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A navigational decision support system for sea-going ships

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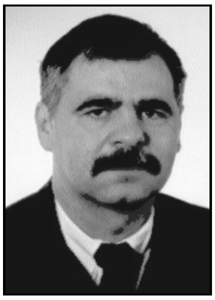

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Abstract

This article presents a model of a navigational decision support system on a sea-going vessel. Apart from basic information functions, the system executes tasks typical of decision support systems. Its basic functions and performance are described. Problems of navigational data acquisition and integration as well as navigational situation analysis and assessment are discussed. The system generates solutions of collision situations. Navigators' knowledge is implemented in the system by using artificial intelligence tools and methods. Its key feature is the capability of explaining generated conclusions. The prototype system, built using the presented model, is being tested in real conditions onboard ship.

Keywords: decision support, navigation, sea going vessel.

Nawigacyjny system wspomagania decyzji na statku morskim

Streszczenie

W artykule przedstawiono model nawigacyjnego systemu wspomagania decyzji na statku morskim. System realizuje obok podstawowych funkcji informacyjnych zadania typowe dla systemów wspomagania decyzji. Przedstawiono główne funkcje systemu oraz ich realizację. Scharakteryzowano zagadnienia akwizycji i integracji danych nawigacyjnych, funkcje analizy i oceny sytuacji nawigacyjnej. System umożliwia generowanie proponowanych rozwiązań sytuacji kolizyjnych. W systemie zaimplementowano wiedzę nawigatorów przy zastosowaniu m.in. metod i narzędzi sztucznej inteligencji. Istotną cechą systemu jest możliwość objaśniania generowanych wniosków. Na podstawie przeprowadzonej analizy modelowanego systemu, opracowano diagramy pakietów, stanowiące agregację elementów modelu. Przedstawiony model struktury systemu stanowił podstawę do opracowania architektury fizycznej. Uwzględniono środowisko funkcjonowania systemu. Stanowią je statkowe urządzenia i systemy nawigacyjne, będące źródłem informacji dla systemu. W systemie wyróżniono trzy moduły – aplikacje działające jednocześnie, realizujące funkcje systemu. Pierwsza z nich odbiera komunikaty z sensorów, a po ich selekcji i integracji przesyła zagregowane dane do drugiej aplikacji - programu zarządzającego. Rezultaty procesów przetwarzania wysyłane są do trzeciej z aplikacji – GUI, której zadaniem jest zobrazowanie sytuacji nawigacyjnej na ekranie monitora oraz komunikacja nawigatora z systemem. Prototyp wykonany na podstawie prezentowanych modeli jest testowany w warunkach rzeczywistych na statku morskim.

Słowa kluczowe: wspomaganie decyzji, nawigacja, statek morski.

1. Introduction

The number of electronic navigational and communication technologies and systems available on ships and in land-based centers is constantly on the rise. These include Automatic Identification System (AIS), Electronic Chart Display and Information Systems (ECDIS), Integrated Bridge Systems/Integrated Navigation Systems (IBS/INS), Automatic Radar Plotting Aids (ARPA), radio navigation, Long Range Identification and Tracking (LRIT) systems, Vessel Traffic Services (VTS) and the Global Maritime Distress and Safety System (GMDSS). Their task is to provide navigators and vessel traffic operators with relevant information.

Of a variety of information systems onboard ship, the importance of ECDIS is growing. The system, supplemented with some standby devices, can be regarded as equivalent to updated navigational charts. ECDIS displays selected information from an intra-system ENC – electronic navigational chart as well as position data coming from bridge equipment. This solves a technically important issue for navigational safety, i.e. one-screen presentation of: information about collision situations (image of surface traffic situation obtained from a radar or ARPA), position (GPS/DGPS), bathymetric data included on the chart. It seems that new solutions in these systems will tend towards decision support systems – intelligent navigational advisory systems. Their functions, apart from information provision, include the identification of hazards in ship movement (e.g. collision situations), warning of hazards and automatic generation of solutions (suggested manoeuvres). Such systems should contain adequately implemented navigators' knowledge enabling analysis of a present navigational situation, identifying and solving a dangerous encounter, using criteria commonly adopted by navigators.

One solution in this field is the navigational decision support system being developed at the Maritime University of Szczecin [9], making use of ENC and enhancing the capabilities of navigational equipment onboard. The system, in the phase of designing, follows current advancements of marine navigation, including e-navigation, the concept developed since 2005. Its working definition [4] says that "e-navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment". Intelligent navigational advisory systems, with their information and decision support functions, will constitute an element of e-navigation.

2. System characteristics

The growing intensity of vessel traffic, maximum size and speeds developed by vessels call for prompt decisions navigators often have to make. Complex situations and a great deal of related information are one potential source of human errors, resulting in marine accidents. Therefore, assisting navigators in decision making processes may substantially reduce human errors onboard sea-going ships [8].

