SAFE SHIP CONTROL SYSTEM

Śmierzhalski Roman

Maritime University, Gdynia, Poland

Keywords
evolutionary algorithms, fuzzy logic, trajectory planning, avoiding collisions at sea, safe ship steering

Abstract
The article presents a control system of ship motion in situations threatening with collision. The goal of the presented system is to support the navigator in decision making, with possible full replacement of his work in the future. In this article, it was introduced a system joining work of two computer techniques, evolutionary algorithms to marking of optimum path of passages and a fuzzy logic to control ship after set path of passage. The introduced system has to assure safe trip of a ship in any navigational conditions with regard of weather conditions and met navigational objects of static or dynamic nature. For testing of the operation, the system and the marine environment a simulator was used to present navigational situations in a 3D graphical mode at the poor hydro-and-meteorological conditions.

1. Introduction

Modern marine transport requires preserving dates of delivery to harbours located all over the world, irrespective of weather conditions and volumes of transported cargo. In case of passenger transport, an additional requirement should be taken into account which is providing passengers with adequate level of comfort. On the other hand, there is a tendency to reduce ship operation costs, and realisation of this task may unintentionally involve threats to human life and natural environment. Losing transported cargo is also possible. That is why securing safety of sailing is one of more important issues in present-time marine navigation.

Among all causes of sea accidents, navigational errors compose a relatively big group [4], [9]. Out of fifteen biggest ships lost in years 2003-2004, as many as nine cases referred to collision or stranding [9]. A method leading to the reduction of sea accident risk may be introducing solutions that support the navigator in decision making in the situations threatening with collisions. For the voyage of the ship carrying passengers and cargo to be safe, a passing path meeting safety conditions should be determined for the ship. A basic safety condition assumes a minimum distance $D_b$ of safe passing of objects. Besides, the determined passing path should meet economic criteria, important for the shipowners, which include the length of the passing path, time needed to cover it, changes of ship’s speed along particular path sections and number of manoeuvres to be performed by the ship.

Taking into account a defined by the operator range of observation of a navigational situation (3, 8, 12, 24, 48 sea miles) covered by the ARPA (Automatic Radar Plotting Aids) system, the time horizon for solving a navigational problem can range from several minutes to 1-2 hours. The area of observation may be obscured by navigational constraints, of static or dynamic nature, which can considerably affect the process of the passing path determination. The task of determining a safe passing path for a ship at sea is reduced to the selection of an optimum solution, or a subset of optimum solutions, from a set of permissible paths. The paths are selected using an assumed cost criterion, provided safety conditions are unconditionally met and constraints taken into account. When determining a safe path for the ship motion, a compromise solution is searched for. The compromise is, generally, made between the cost of trajectory deviation from that assumed, or from the shortest way leading to the assumed endpoint, and the safety of passing navigational constraints. In this situation, steering the ship along the determined path taking into account parameters of ship dynamics and meteorological conditions is reduced to determining a passing trajectory.

In order to determine an optimal passing path for the ship, a evolutionary–fuzzy system PFSS (Path Finder and Ship Steering) has been developed. The system makes use of united work of two computer techniques: evolutionary algorithms (EA) for determining the optimal passing path, and fuzzy steering for
directing the ship along the assumed path. The trajectory of the ship motion determined by fuzzy steering along the assumed path is called a passing trajectory. The information on the navigational environment is delivered to a moving ship by a specialized measuring system ARPA. The navigational constraints, both static and dynamic, which ship meets on its way, compose the navigational environment and are modelled in the form of polygons, the shape and dimensions of which depend on weather conditions, region of navigation, manoeuvring ability of the ship, its dimensions, speed, course and bearing line, as well as speeds of the passed objects. Concluding, the task of the PFSS system is controlling, in a fuzzy way, the motion of the ship in the navigational environment along the passing path determined in an evolutionary way.

An essential feature of the PFSS system is its ability to control safely and automatically the ship motion in navigational situations. The use of the system considerably facilitates operator’s work concerning calculations performed in order to determine the passing path for the ship, as well as actions taken to keep the ship on the already determined passing path. When performing this function, the system takes into account all safety related legal regulations. The proposed solution is expected to contribute in a considerable way to the reduction in the number of accidents recorded, and to the increase of the safety of sea navigation.

The article also presents a simulator used for verifying the operation of intelligent system controlling ship’s motion at sea. Analysed is the operation of the system in the situation threatening with collision, and in the presence of unfavourable hydro-and-meteorological conditions. The developed simulator presents navigational situations using 3D graphics.

