GAČR
GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část A

Návrh Standardního projektu (dále návrh projektu)

Datum podání návrhu projektu: **totožné s datem odeslání návrhu projektu prostřednictvím ISDS**

Číslo panelu(ů): **P103**

Registrační číslo: **15-02532S**

Uchazeč a navrhovatel

Uchazeč:	**Matematický ústav AV ČR, v.v.i.**
IČ:	**67985840**
Sídlo:	**Žitná 609/25, Praha 1**
Navrhovatel:	**Mgr. Jan Komenda Ph.D.**
Datum narození/rodné číslo:	**1971-08-18 710818/1454**
Telefon:	**222090792**
Fax:	**222090701**
E-mail:	**komenda@math.cas.cz**

Název projektu česky:

Modulární a Decentralizované Řízení Diskrétních a Hybridních systémů s Komunikací

Název projektu anglicky:

Modular and Decentralized Control of Discrete-Event and Hybrid Systems with Communication

Klíčová slova česky:

diskrétní událostní systémy; modulární a decentralizované supervizní řízení; koordinační řízení s komunikujícími supervisory; logické, časované a hybridní automaty

Klíčová slova anglicky:

discrete-event systems; modular and decentralized supervisory control; coordination control with communicating supervisors; logical, timed, and hybrid automata

Datum zahájení: **2015-01-01**

Doba řešení (v letech): **3**

Zařazení do číselníku CEP:

BC

Podáním návrhu projektu uchazeč stvrzuje, že:
• navrhovatel je v pracovněprávním poměru k uchazeči nebo tento vztah vznikne nejpozději ke dni zahájení řešení grantového projektu;
• zavazuje se, že po uzavření smlouvy o podpoře grantového projektu bude plnit všechny povinnosti příjemce vyplývající ze zákona č. 130/2002 Sb., zadávací dokumentace a uzavřené smlouvy nebo vydaného rozhodnutí o poskytnutí podpory;
• zajistí, aby řešitel po uzavření smlouvy o podpoře grantového projektu plnil všechny své povinnosti, zejména odpovídal za odbornou úroveň řešení projektu; nastane-li situace, že podmínky na straně řešitele či příjemce znemožní řešiteli pokračovat v řešení projektu v navrhovaném termínu a nedojde-li k ukončení projektu, příjemce zajistí se souhlasem poskytovatele jiného řešitele, pokračování řešení projektu a jeho dokončení v souladu s uzavřenou smlouvou;
• všechny údaje uvedené v návrhu projektu jsou pravdivé, úplné a nezkreslené a jsou totožné s údaji vloženými do návrhu projektu pomocí aplikace, a že návrh projektu byl vypracován v souladu se zadávací dokumentací;
• všichni spoluuchazeči, navrhovatel, spolunavrhovatelé a odborní i další spolupracovníci uvedení v návrhu projektu byli seznámeni s věcným obsahem návrhu projektu i s finančními požadavky v něm uvedenými a se zadávací dokumentací;
• před podáním návrhu projektu zajistil souhlas výše uvedených osob s účastí na řešení grantového projektu uvedeného v návrhu projektu;
• na jiný projekt s totožnou nebo obdobnou problematikou nepřijal, nepřijímá a nepřijme podporu z jiného zdroje;
• obsah návrhu projektu, jehož se v jiných typech grantových projektů nebo v programových projektech účastní stejný navrhovatel nebo spolunavrhovatel, je rozdílný od tohoto návrhu projektu a navržené rozsahy prací umožní navrhovateli nebo spolunavrhovateli řešit všechny jejich projekty;
• souhlasí, aby údaje uvedené v návrhu projektu byly použity pro vnitřní informační systém poskytovatele a uveřejněny v rozsahu stanoveném zákonem č. 130/2002 Sb. a zadávací dokumentací;
• v případě uzavření smlouvy nebo vydání rozhodnutí o poskytnutí podpory na řešení grantového projektu se bude při jeho řešení řídit podmínkami pro řešení grantových projektů uvedenými v Příloze 4 zadávací dokumentace.

Kopie speciálních oprávnění podle zvláštního právního předpisu (viz § 18 odst. (2) písm. b) zákona č. 130/2002 Sb.) jsou přiloženy, zahrnuje-li grantový projekt činnosti je vyžadující.

Uchazeč potvrzuje, že byla zkontrolována úplnost a správnost údajů.

Statutární zástupce uchazeče

GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část Abstrakt a Cíle projektu

Navrhovatel: **Mgr. Jan Komenda Ph.D.**

Registrační číslo: **15-02532S**

Název projektu: **Modulární a Decentralizované Řízení Diskrétních a Hybridních systémů s Komunikací**

Abstrakt - česky

Diskrétní událostní systémy reprezentují důležitou třídu dynamických systémů s diskrétním stavovým prostorem a diskrétní dynamikou řízenou výskytem událostí. Pro velké systémy byly vytvořeny metody hierarchického, modulárního a decentralizovaného supervizního řízení. Protože řešení modulárního a decentralizovaného supervizního řízení často neexistuje bez komunikace mezi supervizory, navrhli jsme koordinační řízení jako formu decentralizovaného řízení s lokálními supervizory komunikujícími prostřednictvím koordinátorů. V tomto projektu budeme studovat nové výpočetně efektivní metody koordinačního supervizního řízení strukturovaných automatů s víceúrovňovou strukturou komunikací, a to jak logických, tak těch vytvořených diskretizací. Stejně tak budeme studovat decentralizované supervizní řízení velkých automatů, které nemají apriori známou strukturou ve formě synchronizovaného součinu menších automatů. Motivací k navržení nových efektivních metod pro decentralizované řízení automatů je zpoždění nebo ztráta komunikací a ztráta součinové struktury diskretizací.

cíle projektu - česky

(Tento text bude v případě udělení grantu uveden ve smlouvě o řešení projektu.)

