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Descriptive And Review Study Adaptive Control Of Nonlinear Systems In Discrete Time

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1. Introduction

Nowadays, analyzing different control systems is a must for virtually all types of modern industries and factories. Analyzing these control systems allows optimizing and streamlining processes, which in many cases are carried out manually, leading to large errors, delays and costly processes.

Continuous-time adaptive control of nonlinear systems has been an area of increasing research activity [1] and globally, regulation and tracking results have been obtained for several types of nonlinear systems [2].

However, the adaptive technique is gradually becoming more dynamic after 25 years of research and experimentation. Important theoretical results on stability and structure have been established. There is still much theoretical work to be done [3]. On the other hand, adaptive control in discrete-time nonlinear systems has received much less attention, in part because of the difficulties associated with the sampled data of nonlinear systems [2].

Thus, it is in some theories where adaptive control laws are implemented admitting the intervening nonlinearities in the real system [4] where investigations about the regulation of the system are created. The purpose of this is to implement a very simple adaptive control law and to check the convergence of the closed loop.

However, Zhongsheng Hou, author of several well-regarded papers proposes a model-free adaptive control approach for a class of discrete-time nonlinear SISO systems with a systematic framework [5]-[6].

Another article states that, instead of identifying the nonlinear model of the plant, a series of equivalent local dynamic linearization data models are constructed along the dynamic operating points of the closed-loop system using a new dynamic linearization technique (DLT) with a novel concept called the pseudo-partial derivative (PPD) [7]. Additionally, the author posits in papers such as "Model-free direct adaptive adaptive predictive control for a class of discrete-time nonlinear system" [8] and "A new approach to data-driven control for a class of discrete-time nonlinear systems" [6] among others; the following, because most adaptive control techniques and methodologies usually assume that the system structure is known to be linear, this motivates to study data-driven control approaches. Since, these focus on the design of a controller simply using input and output measurement data from a plant. Since such approaches do not require a model of a plant in the controller design, the modeling process, the unmodeled model of the dynamics and the theoretical assumptions about the plant dynamics disappear. For adaptive functional predictive control of a class of nonlinear systems, a theorem was derived where it is illustrated that the designed control system can track the set point with zero errors and that the input/output sequences are constrained [9].

In addition, the model-free adaptive learning control of a class of nonlinear discrete-time systems MISO. [10]presents the model free learning adaptive control (MFLAC) based on new concepts called pseudogradient (PG) for a class of nonlinear systems. No structural information, mathematical model, training process or external test signals are required.

Adaptive control is an incredible area for research, since it has multiple advantages over classical control techniques in the vast field of industrial application.

It is for the reasons described above that this paper provides an overview of the different applications and theories of adaptive control of discrete-time nonlinear systems.

2. The Concept of Control Systems.

Control systems, in different parts of the world, are the fundamental basis of a set of processes, consisting of numerous physical elements that are connected or linked together in such a way that they can regulate or direct processes, i.e., without the intervention of agents including the human factor, correcting errors that occur in its operation [11]. Because of this, is that a control system is characterized by performing a function, have a structure and present a behavior so that the resulting conformation is able to tolerate itself.

The way to implement control systems, has undergone an evolution over time, so you can set different phases and methods in its development, from processes carried out by trial and error based on intuition and accumulated experience, through the development of theories that led to control as many variables of interest in a process, to reach automatic controllers feedback, which apart from having the transfer function with its own dynamics, contemplate the coupling of sensor, sensor coupling, and automatic control of the process.The development of theories that led to control the largest number of variables of interest in a process, until arriving at automatic feedback controllers, which apart from having the transfer function with its own dynamics, contemplate the coupling of sensor, actuator and process. In general, the objective of a control system is to control the outputs in some prescribed manner by means of the inputs through the elements of the control system [12].

3. Adaptive Control

Adaptive control includes any control technique that modifies itself as the system evolves and according to the information provided by the system itself [4]. In a forum held in 1961 a large discussion ended with the following conclusion: An adaptive system is a physical system that has been designed from an adaptive point of view. A new approach was made by an IEEE committee in 1973 [13]. This committee proposed terminology based on the MCS (Medium Organization Control System) of adaptive parameters, a definition that helped to observe the regulator through software and hardware methods, in the same way it became clear that a constant gain feed is not an adaptive system.

