

Design and Evaluation of a MIMO ANFIS using MATLAB and V-REP

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Abstract— Employing software computing tools, such as fuzzy logic, neural networks and genetic algorithms, encouraged researchers to design intelligent systems that mimic human behavior. The Adaptive Fuzzy Nervous System (ANFIS) is one of the most useful hybrid technologies for designing intelligent control algorithms. Designing a Multiple-Input, Multiple-Output (MIMO) ANFIS algorithm, is not an easy task for those with limited programming experience. This paper presents a simple way to design MATLAB-based MIMO ANFIS controllers for two mechatronics plants; a two-wheeled mobile robot and a 6DOF KUKA robotic arm. The 3D simulation software (V-REP) has been interfaced directly with the MATLAB Simulink to test the proposed controller. The generated 3D simulation environment given in this paper will help researchers to easily design and test of MIMO ANFIS algorithms. The obtained results demonstrate the performance of the mobile robot and ability of the implemented ANFIS controller to deal with input commands, obstacle avoidances in the working environment.

Index Terms— MIMO ANFIS, V-REP, Obstacle avoidance Control, MATLAB, Simulink, 3D simulation, Real-time Control, ANFIS.

I. INTRODUCTION

Softcomputing tools incorporating fuzzy logic, artificial neural networks and genetic algorithms are widely used to design intelligent control algorithms to mimic human behavior [1,2]. Fuzzy logic is widely used in control and decision making applications. Artificial neural networks are used in simulations of several problems and can perform just as well as fuzzy logic in many cases, while genetic algorithms are used as optimization tools [3]. Fuzzy logic has the advantage of dealing with vague knowledge and approximate reasoning but lacks an effective learning capability. While, neural networks have the positive features of learning and adaptation. Merging these tools provides an opportunity to maximize their strengths and avoid their shortcomings [4,5].

The Adaptive Fuzzy Nervous System (ANFIS) is actually fuzzy inference system optimized by neural networks. ANFIS is one of the most useful hybrid technologies for designing intelligent control algorithms. The MATLAB ANFIS tunes Sugeno-type fuzzy inference system using training data. It can be used to design a Multiple-Input Single-Output (MISO) controller. In fact, designing a Multiple-Input, Multiple-Output (MIMO) ANFIS algorithm, is a big challenge especially in real-time applications [5,6].

The Sugeno-type ANFIS provides more efficient and compact by customizing the membership functions compared to the Mamdani-type fuzzy Inference system. The membership functions and rules are generated automatically by the adaptive techniques and could be used to produce the best result from training data [7]. There is several published papers discuss design of MIMO ANFIS controllers. A MIMO ANFIS controller was designed for obstacle avoidance control of a two-wheel differential drive mobile robot [8]. An ANFIS controller has been designed for each motor (Left and Right). The speed control command of each motor has been trained using MATLAB ANFIS tool box. In such system, there will be two ANFIS algorithms and each one should be uploaded on a microcontroller. Therefore two microcontrollers needed to implement such system.

Pandey and Parhi [9] proposed an ANFIS controller with two outputs was designed for control of a two wheels differential drive mobile robot. They suggested converting the two outputs (Left & Right motor speed) to one steering angle, to be calculated using the mathematical model of the two differential drive mobile robot. The system has been trained using a set of 15 cases in MATLAB ANFIS toolbox. Then, the resulting algorithm has been uploaded on a single-chip ARDUINO microcontroller. In such approach, an accurate mathematical model for the controlled system is required to calculate the required steering angle. Additionally, for a system with many distance measurement sensors, a complex calculation will load the microcontroller to produce the required steering degree.

Tan-i and Dadus [10] proposed another control approach with two Mamdani-type fuzzy inference systems to control a two-wheel differential drive mobile robot. Training data was collected from left and right motors for use in neural network training. The proposed algorithm was implemented in MATLAB and gives good accuracy. It is difficult to deal in the same way with a complex system that has a large number of inputs and outputs due to the need for massive training data.

Coactive Neuro- Fuzzy Inference System (CANFIS) is an extension of ANFIS with MIMO system [11]. The input space of CANFIS is divided into three different parts to group the data using neural network technique. Additional calculations are required with a special software to implement the CANFIS technique. It is difficult to employ this approach when dealing with MIMO systems where the need to cover and train a large number of control cases.

