International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Industry 5.0 based on Hybrid and Nonlinear Systems in Robustness

K. P. Manikandan[1], A. Saravanan[2], A. Kadirvel[3], D. Venkata Subramanian[4], Anitha Jaganathan[5]

Submitted: 16/11/2023 **Revised:** 28/12/2023 **Accepted:** 08/01/2024

Abstract: For wireless communications offered by smart grid technology to be successfully integrated with Industry 5:0 applications, secure and dependable wireless communication technologies are necessary. Our paper presents some of the most current findings regarding hybridization techniques used in nonlinear system analysis. Utilizing the hybrid systems methodology as a methodical approximation technique is the fundamental concept of our hybridization strategy. An overview of current advancements in hybrid controller design for continuous-time control systems with differential state equations that are either linear or nonlinear is given in this work. For both linear and nonlinear systems, hybrid controllers offer an extension of classical feedback controllers. It is stressed that hybrid controllers have the advantage of being able to accomplish closed-loop performance goals that are unachievable with traditional linear or nonlinear controllers. In this paper, switching control architecture—a sort of hybrid controller—is presented, and an overview of newly created control strategies that make use of this control architecture is given. Through simulations with an example of a chemical process, the robust hybrid predictive control structure's application and effectiveness are shown. As a result, the proposed theory offers a wealth of opportunities for further research into hybrid system stability and model predictive control, as well as for future practical applications.

Keywords: *Effectiveness; Hybrid System; Nonlinear Systems; Industry 5.0; Hybrid Controller*

1. Introduction

A wide range of engineering systems and natural phenomena can be effectively modeled mathematically by systems that exhibit both discrete and continuous motion, as well as mixed systems. A chemical batch plant is a well-known example, where complex chemical reaction sequences are monitored by a computer, with each reaction represented as an ongoing process. In addition to the discontinuities caused by the computer, the majority of physical processes involve discrete components and phenomena (such as collisions and tank emptying) that are best described by discrete frameworks. Numerous fields, including molecular biology, aviation, robotics, automotive, and chemical process control, use hybrid system models.

Formal evaluation is a topic of special fascination because many of these applications include properties that are crucial to safety [1]. Formal verification looks to show that the (planned) system meets a property, whereas controller synthesis tries to construct a controller that will operate the system to satisfy a desired specification. The intricacy and scope of real-world applications make autonomous analysis highly desirable. This serves as justification for using the algorithmic approach, which entails developing software tools capable of automatically analyzing behavior exhibited by a certain system. While there has been significant progress in developing theoretical frameworks and practical instruments for the algorithmic examination of hybrid systems, there is still a dearth of applications of this research to real-world issues. An efficient approach for handling the differential equation-defined continuous dynamics of hybrid systems is an essential component of any methodology used for their analysis. Although affine or piecewise affine systems in Figure 1.1, along with other smaller systems, have many well-known properties, nonlinear systems are much harder to analyze, can be used to develop reasonably effective approaches.

[1]*Assistant Professor, Department of CSE (CYBER SECURITY) Madanapalle Institute of Technology & Science, Kadiri Road Angallu Madanapalle, Andhrapradesh - 517325.*
Email: manikandankp@mits.ac.in
ORCID: 0000-0003-4685-1751
[2]*EEE, Smk fomra Institute of Technology, Fomra Nagar, Omr It Highway, kelambakkam, Chennai 60103.*
Email: saravanandr2006@gmail.com
ORCID: 0000-0001-6367-6735
[3]*Professor, Mechanical Engineering,*
R.M.K. Engineering College, Kavaraipettai, Thiruvallur District, Tamil Nadu, India.
Email: kadirvel73@gmail.com
ORCID: 0000-0001-6238-6867
[4]*Professor, Department of Information Technology*
Prince Shri Venkateshwara Padmavathy Engineering College, Ponmar, Chennai.
Email: venkatasubramanian.d.it@psvpec.in
ORCID: 0000-0002-5244-176X
[5]*Assistant Professor, Department of Artificial Intelligence and Data Science*
Panimalar Engineering College, Chennai.
Email: anitha@panimalar.ac.in
ORCID: 0009-0002-7773-0469

