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REVIEW ARTICLE

OPTIMAL WEATHER ROUTING BASED ON ADAPTIVE BACTERIA FORAGING ALGORITHM FOR VESSEL

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ABSTRACT

The economic efficiency, energy efficiency, reduce emission, increasing safety and security play a vital role to develop a sustainable shipping fleet. One of important measures to response these requirment is the optimal weather routing system. Because of the vessel routing is influenced by the quality of meteorological and oceanographic data such as wind, waves, and currents. Therefore, In this study an optimal weather routing model (OWR) considers the meteorological and oceanographic information, ship's characteristics combined with adaptive Bacterial Foraging Optimization Algorithm will be proposed and applied for ship' navigation. The simulation results will be presented to show the effectiveness as well as the reliability of this model. The OWR will make it possible for safe navigation, effective operation, energy efficiency and reduce emission from vessel.

KEYWORDS

Modeling optimization, Weather routing, Adaptive BFOA

1. INTRODUCTION

Shipping activities are strictly dependent on the weather conditions, leading to many weather services that has been developed and provided for a large number of vessels nowadays to increase safety and save fuel. Optimal ship routing plays a vital role for the shipping company to be cost-competitive. The aim can be to optimize a vessel voyage concerning safety, voyage duration, energy efficiency, or/and combination of various factors (Hung et al., 2019). Moreover, ship characteristics are mostly considered by the ship's speed profile and fuel consumption in case of different levels of wind, waves, currents or shallow waters, traffic conditions, and other conditions. Nowadays, thank to the science and technology developments in weather forecasting service and the shipping industry, the officers onboard a modern ship has long range weather forecast with reasonable accuracy. However, a vessel's navigation has never been an easy task and traffic accident are still happening mainly due to human errors in judging the information and in making decision in a specific environment.

During the last several decades, different researches have been conducted on the ocean passage voyage, concerning the ship's characteristics and the weather forecasts as well as the choice of mathematical model and algorithm. Potential benefits of the weather routing and voyage optimization system are well studied etc. (Chen et al., 1998; ABS, 2012). The E-navigation program of the International Maritime Organization is also recommendation to apply the weather routing services (IMO, 2016). The aim of weather routing services is to support to ship master to reach minimum time (Bowditch, 2002). Nowadays, the legal air emissions from the vessel and the increasing oil price, weather routing is combined with optimal voyage in order to plan optimum routing and ship's speed, considering the minimum fuel consumption, reaching time arrival, ship's safety (Krata and Szlapczynska, 2018; Walther et al., 2016; Sun et al., 2021; Fang and Lin, 2015; Kosmas and Vlachos, 2012; Lin et al., 2013). Tthe ship's speed or power performance will operate in different conditions (Notteboom and Carriou, 2009; Coraddu et al., 2017). Therefore, In this study an optimal weather routing model (OWR) considers the meteorological and oceanographic information, ship's characteristics combined with adaptive Bacterial Foraging Optimization Algorithm will be propsoced and applied for ship' navigation. This article is organized as follows: Section "Literature review" reviews the previous studies; Section "Methodology" discuss an illustration of used methods; Section describes the model results and implications. Finally, section "conclusion" the empirical findings with some concluding remarks.

2. LITERATURE REVIEW

The weather routing problem was called by various scientists and shipping companies. There are various algorithms that have been developed that can be divided into four categories, including the isochrone method, genetic algorithms, calculus of variation, and dynamic program (Kurosawa et al., 2020; Szlapczynska and Szlapczynski, 2019; Zis et al., 2020). The Isochrones methods and a modified Isochrone have been widely used by weather routing service providers (Dow and Brown, 1977; Inoue et al., S1989; van den Boom et al., 1991). The disadvantages of these approaches note the phenomenon that some point isochrones can currently be stuck at the landmass, resulting from the inability of creating points for the following isochrones from a point surrounded by shores. Furthermore, this method is less or more based on the Dynamic Programming method that is unsuitable for the changing environments over time, which is actually the case we normally go through at sea (Chen et al., 1998; Krata and Szlapczynska, 2018). According to the genetic algorithm is the strong capability for multi-objective optimization, but it normally needs a long-time to get convergent results (Tewari et al., 2008). The Dividing Rectangles algorithms have been present approaches that are to call the attention of scientists (Jones et al., 1993).

