http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (17): 4026-4032, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.4026.4032
© 2013 Asian Network for Scientific Information

Research on Vessel Intelligent Collision Avoidance System Based on AIS and ECDIS

[1]Guoyou Shi, [2]Shuang Liu, [3]Peng Chen and [1]Shukai Zhang
[1]Navigation College, Dalian Maritime University, Dalian, Liaoning, 116026, China
[2]School of Computer Science and Engineering, Dalian Nationalities University,
[3]Department of Computer Science and Technology,
Dalian Neusoft University of Information, Dalian, 116023, China

Abstract: In view of disadvantages existing in current decision making model for vessel intelligent collision avoidance system, a macro-simulation encounter model is presented based on analysis of domestic and foreign research results including overall design and general consensus for vessel intelligent collision avoidance decision-making. To be consistent with collision avoidance, overall process of the decision-making system and flow chart of the main subsystem are presented in detail. Taking full advantages of AIS (Automatic Identification System), this collision avoidance system can supply a reasonable and effective avoidance scheme when two vessels encounter by analyzing and judging encounter situation. Based on programming with VC++ and simulating with AIS data in electronic chart display platform, the presented model is effective to guarantee vessel safety.

Key words: Intelligent avoidance system, vessel safety, encounter, electronic chart

INTRODUCTION

With rapid development of the global economy, marine economy develops rapidly which promotes more and more maritime transportation. With a large amount of cargo transportation by large vessels, collision accidents are more and more frequent leading to heavy casualties and property losses. How to avoid collision accidents has become one important issue needed to be solved as soon as possible. Intelligent decision-making system for vessel collision avoidance can help promote safety of navigation and reduce impact of human factor. It has become one main research directions for its importance to world shipping industry (Tran *et al*., 2001; Tarnopolskaya and Fulton, 2009; Miele and Wang, 2005; Miele *et al*., 2012; Miele and Wang, 2006; *Li et al*., 2008).

In 1972, International Regulations For Preventing Collisions At Sea provided voyagers the basis rules of preventing collision and constrain behavior of manipulator,playing an important role in reducing the uncertainty of ship behavior and preventing or avoiding collision accidents at sea. But we must realize that International Regulations for Preventing Collisions At Sea presents clear regulation for principles of preventing collisions and it doesn't provide solutions for certain situations. Because of different opinions on International Regulations For Preventing Collisions At Sea, it is different to carry out actions based on this regulations. Vessel navigation is one very complicated system consists of human, ship and environment. When the pilot on duty needs decision-making for collision avoidance,he will take actions according to his experiences. Without a clear mathematical model, it is difficult to supply useful decisions for problems in collision avoidance.

To solve this problem, many countries have done a lot related work (Hu *et al*., 2006; Chen *et al*., 2010; Yang and Li *et al*., 2007a; Yang *et al*., 2007b). For example, Japan and the UK were the first to apply expert system theory and methods into ship intelligent collision avoidance and developed a respective analog collision avoidance expert system in late 1980s. Germany and the United States have also launched their own developed collision avoidance Expert System successively. Comparing to other countries, China started related research work in 1980s. Many researches were mainly theoretical such as applying classical mathematics to intelligent collision avoidance system modeling, so a lot of problems have not been solved.

Currently, all research ideas are generally uniform. First of all, a knowledge base is created to store data such as radar or encounter ships dynamic data, encounter model, avoiding collision judgment model, expert analysis, captain experiences, collision regulations, maneuverability of own ship and the encounter ship, state of motion data.

Corresponding Author: Peng Chen, Department of Computer Science and Technology, Dalian Neusoft University of Information, 8 Software Park Road, Dalian, 116023, China Tel: 86-411-84832265

Secondly, query is carried on knowledge base by analyzing trend of the encounter ship and owns ship as well as the state of motion of the ship to obtain solution scheme. Finally, the avoiding scheme is computed based on processing and reasoning of the built model.

