

Decision-Making in Ship Collision Avoidance based on Cat-Swarm Biological Algorithm

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Abstract. Due to complicated maritime traffic condition, for the sake of offering collision alert and efficient collision avoidance action to mitigate navigators' working burden and fatigue and ensure navigation safety, this paper sets the fuel consumption as the objective function and combine International Regulations for Preventing Collisions at Seas (COLREGS) to provide the optimal collision avoidance action (including rudder steering timing, trueing angle, reorientation timing and reorientation angle) through Cat-Swarm Biological Algorithm

Introduction

Above 80% of collision accidents are attributed to human error at sea according to historical statistics. As the shipping technology developing, the bridge equipment can offer more and more relevant information. Increasing information lowers the probability of accurate judgement for ship encounter situation timely [1]. More automatic navigating can reduce collision accidents which result from human error, as well as mitigate navigators' fatigue. The research on intelligent ship collision avoidance decision-making support have substantial meaning for shipping industry.

The problem of decision-making in ship collision avoidance has attracted attention of many researchers in the past. Ugur Simsir, Mehmet Fatih Amasyah et al [2] predicted the ship position in three minutes through analytical neural network based on ship maneuverability and ship encounter parameters. Through this, it can judge whether collision danger exists between two ships. If collision danger exists, predict the rudder steering timing. Lokukaluge P. Perera, Victor Ferrari [3] proposed a computer simulation to model the ship collision avoidance decision-making using a real ship model. Wentao Zheng, Yuanzhou Zheng [4] extract and acquire the basic ship information from the ship motion images, such as length, width, position and speed through Gauss Hybrid Model, in order to ensure the ship's motion situation and determine a collision danger level. Then it can make a collision alert and propose the collision avoidance decision-making. Guoquan Chen, Lina Li [5] focused on open sea and used artificial intelligent collision avoidance decision-making theory to simulate typical decision-making cases. Yueying Wang, Ashim Kumar Debnath [6] offer a collision avoidance model based on three typical collision avoidance action (speed altering, rudder steering, speed altering and rudder steering).

To solve the problem of ship collision avoidance, this study builds a nonlinear mathematical model Which considers crossing and head-on situation. Cat-swarm biological algorithm which is heuristic algorithm is adopted for solving the model.

The paper is organized as follows. Section 2 introduce ships encounter situation which include head-on, crossing, overtaking. Section 3 gives notation and decision parameters of target ship before building model. Section 4 develops mathematical model. Section 5 provides cat-swarm biological algorithm for solving proposed model. Section 5 carries out numerical experiments based on AIS data. Finally, a conclusion is given in section 6.

Ship Encounter Situation and COLREGS

The ship encounter situation can mainly be divided into three types: head-on, overtaking and crossing.

(1) Head-on: when two ships are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision and only when two ships see each other. In this situation no yielding relationships exists between the two ships. Regulations require each ship shall alter course to starboard so that each ship shall pass on the port of the other.

(2) Crossing: when two ships encounter each other in cross-over courses and pose danger, Regulations require a ship to yield to the other ship on the starboard and avoid crossing the front of the other ship if conditions allow.

(3) Overtaking: an overtaking situation is defined, except when the two ships in sight of on another, as one ship is abaft the other ship abeam in an angle larger than 22.5degree. At night, only sternlight is visible, not the sidelight and any ship overtaking any other shall keep out of the way of the ship being overtaken.