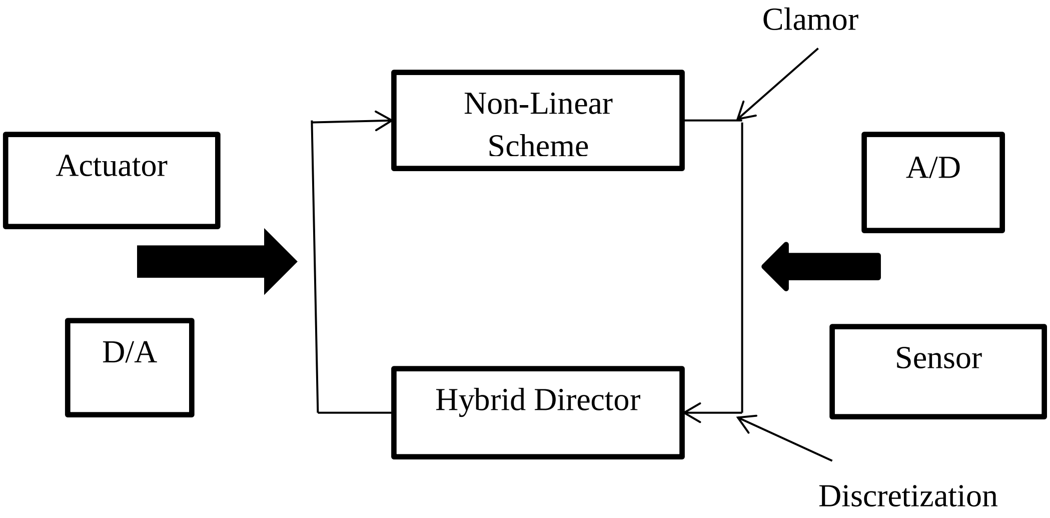

Fig. 1.1. Handling a nonlinear system with hybrid control while accounting for certain disturbances encountered in practical situations

Industry 5.0 acknowledges that industry has the potential to contribute to social goals beyond job creation and development, to become an environmentally friendly means of growth by putting worker health first and considering environmental constraints in production. Industry 5.0 helps to meet the industry's need for technology advancement so that it can be a dependable system for those seeking a happy and healthy career. It prioritises worker welfare and uses emerging technology to produce revenue beyond employment and growth while respecting the boundaries of the planet [2]. It fulfills workers' evolving skill and training needs while also empowering them. It increases industry competitiveness and draws in top talent. Industry 5.0 is being implemented by the Commission with three goals in mind: "Europe fit for the digital age," "an economy that works for people," and "a European Green Deal." As a result, the foundation of Industry 5.0 is not technology but rather values like a social benefit, environmental stewardship, and human-centricity. This reorientation is based on the idea that values can be promoted by technology and that ethical goals can inform technological innovation rather than the other way around.

The structure of the paper is as follows. We go over the model we use to describe hybrid systems in Section 2. After that, we go over a few frequent characteristics of hybrid systems and quickly go over the previous findings about algorithmic analysis. The fundamental definitions and notations required for the topics that follow are included in this section. We go over the key tenets of our hybridization strategy in Section 3. In Section 4, we demonstrate the method's key characteristics and provide a comparison between our approach and earlier findings. We present two efficient techniques for creating hybridizations in Sect. 5. The final section includes a few examples that show how we work.

2. Literature Review

Masoomi, B., et.al [3] It is possible to use FWASPAS as linguistic variables. This benefit could be rather useful if opposing factors are taken into account when making a decision. As a result, the recommended integrated technique might be more applicable to real-world issues related to decision-making. The integration of decision-analysis tools with various aspects allows for the efficient and quick handling of complex decision-making processes. The study's findings will pinpoint the most important and suitable benefit for attaining durability in the ongoing industrial expansion—society involvement and a more expansive sustainable RESC.

Ullah, K., et.al [4] Receiving antennas for Kr are installed on every smart grid equipment to obtain the information that the BS sends. However, the system has an active eavesdropper that can simultaneously broadcast and receive data because it is proficient in both jamming and eavesdropping. Therefore, we will simply refer to it as the eavesdropper equipped with Ki receiving antennae that tries to intercept the secret data being transferred from the BS to the smart grid devices. In order to interfere with smart grid devices and lower the signal-to-interference-plus-noise ratio, a jammer equipped with Kl transmitting antennae is also utilized.

Mirza, M. A., et.al [5] Getting rid of processing, waiting, and delay transmission is the main goal of task offloading. Nevertheless, there are significant obstacles to task offloading in automotive edge computing systems due to their dynamic and complicated characteristics. These obstacles include latency constraints, resource limitations, network variability, mobility, and high computational demands. To meet these issues, creative solutions are needed to manage their complexity and provide accurate results quickly. To overcome these challenges, RL/DRL techniques can be applied, which involve learning directly from the surroundings.

Abdul-Nour, G. G., et.al [6] Organizations' futures are being shaped by Industry 4.0, which is causing radical shifts in how businesses operate. There will be a lot of new challenges and hazards associated with Enterprise Risk Management and Occupational Safety and Health limitations and requirements since there will inevitably be a shift towards a growing number of digital technologies. Severe cyberattacks, digital technology interconnectedness and system interoperability, process standardisation and reengineering, acquiring and storing vast amounts of data, digital supervision, upkeep, and hiring, developing, and retaining talent in the workplace are a few examples.

