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Research Article

Simulation-Based Training with Gamified Components for Augmented Border Protection

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ABSTRACT:

ARESIBO, an EU H2020 funded project, aims to improve the efficiency of border surveillance systems by providing the operational teams and the tactical command and control levels with accurate and comprehensive information by means of augmented reality (AR). This article describes the training system, with gamified modules, that was designed and developed within the project to deliver training on the AR applications developed to operators in border security missions. The ARESIBO Training System is fed by a set of interoperable, distributed simulators (Simulation Engine) comprised of detailed landscapes, realistic assets, and end-user vetted border control scenarios. By generating virtual incidents and situations, the Training System creates realistic operational conditions in which to train and employ the ARESIBO AR devices. It also includes the front-end tools and interfaces for the trainer to setup and execute the training sessions, such as the Trainer Editor GUI. Additional gamified modules were developed to investigate the effectiveness of serious gaming for training; these modules work both on- and off-line and independently of each other to maximize the autonomy of the trainer. This work concludes with a description of the training scenario and training events.

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Introduction

This article describes the work on the design and development of the training system with gamified modules and the delivery of the user training for the H2020 project ARESIBO. This work presents a collaboration between the Bulgarian Defence Institute (BDI) and the NATO Science and Technology Organization Centre for Maritime Research and Experimentation (CMRE), the two ARESIBO project partners involved in the design, organization, and delivery of the training manual, simulation based system, and the on-line and physical sessions.

In developing the training system, CMRE iterated with BDI and other end-users and project partners to determine an effective and efficient training methodology to achieve the project objective. Early designs incorporated serious games, but this approach was not widely embraced by end-users, who preferred a more traditional training approach. Additionally, expectations for the breadth and format of the training varied widely from brief sessions covering ARESIBO technical functions to multi-day operational trainings. As such, a compromise solution was developed as a primary training solution: Scenario-Based Training or SBT. SBT allows the training of ARESIBO technical functions within an operational context. Gamification, or the incorporation of game-like features in a non-game context, was included partly in the Training System and partly as an optional layer.

The ARESIBO Training System is a simulation based training system and, as such, is dependent on a Simulation Engine developed by CMRE. The Simulation Engine is developed in compliance with the IEEE standard HLA (STANAG 4603).[5] The development process followed the standard practice for distributed simulation DSEEP.[6] The developments included substantial customization of the environment to represent the various training areas and the creation of new assets to represent those included in ARESIBO. Enhanced realism in the simulation was a desirable feature to facilitate transfer of the training to real-world use of the ARESIBO system. Furthermore, to increase the immersiveness of the training, the Simulation Engine was set up to interface with the real ARESIBO end-user devices themselves. Finally, land and sea avatars were introduced that could be moved by the Field Officer to increase their feeling of presence in the simulated environment.

All the above designs and features came to fruition in a variety of project demos and training sessions, jointly designed and managed by BDI and CMRE, that are also briefly described in this paper.

Simulation Engine

As shared in the introduction, the foundation of the ARESIBO Training System is an advanced Simulation Engine, developed over the last years by CMRE,[2] that provides the context for the training. It also acts as a hub connecting the disparate parts of the Training System from the virtualized and simulated assets to the ARESIBO devices and applications to the trainers and trainees. CMRE Simulation Engine architecture is based on the High Level Architecture (HLA) standard. HLA is an open international standard, developed by the Simulation

Interoperability Standard Organization (SISO) and published by IEEE. It is a recommended standard within NATO through STANAG 4603.

Figure 1 shows the final ARESIBO federation composed of seven federates (simulators according to HLA terminology). In the schema, each coloured block represents a federate. The central grey rectangle is the federation Run Time Infrastructure (RTI) that allows the data exchange and synchronization among federates. Each federate has an arrow pointing away from itself representing the data published (produced) and an arrow pointing towards itself representing the data required (subscribed). Both arrows have labels, which provide a brief description of the exchanged data.

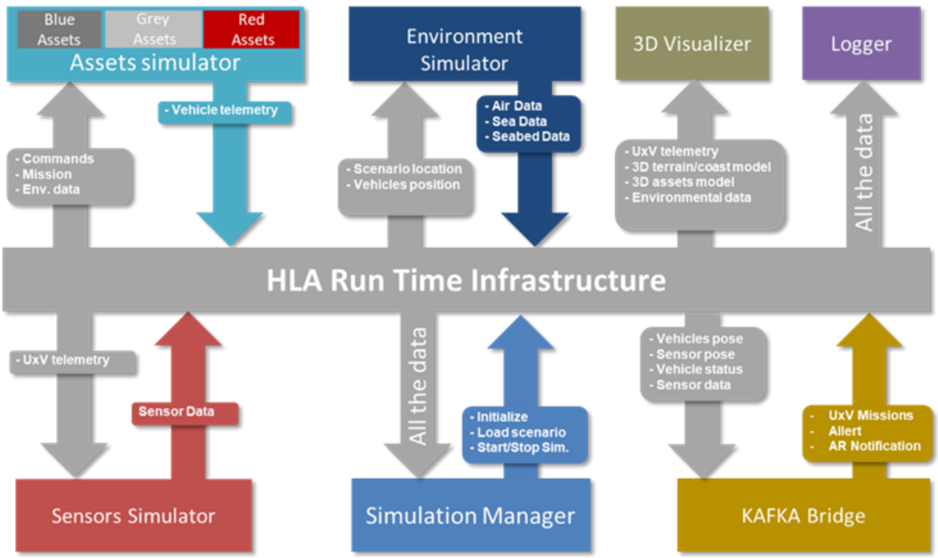

Figure 1: ARESIBO HLA Federation.

