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Depth Controls of an Autonomous Underwater Vehicle by Neurocontrollers for Enhanced Situational Awareness

Igor Astrov and Andrus Pedai

Abstract**—**This paper focuses on a critical component of the situational awareness (SA), the neural control of autonomous constant depth flight of an autonomous underwater vehicle (AUV). Autonomous constant depth flight is a challenging but important task for AUVs to achieve high level of autonomy under adverse conditions. The fundamental requirement for constant depth flight is the knowledge of the depth, and a properly designed controller to govern the process. The AUV, named VORAM, is used as a model for the verification of the proposed hybrid control algorithm. Three neural network controllers, named NARMA-L2 controllers, are designed for fast and stable diving maneuvers of chosen AUV model. This hybrid control strategy for chosen AUV model has been verified by simulation of diving maneuvers using software package Simulink and demonstrated good performance for fast SA in real-time search-and-rescue operations.

Keywords**—**Autonomous underwater vehicles, depth control, neurocontrollers, situational awareness.

I. INTRODUCTION

SITUATION awareness has been formally defined as “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [1]. As the term implies, situation awareness refers to awareness of the situation. Grammatically, situational awareness (SA) refers to awareness that only happens sometimes in certain situations.

SA has been recognized as a critical, yet often elusive, foundation for successful decision-making across a broad range of complex and dynamic systems, including emergency response and military command and control operations [2].

The term SA have become commonplace for the doctrine and tactics, and techniques in the U.S. Army [3]. SA is defined as “the ability to maintain a constant, clear mental picture of relevant information and the tactical situation including friendly and threat situations as well as terrain”. SA allows leaders to avoid surprise, make rapid decisions, and choose when and where to conduct engagements, and achieve decisive outcomes.

In [4] a two stage flight control procedure using two adaptive neural networks to address the dynamics variation and performance requirement difference in initial and final stages of flight trajectory for small-scale unmanned helicopter model was proposed. The chosen helicopter model in terms of a state variable representation comprising five states, two inputs and two outputs. The proposed control strategy for chosen helicopter model has been verified by simulation of descending and landing maneuvers using software package Simulink and demonstrated good performance for fast SA in real-time search-and-rescue operations.

This paper concentrates on issues related to the area of [4], but demonstrates another field for application of these ideas, i.e., research technique using hybrid control system modeling and simulation on the basis of state-space equations of vertical motion of chosen model of an autonomous underwater vehicle (AUV) for fast SA.

The characteristics of an AUV’s motion depend on mode of maneuvering, forward speed, instantaneous attitude, and outside appendages such as measuring instruments. In addition, it is hard to model the system disturbances, cross-flow effects, and the coupling effects. Due to these reasons, a neural network controller is needed to control AUV’s motion.

The AUV is the underwater maneuver commander's primary day and night system. The AUV provides the commander with a number of capabilities including:

- Enhanced SA.
- Target acquisition.
- Enhanced management capabilities (assessment of surface damage and visualization of blockage far and near).

The combination of these benefits contributes to the commander's dominant SA allowing him to shape the field of vision to ensure mission success and to maneuver to points of positional advantage to conduct decisive operations. Some conditions for conducting underwater reconnaissance with AUVs are as follows.

- Time is limited or information is required quickly.
- Detailed reconnaissance is not required.
- Extended duration surveillance is not required.
- Target is at extended range.

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I. Astrov is with the Department of Computer Control, Tallinn University of Technology, Tallinn 19086, Estonia (corresponding author to provide phone: 372-620-2113, fax: 372-620-2101; e-mail: igor.astrov@dcc.ttu.ee).

A. Pedai is with the Department of Computer Control, Tallinn University of Technology, Tallinn 19086, Estonia (e-mail: andrus.pedai@dcc.ttu.ee).

- Verification of a target is needed.
- Threat conditions are known; also the risk of collisions with an obstacle of rough-surfaced sea bottom is high.
- Sea bottom relief restricts approach by large-scale underwater vehicles.

A small size AUV offers many advantages, including low cost, the ability to fly at constant depth levels within a narrow space and the unique diving characteristics.

Autonomous constant depth flight is an important task for AUVs to avoid human intervention under adverse conditions. The fundamental requirement for diving control flight is the knowledge of the depth under the sea surface, and a properly designed controller to govern the process.

