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Unsupervised Real-time Obstacle Avoidance Technique based on a Hybrid Fuzzy Method for AUVs

Arif Reza Anwary, Young-il Lee, Hee Jung and Yong-Gi Kim*

Department of Computer Science, Research Institute of Computer and Information Communication,
Gyeongsang National University.
Jinju, Kyungnam 660-701,Republic of Korea

Abstract

The article presents ARTMAP and Fuzzy BK-Product approach underwater obstacle avoidance for the Autonomous underwater Vehicles (AUV). The AUV moves an unstructured area of underwater and could be met with obstacles in its way. The AUVs are equipped with complex sensorial systems like camera, aquatic sonar system, and transducers. A Neural integrated Fuzzy BK-Product controller, which integrates Fuzzy logic representation of the human thinking procedure with the learning capabilities of neural-networks (ARTMAP), is developed for obstacle avoidance in the case of unstructured areas. In this paper, ARTMAP-Fuzzy BK-Product controller architecture comprises of two distinct elements, are 1) Fuzzy Logic Membership Function and 2) Feed-Forward ART component. Feed-Forward ART component is used to understanding the unstructured underwater environment and Fuzzy BK-Product interpolates the Fuzzy rule set and after the defuzzyfication, the output is used to take the decision for safety direction to go for avoiding the obstacle collision with the AUV. An on-line reinforcement learning method is introduced which adapts the performance of the fuzzy units continuously to any changes in the environment and make decision for the optimal path from source to destination.

Key Words : Fuzzy relation; BK-products; Obstacle avoidance; Autonomous underwater vehicles (AUVs); ARTMAP.

Introduction

This article introduces intelligent obstacle avoidance technique for Autonomous Underwater Vehicle (AUV) using the ARTMAP with Fuzzy Logic BK-Product.

Adaptive Learning Theory (ART) neural networks model fast, on-line, and stable categorical learning and recognition system. The default ARTMAP algorithm (Carpenter 2003) is a supervised learning version of ART for representing discrete categories using real-valued features. During learning, the default ARTMAP algorithm uses a winner-take-all (WTA) category activation scheme, where only the maximally active category representation is updated in response to the input feature vector. During classification, instead of saturating the winner category node and quenching the rest, a weighted sum of category activations is taken to decide the category label. In this case, a subsequent presentation of the same sample guarantees a correct classification. Autonomous Underwater Vehicles (AUVs) are an exciting topic for two reasons. First, there are many interesting real-world applications for such systems. Effective autonomous underwater vehicles would allow or facilitate exploration, salvage, search and rescue, and scientific studies in deep ocean areas. Second, the highly dynamic and noisy nature of the underwater environment makes the problem a difficult one. The intelligent system can be understood as a higher-level control system of the vehicle.

1. ARTMAP:

ARTMAP is an example of a constructive neural network model in that it allows nodes to be added as necessary during training. The growth potential of Fuzzy ARTMAP is similar to that of other constructive learning algorithms such as decision tree learners; they are all allowed to grow as necessary to suite a particular set of training data (Kearns and Mansour, 1995).

During supervised learning, ARTa receives a stream of patterns ạṇ . and ARTb receives a stream of patterns ḅṇ , where ḅṇ is the correct prediction given ạṇ. An associative learning network and a vigilance controller link these modules to make the ARTMAP system operate in real time, creating the minimal number of ARTa recognition categories, or hidden units, needed to meet accuracy criteria. A minimax learning rule enables ARTMAP to learn quickly, efficiently, and accurately as it conjointly minimizes predictive error and maximizes code compression in an on-line setting. A baseline vigilance parameter $\overline{\rho_a}$ sets the minimum-matching criterion, with

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*Corresponding author.Tel.:+82 55 751 5997.
E-mail address:ygkim@gsnu.ac.kr (Y.-G.Kim).
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smaller $\overline{\rho_a}$ allowing broader categories to form. At the start of a training trial, $\rho_a = \overline{\rho_a}$. A predictive failure at ARTb increases ρ_a just enough to trigger a search, through a feedback control mechanism called match tracking. A newly active code focuses attention on a different cluster of input features, and checks whether these features are better able to predict the correct outcome. Match tracking allows ARTMAP to learn a prediction for a rare event embedded in a cloud of similar frequent events that make a different prediction. [1,3].