Below, a brief description of each federate is provided:

- Asset Simulator: The Asset Simulator simulates all moving entities inside the simulation environment.
- Sensor Simulator: The Sensor Simulator simulates the effect of a range of sensors in the ARESIBO operational scenario.
- Environment Simulator: The Environment Simulator generates a meteorological and oceanographic environment to influence a wide range of assets and simulation components.
- Simulation Manager: The Simulation Manager links to a set of modules to support the trainer to set-up and monitor simulations.
- 3D Visualizer: The 3D Visualizer or Visualization Federate displays an intuitive 3D representation in a virtual environment of the entire simulated scenario.

- Logger: The Logger federate collects all relevant information that is generated during the simulation.
- KAFKA Bridge: The KAFKA Bridge helps to reach both Semantic interoperability, by exchanging messages with other ARESIBO modules, and full functional integration, with the capability of reacting to the commands received from other ARESIBO modules and sharing data coherently with the received commands.

In order to build the most effective training environment possible, the authors aimed to develop a training capability that, from the point of view of the trainee, was as similar to the real system as possible. Nevertheless building a high-fidelity replica of the real system did not appear to be the best option, as there were technical, practical and economic constraints that needed to be taken into account. These considerations led to the identification of a final solution built on partial integration of real/existing functionalities integrated with ad hoc developed simulated capabilities. This, along with the analysis of the ARESIBO system characteristics, led to the list of prioritised objectives that guided the development of the Simulation Engine, found in Table 1.

Table 1. Simulation Engine Objectives.

ID	Description
Obj_01	The Simulation Engine must simulate border protection scenarios
Obj_02	The Simulation Engine must simulate the overall performance of the ARESIBO sensing/detecting capabilities
Obj_03	The Simulation Engine must provide a realistic, 3-dimensional synthetic environment representative of the geographical area of interest to allow immersive training
Obj_04	The Simulation Engine must be interoperable with the ARESIBO Training System
Obj_05	The Simulation Engine should be able to send and receive data on the ARESIBO message bus.

The development of the Training System, Simulation Engine and gamified modules followed an iterative Agile approach with multiple spirals. This approach allowed the CMRE to address the complexity of a multi-partner project, with diverging requirements and integration constraints with the technical partners, as well as to overcome the additional complexity introduced by the harsh restrictions imposed by the COVID crisis during the core phases of the project.

Training System and Gamified modules

Serious Game and Gamification Background

Clark Abt is typically credited with coining the term "serious games" and defining them as being games that "have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement." [1] In the last 50 years, this definition has not varied greatly but has been broadly applied to games that have been designed to serve a serious purpose. They are used in a wide variety of fields such as in the corporate world for training and advertising, in the public sector for informational campaigns, in the health sector for rehabilitation, and many more and can be found in almost any format from table-top to digital and from single to multiplayer, both collaborative and competitive.

The use of Serious Games can be an engaging and motivational means to learn new information and/or skills. They should incorporate methodologies for engaging game mechanics as well as cogent learning objectives.[9] There is no single theory that describes how best to achieve this goal,[10] and the effectiveness of the Serious Game will depend in part on the player's mindset.[7] One common aspect in learning theory is the existence of an optimal difficulty to challenge the learner, thus avoiding boredom, without frustrating him/her, which could lead to disengagement.[4] In the world of gaming, this is often referred to as "flow." [3, 8]

In a fully developed game, whether a serious game or an entertainment game, there are myriad game elements that contribute to the experience. Earning rewards, such as points or badges, progressing or levelling up, collecting resources, tackling quests, personalizing avatars, and socializing are all commonly used elements that contribute to and improve the game experience. Bringing some of these elements into a non-game experience is referred to as "Gamification." Gamification can provide many of the benefits of serious games without requiring the complexity or thoroughness of design needed to develop a complete serious game.

