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Accuracy Estimation of GPS Receiver Parameters with Simulator in Dynamic Mode

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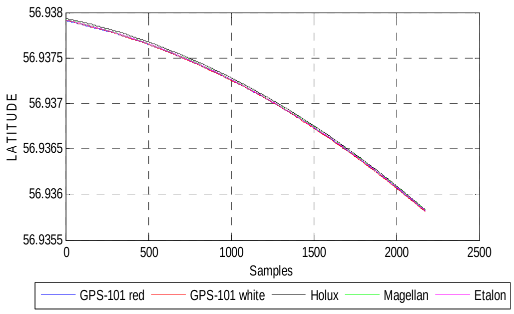
Introduction

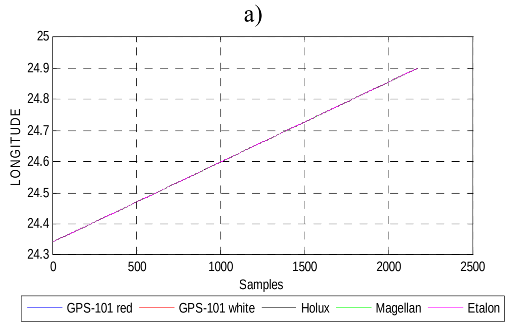
As is described in [1, 2], in order to estimate GPS user device parameters in dynamic mode, a special signal simulator must be used. This article describes testing results when using Satellites Signal Simulator STR4500. For accuracy estimation in the dynamic mode we used different brand devices. The measurements of parameters were implemented in room environments with metallized window glass, as well as in the SAC3 camera, where walls absorb electromagnetic waves. For testing purposes special scenarios for the mobile object movement were generated. The accuracy of the position fix and velocity changes when the parameters of movement change. This article reveals some of results for the natural experiments as well. The accuracy estimation of a GPS receiver parameters in dynamic mode shows that in order to increase the accuracy of the GPS user device in dynamic mode, a complex system (including inertial motion unit) must be used.

The accuracy estimation of user's device by using signal simulator STR4500 in dynamic mode and with the change of signal receiving possibility

Garmin eTrex device The GPS satellite system signals of the STR4500 simulator were used for simulation in dynamic mode, when user's coordinates change as it is shown in Fig. 1a and Fig. 1b. There also are shown measured coordinates of four types of user devices (Graymark GPS-101 "red" and "white", Holux GR-213 and Magellan eXplorist 600). As we can see, the values of simulated coordinates (Etalon) and measured coordinates are almost equal. The next experiment with use of this scenario was following: between signal simulator antenna and receiving antenna of the user device we put metallic screen, so that the signals were blocked. The results (for one coordinate – Longitude) of measurements for three kinds of receivers are shown in Fig. 2. As we can see, measurement system parameters of these receivers are very different. The has no signal integration possibilities and signal blocking leads to data loss. The Graymark GPS-101 device has one integrator and the information is considered to be constant during the time of signal unavailability.

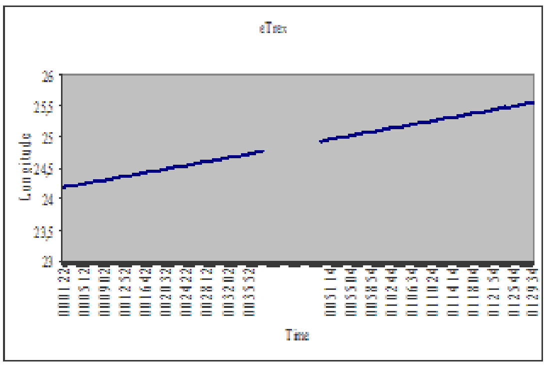


a)

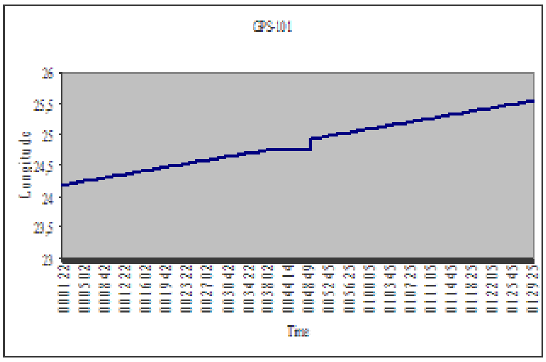


b)