2. Description of the environment and obstacles

The ship, moving in the sea environment, meets various navigational constraints, of both static and dynamic nature. The static constraints include lands, canals, shallows, straits, and/or areas with legal traffic restrictions (traffic separation areas, water lanes, etc.). The static navigational constraints are approximated by polygons in a similar manner to that used for creating electronic vector maps. The dynamic constraints include other ships and moving objects passed by the own ship. These obstacles are modelled as moving hexahedrons. The area surrounding the own ship and all approaching moving objects is called a domain. The dimension of the domain depends on the navigational situation and parameters of motion and positions of the own ship and approaching objects. The positions, speeds and bearing lines of the approaching objects are determined by the ARPA system. Part of the approaching objects create collision threat for the motion of the own ship. In the evolutionary task of avoiding collisions it was assumed that the object is considered dangerous if it has come into the area of observation and can cross the course of the own ship at a dangerously close distance, defined by the operator depending on weather conditions and the navigation area.

Initial conditions, assumed when determining the passing path for the ship, include current position of the own ship and parameters of motion of the strange objects, determined at the initial instant by ARPA. The determined trajectory of the ship motion has a form of a broken line, consisting of line segments, linking the starting point with the assumed target point. Taking into account the hierarchical manner of ship steering, shown in Figure 1, the optimum passing path (trajectory of motion) is determined by EA using a kinetic model of ship motion. Ship’s dynamics is taken into account, when the fuzzy controller steers the ship along the selected trajectory of motion.

The adopted structure of steering secures:

- determining a safe passing path for the own ship on the basis of an assumed target point and current navigational situation in the area of navigation,
- steering the own ship along the selected passing path, time and distance parameters being preserved and disturbances acting on the ship taken into account,
- adaptive correction of the passing path in a navigational situation changing in an unpredicted manner.
3. PFSS system of ship steering in a collision situation

The PFSS system of ship steering makes it possible to reduce the problem of avoiding collisions to a two-stage task (Figure 2):

- at the first stage, an optimal time-parameterised passing path is determined for the ship on the basis of the assumed target. The trajectory consists of a sequence of line segments characterized by constant course and speed depending on the navigational situation recorded by the ARPA system.
- at the second stage, steering is determined for a selected passing path of the ship, taking into account dynamics of the ship, and hydro- and meteorological conditions in the navigational area. This stage consists of two calculation phases, executed simultaneously:
  - phase one, in which the deviation from the assumed course is currently controlled and corrected depending on the navigational situation and effect of sea currents, waves and wind (course controller);
  - phase two, in which the speed of ship motion along the selected path is controlled (speed controller).

The solutions obtained in the above two stages make it possible to perform, with proper time advance, the animation of the possible development of a collision situation taking into account the passing path planned for the own ship.

![Figure 1. The structure of ship control in a collision situation with use of PFSS system](image)

![Figure 2. The structure of ship steering in a collision situation with use of PFSS system](image)
The proposed structure of PFSS secures ship steering in the known environment with navigational constraints of both, static and dynamic nature, and making adaptive corrections of the trajectory in response to the situation at sea, which can change in an unpredicted manner. When parameters of motion of strange objects change, the assumed passing path is also corrected, for the own ship to reach safely the target point.

4. Evolutionary algorithm (EA)

The passing path was determined using an evolutionary algorithm, presented in detail in [1, 7, 8]. On the basis of EA tests (Figure 3) one can conclude that genetic operators are used with different frequencies during particular phases of operation of the algorithm [6]. In order to increase EA efficiency, its operation was divided into two phases. In the first phase, an area of possible solutions is searched, which contains the location of a global optimum. EA procedures used in this phase base on a population consisting of 50 individuals. The task performed by EA in this phase includes the examination of the space of permissible solutions. The individuals composing this population are characterized by increased probability of the use of genetic operators, such as: crossing, soft mutation, and repair of individual, due to the most frequent use of those operators in the initial phase of operation of the algorithm.

In the second phase of EA operation, the area of solutions obtained in the first phase is exploited in order to obtain an approximation of the global optimum. EA procedures used in this phase base on a population consisting of 10 individuals. The individuals composing this population would be characterized by increased probability of use of the genetic operators of mutation, smoothing and gene removal.

5. Fuzzy controller for ship’s position steering

The ship is kept on the assumed passing trajectory using the rules of fuzzy inference, first proposed by Mamdani [3]. The fuzzy controllers are characterized by lower sensibility to disturbances than that revealed by conventional controllers widely used in naval autopilots. Another quality which makes fuzzy controllers more effective than their conventional counterparts is possibility to incorporate expert’s elements and basis of knowledge into the controller’s basis of knowledge.