Based on AIS data (Pitana *et al*., 2010) and support of ECDIS (Electronic Chart Display and Information System) (Shao *et al*., 2007; Wan *et al*., 2005; Yang *et al*., 2006), this study systematically studied vessel intelligent collision avoidance system. By establishing a mathematical model of ship motion, the ship encounter pattern decision-making model, ship encounter action decision-making model and ship collision avoidance action model are studied. Then one simulation system is programmed with VC++ to show different cases of collision avoidance.

VESSEL MATHEMATICAL MODEL

In vessel traffic simulation, vessel motion state can be categorized into three types including steady motion, steering movement and variable motion without consideration of presence of the steering and speed. Thus, movement of the vessel model includes steady motion model, steering motion model and variable motion model.

- **Steady motion model:** Vessel steady movement refers to keeping the ship sailing course and speed constant. Suppose the current plane coordinate is (X_0, Y_0), sailing course is φ, speed is v, then the target position is (X, Y) after a time t as follows:

$$\begin{cases} X = X_0 + v \cdot \cos\varphi \cdot t \\ Y = Y_0 + v \cdot \sin\varphi \cdot t \end{cases} \quad (1)$$

For this method, the results must be transformed from plane coordinate system to latitude and longitude coordinates before sending back to the vessel plus some triangle calculations.

- **Steering motion model:** Ship steering motion refers to maintaining the speed of vessel with only changing the direction of the vessel. This model can only be used to avoid normal aversion and is not applied to emergency operating large rudder angle of collision avoidance. Suppose the current plane coordinate is (X_0, Y_0), sailing course is φ(t), speed is v,then the target position (X, Y) after a time t is as follows:

Table 1: Relationship between k and ($m+m_x$)

Displacement (t)	5000	10000	50000	100000
$k/(m+m_x)$	0.0035	0.0025	0.0010	0.0007

$$\begin{cases} X = X_0 + \int_{t_0}^{t} 0.9v\cos\varphi(t)\,dt \\ Y = Y_0 + \int_{t_0}^{t} 0.9v\sin\varphi(t)\,dt \end{cases} \quad (2)$$

where, φ(t) indicates the steering angle at the time of t and can be calculated as follows:

$$\varphi(t) = k\delta_0[t - (T + \frac{t_1}{2} + \frac{T^2}{t_1}(e^{t1/T} - 1)e^{-t/T}] \quad (3)$$

where, K and T are the vessel maneuverability index and δ_0 is steering angle with general range of 10°~15° and t is time with unit seconds and t_1 represents steering time with general value of 2.5 sec.

- **Variable motion model:** When two vessels are in the head on or in the process of overtaking, it needs to change the speed immediately if only changing the course cannot avoid the risk of collision. The variable motion equation is:

$$v = v_1 + (v_0 - v_1) \cdot \exp\left(-\frac{k \cdot t}{m + m_x}\right) \quad (4)$$

where v_0 represents the speed before the change, v_1 represents the speed it plans to, $m+m_x$ represents virtual mass in forward direction, m represents the vessel quality, k represents vessel drag coefficient. The value $k/(m+m_x)$ has nothing to do with displacement. The specific relations are shown in Table 1.

According to the International Regulations for Preventing Collisions at Sea, there are two cases of vessels in sight and vessels in poor visibility when dividing the ships encounter situations and consider the own vessel as power-driven vessel underway. According to the Rule 13, the vessel overtaking any other should keep out of way of vessel being overtaking when in sight of one another. According to the Rule 14, each should alter its course to starboard so that each shall pass on the port side of the other when two power-driven vessels are in head-on situation which means two vessels have the same avoiding responsibility. According to the Rule 15, the vessel which has the other on its own starboard side should keep out of the way in sight of one another when two power-driven vessels are in crossing situation. According Rule 18, a power-driven vessel underway

