POLISH MARITIME RESEARCH Special Issue S1 (74) 2012 Vol 19; pp. 11-18
10.2478/v10012-012-0017-3

The researching ship "Gdynia"

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ABSTRACT

The paper presents the physical model of the sea-going ship. The wooden hull of this ship was obtained from Ship Design and Research Centre and next rebuilt and reconstructed for future tests of the different control systems in the real-time experiments. The paper describes the succeeding stages of the work, steering and driving devices installed on board, power electric diagrams and navigational equipment designated for ship. The range of the possible applications of the constructed vessel are presented at the end of the paper

Keywords: ship's hull; main engine; tunnel thrusters; electrical motors; marine navigation devices; real-time experiments

INTRODUCTION

The seagoing cargo ship can be considered as a complex control object with its properties very different from manoeuvring inland vehicles or aircraft. One can distinguish, among others, three systems:

- the navigation one with all measurement devices e.g., gyrocompass, log, echo sounder, radar, ECDIS. AIS, etc,
- the ship's movement steering one with subsystems e.g. autopilot, DSP, speed and/or trajectory controller etc,
- and the power one with energy generation and distribution processes.

The dissimilarity of the ship motion process in comparison to the adequate ones for inland vehicles or aircrafts is related to the following aspects:

- very small power of the driving devices. The coefficient power/mass is significantly smaller then in inland vehicles or aircrafts,
- the problem of the fast stopping of the ship movement or changing its direction due to the small water friction,
- the possible large forces and moments from wind and waves, comparable with forces and moments from ship's thrusters.

But the most important problem is related to the fact that the ship is strongly nonlinear, multivariable object with time varying parameters. It' s properties depend on load condition, speed value and direction, drift angle, trim, water depth, proximity of quays, other vessels etc. Very hard cross-coupling between all inputs and outputs also can be observed i.e. thruster action can change surge, sway or yaw simultaneously.

Therefore any mathematical model of the ship dynamics only can approximate the real behaviour of the vessel. Consequently the testing processes of the various control systems dedicated for the ship's motion steering cannot be performed only by simulation runs.

Particular, it refers to the simpler linear models e.g. transfer functions or state space ones. More complex, nonlinear models (so called simulation models) are more accurate but researching results obtained via such tools also have limited accuracy.

One can state that the simulation testing should be the first stage in the valuation process of any control systems but not the last one. Only wide range tests with the real ship during real-time experiments can guarantee that proposed steering algorithms are proper and likelihood.

It was the main reason to decide in Ship Automation Department about building a floating model of the real vessel.

Similar although bigger ships models are exploited in the Foundation for Safety of Navigation and Environment Protection at the Silm lake near Ilawa in Poland. Researching team from Ship Automation Department performed many tests with mentioned models in the past. Their results were published in e.g. [1, 2, 5]. But ship models exploited on the Silm lake are designated for improvement of captains and chief officers skills related to perform manual manoeuvres in different constrained areas but not for scientific researching. Therefore they are not equipped in a few navigational instruments e.g. radar, electronic maps or AIS. The researching ship described here will be provided in needed devices as it will be shown in a further section.

Constructed vessel is designated in the future to two main types of tests. The first one is related to different algorithms of the ship's motion steering e.g. trajectory tracking, precise movement with slow speed and any drift angle, parallel motion of two vessel etc. Anti-collision algorithms, and agent systems state the second type of provided tests.

A few persons from Ship Automation Department besides authors take part in some construction works with the researching ship at the beginning: Krzysztof Dziedzicki, Andrzej Januszewski, Roman Śmierzchalski and Marcin Tobiasz.

THE DESCRIPTION OF THE RESEARCHING SHIP - MANEUVERING SYSTEM

The hull of this ship was built in Ship Design and Research Centre – Ship Hydrodynamics Division as a one from big number of hulls models of the merchant ships.

It was constructed by means of thick horizontal slices of the wood, especially glued one slice to the another. The silhouette of the wooden hull is presented in Fig. 1.

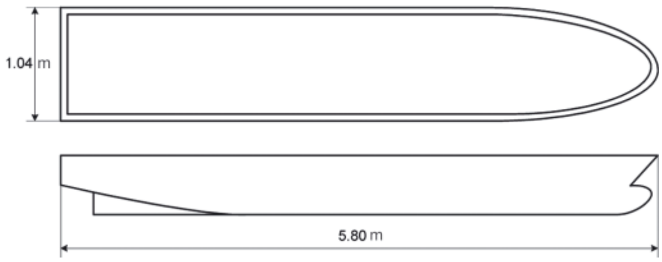


Fig. 1. *The silhouette of the wooden hull*

Such hull was designated mainly to the water drag tests in Towing Tank Centre in Gdańsk-Oliwa. Therefore it was not suitable (in this pure wooden form) to installation of the thrusters and navigational devices.

