Artillery Firing Data Correction Calculation by Using Computers

K. Šilinger, B. Přikryl, M. Blaha, L. Potužák

Abstract**—** The new procedures of the distance and direction corrections calculations within software artillery are suggested in the article. Reported algorithms represent the way of calculations that is not based on commonly used simplification by manual calculations in some of current programs. The first calculated variant allows to determine the distance and direction correction using the derived relationships. The second variant represents an alternative approach to the direction correction calculation, which is based on the general line equation definition.

Keywords**—** Artillery, distance correction, direction correction, adjust fire.

I. Introduction

ARTILLERY shooting is affected by factors that are virtually impossible to identify and include in the firing data calculation for firing artillery with conventional ammunition [1], [2], [3], [4]. Inability to exclude all these influences causes a substantial deviation of the first shot explosion from the target in the direction and in the distance during an adjust fire. [4], [5] According to the measured explosion deviations from the target in the direction and the distance it is then necessary to calculate corrections. [6], [7], [8]

The distance and direction correction for the next shot it is necessary to determine always in the shortest time, since the gradual approaching of explosions to the target (hereinafter referred to as adjust fire of the target) leads to the unveiling of its own military deployment, revealing its project activities, lengthening total time for filling the firing task etc. [4], [9], [10], [11] To minimize the time required to adjust fire of the target are currently various tools (for traditional ways of determining - graphically or analytically) and computer support used by determining the distance and direction correction. [12], [13], [14], [15], [16]

For manual calculations were made several simplifications. The simplification of calculations consists in procedures application that allow to avoid absolute values, trigonometric functions, complicated algebraic expressions, etc. during calculations, since these manual calculations are usually performed by the soldier-arithmetician in the field in difficult conditions and under time pressure.

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Karel Šilinger is an academic worker at the University of Defence in Brno, Czech Republic. He deals with issues of the artillery firing data preparation and of the artillery automated fire control systems. E-mail: karel.silinger@unob.cz.

A variety of simplifications that facilitate manual calculations, however, are also applied by new software applications development. [17] This statement does not imply criticism of recently developed programs, but the impetus for a different approach when future applications covering artillery fire and the implementation of other methods more accurate partial calculations are designed.

The procedures derived in this article represent possible ways in determining the distance and direction corrections without an acceptance of various simplifications, without continuous rounding and with the highest possible precision for the artillery that represents a crucial aspect of the artillery fire effectiveness. Derived formulas are designed to be implemented in software applications focussed on artillery firing data calculations. Presented calculation procedures are not provided in any literature and represent the authors' original approach to solving this problem.

II. Solution Resources

Mil_{6000} angular measure is used in the following text. This measure is used by some army artillery - for example the Czech Republic, Slovakia, Poland and others. One mil_{6000} correspondents to 1/6000 length of the arc of a circle. Further derived calculation procedures, however, can also be used for other angular rate (mil_{6400}, grades, etc.). In relationships are given symbols for values in units of mil_{6000}, so it is necessary to **transfer them to the grades** before their instalment into the formula. The mil_{6000} can be converted to the grades by **multiplying the value in mil_{6000} by the factor of 0.06**. To mil angular rate of 6,400 units for one ring (used in some NATO countries) the mil_{6000} value have to be multiplied by a factor 0.05625. [3], [7], [8]

The following procedures for the distance and direction corrections calculations are derived for plane coordinate system, and therefore it is necessary to eliminate the influence of height differences. Excluding the impact of the differences in height (in altitude) is carried out when the explosion position altitude and the target altitude is different from zero. [3] Altitude of the explosion position is determined by the relationship:

$$A_{vbch} = A_{poz} + d_{vbch} \cdot \sin \varepsilon_{vbch} \ , \tag{1}$$

where: A_{vbch} – explosion position altitude (in metres),

A_{poz} – observation position altitude (in metres),
d_{vbch} – explosion distance measured from observation position (in metres),
ε_{vbch} – explosion positional angle from observation position (in mils).

