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Accuracy Estimation of TOPCON GRS-1 GNSS Receiver Parameters in Static and Dynamic Mode

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***Abstract*—This article describes some of the testing results for TOPCON Geodetic Rover System's (GRS-1) Global Navigation Satellite System (GNSS) receiver in static and dynamic modes. First of all, our attention was focused on estimation of accuracy for GRS-1 receiver in static mode. Then we tried to evaluate these characteristics of the receiver in dynamic mode. Also, the article includes the results of inertial system possibilities to improve vehicle position estimates and movement parameters when the satellite signal is unavailable.**

***Index Terms*—Accuracy estimation, satellite navigation systems, vehicle dynamics, velocity.**

I. INTRODUCTION

The GRS-1 receiver is a multi-function, multi-purpose receiver intended for precision markets. It is a dual-frequency receiver (GPS+GLONASS L1 and L2) and hand-held controller designed to be the most advanced, compact, and portable receiver for the GIS and surveying market [1]. An integrated electronic compass and digital camera make the GRS-1 an all-purpose device that can also be utilized as a field collector. The GRS-1 can receive and process both L1 and L2 satellite signals, improving the accuracy of survey points and positions by increasing the number of satellites the receiver can detect, thus increasing productivity and reducing cost. The dual-frequency and GPS+GLONASS features of the GRS-1 combined provide the only real time kinematic (RTK) system accurate enough for short and long baselines. So, the GRS-1 provides the functionality, accuracy, availability and integrity needed for fast and easy data collection.

The comparison of accuracy for field robots equipped with GRS-1 and other low cost GPS devices' are given in [2]. Also, there are results of RTK possibilities available as well for improving the accuracy of low cost GPS devices.

II. TOPCON GRS-1 RECEIVER TESTING RESULTS IN STATIC MODE

A. Experiment Purpose

The purpose of the testing is accuracy estimation for TOPCON GRS-1 GNSS receiver in short time interval by using Re-Reference system described in [3]. After the coordinates' conversion by standard methods described in [4], it is possible to estimate the radial (horizontal) error of position fix in meters. From here, given the array of radial deviations (in meters) from reference point, we can estimate the statistical characteristics of the random process samples. For example, such statistical characteristics may be estimations of expectation (mean), standard deviation, probability density function (histogram) and cumulative probability function (the probability of error not exceeding the specified value) etc.

We did the similar research for different receivers before [4]. Now we want to compare the accuracy characteristics of simple receivers form [4] with ones for GRS-1.

B. Experiment Parameters

Precise (reference) coordinates in degrees of Re-Reference system antenna are shown in Table I.

TABLE I. ANGULAR COORDINATES OF REFERENCE POINT.

Parameter	Coordinates
Latitude, B, deg	56.941337861111°
Longitude, L, deg	24.15578969694444°

We have collected latitude, longitude, height and other data from GRS-1 receiver over 20 minutes by using special TopSURV software.

C. TOPCON GRS-1 Testing Results in Static Mode

Figure 1 shows radial error of GRS-1 receiver over 20 minutes.

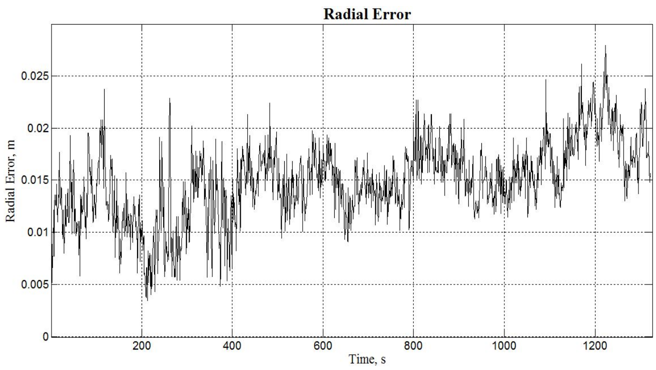

Fig. 1. GRS-1 receiver radial (horizontal) error estimated over 20 minutes.

