

# Ship routing optimization using bacterial foraging optimization algorithm for safety and efficient navigation

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## ABSTRACT

Efficient operation plays a vital role to develop a sustainable shipping fleet with cost competitive. The requirements for economic efficiency, energy efficiency, reducing emissions, and increasing safety and security lead to an innovative model in the optimal weather routing system. The vessel routing is influenced by the quality of meteorological and oceanographic data such as wind, waves, and currents. In this study, the model optimization of weather routing considers the meteorological and oceanographic information, ship's characteristics combined with an adaptive bacterial foraging optimization algorithm (BFOA) will be introduced and applied to the ship's navigation at sea. The simulation results will be evaluated the effectiveness and reliability of the model. This model will support ships' navigation to be safer and more comfortable, operate more efficiently and reduce emissions.

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## 1. INTRODUCTION

Shipping activities play a vital role in the development of the global economy. However, a vessel's navigation has always been a difficult and complex task. There are many marine traffic accidents that still occur mainly due to human error in information judgment and decision-making in a specific context. In the past, there have been a number of studies that have been carried out on ship routing, concerning the ship's characteristics and the weather forecasts as well as the choice of mathematical model and algorithm. The potential benefits of weather routing in navigation and its optimization are well studied in [1]–[4]. The aim of weather routing services is to support to ship master [5], [6] to reach minimum time. Nowadays, with the legal air emissions from the vessel and the increasing oil price, various optimal voyage is combined with weather routing measures [7]–[9] in order to support making optimum routing and ship's speed [10], considering the minimum fuel consumption [11], reaching time arrival, and ship's safety [12]. Therefore, the ship's speed or power performance will operate in different conditions [13]–[15].

The weather routing problem was called by various scientists and shipping companies. There are various algorithms that have been developed can be divided into four categories, including the isochrone method, genetic algorithms, calculus of variation, and dynamic program [3], [11], [16]. The isochrones methods and a modified isochrone [17]–[20] have been widely used by weather routing service providers around the world. The disadvantages of these approaches note the phenomenon that at some point isochrones can currently be stuck at the landmass, resulting from the incapability of creator points for the isochrones. What is more, this method is less or more based on the dynamic programming measure that is unsuitable for the

changing environments over time, which is truly the case we normally go through at sea [1], [11]. The genetic algorithm is a strong capability for multi-objective optimization, but it normally needs a long-time to get convergent results [21]. The dividing rectangles algorithms [22] have presented approaches that are to call the attention of scientists. The algorithm has a significant impact on the determination of optimal 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 [6], [14], [23]. The isochrone measure has been widely used for the estimated arrival time of routing plans, limiting value for other variables and constraints. The Dijkstra and dynamic methods could give the optimal routing for the coastline routing plan from the given grid, depending on the grid solutions and computation [13], [14].

Therefore, this article will be proposed a new efficient and safe navigation model (ES-NAV) for the optimization of vessel weather routing in real-time by using an adaptive bacterial foraging optimization algorithm (BFOA) [24], [25]. In this model, the swarm intelligence-based optimization techniques will detect the best route in real time that considers the ship's characteristics, energy efficiency, and weather forecasts. The model is applied to the specific vessel in the South China Sea for highly rated results.

This article is organized into 4 sections. Section 1, Introduction, reviews the previous studies. Section 2 discusses the optimization techniques, the method, and an illustration of the used methods and model. Section 3 describes the model results and implications. Finally, the section conclusion the empirical findings with some concluding remarks.

## 2. OPTIMIZATION TECHNIQUES

The BFOA is an enhanced optimization measure introduced by Passino, a professor of electrical engineering at the Ohio State University (USA) [26]. In this measure an optimization technique of searching based on an evolutionary process. It is proposed based on the foraging behavior of the *Escherichia coli* (*E. coli*) bacteria living in the human intestine. The bacterium should make its foraging decision by considering two factors in the way of finding nutrients, including energy consumption/time factor and signal transduction with other factors. Therefore, the BFOA was proposed to solve these problems with a fast and optimal measure.