Training System

The ARESIBO Training System went through several design spirals primarily driven by CMRE (as Training System designers and developers), supported by BDI, and other end-users (as primary users of the Training System). Throughout these iterations, input was also given from other project partners, most notably the technical partners developing the Command and Control (C2), Tactical Commander (TC), and Field Officer (FO) applications, as the users of these applications were the targets of the training. Over the course of the project, a variety of ideas and proposals about the simulation based training system setup were presented to other project partners for review. The most important concept emerging from these discussions was "simulation in the loop", while another key idea was a multi-player approach. The former is an inversion of hardware and/or software in the loop simulation, a technique that increases realism and accuracy by bringing real-world elements into a simulated scenario. Similarly, in this project, CMRE brought simulated events and assets into an existing ARESIBO hardware and software system. Training on the real system followed a classic paradigm of training in the defence and security sector: "train as you fight, fight as you train." This paradigm prioritizes realism in training to ensure trainees are ready for real-world situations; incorporating simulated elements with real-world systems ensures effectiveness and efficiency in a safe-to-fail training. The latter, presented in detail below in Figure 2, serves two distinct purposes. Multi-player training can be an efficient method to train different roles to work together in the same system. Mistakes of one learner can be "teaching moments" for the team as a whole. Furthermore, social aspects are an important facet of serious gaming: multiple players working together in a collaborative environment can foster a spirit of camaraderie, helping the unit as a whole maintain motivation during training. Similarly, a competitive aspect between teams can further encourage participants to strive for their best results.

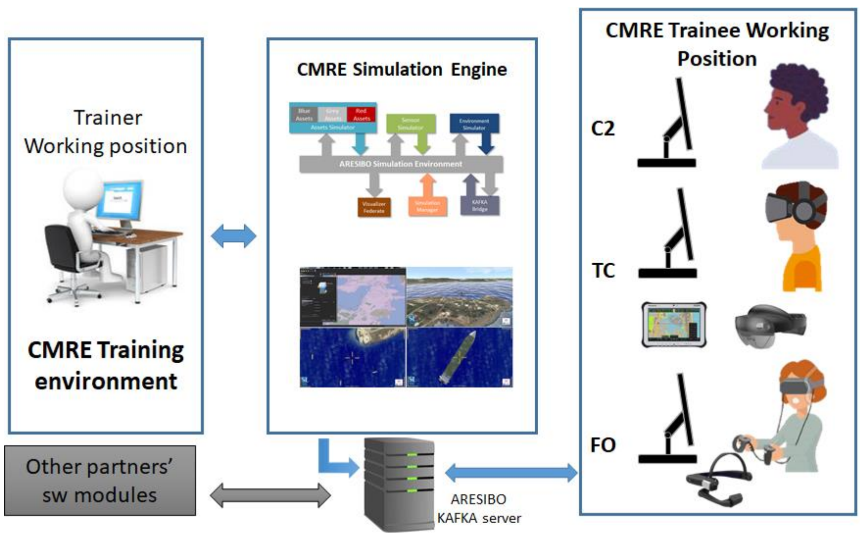

Figure 2: Simulation based Training System architecture.

As stated previously, the design of the Training System ran through several iterations, and among the final requirements that emerged from meetings with end-users and technical partners was to follow a consolidated MEL/MIL approach (Main Event List /Main Incident List)[1]. This implied the development

[1] The main event list/master incident development is the foundation of exercises in security and defence. In essence, MEL/MIL scripting is the content of the exercise along all phases (mainly execution), and it is intended to create training effects/outcomes. The scripting organised hierarchy starts with Storyline, Event, Incident

of a set of deterministic, user-controllable features to allow the trainer to have high level control on the execution of the training event and the fulfilment of the training objectives. The planning of the training followed this guidance and required a scenario to be designed in advance by the trainer targeting the correct events, thus producing or requiring the correct messages for an efficient and effective training. While the setup is more onerous, the operational context and suitability for multi-role training provide benefit to the trainers and trainees. The Scenario Based Training was adopted as the main approach with the possibility to leverage the tools of an alternative approach developed called Command Based Training (CBT). CBT allows the trainer to send commands or messages as desired, thus training ARESIBO functionality without any operational context. Combining SBT with CBT allowed the Training System to gain flexibility and scalability for the organization of the training events. The hybrid approach selected allowed:

1. compensation for missing Command and Control layers (e.g. the Field Officer) in the multi-level training.
2. the trainer to maintain full control of the training event and of the achievement of the training objectives by 'manually' injecting additional events or expanding the existing vignette by sending 'simulated' Kafka messages to the trainees.
3. the Trainer to have a dedicated workspace in the training sessions to monitor the training live and to inject messages. C2 and TC roles were trained simultaneously while the FO was emulated by the training system because the FO application was not stable enough to be integrated in advance with the training system.

Regarding point 3 above, the Trainer Interface was used to choose, set up, start and manage the training session. When the Trainer initiated the training session, the Trainer Interface communicated to the CMRE Simulation Engine to start the simulated training scenario. In turn, the Simulation Engine sent the simulated events/incidents and messages in the scenario to the ARESIBO interfaces in use by the trainees and messages to the ARESIBO KAFKA Server. Figure 3 presents the various interfaces used in the training system. The system involves many native ARESIBO elements in order to increase the realism and effectiveness of the training (as mentioned previously in the discussion of "simulation in the loop"). The three training roles span four interfaces: C2 desktop application, AR Tactical Commander application on Microsoft HoloLens2 or Tablet, and the AR Field Officer application on the Realware HMT-1. Additionally, trainees are supported by a PC screen that, for the FO, provides both the environmental context as well as the gamification layer, if used. The

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and ends with the final product the Inject. Its development is a dynamic and continuous controlled process where some external expertise is required at certain stages.

four trainee devices are in communication with the simulation engine as represented in Figure 3. Finally, the UxV Mission Editor and other Trainer Interface tools are shown on an additional screen.

