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On the possibility of using a surveillance radar station to solve the problem of determining the starting point (firing position)

The purpose of the article was to study the application of a surveillance radar station for solving the problem of determining the coordinates of field artillery when detecting missiles. The experimental data of trajectory tests of field artillery gunnery are analyzed, the parameters of the pattern of change in missile altitude are determined using the developed two-stage approach.

Keywords: radar station, quadratic approximation, trajectory, track.

Introduction

One of the important problems to be solved in modern military conflicts is to counter hostile artillery fire and, therefore, to detect and suppress enemy’s firing positions as soon as possible.

Paper [1] represents the solution to the problem of determining target (impact) points during normal operation of a mobile air target long-wave UHF band surveillance radar station (RS). This publication analyses the application of the same surveillance RS for solving the problem of determining firing positions of field artillery units. To consider the possibility to determine the starting point, we analysed trajectory data gathered during firing tests, using the developed two-stage approach (Fig. 1). The first stage is intended to determine the orientation of the plane of fire on the horizontal plane. The second stage is intended to calculate the parameters of the pattern of change in projectile altitude [1].

In the proposed model, the projectile is assumed to fly without deviations in the horizontal plane. For approximation, we used linear (determination by the least squares method), quadratic (determination by the least squares method) and cubic (plotting a ballistic curve with account for air resistance) functions [2].

In case of linear approximation, the root of the sum of squares of experimental data deviations from the accurate linear dependence, normalized to the number of points, is used as the residual function:

$$R_1 = \frac{\sqrt{\sum_{i=1}^{N}\left(y_i - (A + Bx_i)\right)^2}}{N}, \qquad (1)$$

where $[x_i, y_i]_{i=1,\dots,N}$ – set of N pairs of coordinates of experimental points in the horizontal plane;

A, B – approximating straight line coefficients in the horizontal plane $y = A + Bx$ [2].

In case of quadratic approximation, the root of the sum of squares of experimental data deviations from the accurate quadratic dependence, normalized to the number of points, is taken as the residual function:

$$R_2 = \frac{\sqrt{\sum_{i=1}^{N}\left(h_i - (ay_i'^2 + by_i' + c)\right)^2}}{N}, \qquad (2)$$

where $\left[h_i, y_i'\right]_{i=1,\dots,N}$ – set of N pairs of coordinates of experimental points in the vertical plane of firing;

a, b, c – approximating parabola parameters in the vertical plane $h = ay'^2 + by' + c$ [2].

Similarly, in case of cubic approximation of the trajectory, the root of the sum of squares of experimental track points deviations from the accurate quadratic dependence, normalized to the number of points, is taken as the residual function:

$$R_3 = \frac{\sqrt{\sum_{i=1}^{N}\left(h_i - \left(y_i'\operatorname{tg}\theta_0 - \frac{gy_i'^2}{2V_0^2\cos^2\theta_0}(1 + KV_0^2 y_i')\right)\right)^2}}{N}, \qquad (3)$$

where $\left[h_i, y_i'\right]_{i=1,\dots,N}$ – set of N pairs of coordinates of experimental points in the vertical plane of firing;