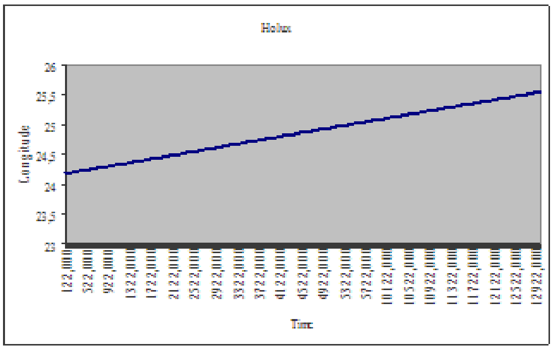
Fig. 1. The mobile object movement scenario (Etalon) for Latitude: a – Longitude; b – measured coordinates for user devices of different kind



a)



b)



c)

Fig. 2. The results of Longitude measurements for three kinds of user devices when the signal is not available for 10 minutes: a – eTrex; b – GPS-101; c – Holux

The Holux GR-213 device has two integrators and when the satellites signals are blocked the information changes with velocity that was determinate before by the device. The same results we have for latitude. In the Fig. 3 there are results for Graymark GPS-101.

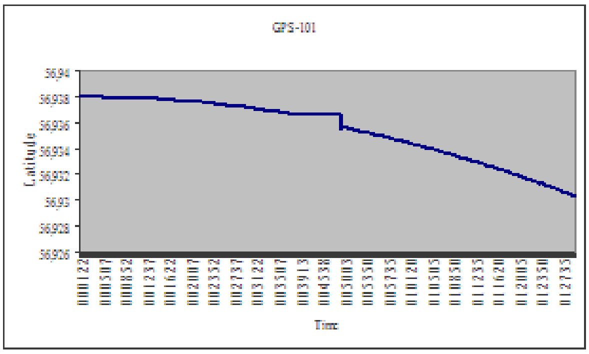


Fig. 3. The results of Latitude measurements for user device GPS-101, when the signal is not available for 10 minutes

The accuracy of position fix and object velocity measurements

The accuracy measurements of the position fix and object virtual velocity were made when different GPS devices received the signals of the STR4500 simulator instead of the real GPS satellites signals of the Re-Reference system described in [1].

In this case, the accuracy of the object position fix was estimated by mean radial error ε_p in the horizontal plane and Root Mean Square deviation RMS_p of this error. The movement speed accuracy was estimated by increments of Latitude and Longitude orthogonal coordinates calculated to position fix over time interval between these two neighbour samples. Then, based on the data of the GPS receiver protocol, we calculated the object velocity vector and its modulus. The same operations were applied to reference data of the simulated scenario in order to calculate a reference velocity vector and its modulus. The estimation of the velocity measurement accuracy was made by calculating difference between modulus of the measured velocity vector and modulus of the reference velocity vector. We calculated mean speed error ε_s and Root Mean Square deviation RMS_s over these difference samples. For error calculations we used the position fix algorithm described earlier in [3].

The plots of the reference velocity samples over time extracted from the simulator scenarios are broken lines with 5 intervals and total length of 2150…2900 seconds. The first interval (varies in range of 200 to 800-850 seconds, depending on scenario and start time of the receiver) has velocity of zero (static). In the second interval (180 sec or 300 sec long, depending on scenario) the velocity increases by linear law from 0 to 180 km/h (the acceleration is 0.2(7) m/sec^2) when length of interval is 180 sec. If the length of the interval is 300 sec, the velocity increases by linear law from 0 to 800 km/h (the acceleration is 0.74(074) m/sec^2). The velocity in the third interval (600 seconds long) is constant – 180 km/h or 800 km/h, depending on scenario. In the fourth interval the velocity decreases with the same law and over same time interval as it was in the second interval. In the fifth interval the velocity is zero (static mode) and length of the interval is 900 seconds (unconditionally).

The object movement is simulated with two described velocity profiles (0→180→0 km/h and 0→800→0 km/h) with one of two directions from Riga: either strictly to the North (along the meridian) or strictly to the East (along the parallel).

