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Intelligent Ship Control System

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ABSTRACT: The article present intelligent 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 system joins work of three computer techniques, evolutionary algorithms to marking of optimum path of passages, fuzzy logic to control ship after set path of passage and multivariable robust control to precise movement of the vessel with very small velocity and any drift angle. Introduced system has to assure safe trip of ship in each navigational conditions with regard of weather conditions and met navigational objects of static or dynamic nature. For testing of the operation the system, the marine environment 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 (Soares, Teixeira 2001). Out of fifteen biggest ships lost in years 2003-2004, as many as nine cases referred to collision or stranding (www.isl.org).

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 Db 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 ISCS (Intelligent Ship Control System) 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 measuring system. 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 intelligent ship control system (ISCS) 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 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. Analyzed is the operation of the system in the situation threatening with collision, and in the presence of unfavorable 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.

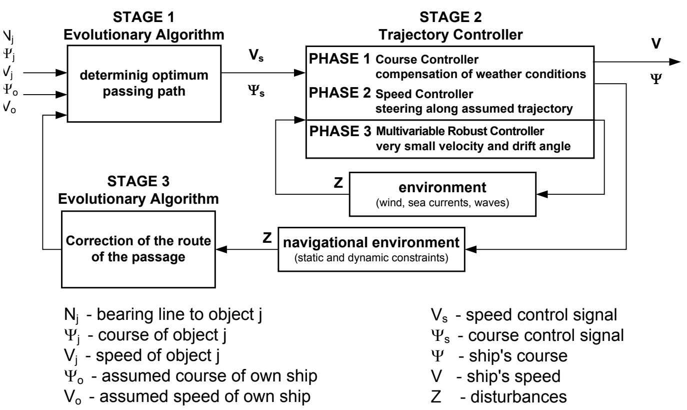

Fig. 1. The structure of ship control in a collision situation with use of ISCS

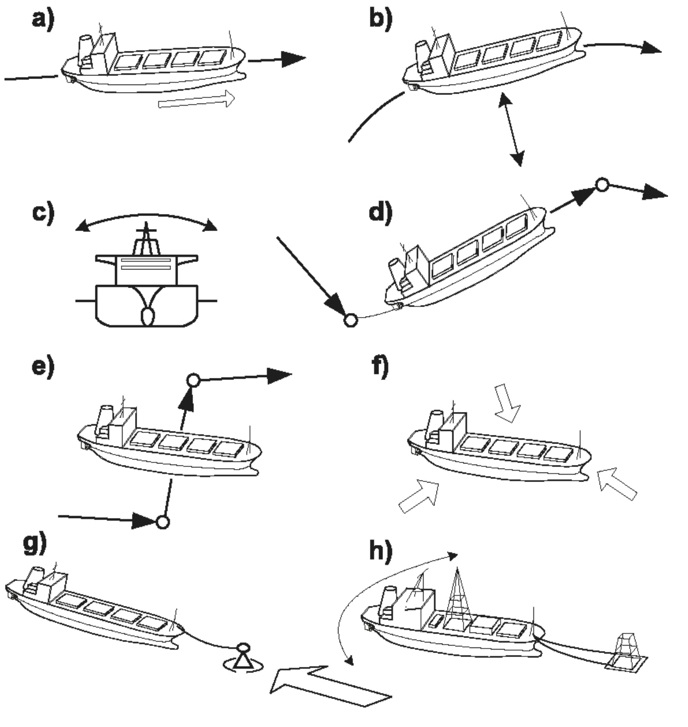

Fig. 2. The control subsystems for the ship motion: a) heading and/or speed stabilisation, b) stabilisation of the turning radius, c) roll damping, d) trajectory tracking, e) precise steering with the low speed, f) dynamic ship positioning (DSP), g) automatic single-buoy mooring, h) turret-mooring for FSO, FPSO or FPDSO ships

Taking into account the hierarchical manner of ship steering, shown in Fig. 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:

- At the first stage: 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. 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 the own ship along the selected passing path, time and distance parameters being preserved and disturbances acting on the ship taken into account. 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 three 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); phase three, is realize precise movement of the vessel with very small velocity and any drift angle (case in Fig. 2). Such kind of the motion is used mainly in harbours or other constrained areas.
- At the third stage: adaptive correction of the passing path in a navigational situation changing in an unpredicted manner.

3 EVOLUTIONARY ALGORITHM (EA)

The passing path was determined using an evolutionary algorithm, presented in detail in (Łebkowski & Śmierzchalski 2003a, Śmierzchalski 1999, Śmierzchalski 2000). On the basis of EA tests one can conclude that genetic operators are used with different frequencies during particular phases of operation of the algorithm (Łebkowski et al., 2005). 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.

4 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 (Mamdani 1974). 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. 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 Fig. 3.

