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MAŠĪNZINĀTNE UN TRANSPORTS

INTELLIGENT TRANSPORT SYSTEMS
INTELEKTUĀLĀS TRANSPORTA SISTĒMAS

INDIKATORS OF THE EFFICIENCY OF AUTOMATIC VEHICLE LOCATION SYSTEMS

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One of the most actively developing spheres of applying modern information technologies is transport. Divisions of different services, departments and organizations are actively introducing and employing the system of Automatic Vehicle Location (AVL).

Currently we are watching only the accumulation of the world experience in applying for these purposes global radio navigation systems (GPS and GLONASS) and technologies based on these systems.

Most vital this issue happens to be for the aviation transport in the zone of airfields. The necessity of developing, testing and introducing the Advanced Surface Movement Guidance and Control Systems (A-SMGCS) on the territory of the airfield is conditioned by the complexity of the movement scheme of modern airfields, high movement intensity and low efficiency of the existing Movement Guidance and Control Systems.

It is obvious that the efficiency of employing transport means greatly depends on the efficiency of their informational support. All this explains the increased number of papers considering the methods of estimating the indicators of the efficiency of Automatic Vehicle Location Systems.

The main indicators of the efficiency of the mobile objects surveillance systems are characteristics of accuracy and reliability (integrity, availability and continuity of service).

The increased requirements to these systems' characteristics are achieved by means of employing the latest equipment and technologies and, particularly, the technologies of global satellite navigation systems (SNS), modern technologies of Self organizing Time Division

Multiple Access (STDMA) and Automatic Dependant Surveillance – Broadcasting (ADS-B) based on the above technologies.

In1998 they began testing and introducing such system for the airport “Riga” (RATMICS project). The aim of the project is to provide accurate positioning information for all transport means located in the system working zone independently from the meteorological and topographic conditions and with the required rate of the data renewal. Some experience in building and testing such systems for CNS/ATM (Communication, Navigation and Surveillance/Airspace and Traffic Management) was received in realizing the CARD (CNS Applications Research and Development) project developed under the aegis of SCAA (Swedish Civil Aviation Administration). The main research performed in the frame of this project is devoted to evaluating the characteristics of the data transmission line. In the frame of the RATMICS project there were carried out works on developing the methods of estimating the efficiency indicators of A-SMGCS (Riga airport) based on the differential satellite radio navigation system and on the experimental estimation of the accuracy characteristics of the subsystem elements. Since there has been no definition of final requirements to such systems in the form of quantitative ICAO indicators by now, approximate indicators from draft protocols have been taken as the basis:

- integrity indicator should not be lower than $2\cdot10$-5 ;
- errors of determining vehicles’ location $2\sigma r \leq 3$m;
- errors of determining movement direction $2\sigma k \leq 2$ degrees;
- errors of determining movement velocity $2\sigma w \leq 5$ knots;
- resolution ability should not be less than 1.5 m.

The first step in developing the methods of estimating the efficiency indicators of и A-SMGCS Riga airport should apparently be the analysis of errors of navigation – time determinations (NTD) of the satellite radio navigation system (SRNS).

The navigation task to be solved in the user’s equipment (UE) SRNS, in its simplest case, lies in defining space – time coordinates $\boldsymbol{P(t)} = |x; y; z; W|^T$. In the latest samples of UE there is adopted a two stage procedure of processing information. At the stage of primary procession they perform those measurements of navigation parameters (distance - D, speed of distance change - $\dot{D}$, etc.), which are only functionally connected with the state vector ***P(t).*** At the stage of secondary procession the received parameters are subjected to transformation based on navigation algorithms with the purpose of calculating vector ***P(t).***

The accuracy of determining by the SRNS user the location coordinates (x;y;z), the speed (W) and other parameters is influenced by many factors. They are connected with the peculiarities of primary and secondary navigation measurements, with the characteristics of the used signals and the media of propagation. To facilitate the influence of different factors on the NTD quality at the primary stage of processing they introduce UERE (User Equivalent Range Error) and speed of its change UERRE (User Equivalent Range Rate Error), conditioned by the non-correlated constituents of measurement errors. Secondary navigation definitions are easily characterized with help of geometric factors indicated as various DOP (Dilution of Precision).

Consider the main sources of these measurements’ errors in application to the adopted in GPS and GLONASS long distance method NTD /1/. The expression of the measured distance to the i- satellite *Di* in this case will look as follows:

$$\boldsymbol{D}_{\mathbf{i}} = \boldsymbol{D}_{\mathbf{0i}} + \boldsymbol{\delta D}_{\mathbf{NS}} + \boldsymbol{\delta D}_{\mathbf{RL}} + \boldsymbol{\delta D}_{\mathbf{UE}} ,$$

where D_{0i} – true value of the distance to the i- satellite; δD_{NS} – errors introduced in navigation satellites (NS) and control measuring set (CMS); δD_{RL} – errors introduced in the radio line "NS - user"; δD_{UE} – errors introduced by UE SRNS.

