IEEE Control Systems Society
Technical Committee on Discrete Event Systems

Newsletter **May 2024**

Editor: Xiang Yin
Chair, IEEE CSS Technical Committee on DES
Associate Professor
Department of Automation, Shanghai Jiao Tong University
SEIEE Building 2-443, Dongchuan Rd 800, Shanghai, 200240, China

Phone: (+86) 021-34204022
Email: yinxiang@sjtu.edu.cn
Website: http://xiangyin.sjtu.edu.cn

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Editorial

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1 Selections of Journal Publications

Contributed by: Xiang Yin (yinxiang@sjtu.edu.cn)

1.1. IEEE Transactions on Automatic Control

Volume: 69, Issue: 5, May 2024

- **Supervisory Control of Time-Interval Discrete Event Systems**
  Authors: Bertil Brandin ; Rong Su ; Liyong Lin
  Abstract: Brandin and Wonham introduced a timed supervisory control framework in 1994. The key innovations arguably were the introduction of tick events to model the passing of time, and the introduction of event forcing. The framework enriches the Ramadge-Wonham framework, albeit with the cost to deal with high modeling and synthesis complexities due to explicit enumeration of ticks. To address these challenges, the framework presented forgoes the explicit enumeration of tick events and instead relies on time-interval automata whose transitions are labeled by events equipped with discrete time-intervals. In contrast to the time-interval resetting mechanism of the Brandin-Wonham framework, where the time-interval of each event is reset either straight after the event occurs or when the event is not defined at a destination state, in the present framework, the time-interval of each event is reset after a new state is reached, where this event is defined. This new framework contains the Brandin-Wonham framework as a special case. After introducing the plant modeled as a free (time-interval) language, and considering the impact of event forcing on plant behaviors with the concept of time-coerced languages, the supervisory control problem is introduced, whose requirements also are time-interval languages. After presenting the concept of controllability in the time-interval framework and demonstrating the surprising existence of supremal time-coerced controllable sublanguages for a given plant and requirements, even though time-coerced languages are typically not closed under union in contrast to free languages, a new supremal controllable sublanguage synthesis algorithm is presented.
- **Symmetry-Based Abstractions for Hybrid Automata**
  Authors: Hussein Sibai ; Sayan Mitra
  Abstract: A symmetry of a dynamical system is a map that transforms any trajectory to another trajectory. Abstractions have been a key building block in the theory and practice of hybrid automata analysis. We introduce a novel abstraction for hybrid automata based on the symmetries of their modes. The abstraction procedure combines different modes of a concrete automaton $\mathcal{A}$, whose trajectories are related by symmetries, into a single mode of the constructed abstract automaton $\mathcal{B}$. The abstraction procedure sets the invariant of an abstract mode to be the union of the symmetry-transformed invariants of the concrete modes. Similarly, it sets the guard and reset of an abstract edge to be the union of the symmetry-transformed guards and resets of the concrete edges. We establish the soundness of the abstraction using a forward simulation relation and provide a running example. The abstraction achieves an order of magnitude speedup when used for the safety verification of vehicles pursuing reach-avoid tasks.
- **Pinning Synchronization of Large-Scale Boolean Networks**
  Authors: Liqing Wang ; Zheng-Guang Wu
  Abstract: Synchronization of large-scale Boolean networks (BNs) is studied in this article. Using semi-tensor product of matrices, the algebraic structure of all subnetworks' relationships is constructed. A necessary and sufficient condition is obtained for synchronization of large-scale BNs. For those asynchronous large-scale BNs, pinning control is first applied to achieve the control objective, including choosing the subnetworks to be controlled, by designing the corresponding feedback control according to the subnetworks' states independently. In this article, for each pinned subnetwork, the related adding approach of feedback control is fixed to be Boolean addition, which is similar to the system addition. An algorithm is presented for getting a desired structure matrix, under which, the solvability of pinning controls including the exact pinning subnetworks and the corresponding feedback control design is addressed to guarantee the synchronization. An example modeled by biochemical oscillator is given to show how to use the results obtained in this article and also show the efficiency of pinning control.