Bakon, K., et.al [7] Our objectives are to give a general overview of how uncertainty influences Industry 4.0 problem solutions and to go over the key solution techniques that are crucial to this problem domain's resolution. Next, we demonstrate how these solution approaches may be applied to produce manufacturing-grade outcomes and how they can be leveraged to develop long-term research opportunities. The goal of the Industry 4.0 guiding concept was initially to increase productivity, revenue growth, and competition rather than to address the ecological issues that production was facing. Pettersson, S., et.al [8] Additionally, robustness properties are obtained and demonstrated once the auxiliary functions that allow for the determination of stability have been identified. In 1121, robustness concerns for hybrid systems are measured and the impact of continuous parameter fluctuations on performance is examined. Stability robustness—the degree to which a stable nominal hybrid system can be altered without turning unstable—is the primary focus of this work. Specifically, the method for obtaining areas surrounding the nominal switch sets—which show when discrete state changes are necessary—will be detailed.

Pettersson, S., et.al [9] Different, more or less conservative energy limits are proposed in the current stability theory for hybrid systems. As an illustration, certain outcomes call for the energy to drop in a region, while others call for the energy to drop when a region is re-entered. The overall energy behavior of the hybrid system determines whether or not it is stable, as this study will demonstrate. Because of this, the energy in the most general stability conclusion given here can behave fairly randomly locally; it can rise both inside a hybrid region and when it enters a new region. The energy is merely limited in that it cannot be greater than the starting energy.

Li, Z. G., et.al [10] At least two continuous variable dynamic systems arise infinitely often during the HNS's infinite running cycle since there are only a limited number of CVDS in the infinite switching HNS. The Lyapunov functions are limited within each cycle by continuous functions that are structured. The Lyapunov functions don't increase towards the end of the cycle. Some adequate conditions for the robust stability of HNS are derived using these. The HNS doesn't need to be periodic to meet these requirements. This means that, in the case of aperiodic HNS, when the switching sequence is irregular, we can also address this issue.

3. Methods and Materials

3.1 Exposure of hybrid controllers

In the past, linear feedback-based control structures have been the most popular kind. The use of control Lyapunov functions, feedback linearization, passivity, adaptability, and other methods in the design of classical nonlinear controllers has grown significantly in the last several years. The resulting feedback controllers in each of these scenarios are smooth in the sense that the feedback variables are, at the very least, continuously differentiable functions. Here, we address control designs that incorporate discontinuous or switched feedback, contrary to these linear and smooth nonlinear feedback-controlled architectures. The notion of a hybrid controller, as it is presented in this work, is not new; ideas along these lines were proposed two decades prior [11]. We do not address hybrid controllers that result from the use of conventional relay controllers, which are based on linear switching functions and have been extensively researched in the literature, even though there is a significant link. Additionally, we do not address the related fields of fuzzy control and variable structure control, which have both attracted a lot of attention recently. Instead, we address logic-based switching discontinuities and "higher level" abnormalities in the controller.

The block diagram in Figure 3.1 serves as a representation of hybrid controllers in this paper. Stated differently, the supervisor chooses a certain feedback component from the family at each instant in the hybrid control architecture, which is made up of a collection of linear or smoothing nonlinear feedback units. The choice of the feedback function and when it is changed is under the supervisor's authority. These hybrid controllers, which are the most extensively researched kind of hybrid controllers, are frequently referred to as logic-based switching controllers. However, distinct classes of hybrid control structures are covered by different papers in the current issue on hybrid systems.

