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Practical Evaluation of Instruments for Determining the Exact Position During Artillery Operations of the Czech Artillery

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Abstract

The thesis deals with the possibility of using civilian devices for position determination in the environment of the artillery of the Czech Army. These devices are discussed in the context of the accuracy of positioning in different environments. For the experiment, widespread and commonly used positioning devices were selected. These means were subsequently measured in spaces corresponding to the spaces in which artillery units could operate if deployed. The experimental results are then used to calculate probable target and firing position errors. Future investigation of the problem will allow the artillery units to be equipped with modern means.

KEY WORDS: *Artillery, determining the exact position, Global Navigation Satellite Systems, Operational Efficiency, Civilian assets in the military.*

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1. Introduction

The primary mission of artillery, along with other combat support units, is to provide support to combat units. Artillery supports combat units primarily by indirect fire. Therefore, for artillery units to conduct fires effectively, they must have accurately calculated firing elements. These elements are calculated according to the technical parameters of the fire vehicle, the ammunition used, the meteorological conditions and the position of the target and the firing position.

The artillery of the Czech Armed Forces can be understood as a system consisting of a target tracking and detection subsystem, an information subsystem for command and control, firing means, ammunition, ammunition supply and security. All these subsystems must have the capability to orient and determine the exact coordinates of their own position and other entities in the battlespace. The accuracy of coordinate determination will be particularly critical and essential for the target acquisition and fire unit subsystems as it will affect firing accuracy, ammunition consumption, and dwell time in firing positions.

There are a multitude of ways to determine position today. For artillery, the means of determining precise position based on satellite navigation system (GNSS) technology, such as the Global Positioning System (GPS) or the European Galileo system, and inertial navigation system (INS) technology are mainly used. These technologies are implemented in assets that are manufactured and dedicated primarily for military use.

Civilian precision positioning technologies, such as smartphones and commercial GPS receivers, offer an interesting prospect for military use in artillery. These devices have become highly accurate and more affordable positioning devices, opening opportunities for their integration into military systems, but with the need to meet strict military standards in terms of communication security and use.

This paper focuses on a practical evaluation of military and civilian precision positioning devices that are currently in use or have the potential for use by the artillery of the Czech Armed Forces. The aim of the investigation is to assess the potential use of commercially available devices for the needs of the artillery of the Czech Armed Forces, including a critical assessment of usability and potential threats.

The analysis will include a comparison of the performance of the devices in different conditions and the possibilities of integration into the artillery of the artillery of the Czech Armed Forces. In support of the proposals resulting from the analysis, a practical experiment based on the identification, comparison, and verification of the accuracy of civilian and military instruments for precise positioning in different terrain conditions was conducted.

2. Literary Research

Nowadays, when new technologies are rapidly developed and integrated in the military sphere, it is essential to continuously evaluate and improve the instruments used to determine the exact position during the activities of artillery units. A number of studies can be found in the literature that address this topic from different perspectives.

According to a study by Andrle and Nghia (2017), a key element of the accuracy of positioning systems in artillery is the modeling and comparison of tracking loops for GPS signals. These systems must be able to withstand interference and provide high accuracy data in real time, which is essential for effective fire control [1]. Another important area is the integration of topographic-geodetic data into artillery systems, as pointed out by Blaha and Silinger (2018). Software support to address these issues allows for faster and more accurate responses to dynamically changing battlefield conditions, which significantly increases the effectiveness of artillery fire [2]. Blaha et al. (2021) discuss simplification methods for exploiting angular and linear measurement rules. Streamlining these processes is essential to speed up decision making and increase the overall agility of artillery units [3]. The impact of modern technology and its potential vulnerabilities is a topic highlighted by Claus (2018). In particular, the growth in anti-rocket capabilities can seriously compromise the reliability of GPS systems, which are the basis for accurate positioning in artillery [4]. According to the new Army doctrine (2021), emphasis should be placed on the integration of autonomous weapon systems and modern reconnaissance units, which require efficient and accurate reconnaissance and correction procedures. Ivan et al. (2019) [6] and Šustr et al. (2022) [7] this approach leads to further development of artillery tactics and technologies that consider the current and future operational environment.

3. Methodology

The research was conducted as part of an experiment. The experiment to compare the accuracy of the positioning means was conducted using four specific means, two means from each category:

- Moskito TI - a multifunctional military acquisition device,
- DAGR (Defence Advanced GPS Receiver) - an advanced military GPS receiver,
- Smartphone - civilian smart phone,
- Outdoor watch - civilian sports watch.

The aim of the experiment was to quantitatively evaluate and compare the accuracy of the determined means in determining the position in four cycles. The first cycle immediately after switching on the device, the second cycle after 5 minutes from switching on the device, the third cycle after 10 minutes from switching on the device and the fourth cycle after 20 minutes from switching on the device, each cycle comprising five consecutive measurements taken at the shortest possible time interval. A total of 20 measurements were taken with each device, at each site. The individual sites were selected to represent possible artillery exposure environments, which are forest, open space and urban. A database of point arrays was used to control the measurements. The coordinates of the point arrays were used as reference values to calculate the measurement deviations of each technical means.