System tasks

The navigational decision support system has the following basic tasks: automatic acquisition and distribution of navigational information, analysis of a navigational situation, solving collision situations and interaction with the navigator.

Putting these tasks in more detail, the system should enable:

– acquisition, fusion and integration of navigational data available onboard,
– navigational situation display,
– analysis of a navigational situation using navigators criteria,
– signalling dangerous situations and showing a present level of navigational safety,
– planning a manoeuvre/manoeuvres and movement trajectory in collision situations,
– display of suggested manoeuvre/s,
– function of explaining (justifying) the worked out solution.

The system should also store data for subsequent ship movement process reproduction and for statistical purposes.

2.1. System environment

The system is intended to complement shipboard navigational equipment. Its correct performance requires co-operation with other systems and devices onboard. Standard equipment carried by ships includes a log, gyrocompass, radar, echosounder, ARPA, GNSS (*Global Navigational Satellite System*), e.g. GPS (*Global Positioning System*) or DGPS (*Differential Global Positioning System*), AIS, ECDIS, GMDSS. When developed, the prototype system will utilize the following sources of navigational information: log, gyrocompass, radar/ARPA, GPS and DGPS receivers, AIS and ENC [15].

The system is viewed as an advisory system. It will be capable of affecting the environment in the process of automatic ship movement control by changing rudder and engine settings according to navigator's decision: the solution chosen from among those suggested by the system or arbitrarily set by the operator.

2.2. Basic functions of the system

A decision support system runs in real time. It is supposed to monitor own ship and the environment and record navigational situation information. On this basis the system identifies and assesses a navigational situation and proposes such solutions, i.e. decisions, that will ensure safe navigation.

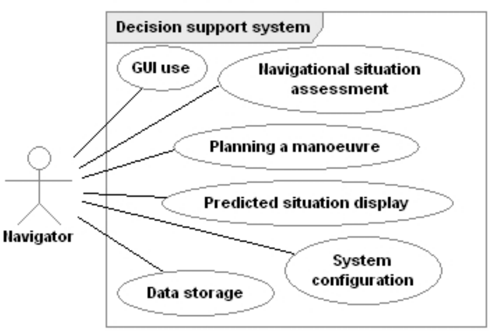

Fig. 1. Use cases of the navigational support system on a sea going vessel
Rys. 1. Diagram przypadków użycia nawigacyjnego systemu wspomagania decyzji na statku morskim

First, procedures and regulations concerning decision making in the process of navigation on a ship were specified. Use case diagrams were applied to describe functional requirements [12, 14]. Basic services (functions) of the system required by the navigator are given in Fig. 1. These include: 1) display of a navigational situation and user's communication with the system (GUI interface); 2) situation assessment, reflecting the regulations in force and assessment criteria defined by the navigator; 3) working out a manoeuvre in a collision situation; 4) displaying a projected situation in a defined future period (situation prediction); 5) data storage, including navigator's commands, in order to reproduce the voyage; 6) system configuration – change of default settings and tailoring them to navigator's individual needs and prevailing navigational conditions (e.g. modification of situation assessment criteria).

Scenarios were then developed for various use cases. The conditions initiating a case were defined, and the system state after the case realization and the main scenario were characterized. A list of possible alternative scenarios and non-functional requirements essential to the realization (implementation in the system) were defined for each use case. Particular attention was paid to time requirements. Events and associated responses of the system were identified. The following events were regarded as essential to navigational safety: appearance of a new object (vessel) in the system, change of vessel(s) movement parameters, detection of a dangerous situation, navigator's commands and system time.

3. Selected system functions

The tasks of the navigational decision support system were analyzed in view of the functions the system executes. The most important were found to be: acquisition and accessibility of navigational information, analysis and assessment of navigational situation, solving collision situations and interaction with the navigator.

3.1. Data integration

Based on an analysis of shipboard navigational equipment and systems and formats of data from them, the scope and form of data necessary for the realization of designed system tasks were determined. Particular focus was put on the accuracy of navigational systems and devices and cases of redundancy (doubled devices enabling reception of data from various sources).

Information on the movements of own ship and other vessels in the vicinity provides a basis for effective solution of collision situations. The accuracy of information the navigator is supplied with is significant for the correct assessment of situation and the decision s/he will make.

An algorithm was developed for the estimation of own ship state vector. The algorithm, based on a multisensor Kalman filter, executes a fusion of data received from GPS receivers, gyrocompass and ship's log [2]. The developed algorithms enhance the reliability of system operation and reduces measurement errors [1].

