Automatic Collision Avoidance Systems: Towards 21st Century

Zhao Jingsong, W.G.Price, P.A.Wilson
Department of Ship Science University of Southampton

May 14, 2008

1 Abstract

The importance of collision avoidance at sea is emphasised to cover four main aspects. A brief review of the research that has been carried out on automatic collision avoidance systems follows. Finally, several issues, which have often been ignored in previous studies are discussed.

2 Introduction

Along with the development of shipping, an automatic collision avoidance system (ACAS) is needed to meet the following requirements :

2.1 Safety at Sea

More than about sixty per cent of casualties at sea are caused by collisions ref.1. So the results from the solution to this problem is the most urgent issue that we must face. Many measures have already been developed, but the ACAS will be new and possibly one of the most effective.

A large proportion of accidents are caused by human error and the right approach to automation could help to reduce the number of accidents ref.2.

2.2 Reduction of Manning

Crew numbers have been reducing as the results of cost cutting due to the prevailing economic climate together with the fact that less people want to work on board ship over the last couple of decades. The inevitable results are that safety levels decrease and the amount of labour increases for deck officers, as more and more of other people's work is transferred to them. According to the Collision Regulations and the SOLAS convention, deck officers must keep proper lookout at all times. So an ACAS is a necessary development to help them to achieve this objective and to supply them with information to make collision avoidance decisions effectively.

2.3 Integrated Bridge Systems

For the above requirements to be achieved, an integrated bridge system is necessary. This can be defined as a system encompassing all the navigation, control, monitoring and communication functions of the bridge in one electronically and ergonomically engineered unit ref. 3. Among the subsystems in it, ACAS will from just a part together with ABS (automatic berthing system ref. 4), and so on, are the more important and the most difficult to develop as they are related to decision making and human factors.

2.4 Vessel Traffic Service (VTS)

VTS has been widely adopted in many harbours all over the world. It is unfortunately difficult for VTS operators to give collision avoidance decision suggestions to ships in the vicinity using present systems. They do need such a kind of device to help them to make more effective control of traffic in restricted waters.

3 Ship and Shore Based Systems

Ship based ACAS can also be divided into two categories: anti-collision in open sea and in restricted waters.

3.1 Anti-collision in Open Sea

Much research has already been done in this field ref.5. These researches can be divided into three areas:

- constant parameter method refs. 6-9.
- consideration of DCPA and TCPA refs. 10-12.
- synthetic analysis of DCPA and TCPA refs. 13-16.

New research methods are typically using fuzzy sets refs. 17-22, catastrophe theory, expert systems refs. 23-25, neural networks, and hypothesis-based reasoning system ref. 26, etc. Some of these works try to simulate mariner's behaviour of collision avoidance with different mathematical models, whereas others are using new AI methods. When we compare these two routes to addressing collision avoidance automation, we have to consider the features of collision avoidance decision making. There are five features of this problem ref. 27:

1. Collision avoidance action is based on the risk of collision, which varies continuously as time passes;

2. Generally speaking, an action is not fixed precisely. For example, if an action is taken such as altering course 20 degrees to starboard at a distance of 4 n.miles between here and the target, this does not mean that it is better than one which has an alteration of course of 19 degrees to starboard at 4.1 n.miles;

3. Such an action is related to the mariner's psychology;

4. It is also bound up with mariner's knowledge and skill;

5. Mariner's experiences are inter-related, too.

Reviewing each of the points above; for the first one, we should use classical mathematics; on the other hand, alternative mathematical approaches, such as fuzzy set or catastrophe theory, might be suitable for the second to the fourth ones; whereas for the fourth and the fifth ones, the various AI methods may be better. Thus, a conclusion is that neither of these three methods can be employed singly to solve the problem. A new way needs to be introduced which combines probably a mix of several different methods.

On the other hand, some studies targeted at decision-making to avoid a single target (which can be called single-target models), whereas others can be used in multiple-ship encounter. It is interesting to notice that a two-step method has been employed to avoid multi-hazard: firstly, the most dangerous target was picked up using risk assessment models, then a single-target model was applied to make a decision regardless of the other targets. It is doubtful if this kind of method can achieve the aim and be successful in multi-ship encounter situations.

3.2 Anti-collision in Restricted Waters

In restricted waters, the shore line, various obstacles, and ship routing scheme makes the problem of collision avoidance even more complex.

The restricted sea area for anti-collision and high traffic density requires highly accurate data and information, and more effective communication. Thus new technology is being asked to fill this gap. One of the new techniques on board ship is the electronic chart ref. 28, which is expected to contribute in the reduction of collisions at sea in the future ref. 29.