The impact of adaptive control did not occur until 1980, when the microprocessor enabled cost-effective implementations. After this, the number of adaptive systems used industrially increased dramatically. The use of adaptive techniques in single-loop PID controllers also became feasible [14], in a way that this process is now a natural part of almost all new single-loop controllers for process control.

Ratia's view, "an adaptive control is a controller with adjustable parameters and mechanisms for adjusting those parameters [15]. This type of control is nonlinear and the same process state can be separated into two time scales that evolve at different rates. The slow scale corresponds to the parameter changes and therefore to the speed with which the controller parameters are modified, and the fast scale corresponds to the dynamics of the ordinary feedback loop" [16].

Similarly, Garrido says adaptive control addresses the problem of controlling plant output in the presence of parametric or structural uncertainties. In traditional adaptive control a linear plant with unknown parameters is assumed to make a problem more manageable. A controller structure is chosen and the parameters were adjusted by choosing an adaptive law, so that the plant output follows asymptotically to the reference [17].

On the other hand, Lazo and Minchala mention, "there are three types of adaptive systems: gain scheduling, reference model adaptive control (MRAC) and self-tuning control (STC)" [18].

"The introduction, the perspective adopted by the authors is that intelligent control is merely the ability of the control system to operate successfully in a wide variety of situations. The main idea introduced in this paper is the use of multiple models, each one of which corresponds to a different environment in which the plant may have to operate" [19].

"The last 40 years have born witness to the fantastic development and enhancement of adaptive control theory and application, which have been meticulously collected and presented in various scientific publications" [20].

Making a brief comparison of controllers "Standard PID must be based on known data, so the system is subjected to set specifications; on the contrary, for adaptive PID it is not necessary to know any data about the system, since the identification of its transfer function is performed in real time" [21].

"Although there are many applications of adaptive control, it is clear that adaptive control is not a mature technology" [14]. Thus, this area should be studied further, since adaptive control is extremely useful in control systems containing equations that are only partially known.

4. Nonlinear Systems in Discrete Time.

Discrete-time control systems differ from continuous-time control systems in that signals are available at one or more points in the system as pulses or as digital numerical codes. Discrete-time systems are divided into discrete data control systems and digital control systems. Typical data management systems refer to general discrete-time systems in which the signals are data pulses or square waves. In recent years it has been shown that nonlinear systems exhibit complex dynamics that cannot be approximated by linear models. Perhaps the clearest example is the Mandelbrot and Julia sets. These are the graphical representations of the infinite behaviors that are obtained by iterating a nonlinear equation [22].

Although many nonlinear systems can be linearized by representing them by means of a differential equation or in differences, modeling nonlinear systems with linear models involves many approximations. Often, these approximations do not sufficiently reflect the actual behavior of the nonlinear system [17].

"Identification is one of the essential points in control theory in the case when complete system information is not available. An effective solution is to use ANNs, as they have been shown to be a very useful tool for identifying complex nonlinear systems [23] even when the plant is considered a "black box" [24].

Dong proposes "A novel adaptive data driven control strategy is proposed for general discrete nonlinear systems" [25]. This control strategy is intended to be eventually applied to solve nonlinear tracking problems for discrete-time nonlinear systems.

In "Control of a class of discrete time nonlinear systems with a time-varying structure" a control methodology is presented for a class of discrete time nonlinear systems that depend on a possibly exogenous scheduling variable. This kind of systems consist of an interpolation of nonlinear dynamic equations in strict feedback form and can represent systems with nonlinear time-varying structure [26].

In "Model-free control of general discrete-time systems" the problem of developing a controller for general (nonlinear) discrete-time systems, in which case the equations governing the system are unknown, was considered. This presents an approach based on the estimation of a controller without building or assuming a model for the system [27].

Finally, in the last decade, the area of nonlinear systems control has become a forum for many researchers. This is further motivated by the fact that nonlinear systems are difficult to control, therefore, general methods for algorithm design are not yet fully developed.

5. State of Adaptive Control in Nonlinear Discrete-Time Systems

A diachronic approach to adaptive control in discrete-time nonlinear systems begins by pointing out that González, Graciela Adriana, mentions in her thesis the implementation of "an adaptive control law admitting the intervening nonlinearities in the real system. Previous results where adaptive techniques are applied on bilinear SISO systems are completed. Precisely, these are bilinear systems that lack a linear term related to control" [4].

