DYNAMIC POSITIONING CONFERENCE
October 13-14, 2015

OPERATIONS

Optimized Offshore Gangway Operations on Monohull Vessels

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Abstract

The task of an accommodation vessel is to supply living quarters to crew personnel that is working on an installation with a shortage of bunks and facilities, which can be the case during commissioning or when extraordinary maintenance programs or upgrades on an installation are carried out. In order to transfer personnel to the installation at hand, a gangway, a bridge between the accommodation vessel and the installation is used. These gangways often have a telescopic function to accommodate relative motion between the installation and the accommodation vessel, as one or both can be floaters. DP systems are often used for positioning of accommodation vessels and the main task for the DP system on such a vessel is to maintain the suspension point of the gangway within a limited range from the installation, to ensure that the gangway can be connected to the installation and available for transfer of personnel.

This paper presents developments which are intended to optimize DP operations for monohull accommodation vessels. There are two main contributions. The first element is an optimization of the DP system control law for operations in harsh weather to efficiently reduce gangway telescopic motion due to incoming waves or wind gusts. The other element presented in this paper is an alternative control strategy suitable for optimizing the fuel consumption of accommodation vessels by keeping the heading of the vessel into the dominating environmental direction. In total, these contributions will hopefully yield a safer and more efficient operation for monohull accommodation vessels, and a higher operability.

Some elements of the work presented here have been carried out as an industrial research project, "Optimized Gangway Operability", funded in part by the Norwegian Research Council. Kongsberg Maritime participates in this project together with The Norwegian Marine Technology Research Institute (MARINTEK) and Østensjø Rederi AS. The research project is affiliated with the design process of Østensjø's new accommodation vessel, Edda Fortis. Another part of the research project is to conduct measurements with the full scale vessel, and to use the full scale data to validate a fully equipped bridge simulator environment located onboard the vessel, which is intended used for operational planning, verification of procedures and ASOGs (Activity Specific Operating Guidelines) for the vessel.

Edda Fortis

The work presented in this paper was initiated as part of the development stages of the new purpose built accommodation vessel from Østensjø Rederi AS, Edda Fortis. Simulations and model tests presented in this paper are carried out for this vessel. Edda Fortis is an Accommodation Service Vessel, designed by Salt Ship Design. It is 155 meter long, has a total capacity of 800 persons. Equipped with a heave compensated telescopic gangway at a length of 45.5 meters, a cargo deck area of 2000 m^2 and a 120 tonnes rig support crane. The Edda Fortis is built on experience from Østensjø's other purpose built accommodation vessel, Edda Fides.

Figure 1, illustration of Edda Fortis.

Optimized Bow Rotation Strategy

Motivation

Consider a vessel that is to reduce a sway offset measured at the bow of the vessel, utilizing a DP system. Intuitively the most efficient way to do this, given that the offset is not too large compared to the vessel length, is to rotate the vessel, as the energy required for yaw motion is less than the energy required for sway motion. This fact however is seldom exploited, for a very good reason; one of the governing criteria's for a generic DP operation is to keep the heading as close as possible to the operator selected heading. But in some operations where accurate heading-keeping itself is less important to the operation, the benefit of slacking the heading-keeping requirement seem so beneficial in terms of increased positioning accuracy, that it just might be worth pursuing. This section of the paper outlines such a pursuit, first by some rudimentary energy considerations, a detailed description of the necessary changes to the control system, and finally some initial results from simulations. The control strategy has also been tested in model basin experiments with success, and the first sea trial with the changes implemented is to be carried out in the imminent future.

Energy Considerations

To illustrate the efficiency of rotating over sideways movement, consider a vessel that is moving with constant speed sideways compared to a vessel rotating in order to move the bow sideways. The forces exerted by the vessel's thruster system must overcome the drag forces acting on the vessel, which is assumed to be dominated by the quadratic drag forces, F_2 where the subscript *2* denotes the sway degree of freedom. This force can be expressed as:

$$F_2 = C_{d2} V_2^2. \tag{1}$$

Here, C_{d2} is the quadratic drag coefficient in sway, and V_2 is the athwart ship velocity. The corresponding quadratic resistance moment in yaw can be expressed as:

$$M_6 = C_{d6} V_6^2. \tag{2}$$

Here V_6 is the rotational velocity of the vessel. The parameter C_{d6} is the rotational drag coefficient for the vessel. A rule of thumb approximation for C_{d6} based on integrating the drag force in sway over the length of the ship can be expressed as:

