UDC 004.942:656.61.052

AUTOMATIC BEAM CONTROL OF LASER-OPTICAL POSITION REFERENCE SYSTEM

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АВТОМАТИЧНА СИСТЕМА КЕРУВАННЯ ЛАЗЕРНО-ОПТИЧНОЮ СИСТЕМОЮ ПОЗИЦІОНУВАННЯ

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АВТОМАТИЧЕСКАЯ СИСТЕМА УПРАВЛЕНИЯ ЛАЗЕРНО-ОПТИЧЕСКОЙ СИСТЕМОЙ ПОЗИЦИОНИРОВАНИЯ

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The dynamic positioning system (DPS) is an automated control system using an onboard computer that automatically maintains the required position and course of the vessel [1–3]. DPS can work with both global (GPS) and local (laser optical system) information systems. GPS provides information about the geographical coordinates of the vessel's location and the laser optical system provides information about the vessel's position relative to the landmark by measuring the bearing and distance to the landmark [4–5].

The laser optical system takes the second place in the list of installed reference systems, because it is characterized by accuracy, low cost, reliability and ease of use, which meets the requirements of the International Maritime Organization, International Association of Marine Contractor and Det Norske Veritas Germanischer Lloyd [6–11].

One of the disadvantages of such a system is the loss of signal due to shading of the reflector by an object or contamination of the lens. Such problems are easily solved by correctly installing the reflector (in the line of sight), cleaning the lens from dirt, etc. [12–13]. A more significant disadvantage of the laser optical system, which leads to the weakening and even disappearance of the signal is the deviation of the optical axis outside the reflector, especially in conditions of pitching and resonant rolling, due to the limited beam width of 12–18 degrees in the vertical plane [14–16].

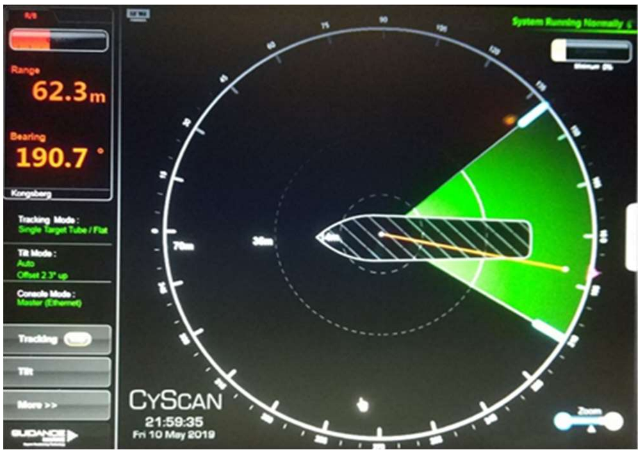
The authors conducted an experiment with a CyScan laser optical system installed on the platform supply vessel (DP-2) “ESNAAD 225” and a reflector mounted on a Jack-Up type platform.

The experimental results are presented in Fig. 1.

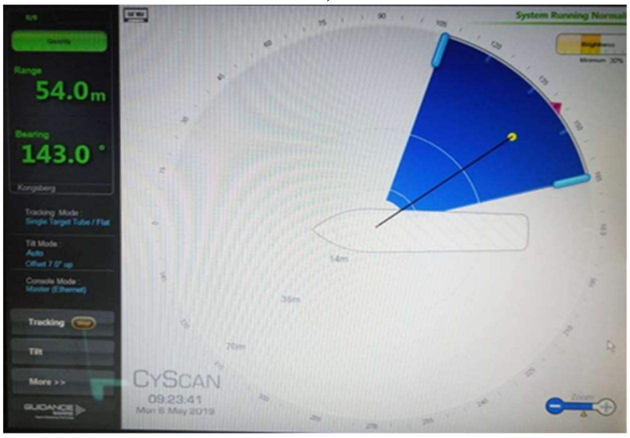
Fig. 1a) shows a CyScan screen without disturbances. Distance to the reflector 62.3 m, bearing to the reflector 190.7°, scanning mode a single reflecting tube, angle beam tilt 2.3° up.