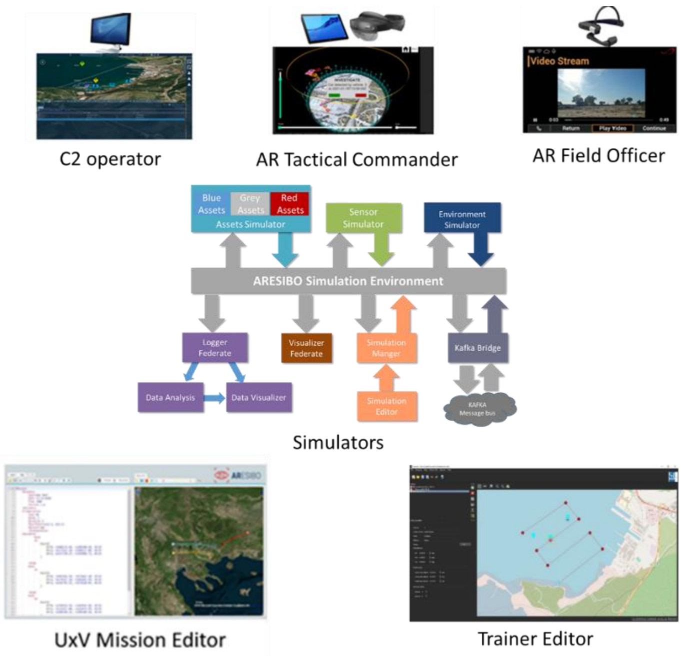

Figure 3: ARESIBO AR interfaces used in the training system.

Gamified Modules

During the collection of requirements, the trainers CMRE interviewed were reticent to include serious gaming or gamification in their training. As such, the ARESIBO Training System was designed to have an optional gamification layer that could be turned on or off at the trainer's discretion and house some gamification in a post-lesson visualizer, described below. To demonstrate the on-line gamification layer, the FO was a prime target.

One of the two major components of the gamification layer was on-line. During the training, the trainee could see an augmented layer that provided additional feedback, such as current position, distance and direction to target, and elapsed time. This allowed the FO trainee to use the HMT-1 hardware as they would in real-world use. Simultaneously, the trainee is able to see a 3D simulated environment, including assets, on a second screen. The gamification layer is superimposed as a Heads-Up Display (HUD) on top of this to create a 3D gaming environment. For other roles, the HUD can be displayed on an additional screen located in a convenient and comfortable location with respect to the player. Of course, the information included in the gamification layer would be optimized for each role. As shown in Figure 4, the gamification layer for the FO provides a sense of progression by showing the duration of the session. Additional information could be added, for instance with scores or performance indicators to increase the level of involvement of the player.

Another example of a useful feature of the gamification layer for training the FO is the blue arrow in the top right. This arrow shows the course to follow, manoeuvring the blue vehicle by a standard gamepad, to intercept the red asset with the distance to the target indicated for reference.

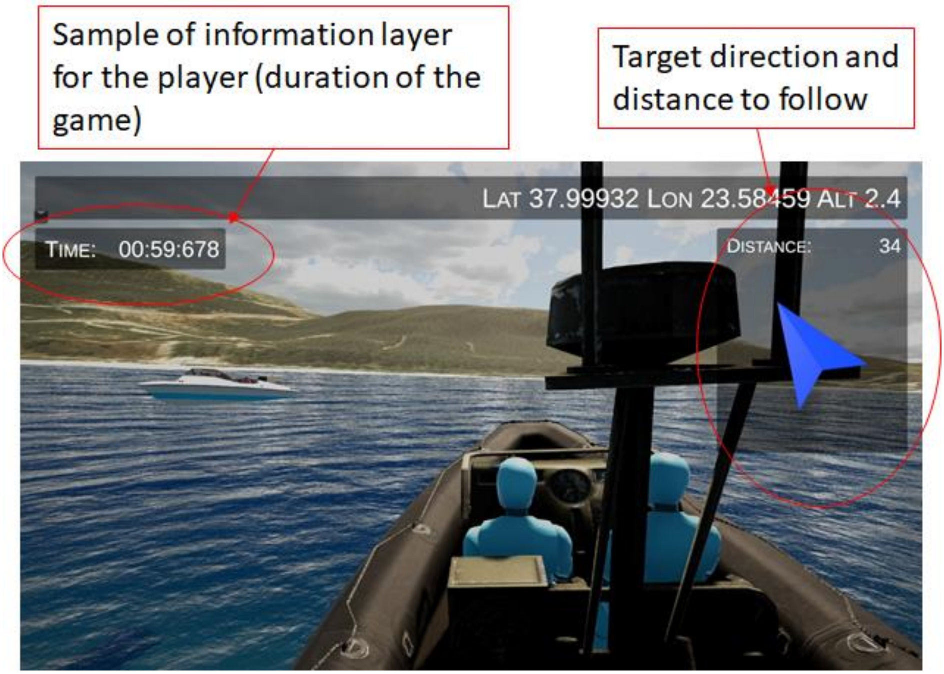

Figure 4: ARESIBO AR interfaces used in the training system.

