Assessing the Potential of Autonomous Multi-agent Surveillance in Asset Protection from Underwater Threats

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Abstract. A Serious Game (SG) system for the assessment of the potential of the multi-vehicle surveillance is presented. The SG system is applied to the problem of protection of strategic assets from underwater asymmetric threats. The SG platform integrates the active sonar performance evaluator able to estimate the real performance on the basis of the environmental conditions. The final goal is to provide new technology tools to realize a Decision Support System (DDS) to support the design phase of a naval unit. The SG system is developed in the framework of the ProDifCon project supported by the (DLTM) (Italy).

Keywords: Serious-game · Asymmetric threat · Active sonar system · Surveillance system

1 Introduction

Nowadays, *Serious Game (SG)* is an emerging technology able to take advantage of the power of computer games to engage users for a specific purpose. Thanks to its ability of combining entertainment in games and seriousness in education, SG is applied to skill training [1], education health care [2], military exercise [3] and various other areas. A gaming system allows scenarios to be played and replayed several times by modifying key-variables to test changes in components or outcomes. Furthermore, a SG system can accumulate learning from user experience, and incorporate the gained knowledge into subsequent rounds. In like manner, starting from the acquired knowledge and the user experience, it is possible to use Serious Games to assist during the design phase but also improve/optimize product requirements. In this context, this paper presents a SG system developed during the Integrated Design Control and Defense of Military Ship (ProDifCon) project to face the problem of asymmetric threats in maritime environment in order to develop and test innovative surveillance systems.

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The ProDifCon project has been designed with the main aim of developing new technology tools in order to realize a Decision Support System (DDS) implementing the idea of Whole Warship (WW): the ship represents a complete complex system composed of the resources of the naval unit, the Platform, and the Combat System (CS). In such framework, an important goal is the identification of a collection of possible countermeasures against asymmetric threats and the determination of the impact of such countermeasures during the project of the ship platform. The available surveillance sensors have reached high level of performance if operating in nominal conditions: these sensors (radar, electro-optic devices, Diver Detection Sonar (DDS) ...) are able to detect and classify asymmetric threats in time to perform deterrence through the proper escalation of forces [4]. However, unfavourable meteorological oceanographic conditions can cause the deterioration of the sensor performance and therefore the reduction of the time required for the proper escalation of forces that may increase the possibility of human errors, especially in stressful conditions [5,6]. In order to overcome the limitations of current surveillance systems and guarantee an adequate supervised area in any working conditions, the Interuniversity Center of Integrated Systems for Marine Environment (ISME) [12] identified as new surveillance systems those obtained by coordinating a heterogeneous network of remotely operated or autonomous vehicles equipped with standard surveillance sensors. The introduction of the innovative surveillance system involves the analysis of new tasks like: how to coordinate the vehicles to guarantee a proper level of coverage? Which kind of vehicles and which on-board sensors to use? ... Furthermore, the innovative surveillance system has direct impact during the design phase of a new ship, e.g. required lodging space for a sufficient number of vehicles, deployment facilities and ship equipment.

To find answers of these open problems, this paper presents a SG system able to test the effectiveness of the new surveillance system proposed within the ProDifCon project. The SG system developed by I.B.R. Sistemi s.r.l. [11] integrates the functionalities provided by the ISME performance evaluator of active sonar systems (e.g. DDS, Side-Scan Sonar (SSS)) able to predict the real performance of sonar system with respect to the environmental variables considered.

The paper is organized as follows. The operating scenario is described in Sect. 2; Sect. 3 presents the SG system and its main components. Section 4 illustrates the active sonar subsystem developed. Finally, Sect. 5 summarizes the work and draws the main conclusions anticipating the next applications.

2 Scenario

As described in Sect. 1 the actual surveillance system is effective for the threat protection if operating at nominal conditions. The deterioration of environmental conditions, and/or the particular tactical situation, can degrade the performance of surveillance systems. The disposition of the heterogeneous network of mobile sensors in the perimeter area of the naval platform may extend the coverage and, as a result, increase the time available for deterrence procedures.

