The possibility of low-budget GNSS equipment using for cadastral work for the Unified State Real Estate Cadastre purposes and transport link

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Abstract. The article considers geodetic methods for determining land plots location during cadastral work. The analysis of technological solutions in coordinates determining of the land plots’ characteristic points and their areas was carried out. The accuracy of geodetic methods in the cadastral work implementation was assessed. The priority technology was identified, including the use of low-budget GNSS equipment for this very task. The areas values were obtained and root-mean-squares of boundary marks position calculated by means of chosen technology are presented. The estimation and justification of the selected technology for cadastral work is given.

1. Introduction
In Russia, with the beginning of land relations formation, the role of cadastral work, as the main instrument of Unified State Real Estate Cadastre formation, increased again. At the same time, the methods of cadastre works performing were improved, and also the regulatory and technical requirements were clarified.

With the development of technical capabilities, the role of modern technological solutions, used in the both cadastral and geodetic works implementation, generally increased. Along with modern solutions integration, requirements for the accuracy of such works still remain. Currently, there is no generally accepted methodology for selecting such solutions, which implementation will improve the quality of cadastral work, and will increase their implementation accuracy, so in its turn, it will have a positive economic effect in reliability of objects’ installed cadastral value[1].

Currently, almost all cadastral work on land areas determining is carried out using a differential method of GNSS technology in real time (RTK), which requires a minimum of two receivers (base and mobile). The emergence of network technology, wireless communication, expansion of coverage area for cellular communication networks, as well as in connection with annual replenishment of PBS base stations networks all over Russia, led to fundamental changes in cadastral management, there was no need for two GNSS receivers to obtain high-accuracy geospatial data [2-3]. On the other hand, another equally important trend in GNSS technologies is actively developing - the introduction of miniature equipment into all production spheres, which is often not inferior to more its expensive analogues in accuracy [4-13].

The purpose of the article is to investigate the possibility of using low-budget GNSS equipment in cadastral work the Unified State Real Estate Cadastre goals.
2. Materials and Methods

In accordance with the land surveying instructions [14], the following difference $\Delta P$ between documentary $P_d$ and actual $P_a$ land plots, is accepted:

$$\Delta P = P_d - P_a = 2 \cdot m_p,$$

where $\Delta P$ – is the divergence of areas; $m_p$ – is the root-mean-squares error in determining the land plot area. The value $m_p$ for the area of any arbitrary form is described by the strict formula of Professor Maslov [15]:

$$m_p = \frac{m_{x,y}}{\sqrt{8}} \sqrt{\sum_{i=1}^{n} (x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2},$$

where $m_{x,y}$ is root-mean-squares error of coordinate’s definition for boundary marks; $x, y$ are coordinates of boundary marks. For the analysis of determination areas accuracy, the results of land plots measurements in different lands categories were used, depending on their purpose, configurations located in the Ob town [16-17]. Based on the results of these measurements, the root-mean-squares and relative errors in the area determination were calculated, which are presented in Table 1.

**Table 1** - Root-mean-squares and relative errors of land areas measurement in different land categories, depending on their intended use, configurations located in the Ob town.

| Area of land plot value (hectare) | Root-mean-squares errors of land area | Relative error of land area |
|-----------------------------------|--------------------------------------|-----------------------------|
|                                   | $m_{x,y} = 0.10$                      |                            |
| 0 - 0.06                          | 1.41-3.89                            | $\geq 1/154-1/425$         |
| 0.06 - 0.15                       | 2.24-6.15                            | 1/154-1/425+1/244-1/671    |
| 0.15 - 0.50                       | 4.06-11.24                           | 1/244-1/671+1/445-1/1232   |
| 0.50 - 1.00                       | 5.81-15.89                           | 1/445-1/1232+1/629-1/1722  |
| 1.00 - 2.50                       | 8.98-25.12                           | 1/629-1/1722+1/995-1/2784  |
| 2.50 - 5.00                       | 12.85-35.53                          | 1/995-1/2784+1/1407-1/3891 |
|                                   | $m_{x,y} = 0.20$                      |                            |
| 0 - 0.06                          | 2.82-7.78                            | $\geq 1/77-1/213$         |
| 0.06 - 0.15                       | 4.47-12.31                           | 1/77-1/213+1/122-1/355    |
| 0.15 - 0.50                       | 8.12-22.47                           | 1/122-1/355+1/222-1/616   |
| 0.50 - 1.00                       | 11.62-31.78                          | 1/222-1/616+1/315-1/861   |
| 1.00 - 2.50                       | 17.96-50.25                          | 1/315-1/861+1/498-1/1392  |
| 2.50 - 5.00                       | 25.70-71.06                          | 1/498-1/1392+1/704-1/1946 |
|                                   | $m_{x,y} = 2.50$                      |                            |
| 0 - 0.06                          | 35.54-98.07                          | $\geq 1/6-1/17$          |
| 0.06 - 0.15                       | 56.37-155.08                         | 1/6-1/17+1/10-1/27       |
| 0.15 - 0.50                       | 102.30-283.17                        | 1/10-1/27+1/18-1/49      |
| 0.50 - 1.00                       | 146.36-400.45                        | 1/18-1/49+1/25-1/68      |
| 1.00-2.50                         | 226.32-633.14                        | 1/25-1/68+1/39-1/110    |
| 2.50-5.00                         | 323.79-895.39                        | 1/39-1/110+1/56-1/154   |
|                                   | $m_{x,y} = 0.50$                      |                            |
| 0 - 0.06                          | 7.33-20.24                           | $\geq 1/30-1/82$         |
| 0.06 - 0.15                       | 11.63-32.00                          | 1/30-1/82+1/47-1/129    |
| 0.15 - 0.50                       | 21.11-58.43                          | 1/47-1/129+1/86-1/237   |
| 0.50 - 1.00                       | 30.20-82.63                          | 1/86-1/237+1/121-1/331  |
| 1.00 - 2.50                       | 46.70-130.65                         | 1/121-1/331+1/191-1/535  |
Analyzing the data given in Table 1, we note the following points: the requirements for estimating the land plots areas are not normatively established, at the same time they are quality indicators of a cadastral work [16]. Further, the root-mean-squares errors values of coordinates determining, which are permissible during cadastral work conducting on the appropriate category lands permitted use are presented in Table 2.