Fig. 1b) shows a CyScan screen for the same conditions as in the previous experiment but in the presence of pitching. Pitching amplitude is 6º–9º, pitching period is 3–4 sec. As can be seen from the Fig. 1b), the CyScan signal is unstable, the quality and brightness of reflection is low.

a)

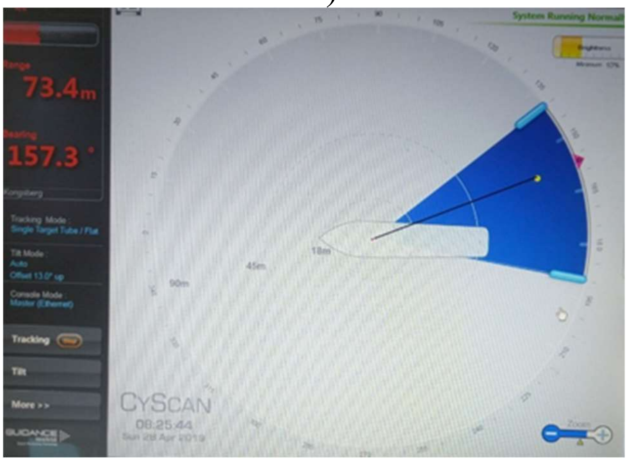


b)

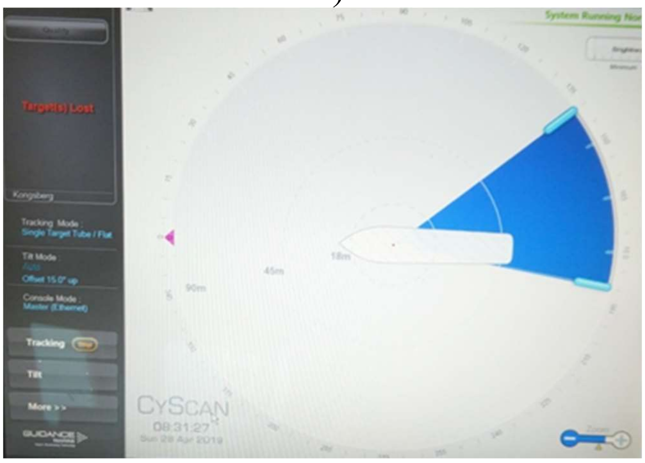


c)

d)



e)



f)

Fig. 1 – Experiment with a CyScan laser optical system

Fig. 1c) shows the CyScan screen without disturbances. Distance to the reflector 54.0 m, bearing to the reflector 143.0°, scanning mode – single reflecting tube, beam tilt angle 7.0° up.

Fig. 1d) shows a CyScan screen for the same conditions as in the previous experiment but in the presence of side rolling. Rolling amplitude is 11º–14º, rolling period is 1.5–2 sec. As can be seen from the Fig. 1d), the CyScan signal is unstable, the quality and brightness of reflection is low.

Fig. 1e)–1f) shows a CyScan screen in the presence of resonance rolling. Distance to the reflector 75.6 m, bearing to the reflector 156.8°, scanning mode –

single reflecting tube, beam tilt angle 13.0° up, resonance rolling amplitude is 11º–14º, resonance rolling period is 1 sec.

As can be seen from Fig. 1e)–1f), the CyScan signal is unstable, the quality and brightness of the reflection is minimal, there is a loss of the reflection signal from the reflector tube.

The laser optical positioning system is an integral part of the entire DP complex which is responsible for data collection. As shown in experiments, in the presence of pitching and rolling, the CyScan has an unstable and low-quality signal, and with resonant pitching it can lose a signal. Since the system can be installed on any type of vessel (DSV, PSV, or Shuttle tanker) [17], an unstable signal or its complete loss can lead to disruption of the reference positioning system and failure as a whole [18–19], which is associated with severe consequences – environmental pollution, accidents on the oil and gas platform, and even human casualties [20–21].

Therefore, improving the quality of the laser optical positioning system is an urgent scientific and technical task.

The aim of the article is to ensure high quality reflection of the beam of the laser optical system, including those with strong pitching and resonance rolling. This goal is achieved by using an additional degree of freedom of the laser beam in the vertical plane, measuring with the laser optical system of the bearing and distance to the reflector, determining the required beam direction (to the center of the reflector), determining the direction of the beam in the coordinate system associated with the vessel, taking into account the roll, yaw and trim of the vessel, determination of required beam deflection angles in the horizontal and vertical plane, formation, using PID – regulators, deviation signals of the current beam position from the required beam position in the horizontal and vertical plane, working out deviation signals by servos.

The unit vector defining the required direction of the optical axis to the center of the reflector in the coordinate system associated with the platform (LCS), has the form (Fig. 2)

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

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

The unit vector components defining the required direction of the optical axis to the center of the reflector in in the coordinate system associated with the ship (BCS) has the form

$$e_x^{BCS} = \cos\theta^* \cos\theta \cos\psi + \sin\theta^* \sin\theta,$$

$$e_y^{BCS} = \cos\theta^* (\sin\varphi \sin\theta \cos\psi - \cos\varphi \sin\psi) - \sin\theta^* (\sin\varphi \cos\theta),$$

$$e_z^{BCS} = \cos\theta^* (\sin\varphi \sin\psi + \cos\varphi \sin\theta \cos\psi) - \sin\theta^* (\cos\varphi \cos\theta).$$

