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THE ASSESSMENT OF POSITIONING ERROR CHARACTERISTICS OF COMBINED GLONASS/GPS RECEIVERS*

The Global Navigation Satellite Systems `(GNSS) such as GLONASS (Russia) and GPS (the USA) systems find wide application in different fields including aviation. The growing demands of different users' groups for accuracy and reliability of positioning can be met by solving a navigational problem with the use of all visible satellites which belong to different systems. This function was implemented in

combined GNSS receivers, the research of performance features and positioning error characteristics of combined GLONASS/GPS receivers under different conditions of use and in different operational modes being relevant. The paper contains the results of natural experiments for investigation of positioning accuracy characteristics carried out with Geos-1M receiver. The experiments were performed in urban settings and in open terrain, in GLONASS and GPS operation modes of the receiver as well as in GLONASS/GPS combined mode. The experimental results were analyzed with the help of special software and algorithms of statistical manipulation. The obtained results allow assessing the main statistical characteristics of positioning errors and operational efficiency of the combined GNSS receiver under different conditions and in different operational modes. It can be used in practice for selecting a more efficient operational mode of the combined receiver for given conditions as well as for validating mathematical models of the positioning errors of SNS receivers.

Keywords: global navigation satellite system, GNSS, combined GNSS receiver, positioning accuracy.

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ОЦЕНКА ХАРАКТЕРИСТИК ПОГРЕШНОСТЕЙ ПОЗИЦИОНИРОВАНИЯ КОМБИНИРОВАННЫХ ГЛОНАСС/GPS ПРИЕМНИКОВ*

Спутниковые радионавигационные системы глобального действия (GNSS), к которым относятся системы ГЛОНАСС (Россия) и GPS (США), находят широкое применение в различных сферах, в том числе в авиации. Удовлетворение все более высоких требований различных групп потребителей по точности и надежности позиционирования может быть обеспечено при решении навигационной задачи по всем видимым спутникам, принадлежащих различным системам. Эта функция реализована в комбинированных GNSS приемниках. При этом является актуальным исследование особенностей функционирования и характеристик погрешностей позиционирования комбинированных ГЛОНАСС/GPS приемников в различных условиях применения и режимах работы. В работе приведены результаты натурных экспериментов по исследованию характеристик точности позиционирования, выполненных с приемником Геос-1М. Эксперименты проводились в городских условиях и на открытой местности, в режимах работы приемника по ГЛОНАСС, GPS, а также в совмещенном ГЛОНАСС/GPS режиме. Анализ результатов экспериментов выполнен путем применения специализированного программного обеспечения и алгоритмов статистической обработки. Полученные результаты позволяют оценить основные статистические характеристики погрешностей позиционирования и эффективность работы комбинированного GNSS приемника в различных условиях и режимах работы. Это может быть использовано на практике для выбора наиболее эффективного при заданных условиях режима работы комбинированного приемника, а также для обоснования математических моделей погрешностей позиционирования приемников спутниковых систем навигации.

Ключевые слова: глобальная навигационная спутниковая система, GNSS, комбинированный GNSS приемник, точность позиционирования.

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Introduction

Nowadays civil users' GNSS receivers of different purpose generally provide processing of signals from one satellite constellation – that of GLONASS or GPS system – received on one L1 frequency. This sometimes doesn't provide the required accuracy, reliability, availability, integrity and operational capability of the navigation system [Skrypnik, 2019]. Gain of additional operational benefits of applying the satellite navigation technologies will be possible due to simultaneous use of GLONASS and GPS constellations of navigation satellites and, in the future, those of Compas (China) and Galileo (the European Union) systems. The GNSS receivers enabling the use of one or several constellations of navigation satellites are known as combined (multi-system) ones.

