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Verification of artillery fire under the influence of random disturbances for the computer game ARMA 3

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ABSTRACT

Computer gaming occupies a firm place in today's media culture and media business. Computer games are widely used both as a means of entertainment and as an educational tool. Military games traditionally hold a place in computer gaming. However, it is in this sector of gaming that a sharp contradiction is observed between the super-realistic quality of the video component and the limited scope of the game's script component. In particular, in the development of military-themed games, the introduction of modern weapon models is rapidly evolving. At the same time, the experience of military conflicts over the last decade and the new tactical techniques developed are difficult to implement in games. This work demonstrates the possibility of improving the artillery component of ARMA 3. In artillery fire, random disturbances are always present. These disturbances cannot be eliminated during the preparation of the firing. In practice, they are compensated by consecutive ranging shots. Modern artillery firing tactics require the maximum reduction of the firing time of the artillery unit. In this regard, methods for verifying each artillery shot are very relevant. Verification is understood as confirming the effectiveness of a shot immediately after it is made. A method for verifying a shot by recording the flight time of a projectile through three control points is proposed and studied. Based on the recorded flight times by sensors, a system of approximating parabolas is constructed. The solution of the system allows determining the expected point of the projectile's burst before it lands. The deviation of the burst point from the aiming point verifies the quality of the artillery shot. Simulation modeling of the proposed method has been conducted. It is demonstrated that parabolic approximation effectively compensates for random disturbances of the shot. A comparison of the proposed method with the method of compensating disturbances through consecutive ranging shots is made. It is shown that the proposed method significantly reduces the firing time of the weapon and the ammunition expenditure for hitting the target for the ARMA 3 player.

Keywords: ARMA game; shot verification; random disturbances; parabolic approximation

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INTRODUCTION

Over the past 20 years, computer gaming has undergone revolutionary changes. As a powerful information technology, computer gaming has taken two positions in societal development – gaming as media culture and gaming as media business [1, 2]. Gaming as a media culture has established strong positions in education, in esports, in the industry of collective and individual entertainment. A special place in computer gaming, from its inception in the form of primitive shooters to the present day, is occupied by military games [3, 4], [5]. If modern military games are at a sufficient level in terms of quality, determined by high and super-high resolution video simulation, the script aspect of military games leaves much to be desired [6, 7]. An integral component of modern military games should be the simulation of the combat use of artillery. Here, the quality of simulation should reflect to the maximum extent the tactical concepts of artillery use in modern combat [8]. These tactical concepts are constantly evolving, taking into account the experience of using artillery as the main striking force in ground operations during local conflicts of

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the 21st century and the Russian-Ukrainian war. In this regard, improving the script aspect of the artillery component of military games in terms of bringing the level of simulation modeling closer to the real tactics of artillery use in modern warfare is a relevant scientific and practical task.

As an example for solving this task, the popular military game ARMA 3 was chosen [9]. In the real application of artillery, the classical concept of counter-battery warfare today has transformed into the “shoot-and-scoot” tactic [10]. Defeating an enemy's artillery unit while maintaining one's own combat capability is possible only by reducing the firing time to hit the target to the minimum possible [11]. Each shot from an artillery installation gives the enemy the opportunity to estimate its coordinates and open return fire. Thus, the side that uses methods of conducting artillery fire that allow accomplishing the task of hitting the target with the minimum number of shots wins. This fully coincides with the main principle of choosing a winner in a military computer game – the one who spends the minimum of the resources provided to him - time and ammunition – to complete a combat task, wins. It is precisely this general principle of modern computer gaming that is embedded in the artillery component of the game ARMA 3.

LITERATURE REVIEW

Modern means of ensuring the accuracy of artillery firing and current accuracy assessment, guidance methods, and adjustment can be divided into the following technological directions:

(i) preliminary preparation for firing [11,12];

(ii) verification of firing results, i.e., confirmation of the projectile hitting the target point or assessing the deviation from the aiming point [13].

The technological direction (i) is aimed at fully accounting for possible firing errors, mainly systematic, and includes:

– reconnaissance and determination of target coordinates;
– topogeodetic preparation;
– meteorological preparation;
– ballistic preparation;
– technical preparation;
– determining settings for firing.

Despite the constant improvement of the means of technological direction (i) and, in particular, the applied IT, random disturbances associated with the following factors, which are difficult to assess, can exist during firing:

– wear of the barrel of the artillery installation that occurred after its last measurement;
– heating of the barrel as a result of intense preceding firing;
– inaccurate information about the charge and its storage method.

Errors in firing due to the action of random disturbances require assessment during verification.

The technological direction (ii) is associated with establishing informational feedback between consecutive shots from an artillery installation [16, 17]. After each shot, a correction of the initial firing settings for the next shot is made. According to [17], the procedures for informational feedback are divided into two categories – “shoot-look-shoot” (SLS) for targets observed from the firing position, or “shoot-adjust-shoot” (SAS) for concealed firing positions. In both cases, the assessment of the coordinates of the projectile burst during firing is required, which significantly complicates and prolongs the verification procedure.

