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Automation of ship and control

Zagadnienia automatyzacji i sterowania statkiem

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Abstract

The article presents the problem of automation of ship's control. This paper will discuss the basic tasks of the track ship control, collision avoidance and automatic dynamic positioning. The following subjects will be presented: the general structure of the ship's control, methods and control algorithms for the above mentioned tasks.

Słowa kluczowe: wielowarstwowa struktura sterowania statkiem, systemy sterowania statkiem, dekompozycja sterowania

Abstrakt

Artykuł przedstawia zagadnienia automatyzacji i sterowania statkiem. W pracy zostały omówione podstawowe zadania sterowania po trajektorii, unikania kolizji oraz automatycznego dynamicznego pozycjonowania. Zostały przedstawione: ogólna struktura sterowania statkiem, metody oraz algorytmy sterowania dla ww. zadań.

Introduction

One man operated bridge [1] and engine operating without watch keeping [2] are the foundations of the modern ship control. The bridge configuration, layout and the location of desktop equipment (Bridge Integrated Navigation) allow one to navigate and guide the ship by a single operator – the watch officer.

The bridge adapted in this way allows an execution of all operations in the normal navigational conditions. Additionally, the construction of the bridge makes it easier to observe all the objects – targets in the maritime traffic and control other ships that may affect the safe navigation of the own ship. Ship with a bridge equipped for a one-man operation complying with the requirements of classification societies may obtain a NAV1 certificate [1].

Introduction of operating without watch keeping and systems for controlling the engine room from navigational bridge or central control room (called ECR – Engine Control Room) are currently a solution used on most of the commercial ships. Difficult working conditions in the engine room of the vessel, caused especially by noise, vibration and high temperature, resulted in the endeavor to replace the crew supervising the engine by ship automation systems.

Construction of ECR, isolated thermally and acoustically from the machinery space is the basic control engine section post. ECR greatly improved the working conditions of the crew operating the engine equipment with an exception of a task where the crew has to perform manual control in an emergency situation using local control directly on the devices (such as loss of the possibility of the remote control).

The crew's proximity to the engine room devices is also a result of regular ship's maintenance, i.e. fuel filters exchange.

The requirements for an automated engine room consist of [2]: The level of the automation of the engine room devices has to ensure unsupervised operations for at least 8 hours. This includes the basic mechanisms and the mobility and safety responsible devices including: The main drive (main engine) [3] with the supporting mechanisms and the propeller, energy sources and distribution systems [4]; steam boilers and boiler waste collection, air compressors, separators and fuel oil, inert gas generators, other mechanisms and devices.

In this case, operation parameters regulation systems (temperature, pressure, viscosity, etc.) have to work in a way, that during regular exploitation, including manoeuvres those parameters are kept in the regular range typical for mechanisms, devices and installations under consideration. It is also required that a crew with specific qualifications, that is able to keep the mobility of the ship in case of an automation system failure, is on board. The crew has to be also able to perform regulation and control over the devices in the engine room. A ship that is equipped with automation systems for no watch keeping operations and meeting the requirements of the classification societies, which were presented in brief above, can be given the AUT certificate [1].

The introduction of a one-man bridge control and no watch keeping engine room imposes certain technical requirements and is possible with a proper high-level control structure and with designing an ISCS (Integrated Ship Control System).

Ship as an object of control should be considered as a system performing complex processes with the participation of the control crew, where some of the processes work in an automated way in a specific environment [5]. The way in which a ship works requires to operate in a specific maritime environment and specific economic and social surroundings. The basic processes performed by a ship include: ship guidance, electric, mechanical and heat energy generation, cargo transportation and other processes connected to the ship's specific purpose [6, 7]. Specific processes can be assigned with proper sub-systems. The sub-systems perform tasks and functions within the process and the ones responsible for ship guidance are: heading control subsystem, ship cruise routing, positioning, etc., electricity production: electricity sub-system with adjustable frequency [8, 9, 10, 11], voltage and speed drive, the mechanical energy production process: the main propulsion subsystem for engine speed, control pitch propeller, auxiliary subsystem and other technical equipment [12]. Some of the subsystems are fully automated and some of them are semi-automated. Taking into account i.e. electricity generation process, a division between devices generating, distributing and receiving the energy has to be made [13, 14].

The functional division between subsystem components allows one to consider the automation tasks of specific elements of the subsystem individually. However, the mutual effect of the subsystem's elements requires an integrated device control system. The structure of the interconnected subsystems operating together in an external environment is presented on figure 1.

External environment consists of: maritime, social and economic environment. The ship is affected by the input signals connected with the transportation plans and those that result in current ship's navigational situation and the hydro-meteorological conditions. The output signals determine the ship's movement parameters.