The transformation process of the hull, enabled the creation of the researching ship which can afloat on the lakes and the sea proceeded in a few steps.

The first step was related to the cleaning of the hull, removing old pain and planning the outer side of the hull.

In the next step the steel cage was constructed. The outward shape of the cage was accurately fitted to the inward shape of the wooden hull. All was joined together by screws (Fig. 2).

Fig. 2. *The steel cage inside the hull. Notice the construction of the hull by red painted slices of wood*

The third step was related to the two holes made in the underwater part of the hull: first hole in the bow and the second one in the stern. They were assigned for tunnel thrusters. The next hole at the end of the hull was designated for main "engine" screw.

Such prepared hull was covered by epoxide resin with a fibre glass mat and white painting special polyurethane paint.

The general intention of the builders was likening of the constructed researching ship to the real ship named m/s "Finntrader" from Gdańsk Shipyard. The side view id the mentioned ship is presented in Fig. 3.

It should be emphasized that the researching ship is not a physical model of m/s "Finntrader", although the ratios of the lengths and the beams are similar. Approximate scale is 1:30.

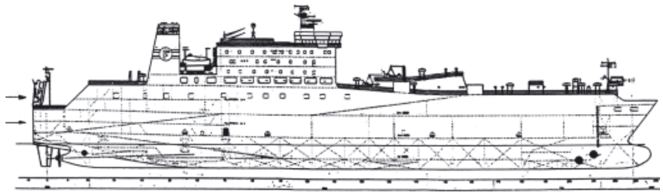


Fig. 3. *The silhouette of m/s "Finntrader" from Gdańsk Shipyard*

The planned silhouette of the researching ship with the superstructure and hath covers is shown in Fig. 4.

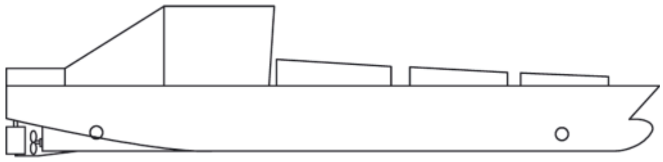


Fig. 4. *The silhouette of the researching ship with the superstructure and hath covers*

The superstructure has the open construction (only the front part and the both side ones) due to necessity of the creation of the stands for two persons. There is also the possibility to mount, for particular tests a short lattice mast for radar antenna. The arrangement of the crew positions and the mast are presented in Fig. 5.

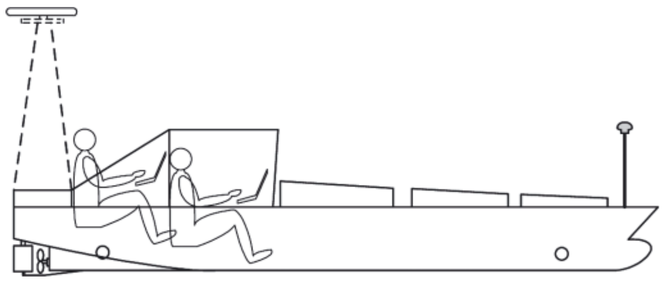


Fig. 5. *The side view of the researching ship with the crew stands. The removable mast are drawn by dashed line*

Described ship is equipped with battery-fed electrical thrusters: one main engine and two tunnel thrusters.

The main engine for ship was adopted from standard outboard electrical drive for touristic boats made by Torqeedo (Fig. 6) [10]. The useless upper part of the drive was cut out.

The specifications of the drives are as follows:

a) electrical motor

type	Base Travel 801L	
P_{nom}	800	W
U_n	12	V
I_n	66	A
n_n	720	rpm

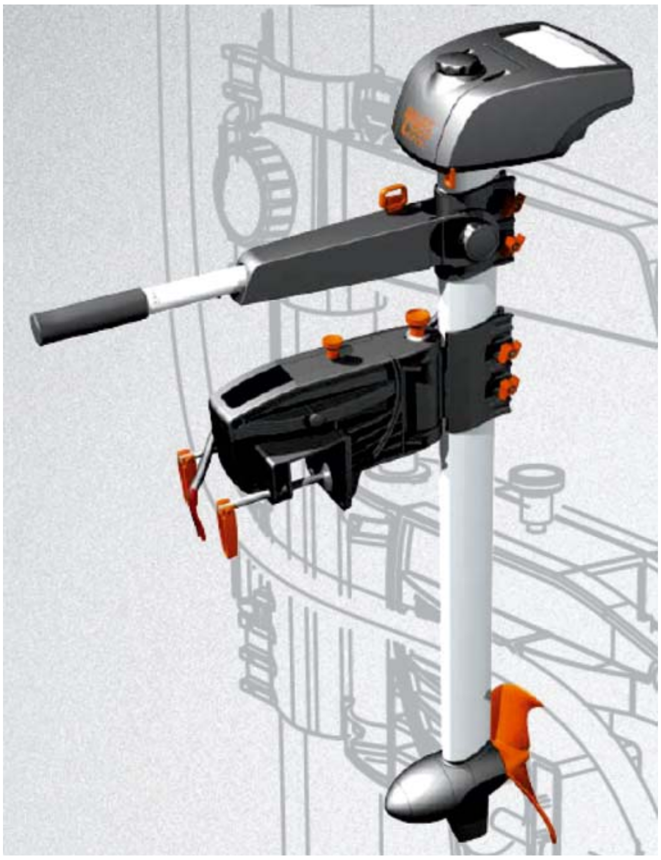


Fig. 6. The Torqeedo electrical drive Base Travel 800L [10]

b) main propeller – diameter 30.48 mm

The arrangement of the main drive elements are presented in Fig. 7 [4].

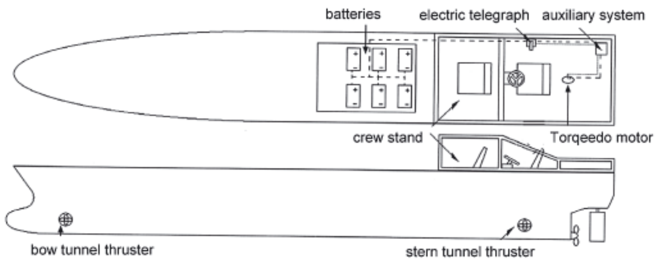


Fig. 7. The elements of the main drive in the hull [4]

The electric telegraph enables manual or computer steering of the main engine (Fig. 8).

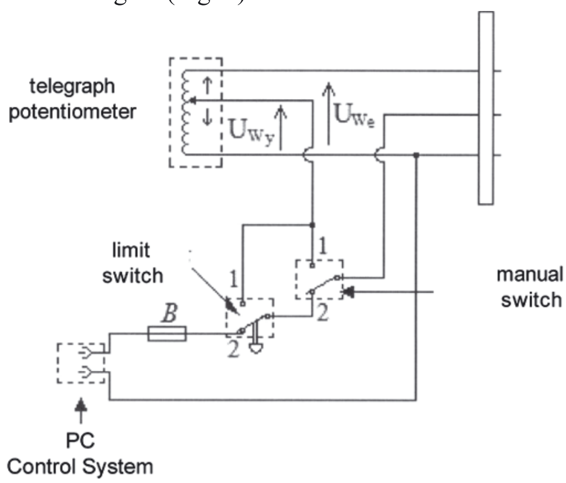


Fig. 8. Electric diagram of the main engine telegraph

Tunnel thrusters:

a) electrical motor

type	Base Travel 801L	
P_{nom}	450	W
U_n	36	V
I_n	16	A
n_n	2150	rpm

b) thrusters screw propeller – type V-SET0086

The block diagram of the tunnel thrusters electric system is presented in Fig. 9.

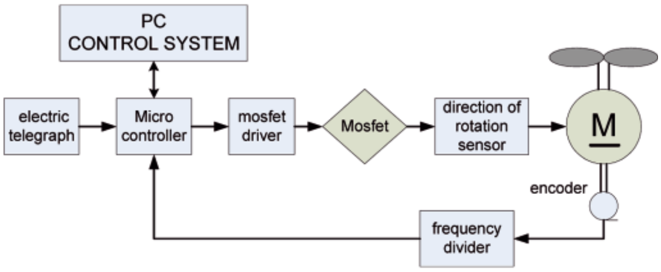
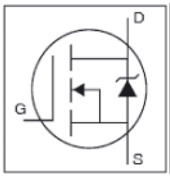


Fig. 9. The block diagram of the tunnel thrusters steering system

The following elements was used in the tunnel thrusters electric system (see Fig. 9):

a) mosfet type IRFP4468PbF from International Rectifier



V_{DSS}		100V
$R_{DS(on)}$	typ.	2.0mΩ
	max.	2.6mΩ
I_D (Silicon Limited)		290A ①
I_D (Package Limited)		195A

b) mosfet driver type TC4420 from Microchip

c) encoder type MOK30 from P.P.H Wobit

The microcontroller and other electronic elements were collected in one cover for every thrusters as it is presented in Fig. 10.