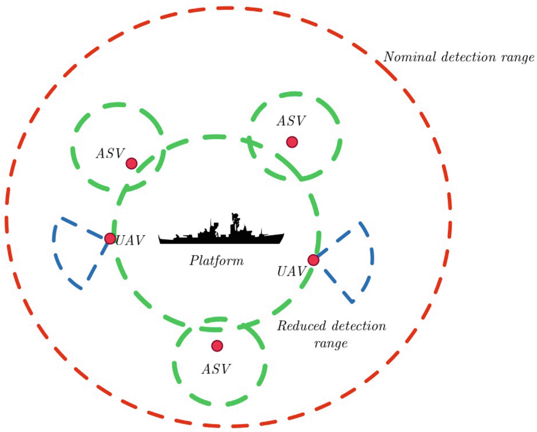

Fig. 1. Typical operative scenario of the proposed surveillance system

As an example, Fig. 1 illustrates the selected operational scenario where the reduced coverage of the on board surveillance system of the mother platform is partially counterbalanced by the use of autonomous or remotely operated vehicles arranged on the perimeter area of the mother platform. The proposed surveillance systems is composed by vehicles operating above the sea-surface, e.g. Autonomous Surface Vehicle (ASV), Unmanned Aerial Vehicle (UAV) and vehicles operating below the sea-surface like Autonomous Underwater Vehicles (AUV). In order to arrange the sensors carriers in perimeter areas of the mother platform, it is necessary to characterize the performance of the sensors used, depending on the environmental conditions. In this family of scenarios, the advantages over real-world exercise are plenty like the ability to include high-density traffic area, with no disruption to port or industrial facilities or the ability to embed new technologies. SG scenarios contribute important elements that real-world exercise has to avoid for economic or safety reasons.

3 Testbed

The partner I.B.R. Sistemi s.r.l. [11] is an Italian software house specialized in virtual reality in the marine simulation domain. As project partner, IBR Sistemi provided a custom version of its Joint Tactical Theatre Simulator (JTTS) [13], an advanced naval scenario simulator, developed for military and civilian maritime industry and research. The JTTS allows wide range of applications ranging from desktop trainer to cooperative full mission bridge simulator. Figure 2 shows an example of a civilian maritime simulation scenario.

The JTTS is characterized by a distributed architecture which components can be summarized as follows and schematically in Fig. 3:

- **Sea Manager** responsible for the management of the simulated scenario. Its components include environmental data (**Environment**) and the entities (component **Entity**), controllable or not involved in the scenario.

Fig. 2. Example of simulation scenario from the JTTS

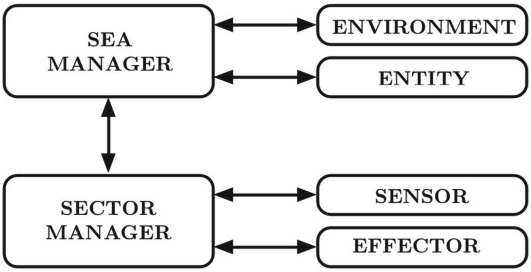

Fig. 3. Distribute software architecture of the JTTS

– **Sector Manager** responsible for the data flow and management between the environment and the controllable units: **Sensors** providing situation awareness by detecting and classifying hostile activities; **Effectors** able to apply stopping force (lethal or non-lethal).

The JTTS provides wide variety of sensors and effectors ranging from radars, binocular, laser range finder to rocket launcher and small arms and naval mines. Given the experience and background grained from the partner I.B.R. Sistemi s.r.l. in the field of naval simulation systems, the sensors deployed above the sea-surface are simulated in realistic way. These sensors, defined *Like Real*, are able to accurately reproduce the real dynamics under varying environmental conditions.

The Automatic Radar Plotting Aid (ARPA) simulator is able to generate the data flow as a real antenna emulating the propagation of the signal and providing as output high fidelity images. The simulator is able to provide different output under varying environmental conditions: e.g. different sea-state levels produce output images characterized by noise and clutter. Figure 4 shows the interface of the radar ARPA simulator.

The Electro Optic Device (EOD) is able to simulate the common electro-optic devices used during surveillance operations, with functionalities of detection and classification of possible threats. The interface EOD is able to

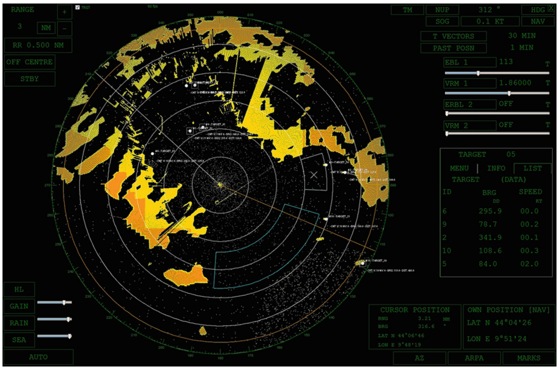

Fig. 4. Interface of the ARPA simulator provided by the partner I.B.R. Sistemi s.r.l.

Fig. 5. Interface of the EOD simulator provided by the partner I.B.R. Sistemi s.r.l.

generate images from the simulated environment. The performance of this family of devices change in particular working-conditions like fog, rain and different time of the day (e.g. daylight and night-time). The system enables the direct interpretation of the data by the human operator or by automated image processing algorithms. As an example, Fig. 5 shows an example of the output generated by the EOD interface. The JTTS platform is used for preliminary exercise of new concepts and evaluate the impact of the proposed surveillance system during the project of the ship platform and the effectiveness of the surveillance coordination algorithms for asymmetric threats protection.

4 Active Sonar Subsystem

Sonar systems represent by far the most reliable platform in the underwater coverage applications. As matter of fact, sound waves present low attenuation and long propagation distance compared to other sensing technologies (e.g. light,

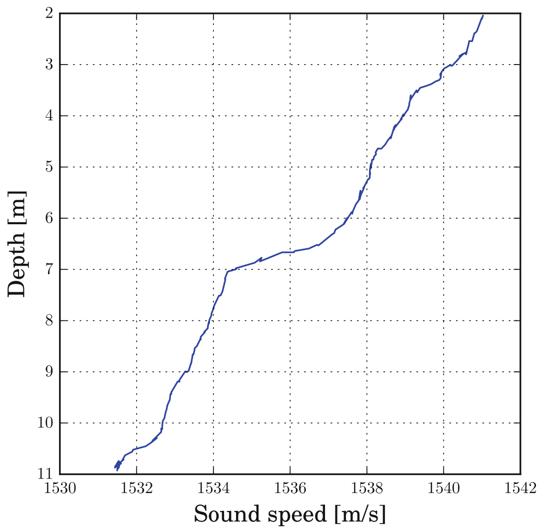

Fig. 6. Sound speed profile from data collected by a CTD during sea-trials in the Gulf of La Spezia (Italy) during July 2015.

magnetism, ...). The leading technology for detecting and tracking underwater intruders is active, monostatic sonar using principles of beam forming in its signal processing [9]. Environmental conditions and/or the particular tactical situation can significantly degrade the performance of sonar systems. The deterioration of performance due to environmental characteristics are mainly a result of meteorological and sea-morphological conditions: presence and variation of the thermocline and the morphology of seabed may reduce the operational range. In the same manner, the tactical choice of positioning components of the surveillance system along a particular route can interfere with performance of other sensors. As an illustration of the environmental variables involved in the computation of the sensor performances, Fig. 6 shows the sound speed profile from data collected by a CTD sensor during sea-trials in the Gulf of La Spezia (Italy).

Under these circumstances, it is necessary to determine the real operative performances of active sonar systems in function of the particular environmental/tactical situation. As matter of fact, Fig. 7 shows the comparison of the Signal to Noise Ratio (SNR) in function of the distance from the emitting source for an acoustic sensor characterized by a transmitting frequency of 70 KHz and source level of 220 dB. Considering a constant sound speed profile of 1500 m/s (green line) the SNR presents a decreasing trend until 70 m from the source and after that an approximately steady trend with a value of 20 dB at the distance of 400 m from the emitting source. On the contrary, considering the sound speed profile illustrated in Fig. 6, the SNR (blue line) is characterized by a decreasing

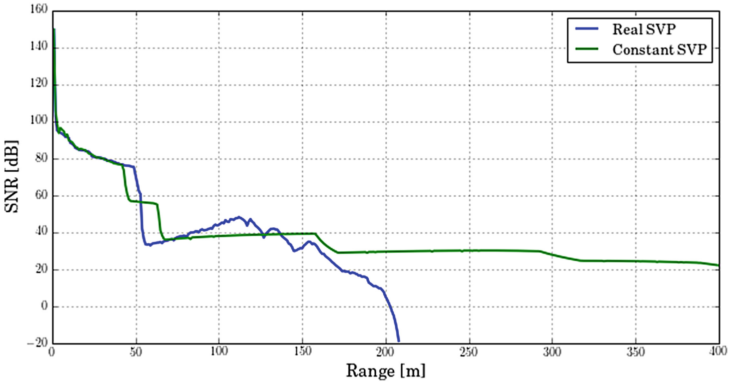

Fig. 7. Signal to Noise Ratio (SNR) in function of the distance from the emitting source, for an active sonar system characterized by a transmitting frequency of 70 KHz and source level of 220 dB. In green is depicted the SNR considering a constant sound speed profile of 1500 m/s. In blue is depicted the SNR considering the sound speed profile illustrated in Fig. 6.

trend similar to the other until 150 m from the emitting source; after that, the SNR continues to decrease reaching a value of -20 dB at the distance of 200 m from the emitting source.