ARPA, a radar with automatic echo tracking function, is a common system used for the identification of other vessels movement parameters. ARPA is an autonomous system, independent of external devices and systems. Radar tracking consists in estimating the state vector of the target whose echo can be seen on the radar screen. As there are a variety of elements affecting this vector, filtration has to be applied to obtain an accurate smoothened vector useful in terms of navigation. An algorithm of another ship state vector estimation in the radar tracking process was also developed. This algorithm utilizes general regression neural networks (GRNN) [5].

The automatic identification system (AIS) is an alternative source of vessel traffic information. Compared to ARPA, this system provides more accurate data on vessel movement parameters. However, smaller vessels are not obliged to carry an AIS (SOLAS, Annex 17). Therefore, there may occur a situation when AIS data will not be identifying all the vessels around navigator's own ship. In this connection, an algorithm for the verification of vessels identified by both systems was designed. If vessels are recorded by both systems, the more accurate data are selected.

Integrated data constitute input data in computing procedures of the decision support system. They are displayed to the navigator on an electronic navigational chart.

3.2. Situation analysis and assessment

An analysis and assessment of a navigational situation of own ship is just one stage in the decision making process. Algorithms of inference in the scope of COLREGs were developed [3]. Principles of ship behaviour implied by the regulations were considered, accounting for good and reduced visibility conditions. The algorithms take into account the phase of ships encounter and ship's navigational status (stand-on or give-way vessel) stipulated by the regulations.

The specification of ship's behaviour complying with the 'right of way' regulations plays an important role in selecting the decision procedure and the verification of its performance in navigational decision support systems.

The basic criteria adopted for navigational situation assessment are the closest point of approach (CPA) and time to CPA (TCPA). Both criteria are commonly used in ARPA systems. These criteria assume that the navigator defines the minimum values: (safe) CPA while passing another vessel (CPA_{limit}) and the time to CPA_{limit} ($TCPA_{limit}$). If the distance at which another vessel will pass is shorter than the defined CPA_{limit} and the respective time to reach that distance is less than the assumed $TCPA_{limit}$, then a collision avoiding manoeuvre has to be performed immediately.

The ship domain was proposed as an additional criterion of situation assessment. The ship domain is an area around the ship that the navigator intends to keep clear of other vessels and objects [13].

3.3. Choice of the route

Deciding on a safe manoeuvre, i.e. solving a collision situation, the navigator chooses the type of manoeuvre (course and/or speed change) and the relevant parameters: time to begin the manoeuvre and the course/speed values. The navigator may determine a safe course such that the object will be passed at a preset distance considered as safe (CPA_{limit}). Shipboard ARPA systems feature a trial manoeuvre function, capable of determining a passing distance for the course and/or speed values of own ship defined by the navigator. The determination of own ship's course needed to pass another ship at a preset distance can be achieved by using analytical relationships [6].

Algorithms for the determination of safe course and speed values were also elaborated for encounters with many vessels. It is then possible to define a trajectory of ship movement by indicating turn points: alteration to a safe course and then returning to the original course. Similarly, from analytical formulas, a safe speed of own ship can be defined.

The choice of way may be considered as an optimization task. Methods used to solve this type of problems include static, dynamic, single- or multi-criteria methods, those based on game theory, genetic algorithms and fuzzy logic.

The developed algorithm of the choice of way (optimization of anti-collision manoeuvre) is based on multi-stage control. The trajectory covered was adopted as a quality indicator, assuming two constraints: preset distance of passing other vessels and minimum value of course alteration. The algorithm takes into account own ship's manoeuvring characteristics and the COLREGs in force.

Navigators often use fuzzy terms such as 'safe distance', 'significant course alteration', 'small loss of way' etc. Fuzzy logic was used to describe these linguistic terms. The problem of the choice of way was approached as a multi-stage problem in a fuzzy environment. Thus a compromise could be reached in a typically human attempt to reach contradictory goals: maintain 'safe distance' to another vessel (object), minimize the trajectory the ship covers and be able to notice a 'significant course alteration'. An optimization algorithm was designed for a problem thus formulated [10].

The proposed solutions supplemented with their justification facilitate navigator's decision.

3.4. Presentation of information

The scope and form of displayed information depend on the user's tasks. Due to a large number of devices the navigator has to monitor, the system interface should be easy to handle and give access to information essential to navigational safety. The symbols and mode of presentation do not differ from standards adopted in other navigational aids such as ECDIS or ARPA. In the process of interface design, much effort was taken to make the system respond in a transparent and straightforward graphic form. The system has a control panel for communication with the user.

The interface model made up a basis for developing a preliminary design of navigator's interface, which was tested and verified in laboratory conditions.

4. Construction of the system

4.1. System architecture

Using the results of an analysis of the modelled system, the authors developed package diagrams, an aggregation of model elements. Figure 2 presents basic system packages. The following packages were distinguished: information (registration of decoding and interpretation of messages from systems and external devices), event identification, situation analysis and assessment, manoeuvre choice, movement prediction, managing, knowledge base and library of navigational procedures.