3.3 Shore Based Systems

The vessel traffic system (VTS) has been developed very well all over the world. It has proved to be the most effective measure to reduce collisions in recent times. But it is still difficult for VTS operators to give collision avoidance decision suggestions to ships in the near vicinity now. Thus a shore-based automatic collision avoidance system is needed to help the operators take more effective control of traffic in restricted waters. The difference is that such a device should be designed to be able to avoid many more ships at the same time, perhaps up to 200 ships in total. On the other hand, fortunately, compared with the ship-based one, a higher standard computer can be used, and the knowledge base and data base can be designed to be much larger. This may make the design a little bit easier.

4 Functions and Features of ACAS

Although many researches have already been done in this field, no device can be used on board, yet. One of the reasons might be that the functions and desirable features of such an automatic collision avoidance system have not been defined in sufficiently correct detail. Some of them are discussed as follows which are regarded as having important aspects, or which are often ignored. It is important to note that the functions and features are not limited to those that follow.

4.1 Ship-ship Communication

A collision avoidance is based on the integration of activities refs. 1,30,31:

1. Identify target ships;
2. Collection of information about the navigation of target ships as well as own ship;
3. Analysis of collected information;
4. Evaluation and judgment of the risk of collision;
5. Taking action to avert own ship from the danger of collision;
6. Repetition of processes (1)-(5).

Through the collision avoidance, a manoeuvre of ships was improved by the assistance of the ARPA, its basic principles have not been changed due to the lack of precise and detailed information about target ships' navigation. Therefore, a new concept of ship collision avoidance is considered as introducing a ship-ship communication into the above process as follows and the principles are integrated to the ship collision avoidance system as shown in fig.1 ref. 32.

- Identify target ships and information exchange between ships as early as possible: improvement of lookout;

- Analysis, evaluation and judgment of the situation, and find the safest and most efficient course for all ships;
- Collision avoidance manoeuvre implementation.

Because the accuracy of analysis depends on the accuracy of information received, from fig.2, it can be seen that the accuracy of information and sea room both are bigger than before. Along with the development of the communication system, and information process system, etc., such a new concept of collision avoidance can be accomplished.

Considering the possibility of absence, failure of such a device on the target, the previous principle of collision avoidance is still needed in order to make a decision of collision avoidance without ship-ship communication system.

4.2 Fast Reasoning

Although the main purpose of the research on automatic collision avoidance system is to solve the technical problem of collision avoidance automation, also the economic aspect must be taken into account. Therefore, when a method is going to be employed, the reasoning time of collision avoidance decision-making needs to be considered, as a real time control is necessary for collision avoidance. It is true that an advanced computer can be used to achieve such a goal. At the same time the cost of such a device is increased. From this point of view, the following discussions have been made on fuzzy control and expert systems.

Several models have already been introduced, mainly by Japanese scholars, to making decision of collision avoidance using fuzzy reasoning and/or fuzzy control ref. 19-22. This is a very easy way to treat with decision-making based on knowledge and experiences. Two main problems are therefore left. First, the input of the fuzzy controller is normally limited to two parameters. That is why the assessment of risk of collision in these studies is mainly based on DCPA and TCPA, but without others such as speed, original DCPA, type and size of own ship and/or target, etc., which are also very important elements in the decision making of collision avoidance. Second, it is worthless if it takes much time in the procedure of decision-making ref. 33. Although a shape of a trapezium and/or triangle is utilised as the membership functions in these models, the calculation time is still unacceptably long, especially when more than two inputs are trying to be used. The application of such models is quite restricted. Usually, they only can be used to avoid single targets. We can not imagine that one ship is equipped with two ACASs, in which one can be used in multi-ship encounter whereas the other with a control fuzzy model only can be used to avoid a single target. Obviously, to avoid multi-targets is important and a system with such a function is necessary on board. Hence, a model which probably can merely be used to avoid single target is far away from reality, although it may be essential to the development of the study on ACAS.

Working on collision avoidance automation with expert system and other AI measurements is another hot point of research, and many papers have already been published in this field. We have to admit that it is an alternative to overcome the problem of automatic collision avoidance at sea. At the same time the features of such a means are needed to be thought about. Expert systems are very good at solving the problems in which the decision is made on the basis of knowledge and experiences, and a mathematical model is quite difficult to develop to describe the relationship between the parameters. For example, china or cement kiln control, and diagnosing a disease with traditional Chinese medical science, etc. According to the discussion in section 3.1, collision avoidance is not such a problem. Expert system maybe can be used to develop a system with a automatic collision avoidance function for VTS. If we talk about ship based systems, the following goals are required, which are difficult to achieve purely with expert systems.

