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Ship Maneuvering Prediction based Pivot Point Estimation

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Abstract

In the last years, the size and the number of ships has grown remarkably. At the same time, the size of harbors and ports remain constantly. Asa result, the ship maneuvering in harbors has become more problematic and harder to execute. This is the reason that many sailors affirm that it is an art than a science to execute some maneuverings. Ship maneuvers represented a complex vessel motions influenced most of the time by external environmental conditions in the navigation area (i.e. ocean and tidal current conditions, water depth, wind and waves). Navigator`s knowledge and experiences overcome to control the ship speed, course and heading in some close encounter situations. For example, combinations of different environmental conditions (draft variations in a passage from fresh to sea water with other ships near the same navigation area), create not only additional navigation difficulties, but also could compromise and threatens the navigation.

1. Introduction

Ship maneuvers represented a complex vessel motions influenced most of the time by external environmental conditions in the navigation area (i.e. ocean and tidal current conditions, water depth, wind and waves). Navigator`s knowledge and experiences overcome to control the ship speed, course and heading in some close encounter situations. For example, combinations of different environmental conditions (draft variations in a passage from fresh to sea water with other ships near the same navigation area), create not only additional navigation difficulties, but also could compromise and threatens the navigation. Another example is represented by the ships under harbor maneuvers, because each port or harbor have different rules for mooring and this thing create additional time consuming and potentially dangerous navigation situations [1]. This is the reason, that the navigation aids of each ships should be available under integrated bridge systems as decision help and support facilities to overcome and prevent the same challenges in shipping [2].

Most of the time, nonlinear ship steering conditions cause difficulties in maneuvering [3] and increase the risk and possibility of collision in harbor and sometimes resulted in environmental disasters. Another factor that increase the risk of collision and grounding is represented by the time delays to different commands.

2. Pivot Point

The pivot point in a vessel has been defined as the center of ship`s rotation and play an important role used in teaching and ship-handling training procedures for predicting vessel behavior. Ship navigators use their experience to estimate pivot point locations and to predict vessel positions and orientations (i.e heading) along his trajectories.

Ship`s motion in 3D space has six degrees of freedom: sway, surge, heave, roll, pitch and yaw. Ship`s motion in a reduce and small area , could be modelled as a General Planer Motion (2D place) involve and take into consideration only two translations (surge and sway) and one rotations yaw. Each elemental motion is linear in nature and threated individually. When all the elemental motions are combined result the ship`s motion.

The pivot point can be considered the center of vessel rotation consisting a zero-drift angle when they are respected the velocity components [4].

An analytic estimate of pivot point position can be calculated be considering linearized and can be approximated as the ratio between yaw rate and sway velocity equations of a turning ship. Therefore, the distance to the pivot point from the center of gravity can be estimated for different vessel. The information from pivot point are used to predict vessel positions and orientations in a turning circle type ship maneuver in a short time interval.

3. Mathematical model

The proposed mathematical formulation of vessel maneuvering with a fixed XYZ right-hand coordinate system (i.e. North, East, Down reference frame) is presented in Figure. 1.

Positions $P_i, P_g, P_p, P_a, P_h, P_q$ represents the center of planar motion.

Is considered a continuous-time curvilinear motion model that represents vessel kinematics and that can be written as [3] :

$$\dot{\chi}(t) = a_{ng}(t)/V(t)$$
$$\dot{V}(t) = a_{tg}(t)$$
$$v_{xg}(t) = V(t)\cos\chi(t)$$
$$v_{yg}(t) = V(t)\sin\chi(t) \qquad (1)$$

Equation (2) represent the surge and sway velocity components of the vessel:

$$u(t) = v_{xg}(t)\cos\psi(t) + v_{yg}(t)\sin\psi(t)$$
$$v(t) = v_{xg}(t)\cos\psi(t) - v_{yg}(t)\sin\psi(t) \qquad (2)$$