Similarly, "the design and development of a robust, optimal and efficient predictive/adaptive control system has been presented, in that the system works with two types of controllers, an optimizer as the primary controller and a controlling neural network as the secondary or backup controller" [28].

From another perspective, the control strategy proposed here is applied to solve nonlinear tracking problems for discrete-time nonlinear systems. The traditional model-free control strategy is presented for comparison, and the feasibility and efficacy of the proposed adaptive data-based control strategy [29].

Therefore, there are several currents, for example, in this paper, they extend the results established in [2]and present a new periodic adaptive control for more general discrete-time nonlinear systems with a nonlinearities sector [1].

Hou's vision, on the other hand, proposes a new quasi-sliding mode adaptive control algorithm. Unlike most of the work reported so far for nonlinear systems, the proposed controller is a model-free scheme, requiring pseudo partial derivative (PPD) derived only from the I/O data of the system [30].

Nevertheless, the different experiences developed that allow us to understand the advances and applications of adaptive control in discrete time are presented below.

Title	Implementation
A class of nonlinear discrete-time system adaptive control based on second level multiple models	"In this paper, we design a controller based on SLAMM for a class of parametric strict-feedback nonlinear discrete-time system. And extending SLAMM from linear systems to a class of nonlinear system, increasing the application range of SLAMM" [31].
A Discrete-time Periodic Adaptive Control for Systems in the Presence of Nonsector Nonlinearities	"A new periodic adaptive control is proposed with Least-Squares algorithm for a class of discretetime systems to address for periodic parameters or periodic disturbances which can be rapidly time-varying" [2].
A novel periodicity-based adaptive control discrete-tieme nonlinear systems	"This work explores a new periodicity-based adaptive control method for nonlinear system. The proposed method can update the unknown parameters periodicall by using a project algorithm" [32].
Adaptive control in the presence of a general nonlinear parametrization	"We have developed globally stable adaptive controllers for a class of nonlinear dynamic systems in the presence of nonlinear parametrizations. By including tuning functions chosen using min-max optimization strategies, we show that nonlinear parameters which are known to lie in an interval can be stably estimated" [33].
Adaptive Control of Discrete-Time StrictFeedback Nonlinear Systems*.	"In this paper we introduce a completely different approach to this problem, which allows us to obtain a global stabilizing controller for discrete-
	time parametric strict-feedback nonlinear systems with unknown parameters without imposing any growth conditions on the nonlinearities. The traditional parameter estimator is replaced by a novel uncertainty identification scheme which, in a finite number

	of time steps, collects all the information necessary to completely identify the uncertain part of the system" [34].
Data-Driven Model-Free Adaptive Control for a Class of MIMO Nonlinear Discrete-Time Systems	"Based on a novel DLT, the data-driven CFDLMFAC, and PFDL-MFAC for a class of MIMO nonlinear discrete-time system are presented. It is shown that the MFAC method is a new adaptive control method, comparing with traditional adaptive control in the aspects of assumptions, designing and analysis" [7].
Direct Adaptive Control of Discrete-Time Nonlinear Systems Using an Input-Output Model	"A direct adaptive tracking control approach for a discrete-time nonlinear system represented in an input-output form with relative degree equal or greater than one is developed. A projectzon algorithm is used to identify the unknown parameters that in turn are utilized in the feedback linearizing controller" [35].
Switching Adaptive Control of a Class of Nonaffine Nonlinear Systems	"In this paper, a performance-oriented switching adaptive control based on adaptive neural networks control and model-free adaptive control is proposed for a class of non-affine discrete time nonlinear systems. The method is composed of adaptive neural networks control, model-free adaptive control and a switching mechanism" [36].
Adaptive Data Driven Controller for Nonlinear Systems	"In this paper, the proposed control strategy is applied to solve nonlinear tracking problems for
	discrete-time nonlinear systems, as well as nonlinear near-optimal control problems. The traditional model-free control strategy is introduced for comparison, and the feasibility and effectiveness of the proposed adaptive data driven control strategy is well demonstrated through simulation comparison results" [37].
Adaptive Control for a Class of Time-varying Uncertain Nonlinear Systems	"This paper develops an adaptive nonlinear control scheme for time-varying parametric uncertain nonlinear system with completely unknown time-varying bounded control coefficient. The proposed design method does not require any a priori knowledge of the sign of the unknown time-varying control coefficient, based on incorporating Nussbaum function gain and smooth projection algorithm into backstepping" [38].
A Novel Nonlinear Adaptive Data Driven Control Strategy	"A novel adaptive data driven control strategy is proposed for general discrete nonlinear systems. The controller is designed based on the Simultaneous Perturbation Stochastic Approximation (SPSA) method, and is constructed through use of a Function Approximator (FA), which is fixed as a neural network here" [29].
Adaptive Estimation of Discrete Time Systems	"This paper reports a new estimator that generates globally stable parameter estimates for discrete-time systems which include both linear and nonlinear parametrizations. Adaptive algorithms distinct from the traditionally employed gradient approach were introduced to achieve this stability property" [39].

