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APPLICATION OF RELATIVE POSITIONING IN TOPOGRAPHIC SURVEY PREPARATIONS ON A FULL BASIS IN ARTILLERY

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Abstract:

The paper deals with the method of GPS relative positioning during topo geodetic survey preparations in artillery. Two Trimble Pro XRS receivers were used as a base station and a rover while a modem was a communication means between the devices. In order to get the results of the survey, statistical methods were applied in the subsequent data analysis. The results show a significantly reduced likelihood of errors at work in comparison to required values. The application of relative positioning during topographic survey preparations on a full basis provides much faster operation and higher accuracy than the prescribed one.

Key words: *global position system, relative positioning, topographic-survey preparation, circular error probable.*

Introduction

One of the main requirements of modern artillery is to determine coordinates of launching sites and observation posts accurately enough and fast enough for artillery firing. The requirement to determine the coordinates accurately enough and fast enough is durable and legitimate. However, in modern operations, less accurate but timely determined coordinations are more acceptable than those perfectly accurate but determined too late.

The application of classical field artillery survey is possible only in conditions of good visibility, which means that there is no procedure which,

in a longer period of time, can provide the determination of coordinates during all day and night. Modern combat effects require that coordinate points be determined in all visibility conditions.

The most modern artillery weapons able to open fire immediately after stoping require to known accurate coordinates at the very moment of halt. An artillery observer whose movements follow the combat deployment of a supported unit also needs to know the current position coordinates in every moment so that he could successfully detect a target and control artillery fire. This sets very strict requirements for rapid and accurate determination of coordinates, which is the essence of one of the basic problems of modern artillery.

GPS NAVSTAR (GPS) and GLONASS created a possibility that any point on Earth, at any time of the day and in all visibility conditions can have its coordinates determined in a very short time, where the accuracy of coordinates usually depends on a user's subsystem, the number of satellites that can be observed simultaneously from a given point, the duration of observations and a GPS method.

Last-generation self-propelled multiple rocket launchers are positioned and oriented to firing positions via GPS receivers. One of the ways of orientation to the North is using a rigid horizontal bar with two GPS antennas. The bar length dictates the accuracy of orientation to the North (Sekulović, Đurković, 2010, pp.32-46).

Conventional field artillery survey

Depending on a combat situation, the number of known points, time available, time of the day, weather conditions, relief and accuracy to be achieved, field artillery survey may be on a full basis or according to a map. After a preparation of topographic surveying, a topographic unit can be set for determining the coordinates of landmarks, benchmarks and targets detected and for controling field artillery survey of artillery battalions.

Actions in field artillery survey are prepared in detail and operable. However, a problem is that some actions are based on old-fashioned, slow, manual and outdated methods in which impermissibly big mistakes occur. Random errors, Table 1 (Priručnik za vojnika topografa zemaljske artiljerije, 1979, pp.181-200) occurring at work with outdated equipment in the operation preparatory phase are reflected in the operation execution phase on a hit probability. Increasingly complex requirements raise a question of efficiency of topographical surveying and preparation of artillery

fire support. The criteria for the evaluation of results are getting stricter. On the one hand, faster and high quality work is requested; on the other hand, tasks grow in number. As a result, there is a discrepancy between effort and results achieved (Glišić, Tugomir, 2007, p.56).

Table 1 – Features of the conventional method of artillery survey

Таблица 1 – Характеристики методов конвенциональных топографо-геодезических учений

Табела 1 – Карактеристике метода конвенционалне топографско геодетске припреме

Preparation	Modes	Ratings			Accuracy
		5	4	3	
Map-based, mark roughly	Backward intersection	10'	12'30"	14'20"	< 50 m
	Sighting with the measurement	10'	12'30"	14'20"	< 50 m
	Comparing charts with the terrain	7'	10'	15'	< 50 m
Map-based, with instruments	Using a short base	14'	16'	18'	< 50 m
	Intersection from reverse rectangular azimuths	7'	10'	15'	< 50 m
	Point of travers	/	/	/	< 50 m
Total-based topographic survey	Computational methods of processing travers	10' 20'	12' 24'	14' 28'	< 2 m
	Graphic forward intersection and a combined	14'	16'	18'	< 12.5 m
	Calculating, forward intersection and a combined	24' 27'30"	29' 33'30"	35' 41'	< 2 m
	Graphically, backward intersection to three points	14'	17'	20'	< 12.5 m
	Calculating, backward intersection to three points	54'	65'	80'	< 2 m