- Can be used in multi-ship encounter;
- Can make decisions according to the collision regulations, and similarly with mariners' behaviour;
- Can make a real time control on the basis on micro-computer.

So that a combined method is needed ref. 34, it is encouraging to notice that this has already been attempted in some studies.

4.3 Keyboard Input and Speech Sounds Output

Mariners generally cannot input data into such a system with a keyboard, as they have to keep proper lookout at all times. For the same reason, the mouse should be used as little as possible. That means a man-machine dialogue system is not suitable for this purpose. Most of data has to be collected from other sensors automatically, and even the data about mariner's opinion should be designed so that these data can be collected before the voyage commences.

As has been mentioned above, mariners have to keep proper lookout at all time. So that the decisions and warnings should be designed as output in speech and/or sound. An option with several different kinds of language would have considerable merit.

Another related point is that, besides the decision of action, a warning on the sounds and/or light signals accompanied with the action is needed to be given automatically, according to the collision regulations, and harbours' regulations, etc.

4.4 Collision Regulations and Mariner's Behaviour

The collision regulations are the most important base for the developing ACAS. Unfortunately, the provisions on the action are all qualitative, but what we need to develop for ACAS are quantitative. So that the study on the interpretation for the provisions in collision regulations by mariners and the courts is necessary.

Besides, the user's (here the officer on duty) behaviour is also very important, but often ignored in the current studies. As it is not guaranteed that such a system can run normally at all times. If it breaks down in mid-procedure of collision avoidance, the task should be taken over smoothly and easily by the mariner. Therefore, that the majority of mariners' opinion (set A in fig.3) has been considered is not sufficient. The user's behaviour (set B in fig.3) has to be taken into account as well. Thus the final decision should fall in set C (the shadow section in fig.3) instead of set A in fig.3.

4.5 Prediction of the Behaviour of Targets

Subject to that, the ACAS is designed without ship-ship communication subsystem, or any such subsystem fails, it will be better if the ACAS can calculate and predict the most likely actions taken by the targets. It is not easy, but the results of the studies on the uncertainty and the unco-ordination of the mariners' behaviour will be likely for it refs. 1,35-41.

5 Conclusion

The whole problem of automatic collision avoidance has been reviewed. Some issues of such a system have been discussed, which have often been ignored or overlooked. The main purpose of this paper is to draw to the readers attention to these issues and constructively discuss them.

Along with the development of automation of ship bridges, more and more tasks have been taken over by electronic systems. Hence, the avoidance of collision at sea is more and more important, it is time to focus on it and try to solve this problem in the next couple of decades. It is likely that ACAS is going to be one of the most effective ways to overcome its occurrence. Although such a system can not be used on board now, it will be used in the near future.

6 References

/1/ Zhao J, Wang F and Imazu H (1994). The Principles of Collision Prevention at Sea (in Chinese). Dalian Maritime University Press.

/2/ Pike D (1990). The potential benefits and hazards of increased reliance on automation at sea. Safety at Sea and in the Air - taking Stock Together, paper 14, 13-15 Nov., UK.

/3/ Coldwell T (1983). Bridge design options. Shipping & Marine Engineering International. December.

/4/ Yamato H, et al (1990).Automatic berthing by the neural controller. Proc. of the 9th Ship Control System Symposium. Maryland, Sept.

/5/ Zhao J, et al (1992). The development of automatic collision avoidance system. The Journal of Navigation, vol.46, no.3, pp.422-437.

/6/ Kwik K H (1988). Systematic determination of ship collision avoidance manvoevres for use in an advanced navigation system. Ortung and Navigation, no.1, pp15.

/7/ Wang C (1986). Computer simulation of the process of ship's collision avoidance (in Chinese). The Journal of scientific Exploration, no.2.

/8/ Cheng J (1981). The principle of automatic collision avoidance system computation (in Chinese). The Journal of Shanghai Maritime University, no.4.

/9/ Guo P . The exploration of ship's collision avoidance method (in Chinese). Shipping Quarterly, vol.23, no.3.

/10/ Goodwin E M (1975). A statistical study of ship domains. The Journal of Navigation, vol.28, no.2, pp.328.

/11/ Davis P V, et al (1980). A computer simulation of marine traffic using domains and arenas. The Journal of Navigation, vol.33, no.1, pp.215.

/12/ Colly B A, et al (1983). Manoeuvring times, domains and arenas. The Journal of Navigation, vol.36, no.2, pp.324.

/13/ Kearon J (1977). Computer programs for collision avoidance and traffic keeping. Conference on Mathematical Aspects of Marine Traffic, Academic Press, London.

