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Water surface and drainage area measuring with satellite navigators

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ABSTRACT

There are several geodesic methods of area measurement. The following article provides description of a non-conventional method which involves the usage of satellite navigation devices. Based on a practical research, the accuracy of the method is being estimated. The analysis of different measuring conditions and factors, regarding their effect on accuracy, is made. The suitable areas, where the method could be used, are mentioned. In particular, the possibility of water surface and drainage area measuring is examined with the usage of previous theoretical base. In addition, the results of a recent field check covering such type of areas are presented in the article.

Contents

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1. Introduction

Nowadays modern geodesic equipment is widely used for solving several tasks, connected with construction and exploitation of different water utilities and hydraulic engineering objects [1, 2].

The problem of definition of land plot area is usually faced when irrigation or drainage systems are designed. On the one hand, it can be solved using specialised geodesic devices like electronic tachymeters and high-precision satellite receivers.

However, favorable conditions are needed for above named devices. For example, when a tachymeter is used, the visibility may be reduced by dust, fog and poor illumination. In addition to that, the measurement process is sometimes interrupted by dense vegetation or buildings. Moreover, the areas with curved perimeter, like water surfaces, are hard to measure, since tachymeter is a device with straight optical beam designed to measure polygons. High-precision geodesic satellite receivers require skilled personnel, furthermore, the cost of such systems is far above average.

On the other hand, there could be a cheaper and less demanding way. Considering the recent situation in Russia, for example, such as tragedy in the Krymsk town and the Amur river spate, areas covered with water appear constantly and the water surface areas are varying rapidly. Those areas should be controlled and measured quickly and efficiently, with a certain level of precision, taking the severe flood conditions into account. Therefore, an alternative method of area measuring, which is based on the usage of common satellite navigation devices, was suggested.

There are two main global positioning satellite systems in existence: GPS and GLONASS. The second one is being developed in Russia and serves a strategic purpose [3]. Despite the recent unsuccessful launches of satellites, the system development will be continued, providing better reliability and accuracy.

The aim of the study was to define, if satellite navigators are suitable for the above-mentioned tasks of area measurement.

2. Literature review

Satellite navigator consists of five main parts: antenna, signal processing module, CPU, interactive information input and output modules. The device exchanges information with satellites via radio waves and determines the coordinates of current location. Accuracy of satellite navigation device depends on the quantity of available satellites and on their geometrical arrangement [4; 5].

There are two main frequencies of radio waves used by satellites. The first one provides standard accuracy of signal and is used in satellite navigators. Therefore, the claimed absolute error of coordinate’s determination is 2-8 meters for GPS (6-11 satellites are exchanging information with the device) and 4-7 meters for GLONASS (7-8 satellites). In case of combined GPS+GLONASS system, the absolute accuracy of 1.5-3 meters could be provided [6-8].

The signal with better accuracy is carried with the second frequency and is used in military devices or expensive geodesic satellite receivers [9, 10].

Coordinate determination precision may be lessened as a result of distortion of radio signal in upper–air or reflection of it by high–altitude buildings and trees [11, 12].

Satellite navigators usually have long time of autonomous work (approximately 25 hours), water-proof and shock-proof case. Furthermore, weight and size of the device are small, special licenses or knowledge are not required for operation. The average price of the navigator is reasonable and much cheaper, than the cost of a tachymeter or geodesic satellite receiver [13, 14].

At first sight, the method of area measuring with the usage of satellite navigator was not mentioned in literature. The relative accuracy of such method was not mathematically estimated as well. Nonetheless, there were some precedents of satellite navigator usage in agricultural land measurements [15, 16]. However, the coverage of the usage of traditional geodesic receivers is wide [17, 18].

To sum up, it can be supposed that the navigator could possibly be conveniently used in area measurement, but there is no practical experience.

3. Problem definition

Based on the information from the literature covering the adjacent topics, it was suggested, that the relative accuracy of area measuring with satellite navigator is lessening on bigger squares. The absolute error of measuring, however, depends on a variety of factors.

Therefore, the first aim of the practical research was to obtain an empiric relation between the area size and the relative accuracy. The second problem was to check the obtained result while measuring the real object, for example, a lake or a drainage area. In addition, the method was tested in unfavorable conditions and a practical assesment of it's usability was made.

4. Description of the research

In our former researches covering the topic [19; 20], two models of satellite navigators were used: Garmin GPSMAP 78S and Garmin eTrex 30. Both of them have pocket size and weight, long time of autonomous work; they are easy-to-operate and are available in common shops. However, the first model works only in GPS network, the second one uses a GPS+GLONASS combination (models with pure GLONASS unfortunately were not available). Therefore, two systems could be tested and compared.

