Increasing positioning accuracy of moving objects using an adaptive algorithm based on diagnostic filtration

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Abstract: This article describes different filtering methods of navigation data that accessing optimization of navigation data. The adaptive algorithm, based on diagnostic filtration, of dropout redundant and erroneous data in real time mode is worked out. This algorithm can reduce the workload of transmission path significantly and increase usability of navigation system. An example of practical use in existing active system of monitoring city passenger transport is described.

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Introduction

Widely used global position systems, in our days, has a number of drawbacks. Low precision in the determination of object position and motion parameters is a particular issue. The problem of insufficient precision is partially caused by the owners of these systems who restrict the access for civilian use. There are also some other factors that affect the precision including errors of satellite navigation equipment, GPS/GLONASS receiver, and satellite signal propagation. In general, positioning precision of domestic GPS/GLONASS receivers is about 15 meters. The following reasons can be the source of errors [1, 2, 3]:

- insufficient number of visible satellites
- inaccuracy of ephemerides and errors of satellite clocks
- interference of echo signal from satellite receiver antenna
- interference caused by changing conditions of reception of signals from satellites (a drive through a tunnel, densely developed or wooded area)
- time delay in the receiver equipment
- problems related to navigation device power supply (for example, terminal power off or a strong interference from the power supply to the terminal equipment)
- ionospheric delay
- tropospheric delay

Positioning precision can be improved by using different algorithms of processing of received navigation data. Filtering of false and redundant data received from GPS/GLONASS module, part of a mobile terminal, is one of the possible ways to increase reliability and reduce the volume of the navigation information transmitted to the user [2].

Common glitches of satellite signals

The use of filtering in the systems of vehicle monitoring contributes to a significant reduction in the volume of information processed, while its precision is improved. Data filtering implies exclusion of redundant information not bringing any new changes in the position of the object, as well as elimination of glitches which lead to data corruption and interference in positioning.

Glitches stand for erroneous readings non-reflecting the real situation, which were obtained as a result of a technical error of the equipment part of the mobile terminal (MT) or an algorithmic error of GPS/GLONASS module [3].

We can distinguish several types of glitches:

Chaotic – glitches of such type can be observed in case of motion at low speed or standing/parking in one place for a short period of time. They appear due to interference of satellite signals reflected from tall buildings or other objects. Such errors appear on the map as a drift (irregular discrepancy) of assumed position.

Rough - occur in case of long-term parking of the vehicle in one place. Represent motion in a certain direction at a constant acceleration during a long period of time. Such errors can be recognized on the map by a characteristic instantaneous (rapid) jump from the latest assumed point of the object position of to its actual position; jump is accompanied by motion acceleration that goes beyond the edge of reason.

Systematic – this type of glitches is caused by changing conditions of reception of signals from satellites. Systematic glitches are characterized by a small deviation in one or several parameters, including the position coordinates. In contrast to chaotic glitches, the error in coordinates' definition is accompanied by a decrease in the inbuilt indicators of precision in the received navigation data.

Any type of glitches in the received navigation data decrease the precision of positioning and increase the delay of displaying the actual position of the object on the map, and has a negative impact on the calculation of the control indicators of the object motion (passed distance, average speed and parking duration, fuel consumption, etc.).

For example: satellite receiver of a fixed object reports the position coordinates randomly scattered in a radius of 20 - 30 meters. At that, navigational equipment treats them as motion, which gradually increases the mileage. As a result, in a few hours of parking the mileage is increased by 200 - 800 meters. (see Fig. 1).