$$C_{d6} = \frac{C_{d2} L_{pp}^3}{32}, \tag{3}$$

where L_{pp} is the length between the perpendiculars of the vessel. Consider a situation where a athwart ship velocity V_2 is required, measured at the bow of the vessel, at $L_{pp}/2$. If this is to be obtained by translation, the expression for the force required can be expressed by (1). If rotation is to be utilized a rotational velocity V_6, expressed as

$$V_6 = \frac{2V_2}{L_{pp}} \tag{4}$$

must be obtained. By substituting (3) and (4) into (2), the required moment to achieve the desired translational velocity V_2 at the bow can be expressed as

$$M_6 = \frac{C_{d2} L_{pp}^3}{32} \left(\frac{2V_2}{L_{pp}} \right)^2 = \frac{C_{d2} V_2^2 L_{pp}}{8}. \tag{5}$$

If now the average distance from the center of rotation of the vessel to the thrusters is denoted $\bar{x}$, the force required to achieve the translational velocity V_{2D} at the bow of the vessel can then be expressed as:

$$F_{2Rot} = \frac{M_6}{\bar{x}} = \frac{C_{d2} V_2^2 L_{pp}}{8\bar{x}}. \tag{6}$$

The ratio between the force requirement for translational motion (1) and the force requirement in rotation (6) can then be expressed as

$$\eta = \frac{F_{2Rot}}{F_2} = \frac{L_{pp}}{8\bar{x}}. \tag{7}$$

Thus the amount of force required will be inversely proportional to the mean distance between the rotation center and the thrusters. If the mean distance exceeds 12.5 percent of the total L_{pp}, the rotation will be equally efficient as the translational motion. However, many ships designed to operate on DP has a mean distance in the range of 30 to 40 percent of the L_{pp} between the thrusters and the center of rotation, yielding a reduction in required force of up to 30 percent compared to the pure translational motion.

A similar relation can be seen for acceleration of the vessel, it requires approximately 30 percent less force to rotate a vessel to obtain a certain translational speed at the bow, compared to performing a translation of the whole vessel, when the thrusters are situated 40 percent of L_{pp} from the center of rotation.

Granted, these calculations are somewhat artificial and crude, but the potential for reducing the required force (or increasing the responsiveness) for the vessel seem present, and worth pursuing.

Implementation

Consider a dynamically positioned vessel operating with a certain desired position and heading denoted by the vector X_d, where the subscript d indicates the desired value, and x is North position, y is East position and ψ is the heading.

$$X_d = [x_d, y_d, \psi_d]^T. \tag{8}$$

The actual current position of the vessel in the horizontal degrees of freedom can be denoted by a position vector X **Error! Reference source not found.**:

$$X = [x, y, \psi]^T. \tag{9}$$

Consider now Figure 2, where the dashed vessel shape indicates the desired position and heading, while the solid figure indicates the actual position and heading of the vessel. The separation between X and X_d is calculated as:

$$\Delta X^G = X_d - X \tag{10}$$

in a global reference frame. In order to calculate the position deviation in a vessel local reference frame, the vector ΔX^G must be rotated according to the instantaneous heading of the vessel:

$$\Delta X^B = R(\psi)\Delta X^G = [\Delta x, \Delta y, \Delta\psi]^T. \tag{11}$$

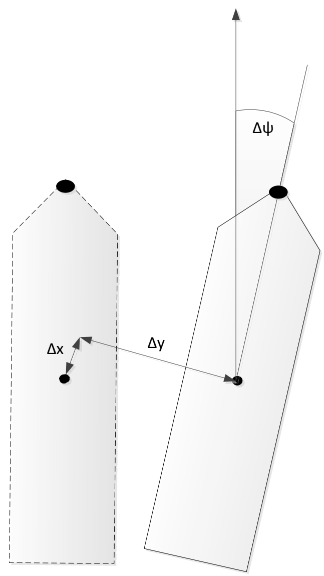

Figure 2, illustration of calculation of position and heading deviation in surge, sway and yaw.

The rotation matrix $R(\psi)$ in (11) can be expressed as:

$$R(\psi) = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{12}$$

The position deviation in the local coordinate frame ΔX^B is used to calculate the control force for each of the horizontal axes in a traditional control system, allowing for minimizing the position or heading deviation in each of the axes separately.

