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Positioning accuracy of the vessel's waterline in the aspect of safety and effectiveness of the manoeuvre

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Abstract

The aim of the pilot and navigation systems is to provide an outline of the vessel according to the surrounding hydro-technical objects and other obstacles to navigation. The article presents the results of simulation studies, which aim was to examine the impact of ship's waterline accuracy, presented in these systems, on safety and effectiveness of the manoeuvre.

Generating of vessel's waterline

The main objectives of navigational systems are following elements: to conduct the ships on the constrained water areas, approach to the quay and mooring them effectively. In such systems important roles meet the appropriate display of vessel's position in relation to the surroundings in which it is located. For the navigation systems used on the high seas or in the large distance from navigational hazards point determining the position of the antenna is enough, while for systems used in confined water, as the pilot and docking systems is also necessary to display the corresponding waterline of the vessel.

Approaching the mooring positions accuracy of the position should be better. The accuracy of GPS position even in differential mode is about 5 m. In addition, the GPS position error has the normal distribution with expected value equal to zero only for long-term observation. In the case of short-term observations that last a few minutes may occur a permanent offset of the position by a few meters with small fluctuations. Therefore, in order to provide adequate accuracy of the vessel's position during the approach to the berth and the berthing manoeuvre, laser rangefinders were selected in the appropriate configuration. The simulation studies described in this article use computer models of laser rangefinders.

To identify the location of the vessel's waterline matching algorithm was used. An algorithm's task is to match the two parabolas to the waterline of the ship. In addition, parallel middle body of the hull is determined by the vertices of parabolas (Fig. 1).

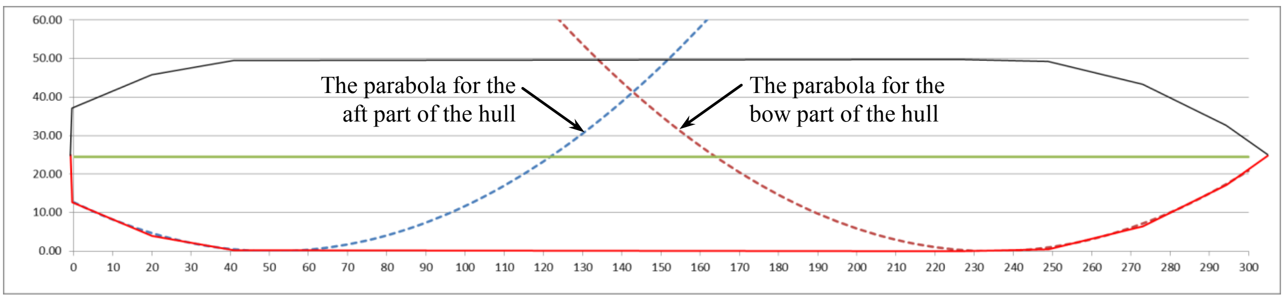


Fig. 1. The analytical representation of the vessel's waterline

The coefficients of quadratic equations for the two curves describing the shape of the hull were determined using the following system of equations (1). The shape of the bow and stern of the vessel depends on its width and type [1]. It was therefore assumed that *a* factor that affects the width of the parabolas describing the shape of the hull at the bow and stern area is calculated as a function of the width of the ship. Moreover, the curves' vertices lie on the abscissa axis, and thus have one solution, and therefore their discriminants are equal to zero.

$$\begin{cases} B \\ y = ax^2 + bx + c \\ \Delta = b^2 - 4ac = 0 \end{cases} \Rightarrow \begin{cases} a = f(B) \\ b = \dfrac{y_p - ax^2 - c}{x_p} \\ c = \dfrac{b^2}{4a} \end{cases} \qquad (1)$$

where:

B – vessel's width [m];
a, b, c – coefficients of quadratic equation;
Δ – discriminant of a quadratic equation;
X_p, y_p – root of the quadratic equation ($\Delta = 0$).

The waterline generated using the algorithm most corresponds with the actual waterline when used in the five measurement points, in such a way that two of them were along the parallel middle body of the hull, one at stern part and bow part and one for a stern position designating (Fig. 2).