Indirect Adaptive Fuzzy Control for a Class of Nonlinear Discrete-Time Systems	"An indirect adaptive fuzzy control scheme is developed for a class of nonlinear discrete-time systems. This method does not need the bound of approximation error because the unknown bound is estimated using the adaptation law and the size of time-varying dead-zone is adjusted adaptively with the estimated bound" [40].
Localization Based Switching Adaptive Control for Time-Varying Discrete-Time Systems	"In this paper a new systematic switching control approach to adaptive stabilization of linear time- varying (LTV) discrete-time systems is presented" [41].
Periodic Adaptive Identification and Control for a class of Discrete Time-varying Systems	"A new periodic adaptive control is proposed for discrete-time systems to deal with periodic parameters or periodic disturbances which can be rapidly time-varying. The only prior knowledge needed in the periodic adaptation is the periodicity" [42].
Adaptation and Learning Using Multiple Models, Switching, and Tuning	In using N fixed models and one adaptive model to control the system, this method can improve the transient response of the plant [43].
Adaptive Control Using Multiple Models	In using all adaptive models or combination of adaptive models with fixed models were proposed for the linear time system [44].
On Model-Free Adaptive Control and Its Stability Analysis	"In this paper, the main issues of model-based control methods are first reviewed, followed by the motivations and the state of the art of the model-free adaptive control (MFAC)" [45].
Adaptive control of a class of nonlinear discretetime systems	"We consider adaptive control via state feedback for a class of feedback linearizable discrete-time systems. To parallel the development in adaptive nonlinear continuous-time control, we employ a
	systematic procedure to design the controllers and the update laws for the so-called parametricstrict-feedback form and the parametric-purefeedback form" [46].
Event-Triggered Adaptive Fuzzy Asymptotic Tracking Control of Nonlinear Pure-Feedback Systems With Prescribed Performance	"This article considers the problem of fixed-time prescribed event-triggered adaptive asymptotic tracking control for nonlinear pure-feedback systems with uncertain disturbances. The fuzzylogic system (FLS) is introduced to deal with the unknown nonlinear functions in the system" [47].
Lazy-Learning-Based Data-Driven Model-Free Adaptive Predictive Control for a Class of Discrete- Time Nonlinear Systems	"In this paper, a novel data-driven model-free adaptive predictive control method based on lazy learning technique is proposed for a class of discrete-time single-input and single-output nonlinear systems" [48].

6. Conclusions

Considering the results and conclusions drawn from the various studies reviewed, it is evident that there is still a significant gap between the studies and the progress made in the development of this subject. This, however, tends to decrease with the passage of time.

Most adaptive control techniques and methodologies generally assume that the system structure is known to be linear and the parameters may be unknown or vary slowly over time. However, for complex practical systems, the plant structure is often difficult to determine and parameters are hard to detect, which calls adaptive control design and applications into question.

The effort made by the additional university institutions of the different research departments in recent years is on the right track as they focus on promoting further research advances and applications of the progressive use of adaptive control for discrete-time nonlinear systems.

Finally, it is expected that the mathematical advances of the different algorithms and applications developed will bring the adaptive control of nonlinear systems to such a point of maturity that everything proposed will allow the various fields of use to continuously contribute to the evolution of science in a more robust and firm way.

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