Control Systems of Underwater Vehicles in Multi-agent System of Underwater Inspection

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Abstract: - Using of autonomous underwater vehicles team for the execution of common underwater inspection task causes a need of particular vehicles coordination. One of the solutions is multi-agent system.
Multi-agent system of underwater inspection will be composed of decision system – generating vectors of desired states for particular underwater vehicle and control blocks – converting vectors of desired states into input function vectors of particular vehicle's driving systems for the common aim execution.
The paper undertakes problem of selection a structure of control blocks for underwater vehicles with different dynamics and different configuration of driving systems.

Key-Words: - multi-agent system of underwater inspection, control of underwater vehicle

1 Introduction

Since several years underwater robotics tends towards fully autonomy robots called AUVs (Autonomous Underwater Vehicles). News from carrying out researches and executed tests by NATO's allies inform about unavoidable way of technological progress in direction of collaborative unmanned systems for exploration of underwater space [2][3].
Examples of Underwater Vehicles UVs could be also noticed in Polish Navy in a form of several constructions, representing both Polish and foreign technological advance.
Using of a team of autonomous underwater vehicles in underwater works for the common aim carrying out generates needs of their actions coordination. One of possible solution is using of multi-agent system, where particular agents are underwater vehicles equipped with "intelligent software" enabling coordinated execution of stated task [4][6].
Implementation of multi-agent system requires designing and tuning of decision system and its elements that are systems controlling movement of particular underwater vehicles [6][7]. Decision system has to work out proper decision for each underwater vehicle for the common aim execution. Decision system calculates its decision on the base of state vectors of objects located beneath the surface of water received from independent devices, which monitor underwater space and on the base of vectors of current AUV's states received from sensors and devices mounted on board of underwater vehicles. While control systems are destined to convert vectors of desired states received from decision system to proper forces and moment of forces and adequate rotational speed of propellers
The paper focuses on the level of control systems executing instructions generated by decision system. In the paper different dynamics and different driving systems of underwater vehicles as control objects have been taken into consideration. As a results of executed analysis projects of control systems of selected underwater vehicles have been presented. Moreover results of numerical researches have been inserted.

2 Dynamics of selected UVs

There are different constructions of autonomous underwater vehicles on the world. Recent projects are inspirited by real construction from nature. Whole analysis of existing constructions exceeds limits of the paper therefore selected constructions of UVs have been presented in the paper. Criteria of the selection of specific type of underwater robots is based on their accessibility in planned experimental research.
The most popular and simple construction of underwater vehicle is one based on a frame with a cubicoid shape. Dimensions of the frame often are chosen in the way that a shape of an underwater vehicle is close to a cube. Driving system and added equipment such as cameras, manipulators, lamps, etc. are mounted to the frame in the way that all elements are located inside the space of the frame. Driving systems of these underwater vehicles consist of propellers acting in horizontal and vertical surface. Most often 3 to 4 propellers are mounted in vertical surface, what gives possibility of control linear motions in X and Y axis (longitudinal and lateral axis of

symmetry) and rotational motion in Z axis (vertical axis of vehicle's symmetry) [1]. Additionally 1 to 2 propellers are usually mounted in vertical surface, which enable to generate driving force in Z axis (in the case of 2 propellers, there is possibility of generating moment of force in Y axis). An example of this kind construction is remotely operated vehicle Ukwial [5], which is equipment of countermine warship (fig. 2 a).
The construction of an underwater vehicle based on a cubicoid frame has comparable motion features in 3 axis of symmetry. Selected representative underwater vehicles based on a frame (Ukwial) can move aside almost as quickly as forward and backward (hydrodynamic dumping of motion in Y axis is approximately only 2 times bigger than hydrodynamic dumping of motion in x axis). While hydrodynamic dumping in Z axis is about 20% bigger than in Y axis, what in connection with small positive buoyancy (about 17 N) gives speed of draught comparable with velocity in Y axis.

a)

b)

Fig. 1. Selected underwater vehicles: a) Remotely operated vehicle Ukwial on board of countermine warship; b) Self-propelled Mine Counter Charge Gluptak

Next large group of underwater vehicles are constructions, whose shape is close to a torpedo. Motion of these vehicles can be described in reduces way with the aid of hydrodynamics of a cylinder moving in a viscous liquid. Torpedo-shape constructions of an underwater vehicle have appeared and have particular use in AUV technology, where robots were devoided of powered cable and additionally loaded by batteries. In the case of limited power source, need of hydrodynamic dumping minimization appears, what is provided by cylinder shape of objects moving below the surface of water.
In the case of torpedo-shape, underwater vehicle driving system usually consist of 4 horizontal propellers situated in back part (on the stern) and 1 vertical propeller situated in axis of a centre of gravity and a centre of buoyancy. An example of this construction is the underwater vehicle Gluptak [5] implemented as a self-propelled mine counter charge on board of the Polish Navy's warships (fig. 1 b).
For the sake almost 10 times bigger hydrodynamic dumping in Y and Z axis than in X axis, Gluptak moves effectively only forward (in direction of longitudinal axis of symmetry). In this case control of rotational motions in Z and Y axis (control of course and trim) is carried out by generating of different rotational velocities of horizontal propellers situated on the stern.
For the sake of different dynamics and driving systems and manoeuvring possibilities of presented underwater robots, designed control systems of them should be different and fitted to their properties.

3 Control of selected UVs

Control system of underwater vehicle Ukwial has been designed in the way that it consists of 4 controllers of:

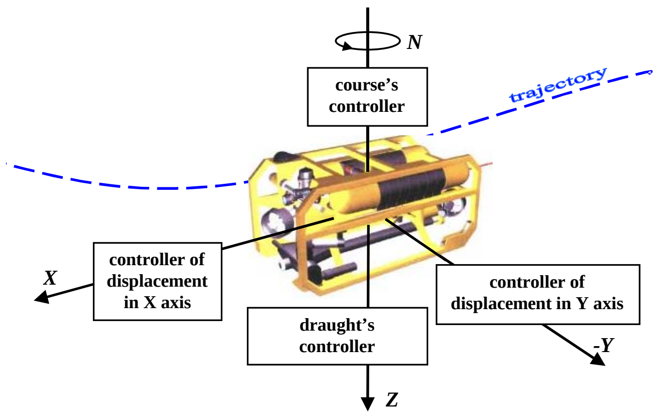
1) course,
2) displacement in X axis,
3) displacement in Y axis,
4) draught,

These controllers are set in 4 degrees of freedom of vehicle adequately: moment of force N in Z axis, force X in X axis, force Y in Y axis and force Z in Z axis [fig. 2 a]. Individual controllers receive desired values of controlled parameters such as desired course and desired coordinate x, y and z from decision system. While current values of mentioned above parameters are received directly from an underwater vehicle (equipped in proper measurement devices).
While control system of torpedo-shape underwater vehicle Gluptak consists of 4 controllers of:

1) course,
2) trim,
3) translation,
4) draught.

Moreover it is equipped with converter of desired states vector (fig. 2 b). A task of the converter is conversion of desired values of position coordinates x, y and z into specified values of desired course, desired trim and desired advance velocity. For the aim of moving to desired aim with possible smallest resistance to motion torpedo-shape vehicle has to move in direction of its longitudinal axis of symmetry (minimization of hydrodynamic dumping).

a)



b)

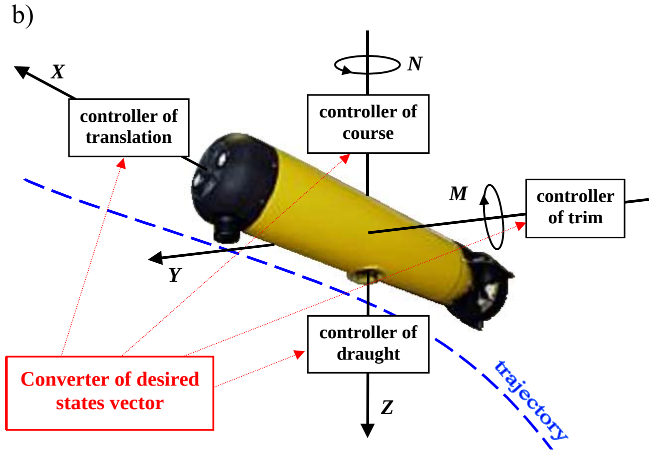


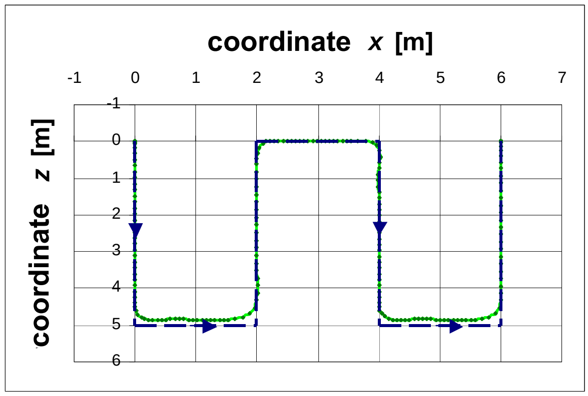
Fig. 2. Designed control systems steering motion of selected underwater vehicles: a) Ukwial; b) Gluptak

For the aim of adequate parameters control (fig. 2) different type controllers were tested: classical PD controllers, PD controllers tuned by genetic algorithm, based on fuzzy logic FPD controllers, slide controllers and neuro-fuzzy controllers. Results of enumerated controllers action were presented in earlier publications [8][9][10].

The best control quantity indexes were received for fuzzy FPD controllers, characterized by nonlinear control surface and big robustness on environment disturbances. Therefore presented in further part numerical researches (fig. 3 & fig. 4) were achieved in result of fuzzy FPD controllers action.

Selected results of underwater vehicle Ukwial control along desired trajectory in vertical surface xz has been presented in fig. 3. While selected results of underwater vehicle Gluptak control along desired trajectory in horizontal surface xy has been inserted in fig. 4.

a)



b)

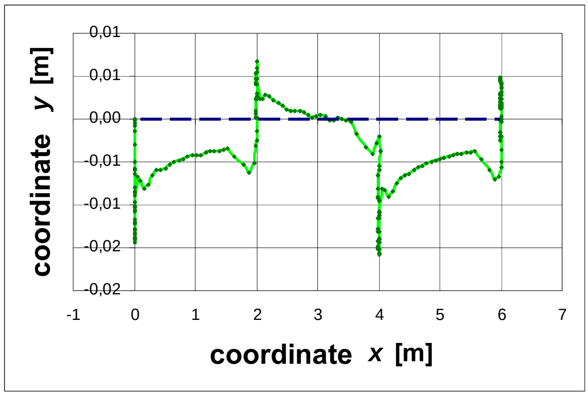


Fig. 3. Control of underwater vehicle Ukwial along desired trajectory in vertical surface xz: a) trajectory of motion; b) deviation in horizontal surface xy

It could be stated on the base of fig. 3, that underwater vehicle Ukwial (representative of constructions based on a frame with a cubicoid shape) has comparable motion features in both longitudinal and vertical axis of symmetry. Therefore this type vehicles are used successfully in inspection of different kind surfaces of objects submerged. Moreover control of underwater vehicle along desired trajectory in vertical surface xz (fig. 3 a) is characterized by small deviation observed in horizontal surface xy (fig. 3 b).

While torpedo-shaped underwater vehicles are usually used to different type search missions. The good example is Gluptak used to searching, identification and destroying of dangerous objects - underwater mines.

For the sake of their hydrodynamic features they are not able to execute precise inspection of submerged objects surfaces. Although they are able to achieve aim of mission in short time (they can move more quickly than constructions based on a frame). Moreover they can be controlled along desired trajectory (fig. 4 a), where trajectory is connected with waypoints forcing big changes of course (fig. 4 b).

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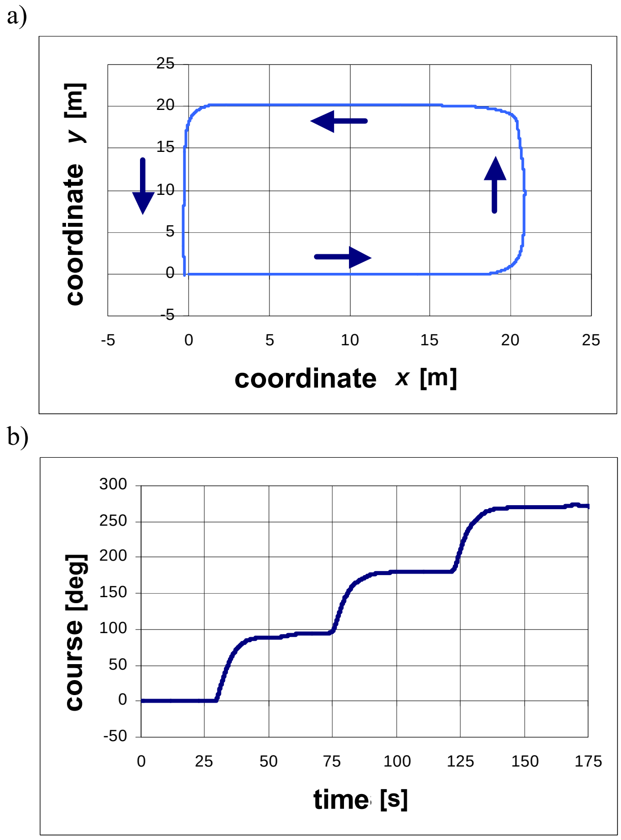

Fig. 4. Control of underwater vehicle Gluptak along desired trajectory in horizontal surface xy: a) trajectory of motion; b) changes of course in following waypoints

4 Summary

As a result of executed analysis of dynamics and configuration of driving systems and manoeuvring possibilities of selected underwater vehicle's constructions, it has been stated that very important is designing of different control systems for different types of underwater vehicles.

In the paper architectures of control systems for underwater vehicles Ukwial and Gluptak were presented, which enable execution of desired states vectors worked out by decision system. Received results of numerical research confirmed correctness of designing control systems and particular controllers.

In the next stage of research multi-agent system of underwater inspection decision system should be designed, tuned and tested.

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