IEEE Control Systems Society
Technical Committee on Discrete Event Systems

Newsletter April 2022

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Editorial

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1 Selections of Journal Publications

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

1.1. Discrete Event Dynamic Systems: Theory and Applications

Volume 32, Issue 1, April 2021

- **Weakly linear systems for matrices over the max-plus quantale**
  Authors: Aleksandar Stamenković ; Miroslav Ćirić ; Dragan Djurdjanović
  Abstract: In this paper we introduce and study weakly linear systems, i.e. systems consisting of matrix inequalities Eqs. 17 - 20, over the max-plus quantale which is also known as complete max-plus algebra. We prove the existence of the greatest solution contained in a given matrix X_0, and present a procedure for its computation. In the case of weakly linear systems consisting of finitely many matrix inequalities, when all finite elements of matrices X_0, A_s and $B_s, s \in I$are integers, rationals or particular irrationals and a finite solution exists, the procedure finishes in a finite number of steps. If in that case an arbitrary finite solution is given, a lower bound on the number of computational steps is calculated. Otherwise, we use our algorithm to compute approximations to finite solutions.

- **Interpreted synchronous extension of time Petri nets**
  Authors: Karen Godary-Dejean ; Hélène Leroux ; David Andreu
  Abstract: Our work is integrated into a global methodology to design synchronously executed embedded critical systems. It is used for the development of medical devices implanted into human body to perform functional electrical stimulation solutions (used in pacemakers, deep brain stimulation...). These systems are of course critical and real time, and the reliability of their behaviors must be guaranteed. These medical devices are implemented into a programmable logic circuit in a synchronous way, which allows efficient implementation (space, consumption and actual parallelism of tasks execution). This paper presents a solution that helps to prove that the behavior of the implemented system respects a set of properties, using Petri nets for modeling and analysis purposes. But one problem in formal methods is that the hardware target and the implementation strategy can have an influence on the execution of the system, but is usually not considered in the modeling and verification processes. Resolving this issue is the goal of this article. Our work has two main results: an operational one, and a theoretical one. First, we can now design critical controllers with hard safety or real time constraints, being sure the behavior is still guaranteed during the execution. Second, this work broadens the scope of expressivity and analyzability of Petri nets extensions. Until then, none managed in the same formalism, both for modeling and analysis, all the characteristics we have considered (weights on arcs, specific test and inhibitor arcs, interpretation, and time intervals, including the management of effective conflicts and the blocking of transitions).

- **Probabilistic state estimation for labeled continuous time Markov models with applications to attack detection**
  Authors: Dimitri Lefebvre ; Carla Seatzu ; Christoforos N. Hadjicostis ; Alessandro Giua
  Abstract: This paper is about state estimation in a timed probabilistic setting. The main contribution is a general procedure to design an observer for computing the probabilities of the states for labeled continuous time Markov models as functions of time, based on a sequence of observations and their associated time stamps that have been collected thus far. Two notions of state consistency with respect to such a timed observation sequence are introduced and related necessary and sufficient conditions are derived. The method is then applied to the detection of cyber-attacks. The plant and the possible attacks are described in terms of a labeled continuous time Markov model that includes both observable and unobservable events, and where each attack corresponds to a particular subset of states. Consequently, attack detection is reformulated as a state estimation problem.

- **Hierarchical planning in a supervisory control context with compositional abstraction**
  Authors: Juliana Vilela ; Richard Hill
  Abstract: Hierarchy is a tool that has been applied to improve the scalability of solving planning

problems modeled using Supervisory Control Theory. In the work of Hill and Lafortune (2016), the notion of cost equivalence was employed to generate an abstraction of the supervisor that, with additional conditions, guarantees that an optimal plan generated on the abstraction is also optimal when applied to the full supervisor. Their work is able to improve their abstraction by artificially giving transitions zero cost based on the sequentially-dependent ordering of events. Here, we relax the requirement on a specific ordering of the dependent events, while maintaining the optimal relationship between upper and lower levels of the hierarchy. This present paper also extends the authors work (Vilela and Hill 2020) where we developed a new notion of equivalence based on cost equivalence and weak bisimulation that we term priced-observation equivalence. This equivalence allows the supervisor abstraction to be generated compositionally. This helps to avoid the explosion of the state space that arises from having to first synthesize the full supervisor before the abstraction can be applied. Here, we also show that models with artificial zero-cost transitions can be created compositionally employing the new relaxed sequential dependence definition. An example cooperative robot control application is used to demonstrate the improvements achieved by the compositional approach to abstraction proposed by this paper.

