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Adaptive Type1 Fuzzy Controller for Lag Dominant First and Second Order Nonlinear Systems †

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Abstract: Most of the current day industries are suffering from nonlinear processes. Thus, both the stability and the process performance of high-degree nonlinear systems with dominating delay might be difficult to achieve. Adaptive and intelligent fuzzy classifiers and controllers have been more popular in recent years as a means of overcoming a significant number of difficulties faced by the industrial sector. A large number of dynamic process plants with a variety of orders and kinds have been represented heuristically and recognized. Fuzzy structures have also been employed for these interactive systems by making use of fuzzy and linguistic techniques. In view of all these initiatives, the purpose of this paper is to conduct an experimental investigation into the performance of a LabVIEW-based Type-1 Adaptive Mamdani Fuzzy Controller (AMFC) that has been designed and applied over a lag dominant and a second-order nonlinear Dual Input Tank System (DITS) and Single Input Tank System (SITS). As compared to other Type-I approaches that were previously experimented with and are now in existence, the adaptability of AMFC demonstrates that it is quite effective. Performance indices such as Integrated / Summated Absolute Error (IAE) and Integrated / Summated Squared Error (ISE) are also computed for several variable set point profiles of DITS. These indices measure errors in integrated absolute value and integrated squared value, respectively. Adaptive Type-1 Intelligent Fuzzy Controller's response and error reduction efficiency have been found for several flow configurations of DITS, namely Multiple Input Multiple Output (MIMO) and Single Input Single Output (SISO). From the results, it can be concluded that the proposed experimental validation may be used for a wide variety of process challenges that are experienced in industrial systems to achieve robust and low error controller performances.

Keywords: Error Performance Index; Lag Dominant Systems; Nonlinear Systems; Spherical Tanks; Type1 Fuzzy Controller

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1. Introduction

Adaptive and Intelligent Fuzzy classifiers and controllers have become more popular in recent years as a means of overcoming a significant number of difficulties faced by the industrial sector [1]. A large number of dynamic process plants with a variety of orders and kinds have been represented heuristically and recognized. Fuzzy structures have also been employed for these interactive systems by making use of fuzzy and linguistic techniques [2]-[4]. A linguistic description and the theory of fuzzy sets were used to implement a heuristic adaptive controller on dynamic processes. This controller was also applied to non-linear and multi-process industrial plants to infer that they were able to control these plants in a relatively short amount of time [5]. This non-linear self-organizing controller's heuristics are described mathematically and may be controlled with the help of the theory of fuzzy sets [6]. They take the shape of a collection of linguistic decision rules. To illustrate a perfect nonlinear controller case study [7], an experimental testing of multiple fuzzy zones was undertaken, with the areas being high/ low-gain, and large/ small time-constant, respectively. This validation was based on previous information. The explanation of what it is that enables fuzzy controllers to provide such good performance has been worked upon in several researches [8]. The dependability of these controllers has been the driving force for the widespread use of them across a wide variety of industrial and real-time control systems [9]-[13].

In recent years, very few attempts have also been made to improve the performance of fuzzy controllers and their precision in decisiveness by applying soft-solving techniques [14]-[17]. These attempts have been made in several different fields. In recent times, a great number of controllers that are capable of self-organization and adaptation have emerged to control dynamic and nonlinear systems. The swift learning and observer-independent decision-making algorithms are always refined to choose the most appropriate quick fuzzy inference rules to produce trustworthy conclusions [18], [19]. Real-time temperature control, heat exchanger systems, petroleum separation processes, and also in effective energy management are just a few of the numerous industrial applications that have made extensive use of fuzzy PI and PD controllers. All of these applications required that critical process parameters be controlled to keep the process stable in the face of a large number of disruptions, both from the outside and from the inside. The above literature only discusses the controllers that were employed to stabilize the control variables of choice using simulations. However, this experimental investigation attempts to implement a model-less type1 fuzzy controller for a real-time system.

