STRUCTURE OF NAVIGATION MESSAGES OF COMMERCIAL VESSEL

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ABSTRACT

The analysis of the main existing modern systems of navigation support is carried out. The article is devoted to an analytical review of the structure of the navigation message of modern navigation systems, namely GLONASS. The structure of the GLONASS navigation message has been determined. The analysis of the composition and placement of operational information in the frame of the navigation message as well as the structure and placement of non-operational information (almanac) in the frame of the GLONASS navigation message.

Keywords: Navigation Systems; Errors; GPS; GLONASS; Positioning; Commercial Operation of a Vessel; Sea Transport; International Transport; Logistics.

INTRODUCTION

Traditional means of navigation are not sufficiently accurate to provide the required reliability and accuracy, are not sufficiently automated and cannot eliminate the influence of the human factor. Global Navigation Satellite System (GNSS) will become the main navigation aids of the future. Currently, two GNSSs are deployed- GPS (Global Positioning System) NAVSTAR (Navigation Satellite Time And Ranging), owned by the United States, and the Russian Global Navigation Satellite System GLONASS.

The Global Navigation Satellite System (GNSS), as the navigation element of CNS/ATM air traffic control systems, includes combinations of the following components located on the ground, satellites and on board an aircraft: GPS; GLONASS; Onboard functional augmentation

Citation Information: Maranov, A., Zahorodnia, Y., Pozdniakova, V., Temerbek, A., Danylenko, O., Lysyy, A., & Smyrnova, I. (2021). Structure of navigation messages of commercial vessel. *Journal of Management Information and Decision Sciences, 24*(1), 1-9.

system (AVAS); Satellite augmentation system (SBAS); Ground-based augmentation system (GVAS); and Onboard GNSS receiver.

Functional augmentation systems improve accuracy to units and fractions of a centimeter (Iasechko, et al., 2019a; Syrotenko, et al., 2019; Turinskyi, et al., (2019a).

The purpose of the article is to provide an analytical survey of the structure of navigation of current navigation systems, and GLONASS itself.

METHODOLOGY

The articles focus on security communication system properties for providing navigation information to everyone type of vessel, the need for a detailed analysis is to target each type of vessel. It is necessary to identify the specifics of their intended purpose with subsequent analysis to complete the main groups of characteristics.

The articles are a comparative method of the real system time taking into account the standards and recommendations of the European Positioning System (EUPOS).

FINDINGS AND DISCUSSION

The navigation message contains operational and non-operational information. Operational information (Table 1) refers to the space agency from which this navigation radio signal is transmitted and contains:

Digitization of time stamps of the navigation spacecraft;

Shift of the time scale of the navigation spacecraft relative to the time scale of the GLONASS system;

The relative difference of the carrier frequency of the emitted navigation radio signal from the nominal value; Space agency ephemeris.

TABLE 1
COMPOSITION, STRUCTURE AND PLACEMENT OF OPERATIONAL INFORMATION IN THE FRAME OF THE GLONASS NAVIGATION MESSAGE

Information word	Number of digits	Least significant bit price	Range of values	Unit of measurement	Line number in the frame	Digit numbers in a line
M	4	1	0…15	Dimensionless	1…15	81-84
tk	5	1	0…23	Hour	1	65-76
	6	1	0…59	Min		
	1	30	0 ; 30	Sec		
tb	7	15	15..1425	Min	2	70-76
M (1)	2	1	0 ; 1	Dimensionless	4	9-10
γn(tb)	11	2-40	± 2-30	Dimensionless	3	69-79
τn(tb)	22	2-30	±2-9	sec	4	59-80
xn(tb), yn(tb), zn(tb)	27	2-11	± 2,7*10-4	km	1, 2, 3	9-35
xn(tb), yn(tb), zn(tb)	24	2-20	± 4,3	km/s	1, 2, 3	41-64
xn(tb), yn(tb), zn(tb)	5	2-30	± 6,2*10-9	km/s^2	1, 2, 3	36-40
Bn	3	1	0…7	dimensionless	2	78-80
P (1)	1	1	0 ; 1	dimensionless	3	66

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NT	11	1	0…2048	day	4	16-26
FT (1)	4		1…512	m	4	30-33
n (1)	5	1	0…31	dimensionless	4	11-15
Δ τn	5	± 2-30	± 13,97*10-9	sec	4	54-58
En	5	1	0…31	day	4	49-53
P1	2		0…60	min	1	77-78
P2	1	1	0 ;1	dimensionless	2	77
P3	1	1	0 .1	dimensionless	3	80
P4 (1)	1	1	0 .1	dimensionless	4	34
ln (1)	1	1	0 .1	dimensionless	3,5,7,9, 11,13,15	65

Source: Oduan & Guinot, 2002; Lipkin, 2006; Afraimovich, 2006; Koshelev & Sinyakin, 2009.