Figure 2 illustrates graph of normalized estimated

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autocorrelation for GRS-1 radial error over 20 minutes.

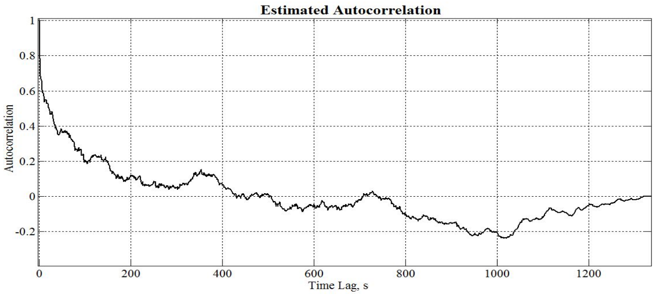


Fig. 2. Normalized estimated autocorrelation for GRS-1 receiver's radial error over 20 minutes.

Figure 3 illustrates graph of estimated probability histogram for latitude error. It is expected for latitude error distribution to be the normal (Gaussian) distribution.

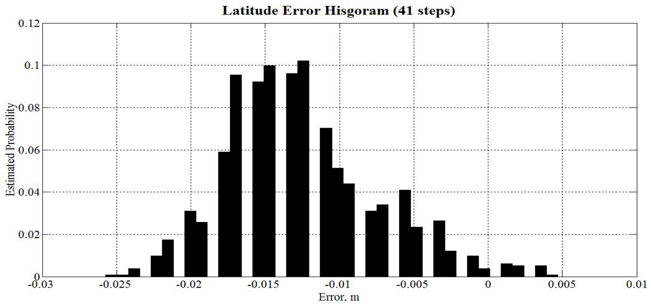


Fig. 3. Latitude error histogram for GRS-1 receiver latitude over 20 minutes.

Figure 4 shows radial error estimated probability, and it is similar to Rayleigh distribution in corresponding graph [5].

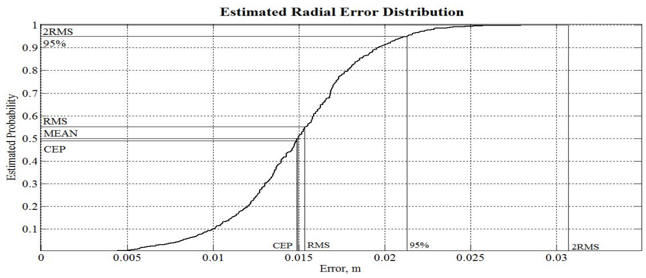


Fig. 4. Estimated radial error cumulative distribution function for GRS-1 receiver over 20 minutes.

Horizontal and vertical lines in Fig. 5 denote accuracy parameters of GRS-1 receiver. Table II summarizes these statistical characteristics for two GPS receivers used in the experiment.

TABLE II. ACCURACY PARAMETERS FOR GPS RECEIVERS ESTIMATED OVER 20 MINUTES OF PROCESS SAMPLES.

Parameter	Topcon GRS-1	Holux GR 213
2DRMS	100 % 0.030674 m	100 % 5.629600 m
95%	95.0 % 0.021303 m	95.0 % 3.521255 m
DRMS	55.068 % 0.015337 m	55.068 % 2.814800 m
MEAN	49.017 % 0.014857 m	52.95 % 2.787824 m
CEP	50.0 % 0.014948 m	50.0 % 2.703778 m

After the comparison of the results from Table II we can conclude, that TOPCON GRS-1 receiver has much higher accuracy parameters than Holux GR 213 and other GPS receivers [4].

We have investigated whether the number of satellites influences GRS-1 accuracy. In Fig. 5 we can see, that when the number of satellites changes from nine to eight, RMS value becomes higher (Fig. 6).