Typically, plants that are complicated and unpredictable cannot be effectively addressed using traditional linear methods. Complex controllers are often necessary to provide the desired stability and robustness. However, they often lack a straightforward design approach and their implementation might be challenging, if not unfeasible. Fuzzy logic control is an intelligent methodology that enables the conversion of logical assertions into nonlinear mapping. Despite its shown efficacy in handling intricate botanical specimens, several subsequent investigations have diverged from the fundamental principle of linguistic interpretability. This study focuses on the development of a straightforward Type-1 fuzzy controller, emphasizing the ease of design and the logical coherence of linguistic operators.

In the next portions of this study, we will go into further detail of the experimental procedure of DITS, as well as the theoretical modelling approaches. The findings, conclusions, and an efficiency study of their use are presented in the last section of the paper.

2. Experimental Process Description

The primary components of the laboratory setup for the chosen system are comprised of two spherical tanks that interact with one another and are joined together by a valve that may be operated by hand. Both of the tanks get water through an input and an outflow that is pushed by the engine, which continually draws water from the water reservoir. Both of the tanks are being filled by the motor. Pneumatic control valves of liquid into the storage tanks. To seal and open the pneumatic valves, a compressor, which has a position that can be altered by the application of air pressure, is used to regulate the flow used to generate pressure in the system. A few circuit systems and pieces of equipment, such as a current-to-pressure converter, a current-to-voltage converter (I-V), and a voltage-to-current converter (V-I), are all components of the integrated experimental process. In addition to this, a rotameter is provided to manually measure the flow rate in one or both of the tanks.

A differential pressure transmitter with an output current range that is typically between 4 and 20 milli-amperes is used to monitor the level that is present in the tanks. This differential pressure transmitter is connected to the personal computer via NI-DAQmx 6211 data acquisition module card, which can handle 16 analog inputs and 2 analog output channels with a voltage range between 10 Volts. The differential pressure readings are displayed on the computer. The acquisition card module has a sampling rate of 250-kilo samples per second and a resolution of 16 bits. After that, the graphical program is connected to the set-up by way of the acquisition module. LabVIEW 8.0 was used to write the application. Figure 1 and Figure 2 show, respectively, the real-time DITS experimental procedure that serves as a standard case and its interface to LabVIEW 8.0. An intelligent Type-1 Fuzzy controller is employed which is discussed in detail in further sections. It is a well-known fact that intelligent controllers do not require the knowledge of the model as they are model-less controllers. The detailed mathematical model of this experimental system has been derived and classical PID control techniques have been also implemented to test their efficacy [7].

Figure 1. Real-time experimental setup of the DITS liquid level process.