Note that in the beginning of the first interval there is possibility to get very unstable measurement results, since the GPS receiver enters the tracking mode and leaves seek mode – and that leads to a transient process. The part of the first interval occupied by this instability can vary, depending on GPS receiver kind (in general, its manufacturer. Some of the GPS receivers (for example, Graymark GPS-101) nearly has no the transient process caused by entering the tracking mode. That may be observed from behaviour (and magnitude) of the radial error plot over time.

In order to minimize an influence of the transient process, the data processing computer program allows blocking the beginning of the measured and reference data files for prescribed number of samples, specified by the SHIFT parameter. For example, in the Fig.4 there are results for the Holux GR-213(09) GPS receiver for two scenarios, when an object moves along parallel with velocity profiles of 180 km/h and 800 km/h. For the velocity measurement beginning, SHIFT=1 (not zero!).

Note, that latitude and longitude samples are written with T=1 sec period for Graymark GPS-101 and Holux GR-213 (both 09 and 10 – the last two digits of serial number). For Garmin GPS-72 and Garmin eTrex GPS receivers latitude and longitude data is written every T=2 sec. The total number of processed scenarios is 22 – 11 scenarios for each velocity profile, 12 when moving along the parallel (variable longitude) and 10 when moving along the meridian (variable latitude).

The analysis of these results shows that movement of object affects the accuracy of position fix and velocity measurement. However, this influence depends on the kind of GPS receiver.

Table 1. Graymark GPS-101, 180 km/h, latitude

Interval number	ε_s, km/h	RMS_s, km/h
1	1.46008e-02	0.09181
2	-6.79178e-04	0.28759
3	-5.33634e-03	0.32241
4	-6.59587e-03	0.26877
5	3.38475e-02	0.13599

The best results were observed for Graymark GPS-101 and Garmin eTrex receivers. However, we should add, that Garmin eTrex occasionally had failures in the measurement results. Graymark GPS-101, in the same time, has always been showing stable working after the end of the transient process. The mean value of radial error for Graymark GPS-101 depends in no obvious way on fact of velocity both in 180 km/h and 800 km/h velocity profiles.

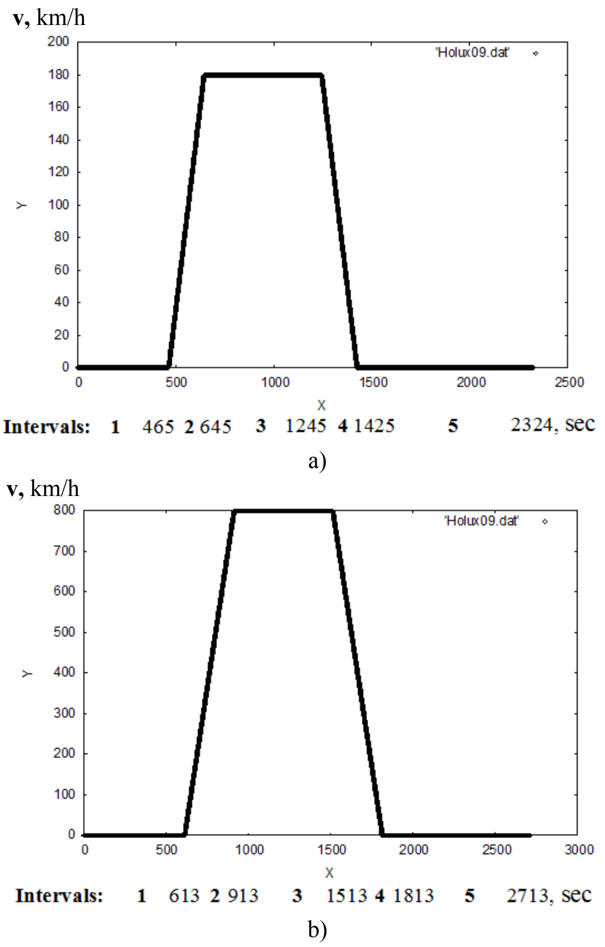


Fig. 4. The law of the velocity changes for Graymark GPS-101 in two velocity profiles: a – 180 km/h; b – 800 km/h. The object moves along the parallel – variable longitude (SHIFT=1)

The mean measurements error of the velocity in the 2-nd, the 3-rd and the 4-th intervals is decreasing, when there are dynamics of the object. The error decreases by order and more, compared to the 1-st and the 5-th intervals, where are no vehicle dynamics. The values of radial error RMS_p and velocity error RMS_s are weakly dependent on vehicle dynamics. In the same time, the behaviour of the current values for position fix error and velocity error changes over time, and it depends on the interval.