Fig. 10. Electronic elements for tunnel thrusters drive

The ship is also equipped with blade rudder made from stainless steel. The rudder is driven by Vetus hydraulic system [3, 11] consists of:

- hydraulic pump type V-HTP2008R,
- electrohydraulic pump typeV_EHPA12R2,
- cylinder (servo-motor) type V-MTC3008,
- nylon tubes,
- rudder angle sensor type RFU1718.

The block diagram of the rudder driven system is presented in Fig. 11 and its installation arrangement photo in Fig. 12.

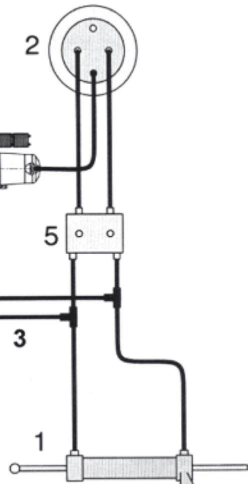


Fig. 11. *The Vetus blade rudder driving system installed on researching ship: **1)** cylinder, **2)** hydraulic pump, **3)** nylon tubes, **4)** electrohydraulic pump, **5)** double check valve [11]*

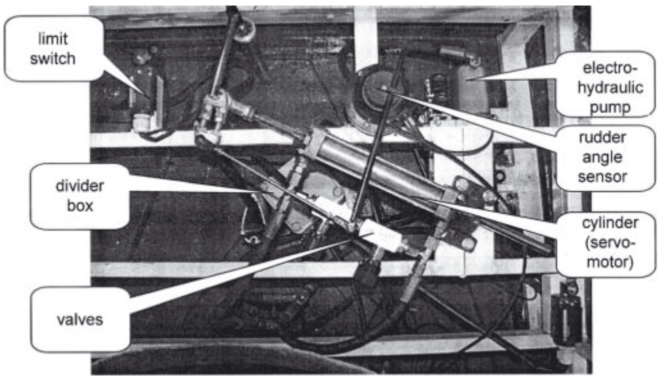


Fig. 12. *The arrangement of the rudder driving system elements inside the researching ship. Notice the fragment of the steel cage [3]*

THE DESCRIPTION OF THE RESEARCHING SHIP – NAVIGATION SYSTEM

To verify the ship's control system one can propose to use a real model, equipped with real navigation devices. Model tests should reflect the real phenomena in a manner as close as possible to reality. In other words, modelling the phenomenon should be modelled similar to the phenomena taking place in reality. Therefore, building a physical model modelled on the real object, consider the need to preserve geometric similarity, kinematic and dynamic between the phenomenon being modelled and the modelling [7].These laws of similarity should be considered during the implementation of physical model tests of a moving ship in a real environment. Therefore, it is an important element to ensure proper operation of all equipment and components used to move the ship as well as to navigate. The manoeuvrability of the model are to provide: electric main drive, two bow thrusters and a hydraulic machine control. To observe the situation of the navigation on the sea area is conducted by: a system of radar, AIS, ARPA, electronic charts, GPS, log, echo sounder, anemometer, and VHF communications system. All the collected measurement parameters are transmitted by the card drivers and USB ports to a central control system through which it can be verified developed algorithm or control system. An additional advantage of using this model is the ability of the physical presence of researchers on board. This allows the continuous supervision and control of the working systems and also the fast identification of any irregularities.

The structure of the measuring system used for the verification process, the ship's control system is presented in Fig. 13.

Developed system to verify the ship's control system includes a number of devices associated with the conditions prevailing on the hydro meteorological sea area as well as equipment and actuators associated with control of the actual model. The model uses real navigation devices which are used on the bridges of merchant vessels. Mainly FURUNO equipment were used here (see Fig. 14) [8].

To determine the navigational situation prevailing at sea area measuring Furuno system was used. The system includes following devices: Marine Radar Unit RPU-015 with electronic maps and ARPA, AIS Transponder FA-150 and Hemisphere GPS. a variety of navigational information like own ship status, other ships status, radar plotting data, wind, water temperature, depth and other information from sensor are given by the system.