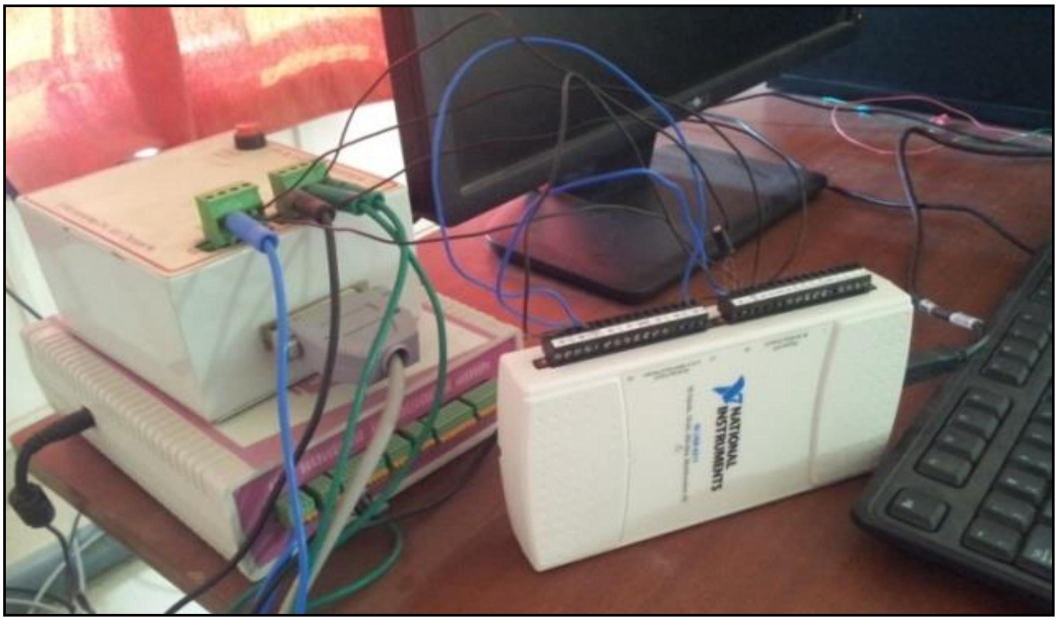


Figure 2. Interfacing computer using NI-DAQmx 6211 data card.

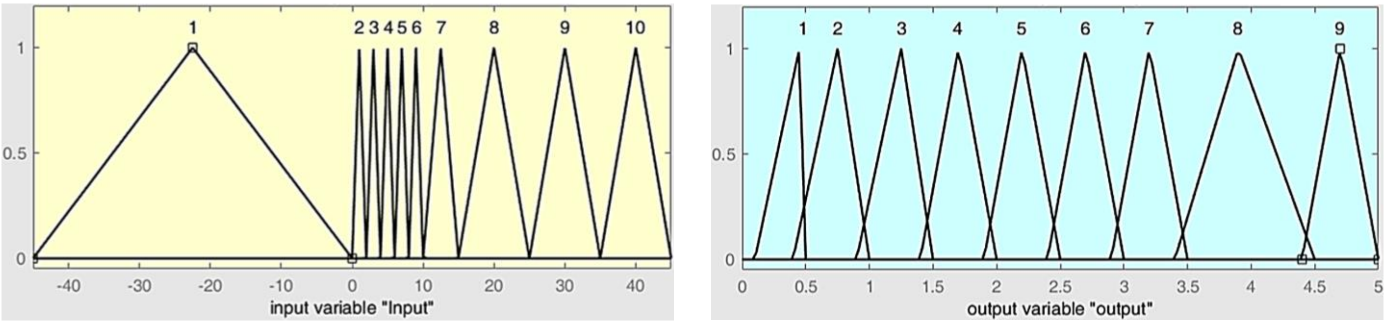
3. Design of Type-1 Adaptive Mamdani Fuzzy Controller

Control over the level parameter of both SITS and DITS may now be achieved using the Type-1 AMFC that has been implemented on LabVIEW. An Adaptive Mamdani fuzzy controller has been developed in order to meet the need for stabilizing the fluctuating degree of non-linearity that is present in the DITS as a result of the varying diameter. The membership functions of the LabVIEW-based AMFC controller have been defined with the help of the triangle function. LabVIEW's integrated development environment (IDE), which supports the fuzzy identification designer tool, is utilized to create the AMFC. The current level in the DITS as well as the change in error are both taken into consideration as input linguistic variables. On the other hand, the voltage applied to the valve that regulates the flow of water entering the tank is taken into consideration as an output linguistic variable.

Mamdani approach of designing the Fuzzy rules is adapted, which follows the if...and...then rules with a combination of inputs. A sample-designed rule can look like, If input 1 and input 2 then output 1. Following the same analogy, a 9 X 7 matrix of rule base has been designed as shown in Figure 3. The rules are defined with 16 input linguistic variables which map onto the scaled range of different outputs. Figures 4(a) and 4(b) show the membership functions of these variables.

Level /ERROR	N	M2	P	VP	VVP	VVVP	VVVVP
VVVL	VS	VF	VVF	VVVF	VVVVF	VVVVVF	VVVVVF
VVL	VS	VF	VVF	VVVF	VVVVF	VVVVVF	VVVVVF
VL	VS	VF	VVF	VVVF	VVVVF	VVVVVF	VVVVVF
L	VS	VF	VVF	VVVF	VVVVF	VVVVVF	VVVVVF
M1	VS	VVF	VVVF	VVVVF	VVVVVF	VVVVVF	VVVVVF
H	VS	VVF	VVVF	VVVVF	VVVVVF	VVVVVF	VVVVVF
VH	VS	VVF	VVVF	VVVVF	VVVVVF	VVVVVF	VVVVVF
VVH	VS	VF	VVF	VVVF	VVVVF	VVVVVF	VVVVVF
VVVH	VS	VF	VVF	VVVF	VVVVF	VVVVVF	VVVVVF

Figure 3. Rule base matrix for Mamdani method-based AMFC controller.