- **Correction to "Current-State Opacity Formulations in Probabilistic Finite Automata"**
  Authors: Anooshiravan Saboori ; Christoforos N. Hadjicostis
  Abstract: This note identifies a flaw in the proof of Theorem 16 in (Saboori and Hadjicostis, 2014). It also discusses how the statement of Theorem 16 can be adjusted and provides the corresponding proof.

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1.2. Automatica

Volume: 163, May 2024

- **Anderson acceleration for partially observable Markov decision processes: A maximum entropy approach**
  Authors: Mingyu Park ; Jaeuk Shin ; Insoon Yang
  Abstract: Partially observable Markov decision processes (POMDPs) is a rich mathematical framework that embraces a large class of complex sequential decision-making problems under uncertainty with limited observations. However, the complexity of POMDPs poses various computational challenges, motivating the need for an efficient algorithm that rapidly finds a good enough suboptimal solution. In this paper, we propose a novel accelerated offline POMDP algorithm exploiting Anderson acceleration (AA) that is capable of efficiently solving fixed-point problems using previous solution estimates. Our algorithm is based on the Q-function approximation (QMDP) method to alleviate the scalability issue inherent in POMDPs. Inspired by the quasi-Newton interpretation of AA, we propose a maximum entropy variant of QMDP, which we call soft QMDP, to fully benefit from AA. We prove that the overall algorithm converges to the suboptimal solution obtained by soft QMDP. Our algorithm can also be implemented in a model-free manner using simulation data. Provable error bounds on the residual and the solution are provided to examine how the simulation errors are propagated through the proposed algorithm. Finally, the performance of our algorithm is tested on several benchmark problems. According to the results of our experiments, the proposed algorithm converges significantly faster without degrading the solution quality compared to its standard counterparts.
- **Computationally efficient guaranteed cost control design for homogeneous clustered networks**
  Authors: Bikash Adhikari ; Jomphop Veetaseveera ; Vineeth Satheeskumar Varma a; Irinel-Constantin Morărescu ; Elena Panteley
  Abstract: We consider a clustered network where connections inside the cluster are dense and between clusters are sparse. This leads us to a classical decoupling into fast (intra-cluster) and slow (inter-cluster) dynamics. Our objective is to provide a computationally efficient method to design control strategies that guarantee a certain bound on the cost for each cluster. Basically, we design a composite synchronizing controller with two terms: one responsible for the intra-cluster synchronization and the other achieving the synchronization between clusters. The first one does not require much computational effort since an analytic expression describes it. The second term is designed through a satisfaction equilibrium approach. In other words, the internal (fast) and external (slow) controllers are independently designed, and they ensure a guaranteed satisfactory cost for each cluster. Moreover, we show that the internal control affects the cluster cost only for a short time period. Finally, numerical simulations illustrate the theoretical results.
- **Finite time quantized average consensus with transmission stopping guarantees and no quantization error**
  Authors: Apostolos I. Rikos ; Christoforos N. Hadjicostis ; Karl H. Johansson
  Abstract: Networked control systems, which are composed of spatially distributed sensors and actuators that communicate through wireless networks, are emerging as a fundamental infrastructure technology in 5G and IoT technologies. In order to increase flexibility and reduce deployment and maintenance costs, their operation needs to guarantee (i) efficient communication between nodes and (ii) preservation of available energy. Motivated by these requirements, we present and analyze a novel distributed average consensus algorithm, which (i) operates exclusively on quantized values (in order to guarantee efficient communication and data storage), (ii) relies on event-driven updates (in order to reduce energy consumption, communication bandwidth, network congestion, and/or

processor usage), and (iii) allows each node to cease transmissions once the exact average of the initial quantized values has been reached (in order to preserve its stored energy). We characterize the properties of the proposed algorithm and show that its execution, on any time-invariant and strongly connected digraph, allows all nodes to reach in finite time a common consensus value that is equal to the exact average (represented as the ratio of two quantized values). Then, we present upper bounds on (i) the number of transmissions and computations each node has to perform during the execution of the algorithm, and (ii) the memory and energy requirements of each node in order for the algorithm to be executed. Finally, we provide examples that demonstrate the operation, performance, and potential advantages of our proposed algorithm.