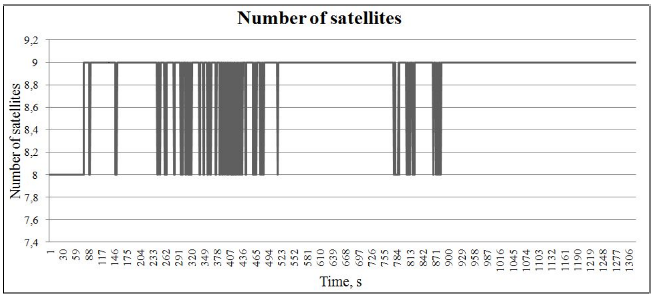


Fig. 5. Number of satellites for GRS-1 receiver over 20 minutes.

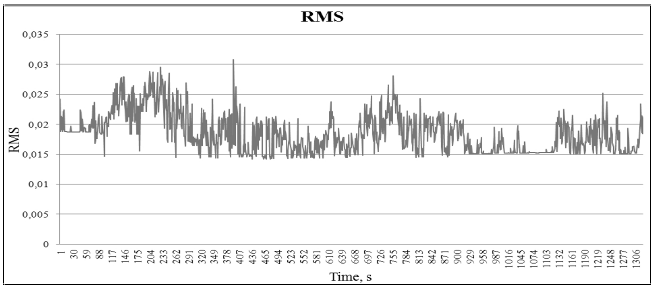


Fig. 6. RMS for GRS-1 receiver over 20 minutes.

III. TOPCON GRS-1 GNSS RECEIVER TESTING RESULTS IN DYNAMIC MODE

The testing results of TOPCON GRS-1 gave us good precision evaluation in static mode. So, we decided to collect measurement data for moving object (vehicle) in order to estimate device capabilities in dynamic mode as well.

A. *The First Experiment Purpose*

The first experiment purpose was to determine the influence of environment (trees and buildings on either side of the road) on the number of satellites available for GRS-1 device and the respective precision errors.

B. *Experiment Equipment and Parameters*

The car with GRS-1 receiver's antenna fixed on the roof was prepared for the experiment (Fig. 7).

(a) (b)

Fig. 7. Equipment of the experiment: GRS-1 receiver with antenna on the car roof.

The path that contains different type of environment on either side of the road (trees and buildings) also was chosen (Fig. 8).

Fig. 8. The first experiment trajectory on the Google aerial map.

C. TOPCON GRS-1 Testing Results in Dynamic Mode

After traveling the chosen path the navigation data from GRS-1 was processed and marked on the map. Figure 9 illustrates the RMS (that is accuracy) dependence on the number of satellites available for every measured position along the path.

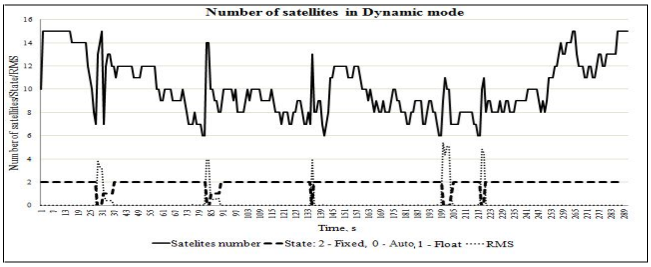


Fig. 9. RMS dependence on the number of the satellites.

TopSURV software provides several types of the position calculation methods: fixed – positions are computed by RTK engine, the carrier phase measurements from a base station and receiver. Integer ambiguities are fixed; autonomous – differential corrections are not available; float – integer ambiguities are not fixed.

D. The Second Experiment Purpose

The purpose of the second experiment was to test GRS-1 receiver at different velocities. The problem was to find a simple way to calculate velocity of the vehicle based on the data provided by GRS-1 receiver. It was impossible to obtain the velocity data directly from the receiver.

E. Experiment Parameters

During the experiment, measurements were carried out for certain vehicle velocity parameters:

Velocity - 40 kilometers per hour. Vehicle begins moving with acceleration, reaching top velocity – 40 kilometers per hour. Vehicle moves at the top velocity then begins to slow down.

