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Creating Defence Models Using V-DEVS Framework

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***Abstract* –The aim of this paper is to present a development technique for virtual/constructive simulation of defence applications. The approach relies on the use of V-DEVS methodology providing a modular, hierarchical modelling structure and enabling to effectively synchronize simulation, visualization and user interaction. The practical importance and application possibilities of the research results are demonstrated by developing simulation models of unmanned aerial vehicles and a flexible manufacturing system producing military SUVs.**

***Keywords* –defence models, DEVS, V-DEVS,virtual/constructive simulation**

I. Introduction

The military is a big user of simulation models. Modelling and simulation are widely used by various defence institutions in the world. Many NATO institutions are now exploiting or planning to exploit simulation technology and techniques for military training and analysis. In recent years, a wide range of novel techniques have become popular for developing defence modelling and simulation (M&S) applications. Traditional analytical models cannot cope with the level of complexity of the systems of interest in this field [1], making M&S a useful tool, as it provides means for better understanding and analysis of the underlying phenomena, permitting evaluation of military logistics, equipment, training and combat situations.

Military simulation falls into three broadly defined categories [2]: live, virtual, and constructive simulation. Live simulations involve real people using real systems. Virtual simulations involve real people using simulated systems. These can be thought of in relation to flight simulators or virtual environments. Constructive simulations are what we usually think of as models, war games, and simulations performed by the computer with the potential for some limited human input.

Existing simulation approaches do not suffice to achieve success in the complex models needed for military applications. We still lack the ability to apply the necessary theory, tools, and primers for building defence applications. Current military applications need further advances and research in numerous important fields [3]:

- Advanced visualization methods: The goal is to provide a deeper real-world understanding and to help in exploring the large set of numerical data produced in simulation execution, which is a concern for model validation. It also allows the creation of mechanisms to exploit human capabilities.
- Multi-resolution modelling: This technique, which permits combining models at different levels of resolution, allows modelling the interaction with the world at many different levels:
- Model abstraction: The concept of model abstraction is closely related to the idea of multi-resolution modelling and provides mechanisms for describing the basic behaviour of model without all the details.
- Hybrid simulation: Simulations should be able to include both continuous and discrete-event model components (hybrid models).

In this paper a development technique for integrated visual simulation of defence applications based on V-DEVS methodology is presented. V-DEVS enables a synchronization of simulation, visualization and interactionthus providing a formal basis for development of virtual and constructive defence simulation models.

II. The V-DEVS Framework

In order to provide conceptualization and specification of simulation models of complex systems, various available paradigms, formalisms, modelling methodologies and simulation methods can be used. The *Discrete Event System Specification* (DEVS) [4, 5] is a general universal formalism of this kind that is provided for the description and definition of discrete-event systems dynamics.

DEVS relies on dividing the system under study into atomic models; each of which can exist in a specific state at any point in time and has input/output ports to interact with other models and with the external world. This allows for building very complex models by connecting different atomic models in a hierarchical manner. In order to attack the complexity of the system under study, the model is organized hierarchically. The second tool used to attack complexity is information hiding, through the provision of a modular interface for each of the models. The use of a formal mechanism to describe each of the components allowed the DEVS methodology to improve the creation of models and the execution of simulations.

Although DEVS-based tools exist which enable the visual design of simulation experiments and visualization of simulation data and results [6], the conventional DEVS formalism in an unmodified form isn't suited well enough for integrated interactive simulation and visualization of hybrid systems.

Visual Discrete Event System Specification (V-DEVS) [7] is an extension of the DEVS formalism that provides an integration of discrete event and continuous systems modelling and interactive 2D/3D visualization. The integration of computer visualization is a feasible and effective strategy for the performance and quality improvement of current simulation technology in military applications. 2D/3D visualization helps users to understand the simulation system more effectively, enables the visual analysis of large sets of simulation related information and improves confidence while studying and analysing the simulation results.

Theformal V-DEVS methodology is suitable as a theoretical basis for these possibilities:

- Hybrid simulation of discrete event and continuous systems;
- Unified basis for integration of systems modelling and 2D/3D visualization;
- Real time simulation;
- Virtual and constructive simulation.