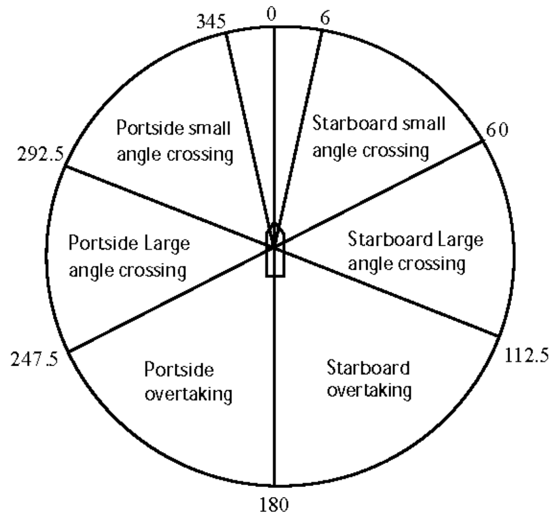

Fig. 1: Encounter cases when in sight of one another

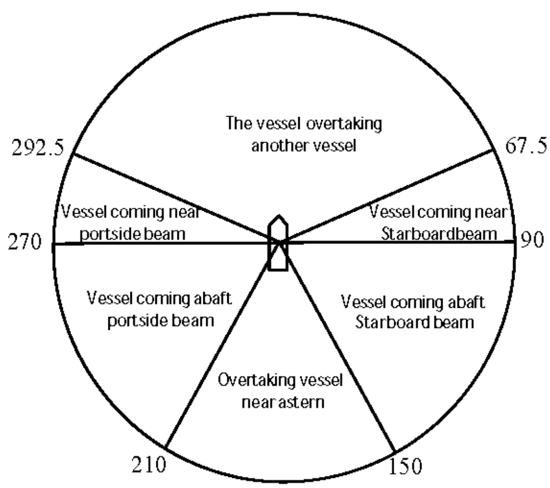

Fig. 2: Encounter cases when in restricted visibility

should if circumstances permitted, avoid impeding the safe passage of a vessel constrained by its draught and keep out of the way for the vessel list as below: (1) A vessel out of control; (2) A vessel with restricted capability of maneuvering; (3) A vessel engaging in fishing; (4) A sailing vessel.

According Rule 19, vessels not in sight of one another have the same avoiding responsibility when navigating in or near an area of restricted visibility.

In macro simulation, vessel encounter cases are too rough if division of vessel encounter situations like this and it is difficult to meet the needs of collision avoidance decision. Therefore, we divide vessel encounter situations into the following seven types, taking into account the characteristics of different bearing on vessel collision avoidance maneuvering. (1) Head-on situation; (2) Starboard small angle crossing situation; (3) Starboard large angle crossing situation; (4) Overtaking situation; (5) Being overtaking situation; (6) Portside small angle crossing situation; (7) Portside large angle crossing situation. Different encounter cases are shown in Fig. 1.

According to the rules, when vessels are not in sight of one another or near an area of restricted visibility, each of them have the same avoidance responsibility and special provision in taking action in alteration of course if there exists a close-quarters situation or risk of collision. Therefore, we categorized these situations into seven types when vessels are not in sight of one another or in restricted visibility case for our intelligent decision system of vessel collision avoidance system.

- The vessel overtaking another vessel
- Vessel coming forward of the beam except for a vessel being overtaken
- Vessel coming near starboard beam
- Vessel coming abaft starboard beam
- Overtaking vessel near astern
- Vessel coming near portside beam
- Vessel coming abaft portside beam

Figure 2 shows these seven cases.

VESSEL ENCOUNTER ACTION DECISION MODEL

As can be seen from the concept of vessel domain, vessel domain refers to its own vessel and other vessel should keep a safe distance. If other vessel sales into domain of own ship, it is a threat to own vessel, the vessel should take corresponding collision avoidance action. Encounter action decision-making model mainly includes the following three models, that is, action decision model in head on situation, action decision model in overtaking situation and action decision model in crossing situation.