- **Supervisory controller synthesis and implementation for safety PLCs**
  Authors: Ferdie F. H. Reijnen ; Toby R. Erens ; Joanna M. van de Mortel-Fronczak ; Jacobus E. Rooda
  Abstract: The development of supervisory controllers for cyber-physical systems is a laborious and error-prone process. Supervisor synthesis enables control designers to automatically synthesize a correct-by-construction supervisor from a model of the plant combined with a model of the control requirements. From the supervisor model, controller code can be generated which is suitable for the implementation on a programmable logic controller (PLC). Supervisors for industrial systems that operate in close proximity to humans have to adhere to strict safety standards. To achieve these standards, safety PLCs (SPLCs) are used. For SPLC implementation, the supervisor has to be split into a regular part and a safety part. In previous work, a method is proposed to automatically split a supervisor model for this purpose. The method assumes that the provided plant model is a collection of finite automata. In this paper, the extension to extended finite automata is described. Additionally, guidelines are provided for modeling the plant and the requirements to achieve a favorable splitting. A case study on a rotating bridge is elaborated which has been used to validate the method. The case study spans all development steps, including the implementation of the resulting supervisor to control the real bridge.

- **Discrete-event systems subject to unknown sensor attacks**
  Authors: Michel R. C. Alves ; Patrícia N. Pena ; Karen Rudie
  Abstract: This work is set in the context of supervisory control of discrete-event systems under partial observation. Attackers that are able to insert or erase occurrences of particular output symbols can tamper with the supervisors observation and by doing so, can lead the controlled system to undesirable states. We consider a scenario with multiple attackers, each one being an element of a set, called the attack set. We also assume that only one of the attackers within an attack set is acting, although we dont know which one. According to previous results in the literature, a supervisor that enforces a given legal language, regardless of which attacker is acting, can be designed if the legal language is controllable and satisfies a property called P-observability for an attack set. The latter is an extended notion of observability and is related with the supervisors ability to always distinguish between outputs that require different control actions, even if the outputs were attacked. We present a new approach for checking if a given language is P-observable for an attack set, by first introducing a visual representation as well as some definitions that capture the attacks effect. Additionally, we present two algorithms that together allow us to verify if a given language is P-observable for an attack set, when it is represented as an automaton.

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1.2. IEEE Transactions on Automatic Control

Volume: 67, Issue: 4, April 2022

- **Controller Synthesis for Linear System With Reach-Avoid Specifications**

Authors: Chuchu Fan ; Zengyi Qin ; Umang Mathur ; Qiang Ning ; Sayan Mitra ; Mahesh Viswanathan
Abstract: We address the problem of synthesizing provably correct controllers for linear systems with reach-avoid specifications. Discrete abstraction-based controller synthesis techniques have been developed for linear and nonlinear systems with various types of specifications. However, these methods typically suffer from the state space explosion problem. Our solution decomposes the overall synthesis problem into two smaller, and more tractable problems: one synthesis problem for an open-loop controller, which can produce a reference trajectory, and a second for synthesizing a tracking controller, which can enforce the other trajectories to follow the reference trajectory. As a key building-block result, we show that, once a tracking controller is fixed, the reachable states from an initial neighborhood, subject to any disturbance, can be overapproximated by a sequence of ellipsoids, with shapes that are independent of the open-loop controller. Hence, the open-loop controller can be synthesized independently to meet the reach-avoid specification for an initial neighborhood. Moreover, we are able to reduce the problem of synthesizing open-loop controllers to satisfiability problems over quantifier-free linear real arithmetic. The number of linear constraints in the satisfiability problem is linear to the number of hyperplanes as the surfaces of the polytopic obstacles and goal sets. The overall synthesis algorithm, computes a tracking controller, and then iteratively covers the entire initial set to find open-loop controllers for initial neighborhoods. The algorithm is sound and, for a class of robust systems, is also complete. We implement this synthesis algorithm in a tool RealSyn ver 2.0 and use it on several benchmarks with up to 20 dimensions. Experiment results are very promising: RealSyn ver 2.0 can find controllers for most of the benchmarks in seconds.

- **On Reachability of Markov Chains: A Long-Run Average Approach**
Authors: Daniel Ávila ; Mauricio Junca
Abstract: We consider a Markov control model in discrete time with countable both state space and action space. Using the value function of a suitable long-run average reward problem, we study various reachability/controllability problems. First, we characterize the domain of attraction and escape set of the system, and a generalization called p -domain of attraction, using the aforementioned value function. Next, we solve the problem of maximizing the probability of reaching a set A while avoiding a set B . Finally, we consider a constrained version of previous problem, where we ask for the probability of reaching the set B to be bounded. In the finite case, we use linear programming formulations to solve these problems.