V-DEVS formalism provides a seamless component-oriented coupling and synchronization of simulation processes, user interaction and visualization.

III. Case Studies

For illustration of the V-DEVS capabilities in the field of defence applications there are two practical examples presented:

- Model of unmanned aerial vehicles;
- Model of an automated manufacturing system.

The main focus of these case studies ison the interoperability of simulation, user interaction and visualization.

The presented defence models are developed with a V-DEVS-based simulation software prototype. The integrated simulation environment is based on Eclipse Rich Client Platform (Eclipse RCP) technology, a Java platform for building and deploying native GUI applications toa variety of desktop operating systems like Windows, Linux, Mac OS X and Solaris. To keep the modular architecture of the V-DEVS environment, the connection to the GIS has been made through a static loose coupling[8]. In this kind of coupling, the data are exported from the GIS to the simulator. The specific GIS data access module is built around GeoTools, an open-source Java library for the development of Geographic Information Systems.

From the user's point of view, the main differences and advantages of the V-DEVS simulation environment in comparison to typical commercial simulation systems are the possibilities of simulating a combined discrete event and continuous processes and modeless interaction with a simulation model during a simulation run.

A. Model of Unmanned Aerial Vehicles

Over the past years the use of unmanned aerial vehicles (UAVs) for public safety and military operations has been growing continuously. UAVs are aircrafts that operate without needing human control and have an autonomous behavior in accomplishing their mission.

The presented simulation model is based on the concept of hybrid multi-agent geosimulation and reinforcement learning for solving UAV patrolling problems proposed in [9].The developed modelis primarily focused on learning team coordination aimed to achieve target allocation and navigation tasks for a distributed patrolling problem instantiated as a team of UAVs continuously monitoring possible moving targets over a given region. The challenge is to solve such a problem taking into account the geographic characteristics of the environment and the fact that targets may move in an unpredictable manner. In order to address such a problem, a V-DEVS based multi-agent approach is used to represent UAVs that may carry out their tasks autonomously, while trying to coordinate their collective action.

In a surveillance scenario, a team of N UAVs patrolling an area continuously monitors a set of M land targets moving freely and in an indeterminate manner. The team objective is to determine a UAV path which minimizes time lags between consecutive target visits over a given time horizon. There is no efficient solution known to such a problem since the number of possible combinations of UAVs' elementary actions in any realistic situation is very large.

The patrolling team's objective isto jointly plan UAV paths by minimizing the average global idleness $\overline{I_T}$ that is the sum of the time lag between successive visits of a target over all targets [9]:

$$\overline{I_T} = \frac{1}{T}\sum_{k=1}^{K} I\left(t_k\right)\Delta t_k \ , \qquad (1)$$

where T : simulation time horizon;

$k \in K$:totalnumber of all target visits;

$\Delta t_k = t_k - t_{k-1}$: elapsed time between two visit events;

$I\left(t_k\right) = \sum_{m=0}^{M} I_m\left(t_k\right)$: the global idleness of the system at a given time t_k ;

$I_m\left(t_k\right) = t_k - V_m\left(t_k\right)$: idleness of target $m \in M$ at time t_k ;

$V_m\left(t_k\right)$: the time at which target m was last visited.

The reinforcement learningapproach, namely Q-Learning,is used for the search of a nearly optimal solution in the patrolling area. The reinforcement learning is a machine learning approach in which transition rules are learned through the experience of agents in their environment.Q-learning[10]is known as the best understood reinforcement learning technique used for maximizing the sum of the rewards received.In Q-Learning, the learning process consists of acquiring a state s_t , deciding an action a_t , receiving a reward r from an environment, and updating Q-value $Q\left(s_t, a_t\right)$ [11] calculated by the following equation:

$$Q\left(s_{t+1}, a_{t+1}\right) = Q\left(s_t, a_t\right) + \alpha\left[r + \gamma \max_{a' \in A(s')} Q\left(s', a'\right) - Q\left(s_t, a_t\right)\right], \quad (2)$$

where $a_t \in A$: the set of actions;

$\alpha \in (0,1]$: the learning rate;

$\gamma \in (0,1]$: the discount rate.