The BFOA measure is a nature-inspired optimization algorithm that has been successfully applied to various majors such as optimal control engineering, network scheduling, and image processing [27], [28]. Until now, this measure has not been applied to the navigation of ships at sea. The BFOA has been an expected efficient solution for various optimization problems [25], [27], [28]. Normally, the BFOA consists of three steps.

- a. Initialization: bacterial population initialization, in which each bacterium is randomly allocated on the finding space.
- b. Evolution: repeated bacterial colon evolution goes through the main four-step.
  - Chemotaxis consists of two processes, swimming in a predefined direction and tumbling in different directions, which are characteristic of the movement of bacteria in search of food.
  - Swarming: bacteria congregate and move in a concentric fashion with high bacterial densities.
  - Reproduction: the healthier the population replaces the bacteria which get eliminated.
  - Elimination and dispersal.
- c. Termination: returns the option for the best individual bacteria, after a certain number of rounds of generational 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, Tripathy *et al.* [29] 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. Mishra proposed a fuzzy method to determine the optimal step length for the BFO algorithm at each time [30]. Singh *et al.* [31] proposed an alternative in which the flocculation is performed similarly to the particle swarm optimization (PSO) algorithm, whereby the position of each individual bacteria after each move is moved. The movement step is decremented after each loop, this algorithm is called the fast bacteria swarming algorithm (FBSA) (1).

$$\text{If } Q(S^b(j)) < Q(S^i(j+1)) \text{ then } S^{i-new}(j+1) = S^{i-old}(j+1) + C_{CC} X(S^b(j) - S^i(j)) \quad (1)$$

where  $b$  is the best bacterium in the previous chemotactic step, and  $C_{CC}$  is an attraction factor.

Similarly, Guo *et al.* [32] 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. 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. METHOD

In the ES-NAV 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, and obstacles. Weather information such as wind (direction and speed), waves (height and direction), and currents (direction and speed). updated in real-time from the service provider. Ship’s own maneuvering characteristics are revolutions per minute (rpm), draft (ship’s draft), and trim (the difference of the draft). By listing and recording the results, the authors build a database of changes in the vessel’s speed under the influence of weather factors (wave, wind, current) in rpm, draft and trim as shown in Figure 1.

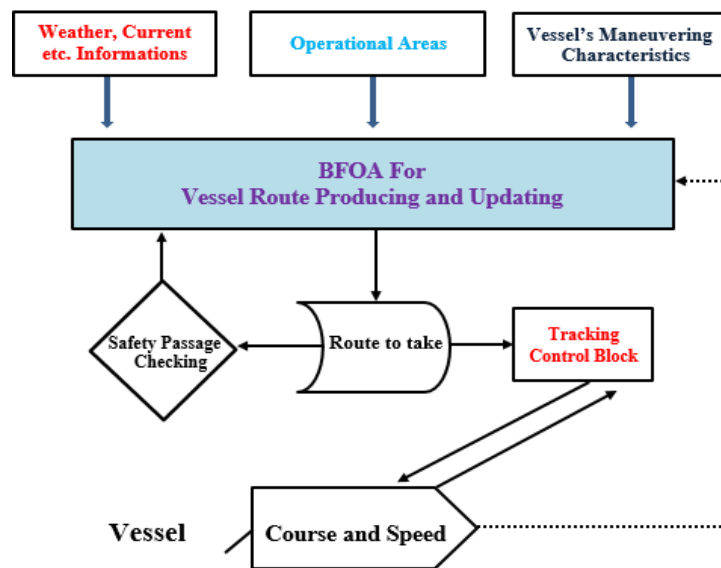


Figure 1. Optimal weather routing for vessel by using BFOA

The specific voyage of the ship is a bacterial individual in a set of bacteria which is considered a swarm. According to the rule of the BFO algorithm, optimal weather routines for bacteria colonies are performed in the flowchart as shown in Figure 2. In bacteria position initialization, it is generated randomly, each bacterium is allocated in a random creation of routing plans. A bacterium position (a solution, a route equivalently) is a combination of  $S$  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.

