Research on Construction of Intelligent Operational Simulation Test Environment

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Abstract. With the development of simulation technologies, simulation test has become an important means of weapon equipment demonstration, finalization and operational test and evaluation, but the simulation test system built for the performance evaluation cannot meet the requirements of system of systems (SoS) operational test and evaluation. This paper analyzes the requirements of the operational simulation test for the intelligent simulation test system and puts forward an intelligent simulation framework of the complex simulation test system and its main elements, which realizes the simulation of the operational activities with uncertain confrontation process and can support the demonstration, construction and evaluation of the weapon equipment system. The research results have been applied to the construction of a certain simulation system and provided support for the test and evaluation of equipment SoS tests.

1. Introduction

With the extensive application of simulation technologies in military fields, simulation test has become an important means for the demonstration, development, finalization and evaluation, operational test, analysis of tactical application, and SoS research of the weapon equipment. However, a simulation test system for performance appraisal test can only implement static, single-sided and non-confrontational test processes, and cannot represent the emergency, flexibility and complexity of the battle fields, therefore, cannot meet the requirements of operational simulation tests in test design, model application and test pattern aspects, which are dynamic, systemic and antagonistic[1]. The operational simulation tests put greater emphasis on their realism, which means the operational environment, tactics, equipment characteristics, and operational experience should be in agreement with the real operations, and thus demands analyzing and evaluating the tactical and technical parameters, operational effectiveness and operational suitability of the weapon equipment in typical scenarios by constructing realistic operational conditions and environments. With the advancement of the operational capability of the weapon equipment, it has gradually become a new trend and a new field to construct a realistic or nearly realistic test environment to test and assess the operational effectiveness of the weapon equipment or its contribution rate to operational system.

Relevant research institutes at home and abroad have made exploratory research on the combination of virtual technology and artificial intelligence. Based on an analysis of the difference between operational simulation test system and conventional performance simulation test system and research on intelligent virtual battlefield environment framework, rules of model confrontation and intelligent behavior, and status detection of model confrontation based on physical effects, this paper
puts forward a construction framework of the intelligent simulation test system which can represent the uncertain confrontation processes in the complex battlefield environment, enhance the effects of the information confrontation tests, and provide technological support for the operational simulation tests.

2. Requirement analysis of intelligent simulation test system

Current tests focus mainly on the tactical and technical performance of the weapon equipment, which are quite different from the operational simulation test. Thus the construction requirements of test environments are different too.

The conventional simulation test system for performance test and evaluation is very different from the intelligent simulation test system. The environment construction of the conventional simulation test system is aimed at testing whether all the parameters of the equipment are up to the design specifications, determining the limits, boundary or benchmark of the equipment. Models are simplified representation of objects, and the current equipment models are just superposition based on static rules, a kind of idealized simple understanding which lacks spatial freedom and cannot perceive environmental changes by itself. Performance tests are all kinds of test tasks carried out according to the test master plan and test plan and in an orderly way. Their processes are planned, definite and static. The test environments will not change significantly and the whole operational process proceeds based on scripts, which cannot show clearly the effects of the complex environments on the operational process. Model executions in the performance test environments are processes driven by time sequence, and the movement tracks of the models won’t change freely. Their unchanged representations cannot show the complex high-level attributes and operational behaviors emerging from the underlying behaviors and interactive behaviors. The data acquired in performance tests are used for the evaluation of the equipment performance and don’t serve the real-time engagement process. They don’t support the effectiveness analysis and calculation of equipment models, intelligent behavior calculation of force models, and interactive processing of models.

The environment construction of the operational simulation test should not only focus on the performance of equipment, but also emphasize the combat capability of equipment in specific conditions, showing more realism and changes of the equipment in the battlefield[2]. The complexity of tests is reflected in the complexity of environments, objects and missions. The complexity of environments refers to the coexistence of conditions such as atmospheric environment, geographical environment, electromagnetic environment and the deployments of adversary and friendly forces. The complexity of objects refers to the complexity involved in multiple platforms, situation awareness, operational decision, fire distribution and interoperability. The complexity of missions refers to the complexity of processes such as operational coordination and SoS confrontation. Therefore, a higher demand is put on the simulation test system, which can be summarized as follows:

- The purpose of the environment construction of the operational simulation test is to test the overall effectiveness, operational suitability and confrontation effectiveness of the weapon equipment, which requires that the simulation models are not only simplified representation of the equipment, but also can represent the complex behaviors of the equipment models and the intelligent decisions of the force models.