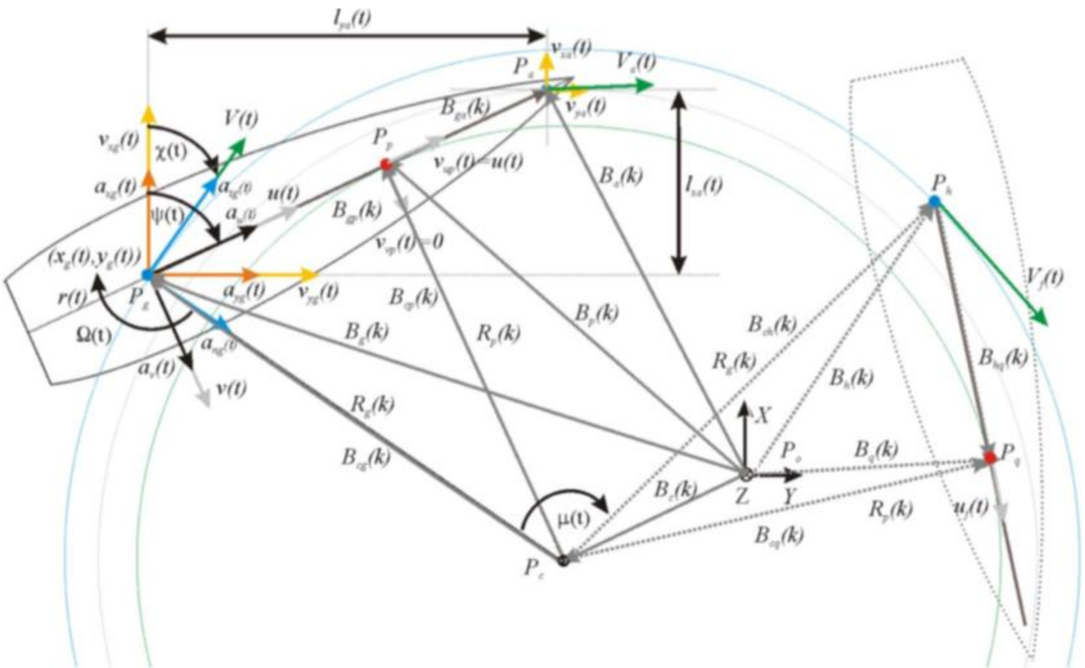

Figure 1. Ship maneuvering model

4. Computational simulation

For simulation we choose two different type of vessel. The characteristics of each ships are presented in Table 1.

Table 1. Ship`s characteristics

General information	
Vessel type	Chemical tanker
Displacement	60976 t
Max speed	15.7 knt
Dimensions	
Length	183.0 m
Breadth	32.2 m
Bow draft	13.0 m
Stern draft	13.0 m
Height of eye	20 m

General information	
Vessel type	Oil tanker
Displacement	77100 t
Max speed	15.0 knt
Dimensions	
Length	242.8 m
Breadth	32.2 m
Bow draft	12.5 m
Stern draft	12.5 m
Height of eye	22 m

In this study, we choose perfect navigation conditions, without any influence on navigation. In this case, are presented the positions of ships when performs a complete turning maneuver without any hydrodynamic influence.

For each vessel are simulated the actual vessel states and parameter. The actual navigation trajectory is simulated in this study for Chemical tanker maneuvering situation are presented in Figure 2. Also, to improve the visibility of figure, the estimated trajectory positions in different time intervals are presented. Furthermore, the scaled heading vectors for Chemical tanker positions are also presented in Figure 3.