In current practice, it is not possible to determine the coordinates of points accurately and quickly at the same time. In order to precisely determine the coordinates of three firing positions and three observation posts of one division on a topographically unprepared terrain, (6 points in two different areas) 6 to 8 people should continuously work for 6 to 8 hours (Maksimović, 1996, p.79). Nevertheless, the required time of NATO artillery units to determine coordinates is up to twenty minutes.

Artillery survey on the total basis

Artillery survey on the total basis is the basic method of artillery preparation, thus ensuring a unique reference system for artillery units and more accurate determination of the initial elements for firing. Artillery survey on the total basis includes:
- Developing artillery trigonometry network;
- Defining the coordinates of launching sites, observation posts and observation stations of artillery units;
- Defining the coordinates of targets and landmarks;
- Defining the data to guide the weapons and orientiring instruments.

The methods for determining the coordinates of points are as follows: 1) polar method; 2) travers; 3) forward intersection and combined intersection; 4) backward intersection with three points; 5) triangulation.

An artillery battery (according to organizational and formational solutions in the training system) is not qualified to perform artillery survey on the total basis, but is capable of map-based artillery survey in 10 to 30 minutes but cannot reach the required data accuracy. The required accuracy can be reached by topographic units composed of 6-9 people, who, after a long specialist training in an artillery battery on topographically processed terrains, take 2 to 3 hours for field measurement and data processing, where very complex data processing consumes about 50% of the available time. The main problem is how to make artillery survey last shorter and enable artillery batteries to execute fast artillery survey on the total basis (Maksimović, 1995, p.45).

Map-based artillery survey

Map-based artillery survey includes determining the coordinates of launching sites and observation posts of artillery units, based on the contour points and ground objects for which data are taken from the map and, if possible, checking the orientation of artillery wepons in the direction and orientation of instruments. Due to various unavoidable errors that occur in operation, this method results in considerably lower accuracy than the preparation on the total basis. It is used when there are no conditions for the application of artillery survey on the total basis.

The accuracy of map-based artillery survey depends primarily on the image scale (accuracy of 1 to 2 mm of the scale), and tools used; therefore, maps with greater scales (1: 25,000 and only exceptionally 1:

50,000) should be used. Contour points on the map and on the ground are taken as the known points for determining the coordinates of launching sites and observation posts of artillery units. For greater accuracy, whenever possible, trigonometric network points should be used. Map-based artillery survey can be performed using instruments or special tools (Uputstvo za topografsko-geodetsko obezbeđenje artiljerije, 1981, pp.209-211).

It is obvious that the modernization of artillery survey is necessary and that the way to solve this problem is the application of methods based on global navigation satellite systems (GNSS).

Methods and features of GPS positioning

Depending on the number of points the positions of which are determined and the relation of the obtained coordinates of the points (dependence of determining the coordinates of one point on the position of the other, referent one), GPS positioning methods can be generally divided into the following main categories: absolute method, relative positioning method and positioning of network points.

With regard to the operation when determining the coordinates of points (absolute or relative ones), both of these methods can be in the static or kinematic mode. The advantage of the static methods is that redundant measurements are obtained while the advantage of the kinematic methods is that measurement results are obtained in real time. Table 2 summarizes the characteristics of GPS positioning techniques.

