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NAVDEC – navigational decision suport system on a sea-going vessel

NAVDEC – nawigacyjny system wspomagania decyzji na statku morskim

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Abstract
This article presents the NAVDEC, a navigational decision support system on a sea-going vessel. The system, developed at the Maritime University of Szczecin, is compared with other systems of this type worldwide. New functionalities of the NAVDEC are highlighted, as they may significantly contribute to the enhancement of navigational safety. As there has always been a growing interest in implementing research results into practical use, the authors describe their experience in transferring new technology to industry.

Słowa kluczowe: nawigacja morska, bezpieczeństwo żeglugi, wspomagania decyzji

Abstrakt
W artykule przedstawiono opracowany w Akademii Morskiej w Szczecinie nawigacyjny system wspomagania decyzji na statku morskim NAVDEC. Porównano system z innymi tego typu rozwiązaniami dostępnymi na rynku światowym. Szczególną uwagę zwrócono na nowe funkcjonalności opracowanego systemu. Funcjonalności te mogą w istotny sposób przyczynić się podniesienia poziomu bezpieczeństwa żeglugi. Ze względu na coraz większe zainteresowanie wdrażaniem wyników badań naukowych do praktyki, w artykule przedstawiono doświadczenia autorów związane z transferem nowych technologii do przemysłu.

Introduction

Rapid development of the Information Communication Technology (ICT) widens the possibilities of navigational data acquisition, processing and presentation, a great step forward in supporting the navigator responsible for safe conduct of the vessel at sea. Navigational equipment and systems on board ships considerably raise the level of navigational safety. These are mostly information systems helpful in the decision making process. The broader application of ICT is ascertained by such concepts presently being developed as e-maritime and e-navigation.

Investigations in a number of research centres are aimed at further enhancement of navigational safety by limiting errors made by the human, as these account for the majority of marine accidents. Consequently, there is a tendency to convert navigational information systems into navigational decision support systems. Apart from navigational information acquisition, integration and presentation, shipboard decision support systems are supposed to analyze and assess the current situation and to determine and submit to the navigator a solution or solutions to any hazardous situation they may encounter.

Designed and created at the Maritime University of Szczecin the navigational decision support system NAVDEC is capable of performing all these functions on a sea-going vessel. Presently actions are being taken to put the system in service. This goes in line with strongly emphasized idea of knowledge-based economy. At the same time, the evaluation of universities' activities to a large extent is based on their contribution to innovation, demonstrated, inter alia, by their capability of implementing research results in industrial applications. In the Polish reality, however, the process of commercialization of scientific knowledge still comes across numerous barriers in terms of organization, financing or awareness [1]. Therefore, it is important to show examples where such barriers could be successfully overcome. The commercialization of the NAVDEC system is one such example.

The competitive position of maritime transport compared to the other transport modes leads to a continuous increase in the carriage of goods by sea, which entails higher traffic intensity, vessel tonnages and speeds. This, in turn, adversely affects the safety of people, ships, cargo and marine environment. To enhance navigational safety, efficiency and competitiveness of transport services in maritime trade, both ships' and land-based vessel traffic centres' equipment and systems are constantly being upgraded. Such facilities perform mainly information functions and in this respect they support the process of safe ship conduct. However, the amount of information available on the ship has been on the rise while the technical systems have become more complex. For these reasons, both information management and the resultant decision making are difficult, e.g. emergency situations may go beyond decision-maker's abilities.

A review of maritime court decisions indicates that human errors are one of the major causes of marine accidents. Elimination or reduction of human errors, which would provide for possibly high safety level, can be achieved only by equipping ships with tools that, apart from information functions, will work out solutions to collision situations accompanied by adequate comments. None of the systems known to date is capable of performing such functions. Therefore, decision support is rather restricted, and, consequently, collisions sometimes are not avoided. A higher level of navigational safety gained through the introduction of the system performing the new functionalities will reduce the risk of marine accidents. This will bring the following advantages:

- social benefits due to lower rate of personnel injuries and loss of life on sea-going ships;
- material benefits due to lower loss of cargo, less damage to ships or sinkings;
- marine environment protection and prevention of ecological disasters that occur as a consequence of collision of ships carrying dangerous goods.