The combined GLONASS/GPS receivers have been successfully implemented for a long time on the market of professional equipment, for example, in geodetic equipment, in Russian-made aircraft receivers (SN-4313, A-737 etc). The combined mode is considered to be used for Advanced Receiver Autonomous Integrating Monitoring (ARAIM) as well [Xueen Zheng, Ye Liu, Guochao Fan, Jing Zhao and Chengdong Xu, 2018]. The use of combined GNSS receivers together with transition to operating in the Dual-frequency multi-constellation (DFMC) mode is one of the navigation-related elements of the roadmap included in the Global Navigation Plan and other ICAO documents [Concept of operations (CONOPS) for dual-frequency multi-constellation (DFMC) Global Navigation Satellite System (GNSS), 2018].

Operation of a GNSS receiver in the combined mode provides better conditions of a navigational session which are characterized by Geometrical Dilution of Precision (GDOP) – a parameter which depends on the number and location of the working constellation of navigation satellites (according to whose signals navigation sightings are performed) relative to the user. An obvious advantage of a combined receiver is its ability to receive a great number of signals from NS of different systems, thus providing a greater possibility of position-fixing under adverse conditions of reception, e.g. with signals shadowed by terrain, high buildings and structures, under complex interference conditions. The accuracy of positioning can be expected to increase due to redundancy of pseudorange measurements to the navigation satellites.

The GLONASS and GPS systems differ in parameters of orbital groups, signal structure, accuracy of ephemeris support, used models of the terrestrial ellipsoid. This leads to a significant difference in the circuit design of radio frequency paths of the receivers and data processing algorithms. It should be noted that, according to ICAO Standards and Recommended Practices (SARPS), implementation and certification of combined GNSS receivers for commercial aviation should be based on assessment of the characteristics of errors in navigational sightings provided under various conditions of receiver operation. Therefore, the study of characteristics of positioning errors of combined receivers both when using separate systems and in operating in the combined mode is of interest.

The purpose of the research

There are studies showing that operation in the combined mode can result in decrease of positioning accuracy compared to GPS-only operation [Скрыпник, Нечаев, Арефьев, Астраханцева, 2015; Скрыпник, Арефьев, Астраханцева, 2015; Скрыпник, 2017], despite significant GDOP reduction. Other studies, e.g. [Shengyue Ji, Wu Chen, Xiaoli Ding, Yongqi Chen, Chunmei Zhao, Congwei Hu, 2010; Philip Mattos, 2011], point out that with regard to restrained urban conditions there is no significant accuracy increase despite the fact that the GLONASS/GPS mode provides greater position-fixing availability and their redundancy which is desirable to enhance reliability of navigation.

Based on the facts mentioned above, the study of characteristics of positioning errors (instantaneous and mean square errors of coordinate determination) in GLONASS, GPS, GLONASS/GPS operational modes of a GNSS receiver under different conditions of a navigational session is an urgent scientific and practical problem. Conduction of such studies, analysis of their results and formulation of practical recommendations to justify the error characteristics of a combined GNSS receiver determines the purpose of the presented paper.

Technique and conditions of conducting the research

For conducting the research the Geos-1M (LLC R&D GeoStar Navigation) receiver was used. The receiver can operate using the GLONASS and GPS systems separately as well as in the combined GLONASS/GPS mode. The mode of dynamic filtration of the receiver output information is also available.

The experiments were conducted at two points. One point (point A) is located in open terrain (with coordinates 52°09’ North latitude, 104°35’ East longitude, height 500.05 meters). Point B is in the city area (with coordinates 52°27 North latitude, 104°36’ East longitude, height 466.15 meters). The distance between the points is 18.6 km, which provided almost coinciding orbital groups in sight. In navigational sightings at point B, however, some navigational satellites were shadowed because of presence of high buildings in the vicinity of antenna location, hence, reception of signals from them was impossible. Moreover, at point B the effect of multipath reception could occur.

While measuring, the receiver coordinates, quantity and number of navigational satellites of the working constellation, VDOP and HDOP were recorded. The measurements were conducted in increments of 1 second within 8 days. For the obtained measurements the statistical processing of positioning data was conducted for determining MSE of measurements for each of the coordinates according to expression:

$$\sigma_x = \frac{1}{N-1}\sqrt{\sum_{i=1}^{N}(x_i - m_x)^2}$$

where N is the number of measurements, x_i is a coordinate value measured by the receiver at ith step, $m_x = \frac{1}{N}\sum_{i=1}^{N} x_i$ is assessment of the true value of the receiver coordinate.

