Design of a Navigator for the Optimized Path-Tracking of Underwater ROVs using a Nero-Genetic Fuzzy Controller

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ABSTRACT

This paper proposes a sub-time-optimum soft- computing based controller to follow a desired path with a desired velocity by mobile robots with identified dynamical behavior. This method consists of a fuzzy controller where a trained Neural Network sets its membership functions values in On-line mode. Training of the Network is done by a Genetic Algorithm for various vehicle initial positions and different path convexities in Off-line. After the training of the network, during vehicle motion, it retrieves sub-optimized fuzziness values and sends them to the fuzzy control algorithm according to the vehicle position. Meanwhile, the influential of the path convexity is considered in fuzziness of membership functions. This method leads us to make almost the best decision for the mobile robot at each moment. This method is applied to an Underwater Remotely Operated Vehicle (ROV) to develop an autopilot for its control system. Simulation results show good performance of the method in this specifics problem.

Keywords

Path Tracking, Soft-Computing, Nero-Genetic Fuzzy Systems, Neural Networks, Genetic Algorithms, Underwater ROV.

1. INTRODUCTION

During these two decades, Soft-Computing based methods have been widely used in the area of Robotics and Control Systems. In crisp analectic systems, finding the optimized solutions is either theoretically impossible or computationally so complex [2, 3,13,14]. In this paper, we propose a simple Nero-Genetic Fuzzy Control System for the path following of ROVs. The On-line pilot of this system is a fuzzy controller and a Multi-Layer Perceptron (MLP) which sets some parameters of the controller during the motion of the ROV. Simulations on a small Underwater ROV (UROV) have shown the high efficiency of it to track different types of paths in a near optimized manner [5,6,8,10,12,15]. Some methods tune the fuzzy parameters of a fuzzy controller for the summation of settling time in different motions with some specific initial vehicle positions and different path convexities [1]. Therefore they can not be claimed to be optimized at each initial condition and path shape. In some other methods, On-line learning systems like evolutionary based algorithms are suggested. They seek many possible solutions and finally find the fittest ones at each state. So it is necessary to have high speed computational platforms on the ROV navigator [4,11]. We have gathered the strong points of these two approaches to gain near optimized solutions without any complicated requirements. Section 2 explains the problem of Path-Tracking for ROVs. A number of spline curves cover a set of the given points in desired order. Section 3 discusses elements of a Fuzzy Decision making System for the path-tracking problem. In Section 4, Genetic Fuzzy systems are introduced to optimize the target function of the control system which is the settling time in Off-line mode. In other applications, factors like obstacle avoidance and fuel usage may also be considered in the optimization. Section 5 is dedicated to development of a neural based learning system to learn optimized parameters of previous stages in the On-line mode of system. In Section 6, simulation results on an UROV are presented. We conclude the discussion in Section 7.

2. PATH-TRACKING OF ROVS

In this paper the most important performance factor is the settling time of the ROV (robot). In this proposed method apart from the physical distance of ROV from the pre-defined path, other criteria including the correct direction and orientation, desired velocity and stabilizing the motion are effectual. As shown in model (Figure 1), three actuators (motors) are specified. Two of them are in longitude direction (X axis) which move the ROV forward and at the same time change the direction of it. This happens whenever they have different speeds. Thus we will have the Maximum X speed (Vx) when they both reach to the Maximum speed (Vx Max).The third actuator is in lateral direction (Y axis) and is the third degree of freedom (Vy).

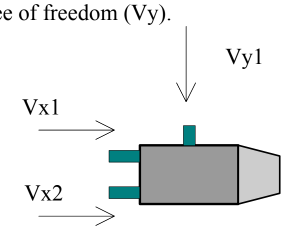

Figure 1. Simple model of a ROV

In order to have a continuous motion, first, we should find a curve to cover all predefined points. (Figure 2)

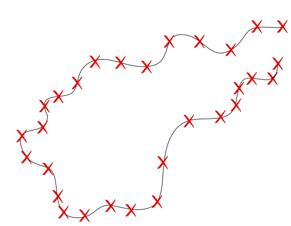

Figure 2. Covering the points with Spline Curves

In this step a collection of target points are determined. The ROV should reach them and traverse them one by one; the curve shaped path could simply be a set of spline curves that covers all predetermined collection of points. ROV start the motion and finally converges to the nearest spline curve and then track it. From now our target is to reach and follow a spline curve in an optimized manner. (Figure 3)