The algorithm has a significant impact on the determination of optimal

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vessel routing and solving time. Each optimal method has its pros and cons and may be suitable for specific ships, depending on the requirement of arrival time, ship motion - safety, or/and energy efficiency. The Isochrone method has been widely used for the estimated arrival time of routing plans, limiting value for other variables and constraints. The Dijkstra and Dynamic programming methods could give the optimal routing from the given grid, depending on the grid solutions and computation. The Dijkstra method is really suitable for the coastline routing plan (Wang et al., 2019). Therefore, in order to give the efficiency optimization of weather routing, this article will be proposed a new model for the Optimization of the Vessel Weather Routing by using an adaptive Bacterial Foraging Optimization Algorithm – BFOA (Abd-Elazim and Ali, 2012; Nair and Aruna, 2015; Guo et al., 2021). This model will detect the best route that considers the weather forecasts, ship' characteristics, and energy efficiency. The model is applied to the specific vessel in the South of China Sea for highly rated results.

3. METHODOLOGY

3.1 Optimal Weather Routing Model (OWR)

In this optimal model, the authors set up 3 groups of input data, including *Area of operation*: Establish a safe sea area to operate the vessel from the port of loading to the port of discharge: depth, width, obstacles, etc. *Weather information* such as wind (direction and speed), waves (hight and direction), currents (direction and speed), etc. updated in Realtime from the service provider. *Ship's own maneuvering characteristics*: Revolutions per minute (RPM); draft (ship's draft), trim (the difference of the draft). By listing and recording the results, the authors build a database of changes in vessel's speed under the influence of weather factors (wave, wind, current) in rpm, draft and trim.

3.2 Bacterial Foraging Optimization Algorithm

The bacterial foraging optimization algorithm (BFOA) is an advanced optimization measure introduced by professor (Passino, 2002). In this measure, the initial method was proposed based on the social foraging behavior of the E.coli bacteria in the human intestine. The bacterium should make its foraging decision by considering two factors on the way of finding nutrients, including energy consumption/time factor and signal transduction with others factor. Therefore, the BFOA was proposed to solve these problems with a fast and optimal measure. The BFOA measure is nature-inspired optimization algorithms that have been successfully applied to various majors such as optimal control engineering, network scheduling, image processing, etc. (Pham and Nguyen, 2019). However, it has not been applied to the vessel operation at the sea. The BFOA has been expected efficient solution for various optimization problems (Bermejo et al., 2015; Nair and Aruna, 2015). Normally, the BFOA consists of the following three steps:

Step 1 (Initialization): Initialize the population of the bacteria, in which each bacterium is allocated randomly over the search space.

Step 2 (Evolution): Repeated bacterial colon evolution goes through 3 three-step procedure: Chemotaxis and swarming; Reproduction; and Elimination and Dispersal.

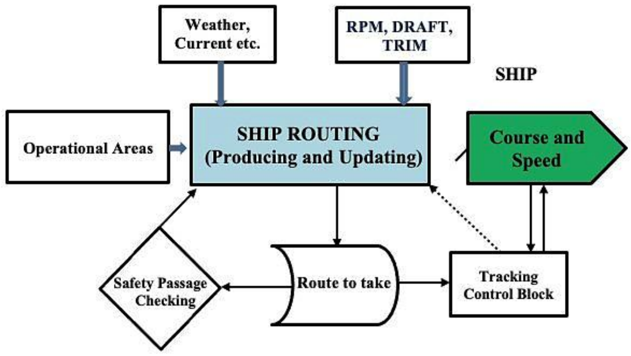
Step 3 (Termination): Returns the option for the best individual bacteria so far, after a certain number of circles of generation evolution.