Table 2. Graymark GPS-101, 180 km/h, latitude

Interval number	ε_p, m	RMS_p, m
1	2.14905	0.13666
2	1.80628	0.06886
3	1.49523	0.14206
4	1.06953	0.05011
5	1.02568	0.04841

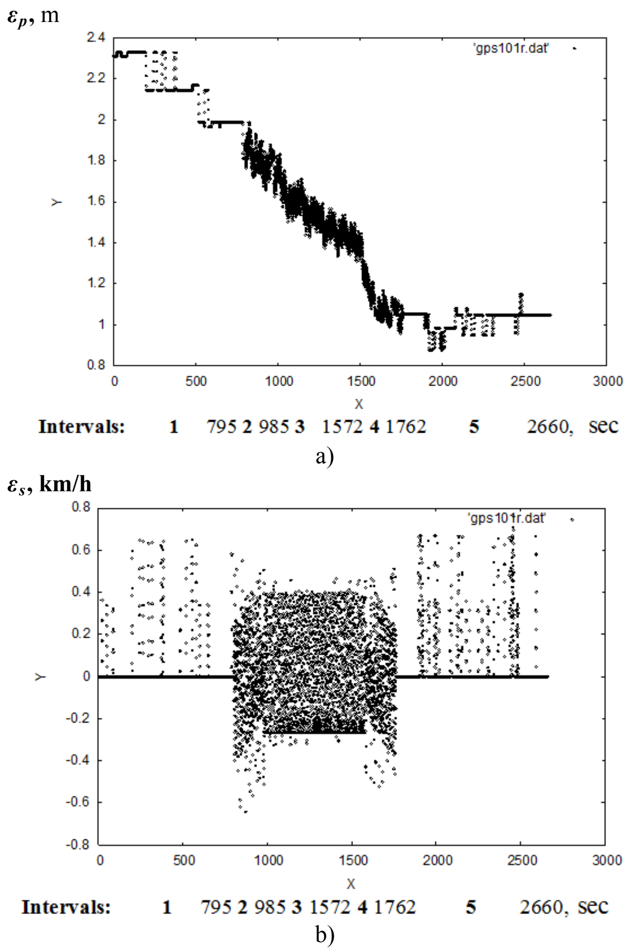
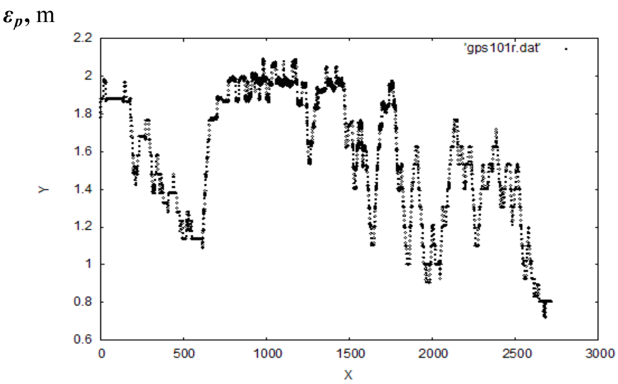


Fig. 5. Current values for: a) radial error (meters) and b) velocity error (km/h) for the receiver Graymark GPS-101 when the object is moving along the meridian with velocity profile 180 km/h (SHIFT=20)

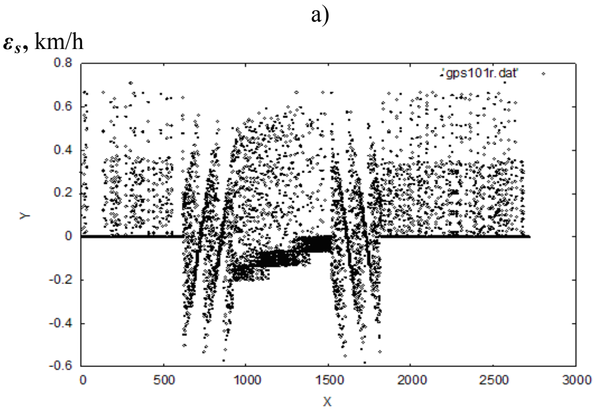
The position fix and velocity error mean values and RMS in the 1-st to the 5-th intervals, when Graymark GPS-101 virtually moves along the meridian with velocity 180 km/h are shown in the Tables 1 and 2. The plots of errors over time for profiles of 180 km/h and 800 km/h are shown in Fig. 5, 6 (respectively). The values of mean radial error ε_p of position fix for 800 km/h velocity profile remain within the same range of 1-2 meters.