In general this method for determining positon and heading deviation is a good approach, as it means that the heading is regulated towards the operator selected setpoint. It is often considered the most critical aspect of a DP operation that the vessel is able to maintain the heading at the desired value. For an accommodation vessel however, the most critical parameter on which it's being evaluated is the ability to keep the gangway suspension point at a fixed position relative to the landing point on the installation which the accommodation vessel is operating close to. Given that a decrease in accuracy in heading is accepted, it is possible to exploit the fact that the gangway is located far away from the natural pivot point of the vessel, and to use the yaw axis to control the gangway suspension point horizontally. The proposed approach in order to do this is to modify the calculated heading deviation, as illustrated in Figure 3.

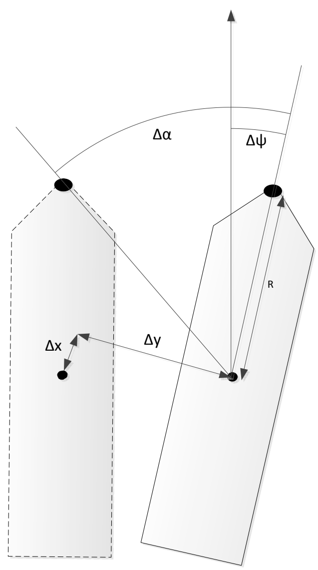

Figure 3, illustration of modified heading deviation calculation.

Here, a new angular deviation, $\Delta\alpha$, is indicated. Given small position deviations, this angle can be approximated as:

$$\Delta\alpha = \Delta\psi + \sin^{-1}\left(\frac{\Delta y}{R}\right), \tag{13}$$

where R is the distance from the origin of the body fixed reference frame to the gangway suspension point. By updating the position and heading deviation vector (11), by substituting the heading deviation element such that

$$\Delta X^B = [\Delta x, \Delta y, \Delta\alpha]^T, \tag{14}$$

the positioning of the gangway suspension point is aided by the heading control of the vessel, since the heading of the vessel is now regulated to point towards the desired position of the gangway suspension point.

Results

The modification to the heading control has been tested extensively in simulations and in a model experiments to fully understand the implications of such a mode. An extract of simulation results are included in Table 1, where different heading setpoints relative to the dominating environmental direction have been investigated, as well as 2 different sea states where Condition 2 is the more severe sea state out of the two.

Table 1, extract of simulation results. The table indicates the maximum offset with the new control strategy as a percentage of the maximum offset with the nominal control strategy.

Heading	Sea State	Offset at gangway suspension point
0	Condition 1	100
0	Condition 2	100
45	Condition 1	67.1
45	Condition 2	70.6
90	Condition 1	68.2
90	Condition 2	67.1

The results from Table 1 shows the maximum offset at the gangway suspension point as a percentage of the same offset when the simulation was conducted with the conventional heading control as in (11). For head seas the modification has no impact on the results. When the environment is attacking from quartering or beam direction, the maximum offset at the gangway suspension point is reduced by about 30 percent.

Figure 4, picture of the model vessel from the basin test where the modified control strategy was tested. Courtesy of Marintek.

