Modeling of underwater vehicle's dynamics

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Abstract: - The paper presents algorithm of underwater vehicle's dynamics modeling using technique of artificial neural networks. Paper includes mathematical description of used dynamical neurons and basis of its learning process. Next the results of research for real underwater vehicle were presented.

Key-Words: - artificial neural networks, dynamics modeling, underwater vehicles

1 Introduction

Modeling in control theory means the process in which results, basing on input and output signals, arise the mathematical model of object admitted as the best according to the accepted criterions. By the object's model it is understood the presentation of interested, essential properties in convenient form. Therefore procedure of modeling can be, in the simplest way, presented as it is done on figure 1 [2].

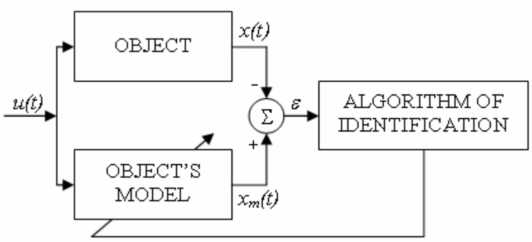

Fig. 1. Schematic presentation of modeling process

Models appear in many fields of human knowledge. In all cases possession of models allow for preliminary testing of creating systems what permits to shorten the time necessary for projection phase and inculcate of system. It also prevents from accidental damage of real object.

Often modeling starts from apply some physical laws which take part in investigated process. But it is only possible when those phenomenon are quite simple. If the numerical values of all external and internal conditions of modeled object are known and physical knowledge about this object is full it is possible to calculate values of all parameters. However those cases are rare because of knowledge shortage about internal process and indefinableness carried in by environment. In other hand very often they are only interesting dependencies between object's input and output signals accepted that inputs signals are control signals and measured output signals give information about object state. In this case object can be treated as single or multi input and single or multi output object with unknown structure. In this case more often the methods which can adjust the established structure basis on the experimental data like artificial neural networks are used. This technique, with regard on its unquestionable advantages, is used as effective methods in modeling of object's dynamics. To the most important feature of neural networks can be included:

- the possibility of approximation of any non-linear representations;
- the parallel processing of information;
- the possibility of learning and adaptation;
- signal processing from many inputs and generating of many outputs (multidimensional systems).

Therefore the paper presents technique of neural networks used to dynamics identification of underwater vehicle.

2 Neural algorithm of dynamics identification

2.1 Dynamical neural network

Because the processes, taking place during movement of underwater vehicle, have dynamic character, neuronal modeling in such cases requires special solutions. One of the possibilities is to use the recurrent neural networks as Hopfield's networks or the simplest backpropagation neural networks with recurrent connections. In the last case the effects of dynamics behavior is obtain by widening input vector with the information of model's output in previous moments.

In last investigations in aim of obtainment of dynamic character of neural network the dynamics becomes introduced to the neuron in such way that neuron activation depends on its internal states [1]. It is done by

introducing a linear dynamic system to the neuron structure.
In this way each neuron in dynamic network reproduces the past signal value with two signals: the input signal and output signal. Figure 2 represents the structure of such neuron with one output and many inputs.

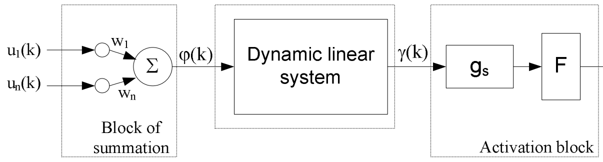

Fig. 2. The model of dynamic neuron

Three main operations are performed in this dynamics structure. First of all, in block of summation, the weighted sum of inputs is calculated according to the formula:

$$\varphi(k) = \sum_{i=1}^{N} w_i x_i \tag{1}$$

where: w – input weights vector; x – input vector.
Calculated weighted sum is processed in filter block which can be the linear dynamic system of any order. This system consists of delay elements and feedback and feed-forward paths weighted by the vector weights $a = [a_1, a_2, \ldots, a_n]^T$ and $b = [b_0, b_1, \ldots, b_n]^T$, respectively as it is shown at figure 3. This structure can be described by the following difference equation:

$$\begin{aligned}\gamma(k) &= -a_1\gamma(k-1) - \ldots - a_n\gamma(k-n) + \\ &+ b_0\varphi(k) + b_1\varphi(k-1) + \ldots + b_n\varphi(k-n)\end{aligned} \tag{2}$$

where: φ – input of filter block; γ – output of filter block; a, b – the vector weights of feedback and feed-forward paths.