In Marine Radar Unit RPU-015 the target detection is realized by sophisticated signal processing techniques such as multi-level quantization (MLQ), echo stretch, echo average, and radar interference rejecter. It is possible to adjust two guard

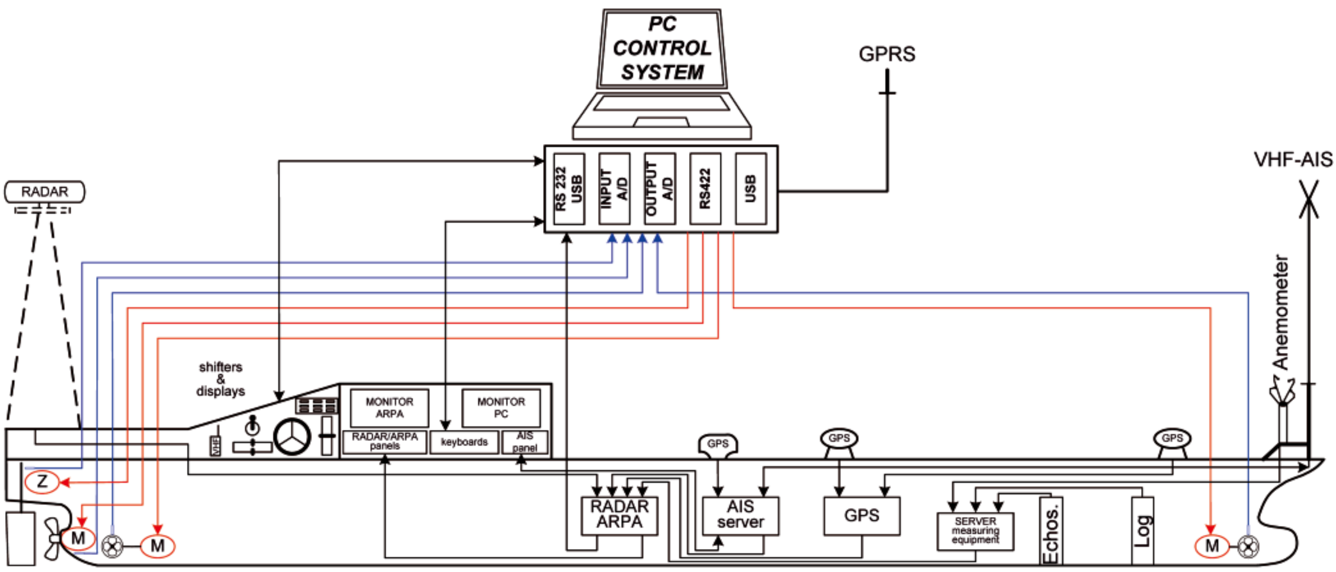


Fig. 13. *Configuration of the devices installed on board*

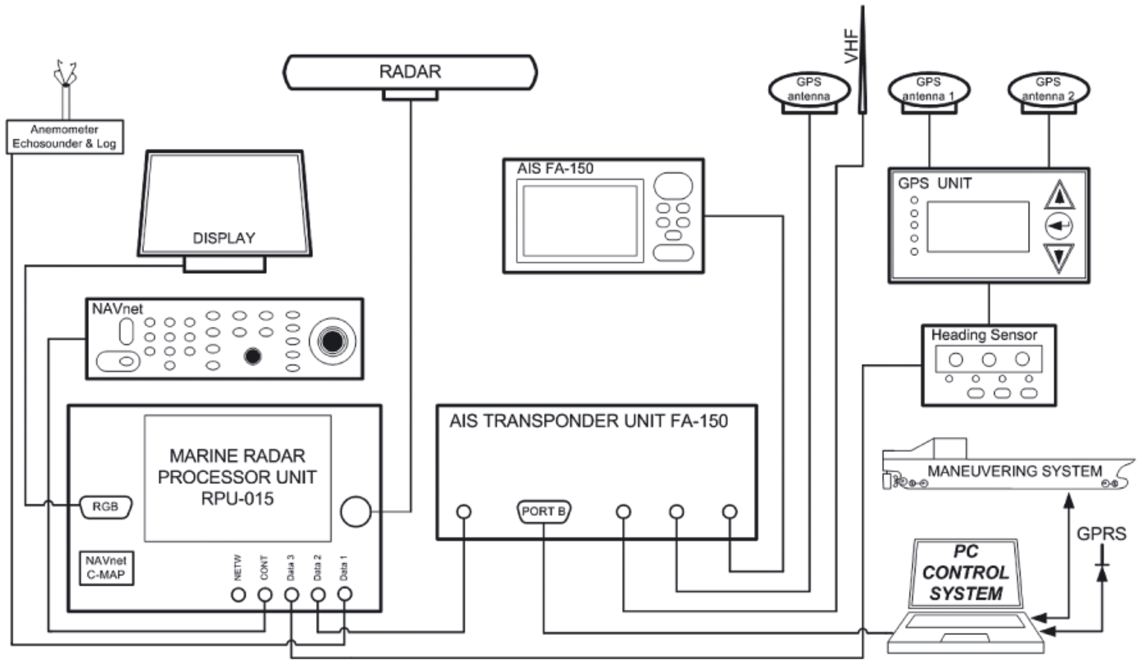


Fig. 14. *Configuration of the navigation system devices*

zones at required ranges in any sector. Other ship's movements are assessed by advanced target tracking software and alerted by CPA/TCPA data readouts. Operation of the radar system at X-band and S-band allows the acquisition of echoes with an accuracy of 1% of range in use or 10 m whichever is the greater.

