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An Integrated Model of Motion, Steering, Positioning and Stabilization of an Unmanned Autonomous Maritime Vehicle

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ABSTRACT: In the paper the aim of an interdisciplinary research is presented. The research method is introduced. An object the unmanned autonomous maritime vehicle is briefly described. The key research problem concerns a combined model of the vehicle motion including the loads of lift and hydrodynamic nature. The model takes into account the gravity and displacement forces, resistance and thrust forces, lift and other hydrodynamic forces. One of the major research tasks is to precisely predict the position of the vehicle. To do that an integrated model of acquiring, analyzing and processing the signals is necessary. The processed signals may then be used for the precise steering of the vehicle. The vehicle should be equipped with a stabilization system. Some information on an integrated steering, positioning and stabilization system of the vehicle is briefly presented in the paper. Such the system enables to obtain a fully autonomous vehicle. Some information on the propulsion and underwater energy supply systems are presented in the paper, too.

1 INTRODUCTION

The autonomous underwater vehicles perform locomotion and manipulation tasks that certainly require a high precision positioning. The main aim of the current research is to work out a precise position stabilization system PPSS that ensures the stabilization of the position and the correct orientation of the vehicle. The PPSS system should operate independently of the main drive. The main drive system is responsible for a good navigation. The PPSS system has a separate electric executive motors. An electric made drive allows the vehicle to work in conditions of immersion and to charge unattended. In the paper the functional structure of PPSS system, some elements of operation of the overall algorithm, a simulation model written in Matlab software and sample simulation results are presented. Having the simulation model the research of the vehicle movements during the planned mission may be carried out. The simulation program also allows to check how the coded algorithms work at each step of operation. The vehicle motion may determined due to the influence of interferences as well. The designers would be able to use the model to determine the possibilities of further development of the vehicle including the energy usage during the mission.

2 THE RESEARCH

The contemporary tasks of navy ships require to apply more and more advanced multi-task ships. Despite of the size the multi-task ships are the platforms for the flying drones and unmanned waterborne vehicles. The unmanned maritime vehicles may be the remote operated vehicles and unmanned autonomous vehicles. The latest may be called as the maritime or underwater drones.

In the paper the maritime and underwater drones will be called as the unmanned maritime objects. The reason is that the unmanned waterborne drones sometimes may not be autonomous.

The primary task of an object should be able to conduct a mission in such a way that the information acquired by the object would directly be sent to, processed and used by the command centre.

The main objective of the current research is to work out a functional model of the advanced object which should be able to move on the water surface with a different range of speed. The same object could move above the water surface for a short period of time but the flight height should be less than 5 meters. The object should have a special power supply system enabling to work for at least 30 minutes up to a few hours before the new set of energy supply is delivered.

The methodology of the current research is based on the holistic approach. The implementation of this approach to the design, construction and operation of the object is novel. The research method combines the performance-oriented approach with the risk-based approach. The research problems associated with development of a concept of the object moving in two specific operational conditions is associated with the following tasks to be performed: object definition, assessment of object performance, steering and control, safety.

The object is defined as a hybrid mono-hull including the hull form, arrangement of internal spaces, propulsion subsystem, ballast system and other functional subsystems

The problem of estimating the object mass requires to estimate the weight of the following items:
– weight of all the materials used concerning the weight of skin plates, main frames, etc.,
– weight of the propulsion system,
– weight of all the sub-systems and equipment,
– payload.

Then the object performance may be assessed. This is connected with estimation the floatability, stability, resistance and propulsion characteristics first of all. After the steering and control characteristics are estimated the maneuverability and seakeeping of the object may be assessed. The assessment of the object performance and risk assessment may be done for the data operational conditions and sequence of events under consideration.

The concept of the object has been developed by Mirosław K. Gerigk, Profesor of Gdańsk University of Technology. He is responsible for the further research and design where the object hull form, choice of materials, construction and strength, propulsion, energy supply, sea loads and object hydrodynamics are the research and design drivers. Dr. Stefan Wójtowicz is generally responsible for the development of the vehicle steering and control systems. The entire research team consists of the specialists from a few Polish research institutions.

3 THE METHOD

The research method is a kind of performance-oriented risk-based method which enables to assess the object safety at the design stage and in operation, Gerigk (2010). The method takes into account the influence of design and operational factors on safety including the safety management related factors as well. The holistic approach to assessment of the object safety is applied. The method is based on implementation of the system approach to safety.

