Study on Costal Intelligent Navigation System

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***Abstract*—The safety and economy of ship transportation is always an important issue in the shipping worlds. Due to complex natural conditions, relatively narrow navigable range and high traffic density, coastal navigation is usually not only an accident-prone area but also the low shipping efficiency. Therefore, an intelligent navigation system for coastal sailing based on numerical forecasting of environmental factors and simulation of ship's motion is put forward. Take the effects of tidal current as an example, the construction and realization approach of the system is discussed. In view of tow key problems of system implementation, the tidal current distribution in coastal waters is successfully predicted by using POM, and the simulation of ship's motion in the real-time tidal current fields was conducted based on MMG. The results show that this method of navigation system is feasible.**

Keywords-coastal navigation; numerical forecasting; navigation simulation

I. INTRODUCTION

Taking advantage of its powerful transport capacity, ship transportation has made a significant contribution for world economics' development. The ship will be influenced by the weather and sea conditions during the whole voyage, which may cause ship's deviation form the plan route, speed loss, low efficiency of navigation, even lead to collision, grounding or other marine accidents. Therefore, how to ensure the safety of navigation and increase economic efficiency is always one of the important issues in the shipping worlds.

With the changes of ship's upsizing and specialization, further stringent requirements of environmental protection and increased competition in the shipping industry, safer navigation and more economical transportation are required. Compared with transoceanic sailing, coastal navigation is usually a shorter voyage, and its navigation range is relatively narrow, for this reason, the research on coastal navigation is often neglected. In fact, the coastal waters are accident-prone areas due to high traffic density and complicated natural conditions. Meanwhile, with the flourishing coastal trade, even a short-distance sailing, its cumulative economic effect is great, especially in today that the cost of fuel keeps rising. Hence a smart solution for safe and economic costal navigation is necessary and urgent.

II. CONSTRUCTION OF COASTAL INTELLIGENT NAVIGATION SYSTEM

While any environment factors may change the status of a ship's transit, it is considered that the wind, tidal current, and waves are the most important ones for ship navigation. In the past, while establishing a sailing plan, the weather and sea conditions in navigable waters was obtained by statistically analyzing the historical observation data of meteorological and hydrological factors. And on this basis, the ship's deviation and speed loss were estimated combined with the ship seakeeping tests[1].

The deficiencies in the method above are mainly manifested in two aspects. First, the judgments of weather, sea conditions on navigable waters is based on historical observation data, such as the annually or monthly average values recorded in nautical charts, hydrographic publications, various weather charts, and wave charts. This static information is the result of long-term observation and statistical analysis, reflecting the average level over a long period of time. This may be feasible for transoceanic sailing, but can not meet the needs of short voyage along the coast. Because the coastal voyage is usually only 2 or 3 days, weather and sea characteristics on such a short period of time are often covered by long-term average and can not reflect the actual state when sailing. Second, the estimation of ship's deviation and speed loss based on empirical formula has a large error, and is insufficient to satisfy a requirement of coastal navigation. In order to achieve the safe and economic coastal navigation, more accurate meteorological and hydrological information is required, and on the other hand, the effects of weather, sea conditions on ship movements must be more scientifically determined.

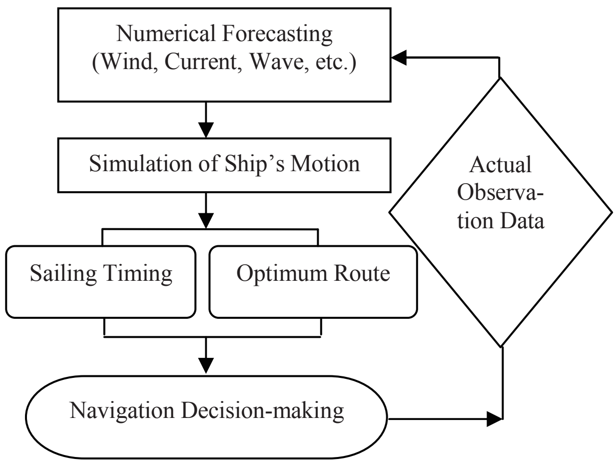

Figure 1. Flow chart of coatal intelligent navigation system

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Therefore, an intelligent navigation system for coastal sailing based on real-time weather and sea information and navigation simulation is put forward, as in Fig. 1.

The process of the system is as follows:

1) Numerical forecasting: Before sailing, the present observation information of weather and sea status is analyzed combined with the historical statistic data. Then, using above data as an initial conditions, the meteorological and hydrological factors on the possible navigable waters are numerical calculated by computer, thus the distribution of the environmental factors on the future voyage can be known in advance.