The using of the maps allows to visualize the situation around the ship by plotting coastline, own ship safety contour, isolated underwater dangers, buoys, traffic routing systems, prohibited areas, fairways as required by IMO. A map is a combination of map lines and symbols to aid route planning and monitoring on the radar equipment. 30 nav lines may be stored and each line may contain up to 30 waypoints. Five nav lines may be simultaneously shown on the display. 200 waypoints are available. Own ship and other ship tracks may be stored at a selected interval for repeated use.

The moving objects are acquired automatically by means of ARPA subsystem. View the traffic parameters for each of the objects is possible by selecting it on the screen. The operator can select and display on-screen performance for the six objects at once. ARPA also allows: acquisition 100 targets automatically or manually; automatic tracking of all acquired targets on the display in the range from 0.1nm to 32 nm; marking from 5 to 10 past positions of tracked targets at intervals of 30 s, 1; 2; 3; 6 min; define suppression areas by combined with two acquisition areas of 3-3.5 and 5.5-6 nm, or 0.5 nm deep sector or circle in 0.3-32 nm; visualization vector true or relative 30 s, 1; 3; 6; 15; 30 min for prediction of target motion; setting the collision warning CPA limit: 0.2-10 nm, TCPA limit: 0-99 min; define guard zone by sector or polygon who may be set in any effective area; and trial manoeuvre realized by dynamic or static, with selected delay time.

The AIS device allows to obtain information about others ships - their type, charge, size and motion parameters. The system also allows the differentiation of individuals: sleeping, activated, dangerous, selected, lost targets. At the same time it is possible to collect information to 1,000 units in the range of VHF system to the sea area of certain frequencies to refresh the data in the range from 30 s to 60 min. AIS allows to define criteria of call CPA or TCPA alarm [8]. The Furuno AIS front panel is presented in Fig. 15.

Fig. 15. *The AIS front panel*

Measurement of the model speed and course is implemented by the GPS system and a log. The measurement system of Hemisphere company ensures a 2D position fix heading accuracy better than 0.1 degree rms with differential

Fig. 16. *The elements of the GPS device [9]*

positioning accuracy of less than 60 cm, 95% of the time. Integrated gyro and tilt sensor deliver fast start-up times and heading provide updates during temporary loss of GPS. Fast heading and positioning output rates up to 20 Hz. Differential options including SBAS (WAAS, EGNOS, etc.) and beacon differentia. COAST ™ technology maintains accurate solutions for 40 minutes or more after loss of differential signal (Fig. 16) [9].

The WINDOBSERVER II anemometer from GILL company is used to determine the velocity and direction of the wind acting on the researching ship model (Fig. 17.), This device is characterized by the following parameters [12]:
- measuring range for the wind: 0 ÷ 65 m / s,
- accuracy of measurement for wind speed: 2%,
- measuring range for the wind direction: 0 ÷ 359°,
- accuracy of measurement for the wind direction: 2%,
- operating temperature: -55şC to +70şC (with heated option).

Fig. 17. *The WINDOBSERVER II anemometer antenna [12]*

The PC Control System

The modern software installed on a PC included the measuring subsystem and also the control one creates the full manoeuvring system. The test, measuring and control signals via the USB and card transmitters are supplied for all devices. The signals are transmitted in the standard NMEA 0183 and standard ± 5V. In addition to transferring data to and from the model, you can use GPRS. Other information signals such as signals from the log, echo sounder and anemometer are fed via RS422 or link directly to the navigation system Furuno. The computer control system allows also to connect signals from other devices, for example wave meter or thermometer, etc., to determine the conditions aroun the ship.

All information can be presented on the screen inside the ship (Fig. 18).

PLANNED TESTS

As it was mentioned in the first section of the paper the researching ship is designated to two main types of tests:
1. The different algorithms for the ship's motion steering will be checked taking into account the influence of the wind and waves.