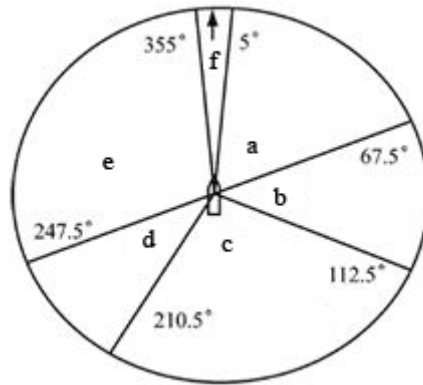


Fig.1 Ship encounter situation

In accordance with the COLREGS, this study focuses on the encounter situation of two ships and divides action modes into six regions labeled *a* to *f*, as shown in Fig.1. A head-on situation is created when ship encounters another ship in region *f* (005°~355°); Two ships encountering each other in region *a*, *b* and *e* are in crossing situation. If ship1 is in an overtaking situation being passed by any ship from the *c* (112.5°~210°) or *d* (210°~247.5°) regions, it is usually required to keep course and speed. This paper focuses on ship collision avoidance decision-making research in head-on and crossing situation based on relevant regulations about overtaking situation[7].

Decision Parameters of Target Ship

The frequently-used decision parameters in decision-making model include the course of the own ship c_o , the course of the target ship c_t , the relative course of the two ships c_{ot} , the speed of the own ship v_o , the speed of the target ship v_t , the relative speed of the two ships v_r , the relative bearing of the target ship to the own ship q , the distance between the two ships d , d_{cpa} (the distance between the own ship and the Closest Point of Approach) and t_{cpa} (the time of the own ship reaching the Closest Point of Approach).

$$c_{ot} = c_o - c_t \quad (1)$$

$$v_r = (v_t^2 + v_o^2 - 2v_t v_o \cos c_{ot})^{1/2} \quad (2)$$

$$\begin{cases} a = \arccos(v_o^2 + v_r^2 - v_t^2) / 2v_o v_r & c_{ot} \geq 0 \\ a = -\arccos(v_o^2 + v_r^2 - v_t^2) / 2v_o v_r & c_{ot} < 0 \end{cases} \quad (3)$$

$$\begin{cases} d_{cpa} = d \sin \beta \\ t_{cpa} = d \cos \beta / v_r \\ \beta = a - q & c_{ot} \geq 0 \\ \beta = q - a & c_{ot} \leq 0 \end{cases} \quad (4)$$

Equation 1 equals the interaction angle between own ship and the target ship before ships' turning, equation 2 provides the relative speed of the target ship according to own ship before the two ships' turning, equation 3 is the interaction angle between the direction of the relative motion of the target ship and own ship's heading; equation 4 is the d_{cpa} and t_{cpa} before ships' turning. The geometrical relationship is displayed in Fig.2.

$$c_{o't} = c_{o'} - c_t \quad (5)$$

$$v_r' = (v_t^2 + v_o^2 - 2v_t v_o \cos c_{o't})^{1/2} \quad (6)$$

$$\begin{cases} b = \arccos(v_o^2 + v_r'^2 - v_t^2) / 2v_o v_r' & c_{o't} \geq 0 \\ b = -\arccos(v_o^2 + v_r'^2 - v_t^2) / 2v_o v_r' & c_{o't} < 0 \end{cases} \quad (7)$$

$$\begin{cases} d_{cpa_1} = d \sin \theta \\ t_{cpa_1} = d \cos \theta / v_r' \\ \theta = b + \Delta c - Q & c_{o't} \geq 0 \\ \theta = Q - b - \Delta c & c_{o't} < 0 \end{cases} \quad (8)$$

Equation 5 equals the interaction angle between own ship and the target ship after ships' turning, equation 6 provides the relative speed of the target ship according to own ship after the two ships' turning, equation 7 is the interaction angle between the direction of the relative motion of the target ship and own ship's heading after own ship' turning; equation 8 is the d_{cpa} and t_{cpa} after ships' turning. Their geometrical relationship is displayed is Fig.3.