2) Navigation simulation: As the external factors, the real-time environmental data forecasted above was input into the mathematical model of ship's motion and navigation simulation is carried out. So that their influences on ship's motion are found, such as speed loss, deviation and so on. Furthermore, different track can be got by setting a different sailing time or initial course.

3) Navigation decision-making: A set of simulated tracks can be obtained by conducting simulation above for many times. Among these, the best sailing time and optimum route can be choose based on the optimization theory.

In addition, the weather and sea state information can be real-time updated by actual observation data during sailing. If necessary, such numerical forecast and navigation simulation can carry out again to amend the navigation plan.

It can be predicted that this system can effectively support the ship management department or the master to make shipping decision or establish sailing plan. The safety improvement and economic benefits it brought are worth to be expectation.

III. REALIZATION OF COASTAL INTELLIGENT NAVIGATION SYSTEM

Generally speaking, the effect of tidal current on coastal navigation is most significant among that of wind, current and wave. As present, only tidal current is discussed to explain the realization of the costal intelligent navigation system. At the same time, because the route optimization theory is relatively mature, two key issues in system implementation are studied: numerical forecasting of tidal current and ship's motion simulation.

A. Numerical Forecasting of Tidal Current in Coastal waters

To predict the distribution of tidal current in coastal waters, the Princeton Ocean Model (POM)[2] is adopted. By using σ coordinates in the z-axis, POM has a strong ability to handle complex seabed topography of the coastal waters and can predict the tidal current with high accuracy. The σ coordinates comes from conventional cartesian coordinate as shown in (1).

$$\sigma = \frac{z-\eta}{H+\eta}, \qquad D \equiv H+\eta \tag{1}$$

where z is the cartesian coordinate; H is the bottom topography and η is the surface elevation. After conversion to sigma coordinates in the z-axis, the basic equations of POM are as follows:

$$\frac{\partial DU}{\partial x}+\frac{\partial DV}{\partial y}+\frac{\partial \omega}{\partial \sigma}+\frac{\partial \eta}{\partial t}=0 \tag{2}$$

$$\begin{aligned}&\frac{\partial UD}{\partial t}+\frac{\partial U^2D}{\partial x}+\frac{\partial UVD}{\partial y}+\frac{\partial U\omega}{\partial \sigma}-fVD+gD\frac{\partial \eta}{\partial x}\\&+\frac{gD^2}{\rho_0}\int_\sigma^0\left[\frac{\partial \rho'}{\partial x}-\frac{\sigma'}{D}\frac{\partial D}{\partial x}\frac{\partial \rho'}{\partial \sigma'}\right]d\sigma'=\frac{\partial}{\partial \sigma}\left[\frac{K_M}{D}\frac{\partial U}{\partial \sigma}\right]+F_x\end{aligned} \tag{3}$$

$$\begin{aligned}&\frac{\partial VD}{\partial t}+\frac{\partial UVD}{\partial x}+\frac{\partial V^2D}{\partial y}+\frac{\partial V\omega}{\partial \sigma}+fUD+gD\frac{\partial \eta}{\partial y}\\&+\frac{gD^2}{\rho_0}\int_\sigma^0\left[\frac{\partial \rho'}{\partial y}-\frac{\sigma'}{D}\frac{\partial D}{\partial y}\frac{\partial \rho'}{\partial \sigma'}\right]d\sigma'=\frac{\partial}{\partial \sigma}\left[\frac{K_M}{D}\frac{\partial v}{\partial \sigma}\right]+F_y\end{aligned} \tag{4}$$

where x, y is the Cartesian coordinates; t is time; U, V is respectively the horizontal and vertical speed component of current; ω is the vertical speed in the σ coordinate; F is the coriolis coefficient; g is acceleration of gravity; F_x , F_y are the viscous diffusion coefficient in the horizontal direction; K_M is the vertical kinematic viscosity.

Based on POM, the tidal current in Osaka Bay, an example of coastal water shown in Fig. 2, is forecasted. Osaka Bay is relatively enclosed coastal water, the tidal current flows in or flows out Osaka Bay from the Akashi Strait and Tomogasima waterways. In order to improve the stability of numerical calculation, the open boundary of calculation domain extended to the south of Tomogasima and the entrance of the Seto inland sea.

