ROBUST FEEDBACK LINEARIZATION CONTROL BASED ON EXTENDED STATE OBSERVER APPLIED TO AN INDUSTRIAL CSTR

**Abstract**

In the chemical and petrochemical industries, the Continuous Stirred Tank Reactor (CSTR) is, without doubt, one of the most popular processes. From a control point of view, the mathematical model describing the temporal evolution of the CSTR has a strongly nonlinear cross-coupled character. Moreover, modeling errors such as external disturbances, neglected dynamics, and parameter variations or uncertainties make its control task a very difficult challenge. This problem has been the subject of a wide number of control strategies. This article attempts to propose a viable, robust nonlinear decoupling control scheme. The idea behind the proposed approach lies in the design of two nested control loops. The correlation between the results of the relationship between the inner loop and the outer loop is visible in the abstract. The inner loop is responsible for the compensation of the nominal model's nonlinear cross-coupled terms via a static nonlinear feedback; while the outer loop, designed around an Extended State Observer (ESO), which the additional state gathers the global effect of modeling errors, is charged with instantaneously estimating and then compensating the ESO extended state. This way, the CSTR complex dynamics are reduced to a series of decoupled linear subsystems easily controllable using a simple Proportional-Integral (PI) linear control to ensure the robust pursuit of reference signals respecting the desired performance is visible on the abstract . The presented control validation was performed numerically by an objective comparison to a classical PID controller. What is conclusion?

Introduction

mathematical rigor of the original approaches or to alleviate some disadvantages presented by the

previously cited controls. However, in the midst of this theoretical revolution in the control field, industry appears uninterested in most of the proposed modern control approaches by presenting a high inflexibility for PID control, despite its shortcomings despite improvements introduced over the last decades. This is most likely due to their pragmatic way of thinking, which aims most of the time to achieve a sufficiently acceptable compromise between controller design simplicity and required performance. But on the other hand, it seems that it is missing out on the opportunities offered by the great digital revolution as it cannot fully profit from the modern digital processors'

capacities [9, 10]. Born as a necessity to establish new bridges between modern industry demands and modern control advances, Active Disturbance Rejection Control (ADRC), introduced for the first time in the original text in [37] and a few years later for Anglo phone society in [38], was the fruit of a long work fed by a deep understanding of both practitioners' and academic researchers' way of reflecting when it comes addressing to control systems problems, the constraints and challenges facing them, and the opportunities offered by the accelerated development of digital technology. Even the ADRC original framework is composed of three main components; the Extended State Observer (ESO) represents the controller cornerstone. The ADRC idea is based on the real time estimation and then the compensation of the total influence of the model nonlinearities combined with the different disturbance types such as external disturbances, modeling errors, and parameter variations or uncertainties, etc. The global effect of model nonlinearities and disturbances is considered as the observer-augmented state. ESO-based robust control, including the ADRC original version, has demonstrated an unmistakable viability to address a wide range of practical control applications owing to its great potential for dealing with a wide range of disturbance structures before even having a rigorous proof of theoretical fundamental questions such as ESO convergence or closed loop stability that came several years later [39-43]. Moreover, it has shown high flexibility to handle many more applications than PID control, such as time-delayed systems control, multivariable decoupled control, cascade control, and parallel system control [10]. Also, ESO-based control has made some major advances in the context of its generalization to much more complex problems in the last few past years, citing as examples:

stochastic systems control [44] and distributed parameter control systems [43]. Motivated by the huge potential, the simplicity of the design procedure, and the wide immergence of the ESO based robust control paradigm in simulation and engineering applications, readers can refer to the literature [45–49]. In this paper, we attempt to illustrate how to use the ESO for improving multivariable decoupled control robustness in a simple and clear manner. The proposed method's main idea lies in the use of conventional exact feedback linearization control, widely used for dealing with multivariable affine nonlinear plants, in association with an extended state observer charged with real-time estimation and then compensating for the whole effect of modeling errors caused by the total difference between the real plant dynamics and the nominal descriptive model used for the design of the decoupling static state feedback. The desired, robust closed-loop dynamics are achieved using a proportional-integral controller in a second external loop. The present article is organized as follows: After presenting this introduction, the second section is devoted to the process presentation and the modeling. Then, the theoretical development of the proposed control is exposed in detail. Once the process model and the control are presented, simulation results are shown and commented on in the third section. Finally, the conclusion

summarizing and giving future perspectives is given in the fourth and last section. What is the gap research, what is the novelty in this research