An additional gamified feature was the possibility to train multiple Field Officers (human in the loop) at the same time with a multi-screen representation of different blue assets operated by different players (see Figure 5). Similar to team training, "squad training" or training a group of people in the same role can improve learning across the group as all are exposed to the lessons from individual mistakes.

The second main component of the gamification layer was off-line; in brief, it provided single and multi-team results in an intuitive, interactive web application. The single-team page highlighted progress, a fundamental aspect of maintaining engagement, while the multi-team page inspired competition through a leader board, motivating teams to strive for their best. In order to

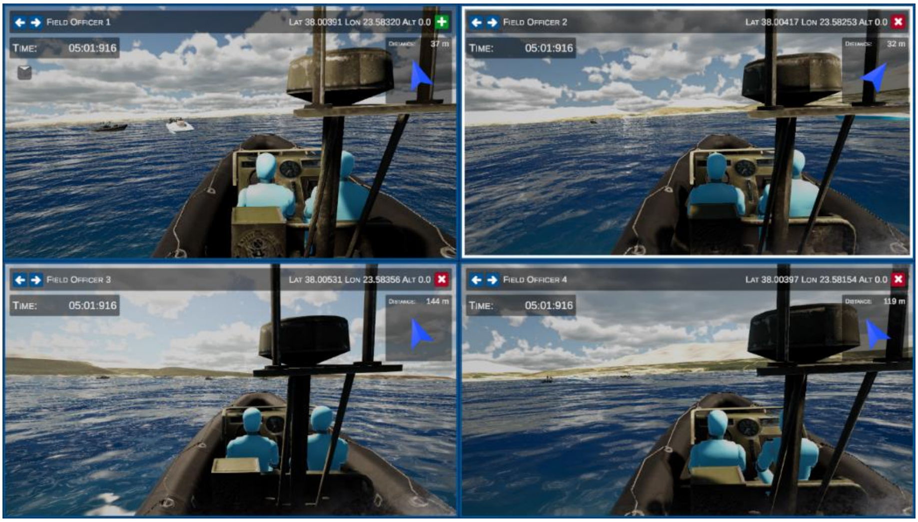

Figure 5: Multi-player mode for Field Officers.

enable efficient display of results, the CMRE Simulation Engine's logger federate produced detailed logs of simulated activities (See Figure 6 for samples of scoring and leaderboard interface). These logs were passed through the CMRE Simulation Analysis tool, which, in turn, produced the processed results that fed the CMRE Simulation Results Visualization tool that provided a fundamental component of the gamification layer.

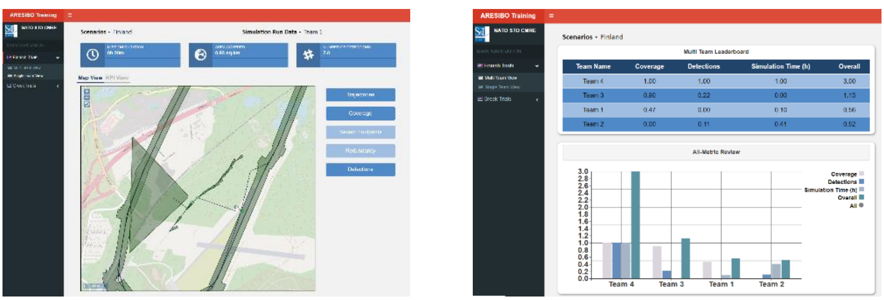

Figure 6: Scoring and Leaderboard.

One final aspect of gamification worth noting is immersion. Typical training, such as classroom training, separates the student from the material. Improving immersion can improve engagement with the material. Gamified scenarios can help achieve this goal by enveloping the student in the material rather than merely presenting it to him/her. In the case of the ARESIBO Training System, a high level of immersion in the training environment was achieved through the use of ARESIBO AR devices and applications in the 3D simulated environment.

Additionally, trainees could train within a fully virtual environment using a VR HMD; while this setup was also developed, it was not prioritized as it limits the use of the real devices.

Training Scenarios and Training Sessions

As detailed in the following paragraphs, the Training System could support both remote and in-person multi-player training sessions. Four different geographical areas were developed to support the different phases of the project.

Bulgaria

The original project plan included a trial, with a training session, in Bulgaria. As such, a dedicated scenario in the 3D Synthetic Environment was designed and developed with realistic characteristics of the area expected to host the trial. Since various circumstances both within the project and in general (such as travel restrictions imposed due to the COVID-19 pandemic) required these plans to change, the dedicated scenario was used for demonstrative purposes rather than for training. Figure 7 shows 3D Synthetic Environment elements of the Bulgarian scenario.