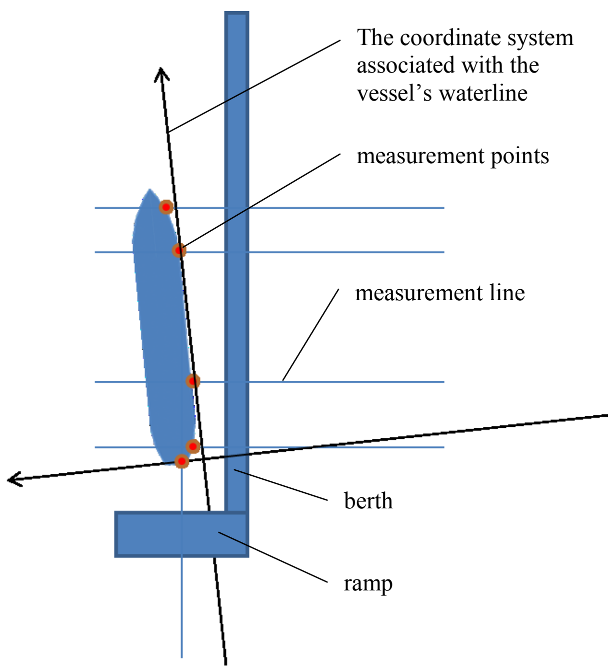


Fig. 2. The determining principle of measurement points on the basis of measurements with laser rangefinders

Precise positioning the waterline of the vessel (about centimeters) is necessary in the most critical, the last stage of mooring. Therefore, Pilot Navigation and Docking System (PNDS) uses five laser rangefinders, four of which are located along quay and measure the distance in a direction perpendicular to it, and one placed at the end of the quay and measured distance in the direction parallel to the quay. Distances between rangefinders should be a function of the vessels' sizes moored to the quay and selected so that the algorithm can determine the waterline of the vessel at a distance of at least 20 meters from the end of the berth, and at least half the width of the vessel to the berth.

On the basis of coordinates and directions of rangefinders, which determine the distance to the hull of the vessel are determined coordinates of measurement points (Fig. 2). These coordinates are then transposed to the coordinate system related to the waterline of the ship and on their basis adjusts the position of parabolic curves. Using obtained quadratic equations can be calculated any number of points designating the location of the waterline. Then all points of waterline are transposed back to the PNDS coordinate system.

The simulation studies

The simulation studies was carried out in order to check the impact of the docking system, whose accuracy of positioning the vessel's waterline is higher than accuracy of the waterline position based on DGPS and gyrocompass, onto the safety and effectiveness of the manoeuvre. The studies consisted of performed by a group of experts, pilots, captains and senior officers with experience in manoeuvring of this type of ships, a series of mooring manoeuvres, of sufficient numbers for each of the assumed options.

The study was planned based on the expertise of the participants. Defined two hydro-meteorological variants:

– zero conditions, wind 0 m/s, current 0 m/s;
– with pushing wind NW 10 m/s, current 0 m/s

and identified the following preliminary principles of manoeuvring by ferry:

– starting position, the ferry was in the fairway axis at the quay No. 2 of Sea Ferries Terminal in Świnoujście;
– movements parameters of the ferry at the beginning were as follows: heading 222° ± 3°, longitudinal velocity 0 w ± 1 w, and transverse velocity 0 w ± 0.5 w;
– trials were finished when the stern touched the fender facilities of the quay;

– the first contact should be performed as close as possible the ramp.

Tests were conducted using a computer model of m/f "Wolin" (Fig. 3) which basic parameters are as follows:

Built year	1986 / 2002
Length over all	188.88 m
Length between perpendiculars	186.02 m
Breadth	23.7 m
Draft (ballast condition/summer load line)	5.64 m /5.9 m
DWT	5143 t
Engine	4 x MAN-B&W 6L 40/45
Propeller	2 x pitch propeller – 150 rpm
Speed	15.5 kt / 18 kt

Fig. 3. m/f "Wolin", the computer model was used during the simulation trials

The following figures show the shot screens of computer monitor during the simulation tests with the vessel's waterline obtained by means of a ship: DGPS and gyro (Fig. 4), and a laser rangefinder (Fig. 5). In addition, for comparison only, these figures also show, marked, in red reference waterline (not available during the trial performed by the experts).