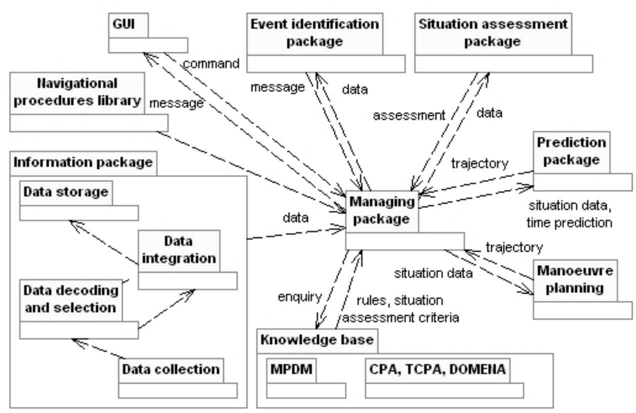

Fig. 2. Package diagram of the navigational support system
Rys. 2. Diagram pakietów nawigacyjnego systemu wspomagania decyzji

Special focus was put on the last two packages. The package of knowledge base contains, among others, algorithms of COLREGs interpretation and the criteria for situation analysis and assessment, providing for their optional personalization, i.e. their modification to suit the preferences of individual users – navigators. This package provides service functions for other packages: navigational and manoeuvre planning.

Due to the specific character of the designed system (real time system) the managing package was separated. Its main tasks are to analyze events, order tasks and manage system resources (task activation and allocation of system resources needed for task execution, etc.).

The knowledge of future positions of own and other ships' is important for effective avoidance of collision situations. Moduł predykcji sytuacji pozwala wyznaczyć pozycje obiektów dla zadanego horyzontu czasowego [11]. The situation prediction module allows to determine ships' positions for a preset future time interval [11].

Besides, the user interface was separated, being that part of the system which the user can see. The basic functions of the interface were recognized to be: 1) display of a navigational situation using ENC; 2) user-system communication; 3) presentation of solutions proposed by the system.

4.2. Physical architecture of the system

When the system structure model had been worked out, physical architecture could be designed (Fig. 3). After laboratory tests the system will be verified in real conditions at sea, therefore the future environment was taken into account, namely shipboard navigational systems and equipment, sources of data input for the system. Messages from the particular devices are generally sent, as a standard, to an RS-232 port at a varying frequency. Due to the range of serial communication and the need to receive signals from many sensors, servers of serial ports were used. They enable integration of signals from serial ports and sending messages through the computer network using the TCP/IP protocol. The speed of signal transmission is also higher than that of serial transmission.

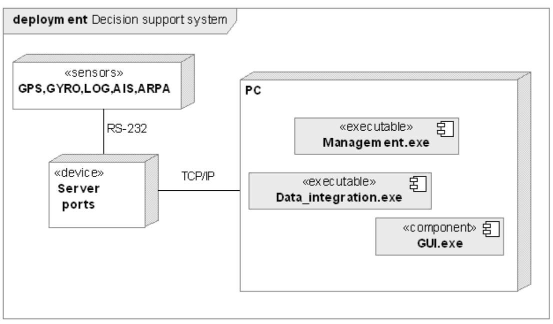

Fig. 3. Physical architecture of the system – deployment diagram
Rys. 3. Architektura fizyczna systemu – diagram rozlokowania

Three modules in the system are applications working simultaneously, executing functions of the system. One module receives messages from sensors, selects and integrates them and sends the integrated data to the next application – managing program.

The managing program gathers data, based on which it carries out cyclical operations (receives and transmits messages on navigational situation, assesses the situation, etc.) and acyclical operations, such as alerting the system that an initiating event has occurred (e.g. a new object in the range) or having received a command from the navigator, (e.g. plan a manoeuvre or display predicted situation).

The outcome of processing is sent to the third of the three applications – GUI – responsible for displaying a present navigational situation on the monitor screen. This application enables communication between the system and the navigator, who can instruct the system by choosing a command from the command list. Requests of executing a command or commands are sent to the managing program. The operator can change the system configuration, i.e. its parameters.

The described physical architecture of the system allows to install the software on one or more (e.g. three) computers. For instance, for testing in laboratory conditions each application was installed on a separate computer. The communication between the programs was provided by a computer network using TCP/IP protocol. This solution enables simultaneous software development (coding of each module) and testing. The final prototype system will be installed on one computer.

5. Summary

The presented model of a navigational decision support system to be used on sea-going vessels will complement the ship's navigational aids. The process of system development included tasks and functions description and the design of system structure. Navigators' knowledge covering navigational situation analysis and assessment and solving collision situations was implemented in the system. Based on the structure model, the physical architecture of the system was designed.

The prototype system based on the model in question is being tested in real conditions, onboard the research-training vessel m/v Nawigator XXI operated by the Maritime University of Szczecin.

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