4. Limitations

All measurements were made in randomly selected civilian areas, without intentional interference, external influence of positional data, magnetic anomalies and other variables affecting the accuracy of the point coordinates determined by the instrument. The influences were based solely on the surrounding environment in which the measurement was made. The baseline against which the deviations were determined was based on the geodetic points of the national geodetic network.

5. Results of the Experiment

The results of the measurements were used to compare individual assets and to verify the hypothesis that civilian assets can be used to the advantage of artillery units under certain conditions. Through experimentation, it was determined which means provides the highest level of accuracy under realistic conditions, and how the measurement results are affected by time and changing spatial conditions.

Table 1.
Results of measurements in the Forest

Forest				
Measure	ΔE	ΔN	ΔA	**distance**
MOSKITO	2,606	4,839	-1,170	**5,496**
	7,206	4,039	5,230	**8,261**
	4,006	4,239	1,030	**5,832**
	2,406	-1,761	1,230	**2,982**
Measure	ΔE	ΔN	ΔA	**distance**
Smart phone	2,406	-0,161	14,630	**2,411**
	2,406	5,639	9,830	**6,131**
	3,606	3,839	8,830	**5,267**
	2,006	3,039	6,830	**3,641**
Measure	ΔE	ΔN	ΔA	**distance**
DAGR	3,806	-2,561	-8,770	**4,587**
	2,806	1,839	-6,570	**3,355**
	6,206	3,639	-1,770	**7,194**
	3,006	1,439	0,630	**3,333**
Measure	ΔE	ΔN	ΔA	**distance**
Outdoor watch	6,606	4,039	3,830	**7,743**
	7,206	1,439	4,430	**7,348**
	4,206	-2,561	0,830	**4,924**
	4,806	-3,961	0,430	**6,228**

Table 2.
Results of measurements in the Open space

Open space				
Measure	ΔE	ΔN	ΔA	**distance**
MOSKITO	3,7	7,732	12,25	**8,571**
	1,3	7,532	7,05	**7,643**
	0,5	5,932	6,45	**5,953**
	-0,5	4,532	4,65	**4,559**
Measure	ΔE	ΔN	ΔA	**distance**
Smart phone	-1,9	8,532	18,25	**8,740**
	-1,3	8,132	17,85	**8,235**
	-2,5	6,532	16,25	**6,994**
	0,7	4,332	14,85	**4,388**
Measure	ΔE	ΔN	ΔA	**distance**
DAGR	-2,5	1,532	-1,15	**2,932**
	-4,7	1,332	-7,95	**4,885**
	0,1	3,932	-0,35	**3,933**
	-0,7	1,132	0,25	**1,330**
Measure	ΔE	ΔN	ΔA	**distance**
Outdoor watch	4,9	8,332	-1,95	**9,666**
	-6,7	6,332	-3,15	**9,218**
	-3,5	2,932	-2,55	**4,565**
	-2,3	0,532	-0,35	**2,360**

Table 3.
Results of measurements in the Open space

Urban				
Measure	ΔE	ΔN	ΔA	**distance**
MOSKITO	7,976	3,509	-7,760	**8,714**
	10,976	6,909	-5,760	**12,969**
	8,976	6,109	2,840	**10,858**
	7,176	1,909	0,840	**7,426**
Measure	ΔE	ΔN	ΔA	**distance**
Smart phone	6,376	0,909	16,240	**6,440**
	5,176	-0,891	15,240	**5,252**
	-1,824	0,509	13,240	**1,894**
	0,176	-0,491	10,240	**0,522**
Measure	ΔE	ΔN	ΔA	**distance**
DAGR	19,776	16,109	7,040	**25,507**
	32,776	24,109	17,240	**40,688**
	10,176	35,309	17,240	**36,746**
	18,176	19,509	25,240	**26,664**
Measure	ΔE	ΔN	ΔA	**distance**
Outdoor watch	20,376	28,309	-3,760	**34,880**
	8,776	13,909	4,240	**16,446**
	7,776	13,709	1,240	**15,761**
	5,576	10,909	1,240	**12,251**

The table 1., 2. and 3. records the average measurement errors of each instrument at all three sites in meters. The error magnitudes are expressed as deviations from the ideal value in east (ΔE), north (ΔN) and altitude (ΔA). From these values the total real distance is calculated.

6. Theory of Artillery Fire Errors

Artillery units conduct mainly indirect fire. In indirect fire, it is not possible to use optical sighting and aim directly at the target. For this reason, it is necessary to know the position of the gun and the target. When these two positional data are available, it is possible to calculate the elements for firing. Under ideal conditions, the calculated elements would be sufficient, but in reality, factors are present during firing that result in the deflection of the projectile's path and thus the position of its impact. These factors cause errors that must be eliminated or at least suppressed in appropriate ways so that they affect the accuracy of the shot as little as possible.