Figure 2. Vessel positions and orientations along the vessel trajectory

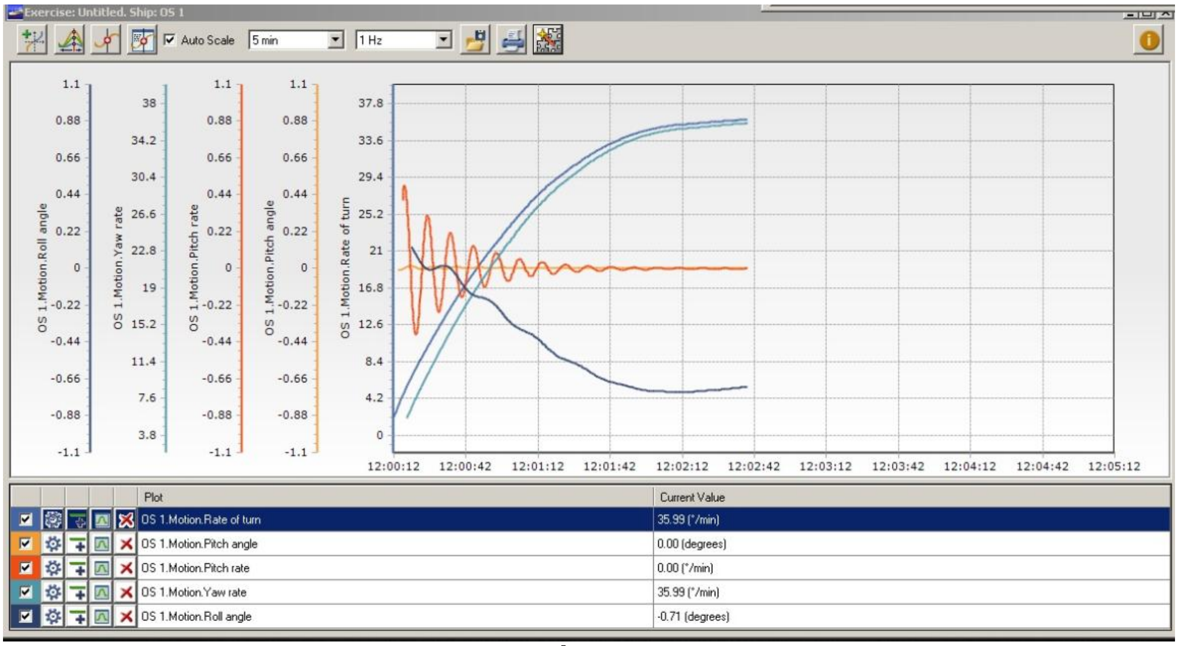

Figure 3. Vessel motion component

As presented in the Figure 2, the actual vessel positions are denoted by orange color and the future vessel is presented with continues blue lines. The pivot point movements within a selected time interval are presented in orange color. Also, the pivot point relationships to the vessel center of gravity are also presented. Furthermore, the respective vessel yaw rate, pitch angle and roll angle are presented in Figure 3 and Figure 4.

