INTRODUCTION

Scientific and methodological foundations of integrated modelling of artillery operations in simulators and computer gaming

Computer modeling of combat operations became important at the present stage of development of the military-technical sphere, while the logic of reproducing the course of combat processes often loses to graphic realization. As some authors note, there is a significant imbalance between the hyperrealism of visualization quality and the simplification of the logic of the simulation scenarios themselves, in the sphere of military computer games. New weapons appear quickly in them, while the implementation of the current tactics and the full functionality of the combat process is implemented with great difficulty. There is currently a lack of ready-made modules sets that allow reproducing the full life cycle of the use of artillery means with a sufficient degree of realism in the process of computer modeling of combat actions. It causes a need for creating generalized models allowing filling such a niche and ensuring a real simulation of the use of artillery means during combat operations.

This book shows a full simulation cycle of artillery operations in the process of a computer modelling environment. For that purpose, we consider every stage of the process of using artillery means beginning from selecting a target to carrying out a shot and including a missile flight, accounting dynamic disturbances, the moment of hitting a target, an explosion, etc. All those stages are considered as separate sections and form a continuous circle of simulation. Such an approach allows showing the logic of using artillery means at each stage and linking the described stages into one simulation system.

The essence of the considered models' importance lies in the possibility of realizing a clear logic of the functioning of artillery means instead of just visually animating the effect of the release of missiles. Implementation of a full cycle of simulation containing all the components provides a possibility to realize the most physical picture of a battle of artillery means. That is, models take into account ballistic regularities of missiles motion, taking into consideration the unavoidable number of stochastic disturbances at each shot, for example, weather conditions, directionality errors, etc. Accounting of applying stochastic methods into modeling makes it possible to more precisely simulate the behavior of artillery units, considering the randomness of many values – starting from the speed of the released missile and reloading time up

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to the probability of being detected by the enemy's reconnaissance assets. According to conducted studies, such models have an ability to significantly increase the realism and efficiency of artillery operations in the simulation process, making the simulation close to real conditions and the combat situation itself. That means, on the basis of the considered models, it is possible to implement not only the exterior of the fire effect but also possible decisions logic and shooting results in typical conditions of the battlefield.

It is possible to note that the developed models are generalized ones; they do not contain any actual secret technical and tactical characteristics. Those were created solely as an initial basis for logic that could be used in the process of computer modeling of combat operations. Thus, the given content may become a foundation for improving the simulation realism of using artillery means without revealing any real information. Such an approach allows combining the scientific value of modeling with confidentiality requirements, enabling the use of the obtained results both for educational goals and for creating software complexes of simulation training experiments.

In this book tasks of modeling, diagnostics and information support of processes of functioning of artillery systems in the cycle of preparation and realization of fire and registration of its effect are considered.

In the first part of the book, the analysis of the current state of the automated control of fires of artillery means on the tactical level is carried out; theoretical aspects of functioning of information control systems; approaches to algorithmization of tasks of the artillery units' management and world experience in creation and use of special purpose automatic control systems are considered. The generalization of functional structure of such systems is received in the result of the research, the place of verification of the firing state in the system of artillery fires' management is defined. Obtained results will be interesting to developers of modern information-control systems and tools of automation of combat application of artillery.

In the second part of the book, the task of localizing of the information about the firing state of artillery systems and its verification is considered. Processes of "propellant charge – firing chamber – barrel – projectile – flying path – ground surface hit" are analyzed, methods of definition of parameters of the processes considering analysis of the accompanying phenomena (acoustic, thermodynamic, video metric) during shot were offered. As a result, it is possible to receive a complex of methods allowing to partially verify the separate shooting stages and to use the obtained information for the estimation of the condition of artillery systems.

In the third part of the book, physicochemical processes occurring during shots, namely the process of formation of free carbon in the gas product of combustion of powder charge was studied. The model of description of gases' temperature distribution in the channel of barrel is proposed, which allows to judge about the conditions of carrying out of thermochemical reaction and formation of muzzle flash. Carried out simulation shows the influence of the parameters of charge and conditions of shots on the character of the muzzle blowout, that can be used for the study of the processes of internal ballistics.

In the fourth part of the book, methods of determining of the condition of artillery systems in the conditions of dynamic perturbations are considered. The model of estimation of the condition of self-propelled artillery systems as multifactor dynamic objects is offered. Using the acoustic, optic, thermodynamic and mechanic parameters allow us to form the system of signs of the suitabilities and estimate the system combat abilities. Obtained results can be used for creation of the blocks of algorithmic decisions of support systems.

In the fifth part of the book, the methods of operational definition of composition and energetic properties of nitro-cellulose powders charges are considered. Library approach of solution of direct and inverse tasks of thermodynamic modeling of process of decomposition of charges is offered. The obtained results allow quickly judging about the conditions of substances taking part in the processes of internal ballistics according to the minimum number of experimental data, also correcting parameters of calculation of the processes of internal ballistics.