The navigational decision support system NAVDEC is the first navigational tool worldwide that performs information functions, as well as those typical of decision support systems. Its innovative functionalities, significantly extending the performance of devices generally carried by ships, have now a status of patent applications filed at home and internationally.

The NAVDEC complements the navigational equipment of the ship. It is a real time system handled by the navigator. The system observes its ship and the environment and records information on the present navigational situation. On this basis the system identifies and assesses the navigational situation (processing) and works out solutions (decisions) assuring safe navigation. For the system to function correctly, it has to co-operate with standard equipment and systems installed on board (often used on leisure craft as well) such as: log, gyrocompas, ARPA (*Automatic Radar Plotting Aids*), GNSS (*Global Navigational Satellite System*), AIS (*Automatic Identification System*), ENC (*Electronic Navigational Chart*), sources of current navigational data (Fig. 1). Similarly to the ECDIS system (*Electronic Chart Display and Information System*) the NAVDEC (Fig. 2) performs information functions – on one screen it presents bathymetric data from an electronic chart, an image of surface situation from a tracking radar, positional information from the AIS and GNSS receivers. Finally, it determines and presents to the navigator movement parameters of targets in vicinity.

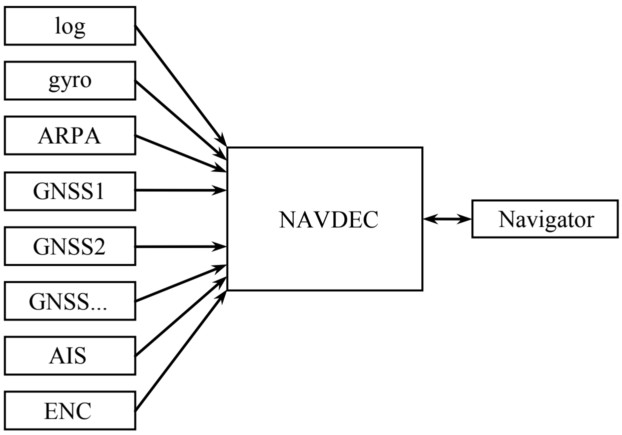

Fig. 1. Schematic environment of the NAVDEC
Rys. 1. Schemat otoczenia NAVDEC

Effective solutions to collision situations are based on the data defining own and other ships' (targets) movement parameters. The accuracy of data presented to navigators is of major importance for their correct situation assessment and decisions to be made. Therefore, the NAVDEC system performs the fusion of own ship data (measurements

Fig. 2. The NAVDEC installed on the m/v Nawigator XXI
Rys. 2. NAVDEC zainstalowany na m/v Nawigator XXI

from a number of shipboard GNSS receivers are used) and integration of data on targets from alternative sources (tracking radar, AIS).

Another novel function of the NAVDEC is an analysis and assessment of the navigational situation done in relation to all other or selected targets located within eight nautical miles. This is one of the decision making steps normally taken by the navigator, simply because the situation assessment takes into account relevant regulations. Thanks to the NAVDEC system, the navigator is currently advised on the identification of an encounter situation in compliance with the Collision Regulations. This is a considerable aid, particularly in heavy traffic, although collisions of one-to-one ships in the open sea are known (m/v Gotland Carolina and m/v Conti Harmony in 2009).

Where a situation is qualified as a collision situation, the navigator decides on a safe manoeuvre, the one that solves a given situation, determining what to do (alter course and/or speed) and the manoeuvre parameters: moment to begin it and values of course and/or speed alteration. The navigator may specify a safe course on which the target will be passed at a preset range considered as safe. To date the NAVDEC is the only tool worldwide capable of performing this function (Fig. 3). The NAVDEC "knows" the Collision Regulations, principles of good sea practice, as well as criteria used by expert navigators. Apart from one specific solution the system submits, alternative solutions conforming with the regulations are also determined (possible range of course and/or speed alterations). Besides, the navigator is given a justification of the proposed manoeuvre. This function refers to all or selected targets.