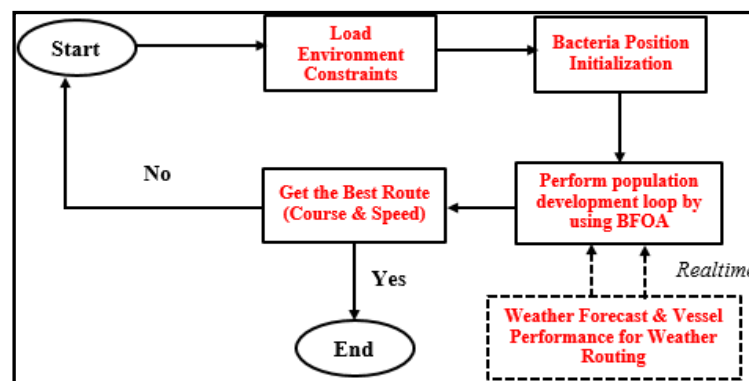


Figure 2. BFOA flow chart of optimal weather routing

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

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

$$S' = S + V * L \quad (4)$$

where  $g(i) = [1 \text{ to number of points on grid line } i^{th}]$ ;  $k(i) = 0$  or  $k(i) = \pm 1$ ;  $k$  is vessel speed [kts];  $N$  is the amount of grid lines; and  $L$  is the selected swimming length.

In the evolution process, it implements development of population loop: local tuning of the search plan can be understood as using specific loops to tune active areas to optimal routing by 4 steps. In termination, after performing the loops, the colonies were sufficiently converged and considered the optimal result for ship, determining the most suitable bacteria location.

#### 4. RESULTS AND DISCUSSION

In this research, the weather forecast information and ship's parameters are continuously updated and applied to calculate the optimal weather routing for a vessel from the port of departure to the destination port (Vietnam's East Sea). The data processing was performed in 3 steps.

Step 1: Collecting data

In this study, the wave and wind data were collected from wave-wind report of Research Institute for Sustainable Humanosphere (RISH), Kyoto University, Japan by gridded binary files or general regularly distributed information in binary form-Grib files [33]. The current data were collected from Ocean Surface Current Analysis Real Time (OSCAR) project by Jet Propulsion Laboratory Physical Oceanography, California technology Institute, USA, global flow forecasting and analysis database system stored in netCDF format (format network common data form) [34].

Step 2: Data decryption

The current data of OSCAR is in the netCDF file. Win-wave data of RISH is in the Grib file. Two files were decoded by using software. They were developed from Visual Basic 2010 platform as shown in Figures 3 and 4.

Step 3: Applying BFOA to optimize

In order to find the best ship routing, a computer program has been developed based on the BFOA algorithm. The waves, wind, and current data were entered into a computer program. This program supports to calculate the best route in a specific course and speed for each distance between two waypoints.

In order to verify the BFOA model, this model was developed to be the optimal route calculation software tested on the M/V gas nirvana as shown in Table 1. The forecast was produced on December 6th, 2020, 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 as shown in Figure 5.