The positioning errors were transformed to the metric reference system according to expressions:

$$\delta B_i = (B_i - m_B)\cdot(a+H), \qquad \delta L_i = (L_i - m_L)\cdot(a+H)\cdot \cos B_0,$$

where δB_i, δL_i are measurement errors of latitude and longitude respectively at the ith step; B_i, L_i are receiver coordinates measured at the ith step; m_B, m_L are assessments of the true coordinates (latitude and longitude) of the receiver; a=6,378,245 m is a semi-major axis of the earth ellipsoid; H is the height of the receiver antenna above the surface of the earth ellipsoid.

With the aid of LabView programing tools, the output information was formed as graphic charts of changes of dilution of precision, the number of visible navigation satellites, instantaneous errors and MSE of measurement, histograms of positioning error distribution.

Research results and their discussion

The results of positioning errors research as diagrams of dispersion of their instantaneous values in latitude and longitude are shown in *fig.1.*

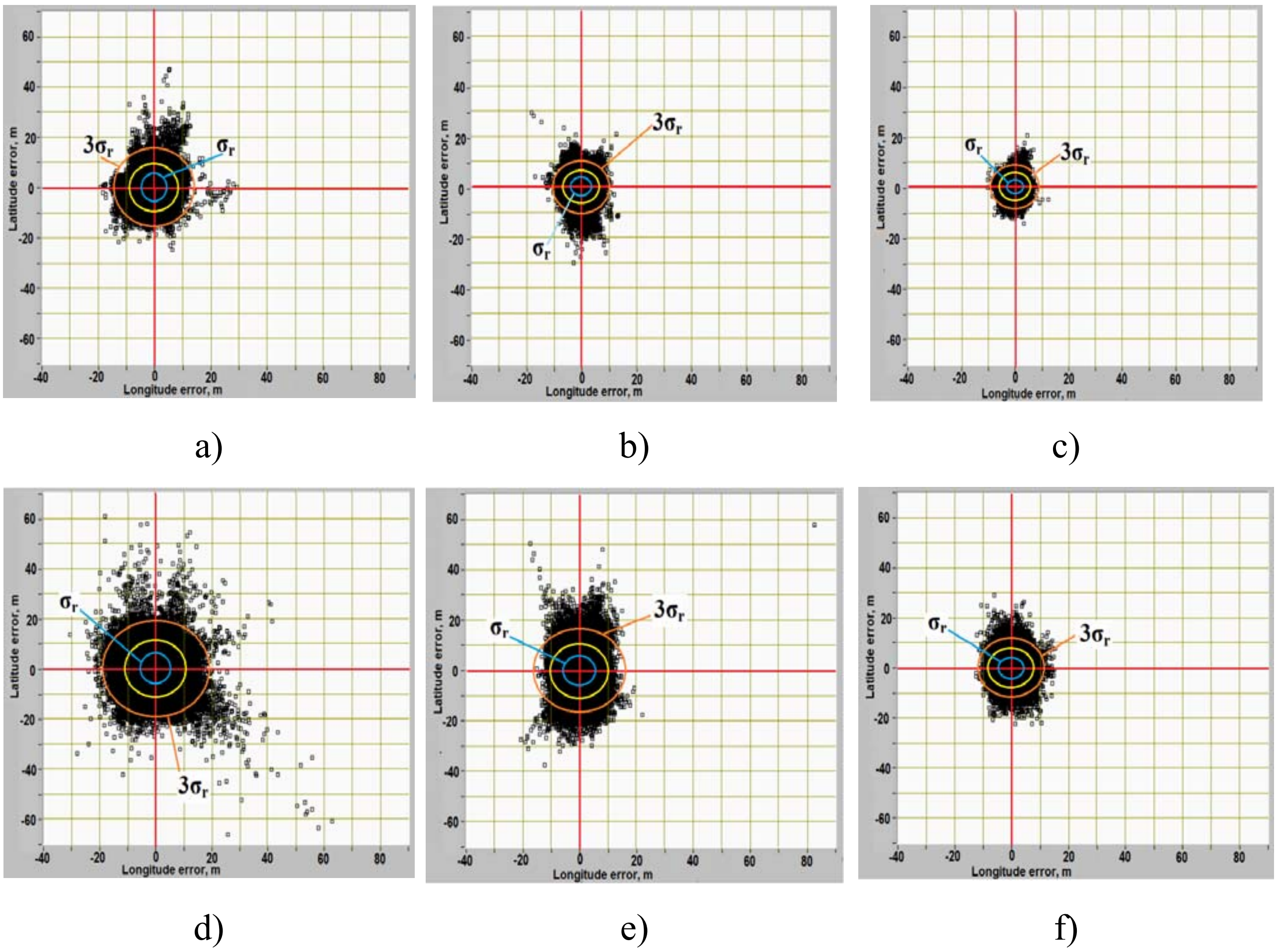


Fig. 1 – Diagrams of dispersion of instantaneous values of positioning errors

Diagrams *a, b, c* were obtained for point A, diagrams *d, e, f,* for point B. The diagrams contain circumferences corresponding to the limit positioning error ($3\sigma_r$), maximum positioning error ($2\sigma_r$) and mean-square positioning error where $\sigma_r = \sqrt{\sigma_B^2 + \sigma_L^2}$.

The results show that the errors of positioning are maximal in the GLONASS operational mode (*fig.1, a*, the scatter of instantaneous values of the errors in latitude is up to 50 m), they decrease in the GPS operational mode (*fig.1, b*, the scatter is up to 30 m) and they are minimal in the combined operational mode (fig. 1c scatter doesn't exceed 20 m). The positioning errors increase by a factor of 1.5-2 with the receiver operating in urban environment, moreover, the errors dispersion degree in GLONASS operational mode (*fig.1, d*) is significantly higher than in the other modes. It can be also noted that in GPS operation (*fig.1, b*, *fig.1, e*) the effect of larger scatter of instantaneous errors in latitude is typical and it gets less explicit in the combined operational mode (*fig. 1, b; fig. 1, f*).

Fig. 2 shows histograms of positioning errors distribution in latitude, longitude and altitude respectively in the following receiver operation modes: GLONASS operation at point A (diagrams *a, b, c*); GLONASS operation at point B (diagrams *d, e, f*); combined GLONASS/GPS operation at point B (diagrams g, h, i).