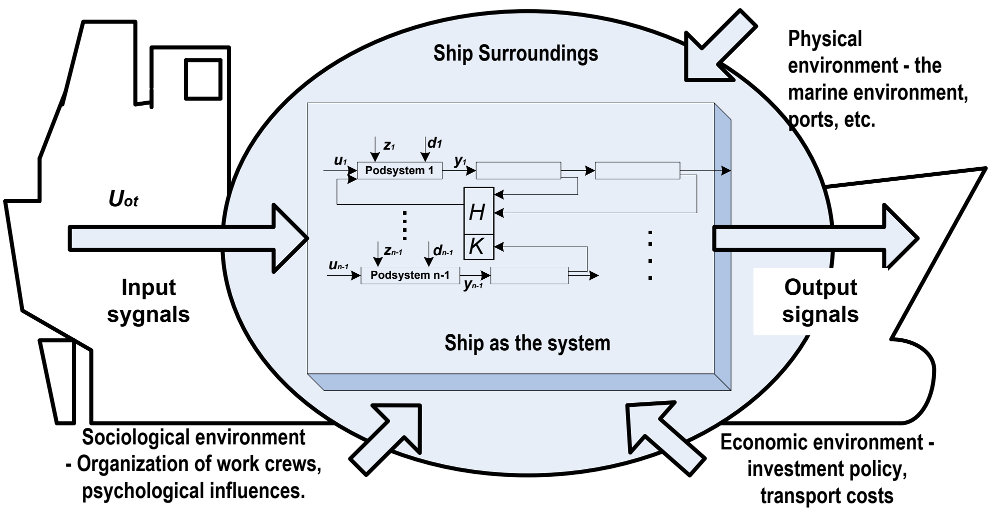

Fig. 1. Ship as a system and its surroundings
Rys. 1. Statek jako system i jego otoczenie

Ship's movement control system

The primary goal of the ship's maritime movement control is to use available technical means and automation systems, allowing to guide the object according to the shipping targets set by the operator. However, the guidance possibilities are limited by a spectrum of factors: physical, technical and legal. Also the economic limitations determine the ship's equipment set that allows the proper ship control.

The most important physical constrains come from ship inertia, hydrodynamic properties of the hull and the ship's marching speed actuators used. Actuators are significant restrictions for the control of the ship due to the limited size of the output signals, the impact of forces and moments on the ship. Furthermore, the effectiveness of such thrusters used for decreases vessel's speed, leaving the ship un-controllable from a certain velocity in a direction transverse to the hull. Physical limitations that affect the geometric and dynamic feasibility of the actual trajectory of the vessel must be taken into account when plotting the trajectory. Considering the control systems, technical limitations can be divided by: the measurement devices, actuators and associated with the use of computer techniques, algorithms, and methods of control. Modern measuring devices, e.g. position, direction, wind speed and direction and other navigational devices adequately ensure the quality of the measurement. However, those are only selected signals measured on the ship, and the existing measuring devices do not allow the direct measurement of forces and moments acting on the hull of the ship during the movement and interference. The greatest ship's movement disruptions come from wind, waves, currents and shallow waters. The control systems indirectly take into account the effect of the marine environment disturbances through the use of signal filtering (Kalman filter), the reference models and the status observer. Furthermore, due to control in real or near real time, simplified models and control algorithms vessels are used in the calculations. The increasing processing power of the ship's computer systems virtually doesn't limit computational capabilities and is no longer a problem in modeling. However, non-linear modeling of the ship control systems is still a very important issue taken into account in the modeling, especially in the control of a large displacement ship and at low speeds.

The rules relate primarily to improving maritime safety and reducing pollution of the marine environment during transport and sea operations. They also specify the parameters and operating range of the security equipment and system configuration. An example of the rules applicable to control systems and computer systems and for vessels under the supervision of the Polish Register of Shipping are in print [15, 16, 17].

Guidance decomposition

The first section presents the overall distribution of interoperable ship systems, including the navigational system, which primarily tasks include the setting of the navigational position, direction and the travel distance of the vessel and directing it's course. Determining the position and direction is taken from the navigational devices: GPS (Global Positioning System), gyro and other devices. However, the task of controlling the ship movement is reduced to a transport problem, where a conveyance of a certain amount of cargo or passengers from the departure port to the destination in a certain amount of time takes place. The inland shipping seeks to optimize the ship's route. The route is considered optimal when it connects the departure with the destination point and meets the safety of people transport, cargo, ship, environment protection and economic criteria, e.g. minimum travel time or minimum fuel consumption criteria. When analysing the problem of controlling a ship, one needs to note that this is a task consisting of path planning and guidance of the ship along that path (control).