In the sixth part of the book, the improvement of the methods and models of management of combat application of artillery systems is devoted. The stochastic models of combat operation of artillery subdivisions on the basis of discrete Markov's processes are offered. Developed approaches allow estimating efficiency of shots and forecast changing of combat ability of artillery system and justify the rational structure of performing of fire tasks.

In the seventh part of the book, the development of the computerized diagnostics system of parameters of shots by analysis of features having various nature is devoted. The approach to synthesis of acoustic signals and video observations of muzzle blowout with the aim of forming of informative diagnostic parameter is offered. Conducted studies have shown the possibility of increase in reliability of determining of the barrel condition and other shooting parameters due to combination of heterogeneous channels of measuring.

In the eighth part of the book, the method of parabolic approximation for determining of the coordinates of the point of fall of an artillery shell is devoted. This method is based on registration of ballistic waves of shots by acoustic spatially distributed sensors and subsequent approximation of the flight path of a projectile by a system of parabolas. Carried out studies show the possibility of determining the coordinates of the falling points of shells with sufficient accuracy on the basis of the results of one shot.

In the ninth part of the book, the problem of optimal choice of acoustic sensors for registering of ballistic waves of shots is considered. The approach of formation of optimal measurement subsystem on the base of multicriterial analysis with the use of fuzzy logic is offered. Obtained results allow increasing the reliability of acoustic measurements, and are the basis for further implementation of the methods of checking the artillery shoots. Thus, the obtained results presented in the monograph form a unified complex of models, methods and algorithms, aimed at studying the processes of shooting, evaluating the technical condition of artillery systems and improving the effectiveness of their combat application.

In general, the idea of this book is that it considers modeling of the functioning of artillery means as a whole cycle, starting from choosing a target up to exploding ammunition. It is shown how such a holistic approach can give a better understanding of combat simulation and make it more realistic. This volume demonstrates such an approach by considering the existing gap in the theory and practice of computer modeling of combat operations, contributing to more realistic and scientifically accurate simulations of the combat operations of artillery means. Now let's list solved tasks ensuring the simulation realism.

Trajectory of motion. To ensure realism, it is necessary to correctly simulate the physics of the movement of objects. A ballistic trajectory of movement of missiles is calculated according to the laws of mechanics – acceleration due to gravity, air resistance, initial speed, etc., so the shots behave exactly as in real-life. So, modern training systems, for example, imitate ammunition flight accounting the distance, flash, target movement, etc., depending on the type of ammunition. This helps soldiers learn how to correctly aim at a moving target to hit it effectively. In other words, the rocket in the simulator hits where it should hit in real life (given that the shooter takes into account all factors), and not flying directly along a straight line like a laser beam.

Sensors/perception. Another key factor is the modeling of the operation of various sensors/perception devices – tools for detecting and observing objects. In the simulator, it is necessary to indicate\ \\ *exactly what game objects**: hear see and feel: a person's field of view, equipment's scanning radius, radars or cameras work, and much more. It defines if an opponent will react to the player's presence or if equipment can be rotated towards him/her. The task of simulating such sensors becomes quite complicated if you want to model something complex – say, a computer vision system. But without such considerations, realistic behavior cannot be obtained: the game needs to ensure that enemies notice the player only after he steps into their sensors range, and not "see" everything beyond walls or at fantastic distances.

Accuracy and randomness. In real life, nothing works 100% accurately, there are always some mistakes and randomness – the same happens in simulation. For example, artillery fire is scattered: fired missiles hit different points, even if the same conditions are met. In simulation, this can be modeled by introducing some randomness: random change in the missile's speed, slight deviation of the missile from the center of aiming, variability of loading time, or chance of spotting by enemy forces, etc. According to the studies, usage of such stochastic models makes it possible to more accurately reproduce the random nature of many factors – from the speed of missile flights to the probability of its detection by an enemy soldier. That is, the system behavior in the simulation becomes much closer to the real one: not every shot is 100% successful, battles are more unpredictable and similar to the real ones.

Reaction to disturbances. Combat unfolds in a chaotic environment. Another modeling task is teaching the system how to react to external factors – i.e., changes in the situation. After all, a believable simulation implies objects reacting to sudden impacts: does a self-propelled gun remain stable if its base begins to sink into the ground? Does a rocket change direction under a gust of wind? If you want to model a system of automatic correction of artillery batteries, for example, you will consider changes in the position of guns in combat and the impact of outside factors on the firing algorithm. You can also plan ahead for random events: anything from breakdowns and failures of equipment to changes in weather conditions and how characters/equipment reacts to these. Correct processing of such situations in the game leads to greater realism; e.g., decreasing shooting accuracy due to mist, slower movement of equipment in wet soil etc. The player gets the impression of a "living" unpredictable world, just like in reality.

