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THE SATELLITE SYSTEMS APPLICATIONS TO AUTOMATE NAVIGATION IN THE COASTAL ZONE

ABSTRACT

The methods of automatic pilotage along a guided path are well known in the practice of navigation. However these methods have a number of drawbacks, which reduce the effectiveness of their application. It is especially important for river-sea vessel in poor visibility. Because of the large inertia of the vessel and its hydrodynamic properties that are changed by external influences, the process has unstable oscillatory nature. Therefore the vessel moves not in a straight line, but on a winding curve having the general direction that corresponds to the specified value. In this paper new method of coastal navigation with invented new devices supported with satellite navigation receiver is presented.

Keywords:
satellite navigation system, automate navigation, coastal navigation.

INTRODUCTION

The methods of automatic pilotage along a guided path are well known in the practice of navigation, e.g. the use of an autopilot and the Electronic Chart Display and Information System [Smirnov et al., 1988; Vaguschenko, 2003; Katenin and Boykov, 2011a; Katenin and Boykov, 2011b]. Unfortunately the mentioned methods have a number of drawbacks, which reduce the effectiveness of their application. For example, in the cases under consideration the assigned path is put into an autopilot as the coordinates of the initial, intermediate and final (route) points, i.e. rectilinear segments of the indicated path, taken from a navigation chart.

If a vessel deviates from the assigned direction or if a lateral deviation of the vessel exceeds the set up calculated value, a steering impact is given to the steering gear to reset the vessel on the present course. Due to a considerable inertia of the vessel and the influence of her hydrodynamic properties, which change under external effects, such a process possesses an unstable oscillatory character, in the result of which the vessel moves along not a straight but an intricate curvy line with the general direction which corresponds to the assigned one.

Besides, nowadays the direction to a buoy is defined by the watch officer of the moving vessel with the help of an optical direction finder and consequently in poor hydro-meteorological conditions (low visibility). The use of a direction finder to take a bearing on a buoy presents difficulty or is impossible. Taking bearings from a vessel underway on a buoy by sight is unacceptable, because their input into an autopilot is to be carried out manually, and this does not provide the automation of navigation along a Guided Path of Motion (GPM).

We suggest a new method of coastal zone navigation automation, which is based on the application of:

- modernized buoys;
- receiver of global navigation satellite system;
- devices for requesting, releasing and receiving information to identify the requested buoy.

THEORETICAL FOUNDATIONS

Figure 1 presents the method of vessels automatic pilotage along a guided path using satellite technologies. A buoy which is established at a waypoint on a guided path of motion is *additionally* equipped with GNSS receiver and a device for releasing at the vessel’s request the information about its number and continuously taken coordinates. Apart from the satellite receiver a device for requesting and receiving the number and the coordinates of the requested buoy is installed on the vessel underway. The observation of the buoy’s location as well as the identification of the ship’s position coordinates are carried out simultaneously.

At the vessel's request (via communication channel) position of the buoy, its number and other identification characteristics are transmitted to the vessel, where the solution of the reverse geodesic task is automatically carried out. As a result the definition of the direction to the buoy and the distance to it are obtained. Since a buoy is constantly effected by external forces (wind, swell) it 'sheers away' — deviates from the initial point of set up, which causes the necessity to timely introduce corrections into the originally assigned direction with the consideration of the vessel's transfer.