However, when applying many multi-model functions with different complexity, there are disadvantages of the classical BFOA: The ability to find the optimal value decreases drastically when the number of dimensions is zero, the time to search, or the complexity of the problem increases. Therefore, proposed BFOA which applies 2 changes: The optimal value at each position is used instead of the average value of all steps; The distance of each bacterium to the bacteria corresponding to the best solution found is used as a factor to change the length of the displacement step (slip), thus increasing the convergence rate (Tripathy et al., 2006). Mishra proposed a fuzzy method to determine the optimal step length for the BFO algorithm at each time (Mishra, 2005). A group researchers proposed an alternative in which the flocculation is performed similarly to the particle swarm optimization algorithm, whereby the position of each individual bacteria after each move is moved (Ying Chu et al., 2008). The movement step is decremented after each loop, this algorithm called the Fast Bacteria Swarming Algorithm (FBSA) algorithm (1).

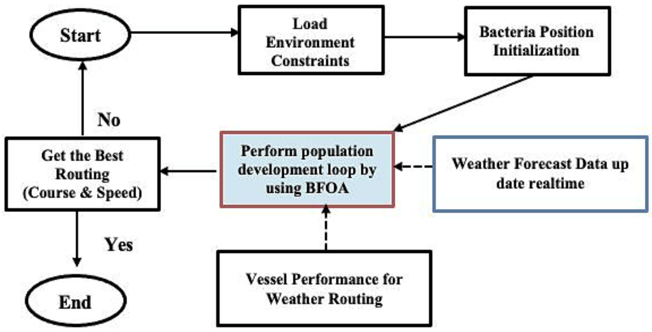
$$if\ Q(S^b(j) < Q(S^i(j+1)\ then\ S^i_{new}(j+1) = S^i_{old}(j+1) + C_{cc}x(S^b(j) - S^i(j)) \quad (1)$$

Where b is the best bacterium in previous chemotacti step, and C_{cc} is an attraction factor.

Similarly, some researchers proposed the Adaptive Bacteria Foraging Optimization Algorithms to adjust the run-length unit parameter dynamically during algorithm execution in order to balance the exploration/exploitation tradeoff (Boughelala et al., 2011). There are also many other modifications to the other BFO algorithm, however, these modifications are application-specific, and there are no general rules for choosing design parameters for the algorithm.



3.3 Applying BFOA to Optimize Weather Routing



The specific voyage of the vessels is a bacterial individual in a set of bacteria which is considered a swarm. According to the rule of BFOA, optimal wether routing based on bacterial colonies that are performed in the following flowchart (Figure 2). *Bacteria Position Initialization:* generated randomly, each bacterium is allocated in a random creation of routing plans. A bacterium position (a solution, a route equivalently) is a combination S of the grid points (one point on each line) as denoted in (2). The search direction (or the tumble of a bacteria) can be expressed as the vector V in (3) and a swim in a direction can be carried out as in (4) with D to be the length (or distance) of swim.

$$S = [p(1), p(2), \dots, p(i), \dots, p(N)] \quad (2)$$

$$V = [v(1), v(2), \dots, v(i), \dots, v(N)] \quad (3)$$

$$S' = S + V.D \quad (4)$$

Select the direction and select WP (Dir) randomly:

$$WP \times Lat = WP \times Lat + Cos(Dir) \times \delta \quad (5)$$

$$WP \times Lon = WP \times Lon + Sin(Dir1) \times \delta \quad (6)$$

Where,

p(i) =[1 to number of points on grid line i^{th}]

v(i) = 0 or v(i) = ± 1

V is vessel speed [kts]