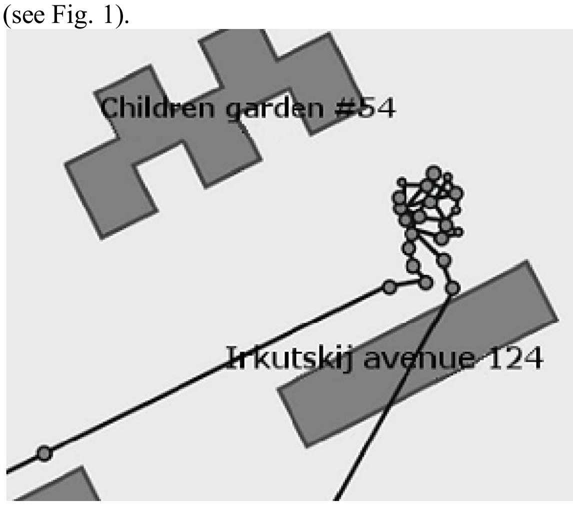


Figure 1. Example of glitches in navigation data from a fixed object

Filtration types

Filtering of navigation data is usually divided into *hardware filtering*, performed by GPS/GLONASS-receiver, and *software filtering*, realized by the software of the monitoring system [2 - 5]. Hardware filtering is an analysis of noise and distortion of signals from the satellites and their subsequent processing by a set of digital mathematical filters, specially designed by each manufacturer for his receiver. Software filtering of data can be executed by the software of the navigation device of the mobile object or the control system of the control center. The process of filtering is a final screening of navigation data obtained from the navigation module including:

- analysis of the registration of the sensors installed on the mobile object and the inbuilt factors of the loss of precision
- application of statistical algorithms of smoothing and other analytical methods.

The use sensors in the inertial monitoring systems help to avoid rough glitches, because getting satellite data from the navigation receiver is carried out only after activation of the sensors. It should be noted that some modern cars as well as the cars manufactured earlier are equipped with the necessary digital sensors (anti-lock braking system ABS) or do not support advanced communication protocols (CAN bus). [6]

Thus, inertial satellite monitoring systems are not applicable for some cars at all, do not consider chaotic and systematic glitches, and, when using this type of equipment the autonomy of the installation of the whole monitoring system is lost. Therefore, in order to ensure smooth operation of the mobile terminal, it is necessary to eliminate the use of sensors completely or take them only as an auxiliary tool for the mobile terminal.

Another solution to the problem of navigation data filtering is the application of statistical filtering methods, including mathematical algorithms of smoothing (Kalman filter, the method of least squares, 3 sigma rule, median filter), as well as criteria for identification of data glitches (Grubbs test, Chauvenet criterion, Pierce test, Dixon's Q test). [2, 4, 7, 8]

In case of little size of iterative glitches, use of statistical filtering methods can get high credibility in navigation data and high precision of determination of an object position.[9] In situation, when consecutive glitches forms some «pack», application of statistical smoothing methods for data processing is not reasonable, because data accuracy stay low. So, in this case, use of methods, that can screen error data, is needed.

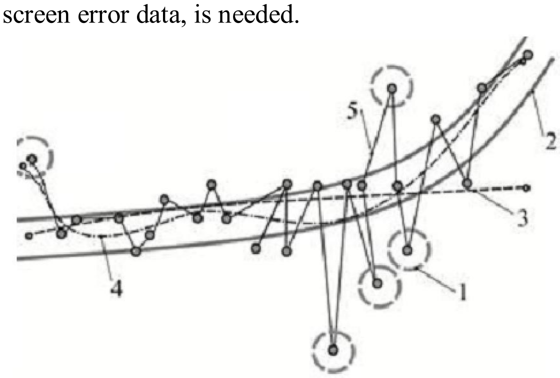


Figure 2. Data filtering statistical filtering methods (1 – glitches; 2 – sample road; 3 – linear smoothing; 4 - smoothing with five-degree polynomial; 5 – track of miobile object)

From Fig. 2 we can see low response of smoothing algorithm to glitches in data and these algorithm can't define errors in the end of experimental period. So, curved line (4) is moving to "glitches" side from real track.