The first step of the study undertaken by the team of Civil engineering institute (Saint-Petersburg State Polytechnical University) students was to divide a series of quadrates on location, with their sides 10x10, 20x20, 40x40 and 80x80 meters, with one common vertex. Another group of quadrates had sides 50x50, 100x100 and 150x150 meters (location and time of measurements for two groups were different). The task was done with the usage of an electronic theodolite Vega Teo-20 and a steel measuring tape, which allowed the areas of the quadrates to be defined with a high degree of precision. Each vertex was marked with a peg (figure 1).To eliminate human factor, strings were tensed between pegs and the navigator coordinate's fixation rate was set to its maximum level (time between two points is one second).

After that, each square from the first group was repeatedly bypassed with Garmin GPSMAP 78S having land plot area and perimeter determined and recorded by a special program, which was installed default on the device. The quadrates from the second group were bypassed with both navigators, having the areas recorded.

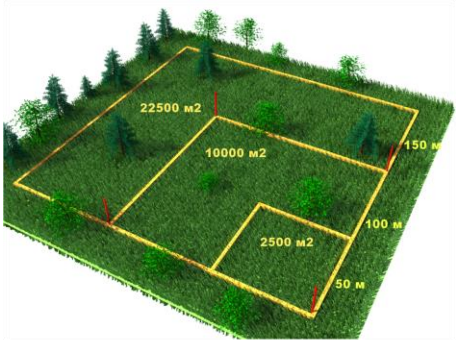

Figure1. Layout of quadrates

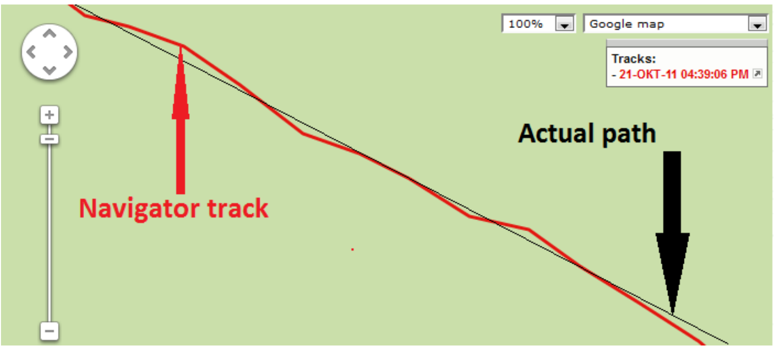

Figure 2. Illustration of "track effect"

The navigator tracks were saved and examined. The results (obtained areas) were compared to the theoretical values (the defined quadrate areas) and the relative accuracy was counted with the usage of the following formula:

$$\delta = \frac{\sqrt{\frac{\sum_{i=1}^{n}(S_i-\bar{S})^2}{n-1}}}{\bar{S}},$$

δ— relative accuracy, S—measured area, *n* — quantity of area bypasses, $\bar{S}$ — theoretical area value.

Moreover, the diagrams of relative accuracy related to land plot size were built. In addition, the general tendencies were discovered, forecast was made and the trend lines were built (figure 3). Two different types of curves were obtained. The first one, theoretical, indicates the result without rude errors (10% and more difference from the initial values). The second one, practical, was built with the usage of all obtained data. The subsequently received results were compared with the second curve.

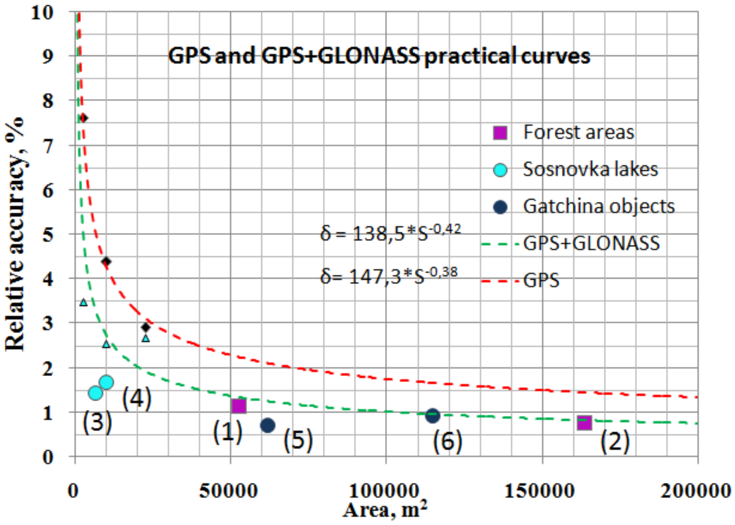

Figure 3. Practical curves (trend lines) and real objects

After the raw data approximation, it was assumed, that the accuracy-area relation curve in case of large quantity of bypasses should conform the following power function:

$$\delta = \frac{a}{S^b},$$

δ— relative accuracy, S—measured area,a and b— parameters which depend on measuring conditions, satellite system used and the navigator model.