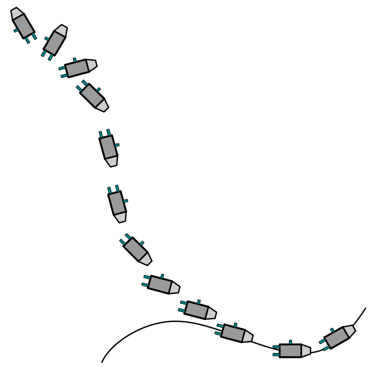

Figure-3: Tracking the Spline Curve

3. FUZZY DECISION MAKING

Due to independence of depth control and dynamical passivity in rotation of ROV in x-z and z-y planes, the goal is reaching and following the path with the desired velocity in x-y plane.

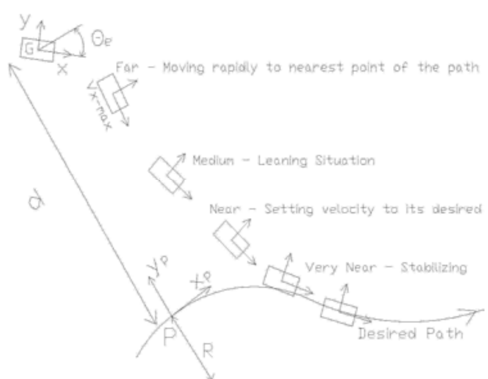

Figure 4. A schematic of different ROV situations

3.1 Inputs and Outputs

The first input is the distance of ROV from the goal path (d). It is the distance of ROV to nearest point of the ideal path (P) which could be far, medium, near or so near. The second input is the error between ROV heading and tangential angle to the desired path at P. Membership functions of error angle are presented in four function-180, -90, 0, and 90. One may propose convexity of the path as an input of the fuzzy logic, but convexity of the path is more influential to fuzziness of parameters rather than being influential to fuzzy laws. Outputs of the system are desired lateral and longitudinal speeds (v_{xd} , v_{yd}) and the desired heading of ROV base (θ_d) in $x_P y_P z_P$ coordinate which is attached to P. In this coordinate, x_P is tangential to the path and z_P is in the same direction with z. In fuzzy point of view, v_{xd} could be fast, zero, desired, fast and v_{yd} could be –fast, zero and fast. Development of fuzzy rules is done in the case that ROV lays above the path. The definition of 'above' is encirclement of y_P by a circle. Therefore, the desired heading varies between -90 and 0. This parameter is presented by vertical, lean and zero in which lean describes the situation of declining of ROV to set on the path. These outputs are inputs to the internal close loop control system. In this case, the close loop control system is a nonlinear adaptive control law obtained by adaptive back stepping method [16].

3.2 Fuzzy Rules

What decision should we make? If the ROV goes to the nearest point of the track, which is perpendicular to the path at that point, it is necessary for ROV to halt on the track. After that it must change its direction in such a way to be tangential to the path, then speed up to the desired velocity. Obviously, it is a simple possible solution but not the optimum one. Better say, this approach is time consuming. We are apt to reach the path by perpendicular way as fast as possible to nearest point of the path when the ROV is far away. In that situation, once the ROV comes near to the path, it is preferred to incline ROV to track's tangential angle at the nearest point. Meanwhile we try to bring ROV's velocity gradually near to its desired value. Also it should be mentioned that nearest point of the track to ROV updates at each moment due to characteristic of the path and ROV's position. By recourse to foretell logic, we set about the development of rules according to ROV's distance from nearest point and its angle. These rules are presented in table 1, 2, 3 and, 4 for the cases that ROV are far, medium and near.[10,12]

Table 1. Fuzzy rules when the vehicle is distance far

If d is	& θ_e is	then	v_{xd} is	v_{yd} is	θ_d is
far	-180	$\Rightarrow$	slow	fast	vertical
far	-90	$\Rightarrow$	fast	slow	vertical
far	0	$\Rightarrow$	slow	-fast	vertical
far	90	$\Rightarrow$	-fast	slow	vertical
far	180	$\Rightarrow$	slow	fast	vertical

Table 2. Fuzzy rules when the vehicle is medium

If d is	& θ_e is	then	v_{xd} is	v_{yd} is	θ_d is
medium	-180	$\Rightarrow$	zero	fast	lean
medium	-90	$\Rightarrow$	desired	zero	lean
medium	0	$\Rightarrow$	zero	-fast	lean
medium	90	$\Rightarrow$	-fast	zero	lean
medium	180	$\Rightarrow$	zero	fast	lean