For the object performance evaluation the investigations using the physical models and numerical simulation techniques may be applied. The object performance estimation enables to take into account the influence of the intermediate events, additional events (releases) and consequences on the object behavior. This may be done for the data sequence of events for a scenario under consideration.

The risk assessment is based on application of the matrix type risk model which is prepared in such a way that it enables to consider almost all the scenarios of events. The criteria within the method is to achieve an adequate level of risk using the risk acceptance criteria, risk matrix, Gerigk (2010). Providing a sufficient level of safety based on the risk assessment is the main objective. It is either the design, operational or organizational objective. Safety is the design objective between the other objectives. The measure of safety of the object is the risk (level of risk).

The structure of the method is presented in Figure 1, Gerigk (2010).

The method is based on the following main steps:
– setting the requirements, criteria, limitations, safety objectives;
– defining the object and environment;
– identifying the hazards and identifying the sequences of events (scenarios);
– assessing the object performance;
– estimating the risk according to the event tree analysis ETA and matrix type risk model (risk is estimated separately for each scenario separately);
– assessing the risk according to the risk acceptance criteria (risk matrix) and safety objectives;
– managing the risk according to the risk control options;
– selecting the design (or operational procedure) that meet the requirements, criteria, limitations, safety objectives;
– optimizing the design (or operational procedure);
– making the decisions on safety.