In this paper our research results in the study of depth flight controls of AUV which make such SA task scenario as “go-search-find-return” possible are presented.

The contribution of the paper is twofold: to develop new schemes appropriate for SA enhancement by hybrid neural control of vertical trajectory of AUVs in real-time search-and-rescue operations, and to present the results of diving maneuvers for chosen model of the AUV for fast SA in simulation form using the MATLAB/Simulink environment.

II. AUTONOMOUS UNDERWATER VEHICLE MODEL

The AUV, named VORAM [5], is 2.82 m in length, 1.10 m in width, and 0.40 m in height. It weighs 357 kg in air and has neutral buoyancy in water, and the flooded mass of VORAM in water is about 887 kg. The maximum speed in calm water is 1.25 m/s.

Numerical simulations and experiments on depth control of the VORAM AUV are carried out using the quasi-sliding mode controller [5]. This controller is composed of a linear feedback input and switching inputs where the switching inputs are determined separately. Experiments are performed in a towing tank. In general, the experimental results agree with the simulation results.

The mission of VORAM AUV in a given context is research and monitoring in deep sea and is aimed to follow the sea bottom by keeping constant altitude or constant water depth and may be called appropriate for SA enhancement using AUVs. It is supposed that this vehicle is operating around a desired forward speed.

The dynamic model for control in the vertical plane yields the general form of state equations for VORAM AUV [5]

$$\dot{x}(\tau) = Ax(\tau) + Bu(\tau) + d(\tau) + v(\tau) \tag{1}$$

$$y(\tau) = Cx(\tau) + w(\tau) \tag{2}$$

where $x(\tau), u(\tau), y(\tau), d(\tau), v(\tau), w(\tau)$ are the state, control input, output, disturbance, process noise and measurement noise vectors, respectively.

The variables of this model are:

x_1 = pitch rate (radn/sec),
x_2 = pitch angle (radn),
x_3 = depth (m),
u=elevator angle (radn),
y = vertical position (m).

Note that vertical position represents the depth of vehicle with the negative sign.

The matrix structure of A, B, C, d for the state-space model of system (1)-(2) is given by

$$A = \begin{bmatrix} -1.8377 & -1.2007 & 0 \\ 1 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix},$$

$$B = \begin{bmatrix} -1.3212 \\ 0 \\ 0 \end{bmatrix},$$

$$C = \begin{bmatrix} 0 & 0 & -1 \end{bmatrix},$$

$$d = \begin{bmatrix} 0.1 \\ 0.1 \\ 0 \end{bmatrix}.$$

III. SIMULATION

Since the depth of AUV is most critical for diving maneuvers, the control mechanization of the vertical trajectory profile will be demonstrated.

To illustrate the performance of the neural control design procedure for the model given by (1)-(2), the simulation example with using of three neurocontrollers to control the desired diving trajectory of given AUV was presented.

The goal of the following simulations is twofold. First, we verify that these neural network controllers are able to control the diving trajectory. Second, we observed the effect of enhancing SA because by variety of such trajectory parameters as maximal depth and constant depth flight easily can be changed the possible diving trajectory of AUV.

Initial and desired constant depths for control subsystems are chosen to be:

$z(0) = 0$ m, $z_1^0 =$ -12 m, $z_2^0 =$ -50 m, $z_3^0 =$ -26 m.

Simulation results for the offered block scheme (see Fig. 1) are shown in Figs. 5-8.

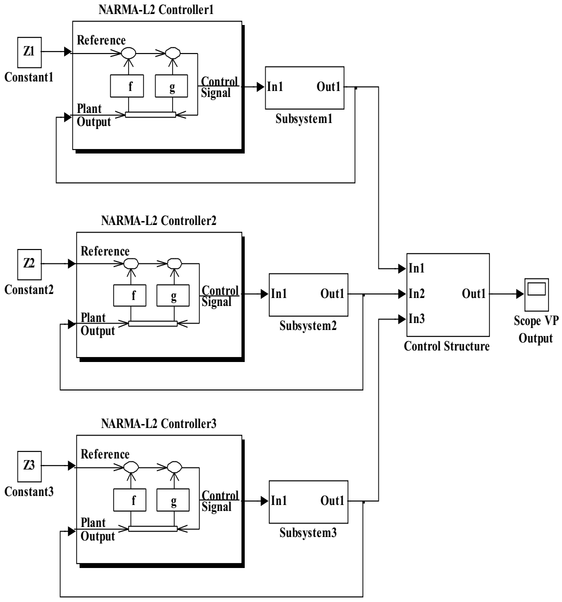

Fig. 1. Block diagram of hybrid control system.