/14/ Imazu H, et al (1984). The determination of collision avoidance action (in Japanese). The Journal of Japan Institute of Navigation, vol.70, pp.31.

/15/ Holmes J D (1980). A statistical study of factors affecting navigation decision making. The Journal of Navigation, vol.33, no.1, pp.206.

/16/ Zhao J (1989). Modeling the ship's risk of collision using the expansional set theory (in Chinese). Proc. of Academic symposium between Chinese and Japan Institutes of Navigation, Tokyo, May.

/17/ James M K (1986). Modeling the decision process in computer simulation of ship navigation. The Journal of Navigation, vol.39, no.1, pp.32.

/18/ Zhao J and Wang F (1991). Simulation model of DCPA decision making. Proc. of the 8th IAIN Congress, Cairo, Otc.

/19/ Shimizu K, et al. A fuzzy control for adjusting the schedule of a ship at waterway intersections (in Japanese). The Journal of the Society of Naval Architects of Japan, vol.156, pp.201.

/20/ Imasaki H, et al (1986). A fuzzy reasoning model to decide the collision avoidance action (in Japanese). The Journal Japan institute of Navigation, vol.75, pp.69.

/21/ Hasegawa K, et al (1987). A automatic collision avoidance system of ship's using fuzzy control (in Japanese). The Journal of the Society of Naval Architects of Kansai, vol.205, pp.1.

/22/ Yamamoto T, et al (1990). Application of fuzzy theory in ship's collision avoidance operation (in Japanese). Hitachi Zosen Technology Review, vol.51, no.2, pp.3.

/23/ Imazu H, et al (1989). Basic research on an expert system for navigation at sea. Proc. of Academic symposium between Chinese and Japan Institutes of Navigation, Tokyo, May.

/24/ Blackwell G K, et al (1990). Onboard systems for automatic ship guidance and intelligent collision avoidance. Proc. of the International Conference on Modeling and Control of Marine Craft, pp.121-135, 18-20, April, Exeter.

/25/ Coenen F, et al (1991). A KBS for marine collision avoidance. The World Congress on Expert Systems Proceedings, pp.2574.

/26/ Tsuruta S, et al (1993). Basic research on the application of hypothesis-based reasoning system to collision avoidance. Proc. of the 10th Ship Control System Symposium, vol.2, pp.409-422.

/27/ Zhao J, et al (1992). An analytical study on the collision avoidance expert systems. Proc. of the International Conference on Information and Systems, pp.52, Dalian, Otc.

/28/ Smeaton G P, et al. The electronic chart in the integrated bridge: an emerging technology at sea. Trans IMarE, vol.104, pp.171-185.

/29/ Wiswall F L (1990). The impact of the electronic chart on the law of collision. Proc. of the International Conference on Maritime Law and the Electronic Chart, pp.97-106. Ottawa, 13-15 Nov.

/30/ Imazu H (1984). Ship collision avoidance and irs devices (in Japanese). Seizando Inc.

/31/ Imazu H (1984). The evaluation of collision risk (in Japanese). Navigation, vol.80.

/32/ Hosoda R, et al (1988). Advanced concept of ship collision avoidance. Proc. of NAV'88–WEMT'88 Symposium, Trieste, Italy, Otc.

/33/ Hasegawa K (1987). Automatic collision avoidance system for ships using fuzzy control. Proc. of the 8th Ship Control System Symposium, vol.2, pp.34-58, The Hague, Otc.

/34/ Zhao J, et al (1990). The evolutionary trend of ship's collision avoidance automation. Proc. of the International Marine Electro-technology conference, Shanghai, May.

/35/ Kemp J F (1973). Behaviour patterns in encounters between ships. The Journal of Navigation, vol.26, no.4, pp.417.

/36/ Jones K D, et al (1976). Automatic plotting radar. The Journal of Navigation, vol.29, no.3, pp.322.

/37/ Riek J R (1978). Collision avoidance behaviour and uncertainty. The Journal of Navigation, vol.31, no.1, pp.82-92.

/38/ Wang X (1987). Study on automatic radar collision avoidance system and the programme design. M.Sc dissertation in Dalian Maritime University.

/39/ Zhao J, et al (1988). The calculating model of critical CPA in uncoordinated action. The Journal of Dalian Maritime University, vol.14, no.3, pp.42-47.

/40/ Taylor D H (1990). Uncertainty in collision avoidance manoeuvre. The Journal of Navigation, vol.43, pp.238.

/41/ Zhao J, et al (1994). The uncertainty and uncoordination of mariners' behaviour of collision avoidance at sea. Proc. of the 8th International Navigation Simulator Lecturers' Conference, Shanghai, 28th Aug.– 2nd Sept.