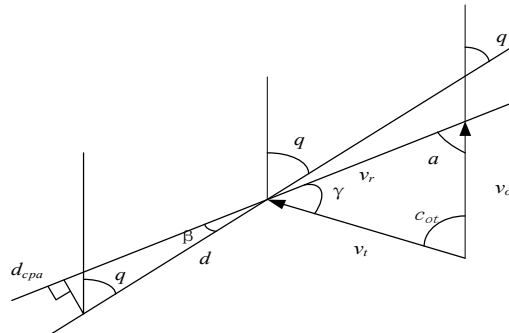


Fig.2. Geometrical situation before turning

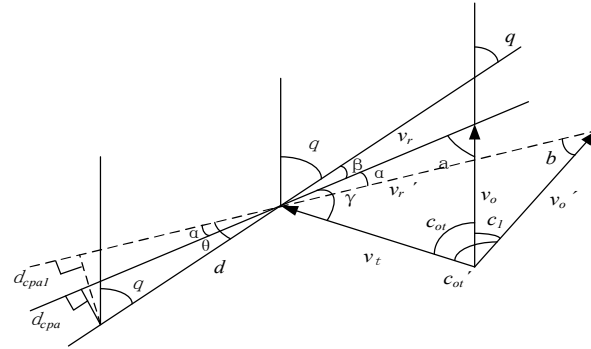


Fig.3. Geometrical situation after turning

Mathematical Model

Problem Description

COLREGS require that ships take relevant collision avoidance actions according to the regulation rules in the crossing and head-on situations. This paper establishes the optimization model to generate the basis for collision avoidance timing and turning angle, navigating timing after turning, timing of ease rudder and rudder angle of course again, pass each other in a safety distance to minimize the fuel consumption during collision avoidance. Offer the following assumptions to facilitate the establishment of the model.

- (1) The ship's turning can be finished in an extremely short time after rudder steering, so ignore the turning time.
- (2) Returning to the original route after collision avoidance procedure.
- (3) No consideration of collision avoidance relating to other ships when own ship takes collision avoidance action.
- (4) Without consideration of overtaking situation in accordance with COLREGS.
- (5) No consideration of the two ships' collision avoidance actions with the aid of VHF communication.

Table1. Notation definition

Notation	Definition or explanation
t_b	The navigating time before the ship taking turning action
t_s	The navigating time in the new course after turning
c_1	The ship's new heading course after turning
c_2	The course during reorientation
v	The ship's speed
$g(v)$	Fuel consumption per nautical mile
l	The navigating distance during the whole collision avoidance action
d_s	Preset safety distance for passing each other

Mathematical Model

$$\min \quad lg(v) \tag{9}$$

Subject to:

$$30^\circ \leq c_1 \leq 90^\circ \tag{10}$$

$$-60^\circ \leq c_2 \leq -30^\circ \quad (11)$$

$$t_{cpa} \leq t_2 \leq 60 \quad (12)$$

$$0 \leq t_1 \leq t_{cpa} \quad (13)$$

$$d_s \geq d_{cpa} \quad (14)$$

$$d_s \leq d_{cpa_1} \quad (15)$$

$$t_1 \geq 0, t_2 \geq 0 \quad (16)$$

The objective function (9) minimizes the fuel consumption during collision avoidance action. Eq. (10) and (11) guarantees the requirement that avoiding small rudder steering angles according to COLREGS. Constraint (12) enforce the lasting time of collision avoidance action. Constraint (13) defines the ship's turning timing. Eq. (14) and (15) are introduced to guarantee the efficiency of collision avoidance action. Constraint (16) requires that t_1 and t_2 are non-negative.

Solution Algorithm

In recent years many researchers have proposed many artificial intelligent algorithms which are evolved through imitation of some biological animals' behaviors. Though all cats are, in most time, inactive and if you spend some time to observe the existence of cats and you may find that the cats spend most of the time on resting and peeping situation when they are awake, all cats have a strong curiosity and the alertness of cats are very high. They always stay alert even though they are resting. Thus, you can simply find that the cats usually look lazy, lying somewhere, but opening their eyes hugely looking around. Once discovering the targets, cats can capture the prey swiftly. The behaviors of cats can be divided into two sub-mode, i.e. tracing mode in which cats are looking around in lazy situation and seeking mode in which cats are tracing dynamic targets[8]. The solution procedure as follows:

- Step 1. Initialize the cat swarm. Every cat has its own position composed of four dimensions: t_1 , t_2 , c_1 , c_2 , v .
- Step 2. Divide the cat swarm into groups, tracing mode and seeking mode, at random based on the grouping rate.
- Step 3. Update the cats' positions via cats' mode identified by the mode flag. If in seeking mode, then activate the seeking mode; otherwise, behaviors of the tracing mode are activated. Resembling Particle Swarm Algorithm, in the every iteration in tracing mode, the cat will update its own position through tracing an extreme value which is the optimal solution in the current whole cat swarm. This tracing mode makes the cats approximate towards the optimal solution in the whole situation. Then update the cat's own position with this whole optimal position in accordance with Eq. (17) and Eq. (18).

$$v_k^d(t+1) = v_k^d(t) + c \times rand \times (x_{best}^d(t) - x_k^d(t)) \quad (17)$$

$$x_k^d(t+1) = x_k^d(t) + v_k^d(t+1) \quad (18)$$

k denotes the k^{th} cat, d denotes the d^{th} dimension of the k^{th} cat. In seeking mode, cats replicate their own positions and put these duplicates of positions into memory pool. Then change the duplicate in

the memory pool via mutation operator to let all the duplicates acquire new positions. Replace the current position with the one which have the highest fitness level.

Step 4. Calculate the fitness value of each cat via the fitness function. Record and keep the cat with the optimal fitness value.

Step 5. Check whether it satisfy the terminate condition. Output the optimal solution and end the procedure if positive. Otherwise, repeat step 2.

