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Ship Collision Avoidance by Distributed Tabu Search

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There are several algorithms to prevent ship collisions,such as ship domain, fuzzy theory, and genetic algorithm. These methods work well in one-on-one situations, however are more difficult to apply in multiple-ship situations. Therefore, we suggested Distributed Local Search Algorithm(DLSA) for preventing ship collision when many ships encounter each other simultaneously. However, according to our recent study, DLSA suffers from Quasi-Local Minimum(QLM), which prevents a ship from changing course even when a collision risk arises. To deal with this issue, we developed a new distributed algorithm called the Distributed Tabu Search Algorithm(DTSA) to escape from QLM. We conducted experiments to compare the performance of DLSA and DTSA. The results shows that DTSA outperformed DLSA.

1. Introduction

Several methods are used to prevent ship collisions, such as regulation or collision avoidance algorithm[IMO 72, Fujji 71, Goodwin 75, Hasegawa 89, Kim 01]. To support the need to find safe routes for ship travel, we proposed the Distributed Local Search Algorithm (DLSA) as a precedent study[Kim 14]. However, according to our recent study, it is sometimes trapped in Quasi-Local Minimum (QLM) that prevents a ship from changing course even when at risk of collision[Yokoo 96]. To deal with this issue, we developed a new distributed algorithm called the Distributed Tabu Search Algorithm (DTSA)[Glover 89]. DTSA enables a ship to search for a new course compulsorily when trapped in QLM, to allow it to escape. Furthermore, DTSA exploits a modified cost function and enlarged domain of next-intended courses to increase its efficiency. The cost function, which computes the collision risk of the current course in DLSA, is modified so that it includes the notion of efficiency. More specifically, we add the relative bearing of the current course to the destination. In this way, DTSA enables ships to find shorter paths to their destinations while avoiding collisions.

2. Background

There are many methods for preventing ship collisions at sea. From a regulation point of view, the 1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREGs)[IMO 72] compels or recommends that ships follow specific regulations, for example, navigational lights, traffic laws of the waterways, and the buoyage system. From a technological point of view, several algorithms are used in ship collision avoidance, such as ship domain[Fujji 71, Goodwin 75], fuzzy theory[Hasegawa 89, Kim 01] and genetic algorithm(GA)[Tsou 10]. The ship domain algorithm computes collision risk depending on whether the ship's safety domain is penetrated. The fuzzy theory computes the membership function for collision risk. To compute collision risk, several parameters - Variation of Compass Degree (VCD), Time to the Closest Point of Approach (TCPA), and Distance to the Closest Point of Approach (DCPA) - are used. The GA is based on the principle of evolution, that is, survival of the fittest. [Tsou 10] used GA to find the safest and shortest path that also complied with COLREGs. The fitness function is defined as the distance from the turning point to the original route. As chromosome constitution, there are four parameters - avoidance time, turning angle, restoration time and limited angle. They found optimum routes under three situations in which a ship can encounter a target ship. Fan Ajit[Fan 14] suggested collision avoidance without mutual communication. They were inspired by nature, such as the behavior of humans in crowded areas. In their study, however, individual agents can stop at anytime, which is impossible for ships. As mentioned previously, these works well in one-on-one situations, but, with multiple ships collisions may be difficult to avoid. To solve this problem, we suggest DLSA as a precedent study.

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3. Algorithm for Ship Collision Avoidance

3.1 Ship Collision Avoidance by DLSA

We propose DLSA to prevent ship collisions as a precedent study. Each ship searches its vicinity to find a target ship. If a target ship exists, it is registered in the neighboring ships list. Individual ships exchange an ok? Message and compute cost function. If a collision risk exists, individual ships exchange improvement messages.

$$improvement = max(0, Cost_{current} - Cost_{candidate})$$

,where $Cost_{current}$ and $Cost_{candidate}$ mean a cost for current and candidate courses, respectively. The ship with the largest improvement has the right to choose the next possible course. A ship with higher priority has the right to select the next course if the improvement for several ships is same. If the collision risk disappears, the ships move to the next position. This process is repeated until all ships arrive at the destination. Simultaneously altering the course of neighboring ships is restricted because of the possibility of

entering into an infinite loop. The ships all have four types of variables Time Step (T), Ship Domain (D), Detection of Range (DoR), and Course (C).