- The operational simulation test must represent the uncertainty, complexity and functionality in the application process of equipment, and the simulation environment reflects an dynamic confrontation process. Therefore, the state of the combat system would change with the engagement progress.

- The models of the operational simulation test should be able to change with the change of environment, that is to say, they should have autonomous ability and adaptive ability, and the interactive activity of models would generate the complexity and non-linearity that conform to system science[3].

- The operational simulation test has a higher demand for the data capture and processing, specifically, the situation and environment information of the system must be captured in a real-time manner, and the format conversion, information filtering and target recognition must be performed
efficiently, so the equipment models driven by the data can conduct the effectiveness analysis and calculation of the equipment models, the intelligent behavior calculation of the force models, and the interactive processing of the models.

- The operational simulation test need the support of more data libraries. In addition to the conventional libraries such as equipment model library, engagement rule library, test scenario library and tactics library, more libraries are needed, such as equipment performance library, accumulative intelligence library, intelligent behavior library and force model library. The equipment model library should be updated to form an equipment model library based on intelligent agent.

Thus it can be seen that the simulation test system constructed for the performance test and evaluation cannot totally meet the need of the environment construction of the operational simulation test, whose test purpose is effectiveness evaluation. A qualified intelligent operational simulation system should be able to address the need of the simulation of complex battlefields, show the uncertainty of the engagement activity and the thinking activity of the forces, emphasize the combat capability of the equipment under specific conditions, reflect the changes of the equipment in the battlefields, and demonstrate the dynamic confrontation process of the equipment SoS.

An intelligent virtual operational environment is a combination of operational environment and artificial intelligence. By using the enhanced reality simulation technology, it will not only construct a virtual, realistic 3D visual battlefield environment and background that can represent the whole operational progress and actual operational effect more visually and vividly and increase the real experience of man-in-the-loop, but also realize the modeling of the living things and the logical mapping of the operational units in the model space by the use of intelligent technology. Through the information exchange between the simulation environment and the equipment under test, a dynamic, controllable, systemic, realistic and visual test process will be created, which will not only test the performance parameters of a piece of equipment under test, but also evaluate its operational effectiveness in the operational SoS and research its contribution rate to the operational SoS.

3. Framework of intelligent operational simulation test

With the advancement of simulation technologies, it is possible to realize the autonomy, initiative and flexibility of the simulation models through intelligent approaches. The force unit model with intelligent properties can react to the environmental stimulus or the dynamic change of the simulation environment, take actions to engage the target under certain boundary conditions and coordinate with friendly sides, which show that the operations are not just mechanical actions, instead, every operational unit is an agent with properties of living things and adaptive capability. All these enhance the fidelity and credibility and also reflect the characteristics of the complexity of the operations[4-6]. The framework of the intelligent operational simulation is a simulation framework proposed to solve the complexity of the operational activity and the certainty and uncertainty when planning the operational simulation test. Figure 1 shows the mappings from the complex battlefield environment to the intelligent simulation, then to the framework of the intelligent simulation test.
Figure 1. Framework of intelligent operational simulation test

The main parts of the intelligent operational simulation framework are as follows:

- **Equipment model library based on the intelligent agent**

  Constructing the behavioral models for the equipment model, such as reconnaissance, maneuver, attack, communication and cognitive models, and then constructing the knowledge library of the intelligent models based on military engagement rules and forming the property vector set of the extrinsic motivators to complete the decision support system, which will enable the single model to independently decide next course of action according to extrinsic motivators under the virtual battlefield environment to have a certain kind of self-organization behaviors.

  Constructing the intelligent behavioral models for the force model, such as analysis, judgment, decision and action models, and then constructing the intelligent force model library based on different level, function, role of the personnel. The force model will determine its next course of action driven by the vector sets of the battlefield situation, the environment data and the mission and task.

- **Driven by test scenario**

  In terms of the performance and effectiveness evaluation of the weapon equipment, test scenarios are the battlefield environment, operational attempt, operational method and operational process designed to fully demonstrate the operational effectiveness of the equipment under test in specific conditions or environments. A test scenario is a plan for the time and space of the whole test in the form of a certain kind of formal description language (XML, MSDL or C-BML), which reflects the equipment application, intelligence exchange, operational progress, states of adversary and friendly sides, tactics and so on. What a test scenario describes is a stable situation instead of a transient situation and cannot directly reflect the confrontation process between adversary and friendly sides and the rapid changes in the battlefield. The changes in the battlefield will evolve through the autonomous behaviors of the models.