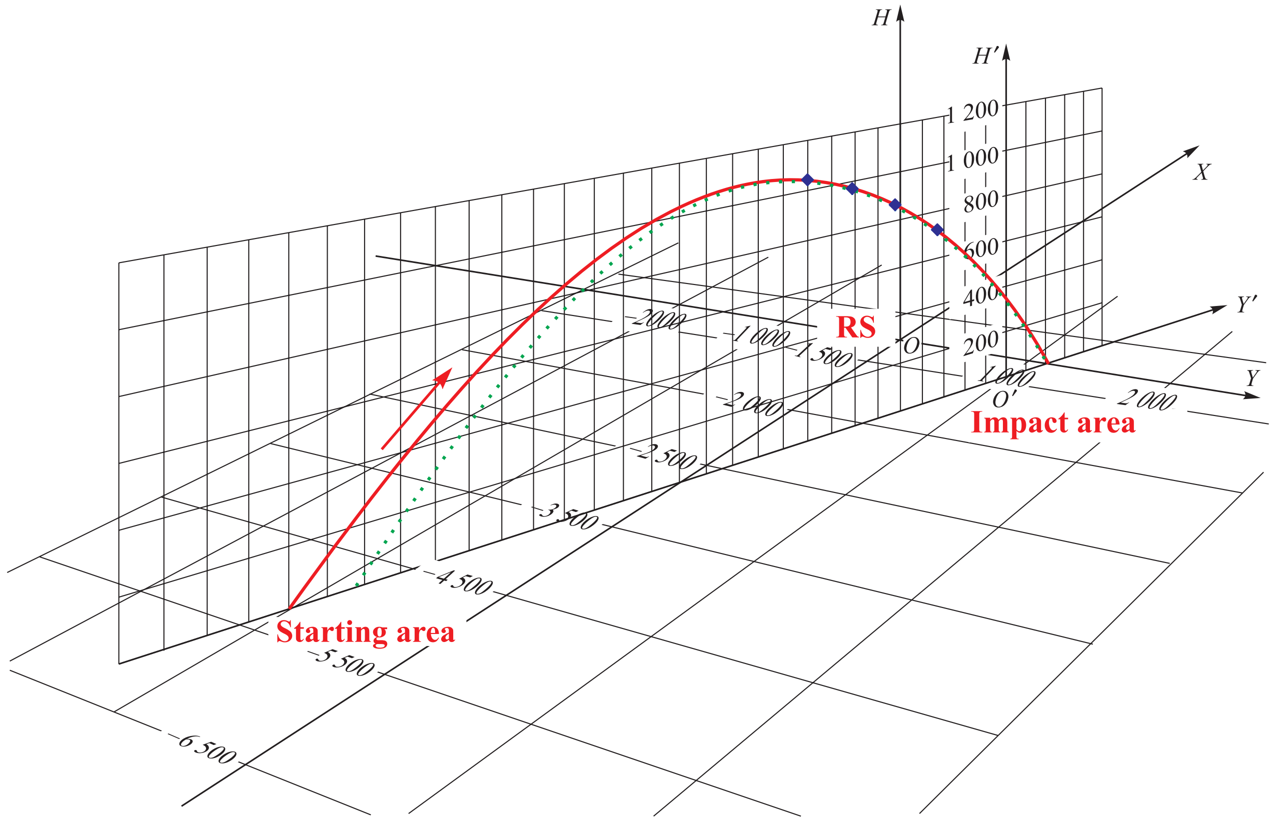

Fig. 1. Diagram of two-stage approach to problem solving

g – gravity acceleration;

θ_0, V_0, K – ballistic curve coefficients [3, 4].

As expected, approximation with account for air resistance gives better results than parabolic approximation. However, plotting a ballistic curve is a numerical construction, while plotting a parabolic trajectory is an analytical one. This allows to obtain an immediate solution by substituting coordinates of observed points into the formula. Numerical construction takes more time to obtain any result.

Full-scale data analysis

The table below contains consolidated data on Day 2 of full-scale firing tests, including reference coordinates of a firing position.

With functions R_1 (1), R_2 (2) not exceeding the relevant threshold values and with parabola branches directed downward (at negative coefficient at high order degree of parabola), the trajectory may be classified as a ballistic trajectory with probability of 85.7 % (see Table). To determine firing position coordinates, we plotted two flight trajectories with account (ballistic) and without

Summary calculation results for Day 2 of firing tests

Projectile calibre, mm	122
Total tracks	21
Tracks with trajectories classified as ballistic trajectories	18
Probability of ballistic target (BT) identification, %	85.7
Stable observation distance range D, m	1245–4443
Elevation angle range by stable tracking points, deg	19.6–51.3
Average elevation angle by stable tracking points, deg	30.6
Average sight angle by stable tracking points φ, deg	39.0
Average amplitude in relative units	1413.0
Average daily value of linear approximation residual function $R_{1,\text{сред}}$, m	34.7
Average daily value of quadratic approximation residual function $R_{2,\text{сред}}$, m	17.0
Distance from firing position (FP) to the median of calculated starting points (parabola/ballistics, m)	92.9 / 151.0