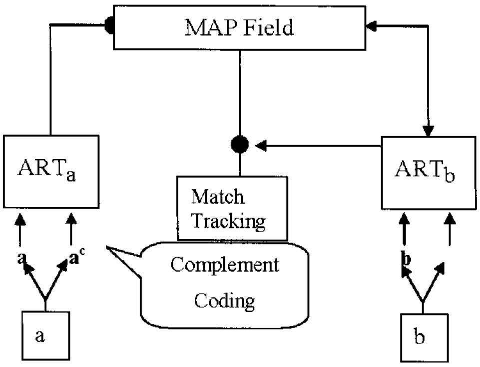


Figure 1.The general ARTMAP network for supervised learning includes two ART modules. For classification tasks, the ARTb module may be simplified.

2. Fuzzy Relational Method of Bandler and Kohout:

Bandler and Kohout were the first to introduce the application of fuzzy relational methods to knowledge representation and this method became known as BK-products nowadays. They introduced special relational compositions called the Triangle and Square products. BK-products have been applied, as a powerful computational tool, in many fields such as computer protection, AI, medicine, information retrieval, handwriting classification, urban studies, investment, control [2,4,5].

BK-relational product can be used to compare and further analyze relational structures [4]. Let R be a relation from X to Y where X is the set of objects and Y is the set of properties. Then Rxy is the degree to which a respondent assigns object x to property y. On the other hand, RT is a relation from Y to X where RT= Ryx is the degree to which a respondent assigns to property y to object x. By composing the relation R with its transposed relation RT, the fuzzy relational subtriangle product R◁RT yields an object-object relation over properties by applying a fuzzy implication operator. The product (R◁RT)ij gives the degree to which object xi implies object xj based on how a respondent applied both objects to the properties[5].

For fuzzy implication, a wide variety of fuzzy implication operators have been proposed, and their properties have been analyzed in detail [2]. For this study, we make use only of operator 5 and Mean criteria. The definition of the subtriangle product is shown in (1) which is used for calculation in this study.

$$x_i(R \triangleleft S)z_j = \frac{1}{n}\sum_{y\in Y}\min(1,\ 1-x_iR(y)+Sz_j(y)) \qquad (1)$$

In addition, alpha cut (α-cut) and Hasse diagram are two important features in this method. The α-cut transforms a fuzzy relation into a crisp relation, which is represented as a matrix. The Hasse diagram is a useful tool, which completely describes the partial order among the elements of the crisp relational matrix by a Hasse diagram structure [8].

3. Applying ARTMAP and BK-Subtriangle products to intelligent Obstacle Avoidance of AUVs:

Three parameters determine the dynamics of an ART network, a choice parameter > 0; a learning rate parameter [0, 1] and a vigilance parameter [0, 1].

The input data will be taken from the camera as a picture format. Computer will analyze that pictures dynamically. This picture is 256x256 pixels and this is divided in to sub division on 32x32 segments. Each segment will be connected as input neuron and ARTa and ARTb will take those data basis on the intensity level of the image (black and white). And it will learn the surrounding environment through Map-field and it will find out the obstacle position of the image. After learning it will find out the possible ways to go that supports the safety paths for Autonomous Underwater Vehicles. Fuzzy logic of BK-Product will chose the optimal safety direction to reach the goal of the mission.

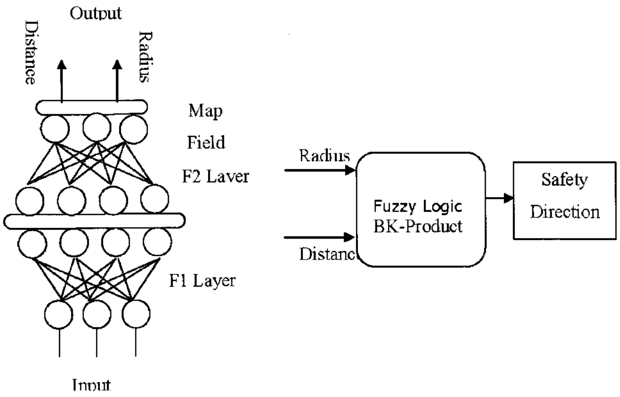


Figure 2. ARTMAP and Fuzzy BK-Product Interaction for AUV

Suppose that the obstacle avoidance distance can be divided into different portions. All these value will come from ARTMAP and those are the size of the possible directions and distance to goal. Whenever obstacle is detected by ARTMAP, obstacles present can be identified in the picture. A property set P describes the possibility of AUVs toward the real time environment. The fuzzy rule bases and membership function for the corresponding property can be estimated subjectively by the expert knowledge. With the set of the candidate $S = \{s_1, s_2, ..., s_i\}$ and the set of environmental properties $P = \{p_1, p_2, ..., p_j\}$, the relation R is built as (2). The elements rij of this relation mean the possibility the section si can be characterized by the property pj. The value of rij is calculated using the rule bases along with the membership functions.