The most commonly used technologies for direction (ii) as of today are:

1. Optical observation, including the use of unmanned aerial vehicles (UAVs) [18, 19]. Drawbacks include the demasking of the observation process and the vulnerability of observation means.
2. Determination of the projectile's landing point by artillery radar [20, 21]. Drawback – demasking of the observation process due to radar radiation.
3. Processing of sound signals from projectile bursts, i.e., the use of sound reconnaissance means for artillery in the “Service of own firing” mode [22]. Drawbacks include the need for large spatially distributed sensor systems, and strong dependence of efficiency on weather conditions.

The issues of the occurrence and accounting of random disturbances during artillery firing are covered in sufficient detail in [17, 24], [25, 26]. It is advisable to use them to improve the tactics of using the artillery component of a military computer game.

GOAL AND OBJECTIVES OF THE RESEARCH

The aim of the study is to develop and investigate a method for verifying artillery fire with random disturbances for artillery shooting using the example of the ARMA 3 game. Verification of a shot will henceforth be understood as the prompt assessment of the deviation of the projectile's burst point from the required point immediately after the shot is made.

To achieve the set goal, the following tasks were accomplished:

– construction of the general scheme of the method;

– development of a method for calculating the landing point of a projectile in a shot with random disturbances based on parabolic approximation;

– conducting simulation modeling of the developed method;

– comparison of the developed method with the method of compensating random disturbances using the artillery bracket method;

– conducting a preliminary field experiment confirming the effectiveness of the developed method.

MAIN PART

GENERAL DESCRIPTION OF THE SHOT VERIFICATION METHOD

Fig. 1 shows the layout of the gun and the target point.

The origin of the coordinates is aligned with the firing position of the gun P_0 shooting a projectile with an initial speed $\vec{v_0}$.The diagram shows the movement of the projectile in the vertical plane. The aiming point P_* is located at a horizontal range X_*. It should be noted that in this study, the lateral deviation of the projectile caused by drift is not considered. If necessary, this phenomenon can be accounted for quite simply using well-known methods [27]. On the surface, at three observation points with corresponding coordinates $P_1(X_1), P_2(X_2), P_3(X_3)$ sets of measuring are located. This points are designed to register the moments of appearance of the ballistic wave at the respective point, $t_i, i=1,2,3$ which correspond to the moment of the projectile's passage over the observation points. The task of the developed method for verifying a shot with random disturbances is to estimate the landing coordinate of the projectile based on the registered times of the projectile's flight over the observation points and to determine whether it satisfies the required accuracy.

METHOD OF MEASUREMENT PROCESSING

Step 1. For the firing point P_0, the projectile's speed is determined from the firing tables for the given type of projectile and charge (full firing preparation, random disturbances are possible). For each of the points $P_j \ (j=1,2,3)$, based on the data from the previous points $P_i \ (i=0,1,2)$ the following calculations are performed.

Step 2. The section of the projectile's trajectory $P_i^{tr} P_j^{tr}$ is approximated by a straight line segment $P_i^{tr} P_j^{tr}$ (Fig. 2).