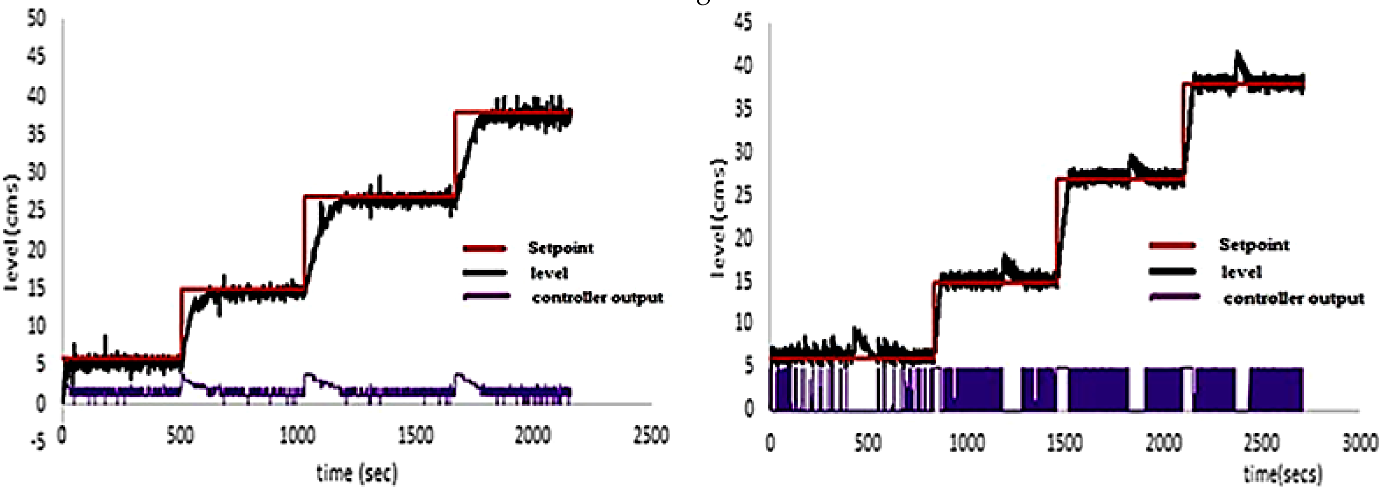


(a) Input membership function (b) Output membership function

Figure 4. Membership functions of the input and output linguistic variables of AMFC.