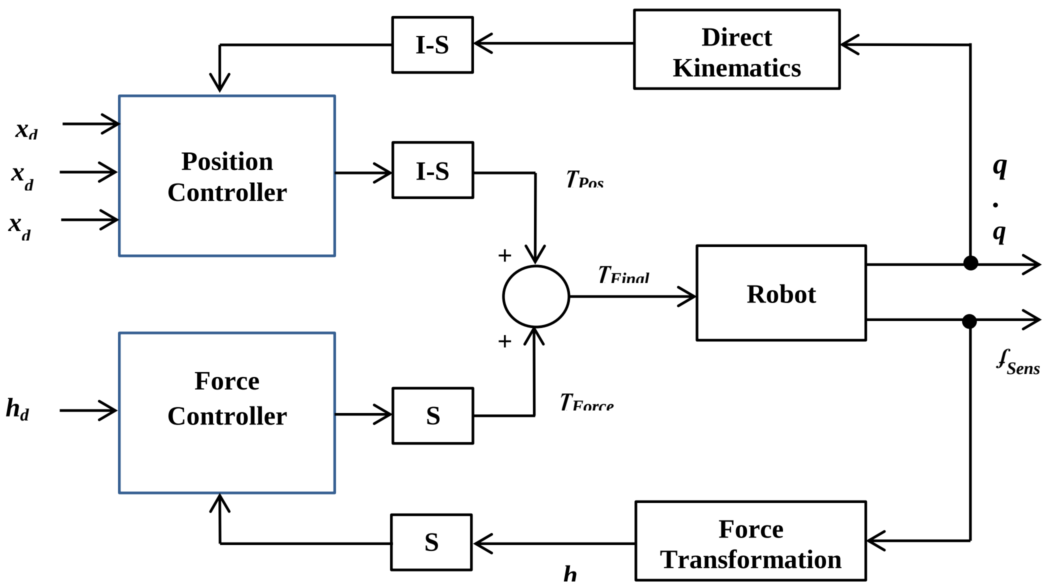

Fig. 3.1. Hybrid Control System's Model

By providing control variable data or a feedback function index, the supervisor can designate which feedback function should be activated. The supervisor may incorporate delays, dynamics, or other memory components, in addition to the family of feedback functions. The supervisor can be event-driven, meaning that switching happens in response to a state partition or a state-dependent changing condition, or time-driven, meaning that switching is planned by a clock, much like in a digital controller. Popular hybrid control architecture, automata models, facilitates switching between feedback processor selections through the supervisor's structure. The supervisor must avoid switching between feedback functions an infinite number of times in a finite amount of time. There are several approaches to accomplish this, as the sections that follow illustrate. The specification of the changing logic as well as the family of input functions is necessary for the full hybrid controller's design. The selection of the family of feedback functions is typically contingent on the particular challenge and is not well-guided in the published literature. By the literature in this area, the majority of our attention going forward is focused on specifying the switching logic under the assumption that the family of feedback functions has already been specified.

3.1.1 Hybrid management for enhanced closed-loop aspects

Better closed-loop performance can be obtained with hybrid controllers than with either smooth nonlinear or classical linear controllers. Here are some reasons why hybrid control is necessary: The hybrid closed loop can, to some extent, reflect various performance attributes connected to the closed-loop attributes given by each distinct feedback function if the hybrid controller is properly defined. A somewhat different way to put this is this: the efficiency of a hybrid closed loop can outperform the efficacy that can be obtained by any fixed feedback loop without switching, which is the purpose of using hybrid control. The realization of this promise is demonstrated by the findings we will subsequently give.

This section covers several traditional control objectives and shows how hybrid controllers can be used to accomplish these objectives. The advantages of these monitors are illustrated with a few basic examples.

- **Enhanced Reaction Time**

Improving the response time, for example, to a step input instruction, is a classical control goal. Hedgehog controllers may frequently provide even faster responses with less overshoot than classical feedback controllers, which are typically set to achieve fast closed-loop answers. A common strategy is to employ a hybrid controller, which alternates between a linear controller close to equilibrium and a time-optimal or nearly time-optimal controller when the system is far from equilibrium [12]. Switching is involved with minimum-time controllers, which are often of the bang-bang variety. Minimum-time controllers may surpass realistic actuator bandwidth or chatter when the control error is modest, either because of noise or discrete-time modelling design that excites high-frequency dynamics. When the minimum time controller significantly reduces the error in this case, it makes sense to convert to a linear controller. If the origin is included in a positively invariant set, chattering can be prevented in the region where the linear controller is active. If all goes according to plan, the state will stay in this region until the minimum-time controller takes it there. A popular method for designing numerous hybrid controllers is to use switching logic to produce a globally appealing, positively invariant collection.

$$y_1 = y_1, y_1 = y_2 \qquad (1)$$

The controller's goal is to move the read/write head as quickly as possible to the point that matches the intended track. The zero value is associated with the chosen track. The minimum-time controller function is preferred in this application for significant faults; a linear control function is suggested to prevent chattering for minor errors. The hybrid controller that combines these two feedback mechanisms is represented by the following:

$$-y_1 y_1 - y_1 y_1, \quad if\ (y_1, y_1) \in \cap \qquad (2)$$

$$v = -2, \qquad if\ (y_1, y_1) \in \cap, y_1 > -\frac{1}{2}\, y_1 |y_1| \qquad (3)$$

$$+2, \qquad if\ (y_1, y_1) \in \cap, y_1 > -\frac{1}{2}\, y_1 |y_1| \qquad (4)$$

where ∈ the term "sublevel set" is defined.

$$\in = \quad \{\ if\ (y_1, y_1) \in \cap, y_1 > -\frac{1}{2}\, y_1 |y_1|\} \qquad (5)$$

As was already indicated, a large body of research has been done on the stability analysis of hybrid systems employing Lyapunov techniques. In theory, a large portion of this material can be used to build hybrid controllers for specific linear or nonlinear control systems. These techniques frequently also enable control over the reaction speed, which is demonstrated by the rate at which a Lyapunov function—or Lyapunov functions—that are understood as generalized energy decreases. Rebooting the state of a dynamic controller to a nominal value, such as zero, has been proposed as a related strategy for increasing reaction speed. This is intended to produce a notable, discontinuous decrease in the Lyapunov function's rate of change.

- **Optimality**

About a particular scalar cost metric, hybrid controls can also be utilized to achieve nearly optimal closed-loop responses. Specifically, if a family of feedback functions is predetermined, switching controls between members of the family can yield better closed-loop achievement than any controller defined by a single feedback function throughout the family, about the given cost measure. In other words, the performance achieved by utilizing a hybrid controller ought to be comparable to that of utilizing a single feedback function in the absence of switching. Productivity using a hybrid controller is often significantly better.

