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Technical Committee on Discrete Event Systems

Newsletter **July 2024**

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Editorial

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Contents

1 Selections of Journal Publications

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

1.1. IEEE Transactions on Automatic Control

Volume: 69, Issue: 7, July 2024

- **A Unified Framework for Verification of Observational Properties for Partially-Observed Discrete-Event Systems**
  Authors: Jianing Zhao ; Shaoyuan Li ; Xiang Yin
  Abstract: In this article, we investigate property verification problems in partially-observed discrete-event systems (DES). Particularly, we are interested in verifying observational properties that are related to the information-flow of the system. Observational properties considered here include diagnosability, predictability, detectability, and opacity, which have drawn considerable attentions in the literature. However, in contrast to existing results, where different verification procedures are developed for different properties case by case, in this work, we provide a unified framework for verifying all these properties by reducing each of them as an instance of HyperLTL model checking . Our approach is based on the construction of a Kripke structure that effectively captures the issue of unobservability as well as the finite string semantics in partially-observed DES so that HyperLTL model checking techniques can be suitably applied. Then for each observational property considered, we explicitly provide the HyperLTL formula to be checked over the Kripke structure for the purpose of verification. Our approach is uniform in the sense that all different properties can be verified with the same model checking engine and also brings new insights for classifying observational properties in terms of their verification complexity. Numerical experiments are conducted, which show that our framework is computationally more efficient for verifying properties involving quantifier alternations, such as opacity, compared with the standard subset-based approaches.

- **Supervisory Control of Networked Discrete Event Systems to Achieve a Required Language**
  Authors: Xiaojun Wang ; Hesuan Hu; Feng Lin
  Abstract: Because of the wide use of networks, supervisory control of networked discrete event systems becomes more and more important. Since the languages generated by a networked supervisor is nondeterministic due to communication delays and losses, large and small languages are defined. While the large language has been investigated in the literature, the small language has not. In this article, we investigate the small language, which is needed for a supervised system to perform some required tasks. Network S-observability is introduced to capture the necessary and sufficient condition for the existence of a networked supervisor achieving a given small language. A method is developed to check if network S-observability is satisfied. We also show that the infimal controllable and network S-observable superlanguage of a language exists and can be calculated using a method developed in this article. Finally, the theoretical results are illustrated by applying them to an autonomous service robot.

- **Secret Protections With Costs and Disruptiveness in Discrete-Event Systems Using Centralities**
  Authors: Ziyue Ma ; Jiagang Jiang ; Kai Cai
  Abstract: In this article, we study a secret protection problem in discrete-event systems. The system is modeled by an automaton in which several states are assigned with different secret levels. Our aim is to protect some of the events in the system such that any sequence yielding a secret state contains a number of protected events no less than the required security level. We first study the secret-protecting problem with minimum cost, i.e., to design a protecting policy whose cost is minimal. We prove that the decision version of such a secret protection problem is NP-hard, which implies that there unlikely exists a polynomial algorithm to solve it. As a result, we developed a heuristic method to obtain a locally optimal solution to protect the secrets using the notion of cost-weighted centrality . Then, we consider the disruptiveness, i.e., the degree of disruptiveness of protecting policies to legal users' normal operations. We formulate the disruptiveness to users incurred by the protection of events as a penalty function, which describes the impact of events

and transitions on the paths leading to marker states. A heuristic method based on the notion of cost-penalty-weighted centrality is analogously developed to obtain a protecting policy, which can well balance the cost and the disruptiveness to users.

- **Formal Analysis of the Sampling Behavior of Stochastic Event-Triggered Control**
  Authors: Giannis Delimpaltadakis ; Luca Laurenti ; Manuel Mazo
  Abstract: Analyzing event-triggered control's (ETC) sampling behavior is of paramount importance, as it enables formal assessment of its sampling performance and prediction of its sampling patterns. In this work, we formally analyze the sampling behavior of stochastic linear periodic ETC (PETC) systems by computing bounds on associated metrics. Specifically, we consider functions over sequences of state measurements and intersampling times that can be expressed as average, multiplicative or cumulative rewards, and introduce their expectations as metrics on PETC's sampling behavior. We compute bounds on these expectations, by constructing Interval Markov Chains equipped with suitable reward functions, that abstract stochastic PETC's sampling behavior. Our results are illustrated on a numerical example, for which we compute bounds on the expected average intersampling time and on the probability of triggering with the maximum possible intersampling time in a finite horizon.

