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The simulation of east-bound transoceanic voyages according to ocean-current sailing based on Particle Swarm Optimization in the weather routing system

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ABSTRACT

In this study, a Particle Swarm Optimizing (PSO) method would be applied to the dynamic routing algorithm of our original three-dimensional modified isochrone (3DMI) method for improving efficiencies of time and fuel consumption by ocean-current routes in the North Pacific Ocean. By comparing the east-bound voyages based on the Ocean-Current (OC) sailing with the ones based on the Great-Circle (GC) sailing in case of dynamic environments, performances of ocean-going ships would be presented including the safety factor, *i.e.* significant roll response. The ship weather routing system is essentially constructed by four modules, consisting of ship-motion module, ocean-environmental module, navigation module and routing-optimization module. After establishing the database of 6-DOF motion response for different combinations of ship courses and sailing speeds from the ship-motion module, ship performances can be estimated according to the encountered sea state interpolated by weather forecasting data from the ocean-environmental module. For different purposes of navigation, the reference routes can be subsequently determined by the Navigation module according to the selection of GC or OC sailing. Eventually, the optimal routes are obtained by setting objectives and constraints in the objective function of the routing-optimization module.

1. Introduction

The Kuroshio Current, also known as the Black Stream, begins off the east coast of East and Southeast Asia island arcs and flows northeastward past Japan, where it merges with the Oyashio Current into the North Pacific Current. Although the Kuroshio is one of the major currents in the ocean, and plays a significant part in the circulation of the North Pacific, it is only a thin narrow band less than one hundred kilometers in width and about one kilometer at maximum depth along the western edge of the Pacific. Current velocity and direction not only vary with season, but also vary in different ways from place to place along the path. When the Kuroshio leaves the east coast of Japan, it begins to turn toward the east with intense flows. This narrow intense flow in this region is termed as Kuroshio extension, which is different from the Kuroshio as a result of no land boundaries.

Like the ship routing in the North Atlantic Ocean, which is probably the region with intensive traffic by taking favorable or avoiding opposed Gulf Stream, it would be beneficial to plan energy-efficient or time-saving routings along the Kuroshio route, especially for eastbound transoceanic voyages in the Pacific Ocean. Benjamin Franklin was the one drawing the first map of the Gulf Stream to expedite voyages between Europe and USA in 1769 based on information provided by the captain of a whaling ship [1]. In

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the mid-19th century, for the first time, M. F. Maury used weather and ocean-current records compiled from log books, combined with a large amount of seasonal data to choose appropriate routes and define required routes in the special sea areas [2]. Lo and McCord [3] suggested that average fuel savings of 7.5% when riding favorable currents and 4.5% when avoiding unfavorable currents for vessels in the Gulf Stream could be reached by using fine-resolution current estimates. Subsequently, Lo and McCord [4] implemented a numerical study to compare the performance of their adaptive-probabilistic formulation with the one of deterministic formulation in an area of the Gulf Stream. For the eastbound voyages riding favorable currents or the westbound voyages avoiding unfavorable currents, their adaptive-probabilistic approach was generally better than the deterministic approach.

The ship weather routing system can be defined as a procedure used to determine an optimal route based on weather forecasts, the characteristics of a specific ship, and sea states for a particular voyage [5–7]. The optimal route can be regarded as the voyage route providing the most safety and comfort [8,9], fatigue estimation [10–12], maximum energy efficiency [6,13,14], minimum time consumption [15,16], or combinations of these factors [5,17] under the anticipated weather conditions. The reliability of the optimal route derived from a ship weather routing system is based on the following parameters: (i) the accuracy of the estimation of ship hydrodynamics [18], (ii) the quality of the weather forecasting data [19], and (iii) the applicability of ship routing optimization [10].

The optimization of ship routing algorithms along with the precise weather forecasting data and ship characteristics has been developed and evaluated. Routing algorithms can be roughly divided into Dynamic Programming [20], Environmental Algorithms [21], Ship Performance Algorithms [22], and Optimization Algorithms [23–25]. The optimization algorithm based on the Three-Dimensional Modified Isochrone Method (3DMI) was examined in our previous papers [10,26]. The Particle Swarm Optimization (PSO) method, which was originally attributed to J. Kennedy and R. C. Eberhart in 1995 [27], was modeled based on the social behavior of birds. In engineering applications, J. E. Onwunalu and L. J. Durlofsky [28] applied PSO to optimally search for oil and gas, and I. Montalvo and J. Izquierdo et al. [29] applied PSO to optimally search for solutions to a water supply system design problem.

In the present study, PSO-based 3DMI method is used to combine the objective function of passage time and fuel consumption to determine the waypoint and create a mechanism to search for ocean-current trajectories in a routing-optimization module. Through the PSO-based 3DMI method and the OC sailing, the captains or ship owners may have more references to explore the different factors of the route trajectories.

2. System architecture

Fig. 1 shows the architecture of the weather routing system mentioned in this study. The system comprises a ship-motion module, a navigation module (including great circle sailing and ocean-current sailing), ocean-environmental module and routing-optimization module. In addition, the ocean-environmental module provides the ocean environmental data for the system. The data sources

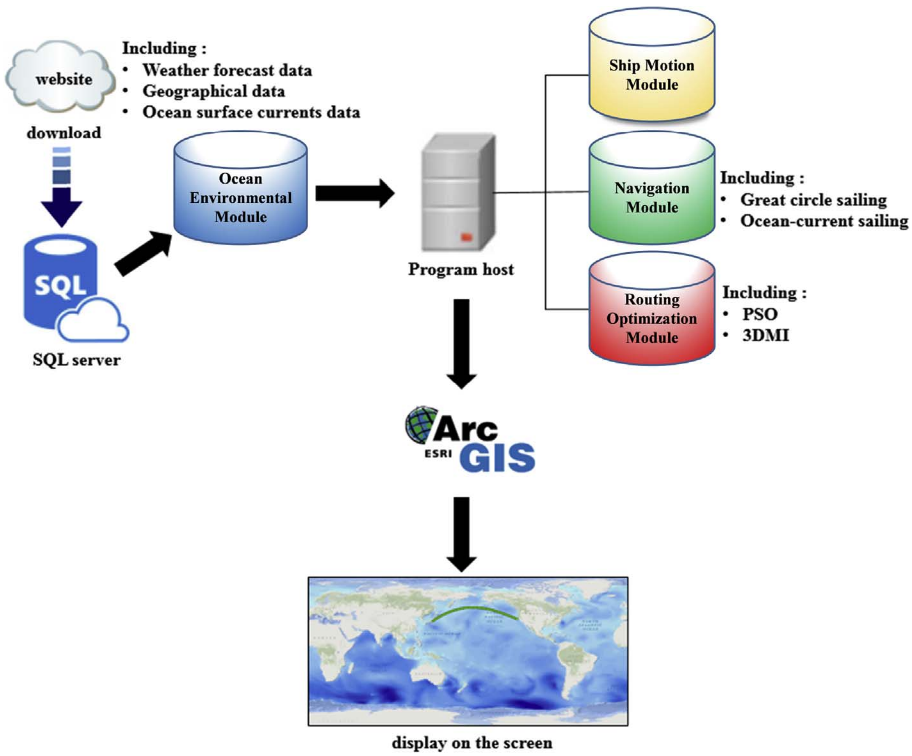

Fig. 1. Sketch of the weather routing system.