$$R = S \times P = \begin{array}{c} \left[\begin{array}{cccc} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{array}\right] \begin{array}{c} s_1 \\ s_2 \\ \vdots \\ s_i \end{array} \\ \begin{array}{cccc} p_1 & p_2 & \cdots & p_j \end{array} \end{array} \tag{2}$$

In the next step, a new fuzzy relation T is computed by using sub-triangle product ◁ to fuzzy relation R and transposed relation of R. The fuzzy relation T as shown in (3) is the product relation between candidate set S that means the degree of implication among elements of candidate set.

$$T = R \lhd R^T = \begin{array}{c} \left[\begin{array}{cccc} t_{11} & t_{12} & \cdots & t_{1i} \\ t_{21} & t_{22} & \cdots & t_{2i} \\ \vdots & \vdots & \ddots & \vdots \\ t_{i1} & t_{i2} & \cdots & t_{ii} \end{array}\right] \begin{array}{c} s_1 \\ s_2 \\ \vdots \\ s_i \end{array} \\ \begin{array}{cccc} s_1 & s_2 & \cdots & s_i \end{array} \end{array} \tag{3}$$

Then, the α-cut is applied to fuzzy relation T in order to transform into crisp relation as shown in (4). It is important to select a reasonable α-cut value because the hierarchical structure of candidate set depends on an applied α-cut. α-cut value depends on the system and for this simulation we chose proper α-cut according to the value of T. Finally, we draw the Hasse diagram, which completely describes a partial order among elements of candidate set, that is to say, a hierarchical structure among the elements of candidate set with respect to the optimality and efficiency. Select then the top node of the Hasse diagram as the successive heading direction of AUVs.

$$R_\alpha = \alpha\_cut(T, \alpha) = \begin{array}{c} \left[\begin{array}{cccc} a_{11} & a_{12} & \cdots & a_{1i} \\ a_{21} & a_{22} & \cdots & a_{2i} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ii} \end{array}\right] \begin{array}{c} s_1 \\ s_2 \\ \vdots \\ s_i \end{array} \\ \begin{array}{cccc} s_1 & s_2 & \cdots & s_i \end{array} \end{array} \tag{4}$$

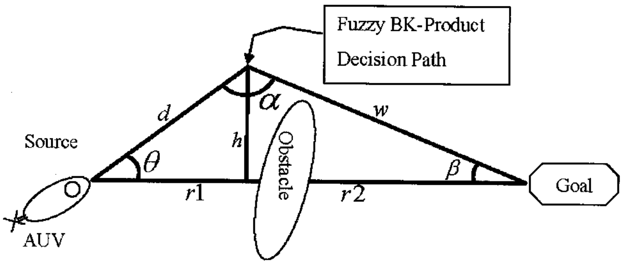


Figure 3. Finding the Angle equation

We know, The value of r =(r1+r2)= source to destination distance; The value of r1= Camera range; The value of θ= angle safety direction; The value of h = perpendicular distance.

We need to know the value of β, as we are considering about the minimum value of β. If the value of β is low, the AUV will reach to the destination within short time with safely and if that value is large, it will take time to reach the destination. For that we need to calculate the value of β.

Here, d is the distance of the camera focus and r is the distance from source to the destination. So

$$\beta = Cos^{-1}\left(\frac{r2}{w}\right) \tag{5}$$

where $r2 = r - r1$ and $w = \sqrt{(r2^2 + h^2)}$

4. Case Studies:

Assume that the radius of circle can be divided into different sections forming the set S={s1, s2, s3, s4, , , , ,si },which are considered as candidates of successive heading. This follows the membership function of equation (6), where the value of X is radius value of the circle. Here the variable "l" depends on the maximum value of the radius.

Actually, we determine the two fuzzy properties radius of the circle and distance to goal forming the set P={p1 ,p2 ,p3 ,p4 , , , , pi}.This follows the membership function of equation (7), where the value of Y denotes the distance to goal. Here the value of depends on the maximum value of distance. So the Fuzzy BK-Product will Chose the high radius circle with minimum distance to the goal position and it will try to make the distance angel near to zero. In the context of underwater obstacle avoidance of

$$\mu_l(x) = 1 - \frac{1}{1 + e^{(l/2 - x)}} \tag{6}$$

$$\mu_\theta(y) = \frac{1}{1 + e^{(\theta/2 - y)}} \tag{7}$$

5. System Overview:

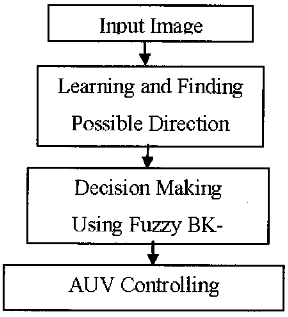


Figure 4. System Overview

When one wants to address the problem of obstacle avoidance in the underwater-unstructured environment, the main problem encountered is the extraction of information from the input data to create a representation of the environment that is as close as possible to the "ground truth" scene and can be interpreted in terms that are suitable for computation.