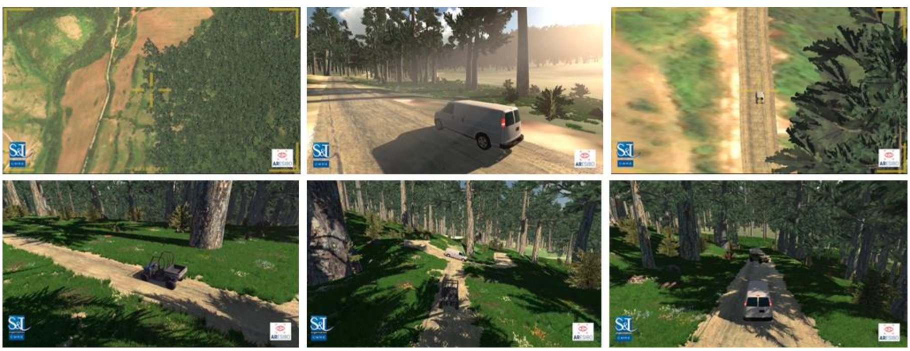

Figure 7: 3D Synthetic Environment elements of the Bulgarian scenario.

Portugal

For the meeting in Troia, during the exercise REPMUS21, a dedicated Portuguese scenario was created. The Simulation Engine was set up to run simulated scenarios non-integrated yet with the ARESIBO System in order to analyse the developments of the Simulation Engine and collect requirements for the Gamified modules and for the overall ARESIBO Training System (CMRE's primary goal for the meeting).

Figure 8 presents the 3D Synthetic Environment elements of the Portuguese scenario with views of the overall scenario, including multiple weather conditions, the blue RHIB avatar, and various assets.

Figure 9 presents the simulated Portuguese scenario designed to support the elicitation of requirements for the Simulation Engine and the Training System.

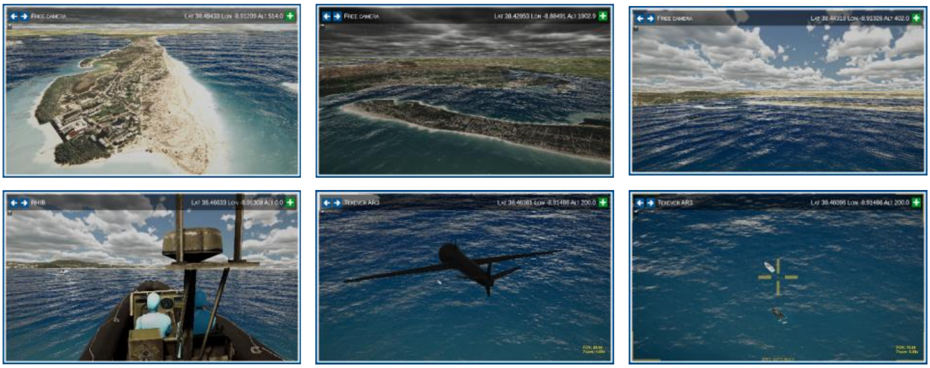

Figure 8: 3D Synthetic Environment elements of the Portuguese scenario (Troia peninsula).

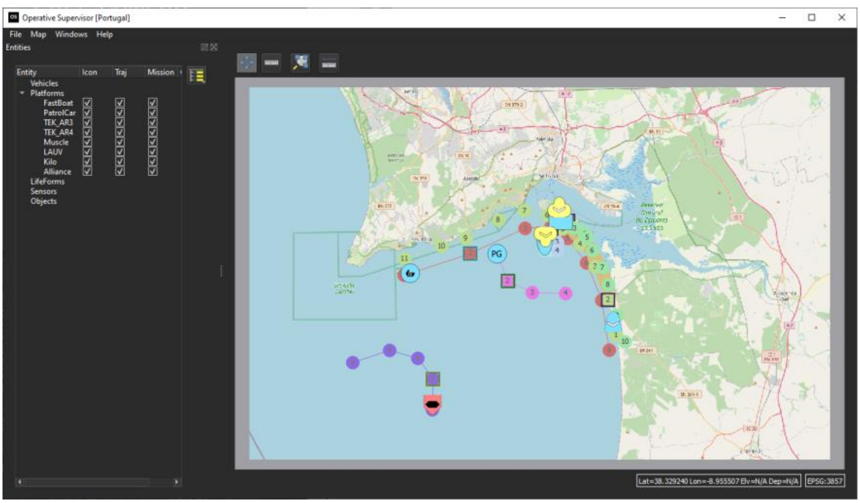

Figure 9: Simulated Portuguese scenario for elicitation of requirements.

Finland

Similar to the methodology used to prepare the Bulgarian scenario, the first step in preparing the Finnish Training Scenario was ensuring that the proper environment could be represented as well as the necessary entities for blue and red teams. In Figure 10, a selection of these are presented, including the appropriate environmental improvements to support the immersiveness of the training. Similarly, improving realism through the use of ARESIBO entities increased the accuracy of the training.