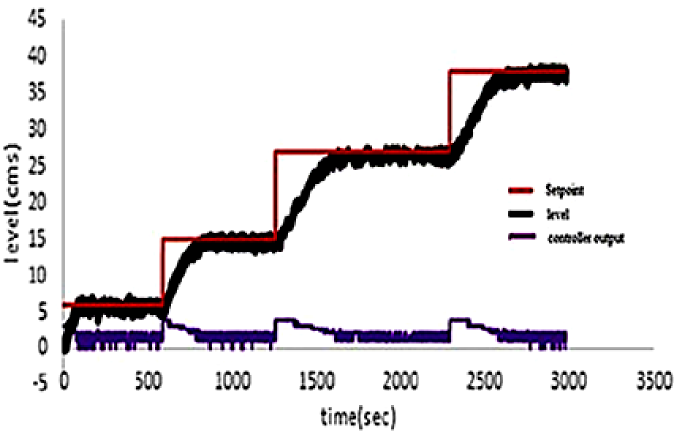
4. Experimental Results and Discussion

LabVIEW has been used to develop AMFC, and it has been used for a real-time nonlinear DITS process. The servo response and the regulatory perturbation rejection response of AMFC have both been seen experimentally. To observe the setpoint tracking and the load rejection capabilities of the AMFC for the selected benchmark system, a varied set point profile of 6 cm, 15 cm, 27 cm, and 38 cm was applied to the DITS. This profile complied with each of the three linearized areas of the system. In the SISO mode of DITS operation, the water enters the spherical tanks by the input of Tank 1, and it leaves the process through the output of Tank 2. Similarly, the flow of water would only occur between the input and output of tank 1 when using the SISO mode of SITS. Figures 5(a) and 5(b) show the servo tracking and rejection regulatory disturbance rejection performances of AMFC over SITS in the SISO mode of operation. Figures 6(a) and 6(b) show its performance over DITS in the SISO operation phase. At extremely close quarters, it is possible to see that the servo response of SITS has a substantially bigger inaccuracy compared to that of DITS. This is something that can be viewed.

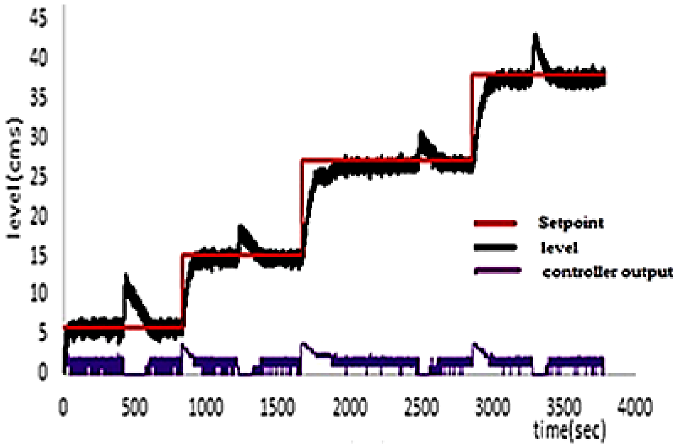


(a) Servo response (b) Rejection regulatory response

Figure 5. Servo and rejection regulatory responses of AMFC for SITS in SISO mode of operation.



(a) Servo response



(b) Rejection regulatory response

Figure 6. Servo and rejection regulatory responses of AMFC for DITS in SISO mode of operation.

Table 1 displays the values of all of the performance indices, including IAE and ISE, for all of the areas of operation, for both SITS and DITS, in both servo and regulatory modes of operation. It should be noted that the performance of Type-1 AMFC, despite the fact that it is not particularly robust, is capable of being applied, at least partially, in an industrial setting, where precision in error reduction is not a prior criterion. When used to SITS in linear areas, the error reduction is most prominently observed in Type-1 AMFC's performance; however, when applied to DITS in regions with a larger degree of non-linearity, it offers an error reduction in DITS. Hence, it can be deduced that Type-1 AMFC provides a lower error for systems that have a larger degree of non-linearity and higher order and that it also provides superior performance for linear system applications.

Table 1. Performance Values of Servo and Regulatory Responses of SITS and DITS on Application of AMFCs.

Setpoint	Performance Index	Servo Tracking Performance		Regulatory Performance	
		SITS	DITS	SITS	DITS
6	ISE	835.491	545.252	1735.49	1045.25
	IAE	1180.16	921.495	2003.34	1956.67
15	ISE	166.719	392.728	834.756	820.154
	IAE	309.133	492.728	1027.54	796.456
27	ISE	343.491	766.536	910.56	1353.95
	IAE	632.499	896.47	1353.78	1659.39
38	ISE	779.68	118.765	1432.34	231.908
	IAE	825.844	237.751	1567.99	430.512

5. Conclusions

The objective of this research is to study the controller effects of Type-1 AMFC on the performance indices of SITS and DITS, which are respectively of the first and second orders. AMFC was shown to be more appropriate for high-degree nonlinear systems, and it also delivers a better response for linear systems. This was discovered via research. It is possible to draw the conclusion that this experimental validation may be used for a wide variety of process challenges that are experienced in industrial systems to achieve robust and low error controller performances.

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