Equation (1) is used for calculating the reward r during the Q-Learning process.

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In the presented simulation model, the *softmax* action selection method is used that calculates action choice probabilities $p(a\,|\,s)$ by the following equation:

$$p(a\,|\,s) = \frac{\exp\left(Q(s,a)/T\right)}{\sum_{a_i \in A} \exp\left(Q(s,a)/T\right)}, \qquad (3)$$

where $T > 0$: the parameter called temperature that controls the effect of randomness.

Each UAV is performing a plan to evolve toward a stable patrolling pattern after a number of simulation steps. Figure 1 shows the simulation algorithm implemented by anatomic UAV model.

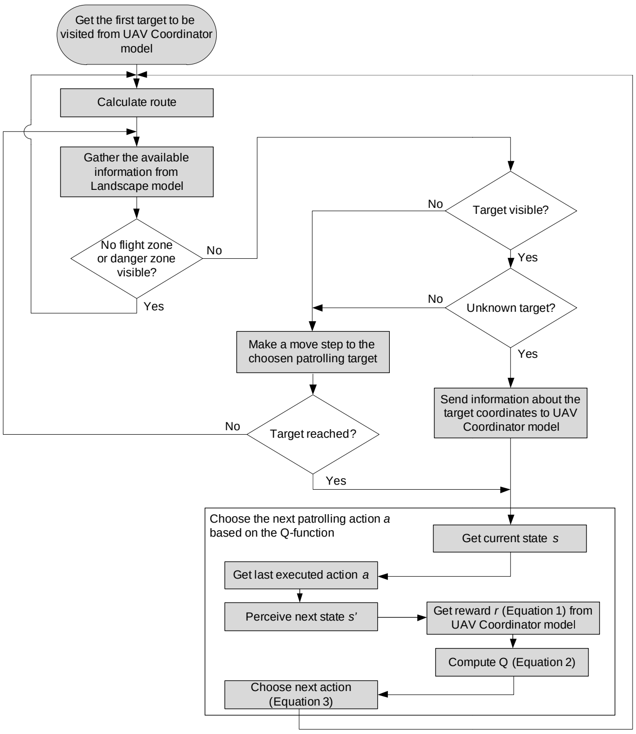

Fig.1. Simulation algorithm of a single UAV sub-model coordinated by UAV coordinator model

In Figure 2 the structure of the whole model is shownthat contains UAV coordinator, UAVs, landscape model, models of no flight and danger zones, as well as experimental and interaction / visualization frames. The experimental frame defines initial conditions for simulation experiments, as well as collects and processes the simulation statistics. The interaction and visualization frame contains GUI controls for interactive steering of simulation experiments and acts as a container for dynamic visualization (animation) of simulation runs.

The spatial information is recorded in the form of GIS raster image and processed by the *Landscape* cellular space model. Each UAV has perception capability which enables it to collect data about its surroundings. The UAV also reasons using the collected data and chooses its next action or goal accordingly.

A user interactively specifies a situation to be solved as a scenario which contains the following objects:

- Geographic environment: the map of the area of interest;
- Targets: the objects that are visited by UAVs are represented by a coloured circle positioned in the geographic area;
- UAV: patrolling agent represented by a coloured aircraft positioned in the geographic environment;
- No flight zone: area characterized by UAV flight interdiction.