Solutions proposed by the system, together with their justifications, do not relieve the navigator

(a)

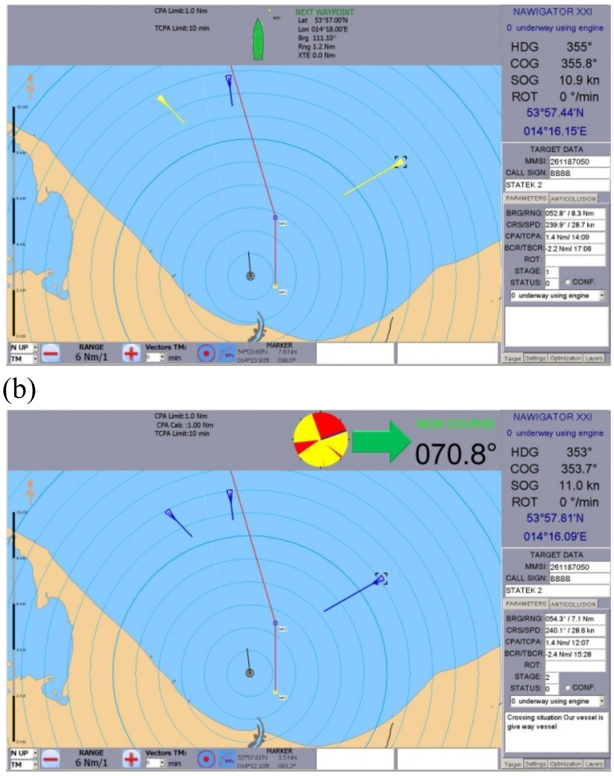

Fig. 3. NAVDEC interface; a) safe situation, b) collision situation
Rys. 3. Interfejs NAVDEC; a) sytuacja bezpieczna, b) sytuacja kolizyjna

from responsibility, but make his/her decision much easier to make. However, it is possible to make the ship control automatic by direct connection of the NAVDEC with the autopilot, steering gear, main engine, engine telegraph and controllable pitch propeller.

The NAVDEC is a product that will find applications on vessels and in land-based centres as an independent system or a module added to the existing navigational systems. Its main areas of use include:

- navigation-related decision support in collision situations – shipboard decision support system installed on the navigational bridge of:
  - merchant vessels (sea-going and inland shipping),
  - leisure boats (e.g. sailing ships, motor yachts);
- navigational decision support in collision situations – component of land-based vessel traffic services systems (VTS, VTMS, VTMIS, RIS);
- analysis and assessment of marine accidents at sea and on inland waterways – a system intended for experts working for maritime courts;
- marine officer training centres offering courses in the Collision Regulations – a module of navigational simulators (e.g. ship-handling, ECDIS).

The implementation of NAVDEC on ships will contribute to the reduction of marine environment pollution. Each ship's collision is a potential environmental threat. According to the Baltic Marine Environment Protection Commission (HELCOM) in the years 2000–2009 there were 1006 accidents on the Baltic Sea alone. Collisions accounted for 77% (775) of that figure. The majority of accidents occurred due to human errors, including incorrect situation assessment and wrong actions resulting from improper interpretation of radar data. 40 of those accidents caused environment pollution.

Comparison to competitive products

The major task of navigation is to conduct a ship efficiently and safely along an assumed trajectory. Bearing this in mind the navigator has to carry out two basic tasks: ship conduct along a preset trajectory and collision avoidance. Effective solutions to collision situations depend on ship movement data (own and others) and constraints resulting from the shape of the area. The accuracy of data presented to the navigator is of importance for the correct situation assessment and his/her decisions.

Navigational systems presently used in the global fleet perform mainly information functions and correspondingly, to some extent provide an aid in safe vessel conduct. However, none of the known systems displays to the navigator ready solutions to a collision situation that are worked out in relation to all vessles in vicinity of their ship. This considerably limits decision support, consequently it limits the effectiveness of collision avoidance.