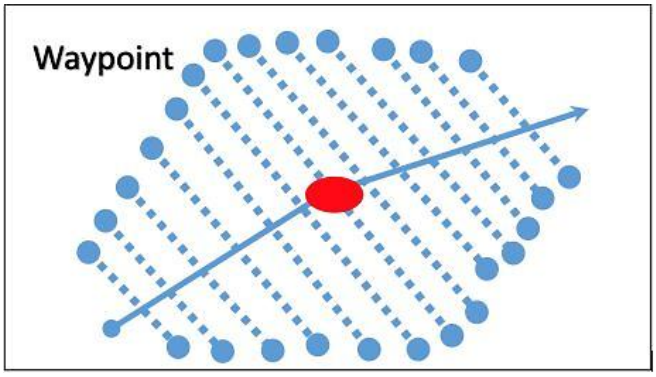
N is number of grid lines

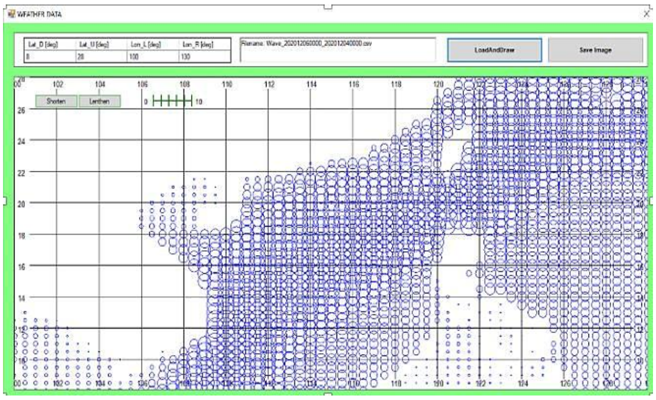
D is the selected swim-length

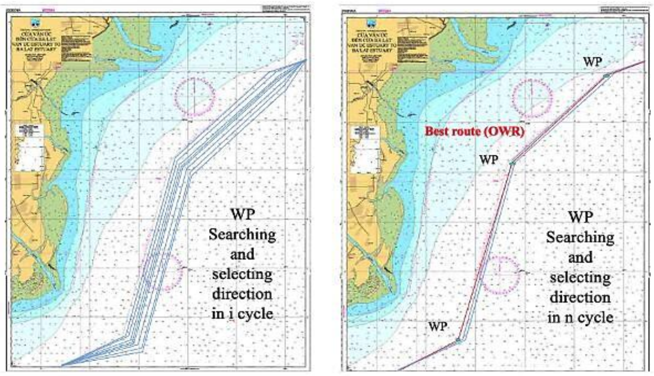
Evolution: Implementing population development loop: local adjustment of searching plans that can be interpreted as using specific loops to adjust the operation areas to the optimal routing by three steps procedure (Chemotaxis and swarming, Reproduction, Elimination, and Dispersal).

Termination: Determining the most suitable bacterial position: After the loops have been implemented, the bacterial colonies have been converged enough and considered the optimal search result for two SAR vessels.

In this research, the weather forecast of up to 72 hours is used to compute the optimal weather routing for a vessel from departure port to the destination port (Vietnam's East Sea). The Figure 3 shows the results of decoding global wave data. The forecast was produced on February 18th 2021 for 6 hour intervals. The results show that the population is distributed over the grid, all the bacteria further converged in a narrow region around the optimal route (Figure 5). The OWR model make various routes and waypoints in the "i cycle" (see Figure 5(a)) and the best route after "n cycle" (see Figure (5b)) considers the meteorological and oceanographic information (win, current, wave, etc.), ship's characteristics using adaptive Bacterial Foraging Optimization Algorithm. This model will make it possible for safe navigation, effective operation, energy effiency and reduce emission from vessel. The OWR method is the best model to the option the vessel routing by the uniqueness of the BFO algorithm.







(a) (b)

4. Conclusion

The optimal routing for a vessel is warm welcome by most people-based on the shipping industry, because of the real benefits that it brings, including cost and time saving, enhancing security and safety level as well as fuel-saving and reduction of air emission in shipping. Therefore, in this study, a model for adaptive BFOA has been proposed and applied for optimal weather routing for vessels. In order to improve the efficiency of the searching algorithm, several modifications have been suggested, taking into consideration the important aspects. An adaptive moving length algorithm is suggested to improve the convergence speed and capacity of the bacteria to jump out of the attractive regions of local optimization. This adaptive BFOA is efficient for optimal weather routing purposes that is possible to apply in realtime. The results have shown that the adaptive BFOA is really reliable and energetic measure. It is expected to be able to good support for captain, the shipping company in the efficient operation of the vessel, safety, saving fuel, and reducing air emissions.

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