



INCREASING THE ACCURACY AND RELIABILITY OF A DYNAMIC POSITIONING LASER SYSTEM

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Introduction. Large number of vessels such as Oil and Gas Platform Supply / Support Vessels (PSV), Offshore Supply / Support Vessels (OSV), Diving Support Vessels (DSV), Remote Controlled Vessels (RSV), Rigging Vessels, Storage Vessels, Cable Layers and cable repair vessels, pipe layers, dredgers, floating cranes, semi-submersible heavy-lift vessels, mobile offshore drilling rigs, shuttle tankers, floating mining, storage and unloading units, passenger and military ships use a dynamic positioning system to maintain a given position of the vessel with great precision. The DGPS satellite navigation system and laser optical system are used as meters for such systems [1] – [5]. The satellite navigation system has a root-mean-square error of position measurement $\sigma = \pm 3\text{m}$. A laser optical system is used for high positioning accuracy [6] – [7]. The laser unit rotates around the vertical axis, emitting a beam with an opening angle of 12° at an angle θ^* to the horizon, which is reflected from reflectors, installed on objects around the vessel, and returns back to the unit. The angle of the position of the laser unit and the delay time of the beam are used to determine the bearing and distance to the reflectors [8]. The root-mean-square error of bearing measurement is $\sigma = \pm 0.5^\circ$, and range $\sigma = \pm 0.5\text{m}$. The disadvantage of the laser optical system is the degradation and even loss of the signal during strong roll and pitching, which, due to the specifics of the vessels on which this system is installed, can lead to unpleasant consequences, environmental disaster and even human casualties. The authors carried out a full-scale experiment onboard the ESNAAD 225 vessel, which confirms the degradation of quality and loss of the signal during a strong roll. The result of the experiment is shown in Fig. 1.

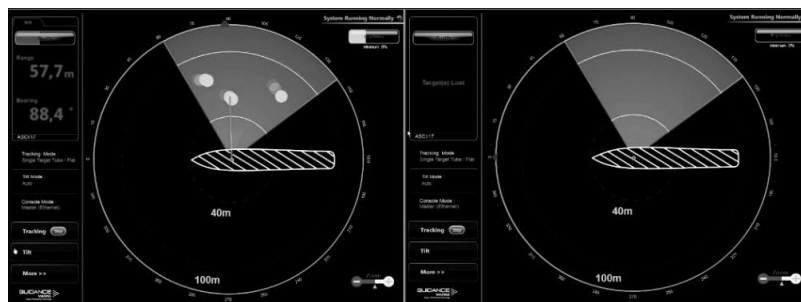


Figure 1. Screen of the CyScan laser system

The relevance of research. As follows from the above, improving the accuracy and reliability of a laser optical dynamic positioning system under conditions of strong pitching and rolling is an urgent scientific and technical problem.

Formulation of the problem. It is required to improve the accuracy and reliability of the laser optical system under conditions of strong pitching and rolling by

continuously measuring the angular position of the vessel relative to the reflector and taking into account the measured angular position to aim the optical axis of the laser unit to the center of the reflector.

Results of researches. Fig. 2 shows a diagram of aiming the laser unit at the center of the reflector.