Result

When parameter uncertainties and variations are equal to zero, the responses of the CSTR under both proposed controllers shown in Figure 3, remain very close to the desired set point after the transient phases. It is also clear that the ESO based robust feedback linearizing controller ensures a better decoupling between the controlled outputs and a faster convergence of the product concentration to its desired value when the process is started.The strong inertia of the process against the conventional PI controller disappears after a certain elapsed period of time,thus allowing a better convergence rapidity when the desired value changes because the corresponding closed loop pole in the neighborhood of the operating point was chosen in the left part of the Laplace plane ten times further than those corresponding to the ESO based robust F-L controller. Concerning the temperature responses, it clearly demonstrates that the conventional PI control exhibits a slightly superior convergence speed, although the closed loop poles were chosen the same. This result is due to the fact that for the conventional PI control, the closed loop temperature dynamics are regulated

What temperature range is set?

as a first order subsystem, whereas they are chosen as a second order critically damped subsystem for the ESO based robust controller. The control signals depicted in figure 4 confirm the high inertia of the controlled process against the conventional PI controller by illustrating the high control effort needed to achieve the desired values when the process is started or when the set point changes. This remark is more evident for the supply control flow FL. From Figure5, it is seen clearly that the convergence of the proposed ESO is very satisfactory. The estimate of the total modeling errors, assumed unknown and considered as an additional state, remains near zero. This expected result is logical since in this scenario the model parameters’

Results discussion when the process is operating in presence of parameters uncertainties or variations In scenarios 2 and 3, our aim was to compare the transient and steady performances of the proposed controllers under the suppositions of uncertain or time-varying parameters. Figures 6 and 9 display the obtained results for different product compositions as ESO based robust controller gains corresponding to two different closed loop pole placements. The results presented in figure 6 show clearly that even nominal performances were considerably degraded; both controllers were able to achieve sufficiently good control performance in the presence of parameter disturbances in the sense that the system responses were maintained around the desired values within a narrow band. By re-tuning the ESO based F-L controller gains in such away that the concentration closed loop poles are the same as those corresponding to conventional PI, it is obvious that the control performance shown in Figure9 is highly enhanced, exceeding largely those obtained with conventional PI. As for scenario 1, Figures 7, 8, 10, and 11 represent the control signals and ESO observed states for tests 2 and 3, respectively. From curves 8 and 11, it is clear that the product composition and temperature estimates converge with accuracy to their respective measurements; and as expected, the estimates of the supposed unknown parameter disturbances are different from zero since in this scenario, the system model was subject to a wide range of uncertainties and parameter variations. The comparative study presented in the discussion given before is summarized based on the error rooted mean square criterion in Table

VI. CONCLUSION The aim of the study presented in this article was to propose a viable extended state observer based robust feedback linearization controller to overcome the shortcomings of conventional PID control design, based on a locally linearized model, when it is applied to control an industrial CSTR. After giving the detailed synthesis approach, presenting the simulation results of the proposed control strategy, and finally comparing objectively these obtained results with respect to the conventional PI controller, we came to the conclusion that even though the conventional control approach gives very acceptable control performance in the presence of modeling errors, the proposed controller offers not only the advantage of being to achieve better set point tracking performance with adequate parameters tuning, but also, it presents a much wider tolerance to a very wide set of disturbance types Does the disturbance have a small or large impact? and sources encountered in real applications and not presented in this simulative study. At the end, notice that the proposed ESO based robust control design can be significantly simplified by merging the inner and the outer loops, tacking advantage of the ESO’s capacity to compensate for the model nonlinearities. This perspective will be the subject of a future work.

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Conclusion: Does the disturbance have a small or large impact?