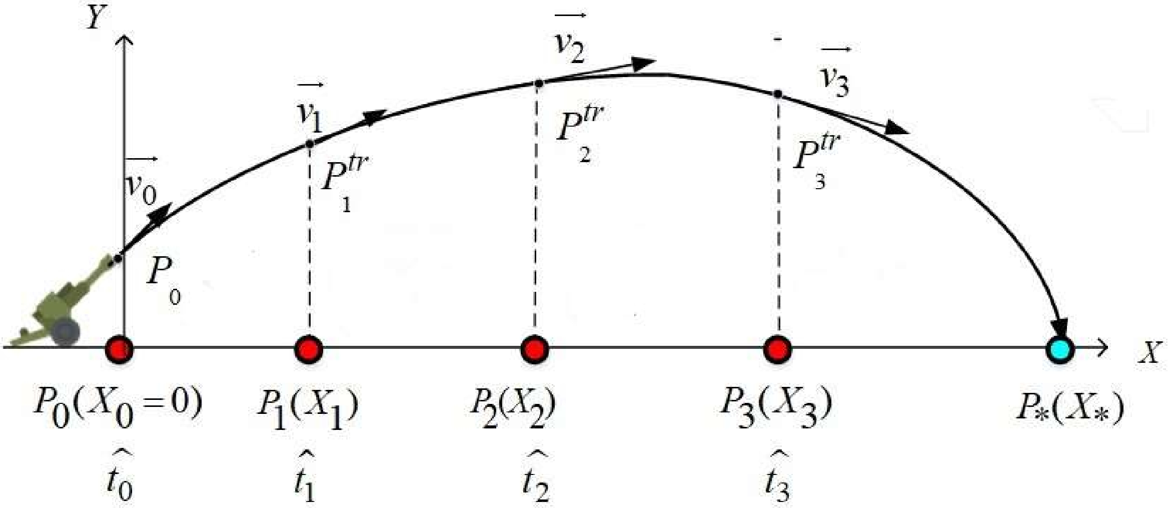

Fig. 1. **Layout of the gun and target point**

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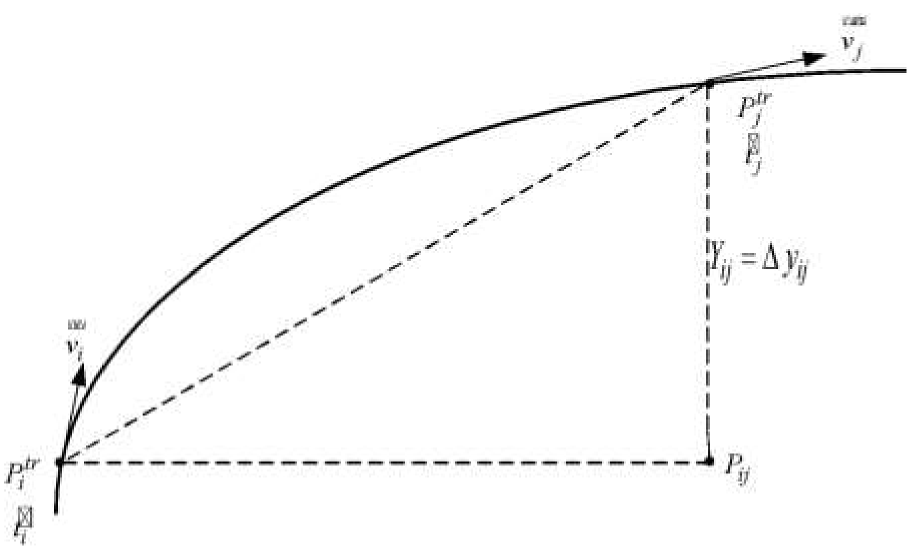


Fig. 2. **Calculated section of the trajectory**
Source: **compiled by the authors**

The air resistance force acting on the projectile in flight is described by a quadratic model [29]:

$$R = C_x \rho \frac{v^2}{2} SM, \tag{1}$$

where C_x is the integral coefficient of resistance; ρ is the air density; v is the projectile speed; S is the cross-sectional area of the projectile; $M = v/c$ is the Mach number; c is the speed of sound in the air.

The vector $\vec{R}$ is directed opposite to the vector $\vec{v}$, therefore the force R gives the projectile a negative acceleration

$$a = R/m, \tag{2}$$

where m is the mass of the projectile.

Then, the speed of the projectile at point P_j^{tr} is

$$v_j = v_j - C_x \rho \frac{v^2}{2} SM/m. \tag{3}$$

The approximate length of the trajectory segment

$$P_i^{tr} P_j^{tr} = v_i \Delta t_{ij} - C_x \rho \frac{v^2}{2} SM/m \Delta t_{ij}^2, \tag{4}$$

where $\Delta t_{ij} = t_j - t_i$.

As a result of performing computational procedures (1-4) in a right triangle $P_i^{tr} P_j^{tr} P_{ij}$ two sides $P_i^{tr} P_j^{tr}$ and $P_i^{tr} P_{ij} = X_j - X_i$ are known.

Then, the elevation of the projectile's flight trajectory along the Y-axis at point P_j^{tr} relative to point P_i^{tr} is:

$$\Delta Y_{ij} = \sqrt{(P_i^{tr} P_j^{tr})^2 - (P_i^{tr} P_{ij})^2}. \tag{5}$$

The height of the projectile's flight over point P_j is

$$Y_j = Y_j + \Delta Y_{ij}. \tag{6}$$

As a result of the described computational procedure, points of the projectile's trajectory elevation over points $P_1^{tr}(X_1, Y_1)$, $P_2^{tr}(X_2, Y_2)$, $P_3^{tr}(X_3, Y_3)$, and for the firing point $P_0(X_0 = 0, Y_0 = 0)$.

Step 3. Approximating parabolas are constructed for each triad of points:

$$(P_0,\ P_1^{tr},\ P_2^{tr}) - Y_1 = A_1 X^2 + B_1 X,$$

$$(P_0,\ P_2^{tr},\ P_3^{tr}) - Y_2 = A_2 X^2 + B_2 X, \tag{7}$$

$$(P_0,\ P_1^{tr},\ P_3^{tr}) - Y_3 = A_3 X^2 + B_3 X.$$

Another approximating parabola can be constructed for four points

$$(P_0,\ P_1^{tr},\ P_2^{tr},\ P_3^{tr}) - Y_4 = A_4 X^2 + B_4 X. \tag{8}$$

Each of these approximating parabolas serves as a model of the projectile's motion, to some extent compensating for the random disturbances in firing. The intersection points of the approximating parabolas with the surface (non-zero roots of the parabolas) $P_*^1, P_*^2, P_*^3, P_*^4$ are approximate estimates of the projectile's landing point. The arithmetic mean of the intersection points of the approximating parabolas with the surface $X_*^0 = (X_*^1 + X_*^2 + X_*^3 + X_*^4) / 4$ is the averaged estimate of the projectile's landing point with compensated random disturbances.

It should be noted that in reality, more than four approximating parabolas are constructed, but in the end, exactly four are selected for the estimate X_*^0 according to the algorithm described below.