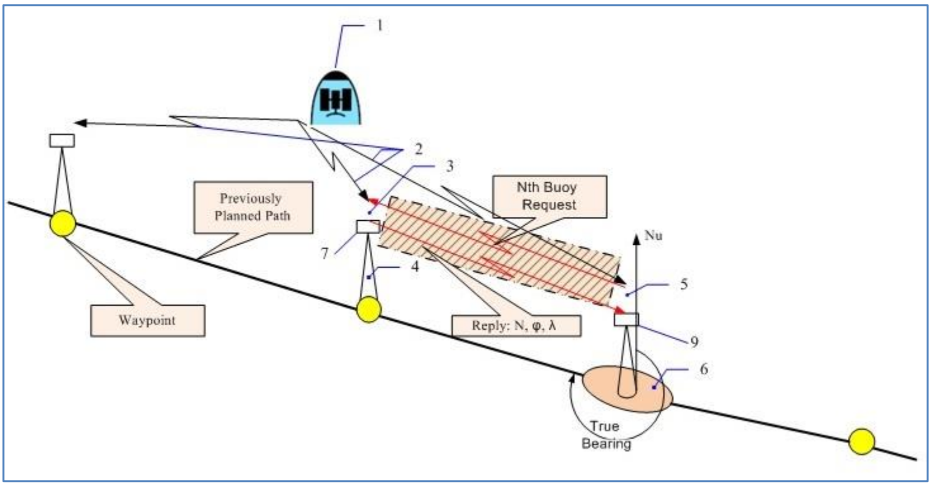

Fig. 1. Method of the vessel's automatic pilotage along Guided Path of Motion with the use of sat navigation receiver

On the Figure 1: marked number 1 is a space vehicle of a navigation system, 2 are signals of Sat nav SV, 3 — sat nav receiver installed on the buoy, 4 — buoy established at a waypoint, 5 — sat nav receiver installed on the vessel, 6 — vessel, 7 — automatic device for receiving and transmitting navigation information via radio channel, 8 — radio channel, 9 — technical device for identification the bearing and distance from the vessel to the buoy

Modernized sea buoys, apart from standard facilities and power supply sources, are *additionally* equipped with sat-nav receiver as well as a device for releasing at a request by radio channel of the identification number and the coordinates of the buoy. At that their outputs are connected with the input of the buoy's electric supply unit and the output of sat nav receiver is connected with the input of the device for the release at the request by radio channel of the identification number and the observed coordinates of the buoy.

Figure 2 presents a modified buoy established at way point. Such buoys are established in the coastal sea zone along the vessel’s motion guided path — axially.

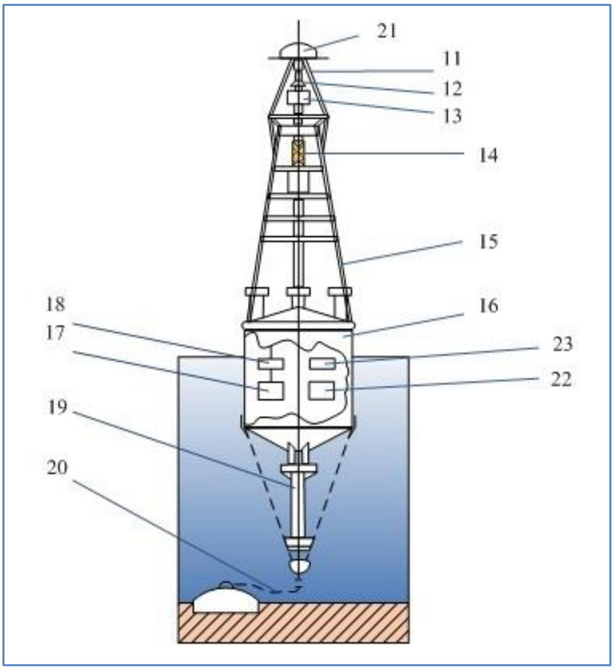

Fig. 2. Modified Sea Buoy

On the Figure 2: marked number 11 is a top marks holder, 12 — light-optical device, 13 — electric equipment, 14 — passive radar reflector, 15 — superstructure of the buoy, 16 — hull, 17 — direct current source, 18 — the device of connecting this direct current source for discharge to the light-optical device, 19 — shank, 20 — anchor gear, 21 — combined antenna, 22 — automatic device for receiving and transmitting navigational information, 23 — antenna switch.

General schema of the device for receiving and transmitting navigational information from a buoy to a vessel is presented in Figure 3.