Since it is frequently impossible to determine an ideal feedback controller for any but the most basic system behaviors and cost measures, this technique has significant practical ramifications.

$$y = g(y) + h(x)u \qquad (6)$$

The ideal control, which minimizes and asymptotically stabilizes the origin

$$K = \int_1^{\partial} K(u, y) ef \qquad (7)$$

It is assumed that all of these feedback functions are asymptotically stable and that a matching family of Lyapunov functions satisfies this requirement, even though none of them is ideal.

3.2 Identification of Non-Linear Systems

The internal impedance's modest magnitude makes measurements difficult. Traditionally, the EIS is used to analyze the battery's internal impedance and identify additional electrochemical systems. Batteries are stimulated with sinusoidal current during the EIS tests, causing a shift in the terminal voltage that provides the impedance. However, because the approach involves injecting sinusoids with varying frequencies, the EIS operates rather slowly.

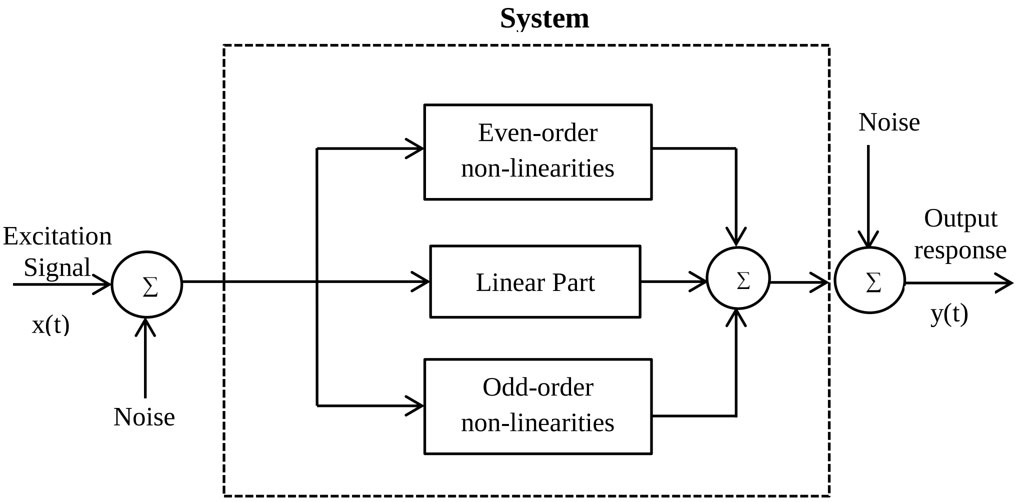

Fig. 3.2. Non-Linear Systems

This adds up to an unfavorable long total measuring time for online apps. Another issue with the traditional EIS is that producing sinusoidal injections in real-world applications would be challenging [13]. Using wideband signals like PRBS is one possible way to lower the system's complexity and the impedance measuring time. More advanced perturbation signals should be used to lessen the impact of the non-linearities. Figure 3.2 examines the usefulness of the non-linear figures. Unfortunately, the non-linear behavior of the battery affects the PRBS's results, which are inaccurate.

3.3 An overall hybrid control system's block model

Since the hybrid controller structure's formalism is vague about the specific kind of force or position control that should be applied, artificial neural networks were employed to operate in tandem with PD/PID controllers. The manipulator was thus positionally regulated in the other orthogonal dimensions and force-controlled in those restricted by contact with the surroundings.