| $m_{txy}$ (sm) | if $m_{txy} = 0.10$ | if $m_{txy} = 0.20$ | if $m_{txy} = 0.50$ | if $m_{txy} = 2.50$ | if $m_{txy} = 5.0$ |
|----------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                | $\leq 0.07$         | $\leq 0.14$         | $\leq 0.35$         | $\leq 1.77$         | $\leq 3.54$         |

Thus, from the analysis of the data in Table 2, it can be concluded that the maximum required accuracy for the determination of landmarks coordinates on the settlements lands should not exceed 7 (sm) and is necessary to meet the requirement for the accuracy definition of landmarks in this land category 10 sm. [18]. As for the remaining land categories, they are subject to commensurate requirements for the location accuracy of the boundary mark during a cadastral work conducting.

### Experimental part:
To solve the problem, the authors used a single-frequency phase GNSS receiver on the basis of the OEM module NV08C-CSM manufactured by CB “Navis”, presented in Figure 1 [12].

![Figure 1. Single-frequency phase GNSS receiver with an NV-2410 antenna from CB Navis](image-url)

The single-frequency phase GNSS receiver has 32 channels, all visible satellites are tracked (all-in-view), and the maximum data discreteness recording is 1 second. The receiver does not have internal memory, the "Accurate Navigation" program was written to get initial measurements from it, based on the source codes of the RTKLib open source version 2.4.2 [19].

The authors performed a number of experiments to determine the achievable accuracy of this equipment class. The first stage of the experiments included GNSS equipment research in the static mode. The reason of this experiment was to determine the point NSKN coordinates, included in the Reference Geodetic Range network of the Siberian State University of Geosystems and Technologies, a single-frequency phase GNSS receiver. The coordinates of the NSKN point were determined by binding to the PBS NR (KOLV, ORDN, ISKT, MHKV) neighboring stations. The baseline length (BS) of NSKN - KOLV was 37 km, NSKN - ORDN - 92 km, NSKN - ISKT - 48 km, NSKN - MHKV - 60
km. In the experiment consisted of two days - data collected, from 1.05.2014 to 2.05.2014. The discreteness of this observation was 30 seconds. After linking the NSKN to the PBS neighboring stations, the equalized coordinates are compared with the "reference" ones. The NSKN point reference coordinates are known in the WGS-84 coordinate system with an error, which is not more, than 3 cm [20].

The NSKN coordinates are determined in the spatial rectangular WGS-84 system, in the licensed software product Topcon Tools version 8.2., According to the following scheme:
- point linking on two-day observations;
- from two-day observation session, observation with duration from 1 day to 30 minutes were taken into the working out processing;
- re-processing of data in the software

The NSKN coordinates processed in the Topcon Tools software were converted from the spatial rectangular WGS-84 (X, Y, Z) system into the Mercator (E, N, U) flat map projection. The errors of the NSKN point "reference" in the Mercator flat cartographic projection were not more, than 3 cm [20].

Table 3 shows the root-mean-square errors of the equated coordinates of the NSKN point in the flat map projection of the Mercator relative to the neighboring stations of the PDSF NSO, depending on the duration of the observation session.

Table 3 Mean square errors of the equated coordinates of the NSKN point in the flat map projection of the Mercator, depending on the observation session duration

| №  | The duration of the observation session | m_N | m_E | m_U |
|----|---------------------------------------|-----|-----|-----|
| 1  | 2 days                                 | 0.010 | 0.007 | 0.021 |
| 2  | 1 days                                 | 0.011 | 0.008 | 0.022 |
| 3  | 12 hours                               | 0.012 | 0.008 | 0.022 |
| 4  | 8 hours                                | 0.013 | 0.008 | 0.023 |
| 5  | 6 hours                                | 0.012 | 0.008 | 0.023 |
| 6  | 4 hours                                | 0.012 | 0.008 | 0.023 |
| 7  | 1 hours                                | 0.030 | 0.020 | 0.056 |
| 8  | 30 hours                               | 0.051 | 0.035 | 0.111 |

From the analysis of Table 3, we can draw the following conclusions. The discrepancies between equalized and standard reference coordinates got in the confidence interval specified by the doubled M.S.E. together with the NSKN point "reference" error position, in all cases. The discrepancy for the U component in five cases out of eight (62.5%) exceeds the allowable value determined in formula.