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1.3. Automatica
Volume: 138, April 2022

- **A new modeling framework for networked discrete-event systems**
Authors: Ruochen Tai ; Liyong Lin ; Yuting Zhu ; Rong Su
Abstract: This paper proposes a new framework for modeling networked discrete-event systems (DES) with channel delays and losses. We construct a more elaborated model for the plant G and supervisor S by endowing them with an embedded module to preprocess the received messages and defining state transition mapping and output mapping to model the dynamics of G and S, which could provide users with flexibility to realize different mechanisms, and thus could potentially generate more permissive controllers. Two sets of new formulations are established to capture the temporal relationships between channel inputs and outputs without assuming the first-in-first-out (FIFO) property, which naturally contains the model without delays and losses in the Ramadge-Wonham framework. Based on the defined mappings of each component, the closed-loop behavior is defined to describe the concurrent system dynamics. We hope the new framework could serve as an analysis tool, and possibly the building block for a synthesis tool, for future theoretical explorations and practical implementations of networked DES control.

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1.4. IEEE Control Systems Letter
Volume: 6, Issue: 3, April 2021

- **Inference of Aggregate Hidden Markov Models With Continuous Observations**
  Authors: Qinsheng Zhang ; Rahul Singh ; Yongxin Chen
  Abstract: We consider a class of inference problems for large populations where each individual is modeled by the same hidden Markov model (HMM). We focus on aggregate inference problems in HMMs with discrete state space and continuous observation space. The continuous observations are aggregated in a way such that the individuals are indistinguishable from measurements. We propose an aggregate inference algorithm called continuous observation collective forward-backward algorithm. It extends the recently proposed collective forward-backward algorithm for aggregate inference in HMMs with discrete observations to the case of continuous observations.

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1.5. Control Engineering Practice
Volume: 121, April 2021

- **Hybrid automaton-based disturbance-aware predictive control with receding horizon optimization for three-phase full-bridge inverters**
  Authors: Zhengxi Chen ; Shen Xun
  Abstract: A data-driven disturbance-aware predictive control policy is proposed for DCAC power inverters based on receding horizon optimization approach. First a discrete event-driven hybrid automaton model has been constructed for the nonlinear inverter system dynamics. A control problem of infinite discrete state-space transition sequence optimization is formulated. A receding-horizon-optimization-based hybrid controller is designed to solve the discrete optimization problem piece-wisely on-line. Accordingly, a disturbance-aware adaptive control is proposed, the external disturbance is sampled and estimated by an on-line Recursive Least Square (RLS) algorithm. It is elaborated that the conventional PWM control solution is a subset of solutions of the proposed control strategy and the code-transition between them is provided. By adding extra PWM constraints to the proposed control strategy, an Optimal PWM Control Mode (OPCM) is introduced as example. The essence of OPCM is still a data-driven optimal solution based on MPC following pre-designated PWM constraints which is a modified sub-mode of ODCM and greatly reduces computational requirement. The proposed controller can freely operate under the original Optimal Discrete Control Mode (ODCM) and the OPCM. Numerical simulation results have verified that the proposed discrete control strategy has realized disturbance-aware adaptive control of DCAC inversion against load-shift, and ODCM has better control performance than OPCM. In addition, the proposed modeling and control frame has potential to support other forms of control modes.

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1.6. IEEE Transactions on Systems, Man, and Cybernetics: Systems
Volume: 52, Issue: 4, April 2022

- **A Liveness-Enforcing Supervisor Tolerant to Sensor-Reading Modification Attacks**
  Authors: Dan You ; Shouguang Wang ; Carla Seatzu
  Abstract: In cyberphysical systems (CPSs), it is of great importance to handle network attack issues. In this article, we consider the supervisory control layer of CPSs, focusing on closed-loop control systems vulnerable to sensor-reading modification attacks (SM-attacks), which may disguise the occurrence of an event as a different event by modifying appropriately sensor readings in sensor communication channels. In particular, we consider the plant modeled as a bounded Petri net and the control specification consisting in liveness enforcing. Based on repeatedly computing a more restrictive liveness-enforcing supervisor under no attack and constructing a so-called basic supervisor, a method that synthesizes a liveness-enforcing supervisor tolerant to an SM-attack is proposed.