Errors introduced in NS and CMS (**δD_{NS}**) are conditioned mainly by the insufficient frequency – temporal and ephemerae support of NS.

- *Errors of the frequency – temporal support* are caused mainly by insufficient procedures of verifying and storing the board time scale (board clock – BC) of NS. For typical caesium board frequency patterns the given errors between the correction moments may be approximated as follows /2,3/

$$\sigma^2(t) = 2{,}5 \cdot 10^{-21}\,(t-t_c) + 5{,}76\;10^{-26}\,(t-t_c)^2 ,\quad \text{where}$$

t – current time; t_c – time of correction BC.
CMS SRNS is correcting the BC in such a way that $\sigma(t)$ of the BC shift would not exceed 10nc. Besides, in the intervals between the apparatus corrections, the algorithmic correction of the BC of the given satellite is performed in UE. And here the unpredictable deviations of the BC of the given satellite in relation to the Time System Scale may reach 1nc (0.3 m) in one hour interval.

- *Errors of the ephemerae support* are caused by inaccurate definitions of orbit parameters NS in CMS and unpredictable shifts of NS in relation to the extra polar orbit. In SRNS GPS the average quadrant value of the ephemerae constituents UERE makes up about 1m /4/.

Errors introduced in the radio line «NS – user» *(δD_{RL})* are caused by insufficient knowledge of the ways of radio waves propagation in the Earth’s atmosphere (refraction of the satellite signals in the ionosphere and the troposphere).

- *Troposphere errors.*

Judging by the experimental data for SRNS GPS additional delays of the NS signal in the troposphere may reach 8…80nc /4/. For average meteorological conditions (temperature, pressure, air humidity) the value of this delay is defined by the expression:

$$\Delta t_{TR} \approx \frac{K_T}{\sin\beta} \cdot \int_0^{S_T} (n-1)\,dS \qquad ,$$

where K_T – parameter characterising the condition of the troposphere; β - angle of the NS place;

n – coefficient of the radio waves refraction; S_T – length of the troposphere line sector.

Troposphere models used in SRNS allow to reduce the troposphere errors up to nanosecond units. In compensating the troposphere refraction, the periodicity of the user corrections is determined by the speed of the corresponding delays’ change, which in normal circumstances does not exceed 10 m/h.

- *Ionosphere errors.*

The additional delay in the ionosphere Δt_{ion} of signal SRNS GPS with frequency – f may be estimated as

$$\Delta t_{ion} = \frac{A}{f^2} ,$$

where A – the coefficient characterising the features of the propagation media. The value of this delay changes widely depending on the Earth region where the mobile object is located, the time of the day, the season of the year, the Solar and the geomagnetic activities, etc., and makes up 5…500ns /6/. The average value of Δt_{ion} for GPS makes up 5…10ns at night and 30…50ns in daytime for the angles of place β reaching 90^0. At $\beta < 15^0$ this delay increases by 2…3 times.

- *Errors caused by the pass variety (multi pass).*

These errors are mainly dependent on the mutual location of the satellite, the receiving antenna and the reflecting objects. Experimental research has shown wide range of values of the long distance errors due to the rays variety, which makes up the best 0,5…2m (using special antennas) and up to 100m the worst in urban high buildings conditions. In most unfavourable conditions failure of surveillance can be incurred.

Errors introduced by UE SRNS (δD_{UE}) are caused by errors in the surveillance at the moment of the satellite signal incoming. Typical error of UE makes up about 1,5…10m – for the standard SRNS GPS accuracy code.

Differential SRNS work mode. The analysis of errors of primary navigation parameters estimation using SRNS has shown that their summarising value ($2\sigma_D$) can reach 100 m and exceeds the limits of acceptable values adopted for mobile objects on the territory of the airfield. Substantial reduction of NTD errors (by up to ten times) can be possible by using the differential SRNS work mode. The basis of the differential method is relative stability of the considerable part of the SRNS error in time and space. The main slightly varying errors of defining distance in SRNS are /7,8/:

- errors in NS synchronisation;
- errors caused by the faulty ephemerae support of NS;
- *non-compensated ionosphere errors.*

Errors in NS synchronisation are constant in space and quite stable in the considered temporal intervals. Fluctuation of board clock NS by about 10^{-14} or 10^{-13} in the time of up to 15 min results in distance errors from 3 mm to 3 sm.

The error effect of the ephemerae information (ξ_i) can be characterised by the following model:

$$\xi_i < \frac{Ld_i}{D_i}, \quad \text{where}$$

d_i, m – error of the i - NS ephemerae (typical d_i value for SRNS GPS makes up 10 m); L, km - UE distance from the control point.