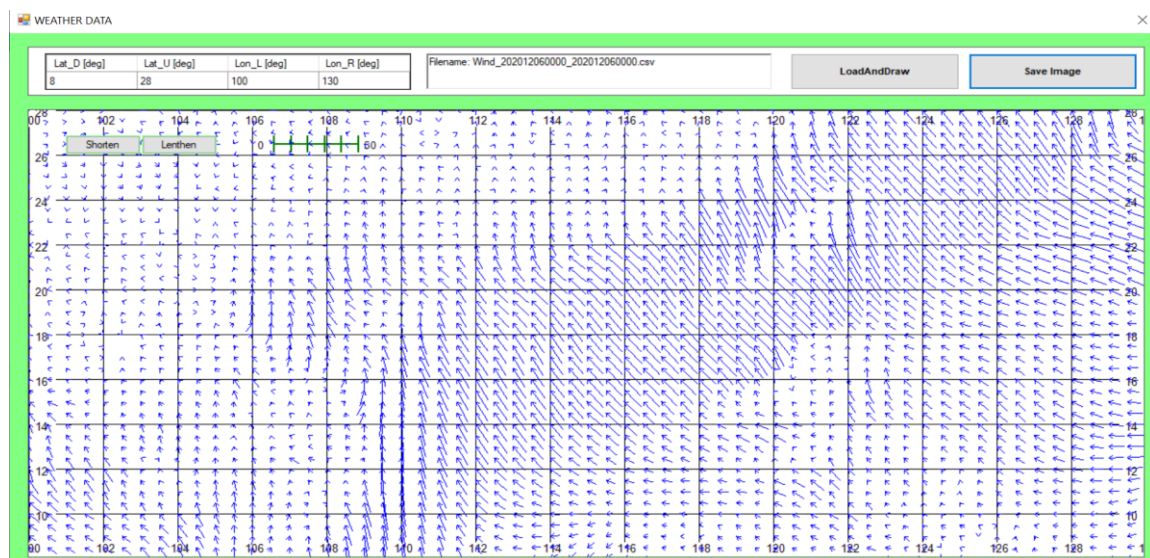


Figure 3. Simulated results of decoding global wind data on Dec. 6, 2020

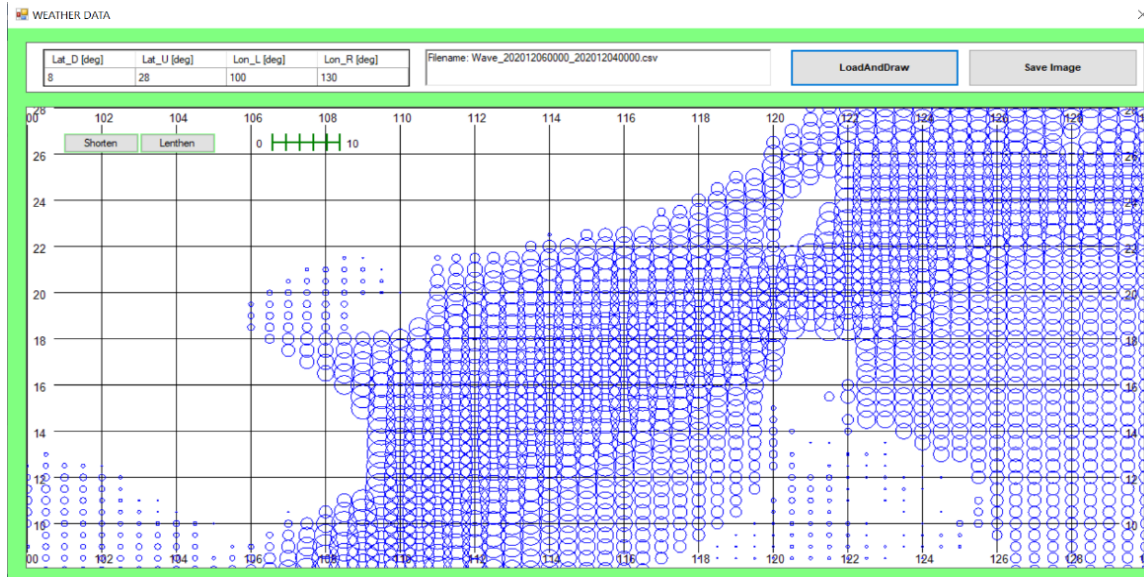


Figure 4. Simulated results of decoding global wave data on Dec. 6, 2020

Table 1. Ship parameters

Ship form parameters	Value
IMO No	9140607
Ship type	LPG Tanker
Length over (m)	105.03
Beam (m)	19.54
Gross Tonnage	4961
Summer Deadweight (t)	5886
Year of Built	1996
k1(kn)	9.0