Non-operational information (Table 2) contains the system almanac, which includes:

Data on the state of all navigation spacecraft of the system (state almanac);

The shift of the time scale of each navigation spacecraft relative to the time scale of the GLONASS system (phase almanac);

Orbital parameters of all systems (orbital almanac);

Shift of the time scale of the GLONASS system relative to UTC (SU).

TABLE 2
COMPOSITION, STRUCTURE AND PLACEMENT OF NON-OPERATIONAL INFORMATION (ALMANAC) IN THE FRAME OF THE GLONASS NAVIGATION MESSAGE

Information Word	Number of digits	Least significant bit price	Range of values	Unit of measurement	Line number in the frame	Digit numbers in a line
τc (1) (2) (3)(4)	28	2-27	± 1	Day	5	38-69(4)
τGPS (1) (2)	22	2-30	± 1,9*10-3	Day	5	32-36
N4 (1)	5	1	0-31	4-Year interval	5	10-31
NA	11	1	1…1461	Day	5	70-80
nA	5	1	1…24	Dimensionless	6,8,10,12,14	73-77
HnA (3)	5	1	1…31	Dimensionless	7,9,11,13,15	10-14
λnA (2)	21	2-20	± 1	Half cycle	6,8,10,12,14	42-62
t λnA	21	2-5	0…44100	Day	7,9,11,13,15	44-64
ΔinA (2)	18	2-20	± 0,067	Half cycle	6,8,10,12,14	24-41
ΔTnA (2)	22	2-9	± 3,6*10-3	Scroll	7,9,11,13,15	22-43
ΔTnA (2)	7	2-14	± 2-8	Scroll 2	7,9,11,13,15	15-21
εnA	15	2-20	0…0,03	Dimensionless	6,8,10,12,14	9-23
ωnA (2)	16	2-15	± 1	Half cycle	7,9,11,13,15	65-80
MnA (1)	2	1	0,1	Dimensionless	6,8,10,12,14	78-79
B1 (1) (2)	11	2-10	± 0,9	Day	74	70-80
B2 (1) (2)	10	2-16	(-4,5…3,5)* 10-3	s/ss	74	60-69
KP (1)	2	1	0,1	Dimensionless	74	58-59
τnA	10	2-18	± 1,9*10-3	Day	6,8,10,12,14	63-72
CnA	1	1	0…1	Dimensionless	6,8,10,12,14	80

Source: Syrotenko et al., 2019); Turinskyi et al., 2019a; Iasechko et al., 2019a; Turinskyi et al., 2019b.

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The GLONASS navigation message is hierarchically structured in the form of lines, frames and superframes (Table 3).

The navigation message line has duration of 2 sec (together with a timestamp) and contains 85 binary characters transmitted in relative code. The first character is blank for relative code (Oduan & Guinot, 2002; Golikov, 2004; Koshelev, 2010; Sotnikov et al., 2019; Iasechko et al., 2019d; Iasechko et al., 2019b; Syrotenko et al., 2019; Turinskyi et al., 2019a; Iasechko et al., 2019a; Iasechko et al., 2020).

The last eight characters on each line are Hamming check characters, allowing you to correct a single character error and detect two characters in error in the line. The system almanac is necessary for the consumer's equipment to schedule a session, i.e. selection of the optimal constellation and prediction of the Doppler carrier frequency shift for its constituent navigation spacecraft. The absence of the system almanac in the memory of the consumer's receiver leads to a significant increase in the duration of the session, due to the time spent on searching for signals and determining the optimal constellation. Nevertheless, the structure of the GLONASS navigation signal provides a faster update (or initial reception) of the almanac due to the shorter duration of superframes (2.5 min) compared to GPS (12.5 min) (Iasechko, 2019c; Iasechko & Sotnikov, 2019; Iasechko et al., 2019a; Syrotenko et al., 2019; Turinskyi et al., 2019a).

Operational information is used directly in the navigation session. Time-frequency corrections are made to the measurement results, and the ephemeris are used to determine the coordinates and the velocity vector of the consumer.

The frame has duration of 30 sec and consists of 15 lines of 2 sec duration each. It contains the full amount of operational information for the emitting navigation spacecraft (lines 1 ... 4) and a quarter of the almanac. In frames one through four, the almanac is transmitted for five satellites, in the fifth frame for the remaining four. The almanac for each satellite occupies two lines.

