A Distributed Simulation Framework Supporting CGF on Networked Virtual Environment

SeongKee Lee, ChanGon Yoo, JungChan Park, JaeHyun Park
Directorate of Information Software
Agency for Defense Development
Songpa P.O.Box 132, Songpa-Gu, Seoul 138-600
Republic of Korea

Abstract: This paper shows a distributed simulation framework for tactical training in networked virtual environment. The existing military training simulation systems are mostly full simulated systems operating on single platform. They are to train individual’s operation skill, but don’t support team level tactical training. In order to train team level combat and command skill in dynamic battlefield, the interaction among distributed combat objects and diverse battlefield composition are required. This paper designs a distributed simulation framework to satisfy these requirements. The framework produces the networked virtual environment using virtual reality, event based simulation and HLA/RTI based interoperation techniques. This paper implements a small scale tactical training system based on the framework.

Key-Words: Modeling and simulation, Simulation Framework, Networked virtual environment, Tactical training

1 Introduction

Modeling and simulation (M&S) technology is an effective method to analyze alternatives, train operation procedure or develop optimal system. It models the real complex environments to the abstract level and simulates diverse solutions. As real environment becomes from static to dynamic and from single platform to system of systems, some requirements must additionally be considered as follows: 1) distribution. The objects are distributed. 2) interoperation/heterogeneity. The heterogeneous objects must be interoperable; 3) virtual environment. Since dynamic environment must be represented, it is effective to represent virtual environments; 4) autonomy. When scale becomes large, autonomous objects are required.

In order to satisfy the requirements or the trends of modeling and simulation technology described above, the networked virtual environment, NVE technique has been developed. This technique provides the environment so that the distributed objects can interact with each other on virtual space. In order to realize the networked virtual environment, some element techniques are needed: networking technique that distributes objects, simulation technique that supports the interaction among objects and virtual reality technique that virtually represents environment. This paper designs a distributed modeling and simulation framework based on the NVE technique and applies the framework to implement the battle simulation system for tactical training. The battle simulation would be one of typical systems that NVE technique is required. The system explained in this paper is a small scale tactical training simulation model that the distributed combat objects share with a virtual digitized 3D battlefield and engage each other under command. Each object can act within its capability: seek, move, fire, etc.

Section 2 explains the general concepts to give a glance about modeling and simulation in military. Section 3 proposes distributed simulation framework based on NVE technique. In particular the design rational and architecture of the for tactical training simulation system are addressed. Section 4 implements tactical training simulation system based on the distributed simulation framework designed in Section 3. Section 5 discusses some technical issues to be considered on the framework.

2 Modeling and Simulation in Military

In military, they say that all but war is simulation. The simulation in military is essential tool to all areas of analysis, training and acquisition. In order to understand military simulation domain, this section explains some related concepts such as layers, type, purpose etc and classifies military simulation domain according to their combination.
3.2 Framework Architecture for Virtual Simulation
Reflecting the design principles discussed in Subsection 3.1 to networked virtual environment technique, the followings must be considered. To satisfy distributed architecture, network component is needed. For interoperation, simulation services such as middleware, message transfer and event processing and time management are needed. Also, in order to real time processing, system services such as multithread are required. In order to satisfy composability, every element composed of simulation environment, for example, entity, natural environment etc, is modeled into a model as a component using appropriate modeling technique. Also the simulation lifecycle modules necessary to prepare, control and execute simulation as well as the analysis of simulation result must be supported. Scalability is supported by hardware, network or interoperation service. To virtually represent simulation situation during and after exercise, 3D display module needs to be included. Also real data such as combat effect data and dynamic physics model must be constructed in database or library. These considerations can be included into a framework. The framework can be architected into layered style by mapping services or components to corresponding layers. Each layer plays its own role and is interconnected with each other. In short, the framework appropriate to virtual simulation system can be established as Fig 2. The framework may be general, but provides fundamental concept to construct simulation systems.

3.2 Framework Architecture for Virtual Simulation

- Interoperability: The framework aims to interoperation among heterogeneous objects on one battlefield environment. To support this principle, interoperation method such as middleware must be supported.
- Real Time: The objects need to feel reaction in real time. The multithread and synchronization methods can be used. Replication may be used to process large size data such as terrain data in real time.
- Composability: Since diverse environments are required, the framework must compose diverse situations. Also already developed objects or environments may be integrated into the framework. The units must be composed and operated together in run time.
- Scalability: Simulation may be executed from small scale to large scale. The framework needs to support extendibility without much performance loss.

Fig. 2 Virtual M&S Framework(VMSF)

4 Tactical Training Simulation System(TTSS)
The virtual M&S framework(VMSF) in Fig. 2 must be used as a baseline to develop many virtual simulation systems. This section applies the framework shown in Fig. 2 to the development of a tactical training simulation system. The simplified system description is below.