V-REP is an open-source 3D simulation framework used for system's design, testing and verification. Currently V-REP has been widely used as robot simulator and controller. It performs several tasks during planning and implementation phases. These tasks include system's verification, algorithm optimization and realization, simulation of complex systems, robot task planner and controller [4, 12]. For the purpose of testing the ability of the proposed ANFIS algorithms and general system behavior, 3D V-REP was used in this research. In fact the 3D visualization simulation is the best way to see the resulting system behavior in the virtual world. One of the most commonly used way to simulate MATLAB work in 3D visualization is by interfacing the MATLAB with V-REP framework. The most commonly used approach to interface the MATLAB/SIMULINK environment with V-REP is by using robot operating system communication libraries for prototyping of robot control algorithms [13, 14].

In this research, the design and evaluation of simple MATLAB-based MIMO ANFIS controllers are considered. The rest of the paper is organized as follows; the design concepts of MIMO ANFIS controllers are given in section 2. A simple and direct interface between MATLAB/Simulink and V-REP simulator is discussed in section 3. Sections 4 and 5 present the application of the proposed MIMO ANFIS controllers for a two-wheeled mobile robot and for a 6-DOF KUKA robotic arm respectively. Simulation results are discussed in Section 6. Finally, conclusion and some suggested future work are given in Section 7.

II. MIMO ANFIS DESIGN

ANFIS combines fuzzy logic and neural networks in a hybrid system that promotes automatic learning, adaptation, and providing a suitable environment for designing smart algorithms. Researchers have used it in various applications for decision making, identification, control and prediction. Most of these applications are single multi-input output systems, since the ANFIS toolbox in MATLAB offers a design tool for a multiple-input single-output controller. In the case of MIMO systems, an ANFIS design is required for each individual output. This research shows a novel method to construct a MIMO ANFIS system based on the available ANFIS design toolbox in MATLAB. The obtained MIMO ANFIS controllers will be applied with two mechatronics systems.

A. Training Data Preparation:

The values of selected cases for each output should be prepared as a dataset according to different cases in the input values. Including as much cases as possible will improve the accuracy of system during the training process. The same cases will be trained separately for each output using the ANFIS toolbox in MATLAB. The number of designed ANFIS controllers is equal to the number of outputs in the system.

B. ANFIS Design and Training:

All cases in the dataset have been trained using the ANFIS toolbox in MATLAB to construct a Mamdani-type FIS, which represents the resulting system after training. For training process, the sub-clustering values given in Table 1 have been used for the two different MIMO systems considered in this research.

TABLE I. SUB-CLUSTERING VALUES.

Range of influence	0.4
Squash factor	1
Accept ratio	0.3
Rejection ratio	0.1

C. Merged ANFIS:

After designing an ANFIS controller for each output using the same training data with the same sub-clustering values, all the resulting controllers have been merged in one controller by adding other outputs to the first one and inter the same output values form the trained ANFIS controllers.

III. SIMULINK AND V-REP INTERFACE

A modified method has been developed to interface the MATLAB-Simulink with the open source 3D simulation engine V-REP software. In general, MATLAB lacks an easy to use 3D simulation options, especially to robotics systems. Therefore, V-REP simulator can be used as an alternative, it is open source and freely available to research applications. In this case, 3D simulation becomes widely spread in robotics system. With V-REP it is possible to simulate different robotic models like KUKA, PUMA and PIONEER robots. The V-REP offers many different possibilities to include its own code or to interface with external software. A direct interface between SIMULINK and V-Rep software has been successfully achieved through four steps. Firstly, preparing a V-REP model to test the designed ANFIS controller. The second step is preparing a SIMULINK model for the ANFIS controller. While, during the 3rd & 4th steps, a MATLAB script code has been designed to send and receive data between SIMULINK & V-REP. Figure 1 shows the direct interface between SIMULINK and V-REP. The following points illustrate the implementation of the proposed interface.

A. Preparing V-REP Module:

The Pioneer and KUKA robot models have been used to simulate the proposed MIMO ANFIS controllers and implement the obstacle avoidance and cups filling tasks. The Pioneer model is equipped with 16 ultrasonic sensors, 6 of them have been used to test the resulting MIMO ANFIS controller for the obstacle avoidance task. While, the KUKA model is equipped with 6 servo motors, all of them have been used to test the resulting MIMO ANFIS controller for the cups filling task.

B. Simulink Design for ANFIS Controllers:

Figure 2 illustrates the designed ANFIS controller of the two-wheeled drive mobile robot using Simulink to implement obstacle avoidance task. The ANFIS controller for the left and right motors of the wheelchair will receive the feedback signals (8 ultrasonic readings from the V-REP Pioneer robot) and make decision according to the training data used to train the ANFIS controller. The sensors reading received in meter from the V-REP are converted to centimeter in the Simulink model using Gain and MATLAB function blocks for each input. The ANFIS controller produces the output as a PWM signal then it will be converted to a rotation speed in round per minute (RPM) to be sent to the V-REP Pioneer model.