- **Robust Event-Triggered Distributed Optimal Coordination of Heterogeneous Systems Over Directed Networks**
  Authors: Chengxin Xian ; Yu Zhao ; Guanghui Wen ; Guanrong Chen
  Abstract: In this article, the robust distributed optimal coordination (DOC) problem over unbalanced directed communication networks is investigated for heterogeneous multiagent systems subjected to external disturbances. First, by introducing an external disturbance observer, a balanced compensation variable and using the output regulation technique, a new robust continuous-time DOC algorithm is developed, ensuring that the sum of the local convex objective functions is optimal and the behaviors of all agents are coordinated. Then, a robust event-triggered DOC algorithm is designed, which consists of an event-triggered closed-loop controller and an event-triggered balanced compensator. Compared with the existing distributed optimization algorithms, the algorithms of this article solve the DOC problem over unbalanced directed communication network. The heterogeneous agent dynamics with external disturbances considered in this article are in a general form. Further, the introduction of the event-triggering mechanism can avoid continuous information transmission and improve the efficiency of system resources utilization. Finally, numerical simulations are shown to demonstrate the effectiveness of the theoretical results.

- **Performance-Barrier-Based Event-Triggered Control With Applications to Network Systems**
  Authors: Pio Ong ; Jorge Cortés
  Abstract: This article proposes a novel framework for resource-aware control design termed performance-barrier-based triggering. Given a feedback policy, along with a Lyapunov function certificate that guarantees its correctness, we examine the problem of designing its digital implementation through event-triggered control while ensuring a prescribed performance on the certificate's convergence rate is met and triggers occur as sparingly as possible. Our methodology takes into account the performance residual , i.e., how well the system is doing in regards to the prescribed performance. Inspired by the notion of control barrier function, the trigger design allows the certificate to deviate from monotonically decreasing, with leeway specified as an increasing function of the performance residual, resulting in greater flexibility in prescribing update times. We study different types of performance specifications, with particular attention to quantifying the benefits of the proposed approach in the exponential case. We build on this to design intrinsically Zeno-free distributed triggers for network systems. A comparison of event-triggered approaches in a vehicle platooning problem shows how the proposed design meets the prescribed performance with a significantly lower number of controller updates.

- **On Objective Function Value Performance of the Scenario Approach Under Regularity Conditions**
  Authors: Zheming Wang ; Raphaël M. Jungers
  Abstract: We study the objective function value performance of the scenario approach for robust

convex optimization. A novel method is proposed to derive probabilistic bounds for the objective value from scenario programs with a finite number of samples. This method relies on a max–min reformulation and on the concept of complexity of robust optimization problems. With additional continuity and regularity conditions, via sensitivity analysis, we also provide explicit bounds which outperform the previously existing bounds. To illustrate our contribution, we also provide numerical examples. Finally, we apply our method to a planar antenna array synthesis problem, where we investigate the overfitting issue based on the derived probabilistic objective value bounds.

- **Distributional Reachability for Markov Decision Processes: Theory and Applications**
  Authors: Yulong Gao ; Alessandro Abate ; Lihua Xie ; Karl Henrik Johansson
  Abstract: We study distributional reachability for finite Markov decision processes (MDPs) from a control theoretical perspective. Unlike standard probabilistic reachability notions, which are defined over MDP states or trajectories, in this article reachability is formulated over the space of probability distributions. We propose two set-valued maps for the forward and backward distributional reachability problems: the forward map collects all state distributions that can be reached from a set of initial distributions, while the backward map collects all state distributions that can reach a set of final distributions. We show that there exists a maximal invariant set under the forward map and this set is the region where the state distributions eventually always belong to, regardless of the initial state distribution and policy. The backward map provides an alternative way to solve a class of important problems for MDPs: the study of controlled invariance, the characterization of the domain of attraction, and reach-avoid problems. Three case studies illustrate the effectiveness of our approach.