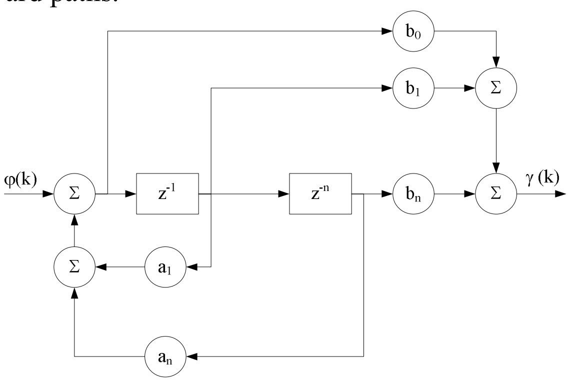

Fig. 3. Dynamic linear system

Finally, the neuron output which is output signal of activation block can be described as:

$$y(k) = F[g_s\gamma(k)] \tag{3}$$

where: F – non-linear activation function; g_s – slope parameter of the activation function.

2.2 Learning process

The main objective of learning algorithm is to adjust all unknown parameters of dynamic neuron such as input weights w, value of filter parameters a and b, and slope parameter of activation function g_s, based on the given data set of input-output pairs [3, 4, 6]. In fact, the training process involves the determination of unknown network parameters that minimize a performance index J based on an error function defined as:

$$J = \frac{1}{2} E\{e(k)^2\} \tag{4}$$

where: E denotes the mean value operator $e(k) = d(k) - y(k)$; $d(k)$ - desired response of neural network, $y(k)$ - actual response of neural network.
To solve the minimization problem (4) and find optimal network parameters the conjugate gradient algorithm may be applied. Assumption that correction of network parameter is done after each learning pattern according to the formula:

$$v(l+1) = v(l) - \eta\nabla_v J\big|_{v=v(l)} + \mu\nabla_v J\big|_{v=v(l-1)} \tag{5}$$

where: $v(w,a,b,g_s)$ - the generalized network parameters, η - learning rate, μ - coefficient of conjugate, l - iteration index.
Taking into account the performance index (4) the gradient is given by:

$$\frac{\partial J}{\partial v} = E\{-e(k)F'(g_s\gamma(k))S_v(k)\} \tag{6}$$

where: $S_v(k)$ - sensitive vector of $g_s\gamma(k)$ to the change o parameter v, $F'(g_s\gamma(k))$ - derivative of the activation function with respect to v.
According to the above formulae can be defined the individual elements of the sensitive vector $S_v(k)$ for the elements of unknown generalized parameter $v(w,a,b,g_s)$

$$S_{w_i}(k) = g_s \frac{\partial \gamma(k)}{\partial w_i} =$$
$$= g_s \left(\sum_{q=0}^{n} b_q x_i (k-q) - \sum_{p=1}^{n} a_p S_{w_i}(k-p) \right)$$
$$S_{a_p}(k) = g_s \frac{\partial \gamma(k)}{\partial a_p} = -g_s \gamma(k-p)$$
$$for \quad p = 1, \ldots, n \tag{7}$$
$$S_{b_q}(k) = g_s \frac{\partial \gamma(k)}{\partial b_q} = -g_s \varphi(k-q)$$
$$for \quad q = 0, 1, \ldots, n$$
$$S_{g_s}(k) = \frac{\partial \gamma(k) g_s}{\partial g_s} = \gamma(k)$$

2.3 Algorithm of identification

Algorithm of underwater vehicle dynamic's identification using neural technique presented above and used in research can be presented as it was done on figure 4 [7, 8].