This system is a battle simulation system which enables the participants to share with common 3D synthetic virtual battle-space and engage with each other on it. The exercise participants are commander, combatant, unit, weapon system, etc. All trainees are connected on local area network. The system provides the functions necessary to prepare, execute and analyze exercise. Also, in order to simulate diverse tactics, this system includes computer generated force with semi-autonomy. Since the system is a virtual simulation system for tactical training of army company level, it is classified as B-V-T-M-A combination, that is, battle layer-virtual type-training purpose-middle scale-army service and belongs to the dot box of Fig.1.

4.1 System Design based on VMSF
Based on VMSF, this paper designs the tactical training simulation system described above. Here, design implies to specify the VMSF framework to the TTSS. Fig.3 shows the TTSS technical architecture(TTSS-TA) which is one of framework views: TA(technical architecture), OA(operational
architecture), SA(system architecture). This shows the technical choices in layers of VMSF to construct TTSS.

**Users**
- Tank
- Helicop
- Infantry
- CGF

**Lifecycle**
- Scenario Gen., Controller, Analyzer, Display

**Application**
- Combat Logic, Dyna/Physi Library, DB

**Model**
- Primitive, Composite Model

**Service**
- Message/Event/Time Management, HLA/RTI

**System & Network**
- OS, LAN & TCP/IP

Fig. 3 TTSS-TA based on VMSF

Fig.3 is to map VMSF into TTSS-TA. Since infrastructure layer of Fig.2 includes components to run system, it is mapped into system and network in Fig.3 and includes network and operating system. Simulation service layer provides the services such as interoperation service, message distribution, time management and event management which are simulation engine functions. In particular, HLA/RTI software, which is a kind of middleware for defense simulation interoperation, is provided to support interoperation with TTSS users. Simulation model layer generates entity to be involved in simulation. Models are composed of primitive model and composite model which is based on DEVS model. A primitive model is a basic model which has specification for the dynamics of entity. It describes the behavior of entity. A composite model shows how to couple several entity models together to form a new compound model. Simulation lifecycle support layer in TTSS-TA provides the functions needed to prepare, execute, control simulation and analyze results: battlefield creator and display, scenario generator, exercise controller, after action review, etc. User layer provides virtual interfaces for real users. TTSS simulates weapon system such as tank and helicopter, infantry, CGF(Computer Generated Force) and commander. Real users participate at exercise through PC-window interface. In application layer, in order to show the effect of interaction(engagement) among entities, the libraries such as damage lib, dynamics lib, physics lib, rendering lib and some databases such as terrain data are supported.

The TTSS technical architecture of Fig.3 reflects some considerations described in Subsection 3.1. For distributed architecture, TTSS-TA provides TCP/IP protocol network and local area network environment. For interoperability, HLA/RTI(High Level Architecture/Run Time Infrastructure, IEEE 1516 standard), which supports interaction among diverse entities. For real time feature, TTSS-TA includes simulation engine which is executed by an event based simulation method. System services such as multithread are included. For composability, entity can be easily added and deleted by creating instance of class. The added entity can interact with existing entities together. Also, exercise participants can join and withdraw in run time. For scalability, TTSS-TA supports the interconnection between HLA/RTI and TCP/IP groups. Since HLA/RTI may reflect to system performance by the number of participants, TCP/IP network is used to expand participants. Fig.4 shows the interconnection concept between HLA/RTI and TCP/IP groups to expand simulation scale to company exercise at least.

Fig. 4 Simulation Expansion
4.2 System Implementation

Based on the TTSS-TA of Fig.3, company level tactical training simulation system, TTSS is implemented. At first, using the components necessary to construct TTSS, this paper designs system architecture in detail. The system architecture is composed of basic modules and interface modules.

Basic modules are essential functions in simulation execution. All components except users interface are included as follows: battlefield environment creation, combat logic, scenario generation, exercise control, simulation engine, after action review and combat situation display.

Interface modules are interface for participants to join in exercise. TTSS includes interface for individual and weapon system as following: infantry, tank, helicopter, commander and computer generated force(CGF). Real users show virtual window interface and execute exercise by manipulating joystick or keyboard. The interactions among users are supported by RTI software. RTI plays a broker to interact with users. That is, each user interacts with others via RTI software. To expand exercise users, federation extender, which is light RTI and acts like a federate of RTI, is implemented as shown in Fig.4.

Based on generated scenario, exercise controller assigns PCs to exercise users. The assigned user logs in the corresponding PC, and according to own role such as unit, infantry, weapon or commander, participates at exercise through interface. Exercise controller start and stop whole simulation, change battlefield environment such as rain, snow, fog, dawn, night etc, supply logistics for request and play high level unit or commander such as indirect fire support. Users share battlefield and engage within their combat capability. Interaction among users is supported by RTI interoperation software. Each user can recognize battlefield within his seek scope. By showing battlefield situation, he can decide his course of action himself or by commander direction. Since all users can execute such actions, tactical training comes true in result. All exercise situations from start to stop are comprehensively displayed on 3D synthetic environment which all moving entities, artificial and natural objects are overlapped in visual. Tactical actions such as fire, move, seek etc and damage effect of engagement such as kill, destruction are represented on synthetic environment. In final, using logged exercise data, AAR can analyze exercise results by 2D and 3D, by individual and whole, by diverse format.