Table 3. Fuzzy rules when the vehicle is near

If d is	& θ_e is	then	v_{xd} is	v_{yd} is	θ_d is
near	-180	$\Rightarrow$	zero	fast	horizontal
near	-90	$\Rightarrow$	desired	zero	horizontal
near	0	$\Rightarrow$	desired	-fast	horizontal
near	90	$\Rightarrow$	-fast	Zero	horizontal
near	180	$\Rightarrow$	zero	fast	horizontal

Table 4. Fuzzy rules when the vehicle is so near

If d is	& θ_e is	then	v_{xd} is	v_{yd} is	θ_d is
so near	-180	$\Rightarrow$	zero	fast	horizontal
so near	-90	$\Rightarrow$	zero	zero	horizontal
so near	0	$\Rightarrow$	desired	-fast	horizontal
so near	90	$\Rightarrow$	zero	zero	horizontal
so near	180	$\Rightarrow$	zero	fast	horizontal

4. OPTIMIZATIN USING GA

In this step we are to develop a system to minimize the settling time of the ROV. This settling time is the time which takes for ROV to start its motion and reach the predefined path with limited error angle and desired velocity. As the vehicle may have different initial conditions and also there are paths with different shapes and convexities, a neural network is used to optimize fuzziness values of membership functions. Now the structure and training process of this neural network is described. Training the neural network needs some previously optimized data for different conditions of ROV position (distance and angle) and path convexity. We use a Genetic Algorithm (GA) to optimize these values for different conditions. In this GA each gene consists of four real values (fuzziness values). The mutation and crossover operators are Nonunifrom with Gaussian distribution and Scattered and also the fitness function simply is the settling time of ROV. In order to gather each sample we run the GA for the specific position and convexity condition (input training sample of the neural network) and save four optimized values of fuzziness (output training sample of the neural network). [4,7]

5. NEURAL NETWORK

Previous mentioned neural network is a Multilayer Perceptron (MLP) with three inputs (path convexity, angle error and distance from the path), two hidden layers (with 12 and 9 neurons at each layer) and finally four output neurons which are related to the fuzziness values (far, medium, near and lean angle).We also use gradient descent learning rule with the momentum term and 600 epochs for training. Figure 5 shows the diagram of the whole system. [9]

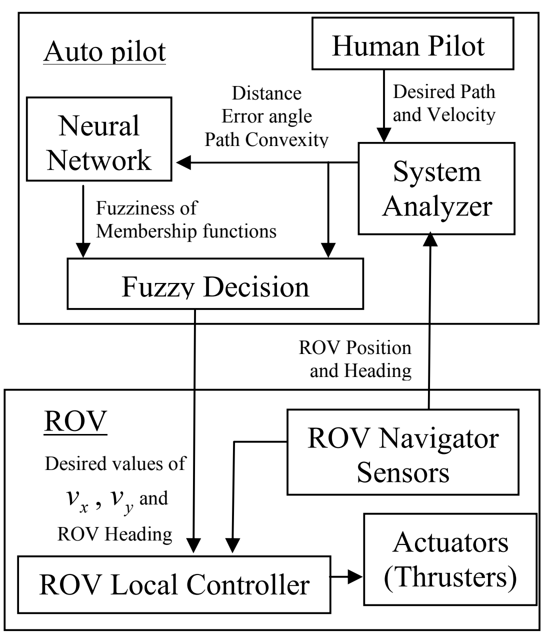

Figure 5. Block diagram of ROV control system

6. SIMULATIONS ON AN UROV

In order to test and examine the proposed algorithm, a simulation is made by Matlab7 [17] software. Simulated Vehicle has determined dynamic characteristics and dynamic equations which are described in [5]. Parameters of the system used in simulation are obtained in [6] are: $m = 170$; $B = 165$;

$$X_G = Y_G = Z_G = X_B = Y_B = 0\ ;\ Z_B = -0.18; X_{u|u|} = -283$$
$$; Y_{v|v|} = -537; Z_{w|w|} = -522; K_{p|p|} = -34; M_{q|q|} = -53$$
$$N_{r|r|} = -3.6; X_u = Y_v = Z_w = K_p = M_q = N_r = -0.1; X_{\dot{u}} = -42$$
$$Y_{\dot{v}} = -106; Z_{\dot{w}} = -193; K_{\dot{p}} = 0; M_{\dot{q}} = -17; N_{\dot{r}} = -2$$
$$I_O^b = diag\{187, 214, 168\}$$

In order to verify the performance of the algorithm, we firstly tested it for following a line with the velocity of 0.5 m/s in different situations (see Figure 6). We obtained promising results; the ROV approached rapidly toward the path in smooth way. More ROV got nearer; it inclined better to its angle and velocity to its final values. Figure-10 shows variation of ROV velocities for line tracking with initial position of (-20,-100).