The influence of the height (altitude) difference is eliminated according the difference in positional angle of the explosion from the gun position and positional angle of the target from gun position (i.e. the angle of the position, which was used in determining the firing data of the first shot):

$$\Delta\varepsilon = \arcsin\left(\frac{A_{vbch} - A_{ps}}{d_{dvbch}}\right) - \varepsilon_c , \tag{2}$$

where: A_{vbch} – explosion position altitude (in metres) counted from relation (1),
A_{ps} – gun position altitude (in metres),
d_{vbch} – the explosion distance from the gun position (in metres),
ε_c – positional angle of the target from gun position (in mils),
$\Delta\varepsilon$ – positional angles difference of explosion and target from the gun position (in mils).

The influence of height differences is usually included in a firing distance (one segment of artillery firing data). Some weapons systems, however, involve differences in height through positioning level, and therefore the relation for the calculation (2). Implementation of the inclusion of the influence of height difference will depend on the type of weapon system.

III. Approaches to the Distance and Direction Corrections Calculation

The corrections of the distance and direction calculation can be realized by calculation of the explosion position Cartesian coordinates and of subsequent assessment of the explosion position in relation to the shooting plane (the first variant), or by determining the general equation of a line passing through the gun position and the target and determining the relative position of the explosion and the line (the second variant). Calculation of the distance and direction corrections can be surely realized by other algorithms not described in this article. But authors propose the use these procedures that represent the simplest approaches in terms of number of executed computations and input variables, while keeping maximum accuracy (without applying various simplification, continuous rounding, etc.).

A. First variant of the distance and direction corrections calculations

Procedures of the distance and direction corrections calculation by using Cartesian coordinates of the explosion position and subsequent assessment of the explosion position in relation to the shot plane can be divided into two consecutive steps:

a) the Cartesian coordinates of explosion position calculation,
b) the distance and direction corrections calculation.

The Cartesian coordinates of explosion position calculation

Further is given a procedure to calculate the Cartesian coordinates of the explosion position by using the site position data of an artillery observer (observation position) and the data from the observation of explosion. This procedure is designed for artillery reconnaissance means, which does not allow the direct Cartesian coordinates and altitudes of individual explosions acquisition. Cartesian coordinates and altitude of individual explosions will be available primarily in collaboration with radars. In case of these means the following counting wouldn´t be made and the direct calculation of the distance and direction correction would be made (step (b)). If the other means of artillery reconnaissance would be used, the position of individual explosions is usually indicated by polar coordinates of the explosion position or by deviations from target (in meters or in mils). The positional angle of the explosion, eventually the increase or decrease of the explosion respect to the target, are simultaneously given to exclude the height difference impact.

If the explosion position is given by polar coordinates (azimuth and a distance from the observation position), it is necessary to perform the conversion using the so called first major geodetic tasks:

$$E_{vbch} = E_{poz} + \Delta E_{poz,vbch} , \tag{3}$$

$$E_{vbch} = E_{poz} + d_{vbch}{}' \cdot \sin\alpha_{vbch}{}' , \tag{4}$$

$$N_{vbch} = N_{poz} + \Delta N_{poz,vbch} , \tag{5}$$

$$N_{vbch} = N_{poz} + d_{vbch}{}' \cdot \cos\alpha_{vbch}{}' , \tag{6}$$

where: E_{vbch} – explosion position coordinate E (East),
E_{poz} – observation position coordinate E,
$\Delta E_{poz,vbch}$ – the difference of explosion position coordinate E and observation position coordinate E (in metres),
$\alpha_{vbch}{}'$ – explosion position azimuth from the observation position (in mils),
$d_{vbch}{}'$ – the explosion distance from observation position (in metres),
N_{vbch} – explosion position coordinate N (North),
N_{poz} – observation position coordinate N,
$\Delta N_{poz,vbch}$ – the difference of explosion position coordinate N and observation position coordinate N (in metres)

Explosion deviation from the target (if the explosion position is given by deviations in the distance and direction in relation to the target) is indicated in the distance in meters (Δd) and in the direction in mils (Δα) or meters (Δs') - see Figure 1.