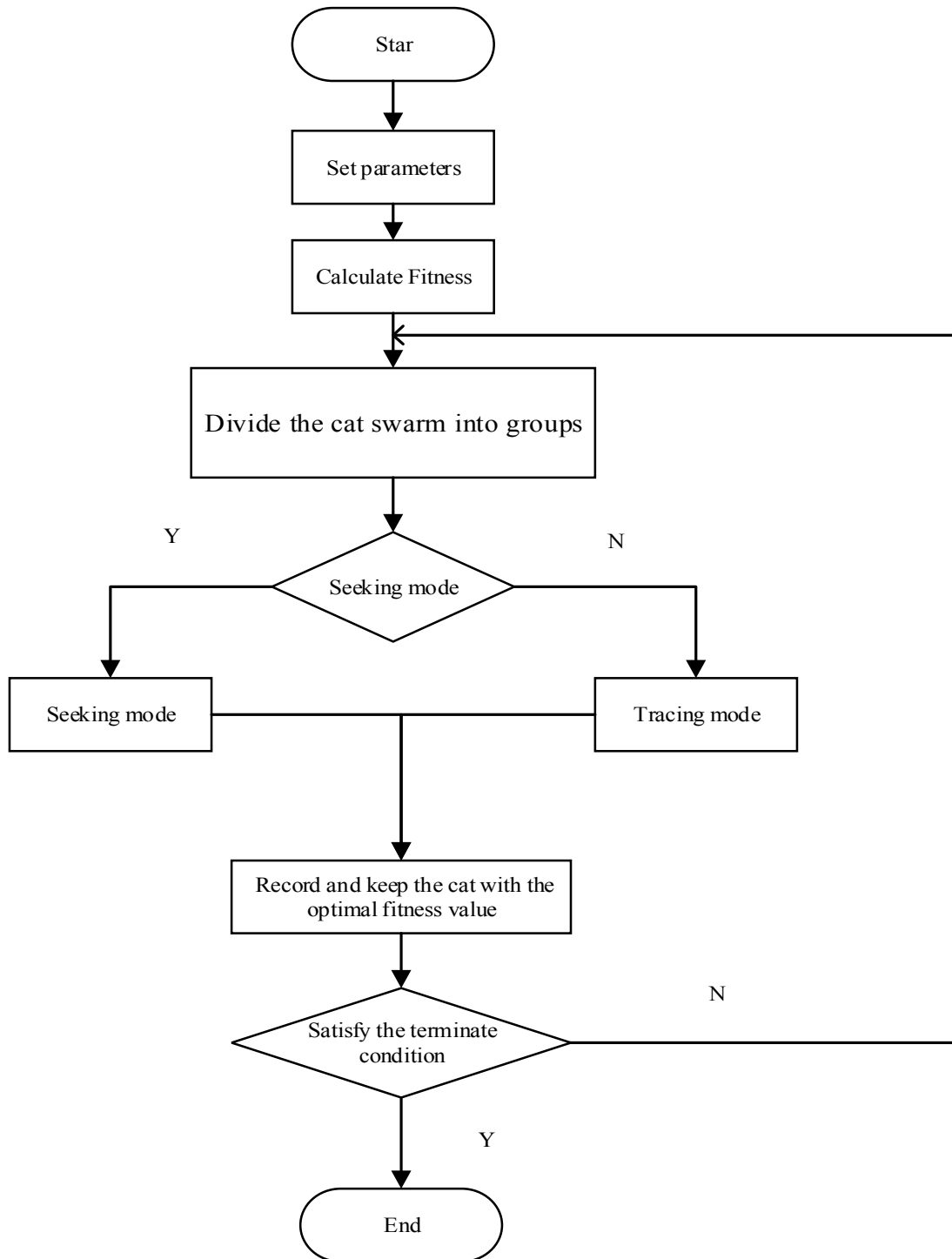


Fig.4. Process diagram of Cat Swarm Algorithm

Simulation and Results

The data resource of the emulation case is the dynamic AIS information. Generate the head-on and crossing situations in this emulation. The course of own ship is 000° . The target ship with the speed of 12 knots is 30° to the starboard of own ship and 20 nautical miles away from own ship. Assume that the two ships just turn around when in collision avoidance action. The optimization results are displayed in Table 2.

Tab. 2 Optimization Result 1

Target Ship	t_1	t_2	c_1	c_2	v
250°	2.85min	37.61min	30°	48°	8kn
181°	10.8min	9.7min	32°	38°	10kn
200°	3min	31min	30°	53°	8.5kn

Tab. 3 Optimization Results 2

Target Ship	t_1	t_2	c_1	c_2	v
250°	17.82min	19.34min	32°	45°	8.6kn
181°	4.6min	13.63min	45°	57°	11.2kn
200°	4.73min	16.17min	65°	58°	8.6kn

Through the comparison of Tab2 and Tab3, we can get that with consideration of fuel consumption, own ship took collision avoidance action earlier than it does which set the shortest collision avoidance route as the objective function. The collision avoidance action considering the shortest collision avoidance route can guarantee the avoidance route shortest. By contrast, the decision-making based on fuel consumption is for the sake of economics. So the final output of this optimization model is to steer own ship earlier and then slow the speed down, which can guarantee the minimum fuel consumption and as well as the safe pass in safety distance, however can not guarantee the shortest route.