3.2 Ship Collision Avoidance by DTSA

DLSA suffers from QLM, in which a ship cannot change its course even though a collision risk still exists. To solve this problem, we applied DTSA. DTSA enables individual ships to choose another course compulsorily. Table 1 shows the difference between DLSA and DTSA. For efficiency and simplicity of the algorithm, we modified the cost function. The **relative bearing** from heading to destination is applied. To get rid of restriction for ship's movement, the **candidate courses** are modified from 3 kinds to user's needs. **Tabu Search** is applied to DTSA for remedy for QLM. Figure 1 illustrates the DTSA procedure. All ships repeat this process until they arrive at their destination. When QLM situation happens, current course is stored in Tabu List(TL) to does not be selected. A ship can search other courses except a course in TL. Figure 2 shows a simulation with five ships. The tracks of 4 ships produced an X shape. A ship located top center cuts across the space simultaneously. All ships arrived at their destination without collision.

Table 1: Difference between DLSA and DTSA

Difference	DLSA	DTSA
Cost function	number of expected collisions + remaining time	number of expected collisions + remaining time + *relative bearing from heading to destination*
Candidate courses	3 kinds	user's needs
Remedy for QLM	none	Tabu Search

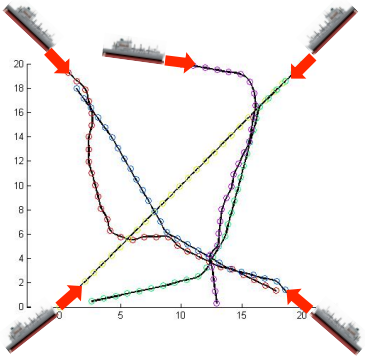

Figure 2: Simulated encounters among 5 ships by DTSA

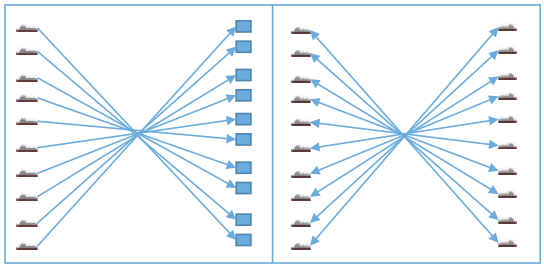

Figure 3: Situation for experiment 1 (left, 10 ships with same direction) & 2 (right, 20 ships with opposite direction)

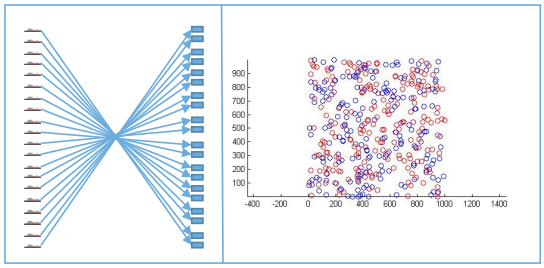

Figure 4: Situation for experiment 3 (left, 20 ships with same direction) & 4 (right, 100 ships initialized randomly)

4. Experiments

Our experiment used four different situations depending on the number of ships and ship position to test the performance of DTSA as compared to DLSA. Figure 3 and 4 show four different situation. Each variable has the following given values: Safety Domain = 2, 3, 4 miles, Range of Detection = 10, 20 miles, and Speed = 1, 2, 3. The minus and plus signs indicate the port and starboard, respectively. To evaluate the performance, we computed an average distance, the number of failures and the number of messages. We used MATLAB for the experiments.

All variables are used by exchanging their values in one situation. First, we experimented with ten ships traveling in the same direction toward the destination, as shown in Figure 3(left). In total, one-hundred twenty-six experiments were conducted. Figure 5 shows the result for experiment 1. Compared with DLSA, DTSA demonstrated better performance overall. All DTSA showed low and uniform average distance. Among all DTSA, only 15 DTSA recorded a failure.

For second experiment, we experimented with twenty ships traveling in the opposite direction away from the destination, as shown in Figure 3(right). In this experiment, DLSA is unable to compute a situation involving more than twenty ships. The compution time was over the limited time. We therefore used DTSA only in this experiment. Figure 6 shows the result for experiment 2: the larger the candidate course, the smaller the failure counts. ALL DTSA performed best in regard to average distance and 45 DTSA had the highest average distance. Only 15 DTSA recorded any failures (seven).