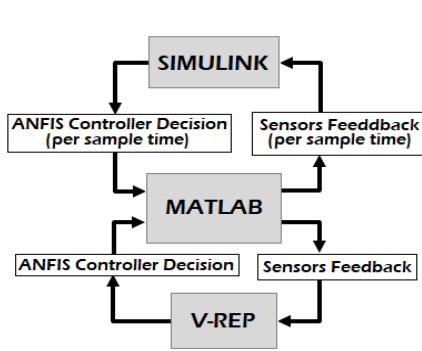


Figure 1. Interface between SIMULINK and V-REP.

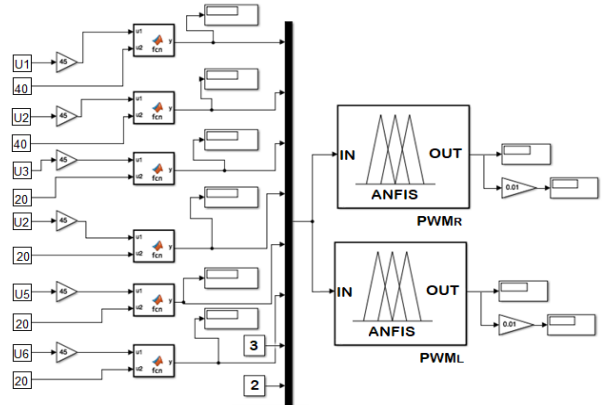


Figure 2. ANFIS Simulink model for a mobile robot.

C. Send Data from V-REP to Simulink:

A script code has been constructed in MATLAB to start communication with the V-REP and read data from sensors during its movement. The remote API function in the V-REP software has been used to define the required variables to be received and sent from V-REP to Simulink. In case of connecting the MATLAB script code to the V-REP, the asynchronous mode should be selected which means that MATLAB and V-REP will run in parallel by sending data and commands back and forth. Figure 3 illustrates the MATLAB-V-REP asynchronous mode.

First of all, the V-REP scripting has been disabled to stop receiving the commands from the same software. To start reading data from the V-REP using the asynchronous mode all the variables need to be defined in the MATLAB script code for each of the 6 ultrasonic sensors and for the two motors in the Pioneer mobile model. The 2 sensors measuring the height on the back and the front of the wheelchair has been set as constant input values.

The command (“set_parm”) has been used in the MATLAB script code to update the Ultrasonic sensors readings in the Pioneer robot in V-REP with sampling rate of 0.01 seconds. The following function has been used to define the V-REP variables needed to communicate with the Simulink model:

```
[number returnCode]= s imxAppendStringSignal(number clientID, string signalName,string
signalValueToAppend,number operationMode)
```

Detailed clarification of the remote API functions could be found on the V-REP manual using this link:
<http://www.coppeliarobotics.com/helpFiles/en/remoteApiFunctionsMatlab.htm>

D. Commands Transfer from Simulink to V-REP:

In the same constructed script code in MATLAB, a communication with the V-REP has been designed to write the output commands produced in the Simulink model of the ANFIS controller to the two motors of the Pioneer robot during its movement. To keep V-REP and Simulink running with asynchronous mode, the Pioneer robot model should continuously receive the updated command in each sample of the Simulink model.

The command “get_parm” has been used in the MATLAB script code to update the motors speed of the Pioneer robot in V-REP according to the produced PWM signal from the simulated ANFIS controller. Then, the received variables from Simulink will be sent using the following remote API function to the Pioneer robot model in V-REP software:

```
[returnCode]=vrep.simxSetJointTargetVelocity(clientID,left_Motor,x,vrep.simx_o1 pmode_blocking);
[returnCode2]=vrep.simxSetJointTargetVelocity(clientID,right_Motor,o,vrep.simo2_opmode_blocking);
```

where (o1 and o2) variables are the control output commands for the two-wheeled drive mobile robot represents the rotational speed of the left and right motor respectively. The same sampling rate has been chosen (0.01 second) for each output to keep the system work in asynchronous.

IV. PIONEER MOBILE ROBOT DESIGN

Figure 4 shows the Pioneer mobile robot which has been used to implement the obstacle avoidance task. The Pioneer model is equipped with 16 Ultrasonic sensors, 6 of them have been used to test the resulting ANFIS controller for the obstacle avoidance task. A 44 cases has been used to train the ANFIS controller of two-wheeled drive mobile robot. Table 2 shows a sample of these cases. The inputs (S1-S6) represent the readings from 6 Ultrasonic sensors distributed on the body of the mobile robot.