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1.3. IEEE Transactions on Control Systems Technology

Volume: 32, Issue: 3, May 2024

- **Decentralized Supervisory Control of Networked Multienergy Buildings**
  Authors: Michael Taylor ; Ognjen Marjanovic ; Alessandra Parisio
  Abstract: A major challenge in the transition to a net-zero energy system is how to decarbonize energy use for heating and cooling via electrification while ensuring the security of a power system with a high penetration of renewable energy generation. One possible way to simultaneously address these disparate objectives is to use model predictive control (MPC) to manage multivector energy consumption and storage in individual buildings so that operational constraints in connecting networks are not violated. However, control of a large number of building energy assets and their multiple shared networks using standard MPC requires the solution of optimization problems that are large, nonconvex, and, therefore, intractable. In this article, a novel MPC scheme is proposed in which the overall control problem is decomposed and solved in parallel by decentralized control agents. Since the uncoordinated actions of decentralized agents could cause congestion in connecting electricity and district heating and cooling (DHC) networks, an energy flow coordinator is also introduced. This coordinator checks agent actions by solving optimal energy flow problems for each network and uses price signals to direct the search for a globally feasible solution. To improve computational efficiency when determining optimal energy flows, the coordinator utilizes a novel model reformulation of a DHC network. An exemplary case study of a multienergy district demonstrates that the control scheme ensures near-optimal economic performance when compared with an equivalent centralized benchmark—in this case, reducing the maximum computation time from over 55 min to just over 1 s. The approach is suitable for online management of buildings within a district, to both minimize costs to end users and to maintain secure, reliable operation of the connecting networks.

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1.4. International Journal of Control

Volume: 97, Issue: 5, May 2024

- **Control laws synthesis for timed event graphs subject to generalised marking constraints by Min-Plus algebra: application to cluster tools**
  Authors: J. Rajah ; K.Tebani ; S.Amari ; M. Barkallah ; M. Haddar
  Abstract: This paper discusses the problem of control laws for Discrete Event Dynamic Systems (DEDSs) represented by Timed Event Graphs (TEGs) under Generalized Marking Constraints (GMCs). The behaviour of TEGs is described using linear equations while GMCs are expressed by weighted inequalities in Min-Plus algebra. We formulate the problem in terms of control linear Min-Plus models. Hence, an algebraic method to calculate control laws ensuring the respect of GMCs is suggested. And once sufficient conditions are satisfied, we propose casual feedbacks to guarantee these marking specifications. Besides, the proposed control strategy is applied to a dual-armed cluster tool, a well-known industrial application.
- **Tracking control for a class of uncertain complex dynamical networks with outgoing links dynamics**

Authors: Peitao Gao ; Yinhe Wang ; JuanxiaZhao ; LiLi Zhang ; Shengping Li
Abstract: A complex dynamical network (CDN) can be considered as the composition system with the nodes subsystem (NS) and the links subsystem (LS), and both subsystems are coupled with each other. In this paper, two vector differential equations (VDE) are used to describe the dynamical behaviours of NS and LS, respectively, in which the dynamical behaviour of NS is considered as the VDE with the second derivative term (SDT). This paper mainly focuses on the dynamics of LS, which is represented as VDE with the intuitive topologic feature of outgoing links, and investigates the design of the tracking controller for NS and the auxiliary tracking objectives (ATO) for LS. Firstly, the dynamical models of NS and LS in CDN are proposed, and the corresponding assumptions are given. Secondly, based on Lyapunov stability theory, the controller of NS and the ATO of LS are designed so that the state of NS can asymptotically track the given reference signal. Finally, the effectiveness of the proposed control strategy in this paper is verified by the numerical simulation example with N two-links robots.