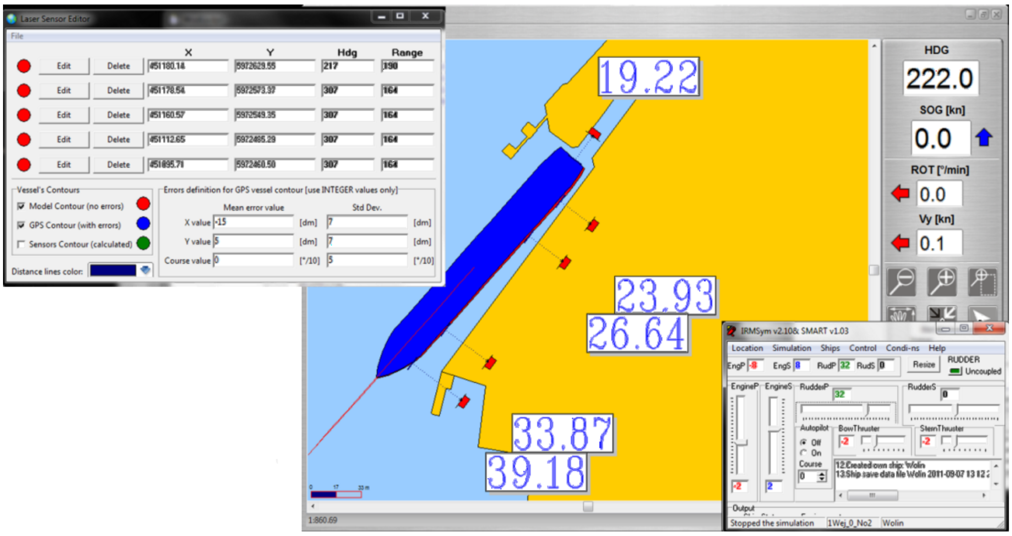


Fig. 4. The shot screen of computer monitor during the simulation with positioning using GPS and gyro (reference waterline marked in red)

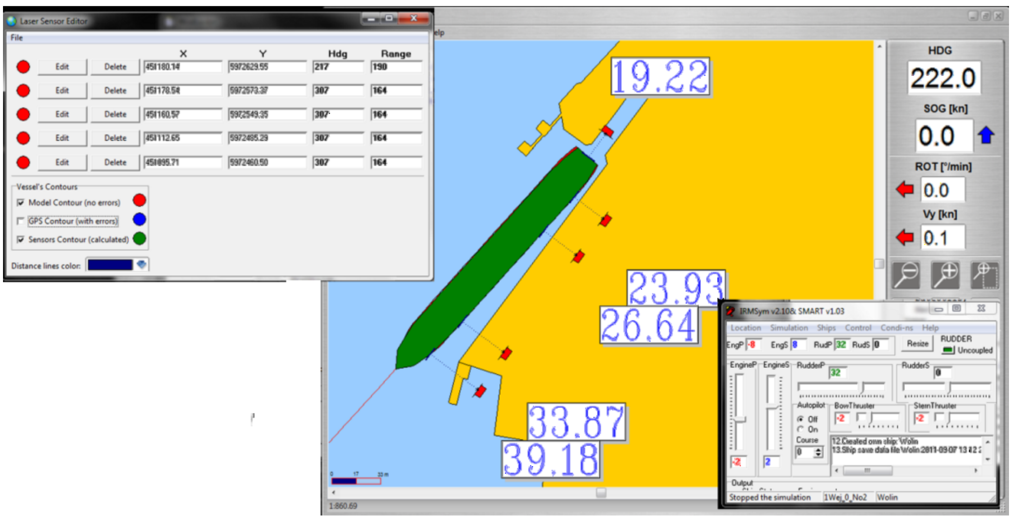


Fig. 5. The shot screen of computer monitor during the simulation with positioning using laser rangefinder (reference waterline marked in red)

The results

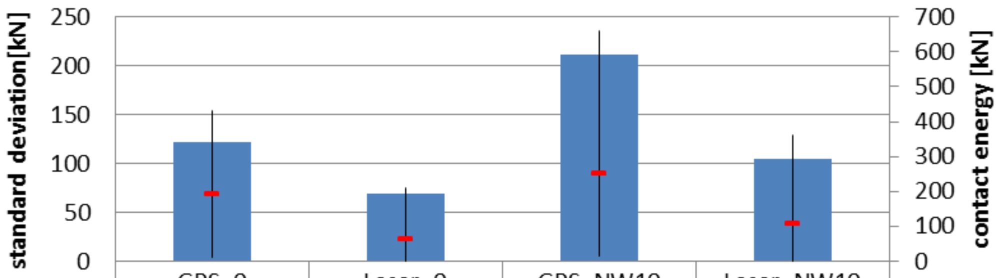
Recorded during simulation trials ferries movement parameters were subjected to analysis under the criteria for verifying the impact of the PNDS for safety and effectiveness of mooring manoeuvre. Following three criteria were taken into account, the first criterion concerns the safety while the others effectiveness of other manoeuvre:

– first contact energy [2];
– time of manoeuvre;
– accuracy of manoeuvre (distance to the end of the berth).