- **Military strength configuration**

  What the military strength configuration does is to determine the virtual equipment of the adversary and friendly sides, construct the operational system of the two sides, deploy the virtual equipment by setting their parameters, and set the maneuverable points for the equipment to form the whole war situation in the battlefield. The equipment model library consists of multiple kinds of equipment meta-models and various types of equipment can be deployed by setting their parameters.

- **Construction of battlefield environment**
The effects of the battlefield environment on the operations are rather complex, and different battlefield environments will not have the same effects on the same or different operations. Even the same battlefield environment affects the attack and defense sides differently. The battlefield geographical, meteorological and electromagnetic environments in which the equipment are used will be constructed. The working states of the physical equipment will be affected through the signal injection and the working states of the equipment models will be affected through the information injection. Although the virtual battlefield environment will not have destructive effects on the physical equipment, it can obstruct and jam the virtual equipment and realize realistic battlefield effects[7].

- The engagement rule and intelligent behavior of the model

Engagement rules for the models of the two confrontational sides such as reconnaissance, jamming, suppression, deception, attack and defense will be laid down and every model has a certain degree of self-organization behavior. For example, the force unit model with intelligent properties can react to the environmental stimulus or the dynamic value of the simulation environment, take actions to engage the target under certain boundary conditions and coordinate with friendly sides. An engagement is a nonlinear comprehensive reaction of all the dynamic and interactive individuals instead of mechanical, one-way behaviors, that is to say, every individual can independently execute behaviors within its function or duty and react to the events in the test process. For example, an individual soldier will adjust his position to shoot again if he has not kill the target in the first try and when a group of fighter planes of the opposing force launch an air strike, if a plane in a forward position has been attacked, the rest will adjust their flight routes dynamically to attack the intended target or assist the attack of a friendly plane timely through coordination. To complete the decision-making support system and realize the independent decision-making ability of the force model, a knowledge library based on military action rules should be constructed and property vectors of extrinsic stimulators should be set up to simulate the psychological reaction of human beings to the outside stimuli[8].

- Exchange mechanism of network information based on TENA

As a kind of system architecture and technological support to the test and training range, TENA can combine the separate equipment, platform, instrument and apparatus, simulation system, database resources and so on into an integrated testing environment and carry out test and training tasks in a realistic, efficient and economical manner. Its functions can be expanded through establishing a kind of battlefield environment with high credibility and strong immersive experience to verify the operational effectiveness of the equipment under test. To form a system architecture based on TENA, it cannot go without the definition of the input and output of the system unit, interconnecting method and information exchange protocol between units, and real-time, dynamic and interactive simulation that can be constructed.

- Detection of the confrontation state of the model based on physical effect

The confrontation processes in operational tests are realized through the simulation of virtual models according to the physical effect of the actual object. For example, when detecting a maneuvering target in the air, a radar will transmit wave beams. After they hit the cross-section of the flying target and return to the receiver, the radar will determine the presence of the target according to the threshold value for the received signals and pass the intelligence information to related models and equipment. Similarly, when hitting a target, a shell will have different effects depending on the point it impacts. The process simulating a confrontation is a collision process between two or more virtual models, which can be divided into soft collision and hard collision according to different objects. Collision detection will detect collision area in terms of the shape of the object model and assess the shape change of the collision area, and then update the data structure of the model and generate the shape change effect of the collision. Finally, the collision data will be processed as detection information and displayed or changed into intelligence information according to related protocol.

- Time scale strategy of the characteristics of the war

The operational simulation test is a kind of dynamic change process of the complex non-linear system and the models within the system run according to the time scale of the system characteristics,
that is to say, every change in the war will have its time restraint. Regardless of whether they are step by step analysis, conventional analysis or faster than real-time analysis tests and training, their time scales change regularly according to the scale features and a time synchronization mechanism consistent with the war will restrict the self-behaviors of the models and systems and their interactions. Therefore, it is necessary to determine the time rhythm of the war process, stick to the principle of observe-orient-decide-act cycle to realize phase control, and let the time become the mechanism that controls the execution and cycle of the battlefield and the key element of the battlefield superiority.

- Evaluation of the performance and effectiveness of equipment

With the combat mode featuring information, network and system becoming the development trend of future warfare, it is necessary to construct an equipment system or equipment SoS under realistic conditions that feature the interoperability, matching degree, performance of equipment system, combat effectiveness and contribution rate of equipment in the SoS. The careful analysis and processing of the testing process and results will conducive to the full evaluation of the performance parameters of the equipment and more accurate and profound understanding of the operational method of the equipment, operational theory of the system and the operational mode of the joint operations.