A structure of the VORAM AUV model (1)-(2) is illustrated in Fig. 2.

In [6] the two approximations to the nonlinear autoregressive moving average (NARMA) model called the NARMA-L1 and the NARMA-L2 are proposed. From a practical stand-point, the NARMA-L2 model is found to be simpler to realize than the NARMA-L1 model.

The controllers used in this section are based only on the NARMA-L2 approximate model [6].

Block diagram of the NARMA-L2 Controller 1 from Fig. 1 is given in Fig. 3. This controller can be implemented with the previously identified NARMA-L2 plant model, as shown in Fig. 4.

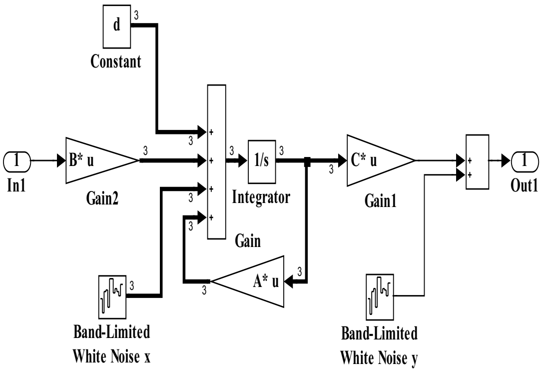

Fig. 2. The internal structure of the Subsystem 1.

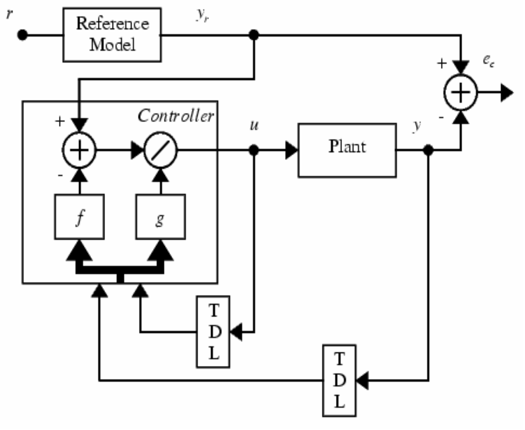

Fig. 3. The block diagram of the NARMA-L2 Controller.

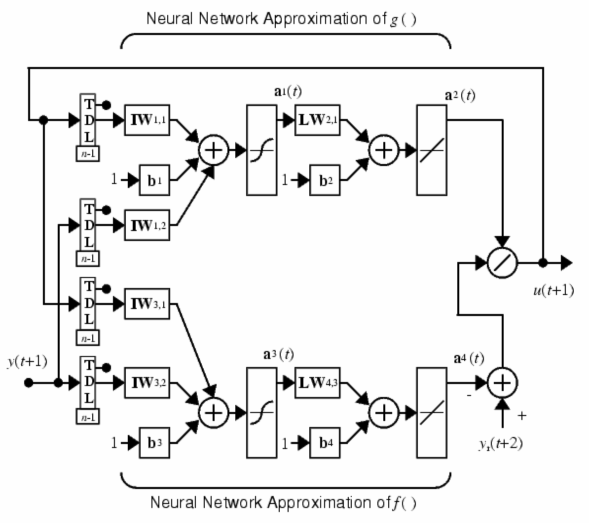

Fig. 4. Structure of a neural network representation for the NARMA-L2 approximate model.

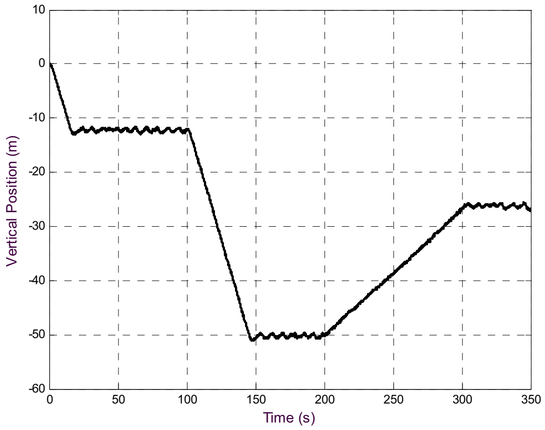

Fig. 5. Depth trajectory of diving control.