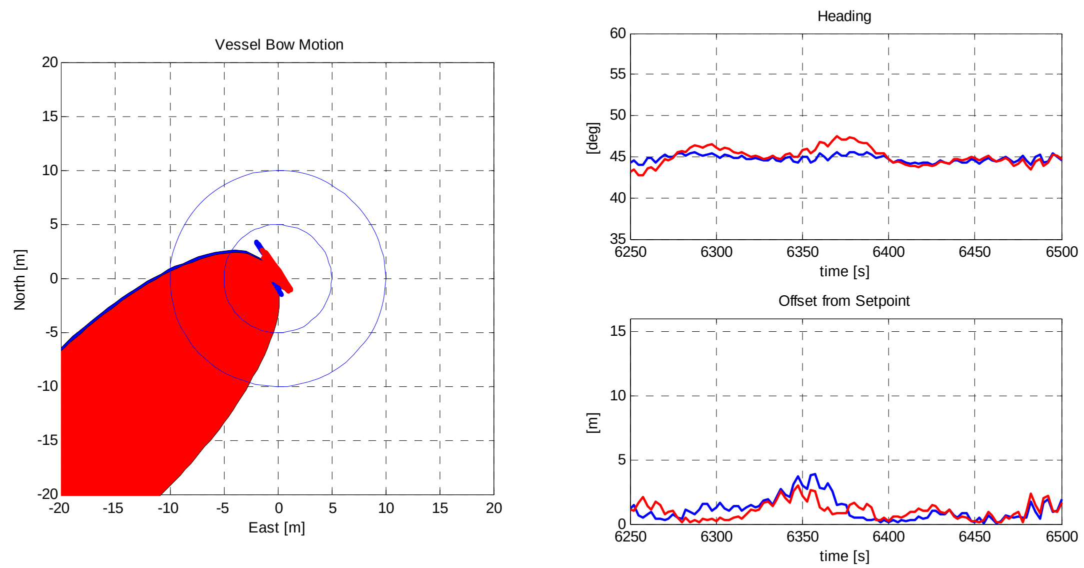

Figure 5, illustration of position excursion with conventional control, and with modified heading control. The blue vessel outline and graphs indicate the motion from a simulation with the conventional heading control, while the red vessel and graph indicates the modified heading control.

Figure 5-Figure 7 shows the result from a simulation with the modified heading control in red compared to the conventional control in blue. The upper right plot shows the heading, while the lower right plot shows the distance between desired and actual bow position. The left plot shows the vessel outline and a time trace of the motion of the bow. In Figure 5, the two heading control schemes yields similar results in positioning, as the vessel is close to both desired position and desired heading. In Figure 6, the vessel is pushed out of position by incoming waves and the difference in heading control between the two becomes apparent. The blue vessel (conventional heading control) tries to move the vessel in a pure sway motion to regain the desired position, while the red vessel (modified heading control) changes the heading to position the bow as close as possible to the desired position. As the wave forces are overcome in both cases, the vessel regains its desired position and heading as seen in Figure 7.

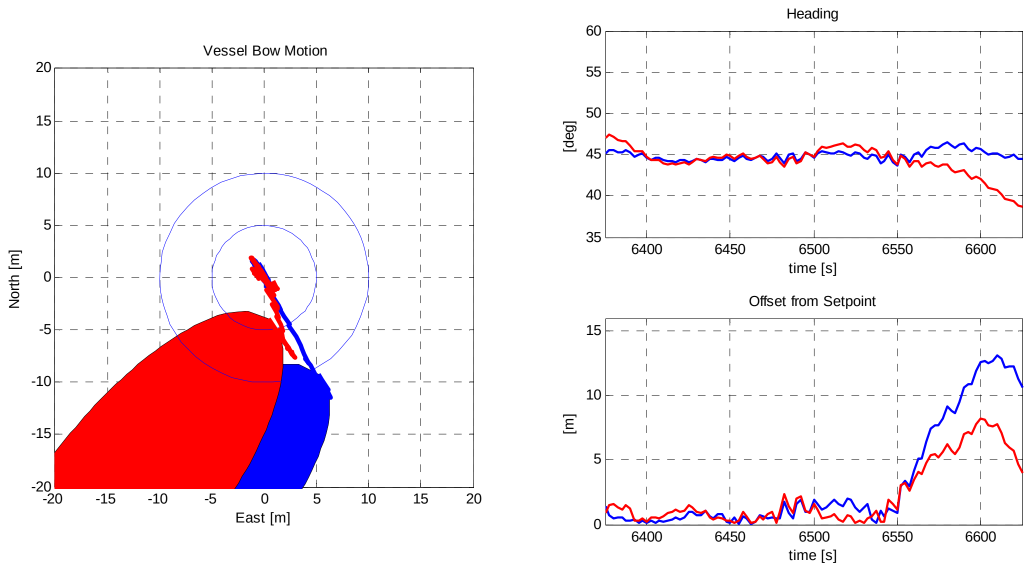

Figure 6, illustration of position excursion with conventional control, and with modified heading control. At this time instance the vessel has been pushed out of position by wave forces, and is trying to regain its desired position.