Algorithm for sign permutation $\Delta \mathbf{Y_{ij}}$

In the calculation using relations (2-6), it was assumed that point j is located on the trajectory above point i. In a real situation, the Y -coordinate of point i may be greater than the Y-coordinate of point j. This can occur, in particular, if point j is located on the descending branch of the projectile's trajectory. Therefore, when estimating ΔY_{ij}, both positive and negative values of ΔY_{ij} should be calculated.

Accordingly, for each point $P_j, (j=1,2,3)$, two values of the projectile's flight height over point P_j should be calculated:

$$\begin{aligned} Y_j^+ &= Y_j + \Delta Y_{ij}, \\ Y_j^- &= Y_j + \Delta Y_{ij} \end{aligned} . \qquad (9)$$

Next, when constructing approximating parabolas for each point $P_j, (j=1,2,3)$, entering the triad (7) or tetrad (8), two parabolas are constructed – $Y_j^+ = A_j^+ X^2 + B_j^+ X$ and $Y_j^- = A_j^- X^2 + B_j^- X, (j=1,2,3)$. Then, for each of the two parabolas, the distance from the approximated landing point $\Delta_j^+ = \left| X_{*j}^+ - X_* \right|, (j=1,2,3)$ and $\Delta_j^- = \left| X_{*j}^- - X_* \right|, (j=1,2,3)$ are determined. The "correct" approximating parabola is chosen as the one with the smaller distance value $\Delta_j, (j=1,2,3)$.

The consideration of the mutual arrangement of points P_j and P_i, which is provided by the proposed algorithm, leads to the formation of four "correct" approximating parabolas in step 3 of the described method.

The general scheme of the presented method is shown in Fig. 3.

The proposed method was modeled for shooting from the M109 howitzer, which is part of the artillery armament in the latest versions of the ARMA 3 game, using the M107 projectile with a caliber of 155 mm.

The initial speed of the projectile and the time moments of flight over the control points were taken from the approximate ARMA 3 fire tables (FT) [28].

Characteristics of the projectile [29]: mass 43 kg, diameter 0.15471 m, initial speed (full charge #4) [28] 684.3 m/s. Preparation for firing – complete. For calculations, the following values were adopted: ρ =1.2041 kg/m^3, c = 341.6 m/s, aiming point coordinate X_*= 15000 m. The integral resistance coefficient C_x was selected from Tables [29]. X coordinates of the measuring points: $X(P_1)$ = 5500 m, $X(P_2)$= 7700 m, $X(P_3)$= 9800 m.

Flight times at measuring points with random disturbances $t_i \, (i=1,2,3)$ were formed as follows: 5 % random disturbances were introduced into the table flight times:

$$t_i = t_i^{FT} + \Delta t_i, \Delta t_i \in rand[0.95\Delta t_i; 1.05\Delta t_i] (i=1,2,3) .$$

Simulated parameters are presented in Table 1.

SIMULATION MODELING OF THE SHOT VERIFICATION METHOD

According to equations (2-9), four approximating parabolas were constructed (Fig. 4). The simulation results are presented in Table 2.

Table 1. **Parameters of the simulation modeling of the shot verification method**

Simulated Parameter	Parameters corresponding to the locations of microphones on the firing line direction		
	1	2	3
Target coordinate by sight, m	15000		
Distance from the gun to the measuring microphone, m	5500	7700	9800
Time of flight, s	10.2	15.4	19.5