Adaptive data proccessing

After analyzing the existing approaches to solving the problems of data filtering, it was decided to combine them and add so-called diagnostic methods. Proposed solution can be divided into 3 stages:

Preliminary screening

At this stage, filtering of data that is already erroneous at first glance is carried out. [10] The screening is performed on the following criteria:

- the number of visible satellites is less than the allowable value;
- positioning mode does not correspond to the selected mode;
- the data on status reliability indications is not valid;
- the values of inbuilt factors of positioning precision exceed the allowable values;
- the speed exceeds the maximum allowed for this type of mobile objects (for example, 300 km/h - for vehicles, 100 km/h - for ships);
- maximum instantaneous acceleration of motion (for example, 6 m^2/s - for vehicles, 3 m^2/s – for ships) can also be a feature of speed.

Diagnostic filtering

The distance between two points, which should not be less than the threshold value, is used as filtering criteria $Dlimit$.

It is shown graphically in Fig. 3.

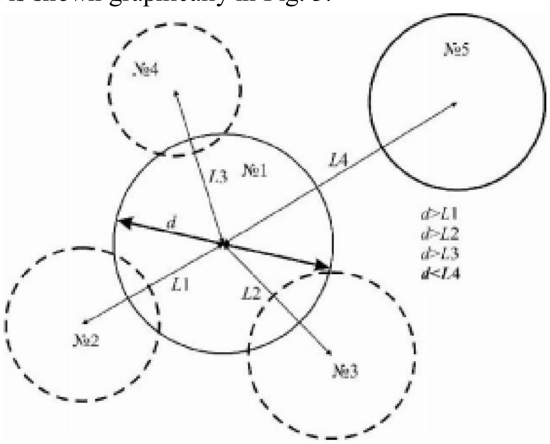


Figure 3. Illustration to the method of diagnostic filtering

The radius of circle or sphere (in case of using height) corresponds to threshold value $Dlimit$ and is calculated on the basis of positioning precision, which is dependent on the values of factors of loss of precision at the moment.

$$Dlimit = HDOP \cdot HFactor + VDOP \cdot VFactor,$$

where $HFactor$ and $VFactor$ are corresponding factors for *DOP* in meters, hereinafter referred to as factors.

It is impossible to recommend strictly defined factors, as positioning precision is dependent not only on the quality of satellite signals, but also on the type of receiver. In general, the range of recommended values can be defined as 7..15 meters for HDOP, and 10..25 meters for VDOP.

The data about current position (CP) undergo filtering on condition that their circumference does not cross circumference the circumference of the previous operating point (OP). In case filtering of this type is not performed, there will be a noise (messy spread around coordinates of the actual location) in addition to unnecessary data not bearing useful information. Let us consider characteristics of the studied mobile objects in details (Table 1), by the example of various vehicles, where: UPT 1,2 stand for urban passenger transport buses; OPC 1,2 – for official passenger cars; S_{day} – distance traveled per day, km; $V_{av.}$– average speed, km/h; V_{max}– maximum speed, km/h; $T_{av.park.}$– average duration of parking, min; $T_{mot.}$– duration of motion per day, hours; $Q_{parkings}$ – quantity of parkings longer than 5 minutes; $\bar{a}_{av.}$– average value of acceleration, m/s^2; $\bar{a}_{max}$ – maximum value of acceleration, m/s^2; $\bar{a}_{av.dec.}$ – average value of deceleration acceleration, m/s^2; $\bar{a}_{max\ dec.}$ – maximum value of deceleration acceleration, m/s^2.

TABLE I. CHARACTERISTICS OF THE STUDIED MOBILE OBJECTS

Object type	Sday	Vav.	Vmax	Tav.park.	Tmot.	Qparkings	āav.	āmax	āav.dec.	āmax dec.
UPT 1	190,3	25,4	70	2,06	11,1	8	0,16	1,16	0,17	1,12
UPT 2	241,4	22,6	66,1	1,94	13,4	5	0,11	0,94	0,12	1,18
OPC 1	85,28	43,1	72,5	82	5,3	8	0,31	1,58	0,26	1,95
OPC 2	46	31,5	92	110	3	6	0,33	1,65	0,27	2,1

Thus, from Table 1, it can be concluded that filtering of data for various types of mobile objects require individual selection of the algorithm parameters values (Table 2).