TABLE 3
STRUCTURE OF THE GLONASS NAVIGATION MESSAGE

Frame number in superframe	Line number in the frame	Type of information			
I	1	0	Operational information for the transmitting navigation spacecraft	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	3	0		Hamming code	Time stamp
	4	0	Non-operational information (almanac) for the navigation spacecraft No. 1-5	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	15	0		Hamming code	Time stamp
II	1	0	Operational information for the transmitting navigation spacecraft	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	3	0		Hamming code	Time stamp
	4	0	Non-operational information (almanac) for the navigation spacecraft No. 6-10	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	15	0		Hamming code	Time stamp

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III	1	0	Operational information for the transmitting navigation spacecraft	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	3	0		Hamming code	Time stamp
	4	0	Non-operational information (almanac) for the navigation spacecraft No. 11-15	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	15	0		Hamming code	Time stamp
IV	1	0	Operational information for the transmitting navigation spacecraft	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	3	0		Hamming code	Time stamp
IV	4	0	Non-operational information (almanac) for the navigation spacecraft No. 16-20	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	15	0		Hamming code	Time stamp
V	1	0	Operational information for the transmitting navigation spacecraft	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	3	0		Hamming code	Time stamp
	4	0	Non-operational information (almanac) for the navigation spacecraft No. 21-24 reserve	Hamming code	Time stamp
	…	0		Hamming code	Time stamp
	14	0		Hamming code	Time stamp
	15	0	Reserve	Hamming code	timestamp

Source: Oduan & Guinot, 2002; Lipkin, 2006; Afraimovich, 2006; Koshelev & Sinyakin, 2009.

The superframe contains 5 frames and lasts 2.5 min. Within a superframe, the live information and line 5 (system data) are repeated in every frame. The boundaries of lines, frames and superframes of various navigation spacecraft are synchronous with an error of no more than 2 ms.

Content of operational information words:

m - line number in the navigation frame;

t_k - frame start time within the current day, determined in the onboard time scale;

t_b - the ordinal number of the time interval within the current day according to the GLONASS system time scale, to the middle of which the operational information transmitted in the frame belongs;

M - modification of the navigation spacecraft emitting a signal ("00" - GLONASS, "01" - GLONASS - M);

$\gamma_n(t_b)$ - relative deviation of the satellite carrier frequency n from the nominal value at the moment in time;

$$t_b\ .\gamma_n(t_b) = (f_n(t_b) - f_{\text{нп}})/f_{\text{нп}}(\text{г}_{\text{де}} f_n(t_b) \qquad (1)$$

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Predicted value of the satellite carrier frequency n, taking into account gravitational and relativistic effects at a time t_b , $f_{нn}$ - nominal carrier frequency of the n^{th} satellite).

The nominal carrier frequencies of the navigation spacecraft in the L1, L2 subbands are determined by the expressions:

$$f_{K1} = f_{01} + K\Delta f_1, f_{K2} = f_{02} + K\Delta f_2 , f_{K2}/f_v = 7/9 \quad (2)$$

$$f_{01} = 1602{,}0 \text{ M}Hz, \Delta f_1 = 0{,}5625 \text{ M}Hz, f_{02} = 1246{,}0 \text{ M}Hz \quad (3)$$

$$\Delta f_2 = 0{,}4375 \text{ M}Hz \quad (4)$$

Where K= (-7, …,13)- carrier frequency numbers), the distribution of K numbers between the navigation spacecraft is displayed in the almanac.

The deviation of the carrier frequency from the nominal value does not exceed in relative value $\pm 2*10^{-11}$);

$\tau_n(t_b)$ - point in time shift t_b time scales (t_n) satellite n relative to the time scale (t_c) системы.

$\tau_n(t_b)= t_c(t_b)-t_n(t_b)$;

$x_n(t_b)$, $y_n(t_b)$, $z_n(t_b)$ - coordinates of satellite n in the PZ-90 coordinate system at the time t_b;

$x_n(t_b)$, $y_n(t_b)$, $z_n(t_b)$ - components of the satellite velocity vector n in the PZ-90 coordinate system at the time t_b ;

$x_n(t_b)$, $y_n(t_b)$, $z_n(t_b)$ - components of the acceleration of the satellite n in the PZ-90 coordinate system at the time t_b , due to the action of the moon and the sun;

B_n - sign of unreliability of the satellite n frame (the symbol "1" in the most significant bit denotes the unsuitability of this satellite for navigation determinations);

P - indication of the mode of operation of the navigation spacecraft based on time-frequency information. (at P=1 time-frequency information is calculated on board the navigation spacecraft, at P=0 it is calculated and loaded on board) ;

N_T - calendar number of a day within a four-year interval, starting with a leap year;

F_T - measurement accuracy factor characterizing the data set error at a point in time t_b, emitted in the navigation message;

n - number of the navigation spacecraft emitting this navigation signal;

$\Delta\tau_n$ - offset of the navigation radio signal of the L2 subband relative to the navigation radio signal of the L1 subband, emitted by the satellite n.