These errors are divided into three types:
- Shot errors;
- scatter errors;
- errors in the determination of the elements to be shot.

The determination of the target position and the errors that arise in this activity are classified in the type of errors of determination of elements for shooting. The magnitude of these errors can be expressed in the form of a probable error in determining the coordinates of the target and firing position, where the most important parameter is the accuracy of the instrument used. The magnitude of these random errors does not change over the course of the firing mission and remains constant for the duration of remaining in firing position or firing at a single target.

Formula for calculating the probable error of target coordinates in distance and direction:

$$E_{x_C} = \sqrt{E_{d_C}^{2} + (E_{A_C} * cotg\theta_C)^2} \quad (1)$$

$$E_{z_C} = \sqrt{E_{S_C}^{2}} \quad (2)$$

Where:

E_{d_C}, E_{S_C} - the probable errors caused by errors in determining the target's coordinates in distance and direction,

E_{A_C} - the probable error due to target altitude errors,

θ_C - the range angle of the projectile, the angle enclosed by the level of the muzzle and tangent to the path of the projectile at the point of range

Formula for calculating the probable error in determining the coordinates of the firing position in distance and direction:

$$E_{x_G} = \sqrt{E_{X_{pp}}^{2} + (E_{A_{pp}} * cotg\theta_C)^2} \tag{3}$$

$$E_{z_G} = \sqrt{E_{z_{pp}}^{2}} \tag{4}$$

Where:

$E_{x_{pp}}, E_{z_{pp}}$ - probable errors due to errors in determining the coordinates of the firing position in range and direction,

$E_{A_{pp}}$ - probable error due to errors in determining the altitude of the firing position.

The probable instrument error is determined at the range and in the direction of fire for each range. Table 4 shows the instrument errors of the instruments used in the Czech Army.

Table 4.

Errors of measurements in the Open space [8]

Means and methods of determining target coordinates	Probable instrument errors	
	In the distance (E_{d_C})	In the direction of (E_{S_C})
Laser rangefinder:		
MOSKITO*	+/- 2 m	+/- 25 m (5 dc)
LEICA-VECTOR IV**	+/- 3 m	+/- 25 m (10 dc)
PLRF 25 C (BT)***	+/-5 m	+/- 10 mil
HALLEM II	+/- 5 m	
LPR-1	10 m	
LDM 38 (PzPK Sněžka, LOV Pz)	+/- 5 m	
Radiolocator ARTHUR:		
20 km	100 m	100 m
40 km	300 m	300 m
* measurements on 5 km, ** measurements on 4 km, *** measurements on 3 km		

According to the latest findings from the ongoing war in Ukraine, it is evident that from the first shot it is standard that the enemy can target and conduct fire on a firing position within 7 minutes. For this reason, it is very useful to conduct fire without being shot. For the artillery of the army of the Czech Republic it is necessary to use an automated fire control system or meteorological preparation which is not followed by adjust fire.

In meteorological preparation are included corrections for ballistic and meteorological conditions in the topographic elements. Therefore, to use meteorological preparation, it is specified that the coordinates of firing positions must be determined by GPS, geodetic means, topographic connector or inertial navigation system and at the same time the target coordinates have been measured with a maximum allowable circular error of 15 m [9]. The effect of survey agent errors in each space over time is listed in Table 5.

Table 5.

Probable errors of positioning devices in distance and side

	Forest		Open space		Urban	
	E_X	E_Z	E_X	E_Z	E_X	E_Z
MOSKITO	5,810	5,496	8,775	8,571	8,915	8,714
	8,473	8,261	7,871	7,643	13,105	12,969
	6,129	5,832	6,243	5,953	11,020	10,858
	3,527	2,982	4,932	4,559	7,661	7,426
	3,059	2,411	8,940	8,740	6,709	6,44

Smart phone	6,414	6,131	8,642	8,235	5,579	5,252
	5,594	5,267	7,243	6,994	2,670	1,894
	4,099	3,641	4,775	4,388	1,954	0,522
DAGR	4,959	4,587	3,484	2,932	25,576	25,507
	3,847	3,355	5,235	4,885	40,731	40,688
	7,436	7,194	4,360	3,933	36,794	36,746
	3,828	3,333	2,305	1,33	26,730	26,664
Outdoor watch	7,969	7,743	9,847	9,666	34,930	34,88
	7,586	7,348	9,408	9,218	16,553	16,446
	5,272	4,924	4,938	4,565	15,873	15,761
	6,507	6,228	3,019	2,36	12,394	12,251

7. Conclusions

The analysis of the results of the research has shown that the use of civilian devices means for determining the exact position is possible, since civilian means achieve the accuracy of military certified means. The proposal resulting from the conducted research is to extend the experiment with additional variables accompanying positioning for the artillery of the Czech Armed Forces and to verify their use directly in the environment of the 13th Artillery Regiment and mortar units of the Ground Forces. Following the verification of the civilian means, analyze the situations in which it is necessary to use the instruments for precise positioning and, according to the specifications of each situation, assign the means for precise positioning that most closely matches the situation.

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