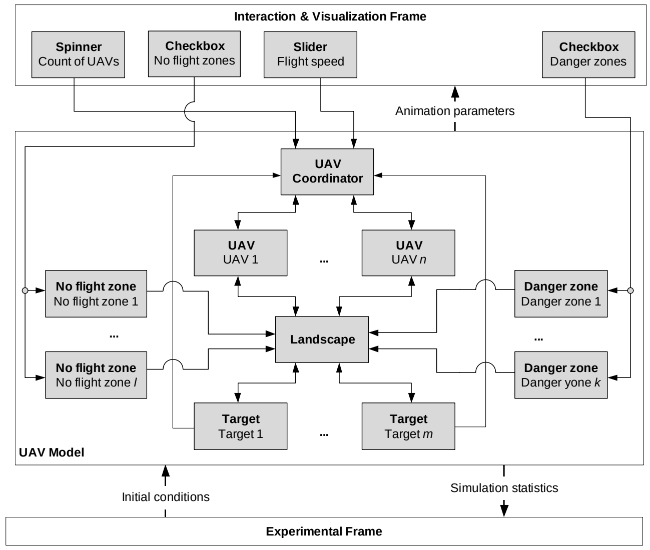

Fig.2. Model structure of UAV patrolling team

Experiments have been carried out to test and illustrate the system capacity in converging toward good solutions over various combinations of UAVs and the number of targets (Figure 3). Although additional experiments and a comparative analysis might be further required, computational results obtained so far show that the V-DEVS approach is suitable for developing defence models by integrating such techniques as reinforcement learning and multi-agent geosimulation.

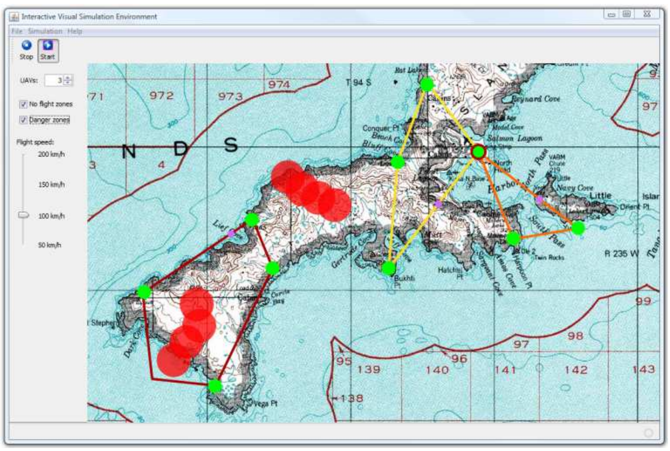

Fig.3. Model of unmanned aerial vehicles in the V-DEVS visual simulation environment

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B. Model of Flexible Military Manufacturing System

A practical application of the V-DEVS formalism for the simulation of dynamic systems is described by examining a simulation model of an automated manufacturing system for the manufacturing of military SUVs. The main goal of simulation model development is to estimate optimal parameters for assembly stations and conveyors, and to illustrate the main advantages of using V-DEVS through these features: integration of simulation and visualization, user interaction, as well as the coupling and reusability of models in a multi-paradigm framework. The purpose of this application is to show practical development possibilities of modelling scenarios based on the realized V-DEVS formalism and to experimentally verify the performance of the realized simulation algorithms. The description and analysis of the examined manufacturing system model are performed based on the V-DEVS theory and concepts by characterizing model architecture, identifying components, their mutual interaction and influence, as well as the type of required specification.

The general model structure (Figure 4) consists of generators, a terminator of simulation entities, interactive elements (slider and check box), workstations of manufacturing production assembly (painting station, assembly robot, assembly station or assembler) and conveyors for production transportation between workstations. Generator models generate the material flow coming into the system like a car chassis and chassis parts. The car chassis and chassis parts go into an assembler model on two different conveyors. The assembler simulates the mounting process of chassis parts onto a car chassis. Further, on another conveyor, the mounted chassis moves forward to the painting station until it reaches a terminator. The terminator model is an element that performs the termination of received entities: a mounted car chassis that corresponds to the exit of material flow in the modelled system.