Table 2 – Features of the GPS methods
Таблица 2 – Характеристики методов GPS
Табела 2 – Карактеристике метода GPS

The method of positioning		Features	Accuracy
Absolute	Static	Using of C / A-code; at least 4 satellites	20 – 50 m
		Using the P-code; at least 4 satellites	5 – 20 m
		Using precise ephemeris; a minimum of 4 satellites	2 – 5 m
	Kinematic	very brief observations (1 msec); at least 4 satellites	20 – 50 m

The method of positioning		Features	Accuracy
Relative	Static	Non-current static observations; database of more than 100 kilometers; at least 4 satellites	1 mm + 1 ppm
		Current observations (8-30 min); short base (less than 10 km); dual-frequency receivers; at least 4 satellites	5 mm + 1 ppm
	Kinematic	Current observations (5 min); necessary to return to the station; up to 10 km; minimum of 4 satellites	1 cm + 2 ppm
		Current observations; necessary connections between cells; up to 10 km; at least 4 satellites	1 cm + 2 ppm
		Without stopping; special software is required; up to 10 km; OTF initialization; a minimum of 4 (5) satellites	1.5 cm + 2 ppm
Differential GPS		Applying code measurements; at least 4 satellites	0.6…10 m

The highest accuracy is achieved with relative positioning methods, phase measurements, especially in the static mode, i.e. with the static relative positioning method.

Methods of absolute positioning

The results of this positioning method are determined, independent (absolute) coordinates of individual points in real time. The main characteristic of the absolute positioning methods is work with a single GPS receiver. Spatial rectangular coordinates are obtained, based on the measured pseudorange from the satellite to the receiver antenna and the antenna height above the point whose position is determined, Figure 1.
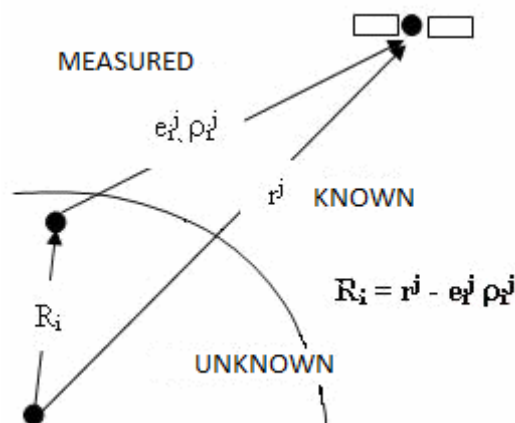
Figure 1 – The principle of absolute positioning
Рис. 1 – Принцип абсолютного позиционирования
Слика 1 – Принцип апсолутног позиционирања

The accuracy that can be achieved with this method within a few seconds is in the range of 5-50 m (With an SA on, accuracy decreases three to four times), or up to about 2-5 m with precise ephemerides. When the R-code is used, accuracy in the determination of the pseudorange is better than when the S / A-code. Absolute positioning methods are used for navigational purposes, on land, at sea and in the air, and partially meet the needs of artillery units.

The accuracy in assessing a position with absolute positioning methods depends on several factors, but generally speaking, positioning accuracy depends on the accuracy of determining the pseudorange. The pseudorange is a value consisting of a geometric distance from the satellite to the receiver and an error in its measuring. There are multiple sources of errors which, together with pseudoranges, represent an effective measure of pseudorange accuracy uncertainty. This total measure is called User Equivalent Range Error (UERE).

The sources of errors that affect absolute positioning are as follows:
– errors of the clock in the satellite,
– errors of ephemerides,
– errors caused by relativistic influences,
– errors caused by the influence of the layers of the atmosphere (ionosphere and troposphere),
– errors caused by the imperfection of the receiver construction, and
– errors caused by multiple reflection of signals.