Nowadays, the navigational bridge of a ship features a number of devices that are supposed to assist the navigator to sail safely. The ARPA (*Automatic Radar Plotting Aid*), a commonly used tracking radar is a marine tool for decision support in collision situations. However, due to its numerous limitations, the ARPA is sometimes ineffective.

In comparison to the tracking radar, presently used on ships for calculating encounter parameters and working out an anti-collision manoeuvre, the NAVDEC has the following advantages:

- takes into account the Collision Regulations, for both good and poor visibility;
- works out a manoeuvre also for the ship located in the radar blind area;
- the operator is immediately notified about a manoeuvre started by another ship thanks to information on target's rate of turn;
- needs just a few seconds to calculate the encounter parameters. On the other hand, the tracking radar, according to test situations defined by the IMO (International Maritime Organization) after one minute of tracking presents the CPA (*Closest Point of Approach*) with a one nautical mile accuracy. After three minutes, the maximum allowable error of CPA and TCPA (*Time to Closest Point of Approach*) calculated by the radar may amount to, respectively, 0.3 Nm and 0.5 minute. These tolerances are given with a 95% probability;
- more accurately calculates the encounter parameters, by:
  - taking account of the ship's size thanks to information on the position of the antenna, received from the AIS (*Automatic Identification System*);
  - use of GPS (*Global Positioning System*) / DGPS (*Differential GPS*) for position determination;
- takes account of the ships' sizes while planning an anti-collision manoeuvre;
- calculates new courses and speeds of own ship, such that other vessels will be passed at a preset CPA.

Another information system commonly used on sea-going ships is the ECDIS (*Electronic Chart Display and Information System*) often referred to as an electronic chart. Apart from displaying the positions and movement vectors of own ship and targets (vessels in vicinity), it also allows to, *inter alia*, obtain information on depths, aids to navigation and coastline. However, it is only an information system. The NAVDEC system moves a step forward. Besides providing the navigator with the same scope of information, necessary for safe navigation, as the ECDIS, the NAVDEC recommends ready solutions enabling the ship to safely pass vessels or stationary objects. Moreover, these solutions take into account ship's manoeuvring ability and the present area restrictions, i.e. existing traffic separation schemes, shoreline and safe depths. The NAVDEC is, therefore, a very useful decision support system.

The innovation that the NAVDEC introduces is that, apart from typical functions of information systems such as ECDIS or ARPA, this system features the following functions:

- fusion and integration of navigational data received from shipboard devices;
- analysis and assessment of a navigational situation taking into consideration the Collision Regulations in force (Fig. 4);
- automatic determination of solutions to collision situations by using dedicated computational algorithms, including optimization algorithms (Fig. 4);