In Figure 11, we show the scenario/mission created for the Finnish trial. During this mission, the TC sends four out of five possible messages and receives all 13 possible messages in compliance with the ARESIBO data model. The C2 sends

Figure 10: 3D Synthetic Environment elements of the Finnish training.

three out of 6 message types and all 17 types of messages can be received. This scenario is efficient and targeted. The training scenario and the training vignette were designed with all the events concentrated in time and space requiring about 20 minutes to complete the execution of the simulation. In reality, each training session lasted about 1 hour with the training system paused several times to allow the technical partners to instruct the end-users and address their questions.

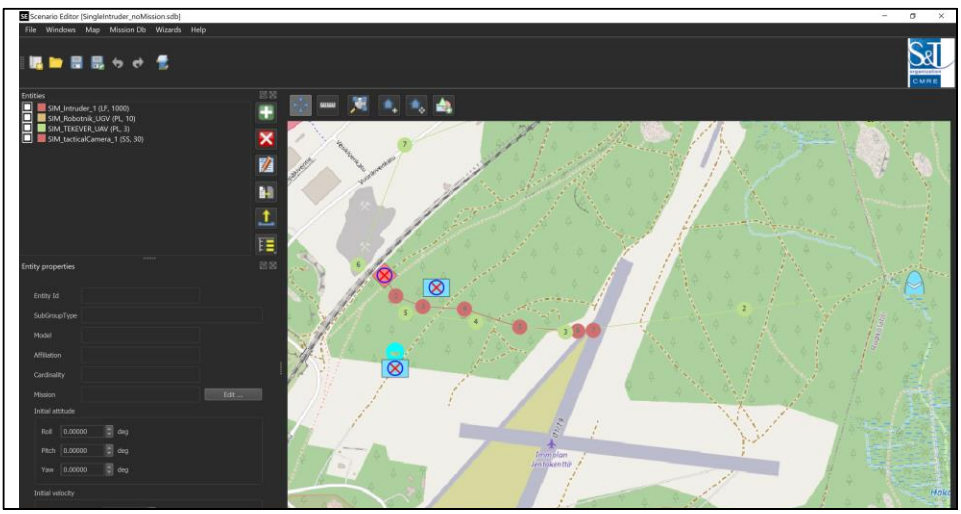

Figure 11: Finnish training simulated scenario.

The training during the Finnish trial was successful and allowed to fully achieve the original intent to "train as you fight" with the training system providing the proper level of realism with a well-coordinated sequence of events and actions on the ARESIBO system.

Greece

Similar to the previous scenarios, the environment was modified to model the Greek trial area, where the final project trial took place. A seacoast environment, including appropriate assets and vehicles for such an environment, were created for this scenario. Examples of this environment and assets can be found in Figure 12.

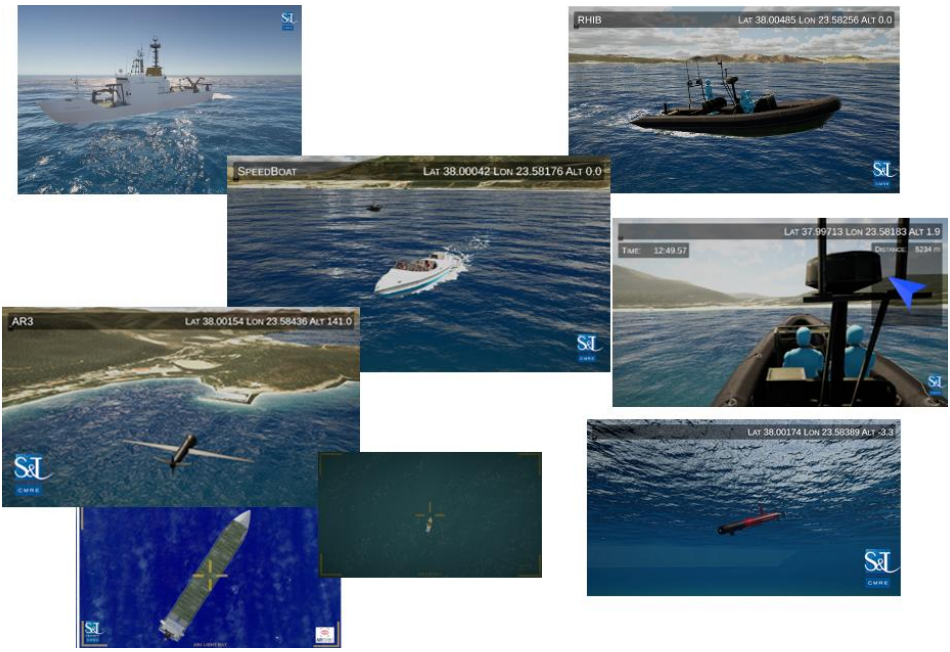

Figure 12: 3D Synthetic Environment elements of the Greek Training Scenario.