On the Figure 3: marked number 2 is navigational information from satellite, 3 — sat nav receiver, 7 — Automatic Device for Receiving and Transmitting Navigational Information on radio channel, 17 — direct current source, 23 — antenna switch, 24 — receiver, 25 — coding device, 26 — operational memory device, 27 — transmitter. In turn the diagram of a ship’s technical device for automatic identification of a bearing from a vessel on a buoy is shown in Figure 4, on which 5 — sat nav receiver installed on the vessel, 9 — Automatic Device for Receiving and Transmitting Navigational Information on radio channel, 28 — computer, 29 — combined antenna, installed on ship, 30 — request device, 31 — ship's transmitter, 32 — ship's antenna switch, 33 — ship's receiver, 34 — ship's coding (decoding) device, 35 — control unit, 36 — electronic chart display and information system (ECDIS), 37 — gyrocompass, 38 — ship's log, 39 – autopilot, TC — true course.

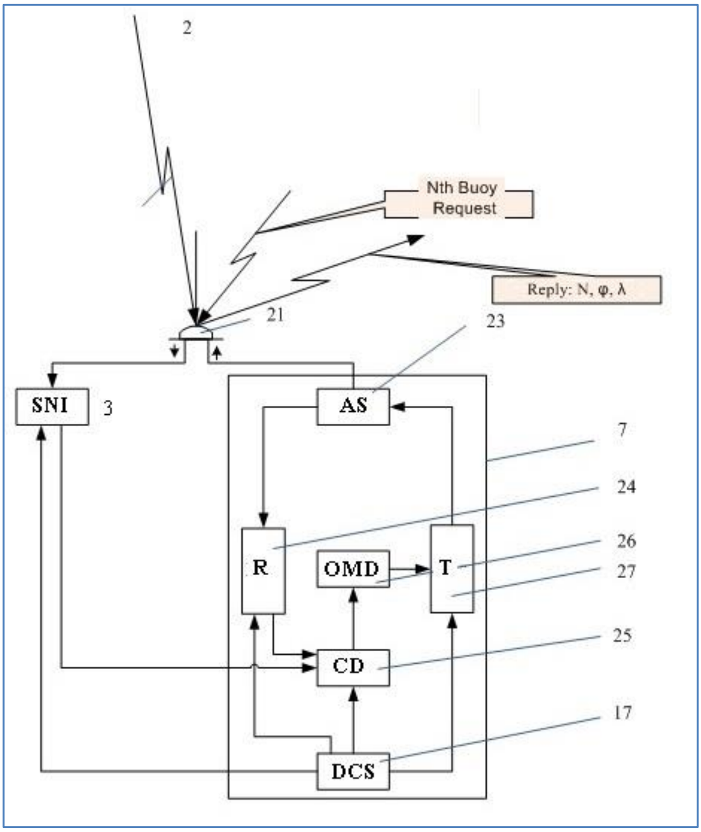

Fig. 3. Diagram of Buoy Device for Receiving and Transmitting Navigational Information

Satellite technologies of automatic pilotage of vessels along GPM function as follows. In the process of the vessel's transfer along GPM in accordance with the guiding signals generated in the control unit (7) a simultaneous identification of the vessel’s position coordinates and the buoy is carried out by sat nav receiver (3) and buoy (9) accordingly.