TABLE II. EXPERIMENTAL RESULT FOR DIFFERENT OBJECT PER DAY AND INDIVIDUAL CRITERIA VALUES

Object type	Observation period, days	Message frequency, per minute	Point count		Point count change, %	Mileage		Mileage decrease, %
			before filtering	after filtering		before filtering	after filtering	
UPT 1	14	6	78349	44972	42,6	3520	3468	1,5
UPT 2	6	6	32506	12157	62,6	1231	1217	1,1
OPC 1	9	6	3807	1439	62,2	466	451	3,2
OPC 2	1	60	23541	776	96,7	46	45	2,2

Data smoothing

The last stage of data processing is averaging of coordinates of the object on the basis of movement history using statistical methods. The reason for the application of smoothing procedure is the fact that the data obtained after preprocessing is of discontinuous character, although the real trajectory of the object is continuous and smooth. The procedure of smoothing helps to obtain realistic picture of motion trajectory, and calculate precise values of traveled distance. Weighted moving average, known as WMA in foreign literature, was chosen as a method of smoothing. Weighted moving average is generally defined as follows: $WMA_t = \frac{\sum_{i=1}^{n} P_i \cdot W_i}{\sum_{i=1}^{n} W_i}$,

where WMA_t is the value of the weighted moving average at the current point t, n is the number of values of the original function to calculate the moving average, and P_i is the value of the original function at the time distant from the current at i intervals.

The main advantage of the method of weighted moving average is the ease of its realization and its computational efficiency in comparison with digital filters.

An additional feature of this method improving positioning precision is the algorithm of assumed position search (APS). When for some reason there is no communication with the satellites, or the incoming data is not valid, the information about the object motion is lost. At that, the observed object remains at the point on the controller's map, where the last communication with the satellites was performed. The basis of APS algorithm is B-spline interpolation of the available points.

The data about the object position before the loss of communication with the satellites is selected as the interpolation points.

Conclusion

Thus, the method including a complex of algorithms to work with navigation data flow allowing to improve positioning precision and significantly reduce the amount of data transmitted is developed (Fig. 4).

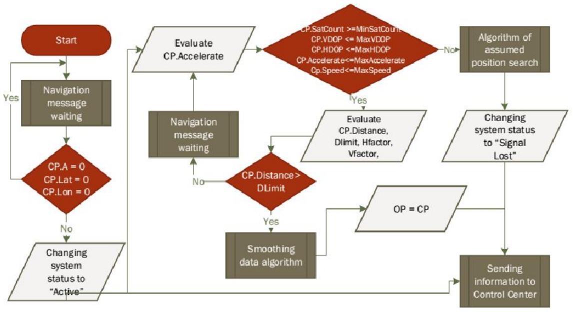
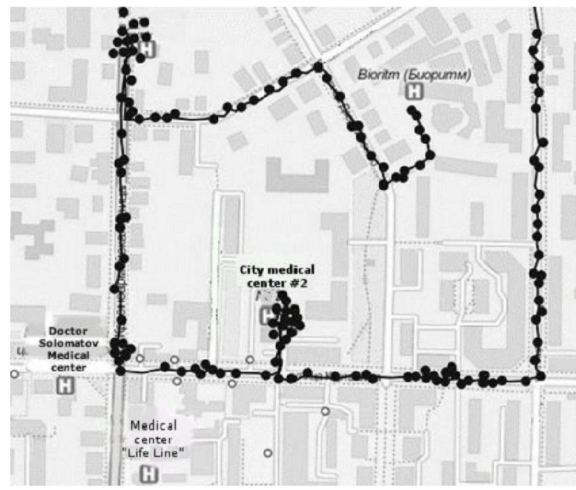