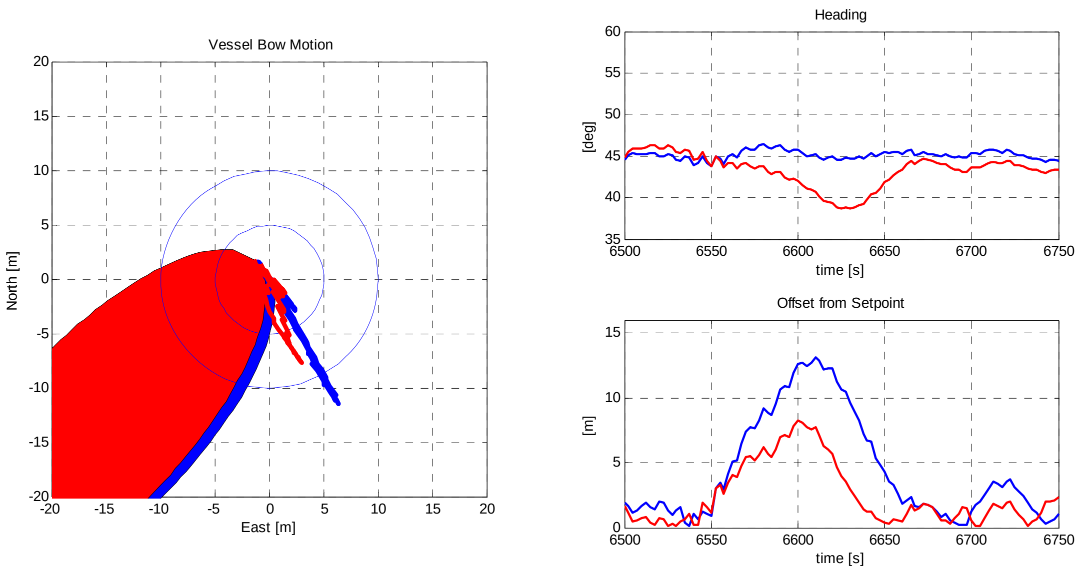

Figure 7, illustration of position excursion with conventional control, and with modified heading control. At this time instance the vessel has just recovered its position after being pushed out of position by wave forces.

Optimized Guidance Strategy

Motivation

In more benign weather conditions, the challenge of maintaining an adequate positioning of the vessel is less demanding. Therefore the operator has the possibility to focus more on maintaining an optimum position and heading with regards to the environmental direction, such that a minimum of fuel is consumed by the vessel. This is often quite a tedious procedure with constantly updating the heading of the accommodation vessel, and possibly also the position of the accommodation vessel, thereby altering the bearing of the gangway relative to the installation where the gangway is connected.

It would be beneficial if the operator could define limits as to what the allowable bearing of the gangway can be, and also the extreme limits of the accommodation vessel heading, and then let the DP system handle the optimization of vessel position and heading within these limits. Such an augmentation of the DP system is described in the following.

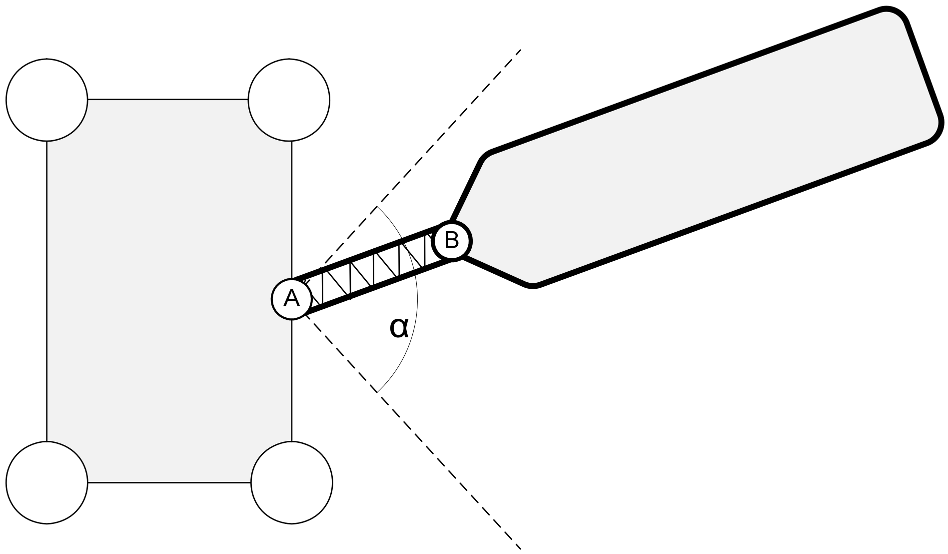

Figure 8, illustration of allowable gangway bearing sector α.

Figure 8 illustrates the accommodation vessel, an offshore installation and the gangway between the two, where crew are transferred back and forth. The angular sector α indicates the allowable bearing of the gangway. This sector is typically limited by obstructions in the vicinity of the landing point onboard the offshore installation. The new functionality for gangway operations allows the DP operator to configure the sector α according to clearly defined limits for each installation defined in the ASOG.