Methods of relative positioning

The relative positioning methods include simultaneous measurements of pseudoranges from two receivers to at least four satellites. One of the receivers must be stationary (GPS base) with known spatial geocentric coordinates (X, Y, Z) - a point of reference, and the coordinates of the second receiver position are relative ($\Delta X, \Delta Y, \Delta Z$) with respect to the first receiver. The relative coordinates form a position vector of the required point in relation to the known one, i.e. the base line. The geocentric coordinates of the required point P2 in relation to a given P1, Figure 2, are determined using the following expression:

$$R_2 = R_1 + \Delta R_{12},$$

where R2 is the geocentric position vector P2,

    – R1 is the geocentric position vector P1, and

    – ΔR_{12} is the spatial position vector P2 with respect to P1 (the relative position vector).
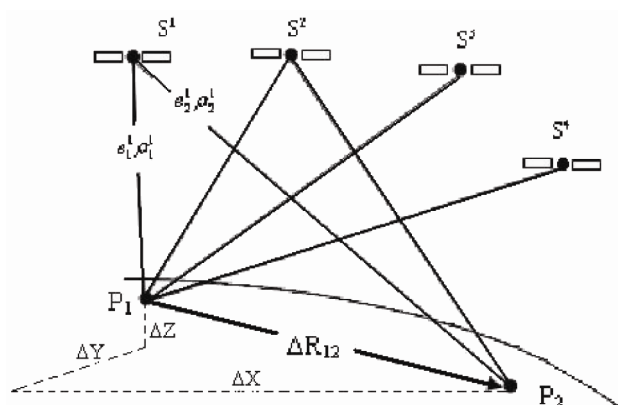

Figure 2 – The principle of relative GPS
Рис. 2 – Принцип относительного GPS
Слика 2 – Принцип релативног GPS

The receiver at the station whose coordinates are determined can be stationary (for a static method) and mobile - rover (for a kinematic method).

Relative kinematic positioning is a GPS procedure that allows, in a short period of time, determining the trajectory of the rover antenna, Figure 3. Therefore, this method determines the relative coordinates of the rover in relation to the base receiver. The method of relative kinematic positioning (RKP) has a characteristic of fast acquiring a large number of

positional data with an accuracy that meets the needs of topographic surveys. RKP accuracy depends primarily on the retention time of the rover at an unknown point, which is from one second to a few minutes, depending on the type of point and the required accuracy. For example, when the rover is at the station for a period of five minutes and 20 registrations with a measurement epoch of 20 seconds, an accuracy of 1 cm + 2 RRM can be achieved. Namely, it is an accuracy in centimeters, and when RKP is applied in real time, accuracy decreases up to a decimeter. In the course of measuring, connection with at least four satellites is necessary.
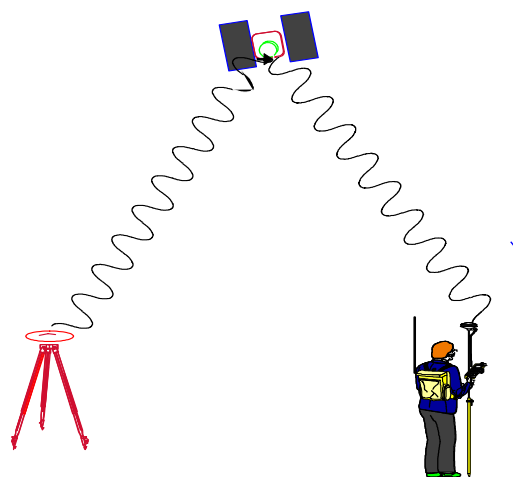

Figure 3 – Relative kinematic positioning
Рис. 3 – Кинематическое относительное позиционирование
Слика 3 – Релативно кинематичко позиционирање

There are two different methods of relative kinematic positioning:
– relative kinematic positioning in real time (Kinematic Survey over a Real Time or Real Time Kinematic - RTK)
– relative kinematic positioning with post-processing (Post-processed Kinematic Survey), (Božić, 2005, pp.14-19).

Processing of the Global Positioning System

Processing means a set of actions and procedures in the planning of processing and preparation of documents in the realization and implementation of the planned processing, processing of the measurement

results and obtaining the required data on the positions of the required points and data analysis.

Planning of measurements

Based on the available equipment and technical and material resources, an analysis for GPS measurements was carried out as well as the planning of measurement realization and necessary actions for determining the coordinates of the primary and other elements of the combat disposition of artillery units.