For thrid experiment, we experimented with twenty ships moving in the same direction toward the destination, as shown in Figure 4(left). Figure 7 shows the result. Failures occurred only in the 15 DTSA case (two). ALL DTSA showed the lowest average distance and 45 DTSA showed

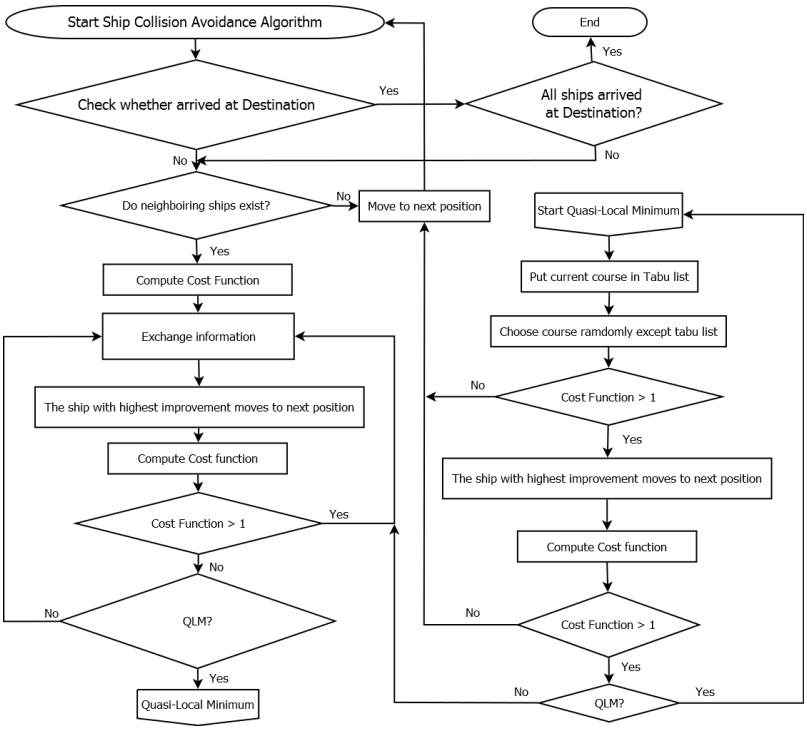

Figure 1: Procedure for DTSA

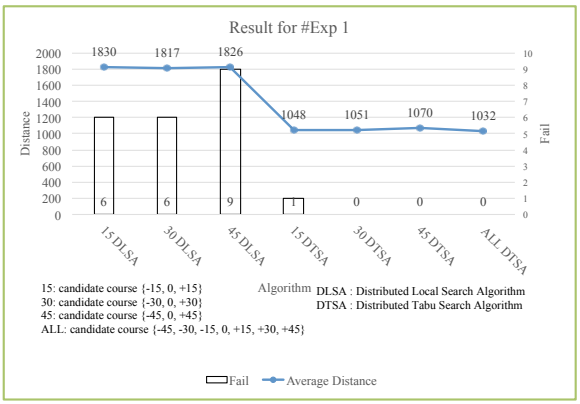

Figure 5: Result for experiment 1

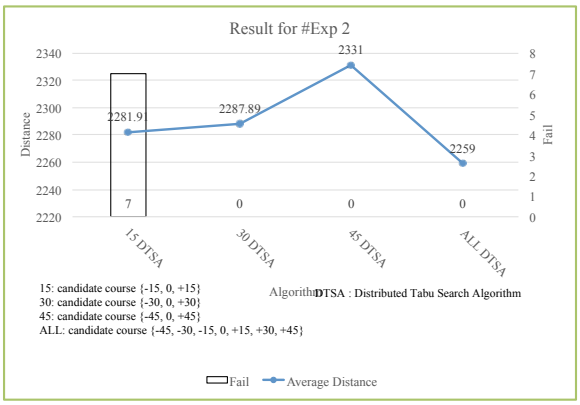

Figure 6: Result for experiment 2

the highest average distance. The pattern of the experimental result was similar to that of experiment 3.

For forth experiment, we used one hundre ship in experiment 4, as shown in Figure 4(right). The ship positions and headings were initialized randomly. The red and blue circles indicate the origin and destination for the individual ships, respectively. Figure 8 shows the result. ALL DTSA had no failure and the lowest average distance. In addition, the pattern of the result showed a similar tendency to that of experiments 2 and 3.