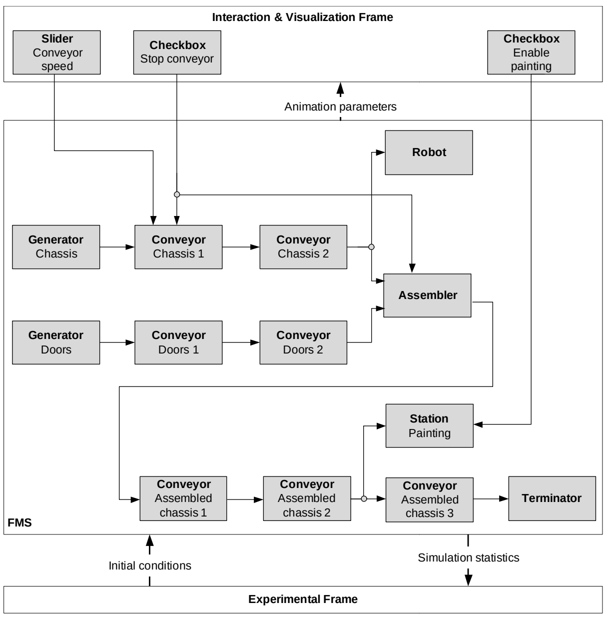

Fig.4. Model structure of flexible manufacturing system

In Figure 5 a screenshot of 3D simulation model is depicted that is developed within the V-DEVS simulation prototype environment.

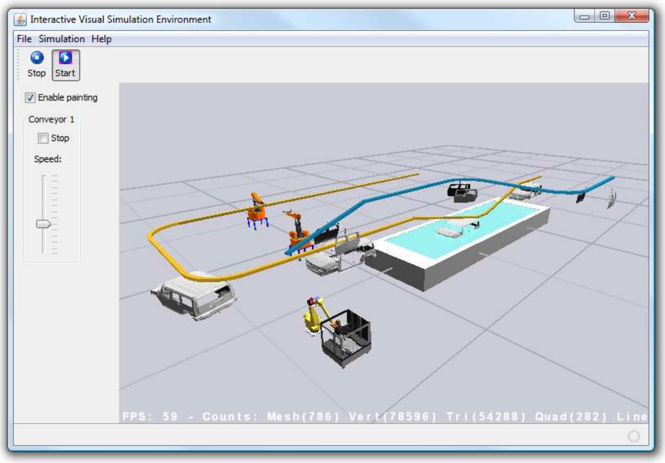

Fig.5. Model of flexible manufacturing system

Figure 6shows the performance measurements of the simulation model indicating the dependence of discrete state S^{discr} and continuous S^{cont} simulation processing time on the count of generated simulation entities in the model.

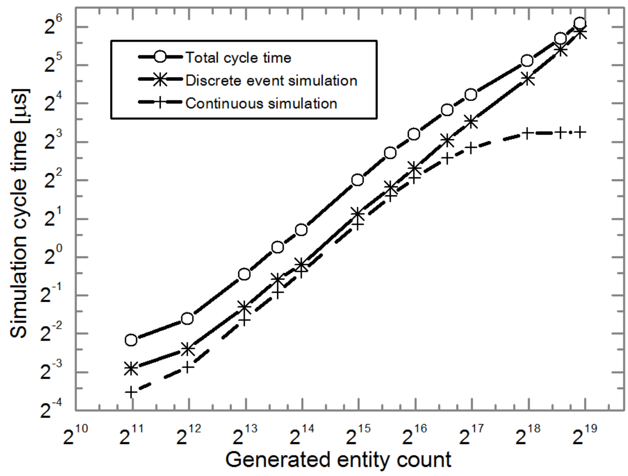

Fig.6.Dependence of discrete state $S^{discr}$and continuous state S^{cont}processing cycle time on the count of generated simulation entities in the model

IV. Conclusions

This paper has presented a development technique for virtual/constructive simulation of defence applications basedon the V-DEVS methodology. The V-DEVS is aformalism that can be used to address fundamental problems when modelling and simulating defence applications. This technique is based on sound mathematical foundations,which offers better interoperability capabilities between different models and provides reach visualization capabilities.

For illustration of the V-DEVS capabilities in the field of defence applications two practical examples, namely, a model of unmanned aerial vehicles and a model of an automated military manufacturing systemare presented.The described

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defence models have been previously presented and well-received at the Baltic Defence Research and Technology Conference, Riga,September 10-11, 2009.

Although additional experiments might be further required, computational results conducted so far clearly show that the V-DEVS approach is suitable for the development and analysis of defence models.Future along this line of research includes improvement and validation of the described simulation algorithms and models.