At first phase of neural algorithm the network is initialized so the following steps are executed:

- generating the neurons with structure described by (3)
- setup the beginning values of network parameters like: input weights, coefficient of weights of filter block paths, slope parameter;
- zero out the other parameters;
- setup the connections between neurons.

The activation function accepted in research is tangensoidal function described by equitation:

$$y(k) = \frac{1}{1+e^{-x(k)}} \tag{8}$$

The number of neurons in input layer of neural networks is determined by control vector size, and number of neurons in output layer of network in equal to size of observed state vector. The hidden layer configuration was specified using Vapnik-Chervonenkis dimension [6]. The connections between neurons were made each other to each other between neighboring layers without recurrent connections and connections which skip any layer because of presented neural networks feature.

The second phase of identification algorithm is taking the control vector, its normalization, and next calculation the response of neural network. Next average square error is calculated based on network response and measured state vector of vehicle. This parameter means about adjustment of neural model to the real object. If network is in research phase of identification the parameters are changed according to backpropagation method [6] basing on value of average square error and method of conjugate gradient presented above.

If the algorithm is not finished by user or after succeed the accepted level of average square error the process begun from taking next control vector.

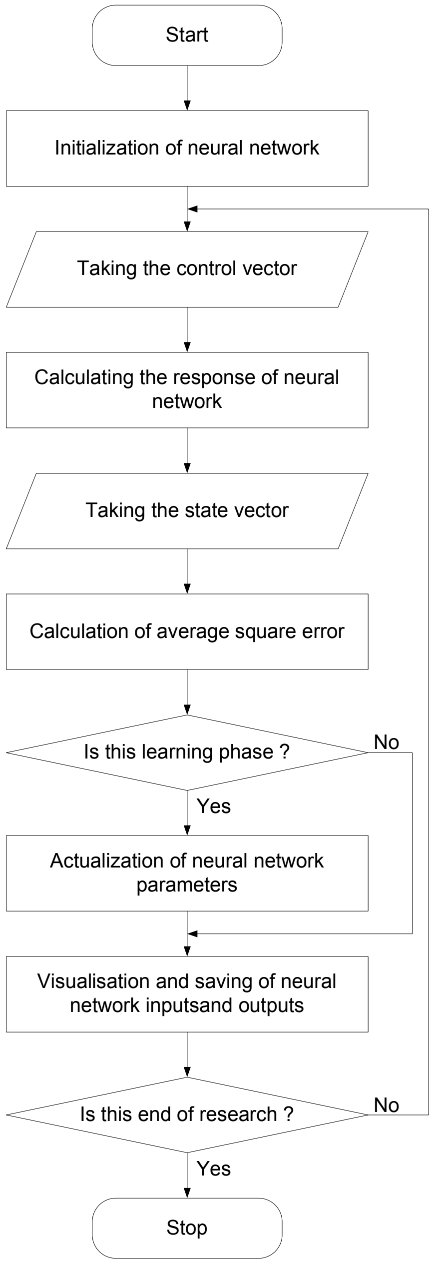

Fig. 4. Algorithm of neural modeling of underwater vehicle

3 Results of research

Remotely operated, underwater vehicle "UKWIAL" which was designed in Poland by team from University of Gdansk was the object of research. Basic technical parameters of this vehicle are:

- working depth: 200 m;
- vehicle's mass: 175 kg;

- equipment:
  - two TV cameras;
  - sweeping sonar;
  - sonic finder;
  - magnetic and electronic compass;
  - electrolytic inclination gauge;
- quantity of thruster: 6, 4 in horizontal and 2 in perpendicular plane;
- force of individual thrusters: 220 N;
- maximum forward speed: 1,5 m / s.

The appearance of object of research is presented on figure 5.