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2 Conferences

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

2.1 **2022 ACM International Conference on Hybrid Systems: Computation and Control (HSCC)**
Milan, Italy, May 4-6, 2022
https://hscc.acm.org/2022/

2.2 **2022 IEEE Conference on Robotics and Automation (ICRA)**
Philadelphia, USA, May 23-27, 2022
https://www.icra2022.org/

2.3 **2022 American Control Conference (ACC)**
Atlanta, Georgia, USA, June 8-10, 2022
https://acc2022.a2c2.org/

2.4 **2022 IEEE Conference on Control Technology and Applications (CCTA)**
Stazione Marittima, Trieste, Italy, August 23-25, 2022
https://acc2022.a2c2.org/

2.5 **2022 IEEE International Conference on Automation Science and Engineering (CASE)**
Mexico City, Mexico, August 20-24, 2022
http://www.case2022.org/

2.6 **2022 International Workshop on Discrete Event Systems (WODES)**
Prague, Czechia, September 7-9, 2022
https://wodes2022.math.cas.cz

2.7 **2022 IEEE International Conference on Systems, Man, and Cybernetics (SMC)**
Prague, Czech Republic, October 9-12, 2022
https://ieeesmc2022.org/

2.8 **2022 IEEE Conference on Decision and Control (CDC)**
Cancun, Mexico, December 6-9, 2022
https://cdc2022.ieeecss.org/

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3 Books

3.1 Analysis and Control for Resilience of Discrete Event Systems

Authors: Joao Carlos Basilio, Christoforos N. Hadjicostis, and Rong Su

Description: System resilience captures the ability of the system to withstand a major disruption within acceptable performance degradation and to recover within an acceptable time frame. In this monograph we consider two possible sources of major disruptions, i.e., component faults and cyber intrusions. A component fault is an indigenous activity that renders unavailability or inaccessibility of certain functions within a component, either permanently or temporarily. It typically generates safety and performance concerns. Cyber intrusion on the other hand is an exogenous activity that tampers privacy, confidentiality, availability, or integrity of the system. These two sources are not always independent from each other. For example, a cyber intrusion may trigger a component fault, whereas a component fault may open a door for cyber intrusion, e.g., by keeping it undetected. For cyber intrusion, we will focus on opacity, which describes the systems ability to hide certain secrets from an external observer (or eavesdropper), and sensor and actuator attacks that exploit the systems existing controller to generate undesirable behaviours.

In this monograph, we provide a detailed account of most recent research outcomes on fault diagnosis, opacity analysis and enhancement, and cyber security analysis and enforcement, within suitable discrete event system modelling frameworks. In each case, we describe basic problem statements and key concepts, and then point out the key challenges in each research area. After that, we present a thorough review of state-of-the-art techniques, and discuss their advantages and disadvantages. Finally, we highlight key research directions for further exploration.

ISBN: 978-1-68083-856-5
https://www.nowpublishers.com/article/Details/SYS-024

3.2 Introduction to Discrete Event Systems

Authors: Christos Cassandras and Stéphane Lafortune

Description: Christos Cassandras and Stéphane Lafortune are happy to announce the publication of the third edition of their textbook, Introduction to Discrete Event Systems, by Springer in November 2021. The first two editions of this popular textbook were published in 1999 (Kluwer Academic Publishers) and 2008 (Springer), respectively. This unique textbook comprehensively introduces the field of discrete event systems, offering a breadth of coverage that makes the material accessible to readers of varied backgrounds. The book emphasizes a unified modeling framework that transcends specific application areas, linking the following topics in a coherent manner: language and automata theory, supervisory control, Petri net theory, Markov chains and queueing theory, discrete-event simulation, and perturbation analysis and concurrent estimation techniques. The third edition is a superset of the second one, with new material added based on our teaching of discrete event systems courses at Boston University and at the University of Michigan, and they reflect active research trends in discrete event systems since the publication of the second edition.

Topics and features:
- detailed treatment of automata and language theory in the context of discrete event systems, including application to state estimation and diagnosis
- comprehensive coverage of centralized and decentralized supervisory control
- timed models, including timed automata and hybrid automata - stochastic models for discrete event systems and controlled Markov chains
- discrete event simulation - an introduction to stochastic hybrid systems
- sensitivity analysis and optimization of discrete event and hybrid systems
- new in the third edition: opacity properties, enhanced coverage of event diagnosis and of supervisory control under partial observation, overview of latest software tools, updated treatment of Infinitesimal Perturbation Analysis and of concurrent estimation

This proven textbook is essential to students and researchers in a variety of disciplines where the study of discrete event systems is relevant: control, communications, computer engineering, computer science, manufacturing engineering, transportation networks, operations research, and industrial engineering. This book is available through SpringerLink as an e-book (PDF and EPUB formats) or as a print-on-demand hard cover at https://link.springer.com/book/10.1007/978-3-030-72274-6 The e-book is available for free download at Springer subscribing institutions.