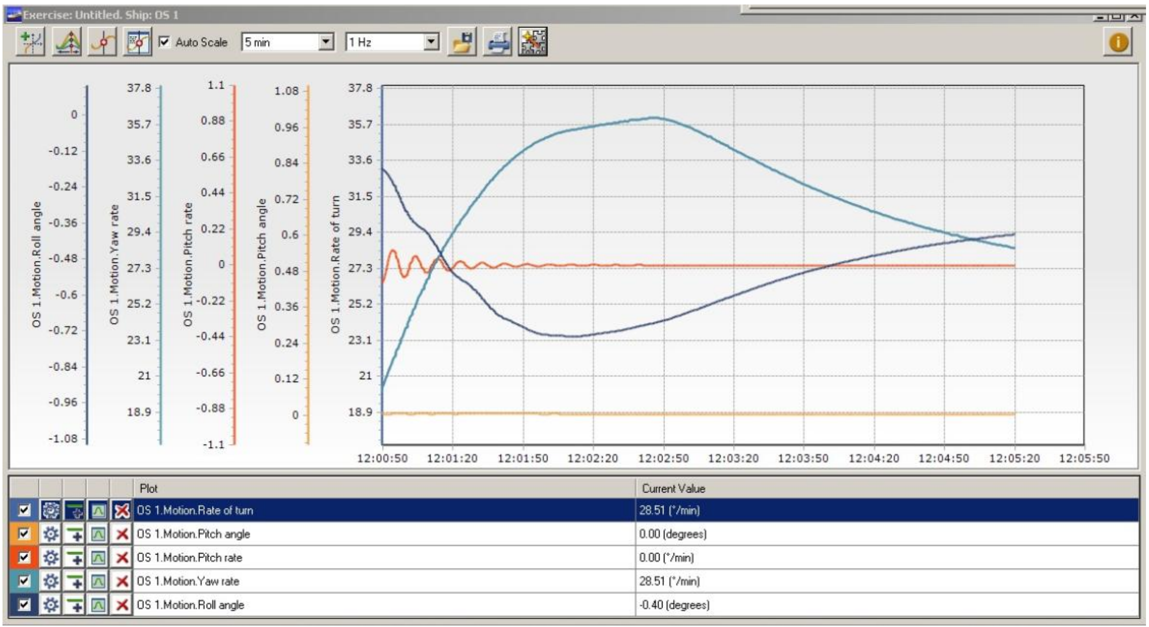

Figure 4. Vessel motion component

As shown in the Figure 3 and Figure 4, Rate of turn and Yaw rate have the same value. Pitch angle and Pitch rate have a constant null value, and Roll angle a negative one.

On the other hand, the movement of Oil tanker is presented in Figure 5-7.