The values of mean velocity error ε_s in 800 km/h velocity profile are the same as were in 180 km/h profile – over the 2-nd, the 3-rd and the 4-th intervals the order of these values is e-3 to e-4. Over the 1-st and the 5-th intervals the order of these values is e-2. The RMS_p is about 2-3 times greater (0.117 m – 0.283 m). The RMS_s in 800 km/h profile nearly remains in the same range of 0.14 km/h – 0.285 km/h.



Intervals: 1 619 2 919 3 1519 4 1819 5 2719, sec

a)



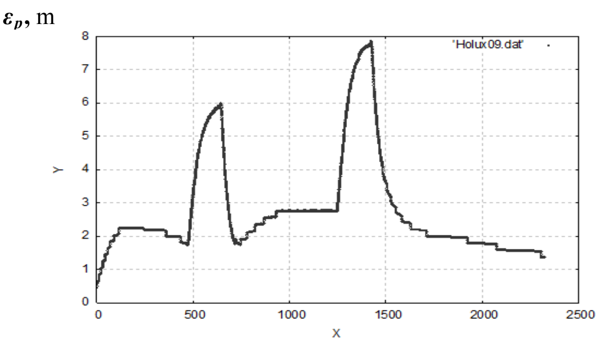
Intervals: 1 619 2 919 3 1519 4 1819 5 2719, sec

b)

Fig. 6. Current values for: a) radial error (meters) and b) velocity error (km/h) for the receiver Graymark GPS-101 when the object is moving along the meridian with velocity profile 800 km/h (SHIFT=20)

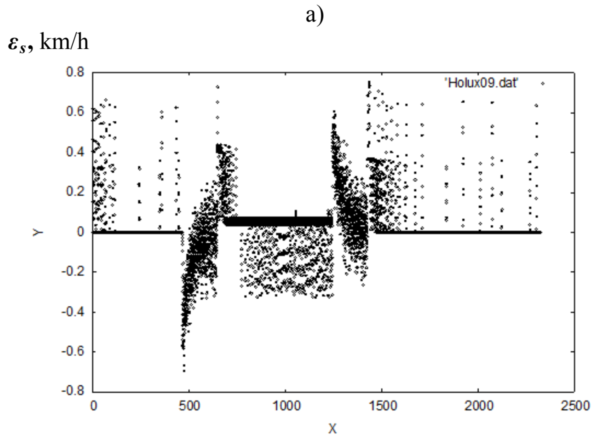
Absolutely different behaviour over time (and greater values) have radial errors and velocity errors of Holux GR-213 (09 and 10) kind GPS receivers. This can be observed by comparing, for example, plots of radial error over time in Fig. 5, a, 6, a and Fig. 7, a, 8, a, respectively (180 km/h and 800 km/h velocity profiles). In the first case (Fig. 5,6), the results are for movement along the meridian, and in the second case (Fig. 7, 8) – for movement along the parallel. When moving over these orthogonal coordinates with given directions, the plots of errors over time are similar to ones shown earlier, and mean numerical characteristics are also close. So we didn't include these results. Numerical characteristics ε_s, ε_p, RMS_s and RMS_p for Graymark GPS-101 and Holux GR-213 GPS receivers can be compared by analyzing Tables 1, 2 and Tables 5, 6, respectively.

By observing plots from Fig. 7, 8, we can see that radial error of Holux GR-213 GPS receivers unambiguously depends on the presence of an acceleration and its value. In the 2-nd and the 4-th intervals, where velocity is linearly increasing from 0 and linearly decreasing to 0, the radial error greatly increases due to the acceleration from 1-3 m to 6-11 m (in 800 km/h velocity profile up to 18-25 m). In the 1-st, the 3-rd and the 5-th intervals, where the velocity is either zero (the 1-st and the 5-th intervals), or constant (3-rd interval), the radial error is significantly decreased and it doesn't exceed value of 3 meters.