$\Delta\tau_n= t_{f2} - t_{f1}$ (where t_{f1} , t_{f2} - hardware delays of the corresponding subbands);

E_n - time interval between the calculation (tab) of operational information for satellite n and the moment in time t_b (characterizes the age of operational information);

P1 - sign of the value of the time interval (min) between the values t_b in this and previous frames;

P2 - odd (character "1") or even ("0") sign of the numerical value of a word t_b;

P3 - a sign showing that the almanac is transmitted in the frame for 5 satellite (symbol "1") or 4 navigation spacecraft ("0");

P4 - a sign showing that updated (symbol "1") ephemeris or time-frequency information is transmitted in this frame;

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l_n - sign of unreliability (l_n =1) satellite frame n. This navigation spacecraft is not suitable for navigation definitions.

(1) - planned to be included in the navigation message GLONASS - M;
(2) - the most significant bit is signed (character 0 corresponds to the sign "+");
(3) - negative carrier frequency (word values 25 to 31);
(4) - it is supposed to reduce the price of the least significant bit to 2-31 sec (to 0,46 ns), increasing the number of bits to 32. The word will be transmitted in the 5th, 20th, 35th, 50th and 65th lines of the superframe (5th line of each frame).

The content of the words of the almanac (non-operational information):
τ_c - correction to the time scale of the GLONASS system relative to UTS (SU). The amendment is given at the beginning of the day with the number N^A;
τ_{GPS} - correction for discrepancy between GPS and GLONASS time scales N4 - number of a four-year period (N_4 =0, since 1996);
N^A - calendar number of a day within a four-year period, starting with a leap year;
n^A - conventional satellite number in the system;
H_n^A - number of the carrier frequency of the radio signal emitted by the satellite n^A;
λ_n^A - longitude in the PZ-90 coordinate system of the first ascending node of the satellite orbit n^A within a day N^A;
t λ_n^A - transit time of the first ascending node of the satellite orbit n^A within a day N^A;
Δi_n^A - correction to mean satellite inclination n^A на момент времени $t\lambda_n^A$ (the mean orbital inclination is assumed to be 63°);
ΔT_n^A - correction to the mean value of the draconic satellite orbital period n^A at time $t\lambda_n^A$ (the average value of the draconian period is taken to be 43200 sec);
ΔT_n^A - the rate of change of the draconic period of rotation of the satellite with the number n^A;
ε_n^A - satellite orbital eccentricity n^A at time t λ_n^A ;
ω_n^A - satellite orbit perigee argument n^A at time t λ_n^A ;
M_n^A - satellite modification sign n^A ("00" - GLONASS, "01" - GLONASS - M);
B1 - coefficient for determining ΔUT1, equal to the value of the discrepancy between UTC and UTC at the beginning of the current day;
B2 - coefficient for determining ΔUT1, equal to the value of the daily change in the discrepancy ΔUT1;
KP - sign of the expected second correction of the UTS scale at the end of the current quarter by an amount of ± 1 sec. ("00" - there will be no correction, "01" - there will be a correction + 1s, "11" - there will be a correction of -1 sec);
τ_n^A - coarse satellite time offset n^A relative to the time scale of the system at the moment of time t λ_n^A ;
C_n^A - generalized satellite condition indicator n^A ("0" - the satellite is not suitable for navigation definitions, "1" - the satellite is suitable) (Golikov, 2004; Afraimovich, 2006; Lipkin, 2006; Koshelev & Sinyakin, 2009; Koshelev, 2010; Iasechko et al., 2019a; Syrotenko et al., 2019; Turinskyi et al., 2019a,b; Iasechko et al., 2020)

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CONCLUSION

Thus, the article provides an analytical review of the structure of the navigation message of modern navigation systems, namely GLONASS. The structure of the GLONASS navigation message has been determined. The analysis of the composition and placement of operational information in the frame of the navigation message, as well as the structure and placement of non-operational information (almanac) in the frame of the GLONASS navigation message.

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