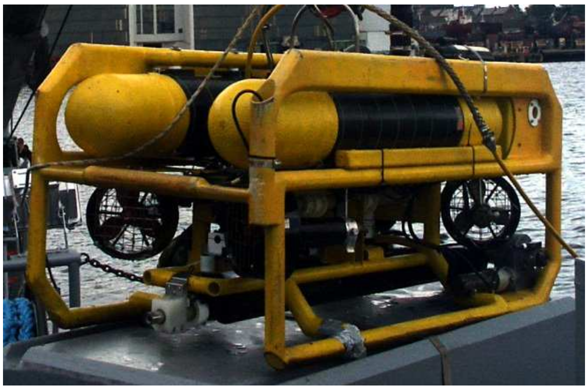

Fig. 5. Object of research - remotely operated, underwater vehicle "Ukwial"

The research process was dividend into two phases. In first phase, called identification, the parameters of created model were changed due to presented above algorithm. In second phase, called simulation, the parameters of model were not changed and only the error of response of object and created neural model was supervised.

The control vector during researches has form:

$$u = u[\tau_X, \tau_Z, \tau_N] \quad (9)$$

where: τ_X - force along longitudinal axis of vehicle; τ_Z - force along transverse axis of vehicle; τ_N - rotatory moment around normal axis of vehicle.

The values for all components of control vector were setup by inclination of two joystick. The state vector which can be observed during researches has form:

$$x = x[d, \psi] \quad (10)$$

where: d - depth of immersion with precision to 0.1 [m]; ψ - bearing angle of vehicle with precision to 0.5°.

The results of researches were presented on figures below. The light line shows values of component of real object control vector or state vector, the dark line shows values calculated by neural model.