- **Action decision model in head on situation:** In head-on situation, the action decision model in Fig. 3

First, we determine the degree of turn to starboard and then determine whether it is possible to beyond the fairway. Next we determine whether it is needed to slow down. At last, we calculate the center of gravity coordinates of the vessel according to steering gear formula or slowing down formula.

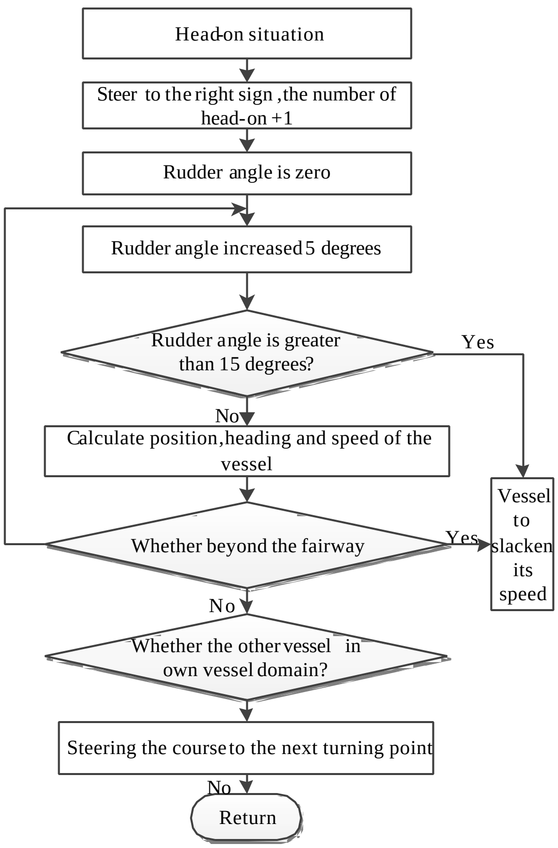

Fig. 3: Action decision model in head on situation

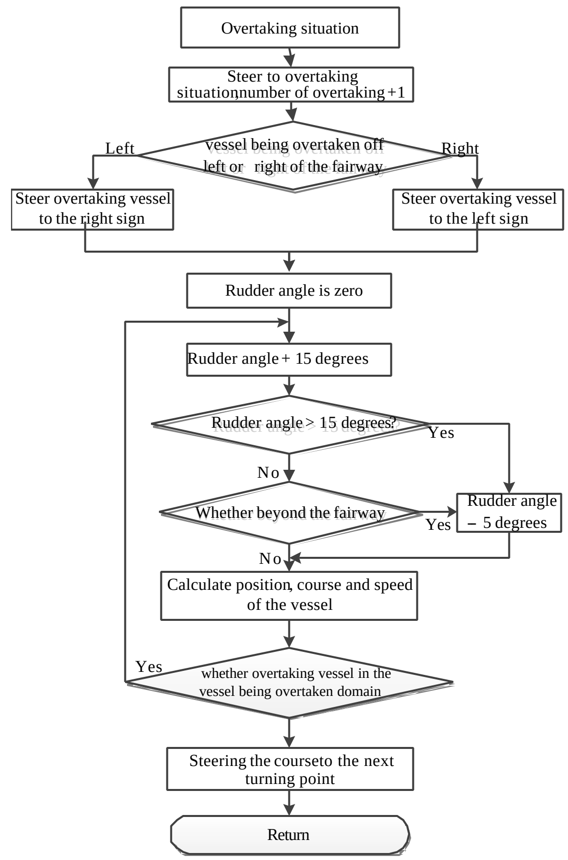

Fig.4: Action decision model in overtaking situation

- **Action decision model in overtaking situation:** When two vessels are in a state of overtaking, we adopt the following methods: Overtaking vessel decides which side of the overtaken vessel is related to the center of the fairway and then it turns to the other side of the direction with steering angle not more than 15°. The overtaken ship perhaps turns to the opposite direction of the overtaking vessel with steering angle 5°. The overtaking vessel returns to its original course if it is safe again, the whole process is shown in Fig. 4