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3.3 Hybrid Dynamical Systems – Fundamentals and Methods

Authors: Hai Lin and Panos Antsaklis

Description: This book is based on courses on hybrid systems, cyber-physical systems, and formal methods taught by the authors in the past years. It is a graduate level textbook and provides an accessible and comprehensive introduction to the theory of hybrid systems with a balanced treatment on fundamentals and methods from both control theory and computer science. It also serves as a reference book for researchers in the fields of hybrid dynamical systems, cyber-physical systems, formal methods and robotics.

More information may be found at the books Springer webpage:

https://link.springer.com/book/10.1007/978-3-030-78731-8

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4 Software Tools

4.1 IDES: An Open-Source Software Tool

IDES, the discrete-event systems software tool in Karen Rudie's lab is now available as open-source software at https://github.com/krudie/IDES. More information on IDES can also be found at https://www.ece.queensu.ca/people/K-Rudie/qdes.html#fndtn-software.

4.2 Supremica 2.7, New Version

The development team has just released a new version of Supremica, Waters/Supremica IDE 2.7.

Supremica is a DES and SCT drawing and calculation tool, that includes a multitude of efficient algorithms for modeling, verification, and synthesis of maximally permissive supervisors. In addition there are general algorithms for standard operations like synchronization, minimization, determinization, etc. Supremica also handles finite automata extended with bounded discrete variables. A feature-full simulation tool is also included.

New in this version:

- Conditional blocks or IF statements can now be created in the components list or on label blocks to allow conditional compilation of automata or events. They can also be used as an alternative to guard/action blocks.
- Update to Log4j 2.17.1 to avoid the Log4shell vulnerability.

Supremica is free to use for education and research; for commercial use, please contact fabian@chalmers.se. Download from www.supremica.org.

4.3 UltraDES 2.2 Release

UltraDES is an open-source library to the modeling, analysis and control of DES, written using C# in .NET Standard 2.0, which allows its use in multiple platforms, such as Windows, Linux, Mac, IOS, Android, so on. The library is under development at LACSED (Laboratory of Analysis and Control of Discrete Event Systems, at the Universidade Federal de Minas Gerais, Brazil) and has basic operations with automata as long as the monolithic, modular and local modular supervisory control (Alves et. al., 2017).

The main improvements of the UltraDES 2.2 version are:

- Supervisor Reduction Algorithm (Su and Wonham, 2004)
- Supervisor Localization (Cai and Wonham, 2010)
- Basic Petri Nets Functions (incidence matrix, coverability/reachability graph, Petri Net marking simulation, etc.)

Knowing that many researchers/students are not familiar with the C# language, we created an experimental python wrapper, that is less object oriented and easier to use.

Another initiative to improve the usability of UltraDES was the creation of a Web Application, developed using Blazor/WebAssembly, that allows the use of UltraDES online. This version is more limited in processing power and memory but it is useful for small examples and teaching.

We invite the community to download and contribute. Algorithms implemented may be integrated to the main distribution. Just let us know. Contact Lucas Alves lucasvra@ufmg.br or Patricia Pena ppena@ufmg.br for more information. Bugs should be informed using the UltraDES GitHub page.
Link: https://github.com/lacsed/UltraDES.

4.4 DESpot 1.10.0 Released

DESpot is a discrete-event system (DES) software, research tool. It supports both flat projects (collection of plant and supervisor DES), and Hierarchical Interface-Based Supervisory Control (HISC) projects.

DESpot 1.10.0 supports a number of new Features:

- DESpot now targets version 4.8.7 of the Qt libraries, RedHat Enterprise Linux 7.x, and MS Windows 10 with MS Visual Studios 2019.
- Support for defining template DES, and then instantiating multiple copies for flat or HISC projects.
- Now includes curved transition arrows for DES diagrams, and the ability to export DES diagrams to EPS.
- Support for verification of timed controllability, including BDD-based algorithms.
- Support for Fault-Tolerant (FT) Supervisory Control, including both timed and untimed controllability and nonblocking BDD-based algorithms, for several fault scenarios.
- Support for specifying decentralized supervisory control structure for a project, and verifying co-observability.

To find out more information and to download a copy, see: http://www.cas.mcmaster.ca/~leduc/DESpot.html

DESpot is open source software, released under the GNU General Public license (GPL), version 2.

DESpot is written in C++ and uses the QT GUI libraries. At the moment, DESpot is available as source code and as a Windows' installer. It runs under Linux, and Windows.

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