When NSKN is connected to the neighboring PBS NR stations, located at an average 50 km distance, the point coordinates can be determined with a single-frequency phase GNSS receiver with 10 sm. error, which meets the requirements for a whole complex of geodetic tasks, including for cadastral works performance. The results obtained are corresponded to the technical characteristics of single-frequency phase GNSS equipment. At the second experiments stage, equipment was studied on short baselines. The studies were performed on the NSKN-WSG2 baseline, which was 6.5 km long.

The binding of NSKN to WSG2 was performed as follows:
- linking a point on twelve-hour observations;
- observation were taken into account from the twelve-hour session;
- observations with 8 hours to 15 minutes duration;
- re-processing of data in the software.

The NSKN coordinates item processed in the Topcon Tools software were converted from the spatial rectangular WGS-84 (X, Y, Z) system into the Mercator (E, N, U) flat map projection.
The errors of the NSKN point "reference" in the Mercator flat cartographic projection do not exceed 3 sm [20]. Table 4 shows the root-mean-square errors of the NSKN point equated coordinates in the Mercator flat map projection relative to WSG2, depending on the observation session duration.

Table 4 - Schedule square errors of the NSKN point equated coordinates in the Mercator flat map projection, depending on the observation session duration.

| №  | Duration of the observation session | The value of the M.S.E (in meters) | mN | mE | mU |
|----|------------------------------------|------------------------------------|----|----|----|
| 1  | 12 hours                           |                                    | 0.002 | 0.002 | 0.005 |
| 2  | 8 hours                            |                                    | 0.003 | 0.002 | 0.005 |
| 3  | 6 hours                            |                                    | 0.003 | 0.002 | 0.006 |
| 4  | 4 hours                            |                                    | 0.003 | 0.002 | 0.007 |
| 5  | 1 hour                             |                                    | 0.006 | 0.004 | 0.012 |
| 6  | 30 minutes                         |                                    | 0.013 | 0.009 | 0.024 |
| 7  | 15 minutes                         |                                    | 0.029 | 0.017 | 0.044 |

From Table 4 analysis, we can draw the following conclusions. The discrepancies between the equated and standard plan coordinates (N, E) and the height component (U) fall within the confidence interval specified by the doubled M.S.E together with the "reference" error position of the NSKN point, in all cases. When the point is connected with a single-frequency phase GNSS receiver from stations located at up to 10 km distance, you can determine the coordinates of the point with 2 to 5 cm total error, with 1 hour to 8 hours duration of the observation session.

At the third stage of the experiments the GNSS equipment in RTK mode was studied. The "Accurate Navigation" software allows receiving RTK solutions with 1 second discreteness. The NSKN coordinates in RTK mode were determined. As a base station, the P.B.S. N.R. NSKW station was used, located 12.7 meters from the designated point. In total, 7 sessions of observations with different duration - from 1 hour to 7 days were performed.

As a result of the conducted studies it is established that the initialization time of the receiver for obtaining a float ("floating") solution (without the permission of phase integer ambiguity) is approximately 5 to 7 minutes with a distance between points of 12.7 meters.

The initialization time between float and fixed solutions is about 1 minute. When obtaining a fixed ("fixed") solution (with the resolution of phase integer ambiguity), the error in determining the coordinates of the point is several centimeters.

The total error was calculated using the formula:

\[ m_{sum} = \sqrt{(N_{s\tan} - N_{meas})^2 + (E_{s\tan} - E_{meas})^2}, \]

where \( N_{s\tan}, E_{s\tan} \) - "reference" planned coordinates;
\( N_{meas}, E_{meas} \) - planned coordinates obtained as a result of measurements.

From the results of studies in RTK mode, the following conclusions can be drawn.

The error in determining the planned coordinates of the NSKN point when using the NSKW base station is 1 - 2 cm, in the case of obtaining a fixed solution. In the case of a "floating" solution, the error is 4 - 6 cm. The discrepancies in the planned coordinates of the NSKN point obtained in the RTK mode with the planned coordinates of the NSKN point from processing in the software product Topcon Tools version 8.2. are 2 - 4 mm.

3. Conclusions

Estimating the obtained results, we should note that at present obtaining reliable data on the areas and location of the boundaries of land plots and other real estate objects for the purposes of the Uniform State Real Estate Cadastre is an urgent task of conducting cadastral work and complex cadastral work
[21]. At the same time, when performing such work, measurement errors associated with the chosen technological solution may occur. In turn, the technological solution related to the use of GNSS equipment in RTK mode is less labor-intensive, and also shows high results of measurement accuracy, in comparison with other technological solutions and meets modern requirements for this type of work. The wider application of this solution will improve the accuracy and quality of cadastral work and integrated cadastral work.

4. References

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