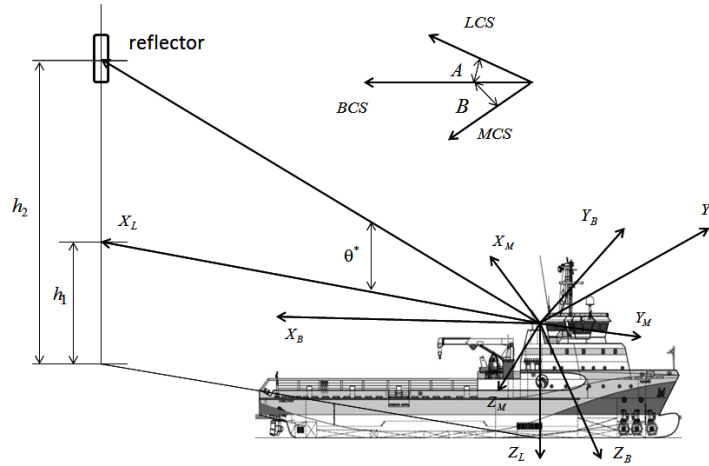


Figure 2. Scheme of aiming the laser unit at the center of the reflector

The coordinate system $X_L Y_L Z_L$ (LCS) is located in the center of the laser unit and is linked to the reflector. The axis X_L lies in the horizontal plane and is directed towards the reflector. The axis Y_L is perpendicular to the axis X_L , lies in the horizontal plane and is directed to the right. The axis Z_L complements the system $X_L Y_L Z_L$ to the "right" one. The coordinate system $X_B Y_B Z_B$ (BCS) is located at the center of the laser unit and is linked to the vessel. The axis X_B lies in the center plane of the vessel parallel to the deck and is directed towards the stern, the axis Y_B is perpendicular to the axis X_B and directed to the right. The axis Z_B complements the system $X_B Y_B Z_B$ to the "right" one. The coordinate system $X_M Y_M Z_M$ (MCS) is located at the center of the laser unit and is linked to the laser unit. The axis X_M is directed along the optical axis of the laser unit towards the radiation. The axis Y_M is perpendicular to the axis X_M , parallel to the deck of the vessel and directed to the right. The axis Z_M complements the system $X_M Y_M Z_M$ to the "right" one. The schematically described coordinate systems are shown in Fig. 2. Table 1 shows the direction cosines of the transition between LCS and BCS.

Table 1.

Transition matrix A between LCS and BCS

A	X_L	Y_L	Z_L
X_B	$\cos \theta \cos \psi$	$\cos \theta \sin \psi$	$-\sin \theta$
Y_B	$\sin \varphi \sin \theta \cos \psi -$ $\cos \varphi \sin \psi$	$\sin \varphi \sin \theta \sin \psi +$ $\cos \varphi \cos \psi$	$\sin \varphi \cos \theta$
Z_B	$\sin \varphi \sin \psi +$ $\cos \varphi \sin \theta \cos \psi$	$\cos \varphi \sin \theta \sin \psi -$ $\sin \varphi \cos \psi$	$\cos \varphi \cos \theta$



where φ is the roll angle, ψ is yaw angle relative to the direction to the reflector, θ is the pitch angle of the vessel.

Table 2 shows the transition matrix B between BCS and MCS

Table 2.

The transition matrix B between BCS and MCS

B	X_B	Y_B	Z_B
X_M	$\cos \theta_m \cos \psi_m$	$\cos \theta_m \sin \psi_m$	$-\sin \theta_m$
Y_M	$-\sin \psi_m$	$\cos \psi_m$	0
Z_M	$\sin \theta_m \cos \psi_m$	$\sin \theta_m \sin \psi_m$	$\cos \theta_m$

where ψ_m, θ_m are the angles that determine the position of the optical axis in BCS.

The unit vector specifying the direction to the center of the reflector in the LCS coordinate system has the form (see Fig. 2).

$$\mathbf{e}^{LCS} = (\cos \theta^*, 0, -\sin \theta^*),$$

$$\theta^* = \arcsin\left(\frac{h_2 - h_1}{D_m}\right),$$

where h_1, h_2 is the height of the laser unit and the center of the reflector at sea level, D_m is the measured distance from the laser unit to the center of the reflector.

The unit vector specifying the direction to the center of the reflector, in the BCS coordinate system, has the form

$$\begin{aligned} e_x^{BCS} &= \cos \theta^* \cos \theta \cos \psi + \sin \theta^* \sin \theta, \\ e_y^{BCS} &= \cos \theta^* (\sin \varphi \sin \theta \cos \psi - \cos \varphi \sin \psi) - \sin \theta^* (\sin \varphi \cos \theta), \\ e_z^{BCS} &= \cos \theta^* (\sin \varphi \sin \psi + \cos \varphi \sin \theta \cos \psi) - \sin \theta^* (\cos \varphi \cos \theta). \end{aligned} \quad (1)$$

The unit vector specifying the direction of the optical axis in the MCS coordinate system has the form

$$\mathbf{e}^{MCS} = (1, 0, 0).$$

The unit vector specifying the direction of the optical axis, in the BCS coordinate system, has the form

$$\mathbf{e}^{BCS} = (\cos \theta_m \cos \psi_m, \cos \theta_m \sin \psi_m, -\sin \theta_m). \quad (2)$$

To determine the required elevation θ_m of the optical axis, we equate the projections on the axis Z_B of the unit vectors that specifying the direction of the optical axis from (2) and the required direction to the center of the reflector from (1)

$$-\sin \theta_m = \cos \theta^* (\sin \varphi \sin \psi + \cos \varphi \sin \theta \cos \psi) - \sin \theta^* (\cos \varphi \cos \theta). \quad (3)$$

From the equation (3), we find the angle θ_m which specifying the required elevation of the optical axis at the moment the beam passes the reflector to aim at the center of the reflector

$$\theta_m = \arcsin(\sin \theta^* \cos \varphi \cos \theta - \cos \theta^* (\sin \varphi \sin \psi + \cos \varphi \sin \theta \cos \psi)). \quad (4)$$



Fig 3, 4 show the results of mathematical modeling in the MATLAB environment of the optical axis aiming processes at the center of the reflector with strong pitching and rolling in the form of time variation graphs of the longitudinal speed V_x of the vessel, lateral speed V_y , longitudinal displacement X_g , lateral displacement Y_g , roll rate ω_x , roll angle φ , pitch rate ω_y , pitch angle θ , yaw rate ω_z , yaw angle ψ , bearing to the platform P_m , distance to the platform D_m , angles that determine the current position of the optical axis in BCS (tetCyScan), (psiCyScan) and optical axis deviations from the direction to the center of reflection in vertical plane dtet and horizontal plane dpsi.