The Greek Training Scenario was created in the Trainer Editor, as seen in Figure 13. The Greek training vignette was significantly longer than the Finnish training vignette because this scenario was also meant to support a live trial (a maritime operation is typically longer than a land operation, and additionally the Greek scenario involved more assets than the Finnish one). The Greek trial had two training sessions: a preparatory one, on-line, and a physical one, at the beginning of the physical trial.

The On-line Training Session was organized one week before the physical training in Greece. CMRE supported this event with the training environment and by providing, in coordination with BDI, Airbus and VTT, a vignette dedicated to this event. The on-line training session represented the first opportunity for the officers of the Hellenic Navy involved in the subsequent trial to operate the ARESIBO AR devices and applications operating in a realistic scenario.

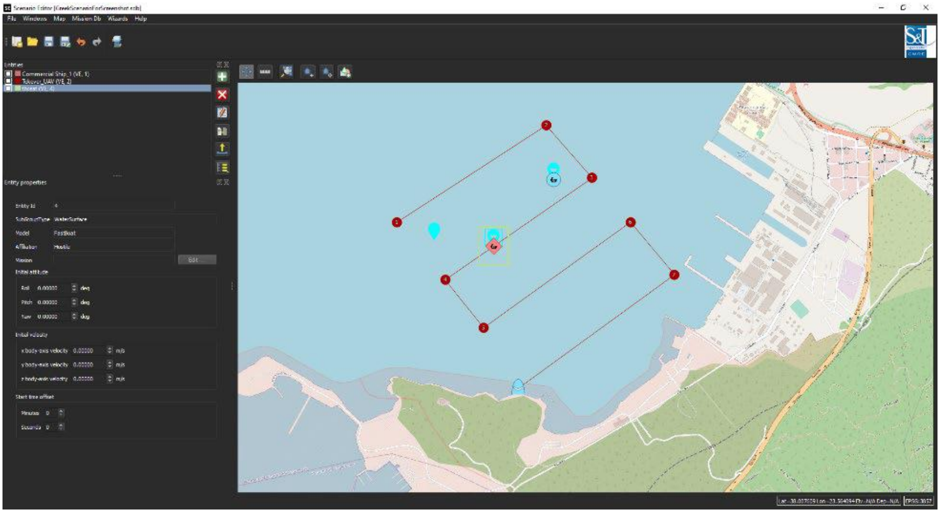

Figure 13: Simulated scenario for the Greek training.

The subsequent physical Greek training sessions were also successful, as with the Finnish ones, providing the opportunity to train the end-users in a realistic scenario. Nevertheless, we collected an important lesson learned: a simplified scenario only dedicated to training and focused on the training objectives (learning how to interact with the C2 and TC applications and devices), as was developed for the Finnish trial, was a more effective approach than focusing on a more detailed recreation of the live trial. The Greek training scenario was probably too long and with too much idle time between events for the trainees, in particular for the Tactical Commander. During the second session, it was decided to skip some steps focusing only on the events that were relevant for the training of the two operators involved in the mission, events that were included in the on-line training that was organized the week before in preparation for the trial.

Conclusions

This paper presents the efforts dedicated to designing, proposing and discussing different solutions for gamification and training with end-users and other partners of ARESIBO, an EU-funded R&D European project aiming at developing innovative AR applications for border protection.

The ARESIBO Training System was used in on line and live training sessions in trials in Finland and Greece. It was possible to configure the training sessions according to the main training objective (to train the ARESIBO System), creating simulated scenarios of variable complexity. In both trials, officers were trained in operationally relevant and immersive scenarios that matched the environmental and available systems conditions. Furthermore, while gamification was not emphasized for the trials, this aspect was explored from a research perspective. Several features were developed to this end that are illustrated and explained in this paper, even if it was possible to test or demonstrate only part of them at the live trials.

The innovative mix of capabilities of the Training System, built upon CMRE's existing High Level Architecture federation, allowed operators to train on a novel and innovative system. The authors were able to evaluate and validate the design of the training events and simulation, training and gamification approaches.

Among the lessons learned from the design, development and evaluation of the Training System, the authors confirmed the increased engagement in shorter, targeted training. Determining whether these shorter sessions are also more effective training tools is a future research goal. Furthermore, the authors note the interesting collection of requirements against gamification in favor of more traditional training features with experienced trainers. This finding requires further research to determine if the trainers would benefit from increased exposure to gamified training and the respective literature surrounding it to decrease its novelty.

By learning lessons in managing multinational, multi-partner M&S projects, the authors successfully supported live trials in Finland and Greece with preparatory on-line and in-person events that replicated the in-field conditions. Future research in this area will dedicate more time to finding a balanced approach between gamification and traditional approaches, with continuous support to the achievement of the training objectives over different phases, not only during the physical training sessions.

The final ARESIBO Training System mirrored the capabilities of the ARESIBO system and was able to provide training for those functions in an immersive form and optionally with gamified setting demonstrating also a great potential for further improvements and exploitation.

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Sasha Blue Godfrey is an interdisciplinary researcher skilled at building bridges between technical and non-technical communities and adept at working in both. With a PhD in Biomedical Engineering, she is experienced in the design of user-facing technology and gamified applications.

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