There were two Pathfinder ProXR GPS receivers. Measurement planning and the subsequent data processing were done on personal computers with the support of software packages. Based on the task, GPS measurements were conducted in the area of the attack zone.

For planning and selecting measurement positions and cells, TK50 (583-1, 583-2, 583-3, 583-4) was used as well as air photos of the area.

For developing an artillery network and determining the coordinates of combat dispositions of artillery units, the following eight points were taken:

VP1 (Launching site 1)
VP2 (Launching site 2)
VP3 (Launching site 3)
O1 (Observation post 1)
O2 (Observation post 2)
O3 (Observation post 3)
B1 (base station, also the aiming point, trig. point of the third order)
B2 (base station, also the aiming point, trig. point of the third order)

Based on the length of the base lines, i.e. the distances between the points, and on the elevation mask for some points, sessions were determined to last 5 minutes and signals from the satellites above the elevation angle of $13°$ were registered.

In the planning phase and the phase of measurement preparation, spatial data (coordinates in the Gauss-Kruger projection - X, Y, and height - Z) were collected, regarding the points agreed to be the basic network points, Table 3.

Table 3 – Spatial data (X, Y, Z) on the points in the G-K projection
Таблица 3 – Пространственные данные (X, Y, Z) на точках в G-K проекции
Табела 3 – Просторни подаци (X, Y, Z) о тачкама у G-K пројекцији

Point Mark	X [m]	Y [m]	Z [m]
B1	4792738.492	7598590.854	467.745

Point Mark	X [m]	Y [m]	Z [m]
B2	4793751.080	7598727.161	400.482
VP1	4793248.929	7598802.074	364.481
VP2	4792501.004	7599499.598	359.116
VP3	4793127.382	7599748.856	306.843
O1	4788875.275	7602116.462	451.331
O2	4790451.471	7603651.004	299.872
O3	4791125.629	7604801.141	357.286

Realization of measurements

After centering and measuring the height of the antenna and connecting the receiver with the antenna and the controller, the receiver and the controller were put into operation. By making the controller oparational, the main menu appears on the display, with appropriate options for entering point data, the antenna heights and types, measurement methods, etc., followed by a signal registration onset.

During the measurement, there were usually five to eight satellites visible, rarely four or nine. The constellation of satellites during the measurement was satisfactory, which is supported by the fact that the value of PDOP factors ranged from 1.8 to 4.4.

Measurement processing and measurement quality control

There are a number of software solutions for measurement processing, depending on the receiver model and equipment. Equipment manufacturers produce software packages for data processing. Despite the fact that there are different developers and companies, all programs are based on the same conceptual principles.

Trimble, as already mentioned, offers the Pathfinder software package for data transfer and post-processing. Pathfinder consists of basic multifunctional modules intended to perform certain phases in measurement processing. Within each module, there are options for processing individual operations in more detail.

The results after processing GPS coordinates are shown in Table 4.

Table 4 – Coordinates of the G-K projection
Таблица 4 – Правоугольные координаты в проекции G-K
Табела 4 – Правоугле координате у G-K пројекцији

Point mark	X [m]	σ_x [m]	Y [m]	σ_y [m]	σ_{2D} or DRMS [m]	CEP [m]
VP1	4793248.929	0.345	7598802.074	0.333	0.47987	0.39998
VP2	4792501.004	0.315	7599499.598	0.304	0.43818	0.36523
VP3	4793127.382	0.389	7599748.856	0.376	0.54139	0.45126
O1	4788875.275	0.407	7602116.462	0.393	0.57419	0.47222
O2	4790451.471	0.286	7603651.004	0.276	0.39833	0.33201
O3	4791125.629	0.327	7604801.141	0.316	0.45591	0.38001
Average						0.40012

The accuracy in determining the point coordinates is defined by the values of standard deviations - σ, histograms of standardized deviations (standardized residuals) base lines / vectors and the ellipses of the errors in determining the point positions based on the measurement results.