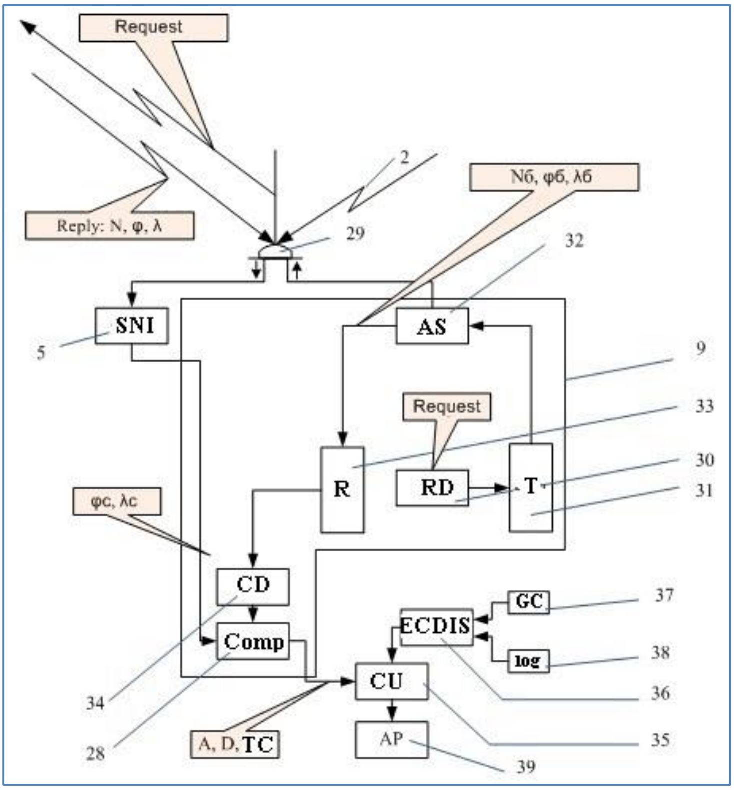

Fig. 4. Technical Device for Identifying a Bearing from a Vessel

The identification number of the buoy and its observed coordinates which are received on the vessel by device (18) via radio channel and transmitted by device (17), enter the input of the technical device for the identification of bearing A on buoy from the vessel in accordance with the following formulas [Gruzdiev et al. 1992]:

$$A = A_S + \Delta A; \tag{1}$$

$$D = D_S + \Delta D, \tag{2}$$

where:

A_S and D_S — orthodromic azimuth (for the Earth — sphere) between a vessel and a buoy;

ΔA and ΔD — correction factors for the conversion of orthodromic values into geodesic ones.

Values of A_S and D_S are calculated according to formulas of spherical trigonometry:

$$A_S = \arctan\left[\frac{sin\Delta\lambda}{tg\varphi_2 cos\varphi_1 - sin\varphi_1 cos\Delta\lambda}\right]; \quad (3)$$

$$D_S = \arccos(sin\varphi_1 sin\varphi_2 + cos\varphi_1 cos\varphi_2 cos\Delta\lambda), \quad (4)$$

where:

φ_1, λ_1 and φ_2, λ_2 — coordinates of antennas od sat nav receivers installed on vessel and buoy accordingly.

Correction factors ΔA and ΔD are calculated according to Lambert formulas:

$$\Delta A = 5{,}762[(1 + D_S^o arc1^o ctgD_S)cos^2\varphi_1 sin2A_S] - D_S arc1^o sin2\varphi_1 sinA_S; \quad (5)$$

$$\Delta D = 1{,}443\left[\frac{3sinD_S - D_S^o arc1^o}{cos^2\left({}^{D_S}/_2\right)}(sin\varphi_1 + sin\varphi_2)(sin\varphi_1 + sin\varphi_2)^2 - \frac{3sinD_S + D_S^o arc1^o}{sin^2\left(\frac{D_S}{2}\right)}(sin\varphi_1 - sin\varphi_2)\right]. \quad (6)$$

Here the correction factors ΔA and ΔD are expressed in the minutes of arc. Since one minute of arc of the sphere with the radius a = 6378245 m is equal to 1855, 3563 m and a nautical mile is equal to 1852 m, the distance in nautical miles is:

$$D = 1{,}0018122(60D^o + \Delta D, \quad (7)$$

The value of correction factor ΔA at distances up to 6000 miles, as a rule, does not exceed 9–32’, so it may be neglected.

The value of the calculated azimuth A is a path angle (*PA*) from the vessel — 1 to the buoy — 9. To assign a true course (*TC*) to the steering gear of the vessel — 1 in the autopilot on the basis of the data received from technical devices 2, 3, 4, 5, 6 it is necessary to carry out its calculation according to the formula [6]:

$$TC = PA - S, \tag{8}$$

where:
S — a total sway of the vessel resulting from drift and current.

It is determined by continuous satellite observations unit for releasing at request of the identification number and the coordinates of buoy as well as unit for requesting and receiving the identification number and the coordinates of a buoy.