F. Preparing for the Experiment

GRS-1 receiver's antenna was fixed on the car roof (Fig. 7). The route for the experiment was selected at the straight stretch of the road. Using GRS-1 in static mode the road has been marked in two points: "start" and "finish". By GRS-1 calculation, the distance between these two points is 182.3728 meters (Fig. 10).

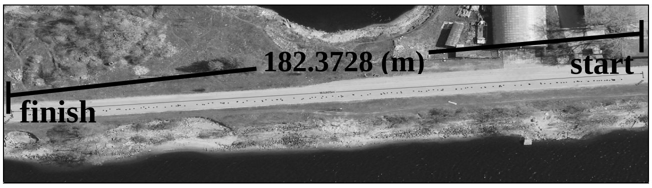


Fig. 10. Orthophoto of the road.

The vehicle moves specified distance at the given velocity parameters, while the GRS-1 measures position every second. As a result, we have obtained the samples of coordinates along the entire route with an interval of one second.

Unfortunately, GRS-1 does not support the calculation of the object's velocity; it measures only coordinates of the position along the route.

G. Processing Data

GRS-1 has the ability to export the location data in meters (X – for the longitude and Y – for the latitude). Getting X and Y for each point of the route in meters and knowing the time intervals between measurements, we can easily calculate the velocity values for each point of the route draw a complete velocity graph.

We use simple relation in among the sides of a right-angled triangle to calculate distance between two points of the way (1)

$$D_i = \sqrt{(X_{i-1} - X_i)^2 + (Y_{i-1} - Y_i)^2}, \tag{1}$$

where D_i is the distance between two points, at the beginning it will be the first measured point (X_{i-1},Y_{i-1}) and the second measured point (X_i,Y_i). X_{i-1} and X_i are the corresponding values of longitude in meters of the first and the second measured point, and Y_{i-1} and Y_i are the values of latitude in meters of the first and the second measured point, accordingly.

We know that the distance between two points is traveled in one second time interval; therefore we can calculate velocity for every point of the route and then convert values to kilometers per hour according to

$$V_i = \frac{D_i}{1000} \times 3600, \tag{2}$$

where V_i is a velocity at the (X_i,Y_i) point of the route.

We can calculate directions for the start and finish points and for every point along the route by using the point's values in meters. We use (3) to calculate direction.

$$\varphi_i = arctg(\frac{X_{i-1} - X_i}{Y_{i-1} - Y_i}), \tag{3}$$

where φ_i is the angle of direction.

The Table III provides the coordinates of the start and finish points in meters.

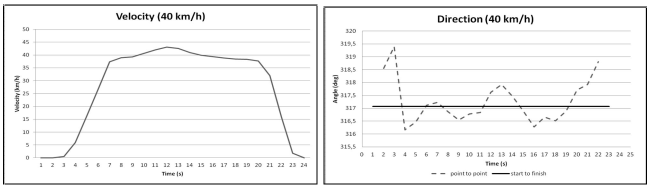
TABLE III. COORDINATES OF THE START AND FINISH POINTS IN METERS.

start	finish
Latitude, Y, m 308760.3291	Latitude, Y, m 308626.801
Longitude, X, m 509416.1671	Longitude, X, m 509540.385

H. TOPCON GRS-1 Testing Results in Dynamic Mode

Figure 11(a) shows the results of velocity calculation by using the algorithm described above. The graph shows the typical velocity increase when the vehicle begins to move, then velocity remains relatively constant for some time interval, and then it decreases.

Figure 11(b) shows the comparison of “point to point” direction related to the straight-way route “start to finish” direction. “Start to finish” direction is 317.0687° relative to the north and marked with solid line. “Point to point” direction is also relative to the north and is marked with dashed line.