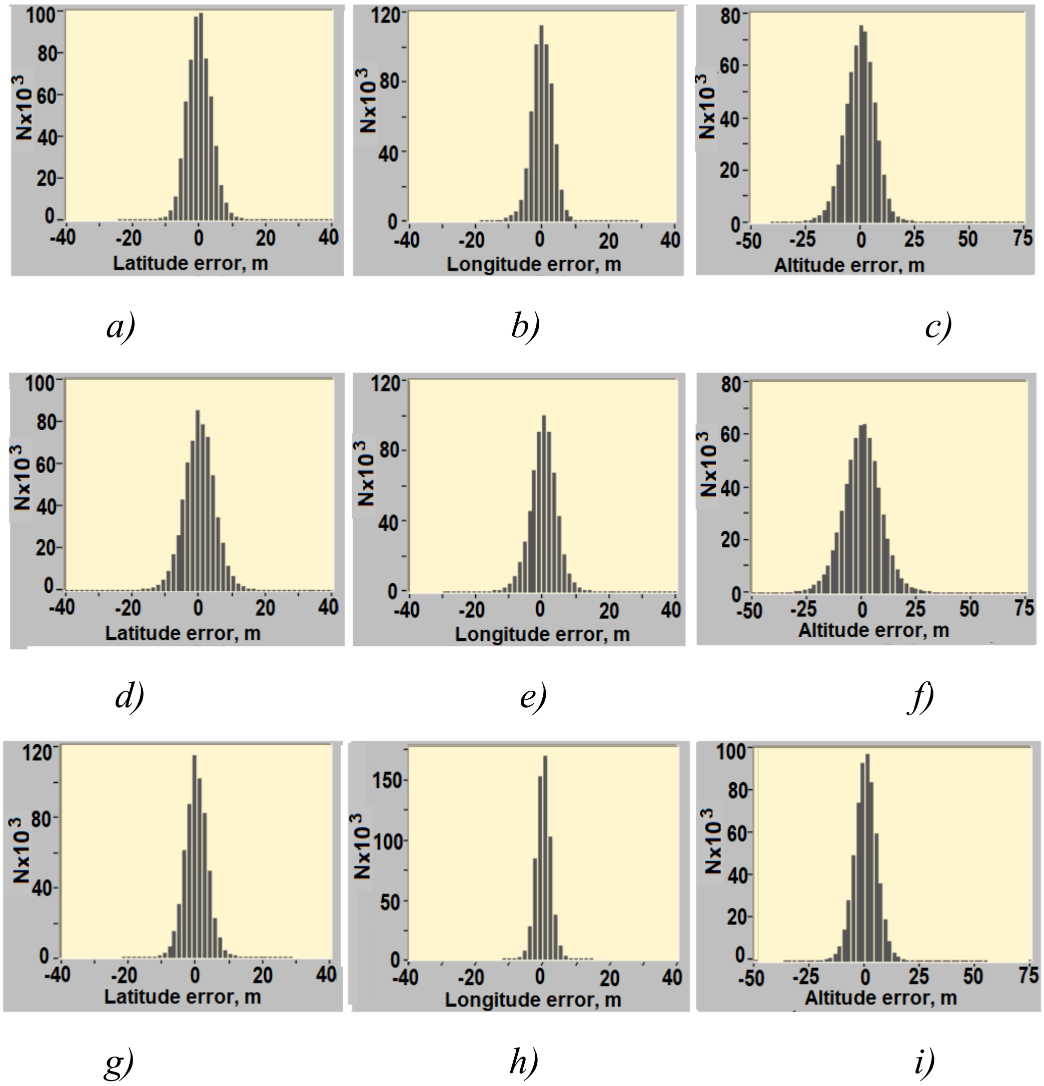