SATELLITE LEADING LINE OPTION

The suggested method may be also extended for setting up satellite leading lines. For this purpose one sat nav receiver must be installed on the front shore leading line and the second one must be installed on the receiving buoy, marking the beginning of the leading line axis, recommended route, channel or fairway. The procedure of a vessel's approaching the receiving buoy does not differ from the one described above. The line, connecting the receiver on the shore leading line mark and the receiving buoy, determines the direction of the satellite leading line. After a vessel arrives at the point, where the receiving buoy is established, the vessel sets the course which corresponds to the direction of the satellite leading line.

The **Satellite Leading Line** (SLL) is a combination of a traditional visual leading line, the front leading line mark of which has an additionally installed sat nav receiver transmitting at the vessel's request its identification number and exact coordinates of the front leading line mark, which have been defined in advance by geodesic methods, as well as of the receiving point (21) equipped with a sat nav receiver (22).

The receiving buoy established at the initial point of the leading line at the shore (port) approach, serves as a floating navigational AtoN, on which a bearing from a vessel is taken when plotting it on the axis of the leading line formed by two receivers. The process of the vessel sailing along a satellite leading line principally does not differ from her sailing along GPM.

On the Figure 5: marked number 2 is navigational information from satellite, 5 — sat nav receiver installed on the vessel (6), 41 — receiving buoy and 42 — Automatic Device for Receiving and Transmitting Navigational Information on radio channel installed on the buoy (41).

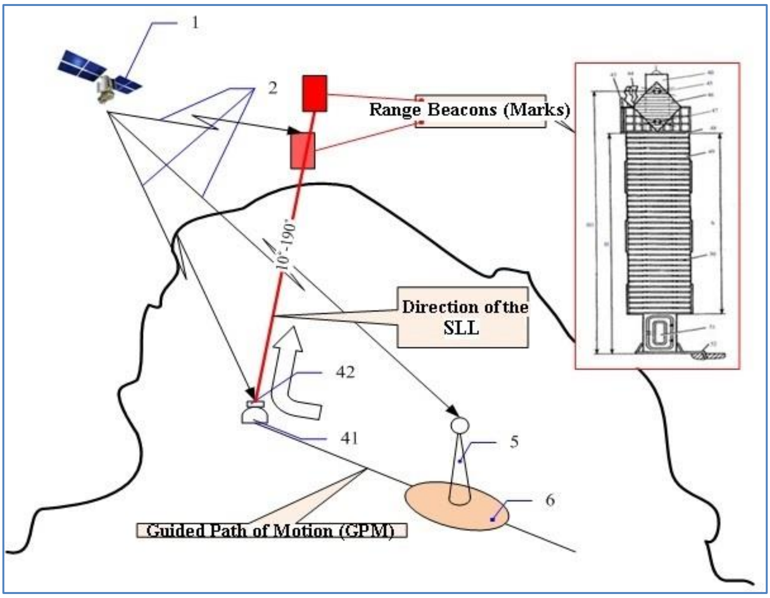

Fig. 5. Satellite Leading Lines

CONCLUSIONS

Such satellite technologies provide automatic safe pilotage of vessels from the point of departure to the point of destination in any conditions with enhanced accuracy within the shortest time. Their technical and economic efficiency is manifested in:

- the provision of automatic pilotage of a vessel along a guided path of motion, including poor hydro-meteorological conditions, with an enhanced accuracy due to the elimination of the error in the buoy location in relation to its anchor, resulting from the buoy drift under the summing action of the wind and the current;
- the decrease of the negative influence of the human factor on making control decisions;
- the decrease in the number of established means of the buoyage system along a transportation route;
- the financial economy in the result of navigation along an optimal path, which minimizes the fuel expenses and the time required for the vessel's transfer from one point to another.

Some possible variant of implementing the suggested technology for the port of Nakhodka in the Far East is presented in Figure 6.