- **Action decision model in crossing situation:** When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on its starboard side should keep out of the way and should, if the circumstances of the case permitted, avoid crossing ahead of the other vessel. In crossing situation, two vessels are not a give-and-take relationship but they are the give-way vessel and stand-on vessel which means the vessel with green light is the give-way vessel, should be responsible for giving way and the vessel with a red light is the stand-on vessel, should maintain the original course and speed. Details process for action decision model in crossing situation is shown in Fig. 5

DESIGNS OF OUR INTELLIGENT COLLISION AVOIDANCE SYSTEM

According to the international regulations for preventing collisions at sea in 1972, we can analyze the avoiding responsibility for vessels under different circumstances. By establishing vessel motion model, vessel encounter pattern decision model, vessel collision avoidance action model, we implemented one intelligent collision avoidance system using VC++ programming language with support of the AIS data and electronic chart display platform. System design and simulation results are discussed as follows.

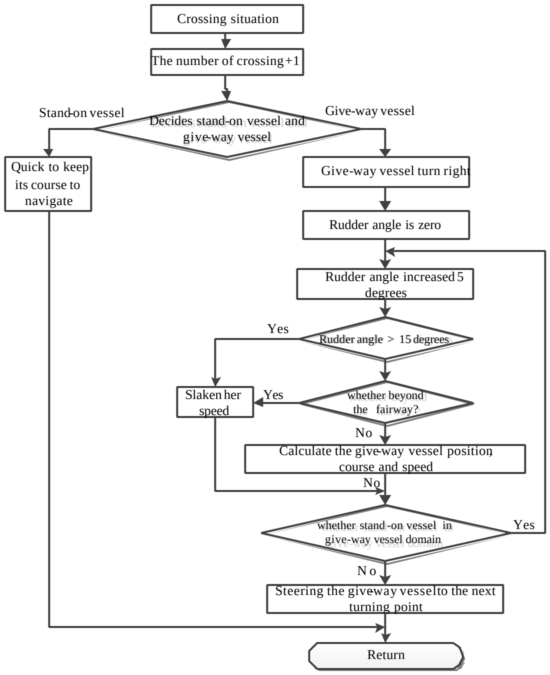

Fig. 5: Action decision model in crossing situation

- **Structure design of the system:** This system consists of five modules such as AIS data accessing module, vessel identification module, encounter decision-making module, collision avoidance action module and course resuming decision-making module. Working process for our system is as follows. First, the system reads AIS data and extracts AIS data of target vessel from the database and obtains basic information such as heading, speed and position of the target vessel. Then the encounter situation decision-making subsystem is called to determine different situations for two vessels in head-on situation or crossing situation or overtaking situation. Next, collision avoidance action decision-making subsystem is called to take the corresponding collision avoidance actions. At last, two vessels start to resume the original course and the original s peed based on the course resuming decision-making subsystem when two vessels are past and clear

Based on the above structure design, head-on action decision-making model, overtaking decision model and crossing action decision-making model, flowing chart of our system is summarized as in Fig. 6.

We selected three simulating results of our system which are shown in Fig. 7-9. Figure 7 shows one collision avoidance action case for head-on situation.