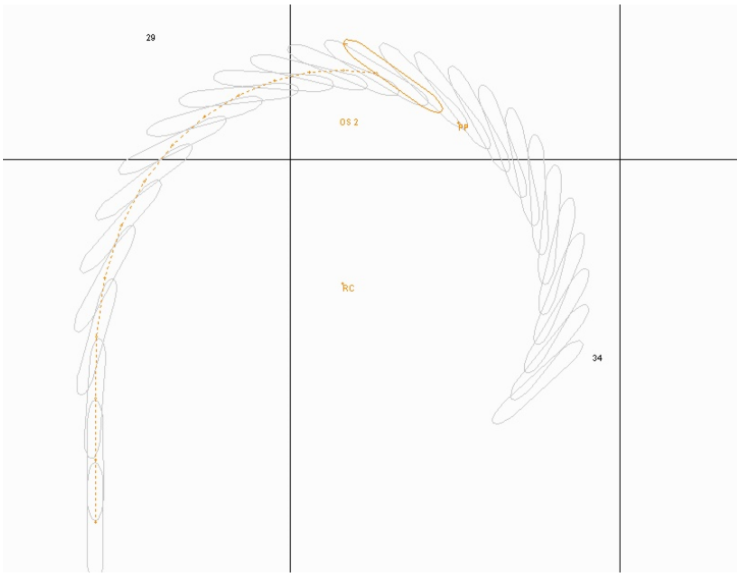

Figure 5. Vessel positions and orientations along the vessel trajectory

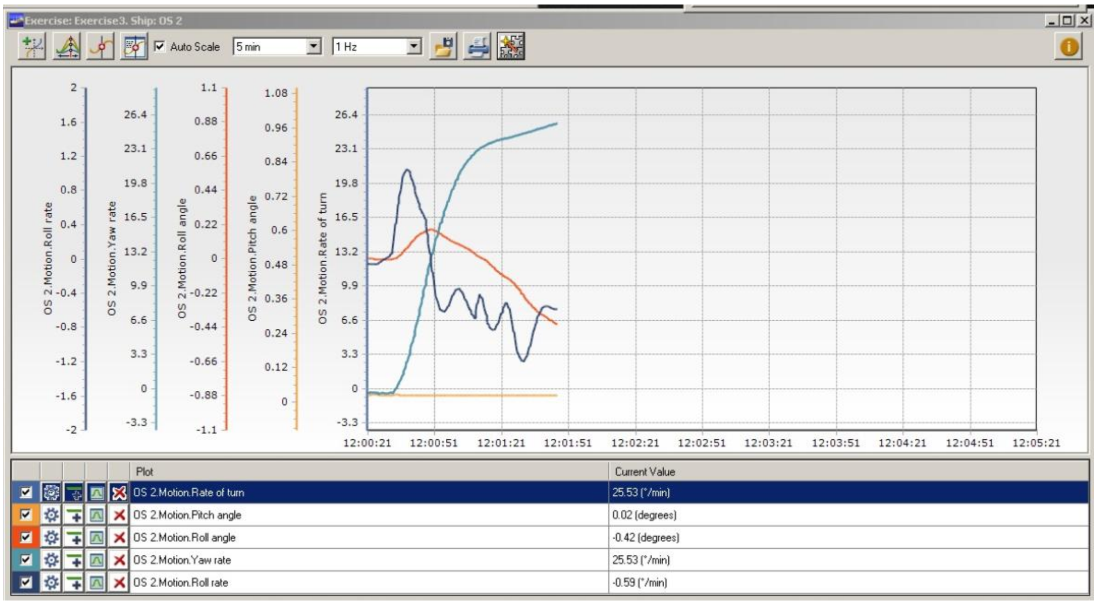

Figure 6. Vessel motion component

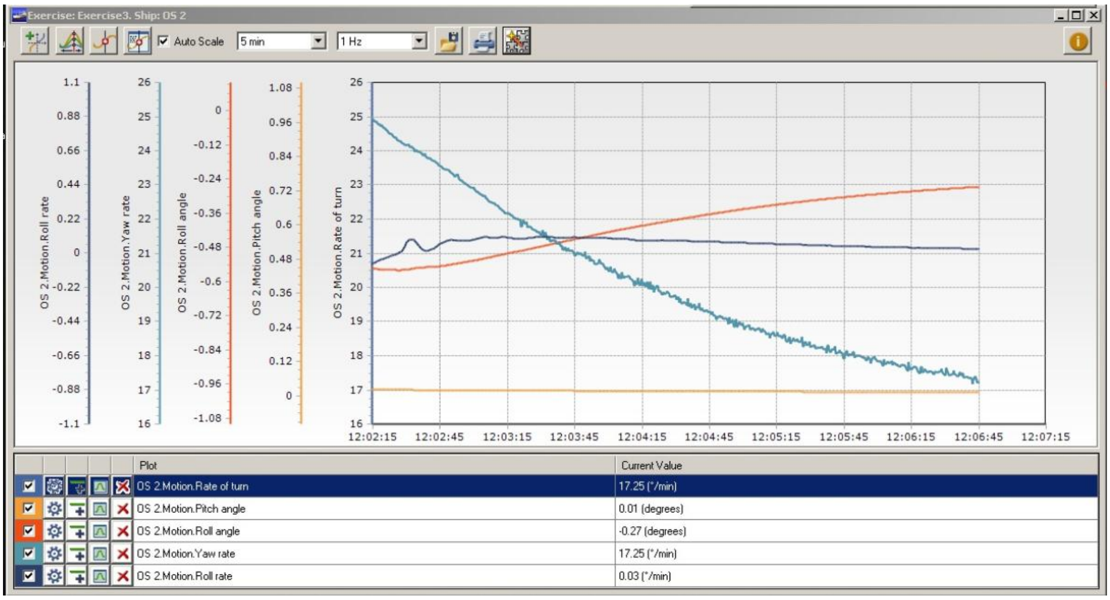

Figure 7. Vessel motion component

Similar to the case of the Chemical tank, is presented the evolution of the Oil tank's movement at time intervals.

5. Conclusion

The estimated vessel position and orientation information can be used for assessing of the prior collision conditions and also can improve the safety of ship navigation. The center of planner motion of the vessel can also change significantly due to various hydrodynamic forces and moments. In the future, is pursued the study of the vessel`s movement under the influence of environmental factors. Therefore, this information should be included into the proposed approach to improve the predictability of future vessel behavior.

Furthermore, it is noted that the pivot point can achieve a steady-state value independent yaw variations, when the vessel is still in the transient phase of a turning maneuver. This helps us to support the accuracy of predicting future vessel behavior. When take into consideration the various hydrodynamic forces and moments, the center of gravity of the vessel can change significantly.

Therefore, these challenges and influence of hydrodynamic forces and moments will be included in the future work to improve the accuracy in the predicted trajectory represented by the vessel position and orientation of the vessel.

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