The values of the standard deviation σ of the coordinates of the spatial position can be assessed separately - the standard according to the X-axis (in the Gauss Kruger projection) σ_x separately from the one according to the Y-axis - σ_y - but also as an overall standard of the 2D position estimate - σ_{2D}. Error ellipses in position estimation represent the measure of the accuracy of estimates of point coordinates, and, consequently, the assessment of measurement quality.

In artillery, average probable error or probable error of a mean is most commonly used as the measure of accuracy. In this context, the 2D standard deviation is converted into a circular error probable, according to the formula (GPS Position Accuracy Measures, 2003, p.4):

CEP = $0.62\sigma_y + 0.56\sigma_x$

Analysis of the results

Based on the data after processing, the results of the research are as follows:
– 0.344 m
– 0.333 m
– CEP = 0.40012m.
When comparing the results of researching the CEP = 0.40012m with the permissible errors of a complet preparation up to 2 meters (Table 1),

we can conclude that the GPS method of relative positioning provides much smaller probable error than the required one.

Conclusion

If we start from the fact that accurate and rapid determination of coordinates of points (launching sites and observation posts) is one of the main problems of modern artillery, the conducted reserch has found the possibilities to solve this problem by using GPS receivers with relative positioning in artillery survey on a full basis. Necessary operational time with conventional methods is 2-3 hours on the prepared terrain and 6-8 hours on the unprepared terrain; when this is compared with the necessary operational time with a GPS relative method of 20 minutes, the necessary time period is 6 to 24 times shorter.

On the other hand, in combat operations of the armed forces of developed countries, impacts on artillery fire support objectives are far higher because the global positioning system is applied not only to determine the combat disposition of forces and as an artillery weapon orientation tool, but also to home projectiles to targets. It can be concluded that GPS technology has certainly not yet reached its peak in terms of applications in the Serbian Army. Of course, with the development of competition in GPS navigation, increase in accuracy and reduction in price, its application will increase consequently.

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ПРИМЕНЕНИЕ ОТНОСИТЕЛЬНОГО ПОЗИЦИОНИРОВАНИЯ АРТИЛЛЕРИЙСКИХ ПОДРАЗДЕЛЕНИЙ В ТОПОГРАФО-ГЕОДЕЗИЧЕСКИХ УЧЕНИЯХ

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Резюме:

В данной статье описаны методы относительного позиционирования, применяемые в топографо-геодезических артиллирийских учениях. В тестовых топографо-геодезических задачах на полной основе использованы два приемника Trimble Pro XRS в качестве базовой станции и ровера, а также модем в качестве связи между устройствами. С целью получения результатов исследования при вторичной обработке данных применялись статистические методы. Результаты показали значительное снижение вероятности ошибок в анализе требуемых значений. Применение метода относительного позиционирования при топографо-геодезических изысканиях на полной основе способствует значительному ускорению работы и обеспечивает высокую точность изысканий.

Ключевые слова: *глобальная система позиционирования, относительное позиционирование, топографо-геодезические учения, круговое вероятное отклонение.*

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ПРИМЕНА РЕЛАТИВНОГ ПОЗИЦИОНИРАЊА
У ТОПОГРАФСКО- ГЕОДЕТСКОЈ ПРИПРЕМИ
НА ПОТПУНОЈ ОСНОВИ У АРТИЉЕРИЈИ

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Сажетак:

У раду је приказана примена GPS метода релативног позиционирања при извођењу топографско-геодетске припреме у артиљерији. При извођењу топографско-геодетских радова на потпуној основи коришћена су два Trimble Pro XR пријемника као базна станица и ровер, као и модем као комуникација између уређаја. Како би се добили резултати истраживања примењене су статистичке методе у накнадној обради података. Резултати показују знатно смањење вероватних грешака у раду од захтеваних вредности. Примена релативног позиционирања при извођењу топографско-геодетских радова на потпуној основи обезбеђује вишеструко бржи рад и већу тачност од прописане.

Кључне речи: глобални позициони систем, релативно позиционирање, топографско-геодетска припрема, кружна вероватна грешка.