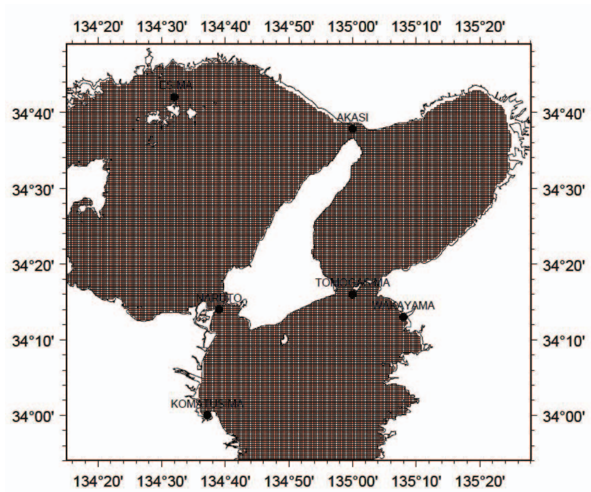
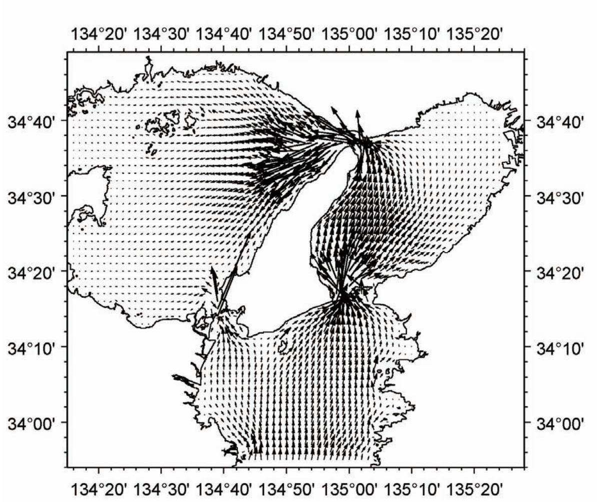
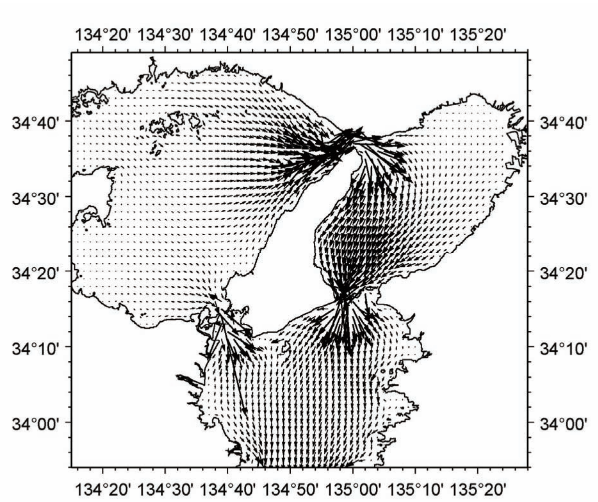


Figure 2. Calculaion domain and grid setting



(a) Flood tide



(b) Ebb tide

Figure 3. Tidal current distribution in calculaion domain

In calculation, the rectangular grid was used in horizontal direction, grid interval is 0.25 '(about 463m), grid number in x, y and z direction, are 293, 221 and 10, respectively. M_2 tide is used as an initial boundary condition. The other calculation conditions were set as: calculation time: 60 hours, about 5 periods of M_2 tide; time interval, 60 seconds. Fig. 3 shows the calculated distribution of tidal current, (a) for the flood tide, and (b) for the ebb tide. On flood tide, the tidal current flowed into Osaka Bay through the Tomogasima from the Pacific Ocean. When the tide was ebbing, it was the exact opposite. Comparing the calculated results in the specified locations with tidal current obtained by harmonic constants of M_2 tide, their consistency can be verified[3]. When necessary, the relevant parameters can be modified to achieve required accuracy of navigation simulation[4].

B. Numerical Simulation of Ship's Motion

In order to master correctly the ship's drift and speed loss caused by the tidal current, the MMG[5] mathematical model of ship's maneuvering motion was adopted. MMG deduces ship's movement through calculating the effect of fluid forces on the hull, and is widely used in the simulation of ship maneuvering performance. At hull fixed coordinate system, the basic equations of MMG are written by (5).

$$\left.\begin{aligned}(m+m_x)\dot{u}-(m+m_y)vr&=X\\(m+m_y)\dot{v}+(m+m_x)ur&=Y\\(I_{zz}+J_{zz})\dot{r}&=N\end{aligned}\right\}\tag{5}$$

where m is the mass; m_x and m_y are the added mass; u, v are the speed components in the x-axis and the y-axis respectively; r is the angular speed. I_{zz} and J_{zz} are the moment of inertia and the added moment of inertia around G, respectively; X and Y are the hydrodynamics forces, and N is the moment around the z-axis.