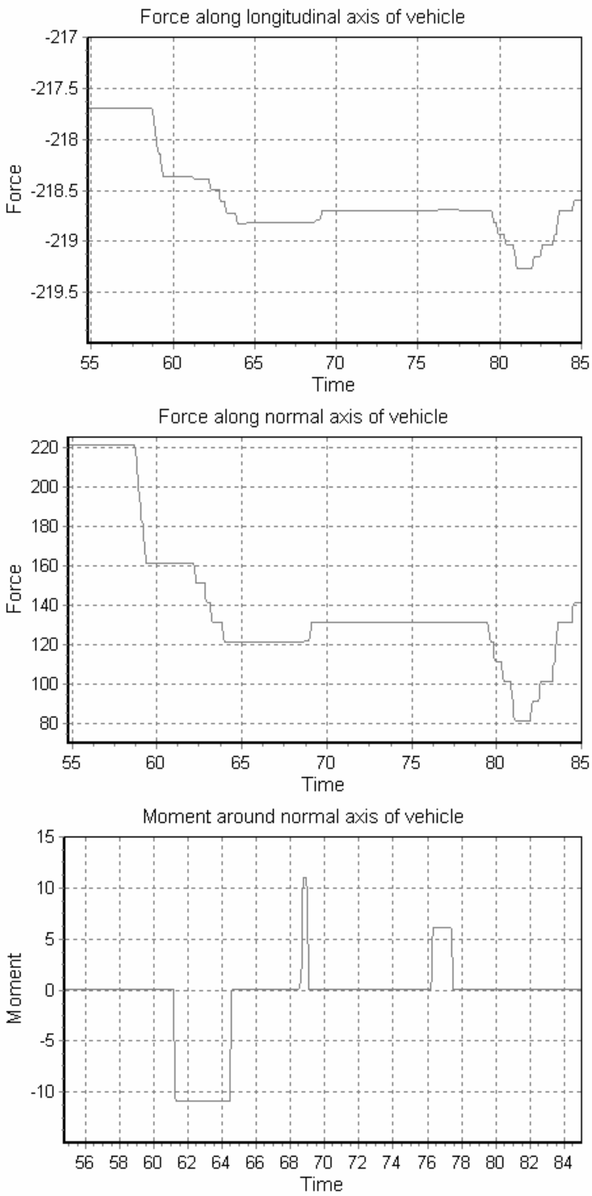

Fig. 6. The values of components of control vector in identification phase

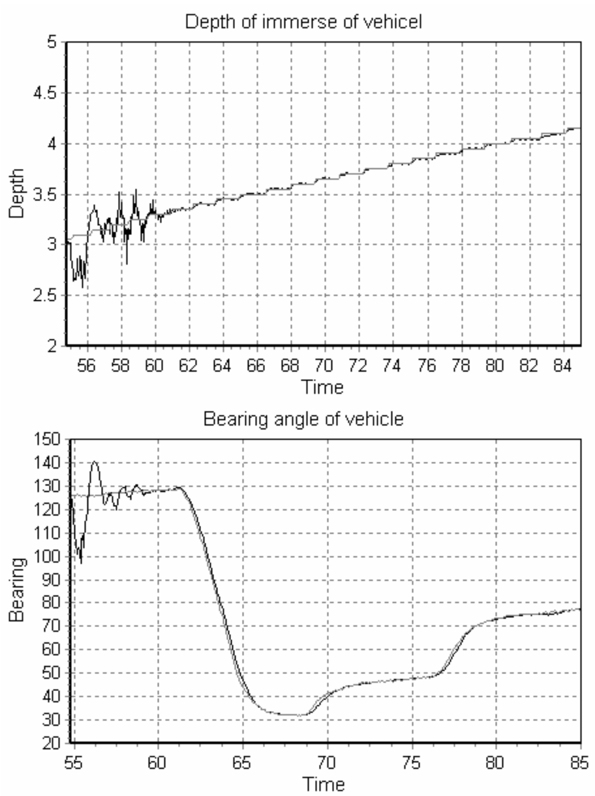

Fig. 7. The values of components of state vector in identification phase

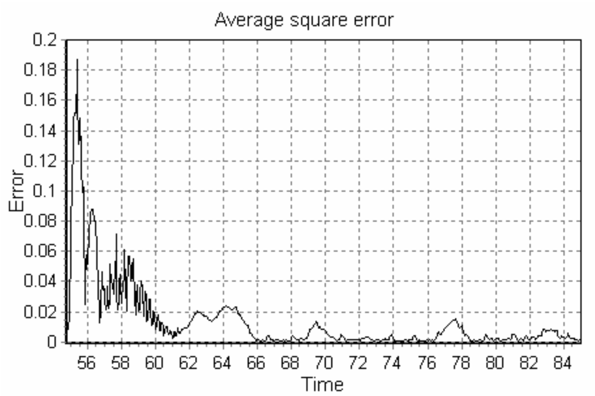

Fig. 8. The sum square error of response of object and neural model in identification phase