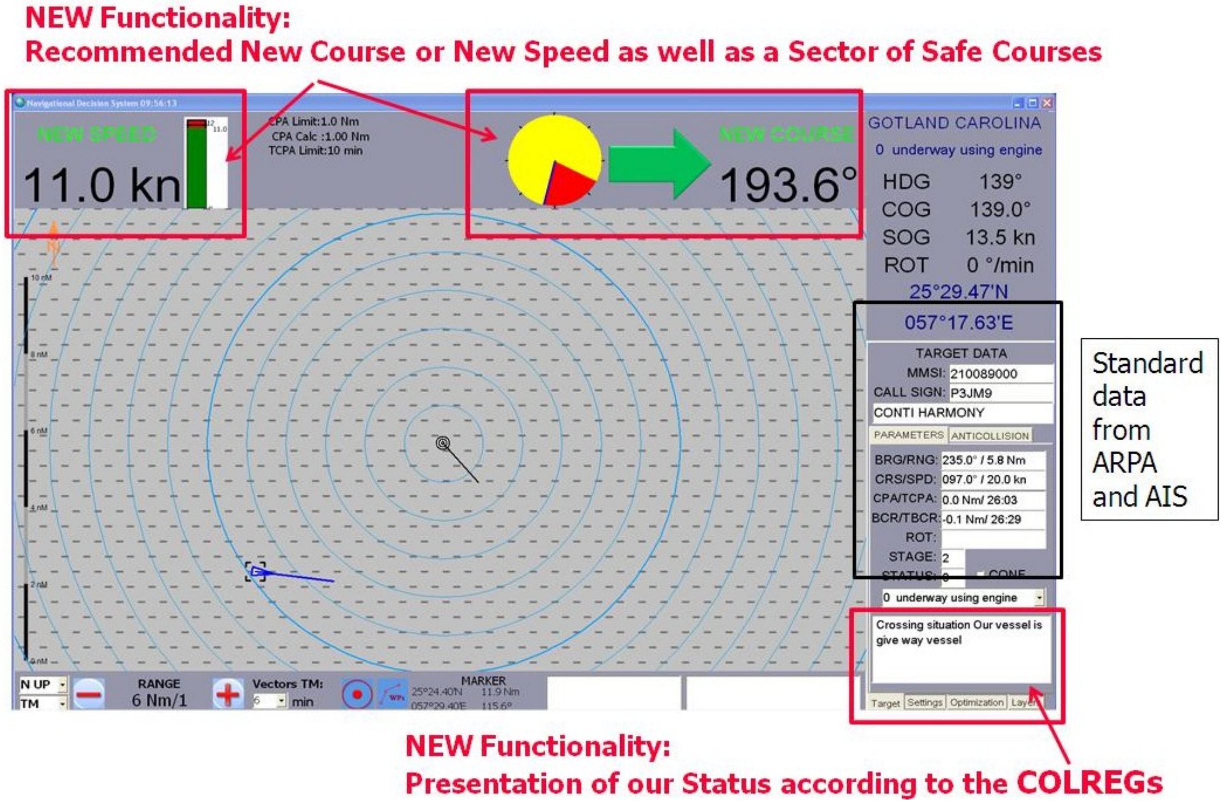

Fig. 4. The NAVDEC interface with its innovative functions
Rys. 4. Interfejs NAVDEC z zaznaczonymi innowacyjnymi funkcjami

- explanation of the present navigational situation making use of a navigational knowledge base (collision regulations, principles of good sea practice, criteria of navigational situation analysis and assessment actually used by expert navigators, Fig. 4);
- justification of the recommended manoeuvre.

The NAVDEC is the first system in the world to offer support in navigation-related decision making on the ship to such a wide extent. It goes in line with the concept of e-navigation that is being developed on the IMO forum. In 2006 a Correspondence Group on E-navigation was established at the IMO. E-navigation is defined as "the harmonized collection, integration, exchange, presentation and analysis of marine 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".

Work on the implementation

The NAVDEC has been developed by a team of researchers from the Faculty of Navigation, Maritime University of Szczecin, Poland, for years working on applications of modern technologies in marine navigation. Initially, the work was performed as statutory research at the Faculty comprising such topics as:

- artificial intelligence methods in marine navigation (1999–2001);
- applications of artificial intelligence methods in marine navigation (2001–2003);
- intelligent computing systems in marine navigation (2004–2006);
- navigational decision support system no board a sea-going vessel (2007–2009).

The results from the research made up a theoretical basis and a starting point for developing a prototype system of shipboard decision support system. R&D work was undertaken by a team headed by Prof. Zbigniew Pietrzykowski as a research project "Development of a navigational decision support system on a sea-going vessel" (N N509 1759 33), financed by the Ministry of Science and Higher Education (started 23.10.2007, completed 22.10.2009). The project outcome was a prototype of a navigational decision support system on a sea-going vessel in open areas as a computer-based system (computer hardware and software), that can be installed onboard and work in real time.

A rerview of solutions used in navigational information systems on board ships has confirmed the innovative character of the system developed by our team. Consequently, the Maritime University of Szczecin submitted a patent application to the Polish Patent Office, Ref. No P.389638: A method and system of navigational decision support in the process of safe vessel navigation (26.11.2009). Additional funds from the budget of Zachodniopomorskie voivodeship made it possible to apply for an international patent under the PCT (Patent Co-operationTreaty): No. PCT/PL2010/ 000112: A method and system of navigational decision support in the process of safe vessel navigation (8.11.2010) (agreement No. WPR-I/27/2010 on the subsidy granted to the Maritime University of Szczecin for covering the costs of international patent application).