If the explosion position deviation from the target is indicated in direction in mils (Δα), the calculation of the Cartesian coordinates of the explosion is as follows:

$$d_{vbch}{}' = \frac{d_C - \Delta d}{\cos \Delta\alpha} \quad , \tag{7}$$

$$E_{vbch} = E_{poz} + \frac{d_C - \Delta d}{\cos \Delta\alpha} \cdot \sin(\alpha_C{}' + \Delta\alpha) \; , \tag{8}$$

$$N_{vbch} = N_{poz} + \frac{d_C - \Delta d}{\cos \Delta\alpha} \cdot \cos(\alpha_C{}' + \Delta\alpha) \; , \tag{9}$$

where:
- $\alpha_C{}'$ – the target azimuth from observation position (in mils),
- $\Delta\alpha$ – the explosion deviation from the target measured from observation position (in mils) – if the explosion is in relation to the target on the right, with the "+" sign, if the explosion is on the left is the sign "-",
- d_C – the target distance from observation position – so called observation distance – (in mils),
- Δd – the explosion deviation from the target (in metres) – if there was explosion behind the target, is a "+" sign, when there was before the target is the sign "-".

If artillery observer instead of deviations explosion reports directly repairs due to the observation line (i.e. explosion deviations with opposite sign), it is required for the programming application to take this fact into account and automatically inputs values multiply by a constant (-1).

Expression $\alpha_C{}' + \Delta\alpha$ represents an azimuth to an explosion from the observation position in mils ($\alpha_{vbch}{}'$).

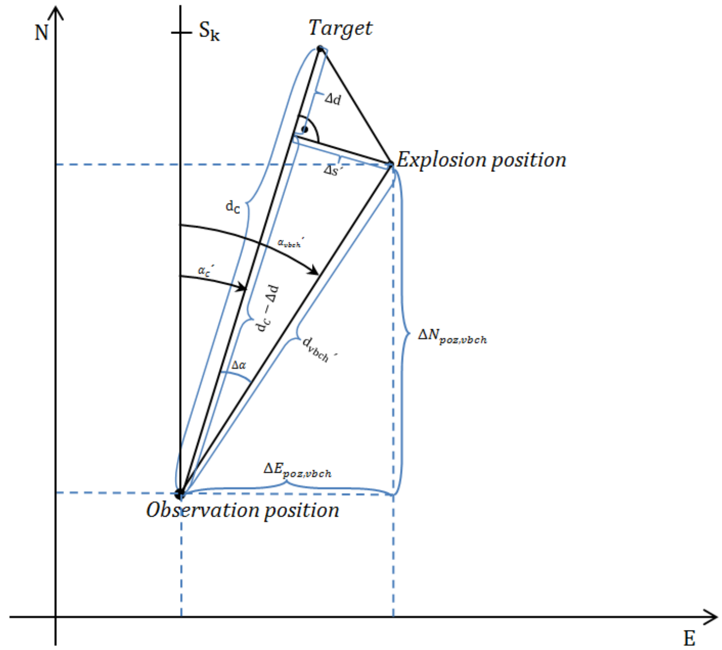

Fig. 1 The explosion position from the target regarding to the observation position

If the explosion deviation from target is indicated in direction in meters ($\Delta s'$), the Cartesian coordinates calculation of the explosion position is as follows:

$$E_{vbch} = E_{poz} + \frac{d_C - \Delta d}{\cos\left(\arctan \frac{d_C - \Delta d}{\Delta s'}\right)} \cdot \sin\left\{\alpha_C{}' + \arctan \frac{d_C - \Delta d}{\Delta s'}\right\}, \tag{10}$$

$$N_{vbch} = N_{poz} + \frac{d_C - \Delta d}{\cos\left(\arctan \frac{d_C - \Delta d}{\Delta s'}\right)} \cdot \cos\left\{\alpha_C{}' + \arctan \frac{d_C - \Delta d}{\Delta s'}\right\}, \tag{11}$$

where the expression $\arctan \frac{d_C - \Delta d}{\Delta s'}$ represents the deviation counting in direction in grades ($\Delta\alpha$).