As mentioned above, the fuzzy controller of ship’s motion is divided into two parts: the course controller and the speed controller, working simultaneously. These two parts are structurally identical. The input signals for the both controllers are: the deviation of the output value from that assumed, and speed of the deviation changes in time. For the course controller the assumed value is the course, while for the speed controller – speed.

The difference between the fuzzy course controller and the fuzzy speed controller consists in the application of different bases of rules in each controller, as presented in Tables 1 and 2. For the course controller, 9 linguistic values have been defined at each input and output. They are: NH, NM, NL, NVL, Z, PVL, PL, PM, and PH which, respectively, stand for "Negative High", "Negative Medium", "Negative Low", "Negative Very Low", "Zero", "Positive Very Low", "Positive Low", "Positive Medium", and "Positive High". Membership functions for rule predecessors and successors are shown in Figure 4. For the fuzzy course controller defined in the above manner 81 possible Mamdani-type rules are obtained and placed in the controller’s basis of rules. The output signal from the controller is the signal for steering the rudder deflection, passed to the steering engine. A positive/negative value means steering the ship to the left/right.

![Figure 4. The shape of the membership function for an 81-rule fuzzy course controller](image-url)
For the speed controller 7 linguistic values have been defined. They are: NH, NM, NL, Z, PL, PM, PH and stand, respectively, for "Negative High", "Negative Medium", "Negative Low", "Zero", "Positive Low", "Positive Medium", and "Positive High". Membership functions for rule predecessors and successors are shown in Figure 5. The fuzzy speed controller includes 49 Mamdani-type rules placed in the controller’s basis of rules. The output signal from the speed controller is the change of position of the speed adjuster lever on the main engine speed governor. A positive/negative value means increase/decrease of rotational speed of the main engine.

The required passing trajectory of the ship, determined by a two-phase EA and corrected by the fuzzy controller, should be an optimal trajectory of the ship motion for given navigational situation taking into account current hydro- and meteorological conditions of the own ship environment. The hydrological conditions, which include wind, sea currents and waves, considerably affect the steering generated by the fuzzy controller. The above weather disturbances are modelled by equations which defining forces and moments generated by them.

6. Operation of the simulator and simulation tests [2]

Parameters of motion of the dynamic objects and the positions of static objects, including land contours and shallow water regions, are initialised once when the programme is starter. During the operation of the programme the information is cyclically exchanged between the mathematical model of the ship and the graphic environment. Changes in ship’s position, course and/or speed are visualized in the displayed graphics. The simulator user can control the ship and particular parameters of its operation. There is also a possibility to observe the vicinity of the ship. The navigating window of the simulator is shown in Figure 6.

In order to model navigational situations, twenty 3D silhouettes were implemented of various types of vessels (tankers, bulk cargo ships, passenger ferries, sailing vessels, and yachts) essential from the point of view of sea low regulations. Some silhouettes available in the simulator are shown in Figure 7.
The simulator user can observe changes in weather situation and sea state, presented in 3D graphical technique. The length and height of waves are changed according to Pedersen scale, while atmospheric conditions are determined using the Beaufort scale, for which the visibility ranges have been determined. Different meteorological conditions are shown in Figure 7.

Static elements, modelled in the simulator, that compose the navigational situation are shown in Figure 8.

The radar screen with the ARPA system implemented in the simulator is shown in Fig. 9, while Figure 10 presents a sample record of the navigational situation.
7. Conclusion

The presented PFSS system for safe ship control in a collision situation, making use of computer techniques: evolutionary algorithms and fuzzy control for determining optimal passing trajectory for the own ship, makes a novel approach to the problem of avoiding collisions at sea, in the environment with navigational constraints of static and dynamic nature.

![Sample operation of the simulator – trajectories of moving objects](image)

Figure 10. Sample operation of the simulator – trajectories of moving objects

The simulator models basic dynamic parameters of the marine environment. Taken into account are phenomena connected with bad visibility, the effect of shallow water, and/or the presence of other navigational objects of static (lands, water lanes, navigational buoys, restricted traffic areas, lighthouses) and dynamic nature (other moving ships and areas of unfavourable weather conditions). The applied mathematical model of the ship maps dynamic characteristics of the B-481 vessel. Further activities in this area will be oriented on complementing the navigational environment by other elements, such as: offings, water lanes, etc. The simulator allows modelling various navigational situations, thus providing opportunities for verification of the proposed ship control system. The presented simulator, operating with the PFSS system, may make an effective tool for learning sea navigation. It can also be used as the system supporting navigators in decision making at sea.

References