Source: **compiled by the authors**

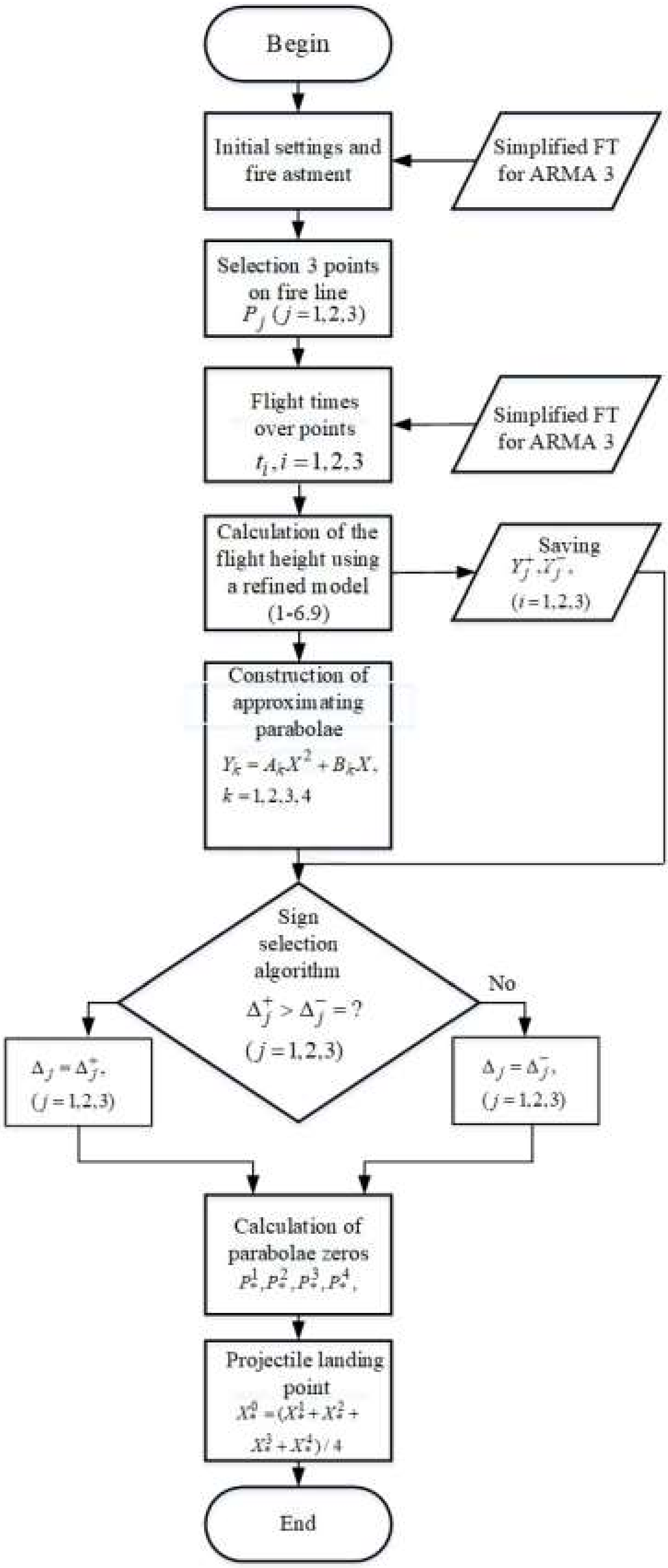
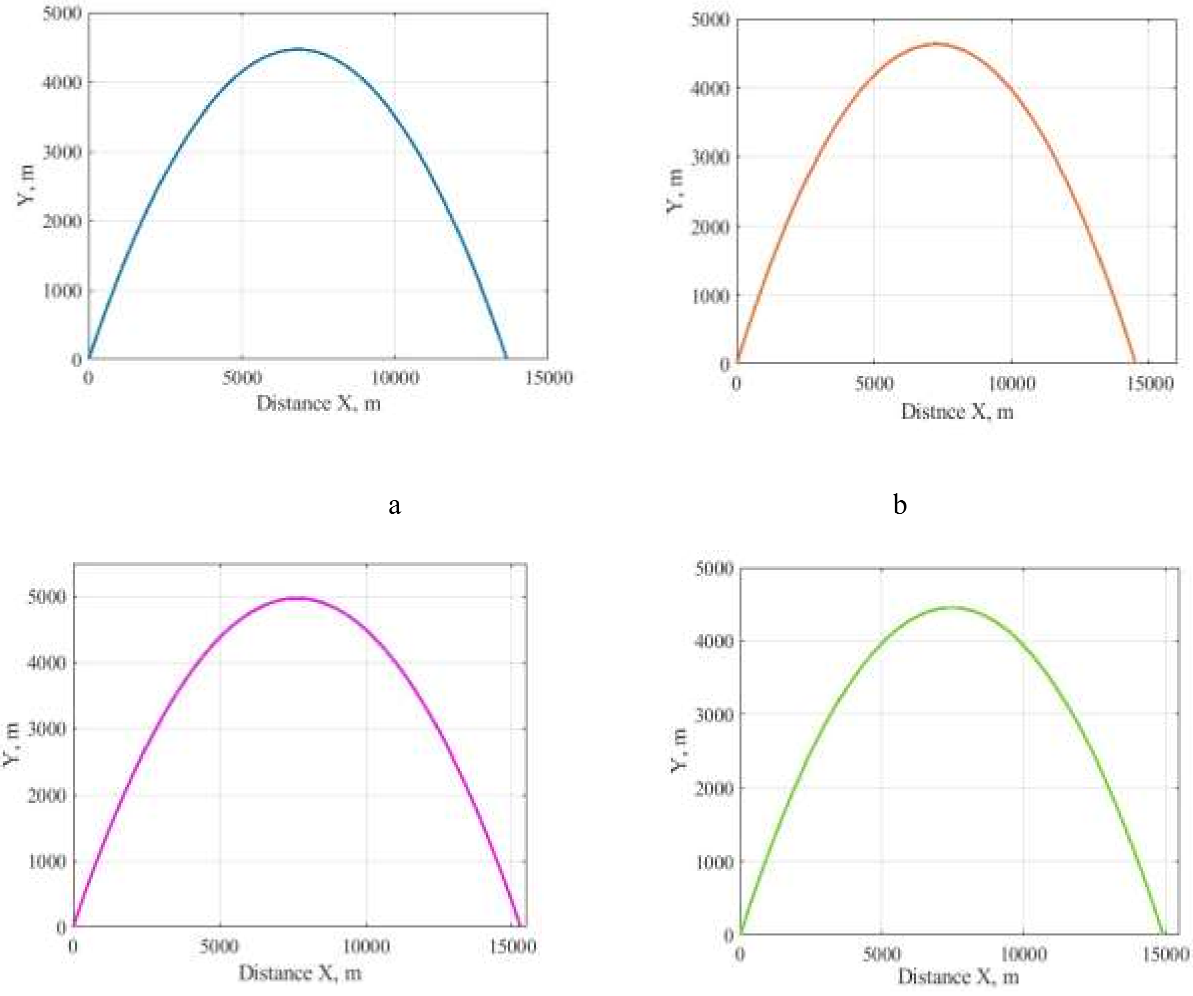