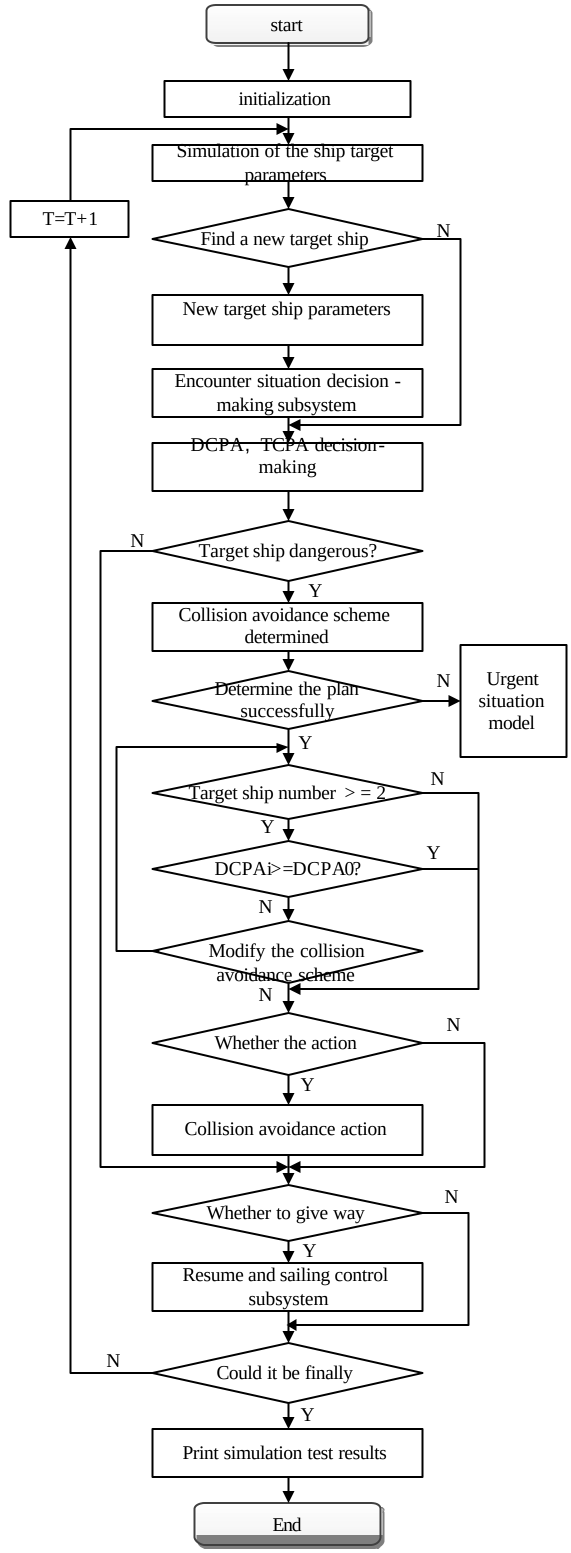

Fig. 6: Flow chart of our intelligent collision avoidance system

Fig. 7: Collision avoidance action for head on situation

Fig. 8: Collisionavoidance action case for crossing situation

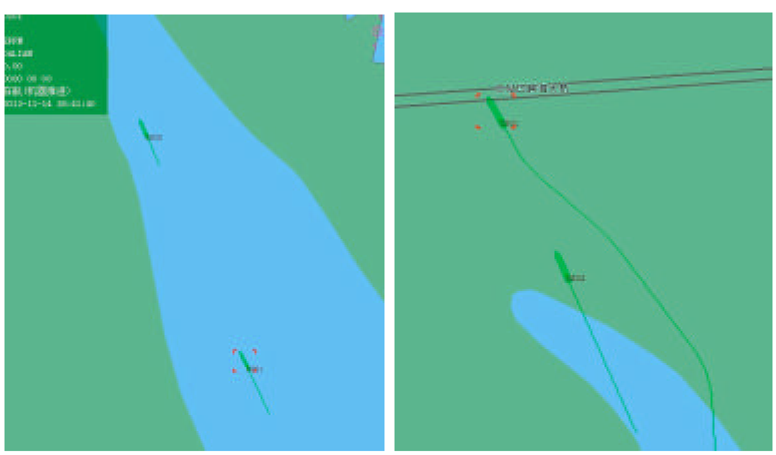

Fig. 9: Collision avoidance action case for overtaking situation

Figure 8 shows one collision avoidance action case for crossing situation.

Figure 9 shows one collision avoidance action case for overtaking situation.