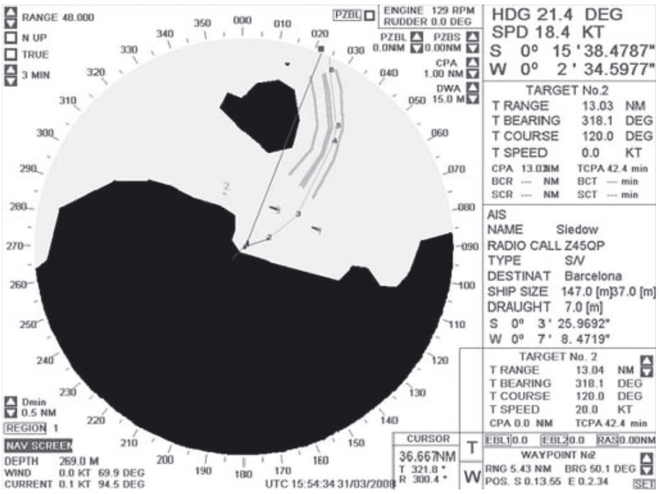


Fig. 18. *View of the exemplary navigation situation from PC Control System [6]*

2. Anti-collision algorithms, and agent systems state the second type of provided tests and will used presented navigational instrumentation (radar, ARPA, electronic maps, AIS, etc.).

The computer algorithms enables full ship motion control can be associated with following control subsystems:
a) heading and/or speed stabilization,
b) stabilization 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.

Systems denoted by letters a) ÷ d) can be treated as one-dimensional control units, but the others only as multidimensional ones. The heading, speed, turning radius stabilization and trajectory tracking can be performed by means of blade rudder or main propeller. Precise steering and DSP processes needs the ship equipped with at least a few driving devices on bow and stern.

The set of the driving devices installed on researching ship enables using any ship motion control subsystems.

There are planned among others the following tests:
a) the heading stabilization by means of adaptive, neural and fuzzy logic autopilots,
b) the trajectory stabilization by means of indirect "line of sight" controller,
c) the translation of the vessel with low speed and any drift angle by means of multidimensional regulator based on robust control theory or LMI approach.

Planned exemplary manoeuvres are presented in Figs 19 ÷ 21 below.

The second type of research is dedicated for verification and develop a reliable anti-collision algorithms and expert systems for navigators. Modern maritime navigation requires the navigator to determine the optimal speed and routes, also in danger of conflict. It is not always the task is completed within a reasonable degree as evidenced by the statistics of accidents at sea. Simultaneously the problem of determining optimum routes for vessel between its current position and given final destination point, including the situation occurring when navigating a particular route to overcome, was the subject of many studies and has not been finally resolved. To determine the optimal (economical and safe) routes and steering the vessel, it is proposed to test the many control algorithms including agent systems. The use of the agent system of navigation is a new approach to the implementation of collision avoidance systems at sea.

