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Switched constrained linear adaptive identifier for the trichloroethylene elimination in sequential upflow anaerobic sludge blanket

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ABSTRACT

Sequential processes appear naturally in all types of industries. Biotechnology is a good example of such schemes. Wastewater treatment using microbiological activity is a particular case having all the characteristics of sequential methods. Sulfate reduction as pre-treatment followed by the decomposition of sulfated compounds using adapted microorganisms is the sequential nonlinear process with state constrains analyzed in this paper. Modeling this procedure is still a difficult task because the number of elements involved in the reaction. This paper presents an adaptive algorithm to obtain a suitable model of this process using continuous neural networks. The adaptive model preserves the sequential nature of the process as well as the bounded nature of all states. The neural network is proposed as a system identifier in terms of the hybrid systems theory. The Lyapunov stability method is used to demonstrate the convergence of the identifier states to the real concentrations of the microbiological system. Experimental results and their corresponding simulation using the adaptive model based on neural networks confirm the theoretical results described in this paper.

1. Introduction

Recent different reports indicated that sulfate reduction (SR) is an alternative to be used in wastewater treatment from many types of industrial effluents containing high sulfate concentrations [1–3]. This treatment method based on SR has been used to eliminate complex and very toxic organic pollutants such as trichloroethylene (TCE) [4].

In fact, some studies have described several experimental methodologies based on microorganisms that can be adapted to the sulfate presence that lately can be exposed to the toxic pollutant [5]. Microorganisms are adapted to increase their ability to degrade complex contaminants [6]. This strategy has shown remarkable results to eliminate different contaminants with high concentrations and cytotoxicity. In recent research studies, the biological process of SR was used for the biodegradation of TCE to

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less toxic compounds such as ethene using an upflow anaerobic sludge blanket (UASB) reactor inoculated [7] with hydrothermal vents sediments.

In this class of reactions, the microorganisms are kept in the reactor due to the production of the highly flocculated, well settling and compact sludge granules [8]. Despite the benefits offered by this type of reactions, several difficulties appear when the experimental setup is operated. These drawbacks also include the selection of the reaction regimen: batch, semibatch or continuous [9].

When the continuous reaction is carried out, the operation conditions play a very important role to optimize the reactor performance [10]. Usually these conditions are adjusted by special laws developed by different automatic methodologies. However, two issues must be solved before the controller can be implemented: the first one deals with the usually necessity of the mathematical model describing the reaction and the second one is associated to the number of variables that must be measured on-line to construct the controller. Actually, these two problems occur when just one single stage is considered (the SR to hydrogen sulfide). The complexity of this problem is severely increased when a second reaction stage is proposed. In this second process, the main contaminant (TCE) is eliminated [11].

The particular study considered in this paper includes an additional problematic: the second stage aggregates new compounds to the reactor that were not there in the first stage. These contaminants appear when the second stage is started after the microorganisms have been previously adapted in the first stage. Therefore, the problem stated in this paper should be considered within the hybrid systems theory. Moreover, this process is by nature, a very nonlinear system with high degree of uncertainties. One extra inconvenience to design a possible controller relies on the state restriction coming from the nature of variables involved in the reaction.

One possible solution to the problem introduced above may be solved using a class of adaptive identifier [12]. This state approximation must be adjusted by the on-line available measurements but considering a general model that maybe does not have any mathematical relationship to the model of the reaction system. Then, the identifier should be constructed based on two main areas: the no parametric approximation methodology [13] and the hybrid nonlinear systems theory [14]. Besides, we tried to design an identifier possessing properties that can simplify some eventual designs based on the approximated model generated by the identifier.

In this sense, scientists as well as technicians have taken advantage of the linear representation of many systems (represented by ordinary differential equations), to use the well known and fully described linear system theory, considering that such approach has been tested many times with a high level of success. Therefore, the identifier is designed to generate an adaptive almost linear approximation of the uncertain system A wide number of linearization approaches have been reported and implemented, in order to obtain a linear representation, from the knowledge of the nonlinear model. Among these approaches, one can find: Jacobian Linearization [15], Carleman Linearization [16], Feedback linearization [17], Linearization via changes of variables [18], linearization by Taylor's method [19], etc. In this sense, the main worry of a researcher is the fulfillment by the system, of the complete set of conditions, imposed by the selected linearization method.

While linearization approaches are known, all of them have shown that it is necessary to know the model in order to replace some of the variables with other ones that linearize the system. If the model is not available, it is necessary to have many values in a period of time and then create the model and linearize it point by point. But,when the model is unknown and the data in every point are not available, it is a challenging problem. Considering the problem described above, the adaptive model method recently described should include the state restriction defined by the nature of variables describing the reactor dynamics. Few methodologies have been developed using adaptive frameworks to overcome the problem recently discussed. Within the field of adaptive linearization, there are some results which have been recently published [20–23]. Several papers introduce the adaptive controller design based on exact linearization methods [13,24–26].

This study presents an alternative method to linearize the uncertain system representing the UASB reaction while keeping the structural properties. The concept of adaptive linearization, may be formulated as the application of a Continuous Neural Network (CNN) to adapt all parameters affecting the UASB reaction, no matter the type of mathematical model considered or its complexity. This means that the set of adaptive ordinary differential equations, proposed with the CNN is able to converge with the system and, despite the noise in the signal or the particularities of the model including the state restrictions, the CNN should be adapted to the trajectories of the uncertain perturbed nonlinear system .The method described in this manuscript has the capability to approximate the model while linearizes the response in a short period of time, as the same time that remainder nonlinearities are estimated. It is worth to remark that such suggested method maintains certain structural properties, particularly the controllability. Such approach is well known in the field of automatic control as *neural network observer*. The core of this estimator is a set of orthogonal functions which are combined in a lineal way by some adaptive parameters.

The identifier designed in this paper considers the combination of different methods. Therefore, the problem analyzed deals with the construction of an adaptive linearization of uncertain hybrid systems considering state constrains This paper is organized as follows: section 2, includes the discussion about the class of systems represented by Ordinary Differential Equations (ODE) describing the sequential system described above. The same section is presenting the main structure of the CNN identifier. In Section 3, the main theorem about the convergence of the CNN identifier is presented, with some comments and remarks. Section 4 shows the application of the proposed identification algorithm to SR as pretreatment followed by the decomposition of sulfated compounds using adapted microorganisms. Finally Section 5, introduces our final comments and conclusions.