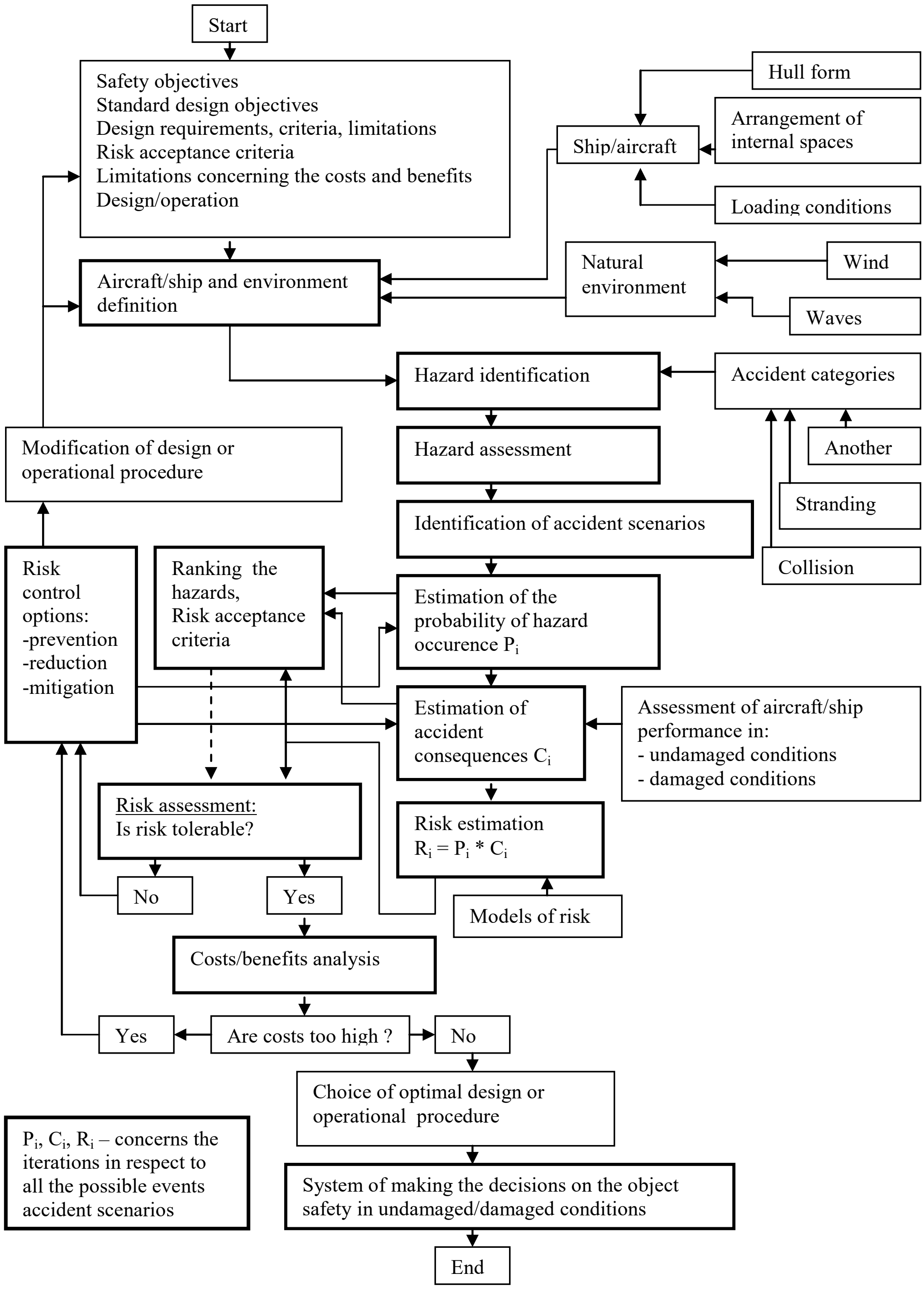


Figure 1. Structure of the method of risk and safety assessment of ships and maritime objects,(M.K. Gerigk, 2010).

4 THE UNMANNED AUTONOMOUS MARITIME VEHICLE

The primary aim of the research is to work out a functional model of the object moving in two specific operational conditions. The operational conditions are related to the tasks the object is designed for.

The novel solutions have been applied regarding the hull form, arrangement of internal spaces, materials and propulsion system. The final hull form is a combined "planning - wing in ground" hull form. The basic arrangement of internal spaces has been designed according to functional requirements. The arrangement of the object internal spaces is very much affected by the sub-systems predicted to be installed. The sub-systems which have been taken into account are as follows:

– air-jet propulsion sub-system,
– water-jet propulsion sub-system,
– power supply sub-system,
– ballast sub-system,
– air supply sub-system,
– hydraulic sub-system,
– steering sub-system,
– communication and navigation sub-system
– multi-task patrol sub-system or combat sub-system.

The stealth technology achievements have been applied to obtain the unique hydrodynamic and other characteristics. The major factors enabling obtaining the object stealth features are: hull form, hull skin cover, modified boundary layer, modified emission of vibrations and acoustic (hydro-acoustic) space.

It has been anticipated that the object may have a possibility to move on the water surface and for a short period of time above the water surface. The flight height is small and it is assumed to be less than 5 meters.

The second version of the object has the main parameters as follows:

– overall length L - is equal to 5.8 meters,
– operational breadth B - is equal to 5.2 meters or 6.0 meters, depending on the wing system applied,
– breadth during transport B_t - is equal to 2.4 meters,
– height H - is equal to 1.1 meters,
– mass is equal to from 1.8 tons to 2.4 tons, depending on the weight of equipment installed,
– maximum object speed on the water surface v_{ws} - is equal to 15 meters/seconds,
– maximum object speed above the water surface v_{aws} - is equal to from 15 meters/seconds to 45 meters/seconds, depending on the air-jet propulsion and wing system applied.

A visualization of the first, second and third version of the object under consideration is presented in Figure 2.

Figure 2. A visualization of three versions of the unmanned autonomous maritime vehicle, (M.K. Gerigk, 2011-2015).

5 THE AIM OF CURRENT RESEARCH

One of the main research and design issues is to work out a precise position stabilization system PPSS for an unmanned autonomous maritime vehicle. This system is independent from the main propulsion system which is responsible for the vehicle motion controlled by the navigation system. Both the main propulsion and PPSS systems have the acting electrical engines. The electric propulsion enables the vehicle to work during the submersible mode and automatic energy uploading.

It should be possible to upload the batteries using the installed photovoltaic batteries. The underwater mobile uploading stands perhaps cause that the vehicle is able to stay submerged without limitations.

The PPSS system should be treated as a separate module because the activity of the vehicle which is connected with collecting the species, detecting the objects, scanning the sea bottom, geometry measurements of the surrounding environment using the tools installed onboard the vehicle. All these activities require a precise determination and keeping the vehicle position and orientation.

Currently, the research is performed for a vehicle model presented in Figure 3.