Intervals: 1 465 2 645 3 1245 4 1425 5 2324, sec

a)



Intervals: 1 465 2 645 3 1245 4 1425 5 2324, sec

b)

Fig. 7. Current values for: a) radial error (meters) and b) velocity error (km/h) for the receiver Holux GR-213(09) when the object is moving along the parallel with velocity profile 180 km/h (SHIFT=1)

Table 3. Holux GR-213(09), 180 km/h, longitude

Interval number	ε_s, km/h	RMS_s, km/h
1	2.28743e-2	0.11233
2	-1.23125e-3	0.19460
3	3.84223e-2	0.15620
4	1.25518e-3	0.19854
5	3.49267e-2	0.12358

Table 4. Holux GR-213(09), 180 km/h, longitude

Interval number	ε_p, m	RMS_p, m
1	1.97650	0.37931
2	4.65123	1.31259
3	2.62875	0.54714
4	6.38951	1.47173
5	2.21920	1.02040

The curves of error changes over time have typical look of exponential increasing curve in the beginning of the acceleration and decreasing curve in the end of the acceleration. These curves are similar to the curves of capacitor charge/discharge processes by rectangular impulses (in our case, the impulses of the acceleration have rectangular form). Since the acceleration values in the 2-nd and the 4-th intervals have the opposite sign ($\pm$0.2(7) m/sec^2 for 180 km/h velocity profile and $\pm$0.74(074) m/sec^2 for 800 km/h velocity profile), the second surge of radial error in the 4-th interval (the acceleration is negative) is always greater than the first surge. This can be observed by comparing curves in Fig. 7, a and Fig. 8, a. The same results were calculated for 6 more scenarios for two Holux GR-213 receivers (10 and 09). Note, that the ratio of absolute acceleration values for 180 km/h and 800 km/h is 2.67, and approximately same ratio (2.29-2.33) can be calculated for the 1-st (more stable) and the 2-nd surge of the radial error for the same velocity profiles.

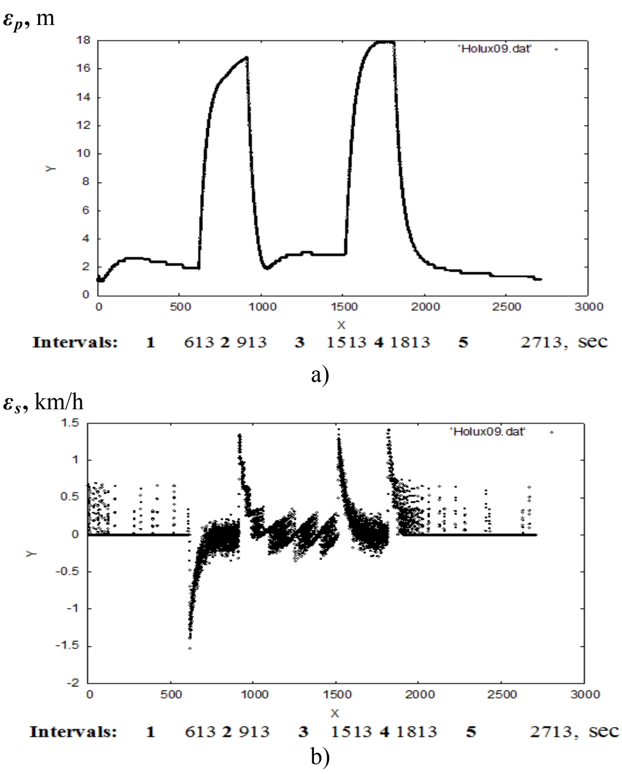


Fig. 8. Current values for: a) radial error (meters) and b) velocity error (km/h) for the receiver Holux GR-213(09) when the object is moving along the parallel with velocity profile 800 km/h (SHIFT=1)