From the usage of the sine function in the denominator indicates the condition that the relations (7) - (11) can be used for Δα in the interval <0 °; 90 °). Due to the probable distance of observation position from the target this limitation in practical terms is not limiting. Situations, where the angle between observational line of the target and direction on an explosion from the observation position reaches or exceeds 90 °, is in practice almost impossible.

The distance and direction corrections calculation

The procedure of distance and direction corrections calculation for a specific gun position follows from figure 2.

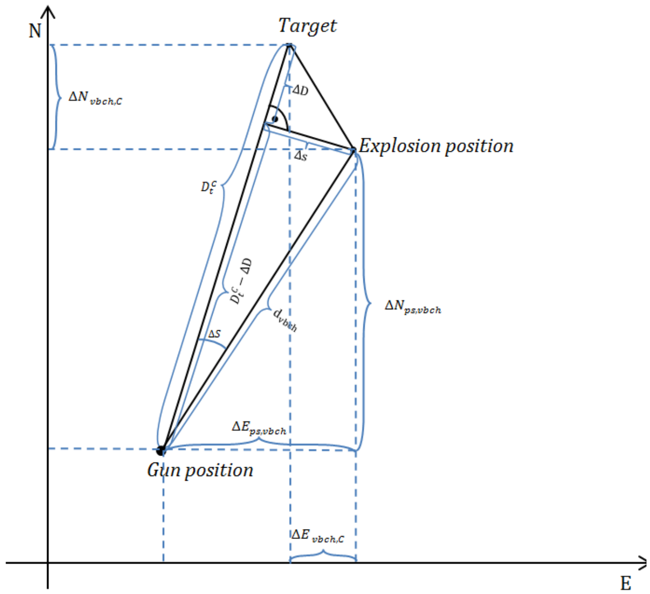

Fig. 2 Illustration of explosion position from the target regarding to the gun position

The explosion distance from the gun position (d_{vbch}) can be expressed from the rectangle coordinates of gun position and explosion position, respectively of their coordinate differences:

$$d_{vbch} = \sqrt{\Delta N_{ps,vbch}^2 + \Delta E_{ps,vbch}^2}\,, \tag{12}$$

where: d_{vbch} – the explosion distance from gun position (in metres),
$\Delta N_{ps,vbch}$ – the difference of explosion position coordinate N and gun position coordinate N (in metres),
$\Delta E_{ps,vbch}$ – the difference of explosion position coordinate E and gun position coordinate E (in metres).

Than the value of direction correction in mils can be expressed by the usage of cosine formula as:

$$\Delta S = \arccos\left\{\frac{\left(\sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2}\right)^2 + d_{vbch}{}^2 - \left(\sqrt{\Delta N_{vbch,C}^2+\Delta E_{vbch,C}^2}\right)^2}{2\cdot d_{vbch}\cdot\sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2}}\right\}, \tag{13}$$

where: $\Delta N_{ps,C}$ – the difference of target coordinate N and gun position coordinate N (in metres),
$\Delta E_{ps,C}$ – the difference of target coordinate E and gun position coordinate E (in metres),
$\Delta N_{vbch,C}$ – the difference of target coordinate N and explosion position coordinate N (in metres),
$\Delta E_{vbch,C}$ – the difference of target coordinate E and explosion position coordinate E (in metres).

After adjustments:

$$\boldsymbol{\Delta S} = \arccos\left[\frac{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2+\Delta N_{ps,vbch}^2+\Delta E_{ps,vbch}^2-\Delta N_{vbch,C}^2-\Delta E_{vbch,C}^2}{2\cdot\sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2}\cdot d_{vbch}}\right], \tag{14}$$

where: $\Delta N_{ps,C}$ – the difference of target coordinate N and gun position coordinate N (in metres),
$\Delta E_{ps,C}$ – the difference of target coordinate E and gun position coordinate E (in metres),
$\Delta N_{ps,vbch}$ – the difference of explosion position coordinate N and gun position coordinate N(in metres),
$\Delta E_{ps,vbch}$ the difference of explosion position coordinate E and gun position coordinate E (in metres),
$\Delta N_{vbch,C}$ – the difference of target coordinate N and explosion position coordinate N (in metres),
$\Delta E_{vbch,C}$ – the difference of target coordinate E and explosion position coordinate E (in metres).