As a result of track examination, so-called «track effect» was discovered. The navigator track differs from the actual path like it is shown on a figure 2. The amplitude of fluctuations is more or less equal to absolute error of coordinate’s determination. It was supposed, that as a result of this effect, the error of the area definition is partly erased and the error of the perimeter measurement is not affected.

During the second stage of the research, real objects in different operation conditions were measured and the relative accuracy was compared to the previously obtained empiric curve (practical). Firstly, the large forest areas (high trees could possibly affect the measurement result) in Komarovo were bypassed with navigator using a bicycle (figure 3, (1), (2)). Secondly, two small lakes in Sosnovka park were measured in condition of heavy rain and poor illumination (figure 3, (3), (4)). Finally, the Chornoye lake (figure 4) water surface and it’s drainage area were measured in Gatchina (figure 3, (5), (6)). The real objects were bypassed only with GPS+GLONASS navigator since it has shown the better accuracy in former tests (figure 3).

Figure 4.Chornoye lake and navigator track

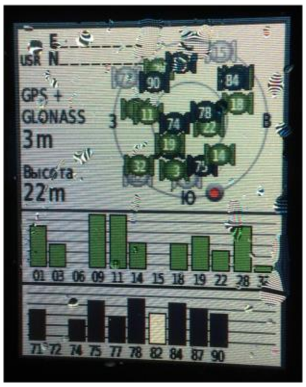

Figure 5. Picture of navigator screen during the measuring

According to the general supervision during the measuring process, the absolute accuracy of coordinate’s determination (it is usually shown on the screen of the device) was not being dramatically affected by unfavorable conditions. The navigator has also proven it’s durability. Nonetheless, there were some significant random errors (difference by 10% and more from the initial value), which could be recognized only in case of known area (quadrates) and increased the final relative error in case of real objects (with not known initial area).

5. Conclusion

According to the diagrams and the trend lines, the general tendency of the decrease of relative error on bigger squares was determined (figure 3). Therefore, based on the results and general supervision, the following conclusions were made:

1. When the land plot size reaches the value of 10 hectares, it is possible to obtain the results as accurate as if the graphical method was used (practically for GPS+GLONASS). The necessary relative accuracy of the graphical method is 1% [21, 22].

2. The «track effect» decreases the relative error in area measurement while the relative error of the perimeter measurement is not affected. This is illustrated by the fact that the relative accuracy of the area measurement in the first group of quadrates is smaller than such error of the perimeter measurement.

3. The absolute accuracy of coordinate determination is more or less constant — approximately 3 meters for non-military devices (when at least 10 satellites are within range). In case of GPS+GLONASS system the absolute accuracy is not seriously affected by the measuring conditions (figure 5).

4. According to the diagram comparison, GPS+GLONASS system provides better accuracy in practical case (figure 3). The theoretical curve is very similar for both GPS and GPS+GLONASS systems.

5. Practical measurement of areas with curved perimeters like water surfaces (figure 4) and drainage areas is possible and provides certain accuracy according to the empiric curve (figure 3). Two conditions should be fulfilled, though. Firstly, the sufficient amount of satellites should be available to provide the best absolute accuracy. Secondly, the area must be bypassed several times because of random rude error possibility.

6. In view of GPS navigation device all-weather and almost all-location operation possibility, reasonable price, simplicity of use and long time of autonomous work without the recharge of batteries, the obtained result indicates, that it is efficient to use such kind of a device to solve some planimetric tasks. For example, it can be determination of water surface and drainage areas, agricultural land areas.

7. In cases of having reliability of the result of utmost importance (measuring a private land, drawing-up large-scale plan) it is not recommended to use the investigated method due to possible precision lessening by the variety of uncontrolled factors [23 - 25].

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Измерение площадей водосбора и зеркала водоемов спутниковыми навигаторами

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ИНФОРМАЦИЯ О СТАТЬЕ	**История**	**Ключевые слова**
УДК 528.441.2:621.396.96	Подана в редакцию 6 февраля 2014 Оформлена 26 февраля 2014 Согласована 27 февраля 2014	инженерная геодезия спутниковый навигатор измерение площадей системы GPS и ГЛОНАСС точность измерения зеркало водоема площадь водосбора

АННОТАЦИЯ

В геодезии существуют разнообразные методы измерения площадей. В данной статье описывается нестандартный метод, подразумевающий использование спутниковых навигаторов. По результатам практических исследований оценивается точность метода. Проводится анализ различных условий измерения и их степени влияния на точность. Определяются предполагаемые области использования данного метода. В частности, на базе предыдущих исследований оценивается возможность измерения площадей водосбора и зеркала водоемов. Более того, в статье представлены результаты недавно выполненных полевых измерений данных типов площадей.

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