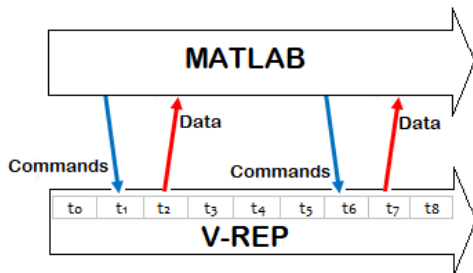


Figure 3. MATLAB-V-REP asynchronous mode.

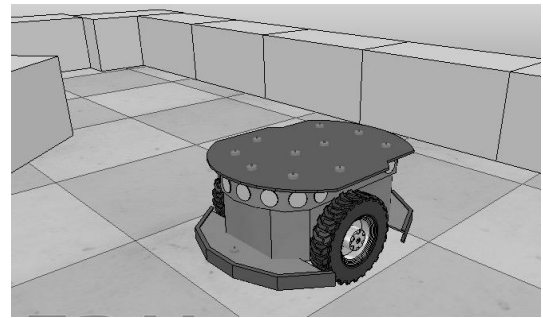


Figure 4. Two-wheeled drive mobile robot model (Pioneer).

TABLE II. SAMPLE OF THE TRAINING DATASET OF TWO0WHEELED DRIVE MOBILE ROBOT.

S1	S2	S3	S4	S5	S6	LPWM	RPWM
40	40	20	20	20	20	80	80
35	40	20	20	20	20	75	80
40	35	20	20	20	20	80	75
30	40	20	20	20	20	60	80
40	30	20	20	20	20	80	60
25	40	20	20	20	20	50	80
40	25	20	20	20	20	80	50
20	40	20	20	20	20	40	80
40	20	20	20	20	20	80	40
15	40	20	20	20	20	30	80

The outputs (LPWM and RPWM) represent the required PWM signals to be sent to the left and the right motors. The dataset (44 cases) have been used to design two controllers using ANFIS tool in MATLAB, one for each output in the two-wheeled drive mobile robot. The resulting controllers have been merged in one controller to construct a MIMO ANFIS by adding the output data from one of them to the other.

V. KUKA ROBOTIC ARM CONTROLLER

Another application to check the ability of the proposed MIMO ANFIS, where a KUKA robotic arm with 6DOF is used to perform the task of filling set of cups on the table, as shown in figure. The KUKA model is equipped with 6 servo motors, all of which are used to test the resulting ANFIS controller for cup filling function. Only 20 cases were used to train the ANFIS controller from the robotics arm.

Table 3 illustrates some of these cases. The entries (X, Y, and Z) represent the position on the table in meters, as given in Fig.6. The reference cup of position (0,0,1) is the first lower one on the left. The outputs (Q_1 - Q_6) represent the degrees of movement that must be performed for each of the six joints of the robotic arm to reach the desired position. The same has been done for the 6-DOF robotics arm by adding 5 outputs to the first joint's controller and inter those values from the designed ANFIS controller for each joint.



Figure 5. 6-DOF robotic arm model (KUKA).

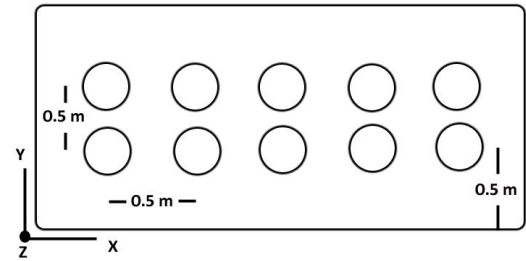


Figure 6. The distribution of cups on the table for the filling task

TABLE III. SAMPLE OF THE TRAINING DATASET OF KUKA ROBOT CONTROLLER.

X (m)	Y (m)	Z (m)	$Q1$	$Q2$	$Q3$	$Q4$	$Q5$	$Q6$
0	0	1	-47°	-22°	-12°	0°	-10°	0°
0.25	0	1	-33°	-22°	-12°	0°	-10°	0°
0.5	0	1	-24°	-21°	-12°	0°	-10°	0°
0.75	0	1	-16°	-12°	-17°	0°	-12°	0°
1	0	1	-09°	-4°	-17°	0°	-15°	0°
1.25	0	1	-1°	-12°	-14°	0°	-12°	0°
1.5	0	1	10°	-22°	-13°	0°	-12°	0°
1.75	0	1	23°	-22°	-12°	0°	-10°	0°
2	0	1	37°	-22°	-12°	0°	-10°	0°
0	0.25	1	46°	-22°	-12°	0°	-10°	0°

VI. RESULTS AND ANALYSIS

Figure 7 shows the decreasing in error during the training process of the two-wheeled drive mobile robot using back-propagation method. The resulting error reduced to (2×10^{-5}) for both outputs during 200 Epochs of training.