The system we have designed (see Fig) is modular in nature. So the purpose of each module handle different needs within the same framework.

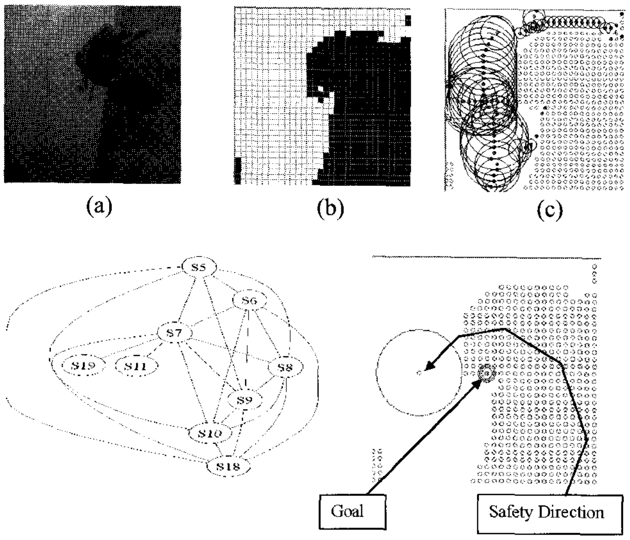
1) Input Image: The Camera will take the pictures from the nature and it will send that data to the computer for analyzing and computation. These pictures are going to send the module frame by frame continuously and dynamically.

2) ARTMAP: First time image will be learned and find out the possible ways to go avoiding potential obstacles and their features (position, moments, area) are computed. These features will be used later to discard false alarms and track the obstacles and the vehicle.

3) Fuzzy BK-Product: This module will collect the possible ways to reach the destination from ARTMAP and using Fuzzy BK-product, it will chose the best and optimal direction to reach the destinations avoiding collision of the obstacle with the AUV.

4) AUV Controlling: After making the safety decision from the Fuzzy-BK product, the hardware (ladder) of the AUV will be controlled by the software to follow the safety direction path. There is real-time ground-level equation [8] to follow the safety direction to reach the goal.

6. Results of the Simulation:



(a) (b) (c)

(d) (e)

Figure 6. (a) the input sample picture; (b) learning my ARTMAP; (c) finding possible ways avoiding obstacle; (d) Hasse Diagram after Fuzzy BK-Product; (e) optimal direction avoiding Collision

Conclusion

ARTMAP and Fuzzy BK-Product based collision avoidance system for underwater-unsupervised environment have been fabricated and tested with good results for Autonomous Underwater Vehicles. Using this technique control for autonomous underwater vehicle that makes possible the integration of fuzzy obstacle avoidance, camera based motions, and robust recurrent neural network control described in this paper, which need to be validated under real conditions. we think that the proposed strategy is an effective approach. Another important result is the effective intelligent motion capability of the proposed scheme. With the help of its ''brain'' (fuzzy-decision), which makes decision about any action of the vehicle that will move the safety position autonomously and stably chooses an optimal direction to reach its target without collision with unknown and/or moving obstacles in unstructured underwater areas. This brings a high level of autonomy to the overall system, and makes the use of the controller very attractive for real-time fast and nonstop camera guidance of intelligent underwater vehicle.

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Arif Reza Anwary,
Ph.D. student in Dept. of Computer Science, Gyeongsang National University
Research Area : Neural Networks, Collision Avoidacne System of Autonomous Underwater Vehicles

Young-il Lee,
Lecture in Dept. of Computer Science and Engineering, Jinju National University
Reseach Area : Path-planning and Collision Avoidance for Unmanned Vehicle, Fuzzy Relational Products

Hee Jung
Ph.D. student in Dept. of Computer Science, Gyeongsang National University

Yong-Gi Kim
Professor, Dept. of Computer Science, Gyeongsang National University
Researach Area: Intelligent System, Soft Computing, Autonomous Underwater Vehicles, Artificial Intelligence
E-mail : ygkim@gsnu.ac.kr