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THE INFLUENCE OF CONTROL ALGORITHMS ON ROV OPERATION

The article presents the scope of research works including the development and analysis of a number of self-teaching control algorithms, which would enable the automation of ROV motions depending on a task given to the vehicle.

Key words: underwater vehicle, underwater investigations, automatics of movement, control

1. INTRODUCTION

In Poland, three centres are active in subsea engineering: Gdańsk University of Technology, Naval Academy in Gdynia and the Western Pomeranian University of Technology (WPUT). The university in Gdańsk specialises in the construction of subsea devices for the military, the Naval Academy concentrates on operation of such vehicles, and the Western Pomeranian University of Technology specialises in monitoring systems dedicated to civilian applications.

The Chair of Ship Design, Mechanics and Technology of Maritime Engineering Faculty at WPUT has carried out design and research works in the field of subsea remotely operated vehicle (ROV) construction and control since 1980s. The subject of the research is a deep sea ROV named MAGIS, which is designed for monitoring tasks and simple underwater works.

Control of the vehicle requires high level of skills and concentration from its operator. Concentration invariably fades in time, and moreover it is only possible to manually control the vehicle in good underwater visibility conditions. It is then necessary to implement an automatic ROV motion control system which is going to support the work of its operator.

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2. TASKS AND TECHNICAL CHARACTERISTICS OF MAGIS ROV

ROV MAGIS has been designed for performing the monitoring tasks at the bottom of Baltic Sea, such as searches for wrecks, natural obstacles, military waste etc.

It may also be used for underwater inspections of seagoing and inland ships, stationary and floating wind turbine generator structures etc.

MAGIS is remotely controlled by the operator from a surface control station via a cable tether (umbilical).

It has a capability to observe the image of an underwater object using the cameras fitted on the vehicle. Another of its capabilities is the use of data sent via a hydroacoustic underwater navigation system with an ultra short base (Tracpoint). Yet another is a measurement system for water physical and chemical parameters. The vehicle may operate at the depths down to 400 m, [1].

Fig. 1. Configuration of the MAGIS ROV [1]: 1 – frame, 2 – buoyancy unit, 3 – container for electronics, 4 – longitudinal thruster, 5 – transverse thruster, 6 – vertical thruster, 7 – light, 8 – compass (hidden), 9 – bacon, 10 – photo camera, 11 – strobe lamp, 12 – colour tv camera and pan&tilt mechanism, 13 – b&w tv camera, 14 – manipulator, 15 – umbilical, 16 – measurement sounder (hidden)

Rys. 1. Konfiguracja pojazdu głębinowego MAGIS [1]
The underwater vehicle is presented in Fig. 1 and in Table 1. It is characterised by high complexity, large number of parameters, non-linearity and time-vari-ance (various types of disturbances from sea currents, waves and the tether).

<table>
<thead>
<tr>
<th>#</th>
<th>Technical data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Task site category</td>
<td>line or area site</td>
</tr>
<tr>
<td>2</td>
<td>Shape</td>
<td>cylindrical</td>
</tr>
<tr>
<td>3</td>
<td>Dimensions [mm]</td>
<td>2250×760×600</td>
</tr>
<tr>
<td>4</td>
<td>Weight in air [kg]</td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td>Operational depth [m]</td>
<td>150 or 400</td>
</tr>
<tr>
<td>6</td>
<td>Speed - forward [m/s]</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>Number of propellers:</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>longitudinal +transverse+vertical</td>
<td>2 + 2 + 2</td>
</tr>
<tr>
<td>9</td>
<td>Supply voltage [V × Hz]</td>
<td>3 × 380 × 50</td>
</tr>
<tr>
<td>10</td>
<td>Basic equipment:</td>
<td>colour video camera, B&amp;W video camera, lights 4 × 300 W, two-function chuck manipulator, pan&amp;tilt platform for one camera and 2 lights, magnetic compass, pressure-based depth gauge, ultra short base navigation system</td>
</tr>
<tr>
<td>11</td>
<td>Optional equipment</td>
<td>magnetometer, water sampling device, sensors for testing physical &amp; chemical parameters of water.</td>
</tr>
<tr>
<td>12</td>
<td>Deck devices</td>
<td>manual control console, computer, two video monitors, keyboard, power supply cabinet.</td>
</tr>
</tbody>
</table>

3. SPECIFICATION OF RESEARCH AIMS

The aim of research focused on the presented system of MAGIS vehicle has been specified as a development and analysis acc. to Model-In-The-Loop, Hardware-In-The-Loop procedures, and in real time, development and analysis of a series of self-learning/self-tuning control algorithms. These algorithms shall enable automation of deepwater vehicle motion fitting its task, which are going to be automatic stabilisation and/or program regulation of:
– depth during manual course control,
– course during manual depth control,
– course and depth.
At the same time, the discussed automation shall not require the knowledge of deepwater vehicle dynamics but only the knowledge/expertise of an experienced operator, recorded in the form of numerical data (records of controlling and controlled signals).

Automatic control shall allow for separate stabilisation of course or depth, or combined stabilisation of course and depth, [1, 2, 4, 7]. This last option allows for moving the vehicle along a set trajectory, which is particularly useful in the task of monitoring some strictly defined area of sea bottom. Examples:

– the depth stabilisation function would be used for pipeline monitoring where the operator would control only the speed and course of vehicle, with some slight adjustments of its depth,

– in case of monitoring of drilling rig legs and fixed wind turbines the course stabilisation function would be used, where the operator would control the depth, parallel vehicle shift and the distance between the vehicle and a structure.

4. RESEARCH INTO THE ALGORITHMS OF ROV CONTROL

Classical control algorithms commonly used in industrial practice (PID) and the synthesis of control algorithm based on the mathematical model of the object are insufficient for the required control quality levels or simply not applicable for the case of underwater vehicle. The knowledge of a mathematical model representing the dynamic characteristics of the object is required for the synthesis of automatic control algorithm when classical methods are used. This model is quite often highly complex or even unknown, [5, 6], while its coefficients are difficult to establish using simple tests, and MAGIS underwater vehicle is exactly one of these cases. The equations of this underwater ROV motion have about 400 coefficients and identifying them all in basin tests is practically impossible task, [2].

Main difficulties and limitations which should be taken into account in the process of designing the control system for underwater ROVs are, [3]:

– technical conditions of implementation (inability to execute all the motions included in the mathematical model) – the model may of course be simplified to the vehicle planar motion, but every such simplification leads to loss of practical value of the model,

– economic conditions – costs of research may surpass the cost of underwater vehicle.

Other difficulties encountered in the process of designing the automatic control algorithm for an underwater vehicle, when basing on classical methods, are:

– nonlinearities of control object dynamic model, e.g. model coefficients depending in a nonlinear way on state variables,
– time-variant characteristics of the object due to use of wire cable, whose weight is of the same order as the vehicle weight, and which has positive buoyancy in seawater,
– static nonlinearities in actuator devices i.e. thrusters, for example thruster power limits (saturation) and insensitivity zones,
– variable character of disturbances, e.g. sea currents, waves, distance to bottom/shore etc.

The scope of research works includes development and analysis of a series of control algorithms over a selection of tracks (e.g. course/depth control), focusing on operational quality and the suitability for ROVs.

Capability to pre-tune the algorithms with data obtained from manual control is assumed. Use of fuzzy structure algorithms is also assumed, their advantage being a simplicity of the model expressed in linguistical terms understandable for humans.

Designed control algorithms shall be trained with I/O measurement data generated by master regulator which may be an expert human being controlling a given technical system, Fig. 2, using a research apparatus developed in the course of the project.

![Control Algorithm Diagram](image)

**Fig. 2.** Control algorithm training on the basis of I/O data base generated by human operator controlling the system

**Rys. 2.** Uczenie algorytmu sterowania na podstawie danych wejście/wyjście ludzkiego operatora sterującego systemem
It is assumed that the control algorithms may also be taught on the basis of any technical regulator controlling a given technical process. However, when we use for this purpose the signals (controlled and controlling) taken from manual control mode with an experienced human operator, it becomes possible to execute the control algorithm tuning process in the conditions of normal ROV underwater operation. A hypothesis is then posed that the tuning process based on manual control data shall yield a control algorithm which is going to be somewhat resistant to the changes in the dynamics of underwater vehicle and the effects of disturbances. Deterioration of control quality in the control mode transfer from manual to automatic as a result of changes mentioned above may be prevented using the self-teaching algorithms based on typical methods of adaptive control.

The element of randomness in the synthesis of fuzzy algorithms is another problem to be solved in the research process. One of the solutions may be the introduction of taught coefficients, analogously to the algorithm of error back propagation carried out with supervision (teaching on the basis of data from reference regulator or an on-line created model of teacher object), which rules out the influence of randomness in the process of control algorithm synthesis and brings the designer closer to the optimal solution. The clarity and comprehensibility of linguistic rules of fuzzy algorithm becomes then bundled with the capability of learning displayed by artificial neuron networks – ANN.

It should be noted, that general structures or techniques such as the Mamdani fuzzy controller or MIT rule do require in practice the execution of a series of experiments and tests for a concrete object, especially when it is as complex as an ROV. Apart from that the application of MIT rule to Mamdani controller is not known in literature.

Preparation of MAGIS deepwater ROV for tests requires that some design-like preparatory works are executed in order to create original test apparatus, including a prototype of control algorithm actuator platform, operator workstation and Human Machine Interface software for the operator workstation. The completed platform shall ensure that the testing and verification of algorithms themselves are relatively easy thanks to fast prototyping of control algorithms dedicated to PLC installed onboard the ROV. A practical quality verification of course and depth control algorithms is foreseen to take place during basin tests and in inland waters.

5. SUMMARY

Development of deepwater technology is in the interest of Poland, in particular in the face of intensive development of oil and gas exploitation infrastructure in the Baltic Sea, as well as development of ecological energy sources. Deepwa-
ter vehicles have a crucial role in this field, so there is a necessity to equip them with systems ensuring highest possible effectiveness of underwater works. One of the possibilities is development of automation and control systems for the vehicles.

Execution of research shall provide support for the deepwater ROV vehicle operator in the following practical fields of applications and tasks:

– sea and land transport – inspection and monitoring of wharf condition, port basins and waterways, underwater surfaces of merchant vessels and their propulsion systems,

– shipyard industry – inspection and monitoring of shipyard structures condition as well as the condition of newly build and repaired vessels during planned overhauls and in emergency repairs,

– water engineering works – inspection and monitoring of dams and other engineering works,

– inland and sea rescue services – monitoring of sunken ships and emergency-stricken ships.

– support for diving teams in their works,

– protection of natural environment – monitoring of water environment condition through the analysis of water physical and chemical parameters, including taking of bottom sediment samples.

From the practical point of view the developed control system should provide:

– releasing the operator from the duty to supervise the vehicle in its operation point after it is brought to its operation station, through stabilisation or programmed regulation of depth or course,

– automatic driving of the vehicle to a set depth and maintaining it there in spite of active disturbances – stabilisation and/or programmed regulation of depth during manual control of course,

– automatic driving of the vehicle at a set course and maintaining it on this course (in longitudinal motion or at rest, in spite of active disturbances) – stabilisation and/or programmed regulation of course during manual control.

REFERENCES


Wpływ algorytmów sterowania pojazdem typu ROV na jego działanie

Streszczenie

W artykule przedstawiono zakres prac badawczych obejmujących opracowanie i przebadanie samoczynnych algorytmów sterowania, umożliwiających automatyzację ruchu pojazdu głębinowego w zależności od postawionego zadania.

Słowa kluczowe: pojazd głębinowy, badania podwodne, automatyka ruchu, sterowanie