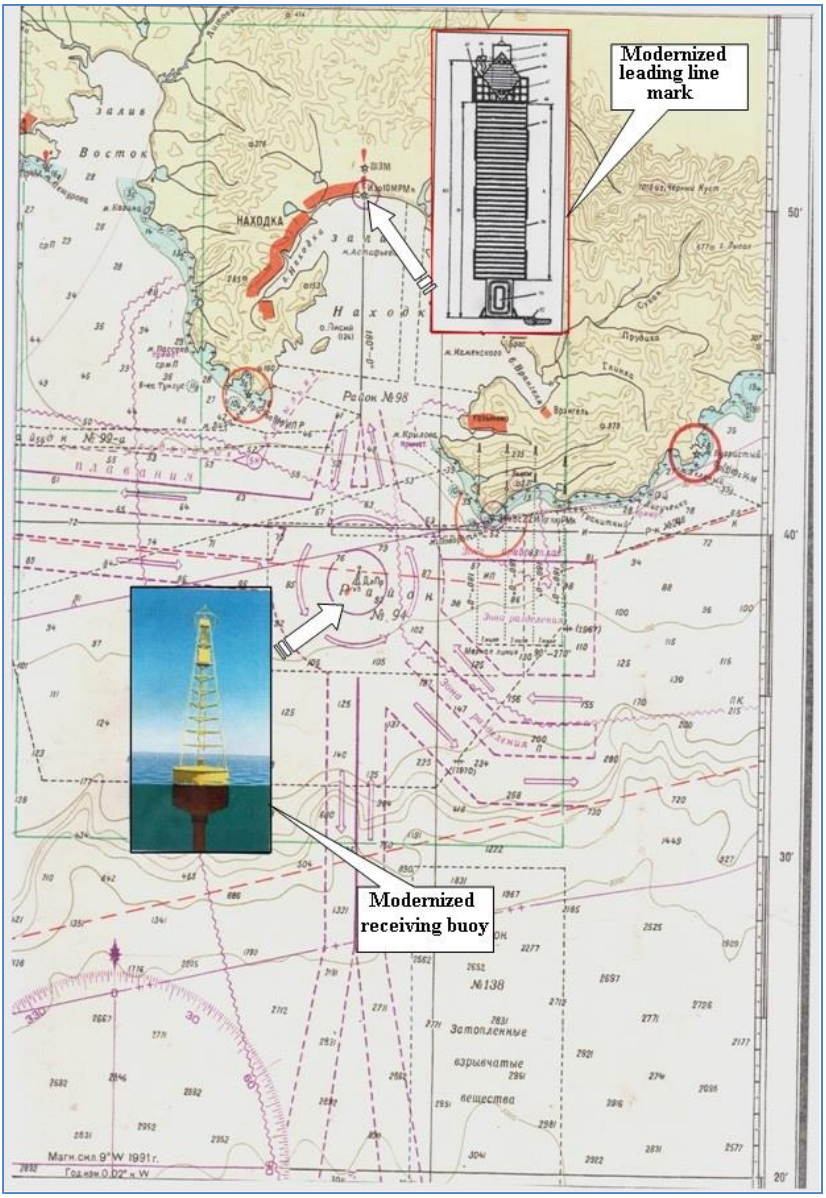

Fig. 6. A possible variant of implementing the suggested technology for the port of Nakhodka in the Far East

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STRESZCZENIE

Metody automatycznego prowadzenia statku po zadanej trasie są powszechnie znane i szeroko stosowane w praktyce. Mają one jednak kilka niedogodności, które częściowo ograniczają ich efektywność. Jest to istotne zwłaszcza dla statków morsko-rzecznych w warunkach ograniczonej widzialności. Z powodu dużej bezwładności statku, a także szczególnych własności hydrodynamicznych, które zmieniają się pod wpływem czynników zewnętrznych, proces ten nie jest stabilny i ma charakter oscylacyjny. W efekcie statek nie porusza się po linii prostej, lecz myszkuje, utrzymując tylko w przybliżeniu

założony kurs. W niniejszym artykule przedstawiono nową metodę żeglugi w strefie brzegowej wraz z propozycją specjalnej aparatury do tego celu, opartej na nawigacji satelitarnej.