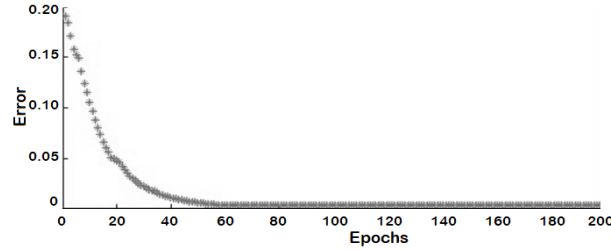


Figure 7. Training Error in the resulting ANFIS after Back propagation training of dataset.

The direct interface between MATLAB Simulink, and V-REP simulator is an interesting approach to simulate any mechatronic system. With simple programming skills on the MATLAB scripting, and using the remote API commands of the V-REP it was easy to test the resulting system on a 3D model. Figure 8 demonstrates the Pioneer robot performance in the V-REP, where the MIMO ANFIS can guide the mobile robot to avoid obstacles in the working area. It is clear from several tests that the mobile robot powered by the proposed MIMO ANFIS controller is able to avoid static and dynamic obstacles on the left and right front sides. This controller showed its ability to make the required decision even without any obstacles in the training data.

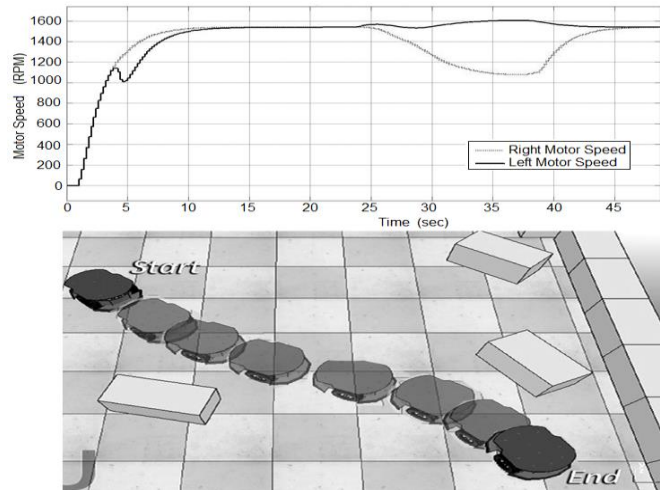


Figure 8. V-REP simulation when the robot facing obstacles.

The performance of KUKA robotic arm was unacceptable using the designed MIMO ANFIS controller due to the high overall error value (about 0.3) in the output values. Figure 9 shows the implementation of the cups filling task with the designed MIMO ANFIS controller where (+) is the desired position and (•) is the actual position. In this MIMO system, it is difficult to design MIMO ANFIS controller with input membership functions that can fulfill all required states for a large number of outputs (6 servo motors). A large number of cases will be included to reduce the error in the training process. In addition, the six outputs of the robotic arm are asymmetric which makes the number of the needed membership functions in the output very high.

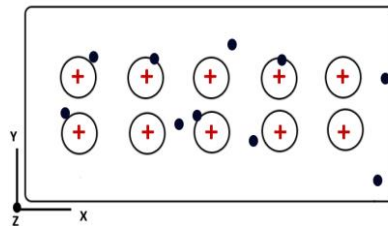


Figure 9. Implementing the cups filling tasks using designed MIMO ANFIS controller.

VII. CONCLUSIONS

MIMO ANFIS has been successfully designed with MATLAB only. The direct interface between MATLAB Simulink, and V-REP 3D simulator is an interesting approach to simulate any mechatronic system. With simple programming skills on the MATLAB scripting, and using the remote API commands of the V-REP it was easy to test the resulting system on a 3D model. The resulting controller is a MIMO ANFIS controller works with the same error vale (2×10^{-5}) to produce the required PWM signal for each motor in the two-wheeled drive mobile robot. The resulting system demonstrates the ability of the MIMO ANFIS controller for a mobile robot to take action to avoid obstacles during testing in a 3D environment. Whereas in the second application, the MIMO ANFIS controller did not perform well due to the ANFIS architecture and training as there are 6 outputs in addition to the different actuating elements un each joint. Such a case requires more dataset and training to overcome this problem. Therefore, using such approach to design MIMO ANFIS controllers will be acceptable with a system that has symmetric outputs.

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