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1.5. IEEE Transactions on Automation Science and Engineering
Volume: 21, Issue: 2, May 2024

- **Supervisor Synthesis for Petri Nets With Uncontrollable and Unobservable Transitions**
Authors: Ning Ran ; Tingting Li ; Shouguang Wang ; Zhou He
Abstract: This paper focuses on designing event feedback supervisors to enforce control specifications on Petri nets with uncontrollable and unobservable transitions. For each observation, the supervisor is able to select some controllable transitions to disable such that the system never reaches illegal markings. Two different methods are given to design such a supervisor. The first method computes the control policy by solving some integer linear programming problems, while the second one designs supervisors by taking advantage of the structural properties of a class of Petri nets. The computational efficiencies of these two methods increase successively at the expense of their application scopes. Two examples are given to illustrate the proposed methods, respectively.
Note to Practitioners: The motivation of this paper consists in ensuring the behavior of a manufacturing system within a given legal behavior. The typical task for a designer is to design a supervisor to restrict that the system never reaches a forbidden state under limited control and observation ability. To this end, this paper proposes two different methods to design such a supervisor. The first one needs to solve integer linear programming problems, while the second one is based on the structural analysis of a special class of systems. It should be noted that although the application scope of the first method is wider, the second method has higher computational efficiency. Therefore, the suitable method can be chosen in accordance with the specific application scenario, which is significant and useful to manufacturing engineers.

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1.6. Nonlinear Analysis: Hybrid Systems
Volume: 52, May 2024

- **Duality of controllability and observability in proportional equal conflict timed continuous Petri Nets**
Authors: J.L. García-Malacara ; César Arzola ; Antonio Ramírez-Treviño ; C. Renato Vázquez
Abstract: Controllability and observability properties have been widely studied in Timed Continuous Petri Nets (TCPNs), a class of piecewise affine systems, in order to analyze and control crowded discrete event systems. This work studies the concept of duality applied to TCPNs as a vehicle to establish links between controllability and observability, i.e., a synergy to improve the understanding of these properties and to enlarge the class of nets that can be analyzed. To achieve this, we study the concepts of rank-controllability and rank-observability. They capture structural conditions for controllability and observability. Afterwards, the computation of dual nets for Fork-Attribution (FA), Choice-Free (CF), Join-Free (JF), and Proportional Equal Conflict (PEQ) TCPNs subclasses are presented. By using the dual definition, several relations between the primal's controllability and its dual's observability are stated. Particularly, in FA rank-controllability

and rank-observability are dual properties. In consistent and strongly connected CF, JF, and PEQ nets, the rank-observability of the dual is sufficient for the rank-controllability of the primal. The opposite implication holds for CF and PEQ if the self-loop places, added by the dual construction methodology, are measurable.

- **Data-driven abstraction-based control synthesis**
  Authors: Milad Kazemi ; Rupak Majumdar ; Mahmoud Salamati ; Sadegh Soudjani ; Ben Wooding
  Abstract: This paper studies formal synthesis of controllers for continuous-space systems with unknown dynamics to satisfy requirements expressed as linear temporal logic formulas. Formal abstraction-based synthesis schemes rely on a precise mathematical model of the system to build a finite abstract model, which is then used to design a controller. The abstraction-based schemes are not applicable when the dynamics of the system are unknown. We propose a data-driven approach that computes a growth bound of the system using a finite number of trajectories. The computed growth bound together with the sampled trajectories are then used to construct the abstraction and synthesise a controller.
  Our approach casts the computation of a growth bound as a robust convex optimisation program (RCP). Since the unknown dynamics appear in the optimisation, we formulate a scenario convex program (SCP) corresponding to the RCP using a finite number of sampled trajectories. We establish a sample complexity result that gives a lower bound for the number of sampled trajectories to guarantee the correctness of the growth bound computed from the SCP with a given confidence. Our sample complexity result requires knowing a possibly conservative bound on the Lipschitz constant of the system. We also provide a sample complexity result for the satisfaction of the specification on the system in closed loop with the designed controller for a given confidence. Our data-driven synthesised controller can provide guarantees on satisfaction of both finite and infinite-horizon specifications. We show that our data-driven approach can be readily used as a model-free abstraction refinement scheme by modifying the formulation of the system's growth bounds and providing similar sample complexity results. The performance of our approach is shown on three case studies.