The vessel is then allowed to weather vane, pointing towards the gangway landing point until the limit of the bearing sector is reached. If the allowable bearing sector is somewhat limited, measures can be taken to let the accommodation vessel obtain an optimum heading while still maintaining the limiting bearing of the gangway. This is obtained by fixing the reference of the gangway suspension point, and then letting the accommodation vessel rotate about its own bow, creating a relative angle between the vessel and the gangway.

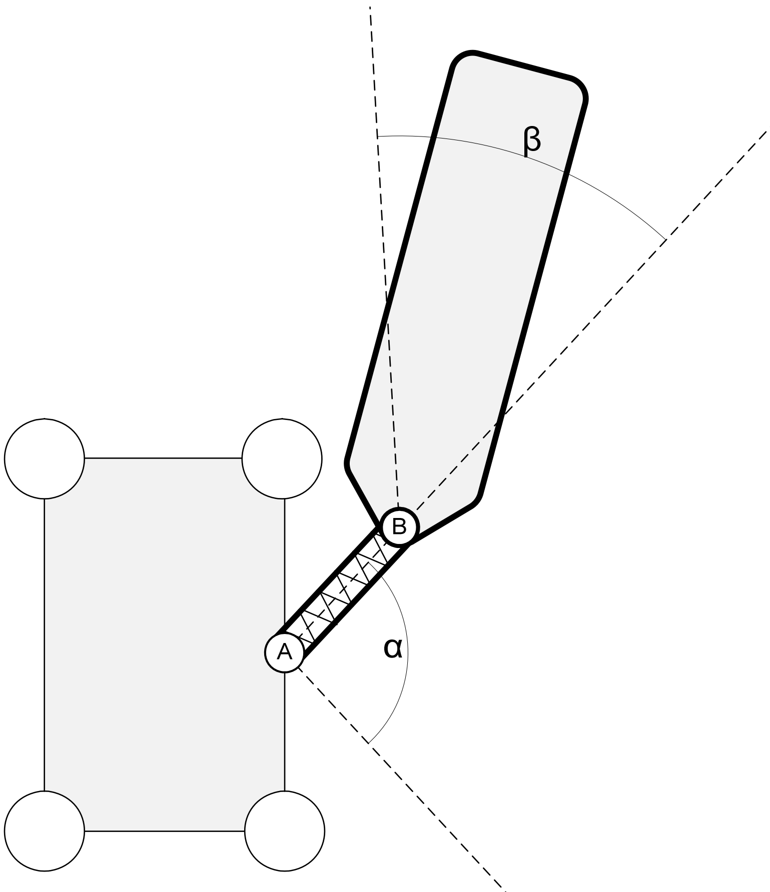

Figure 9, illustration of allowable gangway bearing sector α and the allowable sector which the vessel can rotate about point B in, β.

In Figure 9, a sector of allowable heading, β, is indicated. If the accommodation vessel has reached the gangway bearing limit α, the vessel will rotate about its own bow within the sector β. The limit of β must be set by the operator, and is typically dependent on maintaining a safe separation distance between the accommodation vessel and the offshore installation. The parameter will also typically be defined by the ASOG.

Implementation

While the vessel is in a position such that the bearing angle of the gangway is within the sector α, the principles from the oil offshore loading can be exploited to calculate the reference position and bearing for the vessel. Consider point A in Figure 9, which has the earth-fixed position $X_A{}^G$:

$$X_A^G = [x_A, y_A]^T. \tag{15}$$

The gangway suspension point onboard the accommodation vessel in a global reference frame is denoted as:

$$X_B^G = [x_B, y_B]^T. \tag{16}$$

The nominal length of the gangway, L, can be seen as the desired range between X_A^G and X_B^G. The desired bearing between the gangway suspension point and the opposite landing point, which is coinciding with the desired heading of the accommodation vessel, can be expressed as:

$$\psi_d = \tan^{-1}\left(\frac{y_A - y_B}{x_A - x_B}\right). \tag{17}$$

The desired location of the gangway suspension point, which will be the position reference at the suspension point, is then calculated as:

$$X_d = \begin{bmatrix} x_d \\ y_d \end{bmatrix} = \begin{bmatrix} x_A - L\cos(\psi_d) \\ y_A - L\sin(\psi_d) \end{bmatrix}. \tag{18}$$

In the case that the gangway bearing is within the angular sector α, the sway control is relaxed, such that only the along ship range and the heading of the vessel is actively controlled. When the vessel reaches the limitation of the bearing, the DP system switches strategy, such that position control both in surge and sway is enabled, while the heading control is relaxed. This leads the vessel to pivot about its own bow, while maintaining range and bearing of the gangway.