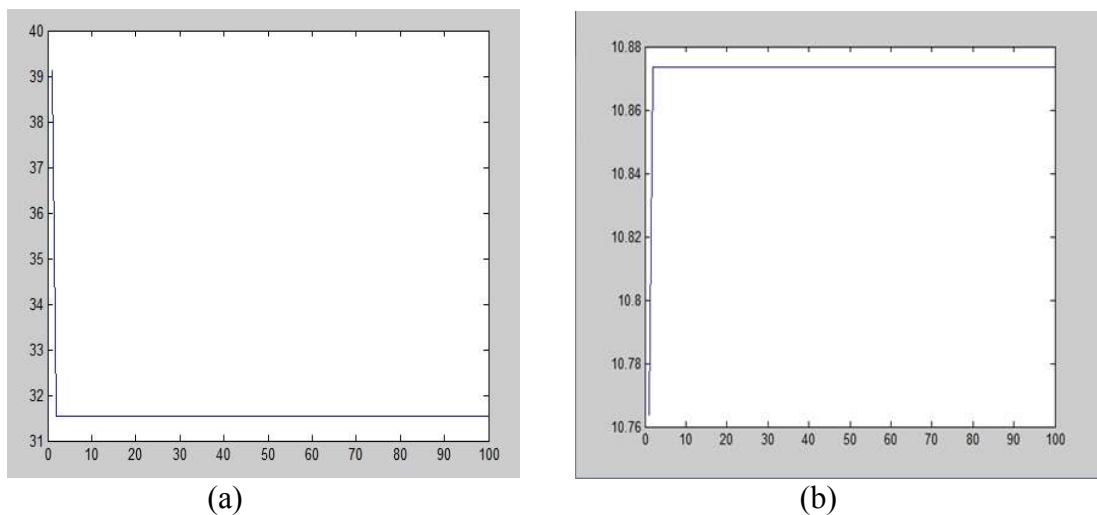


Fig.4. Iteration change of t_1 and t_2

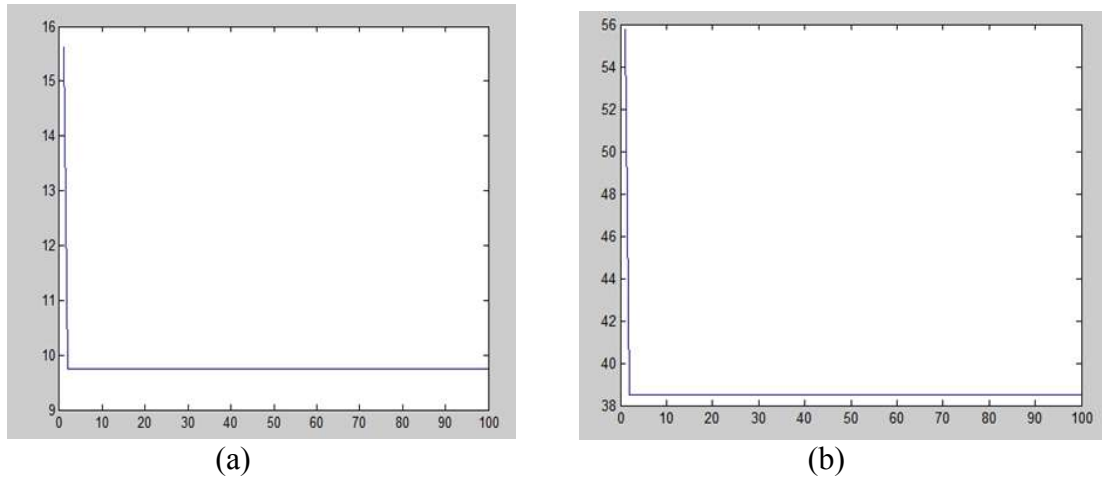


Fig.5. Iteration change of c_1 and c_2

The horizontal axes of Fig.4 and Fig.5 are iteration times. The vertical axes of them are optimization results of t_1 , t_2 , c_1 and c_2 . From the above, we can get the optimal output in ten times of iteration via cat swarm algorithm which has higher iteration efficiency.

Conclusion

Academic research always regards the ship collision avoidance safely as a hot topic. And most of collision avoidance models are established in the view of the shortest route. This paper establish a mathematic model of ship collision avoidance based on fuel consumption with consideration of economics, which is aimed to get the minimum fuel consumption during ship collision avoidance, as well as the two ships passing each other in safety distance. Considering the mixed integer nonlinear programming, we apply the cat swarm algorithm to solve this optimization model and verify the optimal solution via numerical emulation; finally approve the model to be efficient and the algorithm feasible. And this optimization model can provide technique support for ship collision avoidance.

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