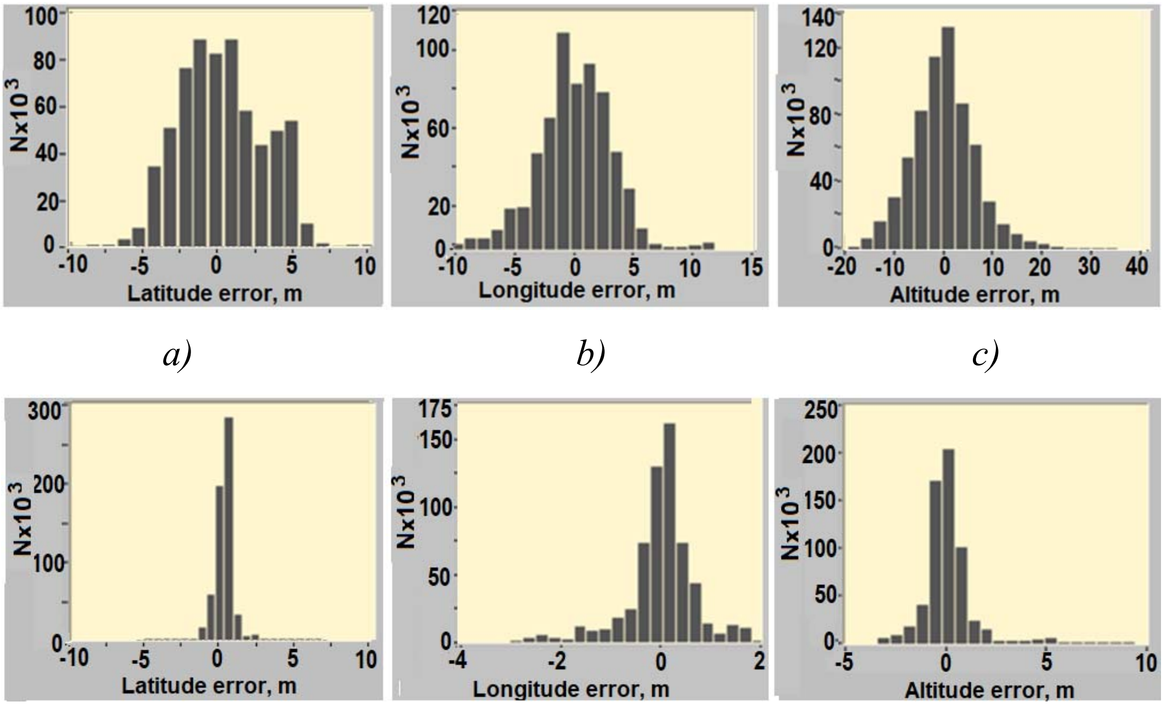