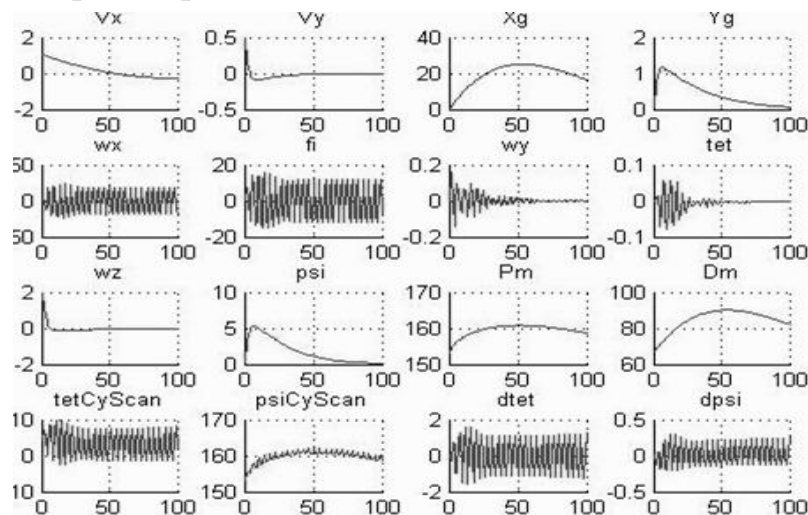


Figure 3. Results of mathematical modeling of the optical axis aiming processes at the center of the reflector with strong pitching

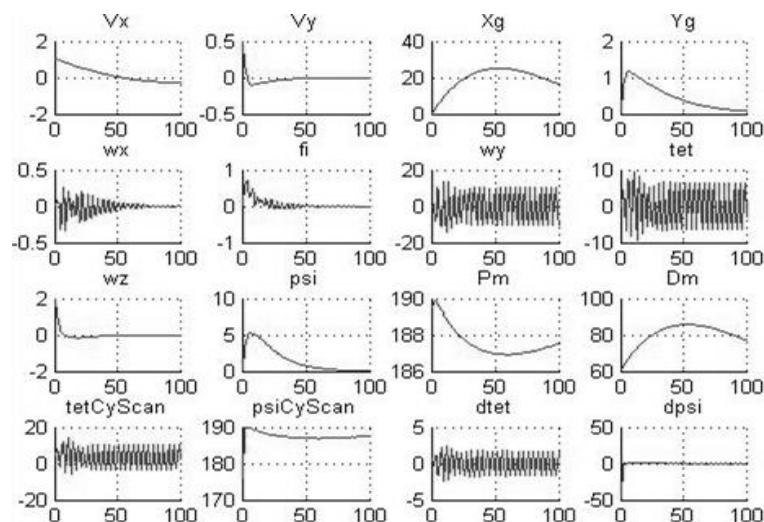


Figure 4. Results of mathematical modeling of the optical axis aiming processes at the center of the reflector with strong rolling

As can be seen from the presented results, despite the more difficult conditions created by mathematical modeling, namely, the presence of an initial longitudinal speed $V_x(0) = 2kn$, initial lateral speed $V_y(0) = 1kn$, initial yaw rate $\omega_z(0) = 2^\circ/\text{sec}$, angles of deviation of the optical axis from the center of reflection in the vertical plane



$|dtet| < 2^\circ$, which is approximately six times less than the beam width in the vertical plane (12°).

Conclusions. The following tasks were solved in the work:

- a full-scale experiment was carried out onboard the ESNAAD 225 vessel, confirming the degradation of the quality and even loss of the signal by the laser system during strong pitching and rolling;
- the reasons of the degradation and even loss of the signal of the laser system during strong pitching and rolling were revealed;
- developed a method and algorithms for automatic aiming of the laser system beam to the center of the reflector;
- the operability and efficiency of the method and algorithms are verified by mathematical modeling in the MATLAB environment;
- the simulation results showed that automatic aiming of the beam to the center of the reflector can significantly improve the quality of the reflected signal, including in conditions of strong pitching and rolling, increase the reliability of the system and reduce the risk of an unfavorable situation;
- automatic aiming of the beam at the center of the reflector allows you to reduce the minimum and increase the maximum distance of operations.

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