6 THE FUNCTIONALITY AND PHYSICAL MODEL OF PPSS SYSTEM

Besides of the main propulsion system the vehicle has a system of precise positioning. The system consists of four thrusters as an example located horizontally or vertically to the vehicle base plane. The PPSS system needs to obtain the required position of the vehicle. The position in 3D space is determined by the N_H i O including point P_1 or by the plane H and points P_1 and P_2. The position of the PPSS system thrusters according to the vehicle base plane is presented in Figure 3.

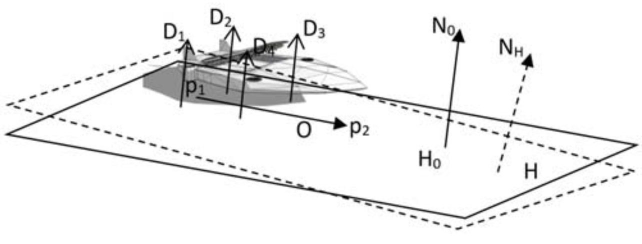


Figure 3. The position of the PPSS thrusters according to the vehicle base plane, (S. Wójtowicz, M.K. Gerigk, 2015).

The physical model consists of the geometrical position of the precise propulsion units, formal description of the sensor system, AI (Artificial Intelligence) system for analyzing the data and system of effectors.

Four thrusters located symmetrically according to the vehicle centre plane are installed in such a way that the thrust vectors may be perpendicular to the vehicle base plane if required. The vehicle motion may be obtained using and steering the rotational speed of four the thrusters in the same time.

For the modelling purposes in the case of small values of vehicle speed during the precise positioning it seems that the positions of the precise propulsion units are very important. It is briefly presented in Figures 4 and 5.

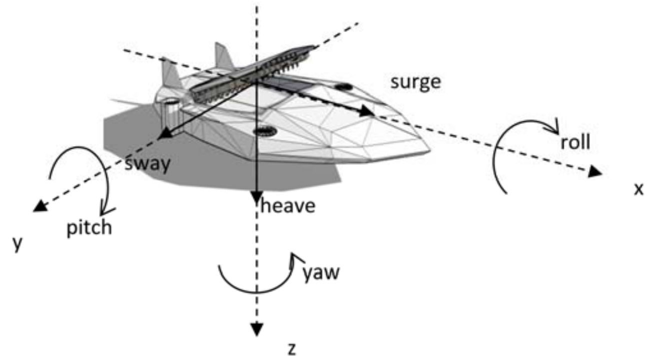


Figure. 4. A standard model using 6DoF, (S. Wójtowicz, M.K. Gerigk, 2015).

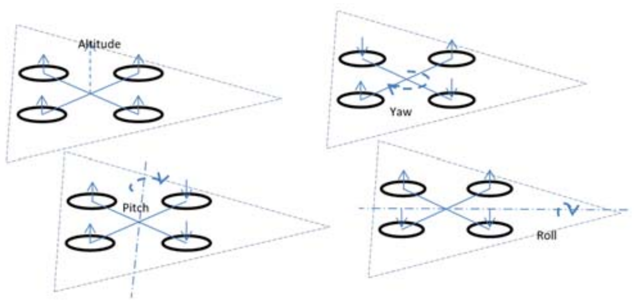
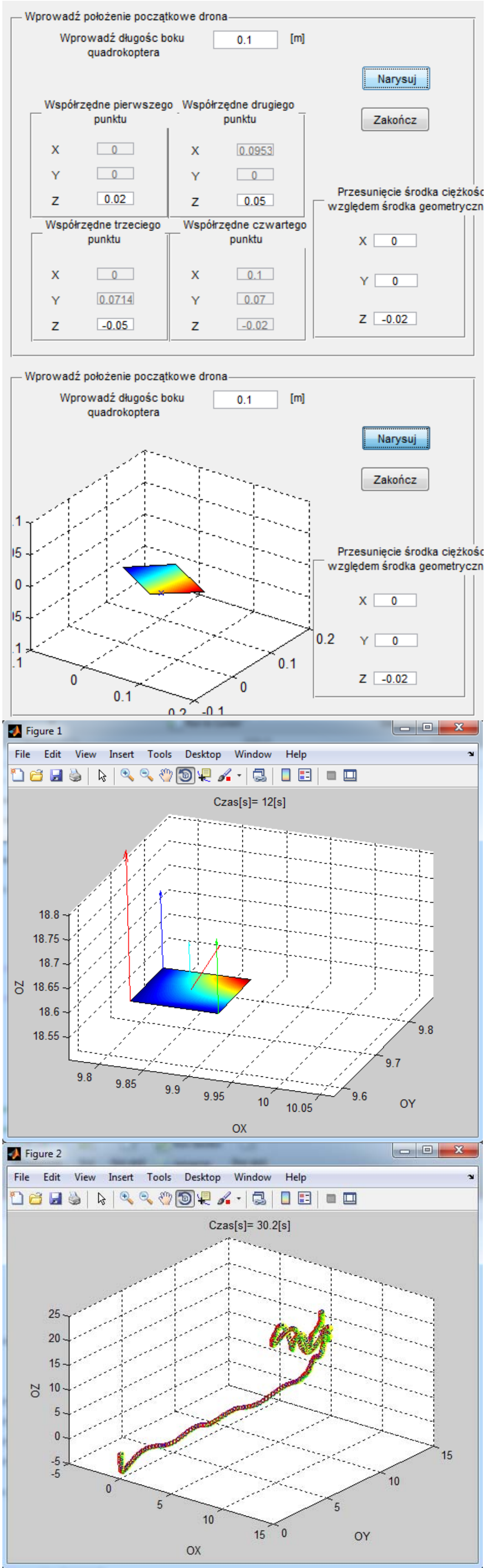


Figure 5. The vectors of the precise propulsion units during the positioning of the vehicle, (S. Wójtowicz, M.K. Gerigk, 2011-2015).

The 6 DOF (degree-of-freedom) model including the linear u,v,w (surge, sway, heave) and angular p, q, r (roll, pitch, yaw) velocities is the base for predicting the seakeeping characteristics of the vehicle. The relative position to the sea bottom (or GPS coordinates) is in the form the vector of position x, y, z and Euler angles φ, θ, ψ.

7 A COMPUTER SIMULATION OF PPSS SYSTEM

The computational model have been prepared using the Matlab environment. There are six main interrelated modules of the computational model. It is possible to put in the preliminary and final position of the vehicle, thrust of the propeller (rotational speed) and expected impacts (current). Some preliminary results of computer simulation of the PPSS system work connected with the precise positioning of the vehicle are briefly presented in Figure 6



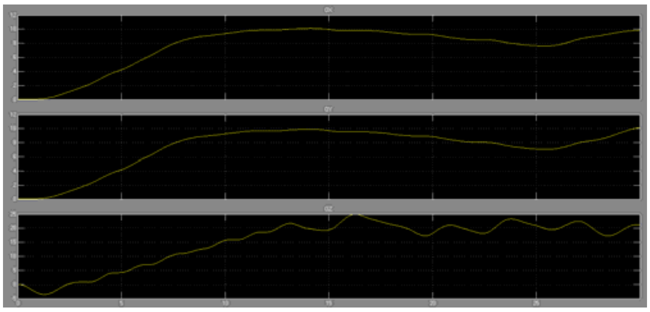


Figure. 6. The preliminary results of computer simulation of the PPSS system work.

8 CONCLUSIONS

The autonomous underwater vehicles performs the motion and manipulation tasks that require the high precision positioning. The subject of the article was to present the preliminary results concerning the precise position stabilization system PPSS that ensures the stabilization of the position and the correct orientation of the vehicle. The paper covers the functional structure of PPSS system, operation of overall the algorithm, simulation model in Matlab environment and sample simulation results.

The PPSS system operates independently of the main propulsion system which is responsible for the vehicle navigation. The PPSS system has a separate electric executive motors form the main propulsion system. Generally, the electric drive allows to work in conditions of immersion and to charge the vehicle batteries being unattended.

Using the simulation model it may be carried out the research of the vehicle motion during the planned mission. The simulation program also allows to check how the developed algorithms are working at each stage of operation. It is possible to analyze how the vehicle motion is affected due to the different interferences like the water current. For the designers it is possible to use the model to further develop the vehicle including tracking the vehicle energy usage during the mission.

At the current stage of research the following tasks have been performed:
- functionality of PPSS system,
- physical model of PPSS system,
- computer simulation of PPSS system.

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