Furthermore the distance from the gun position to the intersection of shot plane with a perpendicular line passing through the explosion position is to be expressed:

$$\sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2} - \Delta D = \\ = cos\left\{\arccos\left[\frac{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2+\Delta N_{ps,vbch}^2+\Delta E_{ps,vbch}^2-\Delta N_{vbch,C}^2-\Delta E_{vbch,C}^2}{2\cdot\sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2}\cdot d_{vbch}}\right]\right\}\cdot \\ \cdot\sqrt{\Delta N_{ps,vbch}^2+\Delta E_{ps,vbch}^2} \tag{15}$$

If we want to express the value of the cosine from the angle, which returns the inverse trigonometric arc cosine function, then the general rule is $\cos(\arccos x) = x$, pro $|x| \leq 1$. Due to the expected values of individual variables in the equation (14) can be argued that in real combat conditions there will be in a fraction of the relation (14) the denominator value always greater than the numerator value. Based on this assumption, the condition $|x| \leq 1$ is valid, and therefore the operation of function cosine and inverse cosine can be omitted. After this adjustment is then possible from the equation (15) express distance correction (ΔD):

$$\boldsymbol{\Delta D} = \sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2} - \\ -\left[\frac{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2+\Delta N_{ps,vbch}^2+\Delta E_{ps,vbch}^2-\Delta N_{vbch,C}^2-\Delta E_{vbch,C}^2}{2\cdot\sqrt{\Delta N_{ps,C}^2+\Delta E_{ps,C}^2}\cdot d_{vbch}}\right]\cdot \\ \cdot\sqrt{\Delta N_{ps,vbch}^2+\Delta E_{ps,vbch}^2}, \tag{16}$$

where: ΔD – is a length correction (in metres),
$\Delta N_{ps,C}$ – the difference of target coordinate N and gun position coordinate N (in metres),
$\Delta E_{ps,C}$ – the difference of target coordinate E

and gun position coordinate E (in metres),
$\Delta N_{ps,vbch}$ – the difference of explosion position coordinate N and gun position coordinate N (in metres),
$\Delta E_{ps,vbch}$ – the difference of explosion coordinate E and gun position coordinate E (in metres),
$\Delta N_{vbch,C}$ – the difference of target coordinate N and explosion position coordinate N (in metres),
$\Delta E_{vbch,C}$ – the difference of target coordinate E and explosion position coordinate E (in metres),
d_{vbch} – the explosion distance from gun position in metres.

B. Second variant of distance and direction corrections calculations

The second method differs from the first one by the procedure of direction correction calculation. Calculation of the direction correction by the second variant consists in the expression of a general equation of a line, where a topographical distance between the firing position and the target lies, and the consequent calculation the perpendicular distance of the point of the explosion position from this line.

The general equation of the line, where a topographical distance between the gun position and the target (later the line *t*) lies, can be expressed by using Cartesian coordinates of the gun position and the target. First is to be expressed the direction vector of the line *t* as:

$$\vec{s} = [E_C, N_C] - [E_{ps}, N_{ps}] = (s_E, s_N) \tag{17}$$

where:
$\vec{s}$ – direction vector of the line *t*,
E_C – coordinate E of the target,
N_C – coordinate N of the target,
E_{ps} – coordinate E of the gun position ,
N_{ps} – coordinate N of the gun position,
s_E – part x of the direction vector of the line *t*,
s_N – part y of the direction vector of the line *t*.

Furthermore the normal vector that is perpendicular to the direction $\vec{s}$:

$$\vec{n} = (-s_N, s_E)\ , \tag{18}$$

where:
– $\vec{n}$ – normal vector to a vector $\vec{s}$.