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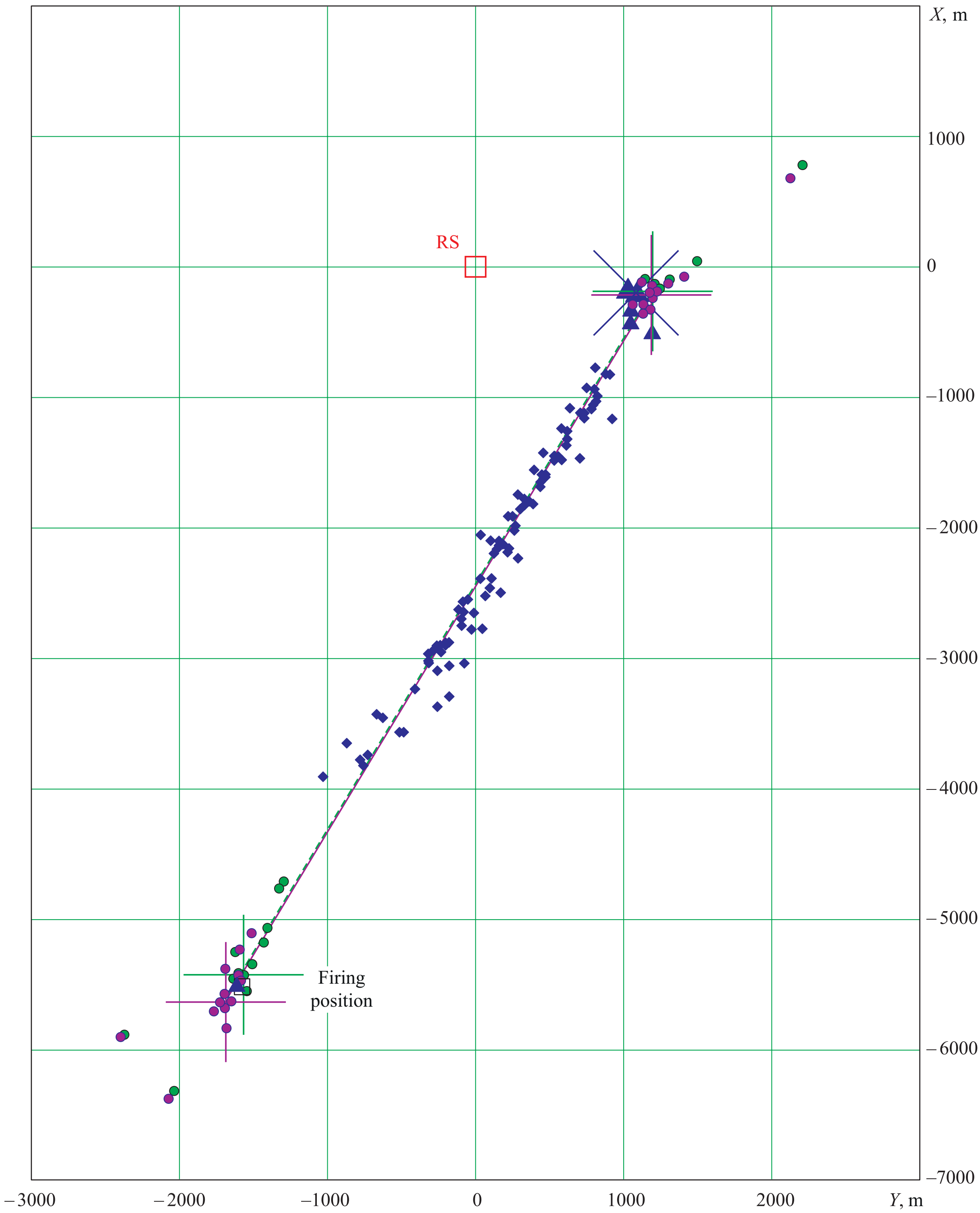

Fig. 2. Results of calculation of starting and impact points in the RS coordinate system: ◆ – stable radar tracking points; ▲ – reference starting and impact points; ✕ – median of reference impact point coordinates; ● – impact points (parabola); ● – impact points (ballistics); + – median of calculated starting and impact points (parabola); + – median of calculated starting and impact points (ballistics)

account (parabolic) for air resistance. The resulting accuracy of firing position coordinates determination verifies the accuracy predicted in the model calculation, and its order of magnitude matches the accuracy of impact point determination [1].

Fig. 2 shows the results of calculation of starting and impact points in the RS coordinate system. To reduce the positioning error, we compensate the system error inherited to mutual orientation of the Gauss – Krüger coordinate system with given reference coordinates of a firing position and projectile detonation points and an RS-bound coordinate system.

Conclusion

We analysed the possibility to calculate firing position coordinates. The results indicating the starting points positioning accuracy were obtained. The starting points positioning accuracy was 92.9 and 151.0 m for parabolic and ballistic approximation, respectively. These values have an order of magnitude near to each other regarding the impact points positioning accuracy [1].

According to our study, a long-wave UHF band surveillance radar station can be used not only for solving the problems of determining projectile impact points, but also for searching the location of enemy's firing positions.

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О возможности применения обзорной радиолокационной станции для решения задачи определения точки пуска (огневой позиции)

Рассмотрено применение обзорной радиолокационной станции для решения задачи определения координат полевой артиллерии при обнаружении снарядов. Выполнен анализ экспериментальных данных траекторных испытаний стрельб полевой артиллерии, с использованием разработанного двухэтапного подхода, определены параметры закона изменения высоты снаряда.

Ключевые слова: радиолокационная станция, квадратичная аппроксимация, траектория, трасса.

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