Table 5. Holux GR-213(09), 180 km/h, latitude

Interval number	ε_s, km/h	RMS_s, km/h
1	2.71259e-2	0.12440
2	-1.40645e-3	0.35310
3	4.55551e-2	0.33728
4	1.66723e-3	0.30558
5	4.55875e-2	0.16115

Table 6. Holux GR-213(09), 180 km/h, latitude

Interval number	ε_p, m	RMS_p, m
1	1.70840	0.38384
2	3.73222	1.60791
3	2.19655	0.75918
4	8.28712	2.33697
5	2.48913	1.71095

Comparing Tables 3, 4 and 5, 6 (respectively) shows that changing a direction of movement to its orthogonal ("parallel" to "meridian" and vice versa) have almost no influence on values of mean errors and RMS both for radial error and velocity error.

Garmin GPS-72 is yet another GPS receiver which shows that mean velocity error value decreases after a movement has been started. The curves of velocity error values for 800 km/h profile are shown in Fig. 9. The curves of errors over time in Fig. 9 are similar to ones from Fig. 6. (Graymark GPS-101) The mean values of ε_p, ε_s errors and RMS of these errors over intervals 1–5 have the same order and are not greater than 2-2.5 times of analogous Graymark GPS-101 and Garmin eTrex values.

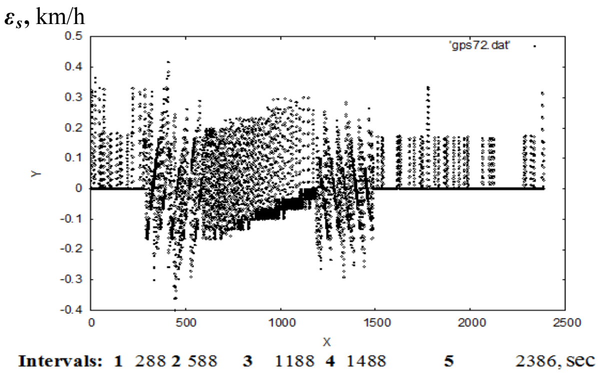


Fig. 9. Current values for velocity error (km/h) for the receiver Garmin GPS-72 when the object is moving along the meridian with velocity profile 800 km/h (SHIFT=40)

Some generalized results

In conclusion we should add, that there is a common regularity in the behaviour of velocity error's RMS_s for all GPS receivers. This regularity consists in the fact, that when the moving begins (and thus, there is velocity), the value of the mean velocity error ε_s is decreasing for all GPS receivers except Holux GR-213, and the root mean square deviation of the error (RMS_s) is increasing. For Holux GR-213 type GPS receivers the mean velocity error is also increasing, however in this case it is caused by acceleration instead of velocity. This RMS_s behaviour is illustraded in Fig.10 for most of GPS receivers used in the experiments with velocity profiles of 180 km/h and 800 km/h.

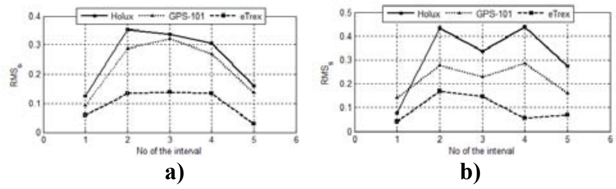


Fig. 10. Generalized results for RMS_s of all receivers (latitude scenarios) with velocity profile: a – 180 km/h; b – 800 km/h

The plots in Fig. 10 show that Root Mean Square deviation of velocity measuring error (RMS_s) is increasing for the most receivers when the movement starts.

Conclusions

1. During the intervals with velocity or acceleration

(intervals 2,3,4) for both velocity profiles (180 km/h and 800 km/h) in both directions (along the meridian and along the parallel), the absolute value of velocity measuring error is being decreased, when movement starts (from 2-3 times up to order and more). That is true for all GPS receivers, except Holux GR-213, for which velocity measuring error can increase when the moving starts.
2. Root Mean Square deviation of velocity measuring error is increased for most receivers when the movement starts.
3. The mean value of radial error has no obvious dependency on velocity factor and its value for all GPS receivers except for Holux GR-213 receiver. If there are no surges in processed data, the mean values of this error does not exceed 0.5–0.7 m for Garmin eTrex and Garmin GPS-72 receivers, and 1–2 m for Graymark GPS-101 receiver.
4. Radial error for Holux GR-213 GPS receivers has determinate dependency on acceleration absolute value. This error increases when acceleration increases. As a result, the fact of acceleration increases mean radial error from 2.5-3.5 m up to 6-11 m for 180 km/h velocity profile. For 800 km/h velocity profile the error increases from 2-3 m up to 15-20 m. When the velocity reaches fixed value (in the 3-rd interval), the error returns to it's normal value of 2-3 m, which was observed in static mode (zero velocity).
5. Root Mean Square deviation of radial error is small value about 0.02-0.3 m for all receivers, if there are no surges in processed data. The only exception is Holux GR-213 receiver for which this value generally is within the range from 1-2 m to 5-6 m.
6. Relative to velocity absolute value, both of the error parameters (mean value and RMS) decreases, when velocity increases.