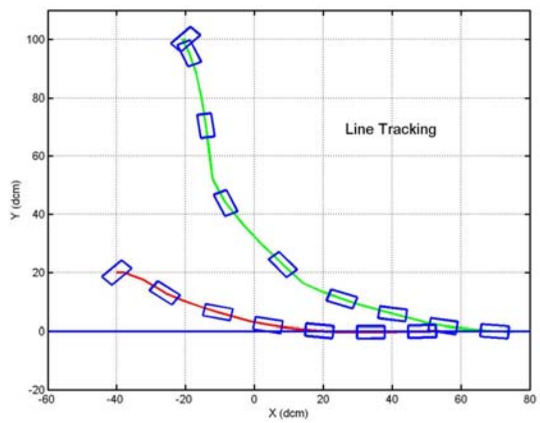

Figure 6. Following a line by 0.5 m/s as desired velocity

At the next step, we tracked a more general path. In this experimentation, the ROV approach is shown for both concave part (see Figure 7) and convex part (see Figure 8) of the path. It can be seen that in different situations, the ROV reasonably reaches the path in a well-shaped trajectory in 3 different situations. The desired velocity was 0.5 m/s.

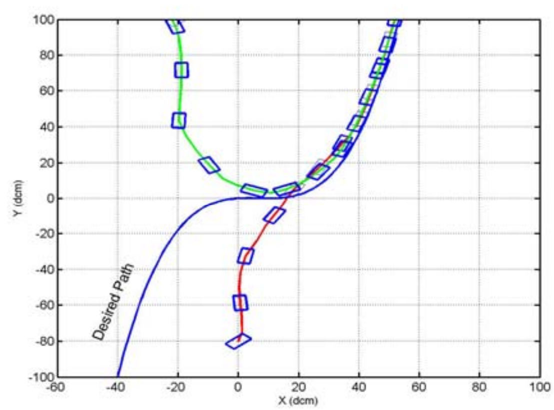

Figure 7. Following a path in its concave part

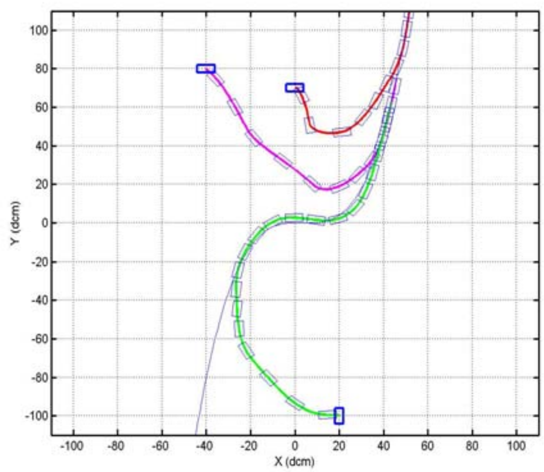

Figure 8. Following a path in its convex part

7. CONCLUSION

In this paper we proposed a fuzzy decision making algorithm for path following of mobile robots. Fuzzy rules were designed according to experiences and simulations, but during this approach, to gain an optimum manner for the path tracking, membership functions were retrieved from a neural network. The network was trained with membership functions values which are optimized, in different vehicle initial conditions and path convexities, by GA optimizer. Applying this method make almost the best decision for mobile robot during the motion to the path. One of the strong points of this work is consideration of path convexity in membership functions (not in rules). This method was applied to an Underwater Remotely Operated Vehicle (ROV) to develop an autopilot for its local close loop control system. As it has been shown in simulations, by applying the fuzzy decision making algorithm, the ROV becomes able to follow all kinds of paths with positive and negative convexities. Besides tracking smoothly without sudden changes in direction and speed, ROV used almost all of its effort for reaching to the path.

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