According to the MMG model, the hydrodynamic forces and the moment in the above equation can be written as (6).

$$\left.\begin{aligned}X&=X_H+X_P+X_R+X_T+X_A+X_W+X_E\\Y&=Y_H+Y_P+Y_R+Y_T+Y_A+Y_W+Y_E\\N&=N_H+N_P+N_R+N_T+N_A+N_W+N_E\end{aligned}\right\}\tag{6}$$

where the subscripts H, P, R, T, A, W, and E denote the hydrodynamic force or moment induced by the hull, propeller, rudder, thruster, air, wave, and external forces, respectively.

The hydrodynamic forces caused by the tidal current are defined in (7).

$$\left.\begin{aligned}X_H&=1/2\rho LdU^2\left(X'_{vv}v'^2+X'_{rr}r'^2\right.\\&\quad\left.+X'_{vr}v'r'+X'_{vvvv}v'^4\right)-R\\Y_H&=1/2\rho LdU^2\left(Y'_v v'+Y'_r r'+Y'_{vvv}v'^3\right.\\&\quad\left.+Y'_{vvr}v'^2r'+Y'_{vrr}v'r'^2+Y'_{rrr}r'^3\right)\\N_H&=1/2\rho LdU^2\left(N'_v v'+N'_r r'+N'_{vvv}v'^3\right.\\&\quad\left.+N'_{vvr}v'^2r'+N'_{vrr}v'r'^2+N'_{rrr}r'^3\right)\end{aligned}\right\}\tag{7}$$

where ρ is the density of sea water, L is the length of the ship, d is the draft, U is the ship's speed, $v'=v/U$, $r'=rL/U$, R is the resistance of the hull, Y'_v, Y'_r, N'_v, N'_r are linear derivatives, X'_{vv}, X'_{rr}, X'_{vr}, X'_{vvvv}, Y'_{vvv}, Y'_{vvr}, Y'_{vrr}, Y'_{rrr}, N'_{vvv} N'_{vvr} N'_{vrr} N'_{rrr} and are non-linear derivatives.

Fig. 4 shows an example of navigation simulation, in which the ship's course was set to 000^{o}, ship speed 12 knots, sailing time 1.5 hours. The arrows indicate the tide vector predicted by POM. Solid line shows the dead-reckoning track which does not take the tidal current effects into consideration. Dashed line shows the simulated track based on MMG.

As the tidal current is constantly changing over time, different sail time or initial course will get different simulated tracks.

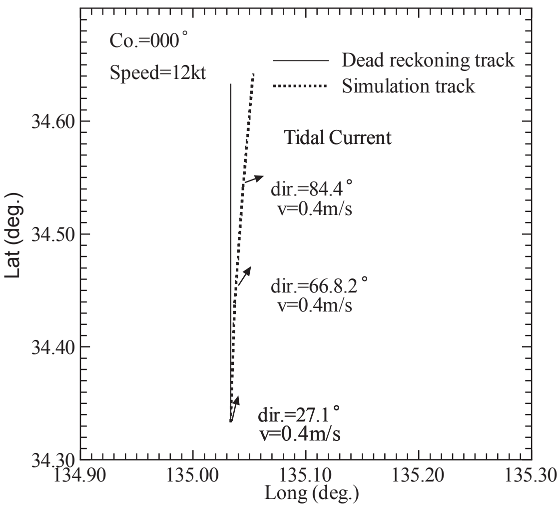


Figure 4. Simulated track in the tidal current field

On this basis, the best sailing timing or optimum route can be determined based on the optimization theory, such as isochrone method, dynamic optimum method and so on.

IV. CONCLUTION

In order to meet the safety and economic needs of coastal navigation, this paper studied the composition and its realization of the intelligent navigation systems on coastal waters. The main conclusions are as follows:

(1) Construct a framework of the intelligent navigation systems for coastal sailing, and taking the effect of tidal current as an example expound its implementation approach.

(2) Conduct the numerical forecasting of the tidal current based on POM model, and obtain the real-time distribution of tidal current in the navigable waters.

(3) Carry out the ship's motion simulation based on MMG model and get the simulated tracks in the dynamic tidal current field, which lay a good foundation for navigation optimization.

However, this is only a preliminary study on coastal intelligent navigation system. Further studies should be done on the forecasting of wind, wave and other environmental factors and their integration.

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