- **Flatness and structural analysis for the design of stream ciphers involving hybrid automata**
  Authors: Hamid Boukerrou ; Gilles Millérioux ; Marine Minier ; Taha Boukhobza
  Abstract: This paper deals with hybrid dynamical systems in the context of cybersecurity and Cyber–Physical Systems. It is shown how the design of a cipher, called self-synchronizing stream cipher, can be recast as control-theoretic issues, in particular left inversion, flatness and structural analysis. From an automatic control point of view, the main contribution lies in a methodology to construct generic flat LPV systems. Beyond pure control theoretic matters, the design also addresses computational complexity and security concerns. Those considerations motivate a hybrid architecture involving switched automata. A Proof-Of-Concept example illustrates the design of a statistical self-synchronizing stream cipher and the way how it operates to encrypt data flows.

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1.7. IEEE Transactions on Systems, Man, and Cybernetics: Systems

Volume: 54, Issue: 5, May 2024

- **Optimal Sensor Selection for Diagnosability Enforcement in Labeled Petri Nets**
  Authors: Shaopeng Hu ; Zhiwu Li ; Remigiusz Wisniewski
  Abstract: This article addresses the problem of optimal sensor selection for diagnosability enforcement of discrete event systems modeled with Petri nets. Given a nondiagnosable labeled Petri net labeled Petri net (LPN) that may reach deadlocks, it can be enforced to be diagnosable by a novel systematic strategy through a mask labeling function. The proposed strategy employs a special nondeterministic finite automaton, namely, a simplified verifier, obtained from the original LPN and a particular set of labels. Since we only need to silence sensors of some particular transitions rather than add or replace new sensors to transitions, it is more computationally efficient compared with other documented methods in the literature. In addition, we formulate and solve an integer linear

programming problem to optimize a set of given mask labeling functions. Finally, an algorithm is constructed to calculate the minimum value of K for a K-diagnosable system with multiple faults under the mask labeling function. Examples are presented to demonstrate the proposed method.

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1.8. IEEE/CAA Journal of Automatica Sinica

Volume: 11, Issue: 5, May 2024

- **State-Based Opacity Verification of Networked Discrete Event Systems Using Labeled Petri Nets**

  Authors: Yifan Dong ; Naiqi Wu ; Zhiwu Li

  Abstract: The opaque property plays an important role in the operation of a security-critical system, implying that pre-defined secret information of the system is not able to be inferred through partially observing its behavior. This paper addresses the verification of current-state, initial-state, infinite-step, and K-step opacity of networked discrete event systems modeled by labeled Petri nets, where communication losses and delays are considered. Based on the symbolic technique for the representation of states in Petri nets, an observer and an estimator are designed for the verification of current-state and initial-state opacity, respectively. Then, we propose a structure called an I-observer that is combined with secret states to verify whether a networked discrete event system is infinite-step opaque or K-step opaque. Due to the utilization of symbolic approaches for the state-based opacity verification, the computation of the reachability graphs of labeled Petri nets is avoided, which dramatically reduces the computational overheads stemming from networked discrete event systems.