In maritime shipping the guidance is defined by waypoints plotting – the route connected with the transportations tasks, which can be updated in real time. On the basis of path planned variable vector is created – the control vector as a reference value for the control system. Therefore, the primary function of the control system is to generate the control vector for the control system which is called the control law. When generating a control vector in the control system yaw, roll, pitch and the speed associated with them are not being considered. It is assumed that the ship's guidance is happening on the horizontal plane and consists of path planning. The primary control system signal will be desired yaw in order to keep up with the set route without having to establish control for the other directions. Guidance in the surge direction – speed control – can be carried out manually or by a separate speed control system. Sway is not being controlled. Analysing the possibility of correcting lateral movement, propellers efficiency decreases with the speed of the ship and they become useless at speeds above 2 m/s [18]. The problem is different at lower speeds (less than 2 m/s), where it is necessary to control

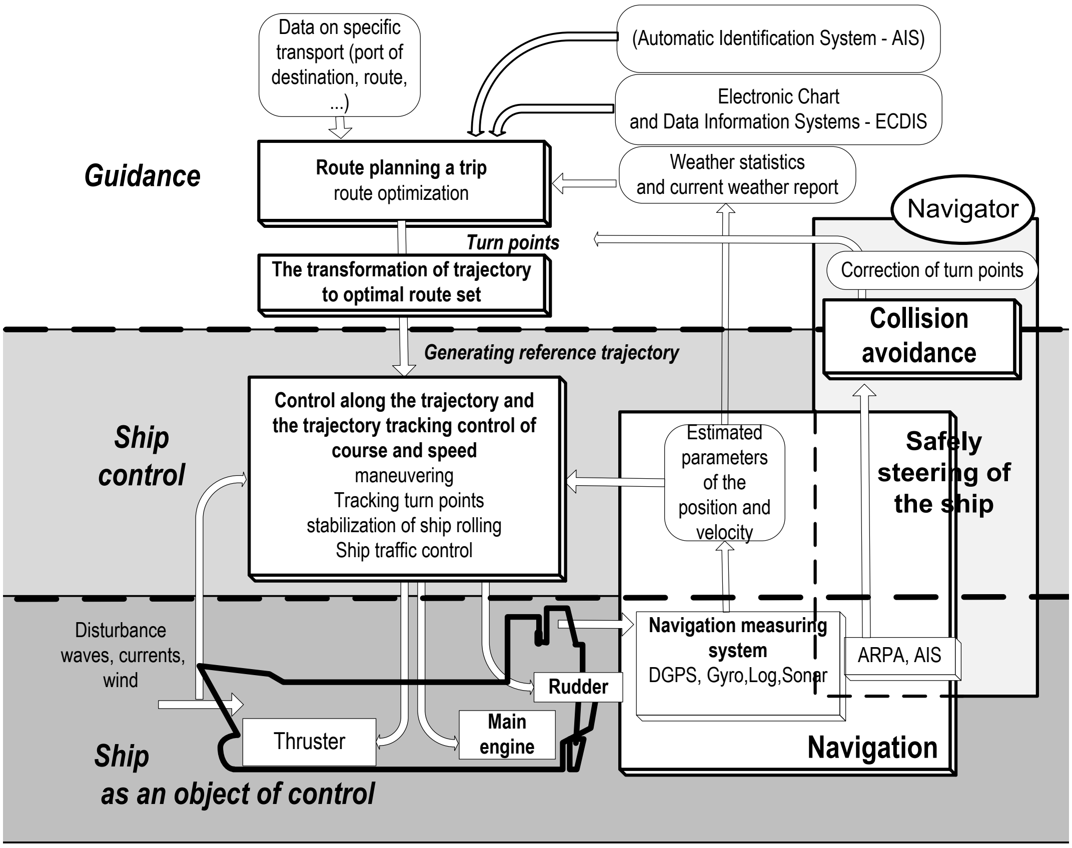

Fig. 2. The structure of multi-layer vessel traffic management
Rys. 2. Struktura wielowarstwowa kierowania ruchem statku

the movement of vessel in all three directions: yaw, roll and pitch, individually. In this case, the signals from the ship control system are secondary, consisting in determining the pre-selected by the operator waypoints or target position. When generating the control vector, the ship takes into account the constrains connected with the ship's physical limitations. It also considers the navigational block information regarding current vessel state vector and the external information: the weather, the position of other vessels, the timing of vessel traffic in the area, etc.

Extracting less complex tasks of less amount of variables is much easier for synthesis and easier to control during the operations phase. In the same time a single task is responsible for a single goal in opposition to a global complex system [19]. A multilevel ship control structure is presented in the paper [20], where path planning, safe, adaptive, optimal and direct control layers are extracted.