The unit vector defining the direction of the optical axis in BCS, has the form

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

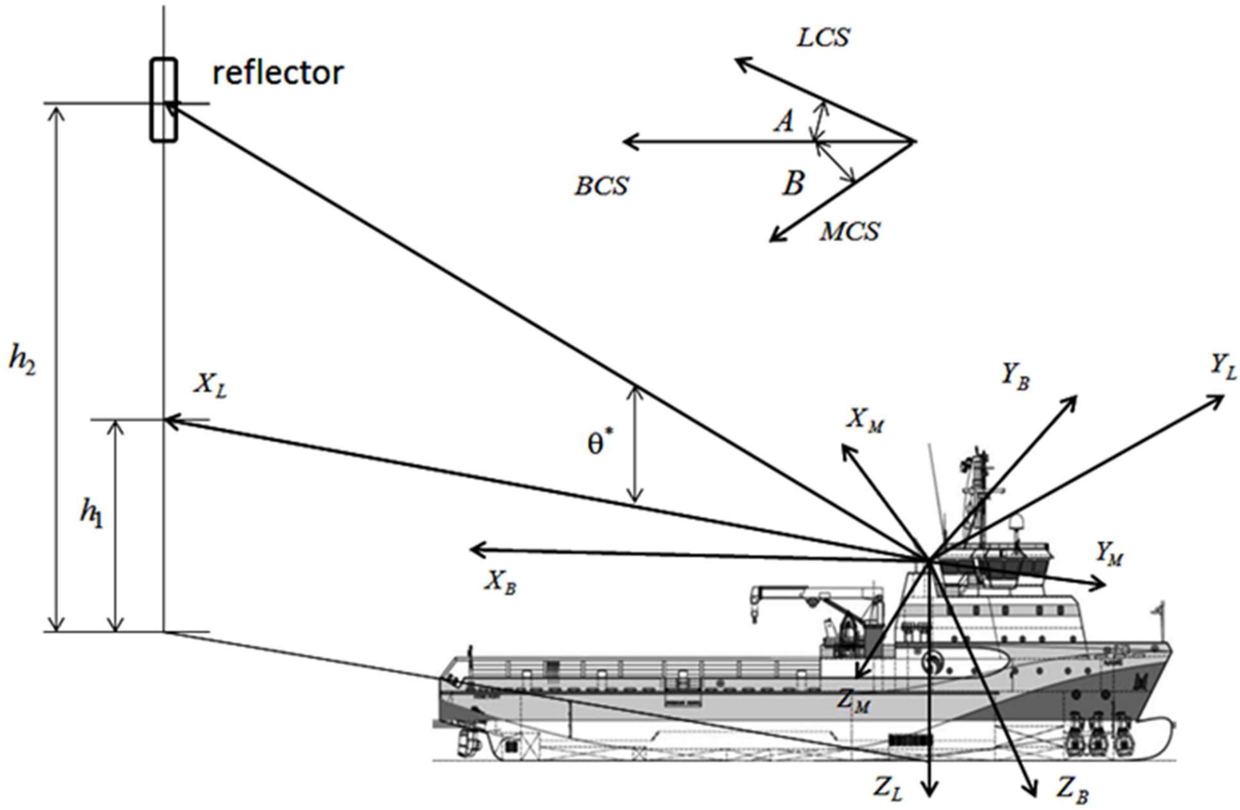


Fig. 2 shows the coordinate systems used in the calculations

From the last equation determine the required beam deflection angles

$$\theta_m^0 = \arcsin(\sin\ \theta^* \cos\varphi\cos\theta - \cos\theta^* (\sin\varphi\sin\psi + \cos\varphi\sin\theta\cos\psi)).$$

$$\psi_m^0 = arct(\frac{\sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi - tg\theta^* \sin\varphi\cos\theta}{\cos\theta\cos\psi + tg\theta^* \sin\theta})$$

To bring the current position of the optical axis to the desired position, use PID-regulators

$$\sigma_1 = k_\psi(\psi_m - \psi_m^0) + k_{\dot\psi}\frac{d}{dt}(\psi_m - \psi_m^0) + k_{\int\psi}\int(\psi_m - \psi_m^0)dt,$$

$$\sigma_2 = k_\theta(\theta_m - \theta_m^0) + k_{\dot\theta}\frac{d}{dt}(\theta_m - \theta_m^0) + k_{\int\theta}\int(\theta_m - \theta_m^0)dt\ ,$$

where σ_1, σ_2 – signals to servos.

Results

1. Regulatory documents on a laser optical system are considered, as well as an analysis of sources devoted to this topic.

2. Full-scale experiments were conducted on the platform supply vessel (DP-2) “ESNAAD 225” with a Jack-Up platform under the conditions of pitching and resonant rolling to identify conditions under which the CyScan reflection signal becomes weak or disappear.