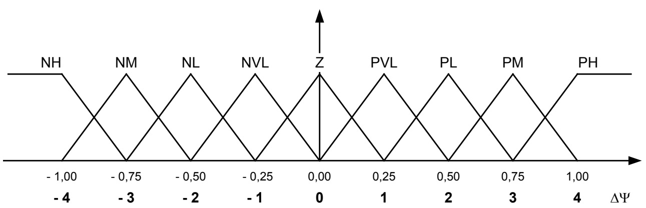

Fig. 3. The shape of the membership function for an 81-rule fuzzy course controller

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.

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 Fig. 4. 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.

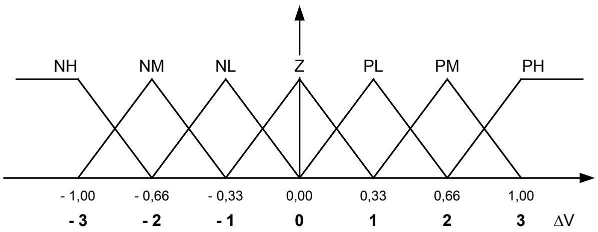

Fig. 4. The shape of the membership function for a 49-rule fuzzy speed controller

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 (Łebkowski & Śmierzchalski 2003b).

5 MULTIVARIABLE ROBUST CONTROLLER

The main goal of the presented control system is the precise steering of three ship's velocities: surge, sway and yaw. The values of velocities during such manoeuvres are very small (often close to zero) and therefore standard navigation logs and angular rate meters are unserviceable due to their poor accuracy. Kalman filters or observators systems should be used for estimation. The block diagram of the process is presented in Fig. 5.

For performing of any manoeuvres the regulator calculates the two demanded forces τ_x and τ_y for longitudinal and lateral directions and one moment τ_p for turning (in the ship-fixed frame).

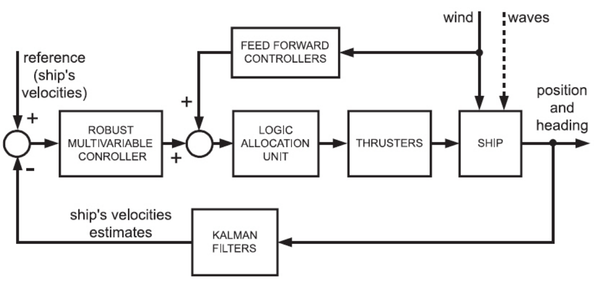

Fig. 5. The block diagram of the robust control system

These signals should be distributed in optimal way between propellers installed on the ship - see Fig. 2.The system for this purpose is commonly named 'thrust allocation unit' and should be created individually for every driving system. One of the possibilities is the algorithm based on the pseudoinverse matrix operations and logic inequalities described in (Gierusz & Tomera 2006). A rational methodology for designing robust regulator for ship velocities can consist of the following items:

- derivation a linear state model or transient functions model of the vessel in the chosen range of velocities,
- estimation of uncertainties in the system,
- defining of performance requirements,
- building open-loop scheme for calculating of regulator,
- computing of the controller by means D-K iteration procedure from ”μ - Analysis and Synthesis Toolbox” (Balas et al., 2001).

Case study

The presented scheme was applied to synthesis of the robust controller for floating training ship. The vessel named 'Blue Lady' is used by the Foundation for Safety of Navigation and Environment Protection at the Silm lake near Ilawa in Poland for training of navigators. It is one of the series of 7 various training ships exploited on the lake. The ship 'Blue Lady' is an isomorphous model of a VLCC tanker, built of the epoxied resin laminate in 1:24 scale. It is equipped with battery-fed electric drives and the control steering post at the stern for two persons.

Details of the robust controller one can find in (Gierusz 2006). Exemplary results of the steering are presented below for two levels of wind. Every Figure is divided into two parts. The left-hand side presents the results of steering for weak wind and the right-hand side presents the same trials performed with medium level of wind. Presented example is illustrated by means of 2 Figures:

- the trajectory, drawn by ship's silhouettes every 30 s, (every trajectory starts from point 0,0),
- ship's velocities (reference signals and real values), supplemented by wind runs recalculated in Beaufort scale.

As one can expect the tracking of the ship's velocities is acceptable when wind is small. If it increasing worse control quality is observed especially in velocities. To compensate additive disturbances we used feedforward regulator, which the scheme was shown on Figure 6.

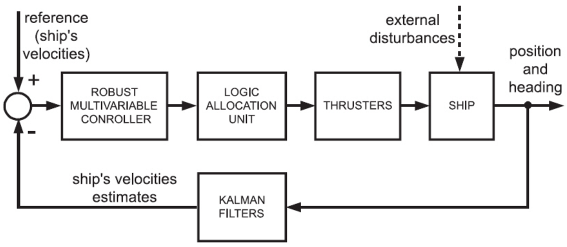

Fig. 6. The block diagram of the robust control system

Figures 7 and 8 present trajectories and velocities of the ship when robust regulator is used with feedforward part.