The team's work and achievements were documented in a monograph [2] edited by Zbigniew Pietrzykowski "Navigational decision support system on a sea-going vessel", partly financed from the Zachodniopomorskie voivodeship budget (agreement No WKNiDN-II/7/2011 on the subsidy granted to the Maritime University of Szczecin for covering the costs of publishing the mentioned monograph). The publication is a major item in the literature on navigational safety and computer-based decision support systems. It is addressed to firms, scientists and specialists dealing with problems of navigation, maritime transport and computer science. Apart from the monograph, several scientific articles written by NAVDEC authors have been published [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

The NAVDEC has successfully passed laboratory tests on an ECDIS Navi-Sailor 2400S simulator from Transas (owned by the Maritime University of Szczecin), as well as field tests on the research/ training vessel Nawigator XXI (also owned by the University). The persons testing and verifying the system unequivocally emphasized that handing that tool to navigators would significantly enhance the navigational safety level and, consequently, reduce risks of marine accidents. Ship masters confirm NAVDEC's usefulness and wish to have their ships fitted with a NAVDEC.

Apart from research and technical work, launching a product on the market requires some formalities and arrangements. One major step in commercializing the NAVDEC was a licence agreement between its creators and the Maritime University of Szczecin. Under its provisions, intellectual property belongs to the University, while the inventors (University employees) get exclusive commercial title to the invention. This means that licensees will deal with the business of transferring the invention to the industry.

Both, Szczecin Maritime University and the licesees are now attempting to draw IMO's interest to the NAVDEC, as this organization is responsible, *inter alia*, for deciding which navigational device is obligatorily carried or recommended to be carried by ships. The attempts are justified if we bear in mind that the system well fits into the concepts of e-navigation and e-maritime, proposed and developed on the forums of the European Parliament and of the IMO.

There are two paths of NAVDEC's commercialization:

– direct commercialization: a spin-off company is established with the aim of launching the NAVDEC as a separate product sold directly to end users (shipowners, sailors, maritime offices, maritime courts, maritime universities and marine officer training centres);
– indirect commercialization: a spin-off company is established that would mainly deal with selling the NAVDEC on a sub-licence basis to equipment manufacturers who, having an organized network of end users or buyers and will incorporate the NAVDEC as a separate module into systems offered to the shipping industry.

The former path requires a major external investor due to considerable costs of implementation, resulting from the necessary creation of building a trading-service network for the marketed product. This model, however, opens a possibility for full use of the market potential and maximized financial profits from NAVDEC's commercialization.

The latter path is more feasible, as it does not call for substantial investment effort. The problem is to attract contractors interested in a licence agreement. This approach yields a prompt source of finance for licensors to continue research aimed at developing the product and conveys a substantial portion of the commercialization risk on sub-licensees. In this case, the NAVDEC will have to be adjusted to systems of various manufacturers.

At present implementation work mainly focuses on negotiations with potential business partners: seed capital funds, computer companies and industrial manufacturers, including iternational corporations. Attempts are also made to acquire public funds, particularly those from EU funding.

Conclusions

The presented herein navigational decision support system NAVDEC is an example of how information systems are gradually transformed into decision support systems.

Apart from functions performed by the existing systems, the NAVDEC also analyzes and assesses the present navigational situation taking into account the COLREGs, generates safe manoeuvres in collision situations (new courses, speeds, trajectories) and justifies its proposals.

The new functionalities of the system may essentially contribute to the enhancement of navigational safety.

As more and more efforts are made to implement research outcome in industry and other fields of human activities, the authors share with readers their experience related with the transfer of new technologies to industry.