3. The reasons for the attenuation and disappearance of the signal due to the deviation of the optical axis of the beam from the center of reflection are revealed.

4. A method and algorithms for automatic beam retention in the center of the reflector are proposed, which ensures a high quality of reflection, including with strong pitching and resonance rolling.

5. Automatic beam retention in the center of the reflector also allows to receive a high-quality signal at short distance, which increases the safety of maneuvering near the platform.

6. Automatic beam retention in the center of the reflector also allows to increase the maximum working distance due to the possibility of reducing the beam width.

7. The operability of the automatic beam guidance system at the center of reflection in the range from minimum to maximum distance, under conditions of strong keel, side and resonance pitching, was verified by mathematical modeling in MATLAB.

References

1. Guidelines for the design and operation of dynamically positioned vessels. The International Marine Contractors Association. (2019). IMCA Marine Division.

2. Bray, D. (2008). DP Operator's Handbook. The Nautical Institute.

3. Requirement for vessels and units with dynamic positioning (DP) system. (2019). Polski Rejestr Statków. (2019). https://www.prs.pl/uploads/p120p_en.pdf.

4. Chas, C. & Ferreiro, R. (2008). Introduction to ship dynamic positioning systems. Journal of Maritime Research, 5 (1), 79–96. http://www.jmr.unican.es/index.php/jmr/article/view/37/35.

5. A Review of Marine Laser Positioning Systems. (2003). IMCA Marine Division. The International Marine Contractors Association.

6. Guidelines for vessels and units with dynamic positioning (DP) systems. (2017). IMO. MSC.1/Circ.1580.

7. Guidelines for Vessels with Dynamic Positioning Systems MSC Circular 645. (1994). IMCA Marine Division. The International Marine Contractors Association.

8. Rules for Classification and Construction Ship Technology. (2016). Det Norske Veritas Germanischer Lloyd.

9. DP Operator Course Training Manual. 2010. Fanbeam System. Kongsberg Maritime AS Training. 6:6.6.1-6.6.7 [Electronic resource]. Access mode: https://www.maritimecorner.eu/media/shuttle/6_Fanbeam_jan_2010.pdf.

10. CyScan Installer's Guide. (2010). Guidance Navigation Limited.

11. Grothusen, J. (2005). CyScan: The Benefits of Multiple Hypothesis Tracking for Laser-Based DP Reference Sensors. Dynamic Positioning Conference. 687–706. https://www.guidance.eu.com/assets/_managed/cms/files/sensors_grothusen.pdf.

12. McKnight, D. & Miles, R. (2014). Impact of reduced visibility conditions on laser-based DP sensors. Dynamic Positioning Conference. https://dynamic-positioning.com/proceedings/dp2014/Sensors_mcknight.pdf.

13. Guidelines for Offshore Marine Operations. (2013). UK Chamber of Shipping, Oil and Gas UK. The Marine Safety Forum. https://dnmf.no/Artikler/Documents/201311%20-%20GOMOfinal.pdf.

14. Operator's manual. (2015). Renishaw Apply Innovation. 2017. Fanbeam 5.

15. Kornev, N. (2012). Ship dynamics in waves. University of Rostock. https://www.lemos.uni-rostock.de/storages/uni-rostock/Alle_MSF/Lemos/Lehre/Sommersemester/Dynamik_ST_II/STII_Ship_dynamics_in_waves.pdf.

16. Erdman, J. (2015). Sea Vipers computer vision and inertial position reference sensor system (CVIPRSS). Louisiana State University. https://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=2207&context=gradschool_dissertations.

17. Dielen & Baldo, A. M. (2008). Offshore support vessel developments for deep water oil and gas E&P. Rio Oil & Gas Expo and Conference. https://www.osti.gov/etdeweb/servlets/purl/21150468.

18. Herdzik, J. (2013). Dynamic positioning systems during emergency or unexpected situations. Journal of KONES, 20 (3), 153–159. https://www.infona.pl/resource/bwmeta1.element.baztech-9b3dbf38-5c86-42e9-bb37-10fb8d2b51a2#.

19. Pil, I. (2018). Causes of Dynamic Positioning System Failures and Their Effect on DP Vessel Station Keeping. Tallinna Tehnikaulikool Eesti Mereakadeemia. https://digikogu.taltech.ee/et/Download/085d6b50-7a00-49e3-b677-ac85ddf12b85.

20. Hauf, K. (2014). Analysis of Loss of position incidents for dynamically operated vessels. Institutt for marin teknikk. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/239192.

21. Chong-Ju Ch. & Yun-Chul. (2017). A Study on FSA Application to PRS for Safe Operation of Dynamic Positioning Vessel. Journal of Navigation and Port Research. 41 (5), 287–296. DOI: 10.5394/KINPR.2017.41.5.28.

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