(a) (b)

Fig. 11. (a) Vehicle velocity reaching 40 km/h, (b) direction comparison for velocity 40 km/h.

I. *TOPCON GRS-1 and Accelerometer Testing Results*

This article presents one more method for motion parameters estimation in dynamic mode. We apply the measurements of the accelerometer, when the signal of satellites becomes temporarily unavailable.

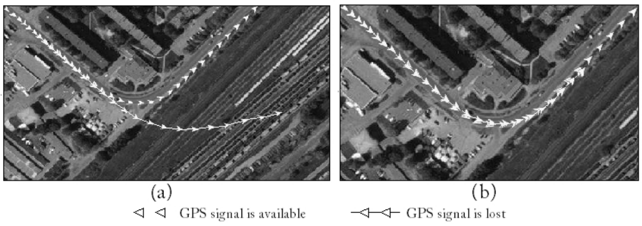
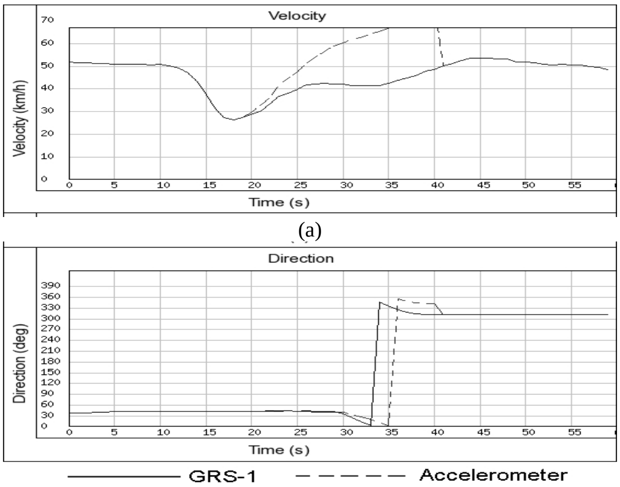


Fig. 12. Position detection by using GRS-1 and accelerometer without (a) and with (b) offsets’ filtering.



(b)

Fig. 13. Velocity and direction for GRS-1 and accelerometer without offsets’ filtering.

Whenever the position (latitude, longitude) was fixed by GRS-1, we calculate the rectilinear and lateral accelerations based on the position, compare these accelerations with ones of the accelerometer and compute the offsets [6]. When the signals of the satellites are available, the trajectory of route goes along the street (Fig. 12(a)), however when the signal is lost during the turn, the only data available is accelerometer data, so the trajectory goes the wrong way (Fig. 12(a), Fig. 13). We use the algorithm of the low-pass offset filtering to correct the measurements of the accelerometer. The last offset of the acceleration is used for correction of the accelerometer’s measurements for the corresponding axis. As a result, the route trajectory for accelerometer is similar to one of GRS-1 (Fig. 12(b)). The velocity and direction parameters are close to the results of GRS-1 as well.

To improve vehicle position tracking when navigation satellite signal is unavailable, it’s possible to use alternative devices, such as vehicle odometer, for distance and velocity measurements, and gyroscopes to measure changes of the direction. As a result, the position and movement parameters can be even more precise comparing to accelerometer’s parameters. However, this system still can’t be used separately, because of possible gyroscope biases, so the complex correction with navigation satellite data is required.

IV. CONCLUSIONS

We put into practice the different methods for position estimation [3] and accuracy improvement [4], [7] in our last researches. Results of our experiments for TOPCON GRS-1 show, that GRS-1 receiver has much higher accuracy parameters than other GPS receivers.

The accuracy of GRS-1 receiver is much affected by the road environment and the number of active satellites in spite of the corrections provided by the base station. The results of the experiments show, that GRS-1 can be used for the different velocities, and it is possible to test this receiver in dynamic mode, which will be our future GRS-1 testing aim.

The article demonstrates the possibility to estimate position parameters by using the accelerometer offset filtering, when satellite signal is temporarily unavailable.

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