Calculations on this model show that space variation of distance measurement errors caused by insufficient ephemerae information is not substantial and at $d_i = 10$ m and $L <$ 200 km does not exceed 10sm and $L <$ 1000 km - $\xi_i < 50$ sm. It is worth noting that with the data about the satellites constellation "aging" the errors of the ephemerae (di) also increase and, therefore, ξ_i increases.

Variation of ionosphere errors in time and space are characterised by the correlation function, which has times and space correlation radiuses at the level corresponding to several house and thousands kilometres /6/. Therefore, in the interval of several minute and in the range of one thousand kilometres ionosphere errors may be considered quite stable. There is some knowledge of the experimental data of the temporal fluctuations of distance (D_i) errors caused by ionosphere /7/. Thus, in 1 min variation made up 0,1…0,2m (σ), and in 6 min – 0,3…1,4m.

Differential work mode of SRNS makes it possible to define and compensate the above errors. At the same time the main sources of errors in evaluating distances are noise constituents of UE, which in measuring curving delays make up metres and in measuring carrying delays – centimetres and even millimetres. Another feasible source of errors is the property of multi pass.

Geometric factor in SRNS

Calculating the user's space – temporal coordinates is performed at the second stage of processing the NS signals. The ratio between the vector of errors in defining space – time coordinates ***P(t)*** $\delta_M = | \delta_x \delta_y \delta_z \delta_{\dot{D}} |^T$ and the vector of errors in measuring distances $\delta_M = | \delta_{D1} \delta_{D2} \delta_{D3} \delta_{D4} |^T$ depends on the geometry of the corresponding location of NS and the user. Due to some special peculiarities of the NS and the user's space locations, the measure of decreasing the accuracy of navigational definitions in SRNS is the geometric coefficient GDOP (Geometric Dilution of Precision). The most important characteristic of SRNS is the precision of place location, therefore for a surface mobile object the Horizontal Dilution of Precision (HDOP) is more often used

$$HDOP = \frac{\sqrt{\sigma_x^2 + \sigma_y^2}}{\sigma_D}.$$

The orbital configuration characteristics of satellites SRNS GPS provide, with the probability of 0.999 plus, the field of vision in a global working zone in any 24 hour interval of four satellites plus, the average value of HDOP making up 1.5 /4/. Increasing the number of visible satellites makes it possible to achieve a good gain in the accuracy of evaluating navigational parameters.

Reliability of navigational – temporal definitions

Besides accuracy properties of SRNS we should also regard reliability indicators of NTD as the indicators of efficiency of SRNS functioning. The main characteristic of reliability – system integrity – is defined as the ability to detect inadmissible system performance deterioration with the preset probability and time lag of informing the users thereabout /5/.

The variety of factors affecting the SRNS integrity has a different impact on the radio navigational parameters to be evaluated. Therefore the integrity control (for SRNS it will be a faulty satellite) should be exercised in all possible ways. That is why the problem of integrity control and developing algorithms and methods of detecting different types of failures are of great practical value.

The analysis of errors in determining mobile objects locations with the help of the satellite radio navigational system has become the basis for the methods of estimating the efficiency of the surveying subsystem A-SMGCS of "RIGA" airport.

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A.Mročko, J.Sikeržickis. Transportlīdzekļu atrašanās vietas noteikšanas sistēmas efektivitātes rādītāji
Kustīgo objektu atrašanās automātiskās noteikšanas sistēmas risina transporta līdzekļu vadības un kontroles uzdevumu. Mūsdienu informatīvo tehnoloģiju pielietošana izmantojot navigācijas satelītu sistēmas padara kustīgo objektu vadību par vienkāršu un efektīvu. Tādu sistēmu efektivitātes rādītāju analīze būtiski samazina to izmēģinājuma un ieviešanas darbu veikšanas termiņus konkrētajā reģionā.

A.Mrochko, J.Sikerzhicky. Indicators of the efficiency of Automatic Vehicle Location Systems
The systems of Automatic Vehicle Location (AVL) solve the task of controlling and guiding transport means. Employing modern information technologies along with satellite navigation systems facilitates and improves controlling mobile objects. Analysis of these systems efficiency indicators sufficiently reduces the periods of their testing and introducing in a particular region.

А.Мрочко, Ю.Сикержицкий. Показатели эффективности систем определения местоположения транспортных средств
Системы автоматического определения местоположения подвижных объектов (AVL) рещают задачу по контролю и управлению транспортными средствами. Применение современных информационных технологий с использованием спутниковых систем навигации делает управление подвижными объектами более простым и эффективным. Анализ показателей эффективности таких систем существенно сокращает сроки проведения работ по их испытанию и внедрению в конкретном регионе.