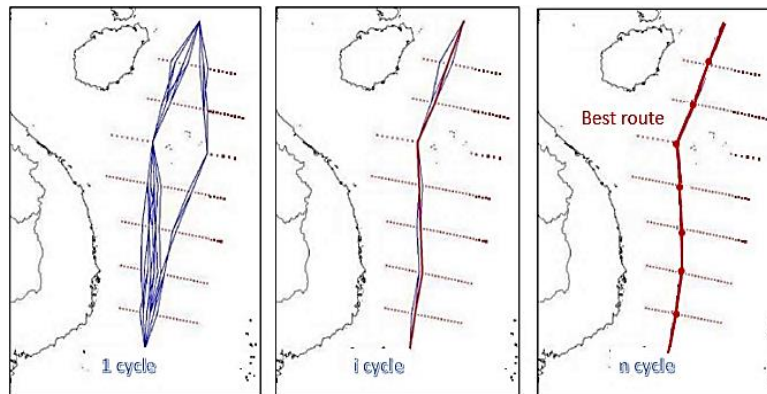


Figure 5. Simulated results of optimal weather routing sample for vessel

The results show that the optimal weather routing using BFOA can save about 10% of fuel consumption compared with normal ship-routing. The currently weather routing method which are assessed by International Maritime Organization (IMO) can reduce fuel consumption by 1 to 10%. Obviously, the BFOA route is more efficient than the currently weather routing methods.

### 5. CONCLUSION

Optimum vessel routing is warmly welcomed by almost everyone in the shipping industry for its real advantages, including time and cost savings, enhanced security and safety as well as saving fuel and reducing emissions in transportation. Therefore, in this paper, a model for adaptive BFOA by improving the efficiency

of the search algorithm has been proposed. The modifications have been proposed, taking into consideration the important aspects. An adaptive length algorithm is proposed to enhance the convergence rate and the bacteria's ability to jump out of the gravitational regions of the local optimization. This adaptive BFOA is effective for real-time applicable optimal weather routing purposes. The results show that adaptive BFOA is indeed a really reliable and energetic measure. This model is forecasted to be able to provide good support to captains and shipping lines in operating ships efficiently and safely, saving fuel, and reducing gas emissions.