For safety criterion can be seen significant declines in average values of the first contact energy, standard deviations and maximum values for manoeuvres performed with the use of laser rangefinders (Fig. 6). The average energies are three times higher in zero conditions and 2.5 times greater in the pushing wind, and standard deviations of energy are 2 times greater for waterline based on DGPS and gyrocompasses.

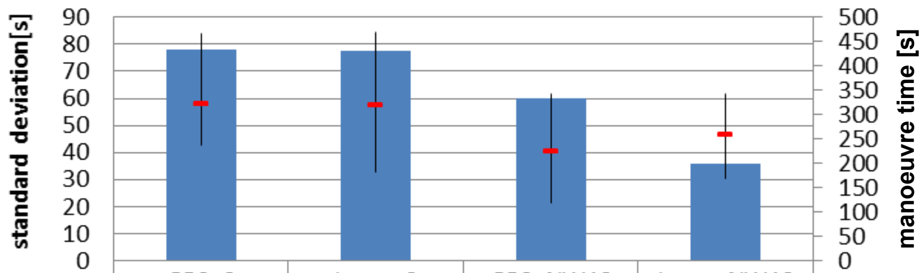
Manoeuvre time was counted from the start of the simulation trials until the vessel's first contact with the quay. For this criterion, significant difference in favor of a waterline based on rangefinders measurement can be seen in the variant with the pushing wind and there are not a significant difference under zero conditions. Most likely this is due to the fact that under zero conditions there is no specific factor that forces use of propellers. Under conditions of zero, manoeuvre can be performed safely with minimum settings of main machinery and thrusters, but during the pushing wind such tactics will push the ferry to the berth. Therefore, strong manoeuvres should be used and thus the time of manoeuvre is shorter.

Average distance from the ramp in all variants and with the use of both ship's equipment based waterline and laser rangefinders' waterline hovers around 10 meters. This shows that the experts tended to actually point to the first contact was as close as the ramp. In favor of the waterline based on a system laser rangefinders indicates the standard



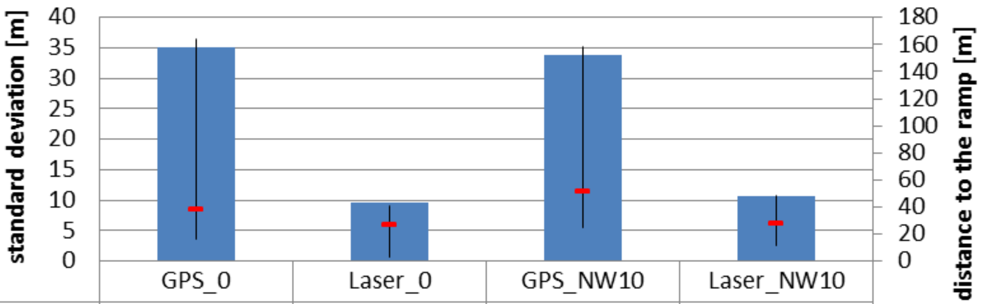
	GPS_0	Laser_0	GPS_NW10	Laser_NW10
Standard deviation	122	69	211	104
min energy	13	3	17	1
max energy	432	211	660	362
average energy	193	63	253	108

Fig. 6. Energy produced during the vessel's first contact with fender facilities



	GPS_0	Laser_0	GPS_NW10	Laser_NW10
Standard deviation	78	77	60	36
minmanoeuvre time	237	182	119	169
max minmanoeuvre time	466	469	341	342
average minmanoeuvre time	322	318	223	258

Fig. 7. Time of berthing manoeuvre calculated until first contact with the berth



	GPS_0	Laser_0	GPS_NW10	Laser_NW10
Standard deviation	35	10	34	11
min distance	16	3	25	12
max distance	164	41	158	48
average distance	39	26	52	28

Fig. 8. Distance between first contact point and the ramp

deviation, which is three times smaller than the waterline based on ship's devices.

Conclusion

The presented results of the analysis indicate a significant impact of Pilot Navigation and Docking System using laser rangefinders for positioning the waterline of the vessel, the safety and effectiveness of the mooring manoeuvre. In most cases, except time of manoeuvre in zero conditions, criteria indicators are at least two times lower, for the benefit of the system, the waterline positioning accuracy is higher.

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