simulated real-world process is shown in Figure 5-2. Starting from a real RAS platform, itis possible to create a high-fidelity model of that entity to be implemented into the synthetic environment that acts as a developed arena of physical and behavioural features of autonomous platforms in military operations. The basic idea to implement this cyclic process lies on an electronic board able to allow the simulated and real world in terms translated through feasible synthetic algorithms tested within the synthetic environment.

Through behavioural programming in a simulated environment, the starting point for a completely innovative and highly technological project is provided. The design of an electronic board integrating the behavioural algorithms defined, tested and validated in a simulated environment, with methods of interconnection with the logic of the autonomous system, would provide a turning point in the sector of robotic autonomous systems. The interconnection and interoperability with the logic functionalities of the platform relating to sensors and dynamics, would allow to assign a specific Level of Autonomy (LoA) level to a COTS (Commercial Off-The-Shelf) platform, with a low/null Level of Autonomy (LoA ≈ 0), implementing autonomous behaviours. This would allow the creation of an electronic behavioural card, whose code is tested, verified and validated in a synthetic environment, operationally usable and adaptable according to the scenario, operational requirements and TTPs. In addition, being capable of defining a predefined and versatile LoA, according to the mission, on an unmanned platform, to face complex scenarios and domains, where the threat is dynamically changing.

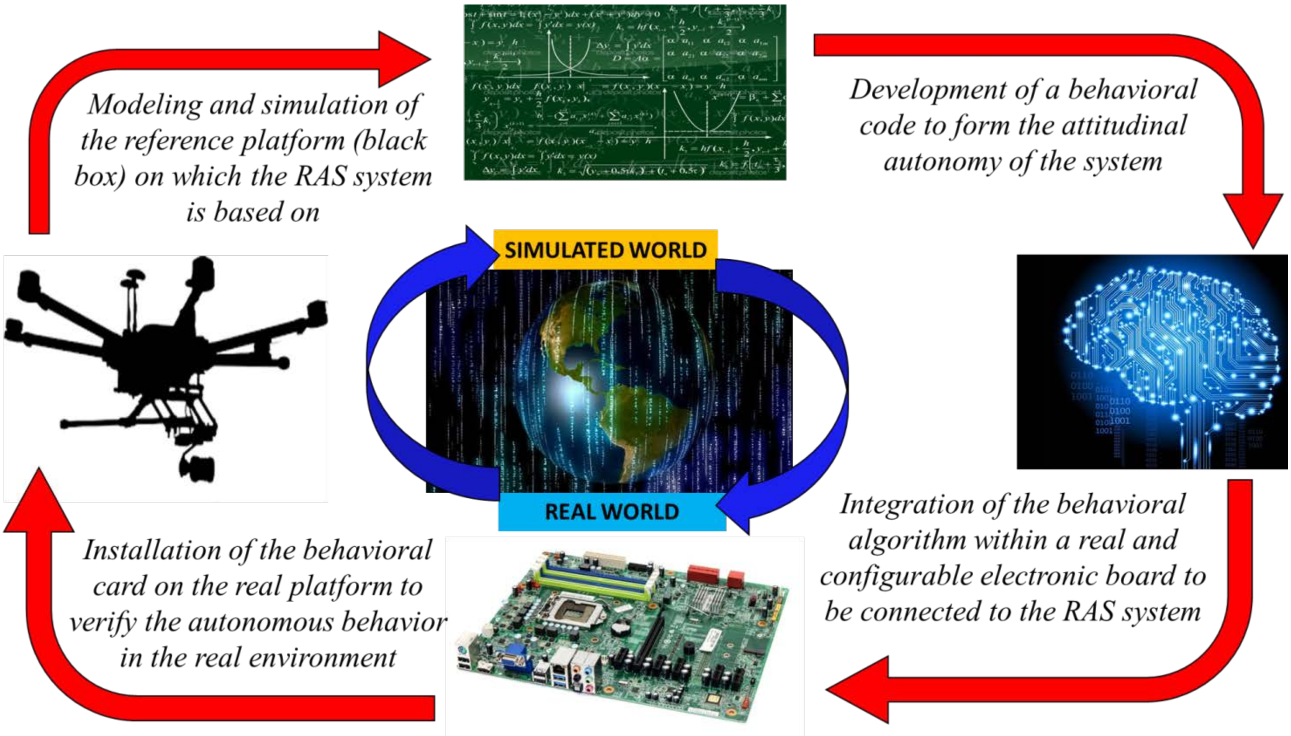

Figure 5-2: Graphical representation of cyclic simulated and real-world process for RAS development.

6.0 CONCLUSIONS AND WAY AHEAD

The RAS-SE is an enabling architecture designed to fully support, with a Modelling and Simulation as a Service approach, Robotic unmanned, autonomous and swarms concept development and proof of concept activities. The full implementation of such environments will allow research and development capabilities to support RAS and swarm capability prototype development and delivery and verification and validation of autonomous behaviours in relevant operational environments leveraging Live, Virtual, Constructive Simulations, as well as Expert and Artificial Intelligence Systems. Furthermore, developing dedicated hardware to port modelled behaviour algorithms, verified with simulations on real RAS, would create high fidelity RAS models.

The RAS-SE research activities to finalize a concept proposal and to design a complete architecture is still under development. A first prototype of the RAS-SE is available at the M&S COE and is scheduled to be used, initially with CAW activities, in support of the Italian Army RAS CD&E campaign.

REFERENCES

[1] Biagini, M., Corona, F.: Modelling and Simulation Architecture Supporting NATO Counter Unmanned Autonomous System Concept Development. In: Hodicky, J. (ed.) MESAS 2016. LNCS, vol. 9991, pp. 118-127. Springer, Cham (2016).

[2] Biagini, M., Corona, F., Casar, J.: Operational scenario modelling supporting unmanned autonomous systems concept development. In: Mazal, J. (ed.) MESAS 2017. LNCS, vol. 10756, pp. 253-267. Springer, Cham (2018).

[3] Biagini, M., Corona, F.: M&S Based Robot Swarms Prototype. In: Mazal, J. (ed.) MESAS 2018. LNCS, vol. 11472, pp. 283-301. Springer, Cham (2019).

[4] Biagini, M., Corona, F.: C2SIM Operationalization Extended to Autonomous Systems. Mazal, J., Fagiolini, A., Vasik, P. (eds.) MESAS 2019. LNCS, vol. 11995, pp. 389-408. Springer, Cham (2020).