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1.2. Automatica

Volume: 165, July 2024

- **An automata theoretic approach to observer design for switched linear systems**
  Authors: Georges Aazan ; Antoine Girard ; Luca Greco ; Paolo Mason
  Abstract: We present an approach for designing asymptotic observers for discrete-time switched linear systems. We first give an automata theoretic characterization of switching signals containing an infinite number of reconstructible sequences, i.e. sequences allowing to estimate the state of the system. We show that such switching signals can be generated by a deterministic Büchi automaton whose construction is given in the paper. Then, we present a methodology to design switched observers. These observers have an internal discrete state variable whose dynamics is given by the transition map of the Büchi automaton. We then present two approaches to design observer gains such that the observer is convergent for all switching signals whose occurrence rate of reconstructible sequences is higher than a tunable threshold. The first approach gives an explicit construction of the observer gains while the second one is based on linear matrix inequalities. For switched systems with invertible state matrices, we show that the proposed observer structure is universal in the sense that it is always possible to design an observer of the proposed form. We use a simple example to illustrate our methodology and then consider a case study in which we design an observer for a multicellular converter.
- **A uniform approach to compare architectures in decentralized discrete-event systems**
  Authors: Kagurazaka Ritsuka ; Karen Rudie
  Abstract: Solutions to decentralized discrete-event systems problems are characterized by the way local decisions are fused to yield a global decision. A fusion rule is colloquially called an architecture. Current approaches do not provide a direct way to compare existing architectures. Determining whether an architecture is more permissive than another architecture had relied on producing examples ad hoc and on individual inspiration that puts the conditions for solvability in each architecture into some form that admits comparison. In response to these research efforts, a method based on morphisms between graphs has been extracted to yield a uniform approach to compare the permissiveness of the architectures.
- **Constrained Motion Planning and Multi-Agent Path Finding on directed graphs**
  Authors: Stefano Ardizzoni ; Luca Consolini ; Marco Locatelli ; Irene Saccani

Abstract: We discuss c-MP and c-MAPF, generalizations of the classical Motion Planning (MP) and Multi-Agent Path Finding (MAPF) problems on a directed graph G. Namely, we enforce an upper bound on the number of agents that occupy each member of a family of vertex subsets. For instance, this constraint allows maintaining a safety distance between agents. We prove that finding a feasible solution of c-MP and c-MAPF is NP-hard. Also, we propose a method to convert these problems to standard MP and MAPF by strengthening the constraints. The method consists in finding a subset of vertices W and a reduced graph G_W, such that a feasible solution of MP and MAPF on G_W provides, in polynomial time, a feasible solution of c-MP and c-MAPF on G. However, since the conversion into standard MP and MAPF is obtained by strengthening constraints, feasible solutions of c-MP and c-MAPF on G_W may exist even if MP and MAPF on G_W do not admit any feasible solution. We also study the problem of finding W of maximum cardinality. First, we show that such problem is strongly NP-hard. Then, we propose a heuristic approach for its solution.

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1.3. IEEE Transactions on Cybernetics

Volume: 54, Issue: 7, July 2024

- **Stochastic Fuzzy Discrete Event Systems and Their Model Identification**
  Authors: Hao Ying ; Feng Lin
  Abstract: We introduce a new class of fuzzy discrete event systems (FDESs) called stochastic FDESs (SFDESs), which is significantly different from the probabilistic FDESs (PFDESs) in the literature. It offers an effective modeling framework for applications that are unsuitable for the PFDES framework. An SFDES is comprised of multiple fuzzy automata that occur randomly one at time with different occurrence probabilities. It uses either the max-product fuzzy inference or the max–min fuzzy inference. This article focuses on single-event SFDES—each of the fuzzy automata of such an SFDES has one event. Assuming nothing is known about an SFDES, we develop an innovative technique capable of determining number of fuzzy automata and their event transition matrices as well as estimating their occurrence probabilities. The technique, called prerequired-pre-event-state-based technique, creates and uses merely N particular pre-event state vectors of dimension N to identify event transition matrices of M fuzzy automata, involving a total of MN^2 unknown parameters. One necessary and sufficient condition and three sufficient conditions are established for the identification of SFDES with different settings. The technique does not have any adjustable parameter or hyperparameter to set. A numerical example is provided to concretely illustrate the technique.