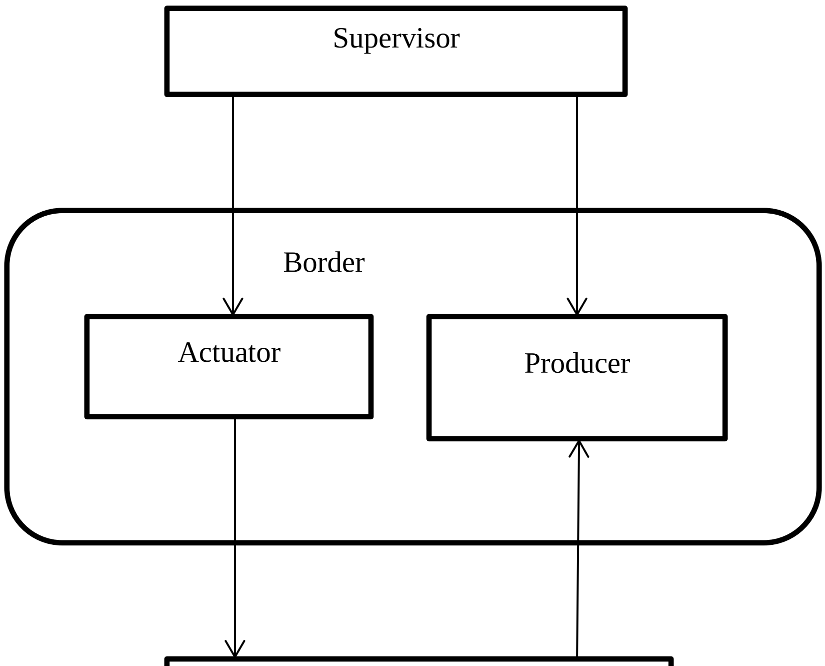

Fig. 3.3. System of Hybrid Controls

Every control loop has its integrated controller (hybrid controls) in Figure 3.3, which implies that a PID operating in conjunction with an MLP or RBF ANN was used for the position control loop and a PI operating in conjunction with another MLP or RBF ANN was used for the force control loop. We explore a few mathematical representations of hybrid systems that have been suggested. The many components of a hybrid control system are depicted graphically in the conceptual model. This illustration depicts a general hybrid control system made up of seven major blocks or elements. The blocks range in complexity from simple to extremely complicated. It is possible to write multiple blocks together in the real implementation. For instance, the decision may be based on the specifications for message flow between the blocks. Between the blocks, there is a combination of discontinuous and constant signals and information.

4. Implementation and Experimental Results

This section presents simulation revisions of real-world natural process examples to illustrate how the suggested hybrid predictive control structure is put into practice and assess its efficacy.

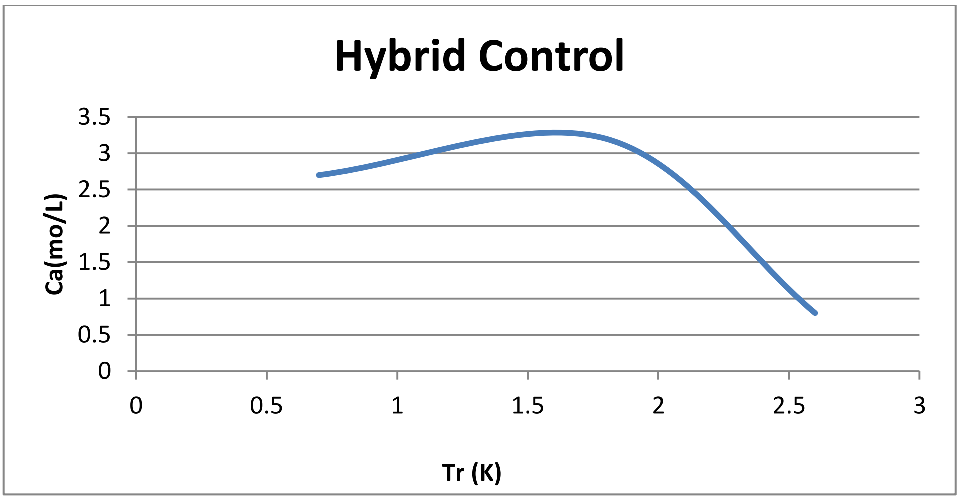

Fig. 4.1. Application of the suggested Hybrid control framework

The nonlinear plant is asymptotically stabilized in this instance as MPC always stays in the closed loop and the value of V3 keeps falling [14]. Observe that, starting from the identical initial state, the MPC produces a workable solution and, when put into practice, increases the horizon length to T ¼ 0:5, which asymptotically stabilises the closed-loop system. The predictive controller may not always be stable or even practicable in the future, even in the event that the linearized model's initial viability is deemed realistic. Moreover, it was not possible to determine the horizon length and closed-loop stability beforehand without running the full closed-loop simulation.

The linearization process in Figure 4.1 limits the stabilizability of a given initial circumstance in addition to the potential for inadequate horizon length. On the other hand, execution is made easier by our particular decision to implement linear MPC (using the linearized model), which simplifies the optimisation challenge [15]. According to the linear model, this first possibility is not within the feasible range because it is not possible to achieve linear MPC for it, regardless of the size of T that is selected.

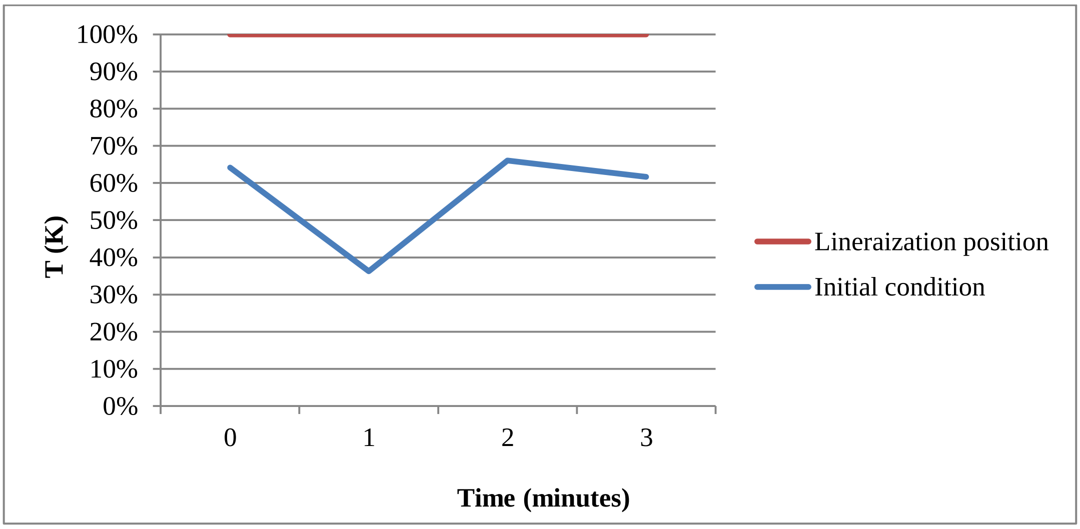

Fig. 4.2. Profile of closed-loop reactant concentration

In this work, a hybrid control structure combining bounded control and MPC was introduced for the stabilisation of nonlinear systems with input constraints. This structure is composed of three main components:

- a high-performing model prognostic controller;
- a collection of limited nonlinear controllers with fallbacks based on Lyapunov, each having a clearly defined stability region;
- a high-level manager in charge of overseeing the changeover from MPC to the limited controllers in a manner.

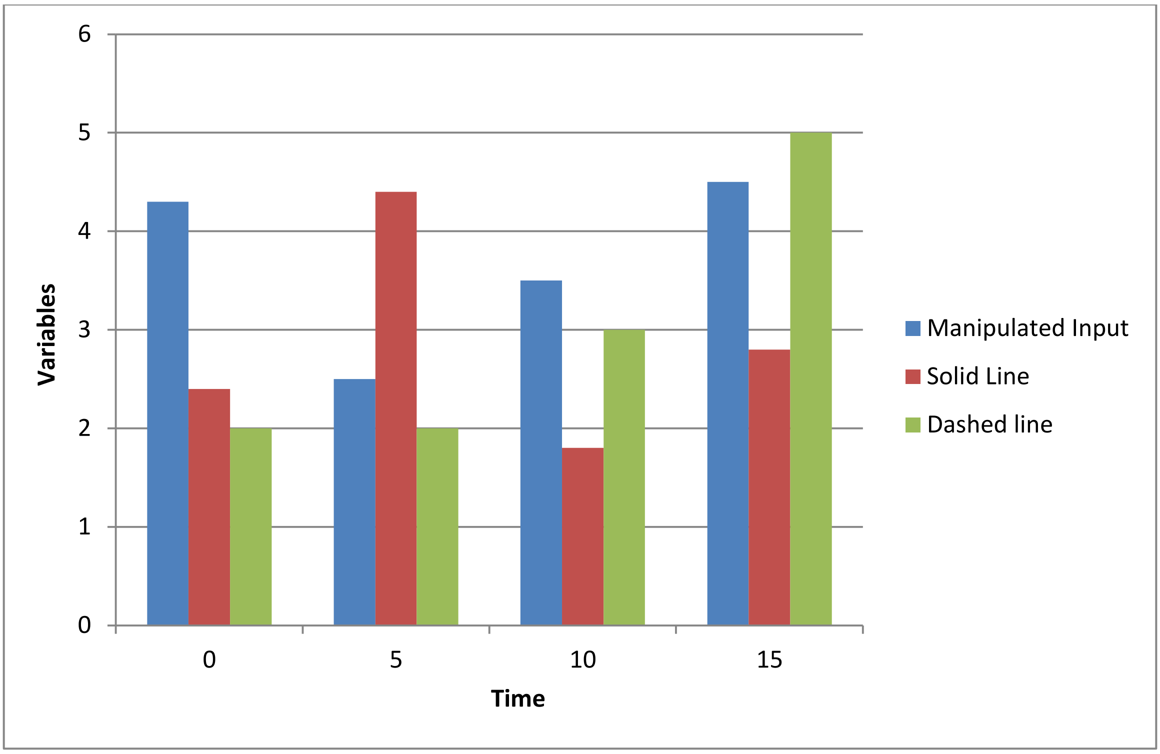

Fig. 4.3. Closed-loop representations of dimensionless crystallizer instants

The dashed lines in Figure 4.3 show that if the terminal equality criterion is dropped to make MPC a feasible solution, the ensuing control action fails to stabilise the closed-loop system and sends the system states into a limit cycle, the moment the supervisor switches to the bounded controller, the closed-loop system is stabilised at the desired equilibrium point. The dotted lines in Figure 4.2 illustrate this.

The main idea was to derive a set of supervisory switching rules that, for every initial condition inside the union of all stability regions of the bounded controllers, ensure asymptotic stability by monitoring the evolution of the closed-loop trajectory and suitably restricting the growth of the Lyapunov functions. This made it possible to embed the MPC implementation inside the bounded controllers' stability areas. Whatever the chosen MPC formulation, it was shown that the hybrid control structure provided a safeguard for the use of predictive control algorithms to restrict nonlinear systems through appropriate switching logic adjustment. Finally, examples of natural reactors and crystallization processes were used to illustrate how the switching systems were implemented.

5. Conclusion

A class of nonlinear hybrid controllers has been shown in this research to be useful to stabilise a group of nonlinear control systems that cascade. Our research shows that although the closed-loop dynamics are connected at both time scales, the slow and rapid dynamics are linear and dissociated. Furthermore, the nonlinear hybrid controller's gain parameters can be readily chosen by normal linear control design requirements because they are presented in a standard form in the equations for the fast and slow closed-loop dynamics.