## REFERENCES

- [1] H. Chen, V. Cardone, and P. Lacey, "Use of operation support information technology to increase ship safety and efficiency," *SNAME Trans.*, vol. 106, pp. 105–127, 1998.
- [2] J. Cho, G. J. Lim, S. J. Kim, and T. Biobaku, "Liquefied natural gas inventory routing problem under uncertain weather conditions," *International Journal of Production Economics*, vol. 204, pp. 18–29, Oct. 2018, doi: 10.1016/j.ijpe.2018.07.014.
- [3] W. Zhao, H. Wang, J. Geng, W. Hu, Z. Zhang, and G. Zhang, "Multi-objective weather routing algorithm for ships based on hybrid particle swarm optimization," *Journal of Ocean University of China*, vol. 21, no. 1, pp. 28–38, Feb. 2022, doi: 10.1007/s11802-022-4709-8.
- [4] M. Grifoll, L. Martorell, M. Castells, and F. X. M. de Osés, "Ship weather routing using pathfinding algorithms: the case of Barcelona-Palma de Mallorca," *Transportation Research Procedia*, vol. 33, pp. 299–306, 2018, doi: 10.1016/j.trpro.2018.10.106.
- [5] L. P. Perera and C. G. Soares, "Weather routing and safe ship handling in the future of shipping," *Ocean Engineering*, vol. 130, pp. 684–695, Jan. 2017, doi: 10.1016/j.oceaneng.2016.09.007.
- [6] P. V. Hung, K.-S. Kim, L. Q. Tien, and N. M. Cuong, "Distribution of oil spill response capability through considering probable incident, environmental sensitivity and geographical weather in Vietnamese waters," *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, vol. 2, no. 1, pp. 31–41, Nov. 2018, doi: 10.1080/25725084.2018.1511240.
- [7] G. S. Georgiou, P. Nikolaidis, S. A. Kalogirou, and P. Christodoulides, "A hybrid optimization approach for autonomy enhancement of nearly-zero-energy buildings based on battery performance and artificial neural networks," *Energies*, vol. 13, no. 14, Jul. 2020, doi: 10.3390/en13143680.
- [8] J. Zheng *et al.*, "A voyage with minimal fuel consumption for cruise ships," *Journal of Cleaner Production*, vol. 215, pp. 144–153, Apr. 2019, doi: 10.1016/j.jclepro.2019.01.032.
- [9] Q. Sun, Q. Meng, and M. C. Chou, "Optimizing voyage charterparty (VCP) arrangement: Laytime negotiation and operations coordination," *European Journal of Operational Research*, vol. 291, no. 1, pp. 263–270, May 2021, doi: 10.1016/j.ejor.2020.09.032.
- [10] L. Walther, A. Rizvanolli, M. Wendebourg, and C. Jahn, "Modeling and optimization algorithms in ship weather routing," *International Journal of e-Navigation and Maritime Economy*, vol. 4, pp. 31–45, Jun. 2016, doi: 10.1016/j.enavi.2016.06.004.
- [11] P. Krata and J. Szlapczynska, "Ship weather routing optimization with dynamic constraints based on reliable synchronous roll prediction," *Ocean Engineering*, vol. 150, pp. 124–137, Feb. 2018, doi: 10.1016/j.oceaneng.2017.12.049.
- [12] N. M. Cuong and P. V. Hung, "An analysis of available solutions for commercial vessels to comply with IMO strategy on low sulphur," *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, vol. 4, no. 2, pp. 40–47, Apr. 2020, doi: 10.1080/25725084.2020.1784080.
- [13] L. Yang, G. Chen, J. Zhao, and N. G. M. Rytter, "Ship speed optimization considering ocean currents to enhance environmental sustainability in maritime shipping," *Sustainability*, vol. 12, no. 9, May 2020, doi: 10.3390/su12093649.
- [14] K. Wang *et al.*, "A novel method for joint optimization of the sailing route and speed considering multiple environmental factors for more energy efficient shipping," *Ocean Engineering*, vol. 216, Nov. 2020, doi: 10.1016/j.oceaneng.2020.107591.
- [15] X. Li *et al.*, "Model of speed optimization of oil tanker with irregular winds and waves for given route," *Ocean Engineering*, vol. 164, pp. 628–639, Sep. 2018, doi: 10.1016/j.oceaneng.2018.07.009.
- [16] F. X. M. de Osés, E. V. Jarrod, and R. B. López, "A ship routing system applied to the statistical analysis of the western mediterranean wave trends," *Journal of Marine Science and Engineering*, vol. 9, no. 6, May 2021, doi: 10.3390/jmse9060599.
- [17] J. Dow and R. Brown, "Isochrone convergence imaging of pulse echoes," *Ultrasonics*, vol. 15, no. 3, pp. 129–135, May 1977, doi: 10.1016/0041-624X(77)90030-0.
- [18] J. Hu, Z. Cheng, G. Zhong, and Z. Huang, "A calculation method and its application of bus isochrones," *Journal of Transportation Systems Engineering and Information Technology*, vol. 13, no. 3, pp. 99–104, Jun. 2013, doi: 10.1016/S1570-6672(13)60111-7.
- [19] P. Ramond and J. Perez, "New methods of isochrone mechanics," *Journal of Mathematical Physics*, vol. 62, no. 11, Nov. 2021, doi: 10.1063/5.0056957.
- [20] Y. Yang *et al.*, "Performance assessment of sponge city infrastructure on stormwater outflows using isochrone and SWMM models," *Journal of Hydrology*, vol. 597, Jun. 2021, doi: 10.1016/j.jhydrol.2021.126151.
- [21] J. C. Tewari, V. Dixit, B.-K. Cho, and K. A. Malik, "Determination of origin and sugars of citrus fruits using genetic algorithm, correspondence analysis and partial least square combined with fiber optic NIR spectroscopy," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, vol. 71, no. 3, pp. 1119–1127, Dec. 2008, doi: 10.1016/j.saa.2008.03.005.
- [22] J. Zhang and M. Hong, "First-order algorithms without Lipschitz gradient: a sequential local optimization approach," *arXiv preprint arXiv:2010.03194*, Oct. 2020.
- [23] P. V. Hung, K.-S. Kim, and M. Lee, "Cooperative response to marine hazardous and noxious substances and oil spill incidents in the ASEAN region," *Australian Journal of Maritime and Ocean Affairs*, vol. 11, no. 1, pp. 61–72, Jan. 2019, doi: 10.1080/18366503.2018.1559524.
- [24] B. Hernández-Ocaña, J. Hernández-Torruco, O. Chávez-Bosquez, M. Calva-Yáñez, and E. Portilla-Flores, "Bacterial foraging-based algorithm for optimizing the power generation of an isolated microgrid," *Applied Sciences*, vol. 9, no. 6, Mar. 2019, doi: 10.3390/app9061261.
- [25] D. Mohal and S. Sharma, "Enhanced security mechanism using hybrid approach of watermarking," *International Journal of Computer Sciences and Engineering*, vol. 7, no. 2, pp. 176–189, Feb. 2019, doi: 10.26438/ijcse/v7i2.176189.
- [26] N. H. Pham and M. D. Nguyen, "Bacterial foraging algorithm for optimal joint-force searching strategy of multi-SAR vessels at sea," *Test Engineering and Management*, pp. 22213–22222, Mar. 2020, doi: 10.20944/preprints202003.0471.v1.
- [27] N. H. Pham and M. D. Nguyen, "An evolutionary algorithm for optimal multi-direction search route in search and rescue operation," *International Journal on Advanced Science, Engineering and Information Technology*, vol. 9, no. 4, Aug. 2019, doi: 10.18517/ijaseit.9.4.8690.