The future of defence simulation will include an increasing level of dynamics in the modelled world. These “extreme dynamic” models will create a more realistic world in all of the ways than a real person would. The described V-DEVS formalism used for the development of defence simulation models acts as an effective basis for achieving such a dynamic multi-resolution representation of the world.

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Arnis Lektauers, Jurijs Merkurjevs. Aizsardzības modeļu izveide V-DEVS ietvarā
Imitācijas modelēšana tiek plaši pielietota militārās aizsardzības jomā, tomēr joprojām daudziteorētiskie un praktiskieaizsardzības lietišķo modeļu izstrādes jautājumi nav atrisināti. Šis raksts piedāvā imitācijas modeļu izveides metodiku aizsardzības lietojumu virtuālai un konstruktīvai imitācijas modelēšanai. Dotā pieeja balstās uz DEVS formālisma paplašinājumaV-DEVS (vizuālā diskrētu notikumu sistēmu specifikācija) izmantošanu, nodrošinot modulāru, hierarhisku modelēšanas struktūru un ļaujot efektīvi sasinhronizēt imitāciju, vizualizāciju un lietotāja mijiedarbību.
Pētījuma rezultātu praktisko nozīmi un pielietojuma iespējas parāda izstrādātie bezpilota lidaparātu un elastīgās militāro apvidus automobiļuražošanas sistēmas imitācijas modeļi.Piedāvātie aizsardzības imitācijas modeļi ir izstrādāti, izmantojot V-DEVS bāzētu imitācijas modelēšanas programmatūras prototipu. Bezpilota lidaparātu imitācijas modelis ir balstīts uz hibrīdas daudzaģentu ģeoimitācijas un apmācības ar pastiprināšanu koncepciju bezpilota lidaparātu komandas patrulēšanas uzdevuma risināšanai. Elastīgās ražošanas sistēmas modeļa mērķis ir parādīt praktisku modelēšanas scenāriju izveides iespējas, balstoties uz V-DEVS formālismu, un realizēto imitācijas algoritmu veiktspējas eksperimentālai pārbaudei.
Lai gan ir nepieciešams veikt vēl papildus eksperimentus, iegūtie modelēšanas rezultāti skaidri parāda, ka V-DEVS pieeja ir piemērota aizsardzības modeļu izstrādei un analīzei. Iespējamais nākotnes pētījumu virziens šajā jomā ir saistāms ar aprakstīto imitācijas algoritmu un modeļu tālāku pilnveidošanu un validāciju.

Арнис Лектауэрс, Юрий Меркурьев. Разработка моделей в сфере обороны с использованием формализмаV-DEVS
Имитационное моделирование широко используется в сфере военной обороны, однако по-прежнему многие теоретические и практические вопросы разработки прикладных моделей обороны ещёне разрешены. Данная статья предлагает методику разработки прикладных имитационныхмоделей для виртуального и конструктивного имитационного моделирования в сфере обороны. Предложенный подход основан на использованиирасширения формализма DEVS с названием V-DEVS (визуальная спецификация систем дискретных событий),обеспечивая модульную, иерархическуюструктуру моделирования и позволяя эффективно синхронизировать имитационное моделирование, визуализацию и взаимодействие с пользователем.
Практическую значимость и возможности результатов исследования показывают разработанные имитационные модели беспилотных летальных аппаратов и эластичной системы производства военных вездеходов. Предложенные имитационные модели обороны разработаны, используя основанный на V-DEVSпрототип программного обеспечения для имитационного моделирования.Имитационная модель беспилотных летательных аппаратов основана на концепции гибридной многоагентной геоимитации и обучения с подкреплением для решения проблемы патрулирования группы беспилотных летательных аппаратов.Целью модели эластичной системы производства являетсяпоказать возможности создания практических сценариев моделирования, опираясь на формализм V-DEVS, а также - для экспериментальной проверки производительности реализованных алгоритмов моделирования.
Несмотря на то, что необходимы дополнительные эксперименты, полученные результаты моделирования наглядно показывают, что подход V-DEVS является подходящим для разработки и анализа моделей в сфере обороны. Возможное направление исследований в будущем связано с последующим усовершенствованием и проверкой достоверности описанных имитационных алгоритмов и моделей.