Since the intelligent operational simulation test process is driven by combat scenarios, so if the information used for the execution and derivation in the scenarios can be determined, the scenario models with normalized descriptions can be automatically created according to the operational intention, operational scale, weapon equipment, offensive course and duration of time and so on. Then the control information flows such as target information driver, signal driver and event driver can be generated by using artificial intelligence technology to direct the information exchange between the models to form the dynamic battlefield situation. The test framework includes the general rule library of military behaviors, validation rules for making combat scenarios, and automatic validation mechanism for the realization of the combat scenarios.

4. Simulation test process

According to logical relationship, the operation of the whole system can be divided into three stages: system initiation, test execution and test evaluation.

In the system initiation stage, the following work should be done according to the requirement of the test scenario:

- Constructing the equipment systems of the red and blue forces, which includes accessing the model library in terms of the initial deployment of the equipment system and searching for the target parameters in the equipment performance library in terms of the unique identifier of the targets, and completing the initiation of the target simulation models, including the simulation entity generation and initiation of the dynamic real equipment involved in the operations.

- Generating the operational environment, which includes generating the information reflecting the natural, meteorological and electromagnetic environments by accessing environment parameter library according to the environment setting.

- Generating virtual forces, which includes instantiating the force models to relate them to intelligent behaviors according to combat scenarios and referencing the force model library that the equipment system need to access.

- Distributing operational missions, which includes distributing operational missions to the operator of the real equipment and virtual force models according to the operational missions of the red and blue sides distributed by the scenarios.

In the test execution stage, the real equipment operators or virtual forces of both the offensive and defensive sides will quickly develop the operational scheme according to operational missions and conduct operational actions with the real equipment operator operating the real equipment and the virtual force operating the intelligent equipment models. The system captures and collects the situation and environment information real-timely and conducts format conversion, information filtering, target recognition, effectiveness analysis and calculation of equipment models, calculation of force intelligent behavior and model interactive processing. The dynamic information about the real
equipment and models constantly updates the battlefield situation and environment and the red and blue sides adjust operations according to battlefield situations. The equipment models will calculate the environment effect on the equipment and change their capabilities accordingly, and then update the equipment capabilities and their effects on the battlefield. Deleting the simulation entities of the destroyed targets or adding the simulation entities of new targets according to battlefield situation and engagement judgment and ruling to bring the simulation situation into conformity with the actual situation. Figure 2 shows the process of the simulation test based on the intelligent operational simulation test system.

![Figure 2. Simulation test implementation process](image)

In the evaluation stage, the combat scenarios, equipment performance data in all stages, data about the engagement process and judgment results in all stages will be sent to evaluation tools to assess the operational effectiveness, degree of fusion between systems, suitability of the SoS and so on.

The intelligent simulation test system can realize multiple test modes, including mathematical, hardware-in-the-loop, human-computer interactive control and combination of both indoor and outdoor ranges test modes. The mathematical simulation mode is a simulation process by means of mathematical modeling and is a kind of constructive modeling. In this simulation mode, the intelligent agents will simulate the operational behaviors of the soldiers and the evolution of the operational process is driven by the models. In hardware-in-the-loop simulation mode, the interaction between the visual simulation system and hardware-in-the-loop simulation system is achieved through hardware-in-the-loop simulation technology. The behaviors of the visual simulation models are driven by signal or information data derived from hardware-in-the-loop simulation and the processes of the hardware-in-the-loop simulation system are driven by the behavioral information of the simulation models. The human-computer interactive control mode is a kind of human-in-the-loop test mode, which regards humans as part of the simulation system and controls the behaviors of the model by human’s thoughts. By this means, the simulation processes will be more in line with the actual operational principles and the simulation war-gaming of different tactics can be implemented in the same confrontation SoS. In the mode of combining both indoor and outdoor test ranges, the indoor range simulation system will be interconnected with the outdoor real equipment. The information of the outdoor test will be passed to the simulation system and the information of the indoor simulation models will be injected into the outdoor real equipment to realize the linked test mode of integrating both indoor and outdoor ranges.

5. Conclusion
This paper analyzes the special requirements of the operational simulation test for the simulation system and puts forward an intelligent operational simulation test framework by using the artificial
intelligence technology to explore complex system and construct the uncertainties of the complex system simulation, which improve the realism of the operational activities and provide a new technological solution for the operational simulation of the complex battlefield.

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