The *active sonar subsystem* is responsible for the generation of joint probability maps of detection in the neighbourhood of the sensor units. This map expresses the probability of detecting an intruder belonging to a given class as a function of the spatial position of the intruder with respect to the sensor. To calculate the real capabilities of the sensor units, the subsystem implements acoustic mathematical models. Starting from the hardware specifications of the sensor units and the environmental information provided by the simulated scenario, the mathematical models are able to evaluate the sensor performance. The active sonar subsystem requires five types of environmental information: *sea state* - describing the general condition of wind waves and swell; *ambient noise* or traffic level; *rainfall intensity* - the amount of precipitations over a set period of time; *sound velocity profiles* - the speed of sound in seawater at different vertical levels and finally *seabed type* - the morphological characteristics of the seabed. The active sonar subsystem requires the operative specifications of the sensor unit including vertical and horizontal transmitter beam width, detection range, bandwidth, frequency and others.

Within the simulation scenario is possible to configure and place a variable number of active sonar systems also characterized by various hardware specifications, in order to define the anti-intrusion system. As shown in Fig. 1, such sonar systems can represent on-board equipment of a moving unit, like ships and AUV, or placed on a fixed position. The developed active sonar subsystem is able to simulate the behaviour of the most common underwater surveillance sensors like: Forward Looking Sonar (FLS), SSS and DDS. Figure 8 shows an example of the probability map of detection computed for a common DDS placed at 5 m

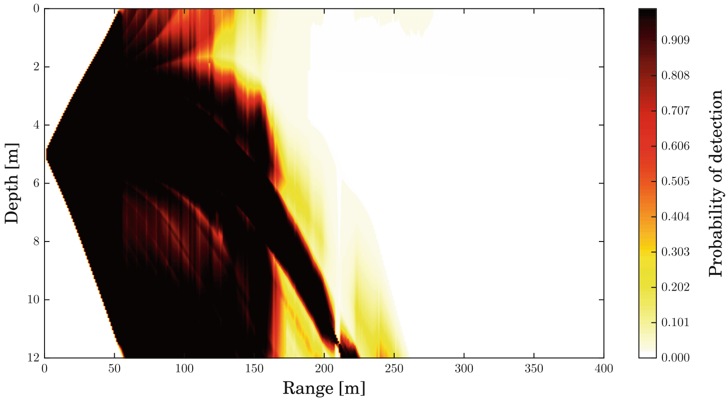

Fig. 8. Probability of detection computed by the active sonar subsystem for a DDS placed at 5 m depth. The environmental information (sound velocity profile, ambient noise ...) considered in the computation are data shown in Fig. 6 collected by real sensors in the Gulf of La Spezia (Italy).

depth considering the environmental information coming from data collected by real sensors in the Gulf of La Spezia (Italy). The sensor unit is characterized by transmitting frequency 70 KHz, source level 220.0 dB, bandwidth 20 KHz and vertical beam width 11°, maximum detection range 500 m (the other sensor specifications are omitted). As shown in figure, the unfavourable environmental conditions produce a reduced detection range from the maximum declared of 500 m to 200 m. This test proves the importance of modelling the performance of sonar system to evaluate the real one.

Recalling the software architecture of Sect. 3, the new component active sonar subsystem has been developed as *plug-in* of Sensor type integrated into the JTTS. The component, starting from the data provided by the Environment (though Sea Manager) builds the performance map as shown in Fig. 8. Furthermore, the new integrated software component is able to generate alarms if new threats are detected.

5 Conclusions and Future Works

A new SG platform to assist the design phase of a new military ship has been presented. The evaluation of the real performance of the on-board sensor starting from environmental conditions and sensor specifications allow to assess the weaknesses and strengths of the actual surveillance system. As an example, active sonar subsystem has been integrated in a custom version of JTTS demonstrating a significant divergence between the nominal and the estimated real performance. To overcome the limitations of the actual surveillance system the deployment of a distributed multi-vehicle surveillance system may restore the operative conditions to detect and classify possible asymmetric threats and apply the proper deterrence procedure. Starting from a mature SG platform, the next step is focused on prove if the available surveillance algorithms are really effective against asymmetric threats together with the determination of the type of vehicles (e.g. AUV, ASV ...) and sensors to be used during operative scenarios. By means of game theory, passivity theory and Monte Carlo simulations, in [14–16] the authors conducted a theoretical analysis of the performance of the surveillance system with autonomous or remotely operated vehicles. In this context, the surveillance mission is faced as dynamic coverage application in a structured environment in which the goal is to maximize a coverage metric of the area around the mother platform. Future works will be focused on testing the above-mentioned contributions in the SG platform to estimate the best surveillance configuration in terms of size and typology during asset protection from underwater threats.

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