Fig. 3. **General scheme of the verification method**

Source: **compiled by the authors**



a

b

c

d

Fig. 4. **Approximating parabolas**

(constructed: a – based on points P_0, P_1, P_2; b – based on points P_0, P_1, P_3;

c – based on points P_0, P_2, P_3; d – c – based on points P_0, P_1, P_2, P_3)

***Source:* compiled by the authors**

Table 2. **Simulation results of the shot verification method**

Simulation Results		Approximating Parabolas			
		#1	#2	#3	#4
Target Range X_*, m		25000			
Parabola Equation Coefficients $Y = AX^2 + BX$	A	-0.000096	-0.000088	-0.000080	-0.000087
	B	1.32	1.27	1.19	1.33
X_*^i, m		13794	14513	15113	14880
$\overline{X_*}$,, m		14575			

***Source:* compiled by the authors**

For clarity, the final sections of the approximating parabolas are shown in Fig. 5.

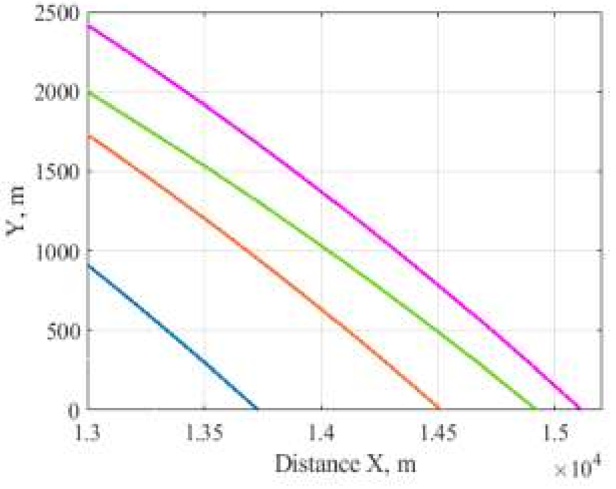


Fig. 5. **Final sections of the approximating parabolas**
Source: **compiled by the authors**

The simulation modeling of the proposed shot verification method demonstrates three main results.

1. The verification method compensates for random disturbances through the use of a system of approximating parabolas, achieving an error of about 0.5 % of the firing range.

2. The proposed method allows for verification based on a single shot, obtaining verification results even before the projectile lands.

3. The approximating parabola constructed from four points allows for better compensation of random disturbances.

Comparative analysis of the proposed method with compensation of random disturbances by consecutive corrective shots

To demonstrate the advantages of the proposed method, a model calculation of firing at the same range was carried out using a precise trajectory calculation program based on the NATO STANAG 4355 standard [30]. The projectile flight model underlying the standard describes the projectile as a moving material point with 5 degrees of freedom. It is currently considered the most accurate description of the projectile's trajectory for large calibers. Full modeling in accordance with [30] was conducted using software code, as detailed in [31].

To create equivalent modeling conditions, random disturbances in this case were introduced by pseudo-randomly changing the initial velocity of the projectile:

$$v_0^{dist} = v_0^{FT} + \Delta v_0, \Delta v_0 \in rand[0.975 v_0^{FT}; 1.025 v_0^{FT}]. \quad (10)$$

After each shot, the deviation of the projectile's landing point was assessed, and its compensation was carried out using the artillery bracket method with aiming angle correction on subsequent shots. Fig. 6 shows the projectile flight trajectories for five consecutive shots. The results of the simulation are presented in Table 3.

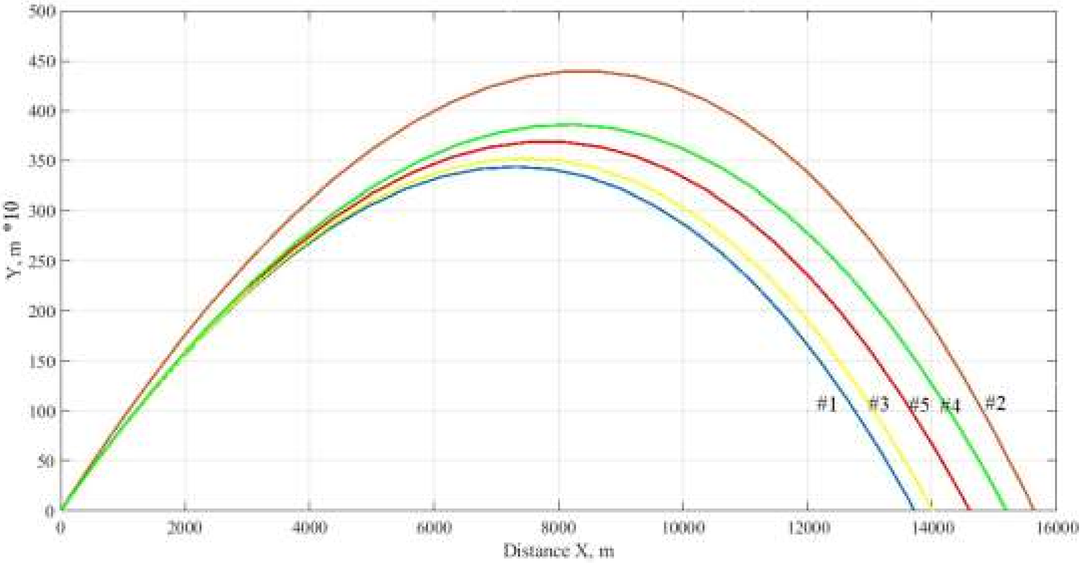


Fig. 6. **Calculated ballistic trajectories for five shots with sequential correction**
Source: **compiled by the authors**