Lastly, we note that since the early days of computer control systems, hybrid control, also known as logic-based switching control, has been widely used in real-world engineering control systems. Even though these control applications were frequently successful in reaching real-world control performance goals, they were typically not predicated on any hybrid control design theory. This is why there has been a big difference between hybrid control theory and practice, with the former frequently coming first and surpassing the latter in terms of explanation or

justification. Currently, significant progress is being made in the theoretical elements of hybrid control design. It is believed that these developments will have an impact on hybrid control engineering practice and offer fresh ideas for solving control issues that were previously unsolvable.

Future study directions on how Industry 5.0 will affect the industrial landscape in the coming years can be recognized and forecasted by looking at the analysis that has been provided. Only the data, or the extracted abstracts, are included in the results. It should be emphasized that these results could alter if more abstracts were utilized for analysis and if the number of digital libraries used to extract the data increased. It is anticipated that in subsequent studies, a thorough examination along with the incorporation of data crawling methods will offer a more comprehensive understanding of Industry 5.0 and its perception among the research community.

References

[1] Asarin, E., Dang, T., & Girard, A. (2007). Hybridization methods for the analysis of nonlinear systems. *Acta Informatica*, *43*, 451-476.

[2] Akundi, A., Euresti, D., Luna, S., Ankobiah, W., Lopes, A., & Edinbarough, I. (2022). State of Industry 5.0—Analysis and identification of current research trends. *Applied System Innovation*, *5*(1), 27.

[3] Masoomi, B., Sahebi, I. G., Ghobakhloo, M., & Mosayebi, A. (2023). Do industry 5.0 advantages address the sustainable development challenges of the renewable energy supply chain?. *Sustainable Production and Consumption*.

[4] Ullah, K., Alohali, M. A., ul Haque, M. I., Mahgoub, H., Nafie, F. M., Assiri, M., ... & Chowdhry, B. S. (2023). Hybrid precoding design for secure smart-grid enabled MIMO wireless communications in Industry 5.0. *Journal of King Saud University-Computer and Information Sciences*, *35*(7), 101579.

[5] Mirza, M. A., Yu, J., Raza, S., Krichen, M., Ahmed, M., Khan, W. U., ... & Shongwe, T. (2023). DRL-assisted delay optimized task offloading in Automotive-Industry 5.0 based VECNs. *Journal of King Saud University-Computer and Information Sciences*, 101512.

[6] Abdul-Nour, G. G., & Komljenovic, D. (2022). A High-Level Risk Management Framework as Part of an Overall Asset Management Process for the Assessment of Industry 4.0 and Its Corollary Industry 5.0 Related New Emerging Technological Risks in Socio-Technical Systems. *American Journal of Industrial and Business Management*, *12*(7), 1286-1339.

[7] Bakon, K., Holczinger, T., Süle, Z., Jaskó, S., & Abonyi, J. (2022). Scheduling under uncertainty for Industry 4.0 and 5.0. *IEEE Access*, *10*, 74977-75017.

[8] Pettersson, S., & Lennartson, B. (1996, December). Stability and robustness for hybrid systems. In *Proceedings of 35th IEEE Conference on Decision and Control* (Vol. 2, pp. 1202-1207). IEEE.

[9] Pettersson, S., & Lennartson, B. (1997, June). LMI for stability and robustness of hybrid systems. In *Proceedings of the 1997 American Control Conference (Cat. No. 97CH36041)* (Vol. 3, pp. 1714-1718). IEEE.

[10] Li, Z. G., Soh, Y. C., & Wen, C. Y. (2001). Robust stability of a class of hybrid nonlinear systems. *IEEE Transactions on Automatic Control*, *46*(6), 897-903.

[11] Malmborg, J. (1998). Analysis and design of hybrid control systems.

[12] Passold, F., & Stemmer, M. R. (2004, June). Force control of a Scara robot using neural networks. In *Proceedings of the Fourth International Workshop on Robot Motion and Control (IEEE Cat. No. 04EX891)* (pp. 247-252). IEEE.

[13] Sihvo, J., Messo, T., Roinila, T., Luhtala, R., & Stroe, D. I. (2018, September). Online identification of internal impedance of Li-ion battery cell using ternary-sequence injection. In *2018 IEEE Energy Conversion Congress and Exposition (ECCE)* (pp. 2705-2711). IEEE.

[14] Manikanthan, S.V., Padmapriya, T., Network lifetime maximization in WSN based on enhanced clustering techniques, International Journal of Advanced Science and Technology,2020, 29(6 Special Issue), pp. 1140-1146.

[15] DeCarlo, R. A., Branicky, M. S., Pettersson, S., & Lennartson, B. (2000). Perspectives and results on the stability and stabilizability of hybrid systems. *Proceedings of the IEEE*, *88*(7), 1069-1082.