If the limitation of the allowable heading sector β is reached, a full heading and position control is enabled to restrain the vessel from further rotation.

Results

Figure 10-Figure 12 shows the results from at 3 different time instances in a simulation where the accommodation vessel starts out South of the offshore installation with its bow pointing North. The green solid line indicates the allowable gangway bearing sector α, from Figure 8. The dotted green radius indicates the separation distance that the accommodation vessel should strive to maintain, while rotating within the aforementioned bearing sector. The red line indicates the maximum heading that the accommodation vessel can have, before full auto position and heading is enabled.

The environmental forces are in the beginning acting from North and gradually turn over to North North-East, in order for the simulation to illustrate the different stages of the control strategy. In Figure 10, the gangway is inside the bearing sector α, at the start of the simulation.

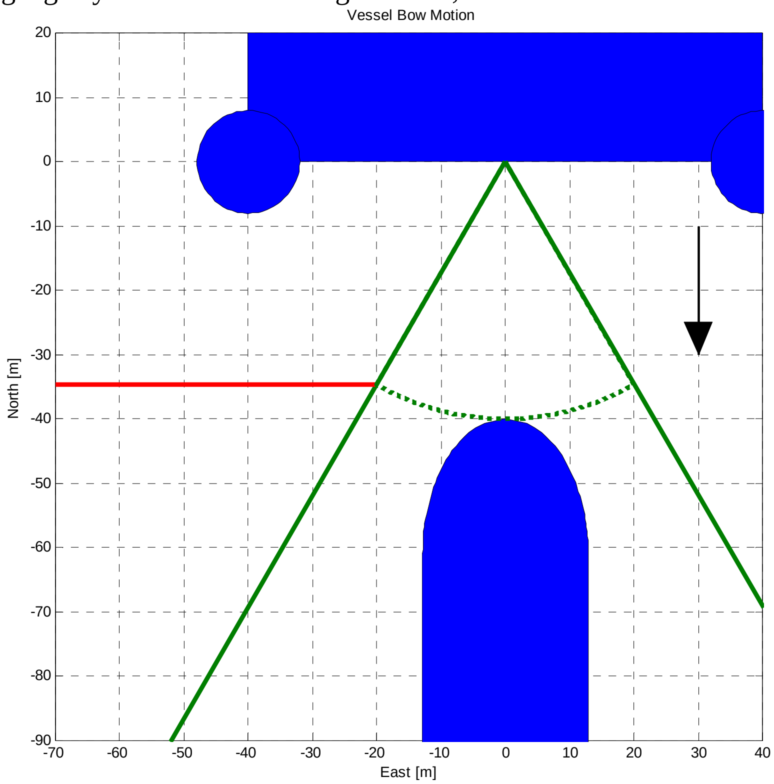

Figure 10, simulation results where the new guidance mode is applied. The figure shows the initial position of the accommodation vessel in a simulation. The DP system seeks to maintain a fixed separation distance (indicated by the dotted green line) to the offshore installation, and to keep a heading such that the vessel is pointing towards the installation. The black arrow indicates the direction of the weather, while the solid green line indicates the angular sector which the vessel is free to rotate within. The red line indicates the angle at which full position and heading control will be applied.