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

Volume: 54, Issue: 7, July 2024

- **An Efficient Liveness Analysis Method for Petri Nets via Maximally Good-Step Graphs**
  Authors: Hao Dou ; MengChu Zhou ; Shouguang Wang ; Aiiad Albeshri
  Abstract: Liveness is among the most significant properties when Petri net (PN) models of automated systems are analyzed, which ensures systems' deadlock-freeness. Traditionally, the liveness analysis methods based on reachability graphs (RGs) of PNs often suffer from state-space explosion problems. In this article, we propose a novel liveness-analysis method for PN based on maximally good-step graphs (MGs), namely, the reduced form of RGs, which can effectively alleviate such problems in liveness analysis. First, we introduce the concept of sound steps and establish an algorithm for assessing the soundness of an enabled step at the current marking from a practice point of view. Second, we propose a definition of maximal sound steps and construct an algorithm for calculating a maximal-sound-step set at each marking whose computational complexity grows polynomial with the number of places and transitions. Then, we introduce a definition for good steps and an algorithm for generating maximally good step graphs of PN; and discuss its computational complexity with respect to the net size and initial marking. Next, we for the first time answer how to evaluate the liveness of PN by using MGs. Experiments in diverse large-scale automated

manufacturing systems demonstrate that the proposed method significantly reduces state space and time consumption in the liveness analysis of network systems.

- **Estimation of State and Mode for Boolean Networks With Markov Jump Parameters**
  Authors: Liqing Wang ; Zheng-Guang Wu ; Ying Shen
  Abstract: First, state estimation for Boolean networks (BNs) with Markov jump parameters (MJPs) is studied in this article. Using semi-tensor product of matrices, the algebraic form of the considered BN with MJPs is constructed. State estimation and mode estimation algorithms based on the output feedback values are presented respectively for the two cases where the output of the observer is deterministic and contains perturbation. Precisely, a recursive matrix-based algorithm, Algorithm 1, is presented to predict the forward state based on minimizing the mean square error. Further, with the help of Bayes Theorem, the optimal system mode estimation is solved and Algorithm 2 is presented to show how to estimate the optimal one from all candidate modes. Finally, a BN with MJPs is constructed from network p53-MDM2 and the simulation process shows that the results obtained in this article is effective.

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2 Conferences

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

2.1 **2024 IEEE Conference on Control Technology and Applications (CCTA)**
Newcastle upon Tyne, UK, August 21-24, 2024.
https://ccta2024.ieeecss.org/

2.2 **2024 International Conference on Automation Science and Engineering (CASE)**
Bari, Italy, August 28-September 1, 2024.
https://2024.ieeecase.org/

2.3 **2024 International Conference on Systems, Man, and Cybernetics (SMC)**
Sarawak, Malaysia, October 7-10, 2024.
https://www.ieeesmc2024.org/

2.4 **2024 IEEE Conference on Decision and Control (CDC)**
Milan, Italy, December 16-19, 2024.
https://cdc2024.ieeecss.org/

2.5 **2025 IEEE International Conference on Robotics and Automation (ICRA)**
Atlanta, USA, May 19-23, 2025.
https://2025.ieee-icra.org/

2.6 **2025 European Control Conference (ECC)**
Thessaloniki, Greece, June 24-27, 2025.
https://ecc25.euca-ecc.org/

2.7 **2025 American Control Conference (ACC)**
Denver, Colorado, USA, July 8-10, 2025.
https://acc2025.a2c2.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 4.0 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 June 2024, ESCET version 4.0 has been released and can be downloaded from https://www.eclipse.dev/escet/download.html. he main changes in this version are

- Several improvements to model annotations, including a new annotation 'controller:properties'. Furthermore, annotations can be added to wider range of elements of the CIF language.
- The CIF controller properties checker now has an additional check, the bounded response check. The bounded response check improves upon the finite response check by checking for finite response also for uncontrollable events, not just for controllable events. Additionally, for both controllable and uncontrollable events, the new check also computes the bounds on the number of transitions that can be executed. Furthermore, the new check does not suffer from false negatives. The bounded response check is now recommended instead of the finite response check.
- The CIF controller properties checker now has an additional check, the non-blocking under control check, that should hold for all supervisor models before controller code is generated from them.
- Several improvements to the (still experimental) new CIF PLC code generator have been included.
- The CIF data-based synthesis tool has improved performance by using compounded operations for applying edges, using partial transition relations, and taking runtime errors into account once before the main synthesis fixed point computations, rather than repeatedly during synthesis. On average it is about 3.4 times faster, and it also uses less memory. However, the gain depends on the model being synthesized.

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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