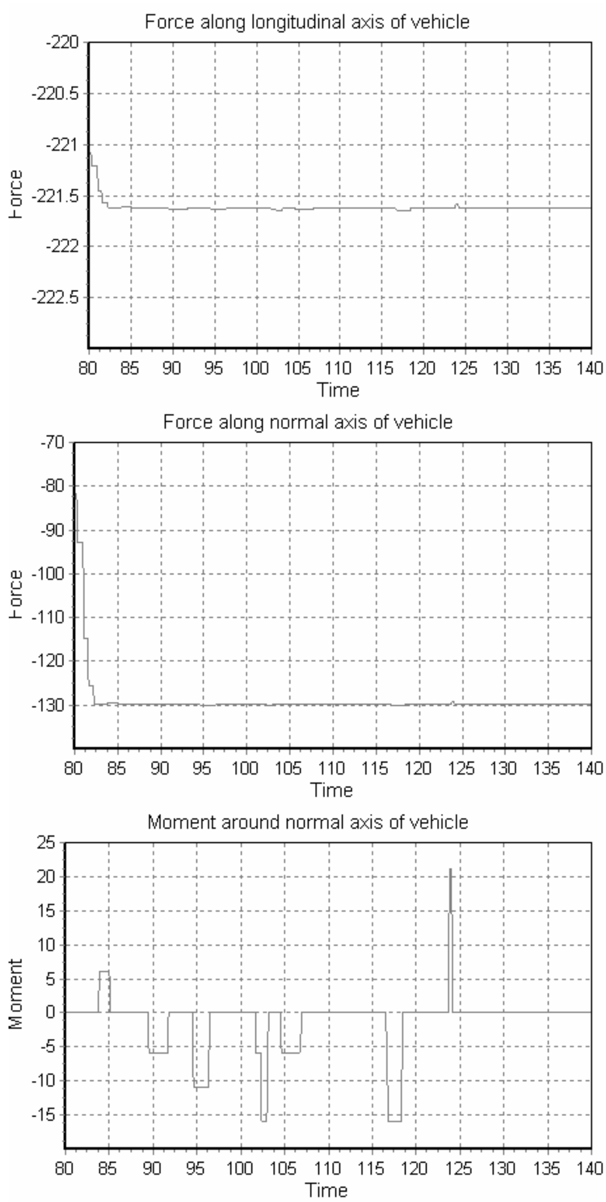

Fig. 9. The values of components of control vector in simulation phase

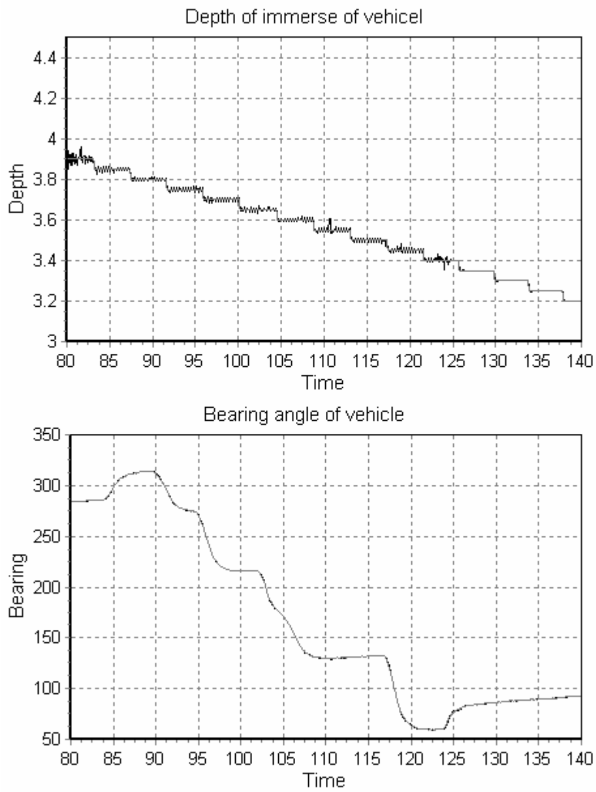

Fig. 10. The values of components of state vector in simulation phase

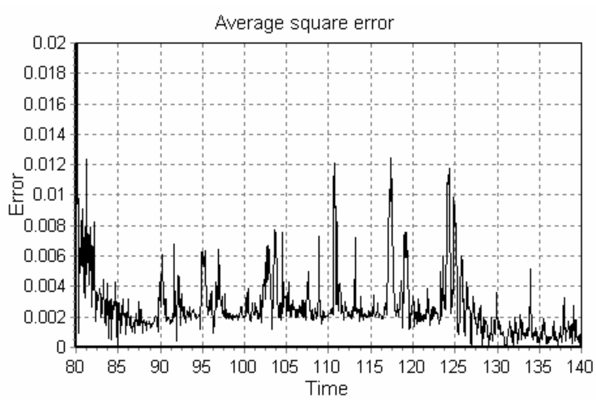

Fig. 11. The sum square error of response of object and neural model in simulation phase

4 Conclusion

As it is shown at results of researches the presented neural networks technique is useful for modeling the dynamics of underwater vehicle.

Mean value of average square error in phase of identification during research was about 0.03 and in simulation phase it takes about 0.004. It means that accepted methods of learning and the configuration of neural networks used as vehicle's dynamic neural model was properly chosen. Moreover the small different between response of object and neural model means about its very good precision necessary during another feature research.

The feature research will concentrated on using the self-organization method for neural network used for modeling dynamics of underwater vehicle. More over the other methods of learning neural network should be checked at purpose to speed up the learning process. Another point is to use this algorithm for another, multidimensional objects.

Created neural model can be used as platform for simulation during projection phase of building control systems and also as basis of simulator for training of pilotage of underwater vehicle.

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