Fig. 5 is implemented on PC based environment in which Window XP is used. For interaction among users, MakRTI software and federate extender of Fig. 4 has been used. For message transfer, XML format has been used. Programming language is C++. For effective development, object oriented development methodology is used during whole development cycle. Most modules of Fig.5 have been coded in manual rather than COTS products. This approach is much effective to reuse and upgrade software modules.

The software modules support whole exercise cycle of pre-exercise, exercise and post-exercise as follows.

- **Pre exercise**: battlefield authoring by environment generator module, combat effectiveness data preparation by combat logic module and exercise situation deploy by scenario generation module.
- **Exercise**: simulation execution by simulation engine module, simulation start/stop, battlefield situation change, logistics’ supply etc by exercise controller module, exercise situation display by environment display module, exercise execution by infantry interface, weapon interface and commander interface.
- **Post exercise**: exercise result analysis by after action review(AAR).

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Fig. 6 shows that battlefield is shared with all users and displayed. The battlefield sharing makes users have common view about battlefield even though their own capability. That makes tactical training possible. It overcomes the limit of
individual exercise which only focuses on driving or fire technique exercise. Synthetic battlefield environment of Fig. 6 comprehensively represents situation that a helicopter attacks a tank and a bridge has been destroyed, etc.

5 Technical Issues
This section discusses some technical issues which have been identified during TTSS development.

5.1 Performance Estimation for Expansion
Although TTSS is tested at company level tactical training, it is necessary to review whether it may be used for battalion level training since most modules for tactical simulation have been already prepared and may be reused for more large scale exercise. The point is not technique but data. In general, as scale increases, transmission data increases in exponential because entities increases and battlefield expands. This paper estimates the transmission load of battalion level exercise based on the company level transmission rate defined in test. The estimation results are as follows. In case of company-level tactical exercise among infantry, helicopter and tank, the transmission load is about 571.2 Kbps. Expanding to the case of battalion level, it is estimated that transmission load is about 2.23 Mbps, 4 times of that of company-level. This load rate can be adapted enough on local area network. Shortly, in view of number of entities and transmission load, TTSS can afford to use for battalion level exercise as well as company level exercise. Here doesn’t discuss this in detail. The detail evaluation and estimation will be described at other papers.

5.2 HLA/RTI based Interoperation
HLA/RTI is a standard for interoperation among heterogeneous defense simulation systems and also IEEE 1516 standard. Many systems have applied to interoperate diverse systems. Many RTI software products have been supplied by COTS, for example, MakRTI, pRTI etc. Although COTS usage increases, the cost for one server with eight clients is about twenty thousands dollars. If users increases, much cost is required for only interoperation. The ‘light’ RTI version shown at Fig. 4 may be one of the solutions to reduce the RTI based expansion cost. Federator extender, called in this paper, is simplified RTI software which includes subset of full RTI functions. It doesn’t greatly influence to performance and supports expansion. Fig. 4 help expand to large scale exercise. In order to enhance to HLA/RTI based interoperation, researches on interoperation among heterogeneous RTIs, real time of RTI, light RTI etc are needed.

5.3 Reconfigurable Simulation
Differing from existing full simulation, tactical weapon simulator has selectively chosen functions so that it can execute team tactical exercise rather than individual exercise. This paper has designed software based reconfigurable tactical weapon simulators. The display for pilot is changed by software according to weapon model without hardware platform change, for example, from Cobra to Apache helicopter. Fig. 7 shows the display example implemented in this paper. Although reconfigurable tactical simulator doesn’t similar to real platform, it is possible to exercise tactics with other opponents and friendly forces on one synthetic battlefield as shown in dot part of Fig 6. Since this simulator type can be constructed by low cost, expansion cost is low and easy. Also since models can be transferred by selecting model display, diverse weapon models can be simulated easily. If diverse models future are models and
included in battlefield, any war game may be possible. Software based tactical simulation will be an essential technique for weapon tactical simulation.

These technical issues identified during TTSS implementation must be more researched in deep and included as essential techniques in VMSF of Fig.2 as follows: Performance issue for expansion and HLA/RTI interoperation enhancement in simulation services layer; Reconfigurable simulation issue and unmanned simulation in simulation models layer.

6 Conclusion

According to level, type, purpose, scale and force, many simulation systems exist. The framework approach is effective method to build up many simulation systems. The framework must have features such as distribution, real time, composibility, interoperability, scalability etc. In particular, for virtual simulation systems, the networked virtual environment technique can be used as a framework.

This paper shows how to construct a tactical training simulation system(TTSS) using virtual modeling & simulation framework(VM&SF) based on networked virtual environment technique. Many other virtual simulation systems in military field can be designed and implemented on VM&SF.

From implementation experience, this paper identifies some technical issues such as performance estimation, HLA/RTI Interoperation, reconfigurable simulation, unmanned simulation etc. These issues must be more enhanced or researched in future. The framework approach will be useful way to engineer many simulation systems in other fields as well as military field.

References: