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## **MULTI-AGENT SYSTEM OF AUTONOMOUS UNDERWATER VEHICLES — PRELIMINARY REPORT**

### **ABSTRACT**

In recent years increasing interest in autonomous underwater vehicles (AUV) has been observed. AUVs can be applied to a wide range of tasks, for example, to inspect various underwater objects. Many applications require cooperation between AUVs. In order for AUVs to cooperate, the system coordinating movements of individual AUVs has to be designed. To obtain such system different solutions can be used. One of them is proposed in the paper.

### **INTRODUCTION**

An inspection of underwater objects very often is strongly challenging task which requires cooperation of a team of AUVs. In order for AUVs to cooperate, the system, whose task is to coordinate actions of all AUVs, has to be build. The system mentioned should consist of two elements. A decision sub-system is the first of them. The main its role is to make high-level decisions regarding the strategy of the whole team. The second element of the system mentioned is a team of AUVs with their steering systems. The task of the steering systems is to convert high-level decisions into low-level ones. The general structure of the system is depicted in figure 1.

### **STEERING SYSTEM**

There are many diverse constructions of AUVs in the world and their comprehensive analysis is impossible within the confines of the paper. Hence, we focused on examples of AUVs presented below. The main criterion which was taken into consideration when selecting AUVs to describe was their usefulness in military tasks and their accessibility in future research.

The simplest and probably the most frequently used in practice is the construction based on carrier frame which has cuboids shape. The propulsion system and additional equipment like cameras, searchlight and manipulators are assigned to carrier frame. The propulsion system consists of propellers which work in horizontal and vertical planes. Three or four propellers are placed in vertical plane. It makes it possible to control the linear movement along X and Y axis, and rotation movement around Z axis. In vertical plane, usually 1 or 2 propellers are used. It allows AUV to generate propulsion force along Z axis and rotation around Y axis (in the case of 2 propellers). An example of such construction is AUV ‘Ukwiał’ (fig. 2), which can move equally fast in all directions, i.e. ahead, astern and aside.

Other group of AUVs are torpedo-shape constructions. Motion of this type of AUVs can be described in simplified form in which hydrodynamics of cylinder moving in the water is assumed. The propulsion system of torpedo-shape constructions consists of 4 horizontal propellers placed astern and 1 vertical propeller placed in the centre of the gravity. An example of such construction is AUV ‘Głuptak’ (fig. 3) used on Polish Navy ships as Self-propelled Mine Counter Charge (SMCC).

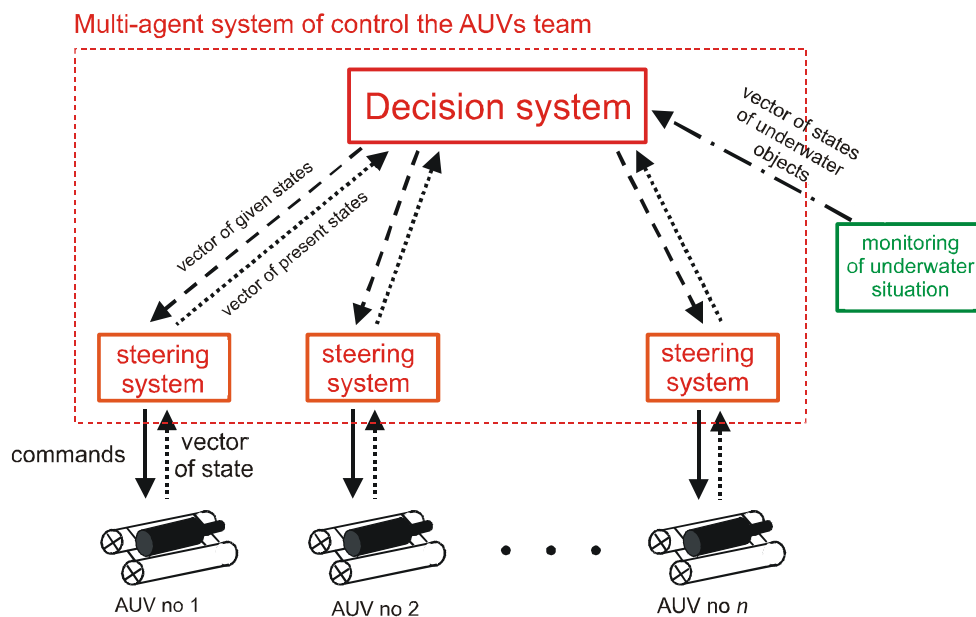


Fig. 1. Diagram of the system proposed



Fig. 2. 'Ukwiał' AUV



Fig. 3. 'Głuptak' AUV

Because AUV 'Głuptak' has almost ten times bigger hydrodynamic damping along Y and Z axis than along X axis, it can effectively move only forward.

In consequence of different hydrodynamics of two types of AUVs presented above, two different steering systems have to be designed.

The steering system of AUV „Ukwiał” proposed in the paper consists of 5 controllers (course, shift in X, Y and Z axis, draught and trim) and 5 moments put in five degrees of freedom of AUV (moment of  $N$  force in X axis, force  $X$  in X axis, force  $Y$  in Y axis, force  $Z$  in Z axis and moment of  $M$  force in Y axis). The coordinates  $x$ ,  $y$ ,  $z$  and velocity of AUV, the controllers receive from the decision system (fig. 4). Current values of the parameters mentioned above are taken directly from AUV.

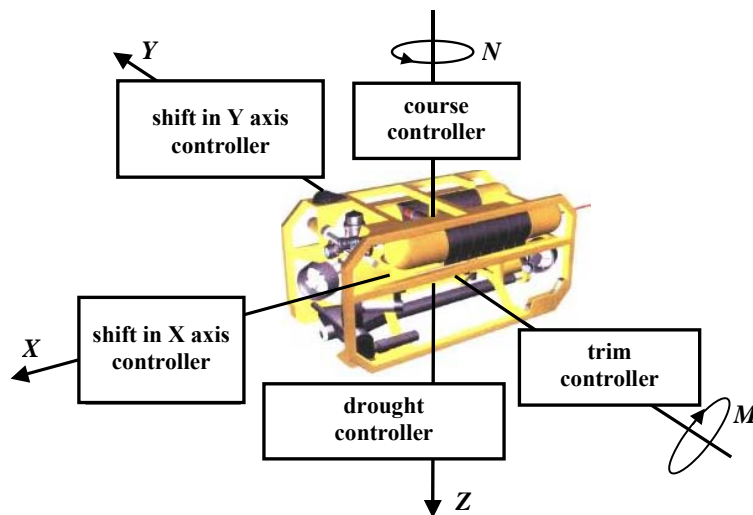


Fig. 4. Steering system of AUV 'Ukwial' type

The steering system of AUV 'Głuptak' is presented in figure 5. In addition to four controllers, i.e. course, trim, velocity and drought controllers, the vehicle is equipped with supervisory control unit.

The task of the supervisory control unit is to transform coordinates  $(x, y, z)$  into course, trim, velocity and draught so as to enable AUV to move to given location with the smallest hydrodynamic damping as possible. To accomplish such effect AUV 'Głuptak' should move mainly forward.

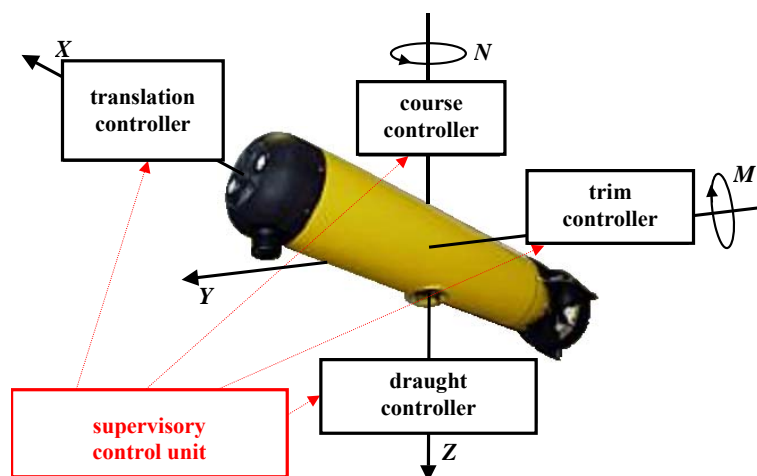


Fig. 5. Steering system of AUV 'Głuptak' type

The controllers shown in figures 4 and 5 were tentatively tuned during experiments reported among other things in [10, 11].

## DECISION SYSTEM

The task of the decision system is to coordinate actions of a team of AUVs. The decision system determines the course of action of all AUVs included in the team. It decides about the velocity and the direction of movement of each AUV. The decisions made by the decision system are transformed into activities of individual AUVs and their controllers. Each decision is made based on the information about the state of each vehicle. The state of a vehicle is determined by its parameters (velocity, course, trim etc.) and by signals from sensors. Generally, the process of control of group of AUVs, in the case of a single deterministic decision system (actions of the system are performed deterministically), can be viewed as a simple function which assigns an action (the action of the whole team) to each state of the team. The function mentioned can be implemented in various ways, e.g. by means of artificial neural network (ANN).

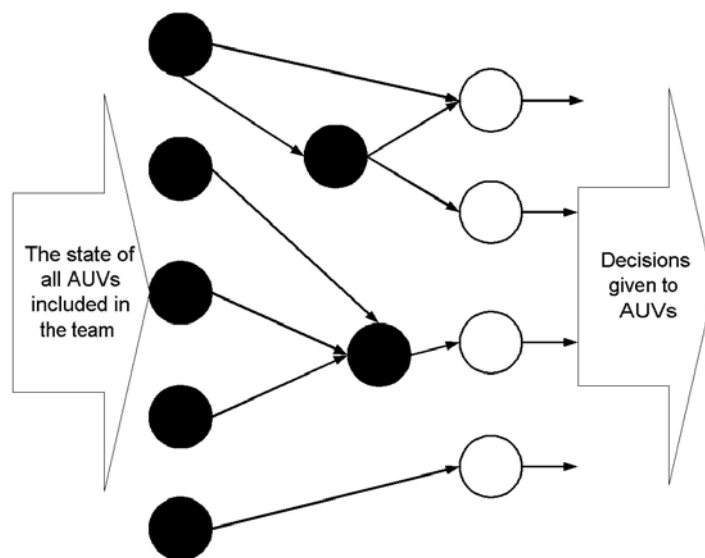


Fig. 6. ANN as the decision system

To construct the decision system implemented as ANN different methods can be used. One of them is an evolutionary approach. It requires encoding ANNs in the form of chromosomes. There are many encoding methods. The concept presented in the paper uses the so-called Assembler Encoding (AE) [4, 5, 6].

In AE, ANN is represented in the form of a program called AEP. AEP is composed of two parts, i.e. a part including operations and a part including data. The task of AEP is to create Network Definition Matrix (NDM) and to fill it with values. To this end AEP uses the operations. The operations are run in turn. When working the operations can use data located at the end of AEP (fig. 7).

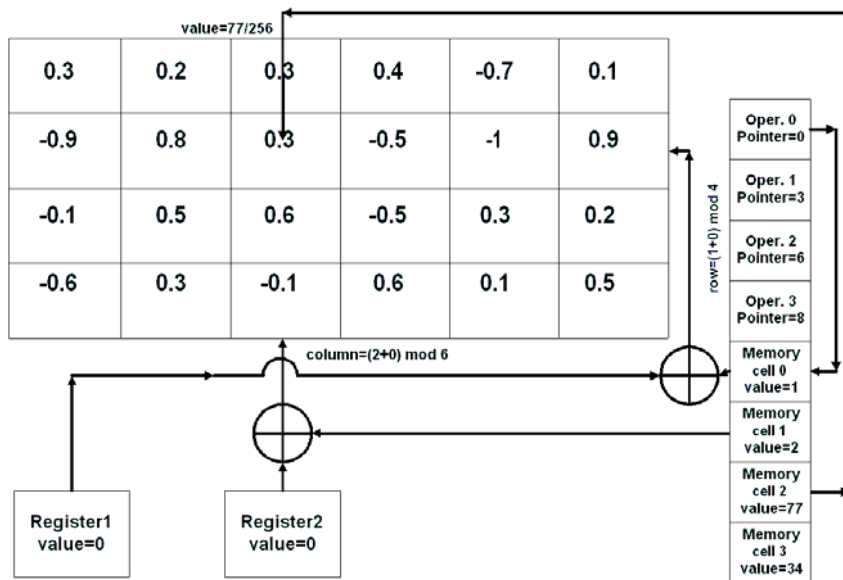


Fig. 7. Diagram of AE

Once the last operation ends the process of creating NDM is completed. NDM is then transformed into ANN. AEPs can use various operations. The main task of most of operations is to modify NDM. The modification can involve a single element of NDM or group of elements. Fig. 8 presents the example operation used in AE.

```

CHG(p0, p1, p2, *)
{
row=(abs(p1)+R1) mod NDM.width;
column=(abs(p2)+R2) mod NDM.height;
NDM[row,column]=p0/Max_value;
}
    
```

Fig. 8. CHG operation changing single element of NDM

The task of CHG is to change a single element of NDM. The new value of the element, stored in parameter  $p_0$ , is scaled to  $\langle -1, 1 \rangle$ . An address of the element being changed depends on both parameters  $p_1, p_2$  and registers  $R_1, R_2$ .

Once AEP finishes its work the process of transforming NDM into ANN is started. To make it possible to construct ANN based on NDM the latter has to include all the information necessary to create ANN. When we wish to create the same skeleton of ANN, i.e. ANN without determined weights of interneuron connections, NDM can take the form of the classical connectivity matrix (CM) [3], i.e. a square, binary matrix of a number of rows and columns equal a number of neurons. The value '1' in  $i^{\text{th}}$  column and  $j^{\text{th}}$  row of such a matrix means a connection between  $i^{\text{th}}$  neuron and  $j^{\text{th}}$  neuron. In turn, the value '0' means lack of the connection between these neurons. When the purpose is to create complete ANN with determined values of weights, types of neurons, parameters of neurons then NDM should take the form of a real valued variety of CM with extra columns or rows containing definitions of individual neurons. The example of such a matrix is presented in fig. 9.

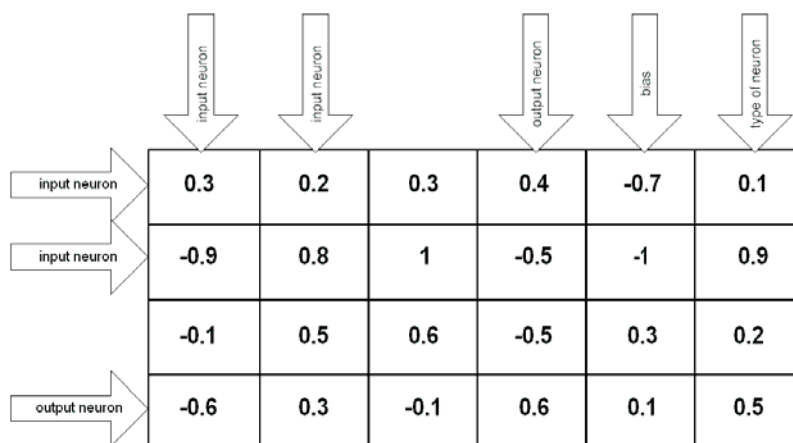


Fig. 9. NDM as Connectivity Matrix

In AE evolution of AEPs proceeds according to a scheme proposed by Potter and De Jong [7, 8, 9]. The scheme assumes a division of evolutionarily created solution into parts. Each part evolves in a separate population. The complete solution is formed from selected representatives of each population (fig. 10).

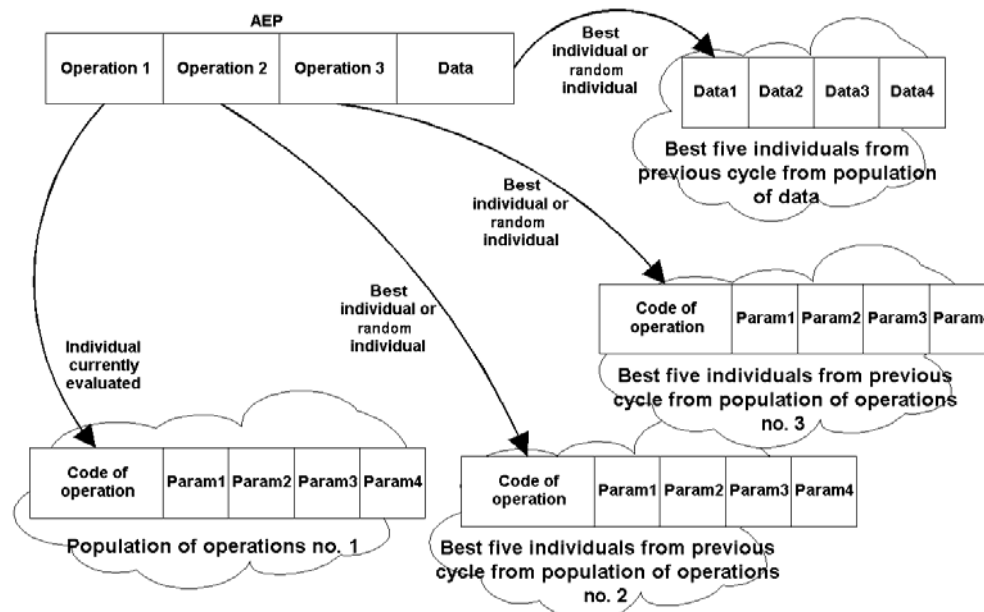


Fig. 10. Evolution of AEPs

## CONCLUSIONS

The paper presents the concept of the system to control a team of AUVs. In fact, the whole system consists of two basic elements. The first of them is the decision (sub)system. A team of AUVs with their steering (sub)systems is the second out of the elements mentioned. The task the decision system is to made high-level decisions as to behaviour of the whole team of AUVs. The decision system decides about movements of each AUV included in the team. To transform high-level decisions into concrete activities of propellers, AUVs use their steering systems.

To test the concept presented above experiments will be performed. In the experiments mathematical models of AUVs described in the paper will be used. A predator-prey problem will be a test-bad for the concept. During the experiments, the task of a team of AUVs-predators will be to capture a single escaping AUV-prey. Because of greater speed of AUV-prey, AUVs-predators will have to cooperate to perform the task.



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## **STRESZCZENIE**

W ciągu ostatnich lat obserwuje się wzrost zainteresowania autonomicznymi pojazdami podwodnymi (AUV). Mogą być one stosowane w różnego rodzaju zadaniach, w tym do inspekcji obiektów podwodnych. Wiele aplikacji wymaga współpracy pomiędzy pojazdami AUV. W związku z tym pojawia się problem sterowania grupą robotów, które realizują wspólne zadanie. Jednym z rozwiązań może być zastosowanie wieloagentowego systemu kontroli, w którym poszczególne pojazdy AUV wyposażone są w „inteligentne oprogramowanie” realizujące przydzielone zadania. W artykule przedstawiono koncepcję wieloagentowego systemu kontroli pojazdów podwodnych.

Recenzent kmdr dr hab. inż. Jerzy Balicki, prof. AMW