For fifth experiment, we computed the number of message for communication as per above experiments. A message includes *ok? and improvement message.* Figure 9 and 10 showed the number of messages. Ok? message includes information on future position. Improvement message includes the number indicating how much cost is reduced. In the result of experiments, the less the ships used in experiments, the less the number of message for communication. ALL DTSA showed much more the number of messages. The bigger the candidate courses, the bigger the the number of messages. In case of experiment 4, most of result values showed the number of message for communication similarly. The number of message for communication depends on the condition for experiment.

5. Conclusion

We applied DTSA and DLSA as a precedent study. We used the tabu search algorithm to avoid the QLM problem. Our experiments demonstrated how individual ships can avoid collisions in multiple-ship situations. In the experimental results, DTSA outperformed DLSA. Some ex-

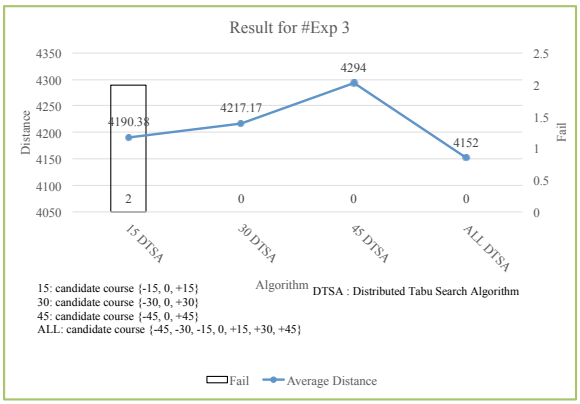

Figure 7: Result for experiment 3

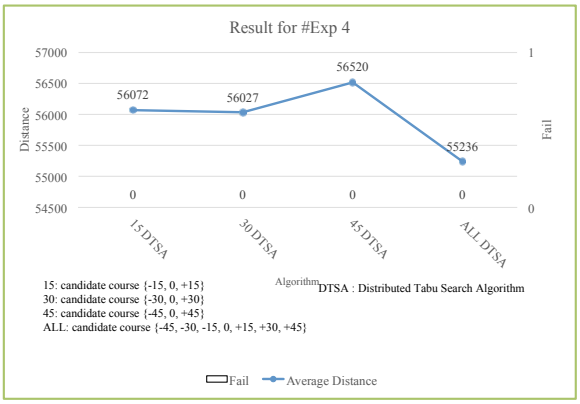

Figure 8: Result for experiment 4

periments showed similar patterns: The more the number of candidate courses is increased, the shorter the average distance; the less the size of the degree of the candidate course, the greater the failure count. In experiments 2, 3, and 4, the pattern of experimental results was similar. 45 DTSA recorded the highest average distance. In the case of 45 DTSA, the range of fluctuation for the candidate course was larger. ALL DTSA showed the lowest average distance in most cases. This means that the more candidate solutions, the better the performance. The number of messages for communication presented a great contrast to the given situations.

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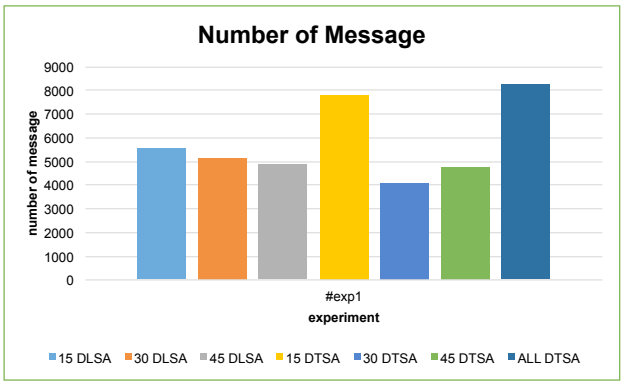

Figure 9: Number of message for experiment 1

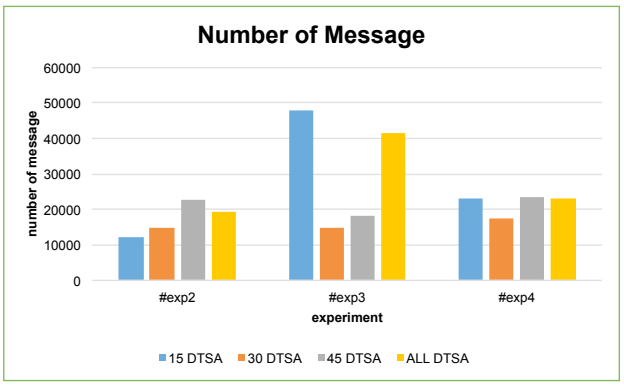

Figure 10: Number of messages for experiments 2, 3 and 4

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