References

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2. **Kluga A., Kulikovs M., Semjonova V., Zelenkovs A.** GPS user devices parameter control methods // Telecommunications and Electronics. – Riga: RTU, 2007. – Vol. 7. – P. 45–48.
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The paper reveals results of satellite system users' devices testing in dynamic mode using signal simulator STR4500. Testing was made in the laboratory with metallized window glass and in reflectionless camera SAC3. Testing results have shown the possibility to determine parameters of user devices and dependence of accuracy of user device parameters and movement mode. For accuracy parameters estimation in dynamic mode we used 4 GPS receivers of the different kind: Graymark GPS-101, Garmin GPS-72, Garmin eTrex, Holux GR-213. The movement was simulated with two different velocities – 180 km/h and 800 km/h. It was also simulated in two orthogonal directions – to the North and to the East from Riga (total 4 scenarios). The following parameters were estimated: fix position error in horizontal plane (radial error), its mean value and Root Mean Square (RMS) deviation, as well as current velocity error, its mean value and RMS. Ill. 10, bibl. 3 (in English; abstracts in English, Russian and Lithuanian).

А. Клуга, А.Зеленков, Э. Граб, В. Белинская. Оценка точности параметров GPS приемников с использованием имитатора в динамическом режиме // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 9–14.

Рассмотрены результаты тестирования аппаратуры потребителя спутниковой навигационной системы GPS с помощью имитатора сигналов STR4500. Тестирование проводилось в лаборатории с металлизированными окнами и в безэховой камере SAC3. Результаты тестирования показали возможность определить динамические погрешности и их зависимости от параметров движения. С целью определения точностных характеристик в динамическом режиме использовались 4 типа приемников Graymark GPS-101, Garmin GPS-72, Garmin eTrex и Holux GR-213. Движение имитировалось со скоростями 180 км/час и 800 км/час в двух ортогональных направлениях – на север и на восток от Риги (в сумме 4 сценария). Определялись текущая ошибка позиционирования в горизонтальной плоскости (радиальная ошибка), ее среднее значение и среднеквадратическое (RMS) отклонение, а также текущая ошибка измерения скорости, ее среднее значение и среднеквадратическое отклонение. Ил. 10, библ. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Kluga, A. Zelenkov, E. Grab, V. Belinska. GPS imtuvų parametrų tikslumo analizė naudojant imitatorių dinaminiu režimu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 9–14.

Pateikti palydovinės sistemos testavimo rezultatai, gauti naudojant signalų imitatorių STR4500 dinaminiu režimu. Testavimas atliktas specialiai tam skirtoje laboratorijoje su metalizuotais langų stiklais ir spec. kamera SAC3. Pastebėta, kad yra galimybė nustatyti GPS imtuvų parametrus, tikslumo priklausomybę ir judėjimo tipą. Tikslumo parametrų įvertinimas buvo atliktas taikant keturis GPS imtuvus: „Graymark GPS-101“, „Garmin GPS-72“, „Garmin eTrex“, „Holux GR-213“. Judėjimas imituotas esant dviems skirtingiems judėjimo greičiams: 180 km/h ir 800 km/h. Įvertinti šie parametrai: nuolatinė pozicijos klaida horizontalioje plokštumoje, jos vidutinė vertė ir vidutinės kvadratinės vertės (angl. RMS) nuokrypis, taip pat greičio paklaida, jo vidutinė vertė ir vidutinės kvadratinės vertės nuokrypis. Il. 10, bibl. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).