Fig. 2 – Histograms of positioning errors distribution

The analysis of the obtained results shows that in all situations the law of positioning errors distribution is close to the Gaussian law with zero mathematical expectation. A similar law of the positioning errors distribution was observed while operating in the GPS mode as well. Thus, in developing mathematic models of random positioning errors of a GNSS receiver, we can consider their distribution law as the Gaussian law.

Figure 3 demonstrates the histograms of positioning errors distribution at point B in latitude, longitude and altitude respectively with enabled dynamic filtration in the GLONASS (diagrams *a, b, c*) and GLONASS/GPS (diagrams *d, e, f*) operational modes of the receiver.

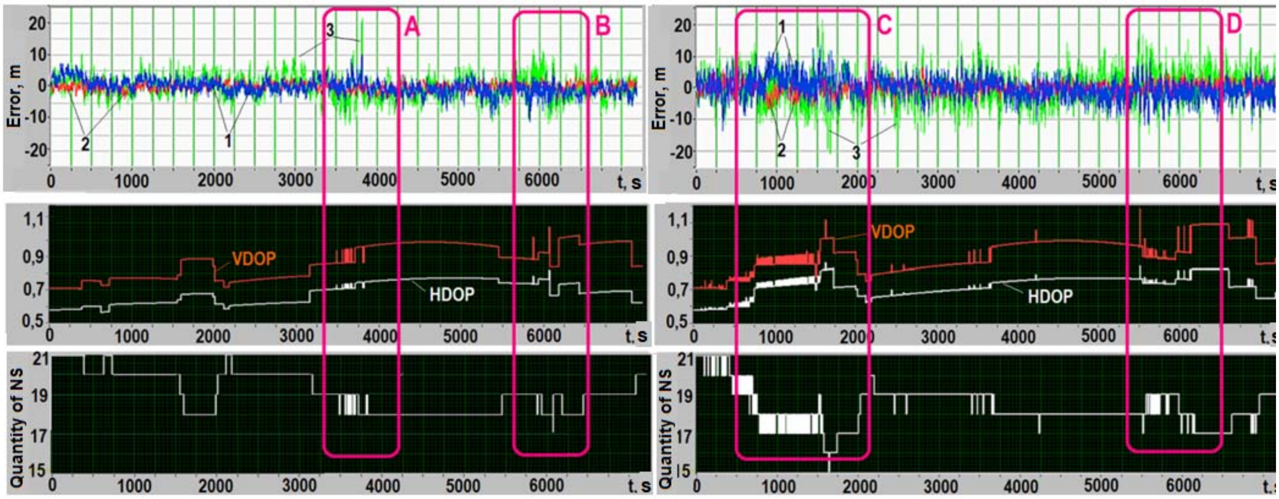


d) *e)* *f)*

Fig. 3 – Histograms of error distribution with enabled dynamic filtration

As seen in the demonstrated diagrams, activation of the dynamic filtration mode makes the degree of correspondence of positioning errors to the Gaussian law reduce. This effect should be taken into account in constructing models of GNSS receiver positioning errors with enabled additional options for processing of output information (in our case it is dynamic filtration).