Table 3. **Simulation results of compensating random disturbances with sequential shots according to the STANAG 4355 model**

Simulation Result	Shot Numbers				
	#1	#2	#3	#4	#5
Target Range X_*, m	15000				
X_i, m	13750	15520	14630	15200	14600
$\overline{X_*}$, m	14740				

Source: **compiled by the authors**

Fig. 7 shows the final sections of ballistic trajectories for five consecutive shots.

The simulation results show that to compensate for random disturbances to a level of error of 0.5% of the range, the method of traditional ranging shots requires at least five consecutive shots.

Fig. 8 shows the simulation results on the maps of the ARMA 3 game.

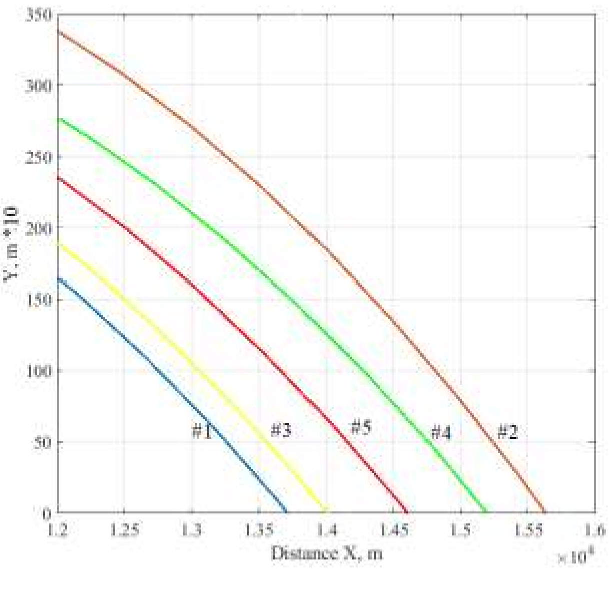


Fig. 7. **Final sections of ballistic trajectories for five consecutive shots**
Source: **compiled by the authors**

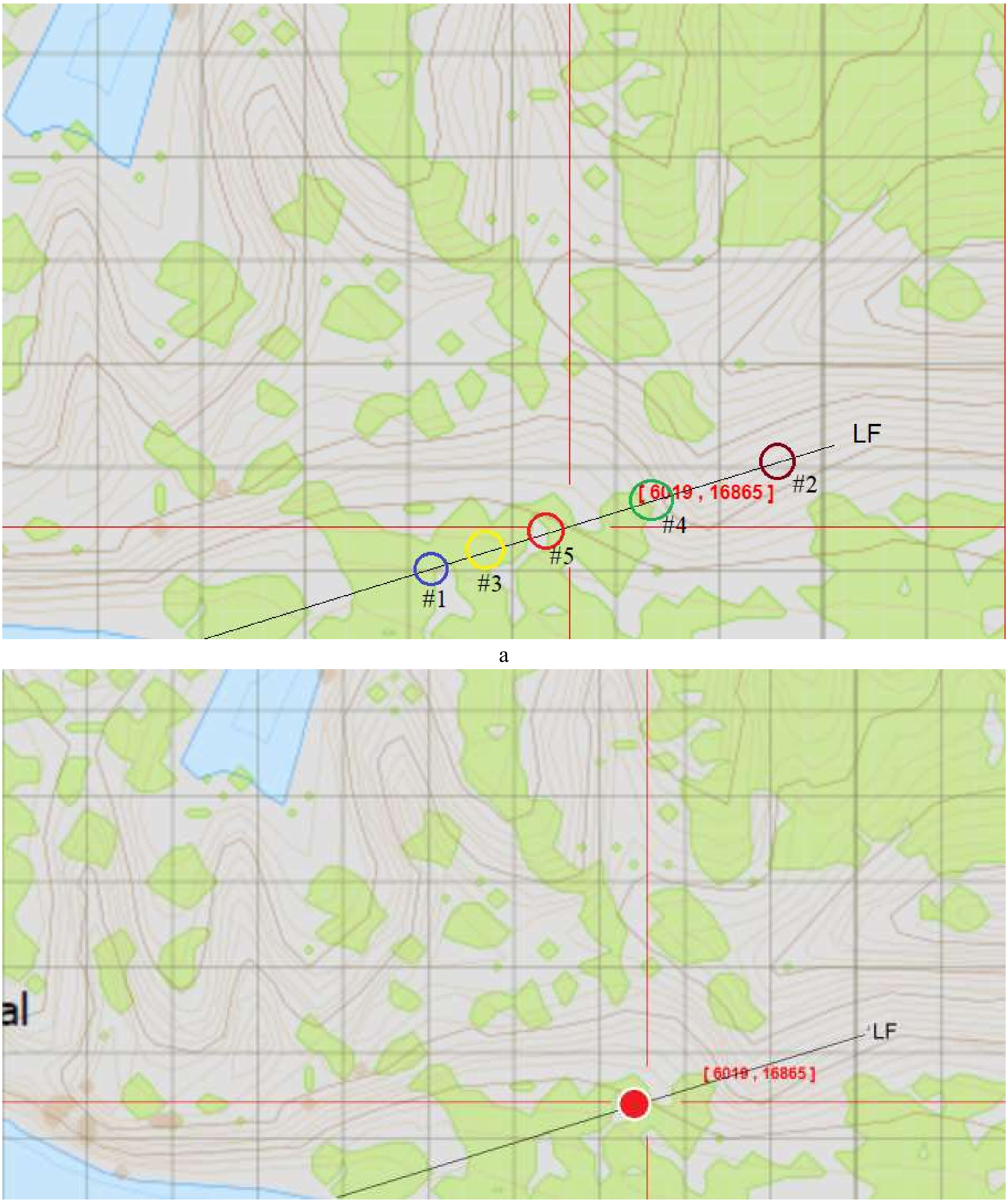
ADVANTAGES OF THE PROPOSED SHOT VERIFICATION METHOD