The solution of the listed tasks influences the logic of the simulator. It is exactly the models of trajectories, sensors, accuracy and robustness against disturbances that define the rules of interaction in the virtual world. For example, if your algorithms take into consideration limitations of the field of view, then you get gameplay rules: it becomes possible to sneak past a watchtower without being noticed. If you correctly implement the modeling of ballistic curves, the player must take into account distance and wind when firing a sniper rifle or a mortar. The reactivity of systems to damage or changing weather conditions defines the level of unpredictability of the battle – whether vehicles get stuck in swamps, or tanks survive an explosion at close range. And so on. As a result, a whole set of models obtained by research turns into a certain number of game rules, and the laws of physics become the rules of the game. This allows to create a unified, coherent gameplay, where the events happening on the screen follow the same laws that apply to the real world.

From a toy to education: the didactic potential of simulations.

Of course, a computer simulator can serve not only as an entertaining game. Thanks to realistic models, it can be used as an educational tool. A realistically reproduced environment allows one to simulate various combat situations and rehearse them many times. And the possibility of repetition is incredibly important both in preparation and in practical training. Special systems of simulating different combat situations allow soldiers and officers to repeat the fight as often as necessary to learn good skills. Thus, a person learns something new in small portions with frequent repetition, gradually moving from simple things to complex ones. An illustrative example of this is the Synthetic Training Environment: here you can model almost any battlefield configuration and rehearse difficult stages several times before going into battle – up to 25 hypothetical battles before the first real one! Rehearsal helps to understand the complexity of combat actions: the commander and soldiers see the results of their decisions in different situations, learn to act properly and develop strategies. Moreover, there is no threat to life and health, and you can afford mistakes, repeating the exercise again.

In addition, a realistic simulator creates a safe space for training. By placing a soldier in a virtual battle that resembles a real one, the training system gives him/her the required amount of practice, very similar to the real thing. In serious educational games, players achieve a high level of immersion: they feel like heroes acting out events and experiencing stress akin to real-life stress. At the same time, a virtual environment allows for experimentation, making mistakes and learning from them without real negative consequences. For example, a squad commander in the game can experiment with a risky raid tactic: if it fails, nothing terrible happens – but the lesson about how better to conduct operations stays. So the simulator combines entertainment and training: interactive, interesting gameplay makes it easier to immerse yourself in the game, and the realism of the tasks and ability to draw conclusions improve knowledge of a profession and military affairs.

Realism because it's science.

At the same time, realism is due to the fact that the game simulator uses scientific models. Or, in other words, the backbone of a quality military game is built around the same laws as are used for the relevant calculations in science, or to train engineers. That is, modern game engines rely on the laws of mechanics: using mathematical models, they reproduce the true movement of objects in a virtual world. It means that during the game, equations of movement and interaction are somehow solved: Newton's mechanics determine acceleration and trajectories, the algorithms of collisions handle explosions and collisions, algorithms for working with rigid bodies help determine the behavior of a vehicle when rolling over or colliding with obstacles. Likewise, the modeling of sensor readings relies on real data about the parameters of sensors: their sensitivity, operating radius, delay and signal noise. That is why a simulator seems to us realistic: its core consists not of invented rules, but of natural laws and proven algorithms.

And in fact, the approach described in this book resembles scientific activity: at first, the problem is formulated (for example, to build a trajectory or sensor model), then mathematical models are created, experiments are carried out (simulations are run), adjustments are made and only after that the obtained solution is integrated into the game. It resembles the creation of a digital copy of the real system: our simulator becomes a model that reproduces the behavior of a tank, plane or soldier as if we were researching a real object. Like in science, simulation allows to check hypotheses: what happens if you increase the weight of the armor piercing shell or reduce the reaction time of the pilot? The answer gives the model. Science and games are therefore related: the scientific approach gives the game mechanics depth and realism, and gaming becomes the embodiment of science.

Implementation of models: from the training system to the game. Everything said above can help the creators to create an effective simulator for training soldiers or for creating exciting video games. The key thing here is the principle: if you want a serious and convincing tool, then use models and do not forget about the "black boxes" and disturbances. Otherwise, there will be no realism, only a showy game.

What does the reader get?

So, after reading this book, a developer or scientist receives a number of significant benefits.

A general understanding of the gunpowder artillerist problems in modern conditions, a comprehensive idea of the essence of shooting as a process, and an idea of possible ways of modeling and optimization.

An arsenal of mathematical tools, methods, and algorithms for solving specific problems.

Knowledge of the principles of building simulation models on the basis of available data and assumptions; examples of using existing databases to build simulation tools.

Recommendations on the choice of methods depending on the tasks solved, the level of available data and knowledge, and the desired level of accuracy.

Information about software solutions used in modeling, and ready-made libraries.

Examples of implementation, analysis, and comparison of results with real ones and with known works.

Information about open problems and further prospects for work in this area.

We think that this list itself makes the book interesting and necessary for those who are faced with the task of solving specific problems associated with modeling processes in artillery.