Figure 4 demonstrates the results of the experiments carried out with Geos-1M receivers located at points A (*fig. 4*, *a*) and B (*fig. 4, b*) and operating simultaneously in GLONASS/GPS mode. The pictures show positioning errors realization (1-latitude, 2 – longitude, 3 – altitude) as well as graphic charts characterizing HDOP and VDOP change and the number of satellites pseudarange measurements for which are included into processing when solving the navigational problem.



a) *b)*

Fig.4 – The results of the experiments for different receiver locations

For the considered time interval the average number of navigation satellites was 19.12 (from 17 to 21) at point A and 18.41 (from 15 to 21) at point B. There is a DOP influence on values of positioning errors as well as an obvious DOP dependence on the number of visible navigation satellites. At the same time instability of tracking individual navigation satellites (areas A, B, C, D in figures) leads to a noticeable increase of instantaneous errors.

Summarized results of the conducted experiments are shown in *Table 1*.

Table 1 – Summarized results of the experiments

	GLONASS		GPS		GLONASS /GPS	
	p. A	p. B/d.f.*	p. A	p. B/ d.f.	p. A	p. B/ d.f.
Latitude MSE, m	3.58	4.73/2.83	2.86	4.81/0.41	2.29	3.31/0.53
Longitude MSE, m	3.07	3.99/3.04	1.83	2.7/0.36	1.57	2.13/0.63
RMSE, m	4.7	6.2/4.15	3.4	5.5/0.55	2.8	3.9/0.82
Altitude MSE, m	6.82	8.72/6.32	4.92	7.05/0.44	3.88	5.23/1.02
Average number of navigation satellites	8.58	7.89	10.04	9.77	18.55	17.61
Mean VDOP	1.39	1.52	1.26	1.29	0.87	0.9
Mean HDOP	1.09	1.21	0.93	0.96	0.66	0.69

*d.f. – with the mode of dynamic filtration activated

The analysis of the obtained results showed the following:

– Positioning accuracy was 4.7m (GLONASS mode), 3.4m (GPS mode) and 2.8 (GLONASS /GPS mode). Operation in the combined mode increased the positioning accuracy by 40% (that of the altitude by 43%) compared to GLONASS and by 18% (that of the altitude by 21%) compared to GPS;

− Operation in urban conditions led to positioning accuracy degradation by 34% (GLONASS mode), by 62% (GPS mode) and by 39% (GLONASS /GPS mode). HDOP degradation was 11% ,2% and 5%, correspondingly, and the reduction of the average number of visible satellites was 8%, 3% and 4.5%;

− Use of the dynamic filtration mode led to increase of accuracy by a factor of 1.5 (GLONASS mode), 10 (GPS mode) and 4.8 (GLONASS /GPS mode).

Conclusion

The conducted research provides the assessment of accuracy characteristics and operation peculiarities of a GLONASS /GPS receiver in different operational modes and conditions of use. The obtained results prove an opportunity to approximate the positioning errors of GNSS receiver in synthesis of algorithms for optimal information processing using Gaussian distribution law random values.

It was experimentally proved that operation in the combined mode caused a significant increase of positioning accuracy compared to GLONASS operation and a quite significant one compared to GPS operation. It is of great practical importance that the GPS mode is more sensitive to the urban environment although the conditions of a navigational session (DOP value and the number of visible navigation satellites) vary insignificantly. Use of the dynamic filtration mode in Geos-1M receiver is the least efficient when operating in GLONASS mode and this could be related to availability of the constituents in the positioning error which are not taken into account in the used algorithm of dynamic filtration.

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