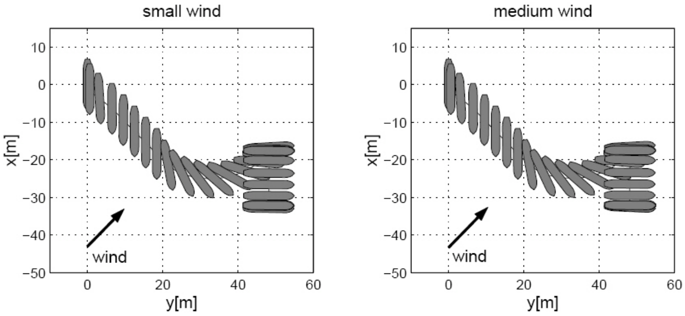

Fig. 7. The trajectory of the ship when feedforward controller is implemented in the system, drawn by silhouettes every 60 s. Initial heading [illegible]180 deg, the trial period t = 1950 s. The arrows indicate the average wind direction

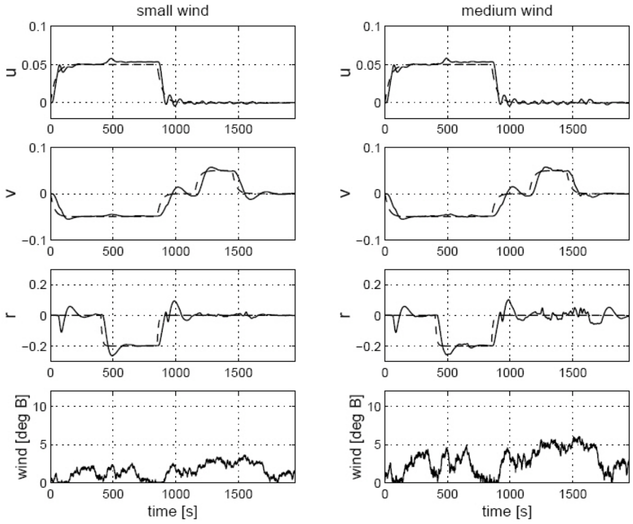

Fig. 8. The velocities of the ship - from the top: surge, sway and yaw. The bottom figures present the wind speed in Beaufort scale. Solid lines denote real values, dashed lines – commands

The feedforward regulator used in presented control system consists of three parts:

- low pass filters for relative wind speed and direction, measured by means of the ultrasonic anemometer, installed on board,
- calculation unit for wind forces and moment estimation,
- simple regulators for three channels (longitudinal, lateral and angular ones).

6 OPERATION OF THE SIMULATOR AND SIMULATION TESTS

Parameters of motion of the dynamic objects and the positions of static objects, including land contours and shallow water regions, are initialized once when the program is started. During the operation of the program 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 ssibility to observe the vicinity of the ship. The vigating window of the simulator is shown in Fig. 9.

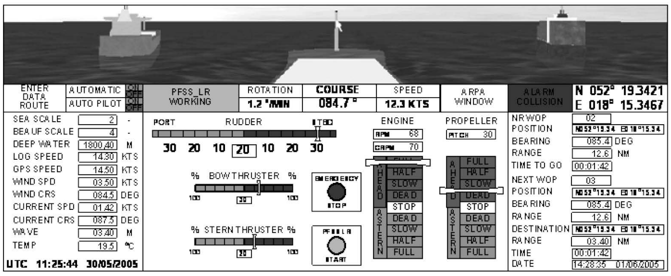

Fig. 9. Simulator navigating window

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. 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. The radar screen with the ARPA system implemented in the simulator is shown in Fig. 10.

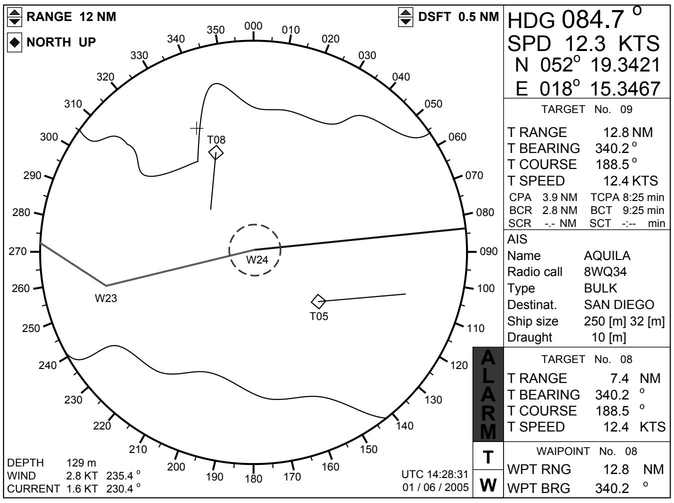

Fig. 10. The window of the radar simulator

7 CONCLUSIONS

The presented Intelligent Ship Control System in a collision situation, making use of computer techniques: evolutionary algorithms, fuzzy control and multivariable robust controller. 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 unfavorable weather conditions). The simulator allows modeling various navigational situations, thus providing opportunities for verification of the proposed ship control system. The presented simulator, operating with the ISCS, may make an effective tool for learning sea navigation. It can also be used as the system supporting navigators in decision making at sea.

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