Figure 4. Common diagram of diagnostic filtering method

The main advantages of this method are:

- the possibility to introduce the algorithm in the moving object terminal software with the ability to work in an online mode
- the ease of implementation of the method (from the standpoint of the terminal equipment processing time), i.e. the possibility to use low-power and low-cost microcontrollers in the mobile terminal equipment
- a significant reduction in the flow of data transmitted to all types of observable objects, resulting in reduction of the load on the transmission channel between the control center and the mobile object (see Fig.5 and Table II)



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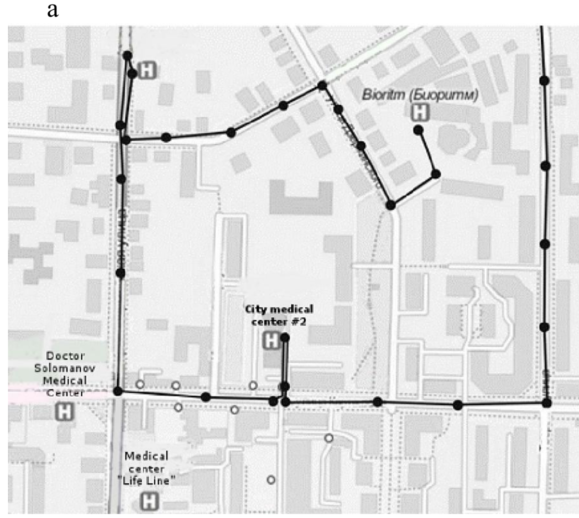

b

Figure 5. Example of usage adaptive method of filtering navigation data in monitoring system of city passenger (*a* – before use of filtering method, b– after use of filtering method)

- increase in the precision of positioning and derived parameters (path, speed, motion time, etc.) with the help of glitches filtering and smoothing of the motion path
- restoration of the route trail in case of absence of connection with the satellites

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References

1. Vladimirov, V.M., A.K. Grechkoseev and A.C. Tolstikov, 2004. The simulator of measurement information for working ephemeris-time support GLONASS satellite navigation system. Measuring equipment, 8: 12–14.
2. Koshaev, D.A., 2010. Multiple-choice method for the detection and assessment of disorders based on extended Kalman filter. Automation and Remote Control, 5: 70–83.
3. Klobuchar, J.A., 1996. Ionospheric effects on GPS. Global Positioning System: Theory and Applications. Washington DC.: American Institute of Aeronautics and Astronautics, 2, pp: 485–516.
4. Adrados, C., 2002. Global Positioning System (GPS) location accuracy improvement due to Selective Availability removal. Comptes Rendus Biologies. Elsevier, 325 (2), pp: 165-170.
5. Langley, R.B., 1999. Dilution of Precision. GPS World, 10 (5), pp: 52–59.
6. Ramani,R., S.Valarmathy, N.Suthanthira Vanitha, S. Selvaraju, M.Thiruppathi and R. Thangam, 2013. Vehicle Tracking and Locking System Based on GSM and GPS. IJISA, 5(9), pp: 86-93.
7. Brilingaite, A. and C. Jensen, 2006. Online Route Prediction for Automotive Applications. Proc. of the 13th World Congress and Exhibition on Intelligent Transport Systems and Services. London, pp: 168–175.
8. Guo, H., M. Yu, C. Zou and W. Huang, 2010. Kalman filtering for GPS magnetometer integrated navigation system. Advances in Space Research, 45 (11), p: 1350-1357.
9. Chen, H., Y. Chiang, F. Chang and H. Wang, 2010. Toward Real-Time Precise Point Positioning: Differential GPS Based on IGS Ultra Rapid Product. SICE Annual Conference, pp: 355 – 358.
10. Minni, R., 2013. A Cost Efficient Real-Time Vehicle Tracking System. International Journal of Computer Applications. New York: Foundation of Computer Science, 81(11), pp: 29-35.

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