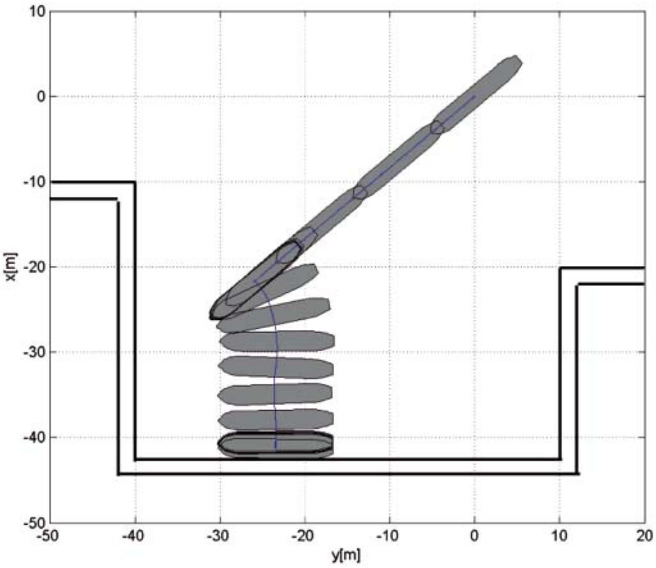


***Fig. 19.** The approaching quay manoeuvre*

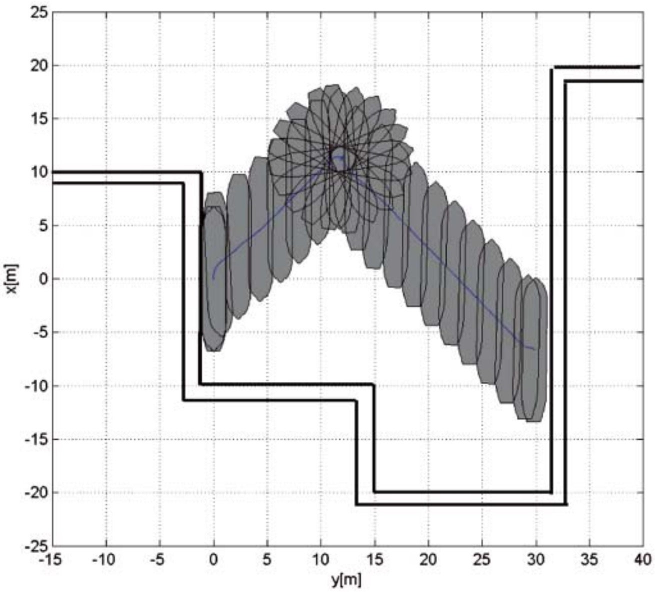


***Fig. 20.** The changing of the quay with rotating manoeuvre*

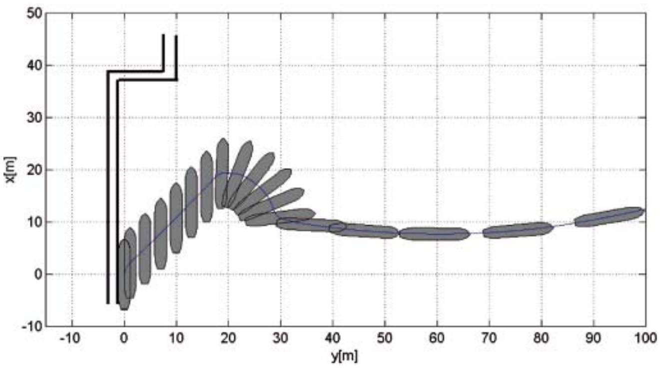


***Fig. 21.** The leaving harbour manoeuvre*

The agent system is the one that consists of a number of agents that cooperate with each other in order to solve a particular problem in this case - maximum level of safety at sea. The proposed system would automatically pursue three fundamental tasks related to ensuring safety at sea: data collection and analysis of the current situation around the ship's own navigation, automatic negotiation between ships in the sea area or shore stations to determine the potential area in which it would be the route transition (the job has not yet found in decision support systems) define routes and its auto correction depending on changes in current navigational situation. The Particular platforms of agent system Could be installed at different ships or waterside stations [6]. The agents work within a single platform of the agent system for exchanging data between them (Fig. 22).

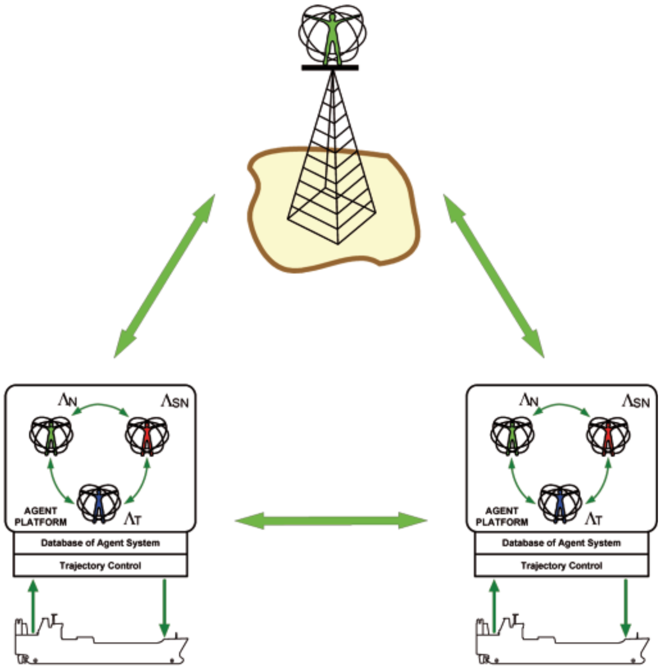


***Fig. 22.** The structure of the agent system*

Practical implementation could have promising effects in the form of relief work of the navigator, increase safety at sea, and reduce operating costs of the vessel. Agent system in its simplicity, offers the opportunity to review other methods and algorithms to determine optimal routes including anti-collision manoeuvre.

CONCLUSIONS

The proposed process for reviewing the ship's control system is an indirect method of verification between the low-cost methods of conducting research using computer simulations and tests with the use of expensive full-sized ships. Despite the use of the model constructed on a large scale, potentially results obtained may be considerably closer to the phenomena occurring in reality than the results that may be obtained through computer simulations. Thanks to electronic navigation modelling environment, which moves in the actual model of the ship, it is possible to very accurately modelling a wide variety of situations that contain various combinations of navigational limitations of a static (land, shoals, channels, fairways, engineering structures, etc.) and dynamic (icebergs, the other moving ships and facilities, etc.). Application submitted verification process decision support systems and vessel traffic management can contribute significantly to the improvement of maritime safety and reduce operating costs of the ships.

Note

This project was partially sponsored by grants: 03T11A02427, 3T11A00326, N51401532/1712.

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