It is proposed that due to such decomposition, the control problem has to be modified to include basic optimization tasks, interconnected by a multilevel control structure (Fig. 2) such as:

– planning the optimal path;
– minimizing the deviation from the desired trajectory;
– course and speed control along the trajectory;
– in case of a possible collision, supporting an optimal decision in order to avoid the collision and maintain safety.

According to the multilevel ship's control system concept (Fig. 2) and the implementation of the partial tasks in the navigational system, where the ship is the control object, the following layers are present:

– guidance layer, where the strategic optimization tasks with a time limitation fixed during the shipping;
– control layer, where the tactical tasks including traffic control for the short-term, the consist of utilizing, by the use of control and optimization methods for achieving the desired control objectives including minimizing the deviation from the desired trajectory and minimize yaw and speed loss;
– control level layer for a moving ship.

Navigation block on figure 2 refers to the measurement and estimation of signal filtering position, direction, speed, depth of the bottom and the other the navigational parameters. In literature, Guidance, Navigation and Control are tasks implemented as subsystems in a closed control system [21].

In the ship control layer the primary task is to generate a desired state vector for the control layer. The strategic tasks include:

– path planning by plotting the waypoints, including the shipping plans and the navigational constrains;
– weather routing, to be used mostly in planning the ocean path planning.

The ocean weather routing considers ship's navigation, including current, static and forecasted hydro-meteorological [22]. Additionally, when path planning, the drive type can be included as it was presented in [23]. In this case, the path planning consists of a search for a route meeting the weather danger and transport cost reduction criteria using optimization methods.

The optimization task's result, the waypoints, are being converted into a set trajectory that takes into account ship's dynamic properties. The set trajectory is an input value (guidance law) for the guidance level (Fig. 2).

Guiding ship along a trajectory is connected with a series of manoeuvres and ship's speed correction. Control is of programmable nature, because the ship moving along a trajectory should reach predefined values, in this case the waypoints and the destination point. While calculating the control, the control goals have to be set. Those goals will differ depending if one is shipping on open seas, narrow crossings, canals or areas of limited accessibility. In case of an open sea shipping, one will minimize the route loss and the fuel consumption. On the other head, narrow crossings will require precise manoeuvring along the trajectory with minimal trajectory possible deviation, which ensures ship's movement safety on the restricted water lane. It can be assumed that guiding a ship is a special case of guiding a ship along a trajectory, where the position is arbitrary, but the course is fixed. An autopilot in the control system compensates for the disturbances acting on the ship [24] using steering gear control signals. In the automatic guidance mode, the autopilot accomplishes the preprogramed set trajectory, presented in the ECDIS (*ang. Electronic Chart Display and Information System*) [25].

In the maritime shipping an excessive close up of moving ships and course parameter changes of the encountered ships are an important disturbance. Such event may lead to a collision. The encountered objects treated as dynamic obstacles and the changes in their movement parameters – course and speed, are identified by the radar and anti-collision systems. In an event of recording an excessive close up or parameter change during ships' passing, a navigator's decision, a correction of the plotted path, ship's route has to be made. This is done on the ship's guidance level in the on-line tracking by displaying new waypoints, that will allow ships' avoidance within a safe distance. The task of collision avoidance is included in the process of safe ship guidance and is found in the multilevel guidance structure as a combination of the control level with the navigational level. It's a decision support system by nature and works by plotting additional waypoints that allow to correct the previously set trajectory. Automatic tracking of the encountered objects trajectory in an event of possible collision is accomplished by the ARPA (*Automatic Radar Plotting Aids*) system by analysing radar data and visualizing the results in a specific form, without the necessity of navigator's active tracking [26]. Based on the radio signals, the system allows for a simulation and determining the avoidance of other moving object within safe distance manoeuvre. Automatic tracking system also supports avoiding static under and above water constrains that cooperate with the ECDIS electronic map. In this task according to SOLAS rules, the final decision is made by the navigator, and the collision avoidance system has a navigator supporting role in nature.

Conclusions

In most of the currently exploited vessels a one man bridge and no watch keeping are being used. Such conditions set specific technical requirements and specific control structure for the automation system. In the same time, a ship has to meet specific technical requirements connected with the crew's safety and the transport tasks optimization. The implementation of a multilevel control structure and a unified control system allows to achieve the above conditions. The basic tasks for unified control system include: automatic and remote control from the ship's control posts, indicating alarm states and security systems activation in case of exceeding an acceptable parameter values of the exploited machines, remote measurements of the parameters necessary for the correct watch over ship's mechanisms, controlling the values of any chosen parameter, it's work state and other functions.

This article presents the general multilevel control structure including guidance, the goals of the guiding system and the usage limitations. A decomposition of the control tasks with a distinction of layers that create multilevel guidance structure has been presented. The control structure was shown as an example of a dynamic ship's position system.

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