- [28] P. Bose and M. Gurusamy, "Bacteria foraging algorithm based optimal multi sink placement in wireless sensor networks," *Journal of Intelligent Systems*, vol. 27, no. 4, pp. 609–618, Oct. 2018, doi: 10.1515/jisys-2016-0271.
- [29] M. Tripathy, S. Mishra, L. L. Lai, and Q. P. Zhang, "Transmission loss reduction based on FACTS and bacteria foraging algorithm," in *Parallel Problem Solving from Nature-PPSN IX*, Springer Berlin Heidelberg, 2006, pp. 222–231. doi: 10.1007/11844297\_23.
- [30] J. Li, J. Dang, F. Bu, and J. Wang, "Analysis and improvement of the bacterial foraging optimization algorithm," *Journal of Computing Science and Engineering*, vol. 8, no. 1, pp. 1–10, Mar. 2014, doi: 10.5626/JCSE.2014.8.1.1.
- [31] A. Singh, A. Sharma, S. Rajput, A. Bose, and X. Hu, "An investigation on hybrid particle swarm optimization algorithms for parameter optimization of PV cells," *Electronics*, vol. 11, no. 6, Mar. 2022, doi: 10.3390/electronics11060909.
- [32] C. Guo, H. Tang, B. Niu, and C. Boon Patrick Lee, "A survey of bacterial foraging optimization," *Neurocomputing*, vol. 452, pp. 728–746, Sep. 2021, doi: 10.1016/j.neucom.2020.06.142.
- [33] RISH, "Database of research institute for sustainable humanosphere, Kyoto," *Research Institute for Sustainable Humanosphere*, Kyoto University, [https://www.rish.kyoto-u.ac.jp/category/news\\_en/?lang=en](https://www.rish.kyoto-u.ac.jp/category/news_en/?lang=en) (accessed Dec. 06, 2020).
- [34] JPL NASA, "Ocean surface current analyses real-time (OSCAR) surface currents - Interim 0.25 degree (Version 2.0)." OSCAR\_L4\_OC\_INTERIM\_V2.0, *Jet Propulsion Laboratory Physical Oceanography*, 2020. [http://podacc-opendap.jpl.nasa.gov/opendap/hyrax/allData/oscar/preview/L4/oscar\\_third\\_deg/](http://podacc-opendap.jpl.nasa.gov/opendap/hyrax/allData/oscar/preview/L4/oscar_third_deg/) (accessed Dec. 06, 2020).

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