The proposed method of verification with parabolic approximation, as shown by simulation modeling, provides the ability to compensate for random disturbances to quite acceptable levels of shooting errors with just one shot. The calculations related to the construction of approximating parabolas are fairly simple and can be obtained by the player even before the projectile lands. The proposed method reduces the firing time of the weapon, decreases the expenditure of ammunition. In this regard, it opens new possibilities for the player to maintain the combat capability of the weapon.

CONCLUSIONS

A method for verifying artillery fire with random disturbances has been developed and studied. The method is based on the approximation of the projectile's flight trajectory by a parabolic relationship using three or four points. The developed method makes it possible to verify a shot even before the projectile lands and bursts. Computational simulation experiments demonstrated that the developed method significantly limits the firing time of the weapon and the expenditure of ammunition when compensating for random disturbances compared to traditional ranging shots. Depending on the player's goals, the method allows either to significantly increase the likelihood of winning by saving time and ammunition resources, or to enable the player to master real techniques of using modern artillery included in the latest versions of the ARMA 3 game.

Since this study investigated the firing of a single weapon, as a perspective for further research, it is planned to generalize the results to the firing of a weapon as part of a battery.



a

b

Fig. 8. **Comparative results of simulation shooting on ARMA 3 Maps (LF – line of fire, lateral deviation due to drift not shown): a – refined method of sequential ranging; b – verification method with compensation of random disturbances using approximating parabolas**

Source: **compiled by the authors**

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Верифікація артилерійського пострілу під впливом випадкових збурень для комп'ютерної гри ARMA 3

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АНОТАЦІЯ

Комп'ютерний геймінг займає міцне місце в сьогоднішніх медіа-культурі та медіа бізнесі. Комп'ютерні ігри широко застосовуються як засіб розваги, і як засіб освіти. Традиційне місце у комп'ютерному геймінгу посідають військові ігри. Однак саме в цій галузі геймінгу спостерігається гостра суперечність між суперреалістичною якістю відео компонентів та обмеженістю сценарної компоненти гри. Зокрема, у разі розвитку ігор військового напряму швидко розвивається впровадження сучасних зразків зброї. У той же час досвід військових конфліктів останнього десятиліття та вироблені нові тактичні прийоми в ігри впроваджуються насилу. У цій роботі продемонстровано можливість вдосконалення артилерійської компоненти ARMA 3. В артилерійському пострілі завжди є випадкові обурення. Ці обурення не можна усунути в процесі підготовки стрілянини. Насправді вони компенсуються шляхом послідовної пристрілки. Сучасна тактика стрілянини потребує максимального скорочення часу вогневого прояву артилерійського підрозділу. У цьому вся плані дуже актуальні методи верифікації кожного артилерійського пострілу. Під верифікацією розуміється підтвердження ефективності пострілу одразу після його здійснення. Запропоновано та досліджено метод верифікації пострілу з реєстрації часу прольоту снарядом трьох контрольних точок. На підставі зареєстрованих часів прольоту сенсорами будується систем апроксимуючих парабол. Рішення системи дозволяє визначити очікувану точку розриву снаряда ще до приземлення. Оцінкою відхилення точки розриву від точки прицілювання верифікується якість артилерійського пострілу. Проведено імітаційне моделювання запропонованого методу. Продемонстровано, що параболічна апроксимація дозволяє ефективно компенсувати випадкові збурення пострілу. Проведено порівняння запропонованого методу з методом компенсації збурень шляхом послідовного пристрілювання. Показано, що запропонований метод дозволяє суттєво скоротити час вогневого прояву зброї та витрати снарядів на ураження мети для гравця ARMA 3.

Ключові слова: гра ARMA; верифікація пострілу; випадкові обурення; параболічна апроксимація

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