General equation of the line *t* can be expressed as:

$$t\colon -(N_C - N_{ps}) \cdot x + (E_C - E_{ps}) \cdot y + c = 0\ , \tag{19}$$

Constant c can be gain by putting into the equation a random point that lies on the line *t* into equation (19). The point that lies on the line *t*, is i.e. the target. So the constant c can be expressed as:

$$c = (N_C - N_{ps}) \cdot E_C - (E_C - E_{ps}) \cdot N_C\ . \tag{20}$$

General equation of the line *t* will be:

$$\begin{aligned} t\colon & -(N_C - N_{ps}) \cdot x + (E_C - E_{ps}) \cdot y + \\ & +(N_C - N_{ps}) \cdot E_C - (E_C - E_{ps}) \cdot N_C = 0\ . \end{aligned} \tag{21}$$

Furthermore the explosion position rectangular coordinates are to be calculated. To do this the same procedure as in previous case is to be used, i.e. in case of explosion deviation from the target given in meters is be used relations (10) and (11), and if the explosion deviation from the target given in miles are to be applied relationships (8) and (9). If artillery observer reports the polar coordinates of each explosion, relations (4) and (6) are to be applied.

Direction correction for gun position in meters (Δs) is then determined as:

$$\Delta s = \frac{\left|-(N_C - N_{ps}) \cdot E_{vbch} + (E_C - E_{ps}) \cdot N_{vbch} + (N_C - N_{ps}) \cdot E_C - (E_C - E_{ps}) \cdot N_C\right|}{\sqrt{(N_C - N_{ps})^2 + (E_C - E_{ps})^2}}\ , \tag{22}$$

where:
N_C – coordinate N of the target,
N_{ps} – coordinate E of the gun position,
E_{vbch} – coordinate E of the explosion position,
E_C – coordinate E of the target,
E_{ps} – coordinate E of the gun position,
N_{vbch} – coordinate N of the explosion position.

Direction correction for the gun positon in meters (Δs) can be in mils (after conversion from degrees) expressed as:

$$\Delta S = \arcsin \frac{\Delta s}{d_{vbch}} \tag{23}$$

where: d_{vbch} is the explosion distance from the gun position in metres.

In case o;f general equation of the line *t* the distance correction is find by the same way as in the previous variant, i.e. according to relation (16).

IV. The Current Analytic Method Accuracy Comparison with the Proposed Methods of the Distance and Direction Corrections Calculations

To determine the inaccuracies that can occur by manual calculations, i.e. with the application of appropriate simplifications, has been compared results of suggested ways using software form with results gained by using existing procedures.

To evaluate the errors was made set of simulated combat situations. During the simulations were deliberately changed the position of elements of combat assemblies and azimuths and distances to the target, in order to get different variants of mutual positions and different viewing angles (angle between gun-target line and artillery observer-target line).

After evaluation all of the simulations the following conclusions can be accepted:

- using the original method of the distance correction calculation fixes an error in the interval <0; 50) meters;
- using the original method of the direction correction calculation an error occurs in the interval <0; 2.5) mils;
- error in the distance and direction correction calculation by the old way, the greater the greater the viewing angle;
- error in the direction correction calculation is not proportional to the measured explosion deviation in direction. They were identified when the absolute value of the error with increasing size of the measured explosion deviation in a direction initially decreased, and then the increased;
- the magnitude of the error of distance corrections calculation using the original way is the greater, the larger is the value of explosion deviations in the distance.

V. Conclusion

A significant reduction of errors in the distance and direction corrections calculations can contribute proposed calculation procedures. Their use in the software of artillery will increase the accuracy of up to 50 meters with the distance corrections calculation, and up to 2.5 mils at the direction corrections calculation. To further increase the accuracy of the calculations will also contribute the fact that within the calculation algorithm eliminates rounding.

The only (in practical terms negligible) limitation is caused by using trigonometric functions in the calculations. Both variants of calculations are therefore applicable to the absolute value of explosion deviations from the target measured from the observation position in mils on the interval of <0; 1500). If the explosion deviation from the target is determined from the observation position in meters, then this restriction does not apply.

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