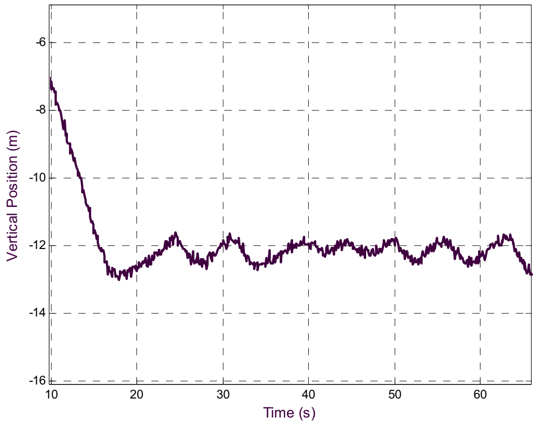

Fig. 6. Depth trajectory near the first lag.

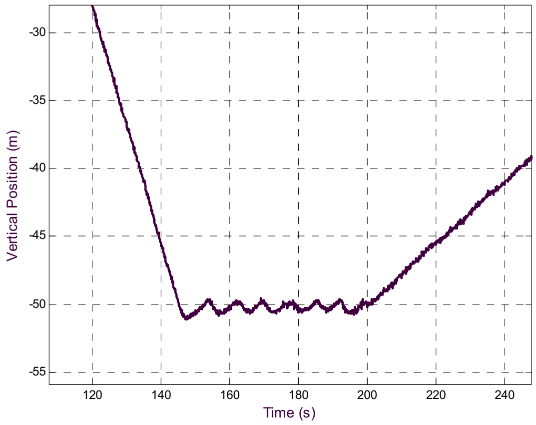

Fig. 7. Depth trajectory near the second lag.

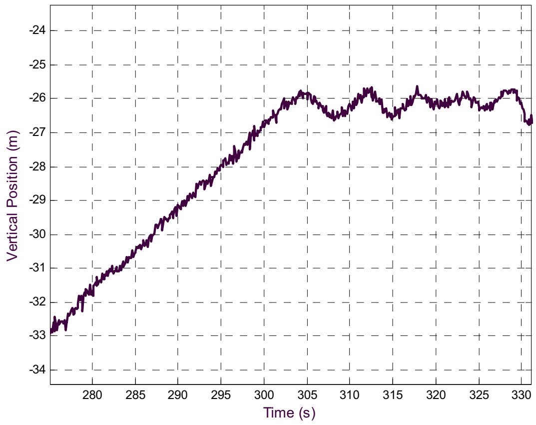

Fig. 8. Depth trajectory near the third lag.

Some advantages of this example are as follows.

- Opportunity of smooth switching of regulation from one neurocontroller to another.
- Possibility to consider a rough-surfaced sea bottom in a place of a constant depth flight.
- Possibility of lag in the various constant depth levels.
- Fine and simplified adjustment of these neurocontrollers for any changes of desired constant depths.

These results support the theoretical predictions well and demonstrate that this research technique would work in real-time diving conditions.

IV. CONCLUSIONS

The need for accurate and directionally stable diving for AUV class autonomous vehicles has increased morbidly for critical situations in real-time search-and-rescue operations for fast SA.

Three NARMA-L2 neural controllers are designed for fast and stable diving maneuvers of the VORAM AUV model. The effectiveness of the proposed depth neural control technique has been verified in field of diving simulation tests for chosen model of the AUV using software package Simulink.

From the simulation studies of diving tests, the following can be observed:

- The block diagram of depth neural control is very useful for graphic representation of the depth trajectory.
- The depth trajectory tracking display forms give a researcher an immediate view of a VORAM AUV motion with a range of such depth trajectory parameters as maximal depth and constant depth flight. This enhancing the researcher's understanding of diving maneuvers.
- The control using three neurocontrollers works more qualitatively than the control using only one neurocontroller.

From the applications viewpoint, we believe that this flexible and effective neural control furnish a powerful approach for enhancing SA in applications to AUV class autonomous vehicles in real-time search-and-rescue operations.

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