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2 Conferences

Contributed by: Xiang Yin (yinxiang@sjtu.edu.cn)

2.1 **2024 IFAC Conference on Analysis and Design of Hybrid Systems (ADHS)**
Boulder, Colorado, July 1-3, 2024.
https://www.colorado.edu/conference/adhs2024/

2.2 **2024 American Control Conference (ACC)**
Toronto, Canada, July 8-12, 2024.
https://acc2024.a2c2.org/

2.3 **The IEEE Conference on Control Technology and Applications (CCTA)**
Newcastle upon Tyne, UK, August 21-24, 2024.
https://ccta2024.ieeecss.org/

2.4 **2024 International Conference on Automation Science and Engineering (CASE)**
Bari, Italy, August 28-September 1, 2024.
https://www.ieeesmc2024.org/

2.5 **2024 International Conference on Systems, Man, and Cybernetics (SMC)**
Sarawak, Malaysia, October 7-10, 2024.
https://www.ieeesmc2024.org/

2.6 **2023 IEEE Conference on Decision and Control (CDC)**
Milan, Italy, December 16-19, 2024.
https://cdc2024.ieeecss.org/

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3 Books

3.1 Graph-Theoretical Methods in Systems Theory and Control

Author: Jan Lunze, Ruhr-University, Germany

Description: The book describes for numerous scenarios how to use the structural properties of a system represented by a graph to simplify modelling, analysis, and design tasks. For example, block diagrams and coupling graphs can be used to decompose systems, automata graphs to analyse discrete-event systems and Markov chains, structure graphs to find generic properties of linear systems or communication graphs to design networked control systems. The book includes many examples derived from diverse fields of application, exercises with solutions and MATLAB scripts to implement graph-theoretical methods for systems analysis

Additional information on the book can be found at
www.editionmora.de/gmsc

The book is produced as "print-on-demand" and can be ordered directly at the printer:
https://publish.bookmundo.de/books/349971

3.2 Safe Autonomy with Control Barrier Functions: Theory and Applications

Authors: Wei Xiao, Christos G. Cassandras, and Calin Belta

Description: The book presents the concept of Control Barrier Function (CBF), which captures the evolution of safety requirements during the execution of a system and can be used to enforce safety. Safety is central to autonomous systems since they are intended to operate with minimal or no human supervision. The book includes both theoretical and application perspectives on how safety can be guaranteed. It explains how the CBF approach is computationally efficient and can easily deal with nonlinear models and complex constraints used in a wide spectrum of applications, including autonomous driving, robotics, and traffic control. Safety guarantees can be integrated into the operation of such autonomous systems, including typical safety requirements that involve collision avoidance, technological system limitations, and bounds on real-time executions. Adaptive and event-driven approaches for safety are also discussed for time-varying execution bounds and noisy dynamics, as well as for systems with unknown dynamics.

Additional information on the book can be found at
https://link.springer.com/book/10.1007/978-3-031-27576-0
where an eBook version can also be downloaded (free for some educational institutions).

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4 Software Tools

4.1 Eclipse ESCET™ version 3.0 release

The Eclipse Supervisory Control Engineering Toolkit (Eclipse ESCET) project provides a model-based approach and toolkit for the development of supervisory controllers. It includes the languages CIF, Chi and ToolDef. ESCET, initially developed by Eindhoven University of Technology, is since January 2020 an Eclipse Foundation open-source project. More information can be found on the toolkit's website at https://www.eclipse.dev/escet/.

In March 2024, ESCET version 3.0 has been released and can be downloaded from https://www.eclipse.dev/escet/download.html. The main changes in this version are

- ESCET now has a logo. So the appearance of the application might be different from what you are used to (only Windows for now, macOS and Linux will follow soon).
- Several improvements to the (still experimental) new CIF PLC code generator have been included.
- The CIF code generator for HTML files and JavaScript code has received several (performance) improvements and bug-fixes.
- SVG input mappings can now either assign values to input variables (new feature), or map to an event to take (existing feature). This new feature is currently an experimental work-in-progress language feature, and is not yet supported by all CIF tools.
- All CIF tools now support reading .cifx files, CIF files in an XML format. CIF tools that write CIF specifications also support writing .cifx files. See the CIF reference manual for more information. Similarly, the ToolDef interpreter now supports reading .tooldefx files, ToolDef files in an XML format.
- The CIF benchmark models have been extended with the mri_event, mri_state and wafer_scanner benchmark models.

The full ESCET release notes, including links to the language specific release notes and release notes from previous versions, are available from https://www.eclipse.dev/escet/release-notes.html.

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