CONCLUSION

How to avoid collision in marine transportation is very important for safety and efficient navigation. This study mainly studied the ship intelligent collision avoidance system based on AIS and electronic chart. Based on the International Regulations for Preventing Collisions at Sea, we carefully divided various encounter situations for vessels and designed one vessel intelligent collision avoidance system framework and collision avoidance action decision model. With VC++ as software development platform, we realized a good visual man-machine interface of intelligent collision avoidance simulation system software combining the AIS data. In order to test the feasibility of this system, several typical encounter situations have been carried out and the simulation results show efficiency and feasibility of our system.

REFERENCES

Chen, G.Q., Y. Yin, L. Li and S.H. Yang, 2010. Mechanism and simulation of personifying intelligent decision making for vessel collision avoidance. Proceedings of the International Conference on Computer Application and System Modeling, Volume 4, October 22-24, 2010, Taiyuan, pp: V4-681-V4-686.

Hu, Q.Y., Q.E. Hu and C.J. Shi, 2006. A negotiation framework for automatic collision avoidance between vessels. Proceedings of the IEEE/WIC/ACM International Conference on International Conference on Intelligent Agent Technology, December 18-22 2006, Hong Kong, pp: 595-601.

Li, L.N., S.H. Yang, Y.F. Suo, G.Q. Chen and J.L. Wang, 2008. Automation method for personifying intelligent decision-making for vessel collision avoidance. Proceedings of the IEEE International Conference on Automation and Logistics, September 1-3, 2008, Qingdao, pp: 1876-1881.

Miele, A. and T. Wang, 2006. Optimal trajectories and guidance schemes for ship collision avoidance. J. Optim. Theory Appl., 129: 1-21.

Miele, A., T. Wang, J.A. Mathwig and M. Ciarcia, 2012. Collision avoidance for an aircraft in abort landing: Trajectory optimization and guidance. J. Optim. Theory Appl., 146: 233-254.

Miele, A. and T. Wang, 2005. Maximin approach to the ship collision avoidance problem via multiple-subarc sequential gradient-restoration algorithm. J. Optim. Theory Appl., 124: 29-53.

Pitana, T., E. Kobayashi and N. Wakabayashi, 2010. Estimation of exhaust emissions of marine traffic using automatic identification system data (case study: Madura Strait area, Indonesia). Proceedings of the IEEE OCEANS, Sydney, May 24-27, 2010, Sydney, NSW, pp: 1-6.

Shao, Z.P., T.D. Sun, J.C. Pan and X.B. Ji, 2007. Development of the integrated vessel information service system based on ECDIS and AIS. Navigation China, 2: 30-33.

Tarnopolskaya, T. and N. Fulton, 2009. Optimal cooperative collision avoidance strategy for coplanar encounter: Merz's solution revisited. J. Optim. Theory Appl., 140: 255-375.

Tran, T., C. Harris and P. Wilson, 2001. Vessel management expert system. Proceedings of the IEEE Intelligent Transportation System Conference, August 25-29, 2001, Oakland CA., pp: 1102-1107.

Wan, X.X., C.H. Gan and C. Huang, 2005. An electronic chart display and information system. Mar. Geodesy, 28: 175-189.

Yang, S.H., L.N. Li and C.J. Shi, 2006. ECDIS based decision-making system for vessel automatic collision avoidance on restricted water area. Proceedings of the 6th World Congress on Intelligent Control and Automation, June 21-23, 2006, Dalian, pp: 7118-7122.

Yang, S.H., L. Li, Y.F. Suo and G.Q. Chen, 2007a. Study on construction of simulation platform for vessel automatic anti-collision and its test method. Proceedings of the IEEE International Conference on Automation and Logistics, August 18-21, 2007, Jinan, pp: 2414-2419.

Yang, S.H., C.J. Shi, Y.H. Liu and Q.Y. Hu, 2007b. Application of multi-agent technology in decision-making system for vessel automatic anti-collision. Proceedings of the IEEE International Conference on Automation and Logistics, August 18-21, 2007, Jinan, pp: 521-525.