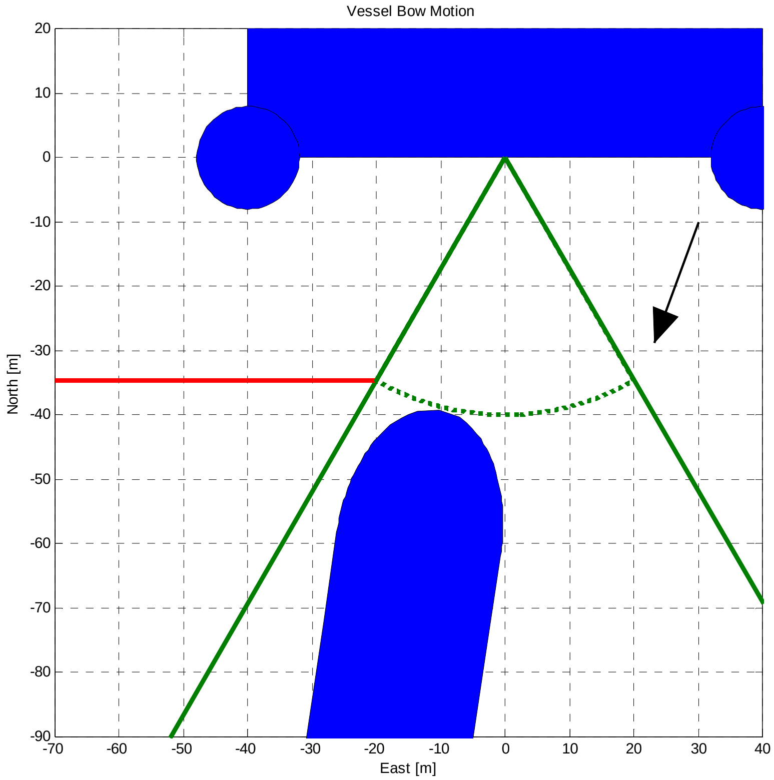

Figure 11, simulation results where the new guidance mode is applied. The figure shows that the accommodation vessel updates the desired heading when moving within the allowable bearing sector (solid green line) such that the vessel is pointing towards the installation. The separation distance is regulated towards the desired value indicated by the dotted green line.

As the accommodation vessel is exposed to environmental forces acting from East, it will drift towards West, constantly maintaining the separation distance between the gangway suspension point and the gangway landing point at the offshore installation, and pointing towards the gangway landing point at the installation, as illustrated in Figure 11.

When the allowable bearing sector is exceeded, as shown in Figure 12, the DP system controls the gangway suspension point to the intersection of the desired separation radius (dotted green) and the allowable bearing limit (solid green), while the heading of the accommodation vessel is free to assume any heading within the sector between the bearing limit and the heading limit, indicated by the red line.

Although not demonstrating quantifiable improvements, these results demonstrate that the vessel can obtain an optimum heading with regards to dominating environmental direction, with a reduced effort for the operator.

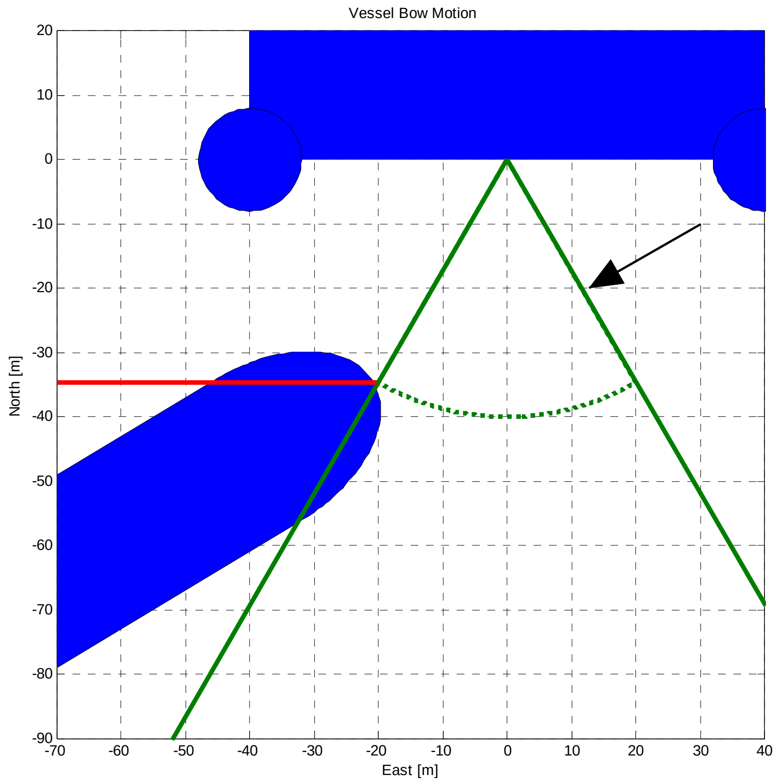

Figure 12, simulation results where the new guidance mode is applied. The figure shows the vessel after reaching the limit of the allowable bearing of the gangway. The accommodation vessel will then rotate about its own bow to keep the bearing of the gangway within the allowable sector, while still optimizing its own heading with regards to the environmental force direction.

Conclusion

This paper has presented two new possible approaches to increase the operability of an accommodation vessel, by making adaptations to the DP control system. The presented adaptations of the DP system are installed on the Edda Fortis, which is scheduled for initial sea trials during the fall of 2015. A complete evaluation of the concepts presented will be carried out once this vessel is in operation.