Actually, the list of Polish firms dealing with the commercialization of scientific accomplishments is rather short. It is estimated that over the last two decades a two-digit number of such companies have been established [1]. This refers to both, direct commercialization (e.g. *Bioton*, *Pharmena*, *Read Gene*) and indirect one (e.g. *Immunolab*).

These authors are co-ordinators of NAVDEC system commercialization. Demand for this innovative solution on the Polish and global markets creates a basis for wide implementation of the system and may be just one little step on the way towards the innovative economy in Poland.

References

1. Tamowicz P.: Przedsiębiorczość akademicka. Spółki spin--off w Polsce. Polska Agencja Rozwoju Przedsiębiorczości, Warszawa 2006.
2. Pietrzykowski Z. i inni: Nawigacyjny system wspomagania decyzji na statku morskim. Akademia Morska w Szczecinie, Szczecin 2011.
3. Borkowski P.: Algorithm of multi-sensor navigational data fusion – testing of estimation quality. Polish Journal of Environmental Studies, vol. 17, 3B, 2008, 43–47.
4. Borkowski P.: Algorithm of the probabilistic assessment of two dynamic objects passing safety. Computational intelligence in applications, University of Szczecin, 2009, 37–50.
5. Borkowski P.: Prediction of movement trajectories of manoeuvring ships. Polish Journal of Environmental Studies, vol. 18, 5A, 2009, 15–20.
6. Borkowski P.: Statistical verification of algorithm of the assessment of two ships passing safety. Polish Journal of Environmental Studies, vol. 18, 3B, 2009, 44–47.
7. Borkowski P., Magaj J., Mąka M.: Pozycjonowanie bazujące na wielosensorowym filtrze Kalmana. Zeszyty Naukowe AM w Szczecinie, 13(85), 2008, 5–9.
8. Borkowski P., Pietrzykowski Z., Magaj J., Mąka M.: Fusion of data from GPS receivers based on a multi-sensor Kalman filter. Problemy Transportu, tom 3, zeszyt 4, 2008, 5–11.
9. Magaj J., Wołejsza P.: Algorithm of working out anticollision manoeuvre by decision-supporting system. Polish Journal of Environmental Studies, vol. 17, 4C, 2008, 14–18.
10. Magaj J., Wołejsza P.: Verifying the decision-support navigational system in real conditions. Polish Journal of Environmental Studies, vol. 17, 3B, 2008, 581–586.
11. Pietrzykowski Z.: Ship's fuzzy domain – a criterion for navigational safety in narrow fairways. The Journal of Navigation, 61, 2008, 501–514.
12. Pietrzykowski Z., Borkowski P.: A method of ship movement parameters prediction. Zeszyty Naukowe AMW w Gdyni, 175 A, 2008, 189–196.
13. Pietrzykowski Z., Borkowski P.: Algorithm of safe course determination based on the probabilistic assessment of a navigational situation. Polish Journal of Environmental Studies, vol. 17, 4C, 2008, 9–13.
14. Pietrzykowski Z., Borkowski P.: Prediction of ship movement parameters in a navigational decision support system. Monograph No. 122, Kazimierz Pułaski Technical University of Radom, 2008, 479–486.
15. Pietrzykowski Z., Magaj J., Chomski J.: A navigational decision support system for sea-going ships. Pomiary Automatyka Kontrola, 10/2009, 860–863.
16. Pietrzykowski Z., Uriasz J.: The ship domain – a criterion of navigational safety assessment in an open sea area. The Journal of Navigation, 62, 2009, 93–108.
17. Wołejsza P.: AIS jako uzupełnienie radaru. Nawigacja radarowa, Gdańskie Towarzystwo Naukowe, Gdańsk 2011, 311–328.
18. Wołejsza P.: The application of automatic identification system of vessels in inland shipping. Polish Journal of Environmental Studies, vol. 18, 5A, 2009, 228–232.
19. Wołejsza P., Szewczuk T.: Analiza dostępnych na statku informacji nawigacyjnych na podstawie m/s Nawigator XXI. Zeszyty Naukowe AM w Szczecinie, 13(85), 2008, 115–119.