Cílem projektu je navrhnout nová řešení problémů decentralizovaného supervizního řízení automatů s komunikujícími supervizory. Komunikace budou založeny na víceúrovňovém koordinačním řízení. Budeme brát v úvahu i problém opožděné a ztracené komunikace a navrhneme robustní řešení těchto problémů.

Abstrakt - anglicky

Discrete-event systems represent an important class of dynamical systems with discrete state spaces and event-driven dynamics. For large systems, methods of hierarchical, modular, and decentralized decentralized supervisory control have been proposed. Since a solution to modular and decentralized supervisory control may not exist without communication between controllers, coordination control has been proposed as a form of decentralized control with supervisors communicating via coordinators. In this project we will study computationally efficient solutions to coordination supervisory control of large automata with product structure based on multi-level communication structure. Both logical automata and those stemming from discretizations will be considered. Decentralized supervisory control of automata without a priori known modular (product) structure will also be investigated. The motivations for investigating new efficient methods are that communications are sometimes lost or delayed and the original product structure is often lost after discretization.

cíle projektu - anglicky

The goal of this project is to propose new efficient solutions for decentralized supervisory control of large automata with communicating supervisors. Communications will be based on multi-level coordination control. Robust solutions to problems of communication delays and losses will be proposed.

GAČR
GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část B - finanční prostředky celkem

Uchazeč: **Matematický ústav AV ČR, v.v.i.**

Navrhovatel: **Mgr. Jan Komenda Ph.D.**

Registrační číslo: **15-02532S**

1. Celkové předpokládané uznané náklady na řešení projektu ze všech zdrojů financování na jednotlivé roky jeho řešení

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

	1.rok	2.rok	3.rok	4.rok	5.rok	**Celkem**
Náklady ze všech zdrojů financování	338	395	620	0	0	**1353**

2. Celkové předpokládané uznané náklady na řešení projektu z jednotlivých zdrojů za celou dobu jeho řešení

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

Jednotlivé zdroje finančních prostředků na řešení projektu	**tis. Kč**
Celkové grantové prostředky požadované od GA ČR	1353
Podpora z jiných tuzemských veřejných zdrojů (z jiné kapitoly státního rozpočtu nebo rozpočtů územních celků), pokud existuje	0
Podpora z ostatních veřejných zdrojů (nepatřících do státního rozpočtu nebo rozpočtů územních správních celků), pokud existuje. (veřejné zdroje v ČR i v zahraničí)	0
Podpora z neveřejných zdrojů (zahraniční zdroje, neveřejné tuzemské zdroje, vlastní neveřejné zdroje), pokud existuje	0
Celkem	**1353**
Míra podpory	**100 %**

3. Celkové náklady na řešení projektu požadované od GA ČR

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

	1.rok	2.rok	3.rok	4.rok	5.rok
Ostatní provozní náklady celkem	142	199	264	0	0
Osobní náklady celkem	196	196	356	0	0
Náklady na řešení projektu celkem	**338**	**395**	**620**	**0**	**0**

GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část B - rozpis finančních položek

Uchazeč: **Matematický ústav AV ČR, v.v.i.**

Navrhovatel: **Mgr. Jan Komenda Ph.D.**

Registrační číslo: **15-02532S**

Finanční prostředky požadované od GA ČR pro uchazeče

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

Ostatní provozní náklady	1. rok	2.rok	3.rok	4.rok	5.rok
Materiální náklady	5	5	5	0	0
Cestovní náklady	55	85	95	0	0
Náklady na ostatní služby a nemateriální náklady	15	30	40	0	0
Doplňkové (režijní) náklady	67	79	124	0	0
Ostatní provozní náklady celkem	**142**	**199**	**264**	**0**	**0**

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

Osobní náklady (Podrobný rozpis v části B - osobní náklady)	1. rok	2.rok	3.rok	4.rok	5.rok
Mzdy navrhovatele a spolupracovníků	144	144	262	0	0
Mzdy technických a administrativních pracovníků	0	0	0	0	0
Ostatní osobní náklady (celkem)	0	0	0	0	0
Sociální a zdravotní pojištění a SF (FKSP)	52	52	94	0	0
Osobní náklady celkem	**196**	**196**	**356**	**0**	**0**

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

	1. rok	2.rok	3.rok	4.rok	5.rok
Náklady celkem	338	395	620	0	0

Náklady z dalších zdrojů předpokládané za celou dobu řešení projektu

(finanční údaje se uvádějí jako celočíselné hodnoty **v tisících Kč**)

	1. rok	2.rok	3.rok	4.rok	5.rok
Účelová podpora - dotace z jiných tuzemských veřejných zdrojů (z jiné kapitoly státního rozpočtu nebo z rozpočtů územních správních celků)	0	0	0	0	0
Podpora z ostatních tuzemských veřejných zdrojů (nepatřících do státního rozpočtu nebo z rozpočtů územních správních celků)	0	0	0	0	0

Podpora z neveřejných zdrojů	0	0	0	0	0

Míra podpory	**100 %**

GAČR
GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Uchazeč: **Matematický ústav AV ČR, v.v.i.**

Navrhovatel: **Mgr. Jan Komenda Ph.D.**

Registrační číslo: **15-02532S**

Specifikace a zdůvodnění nákladů pro 1. rok řešení

Část B - zdůvodnění finančních položek je nedílnou součástí návrhu projektu a obsahuje v souladu s ustanovením Zadávací dokumentace čl. 3.2. specifikaci a zdůvodnění všech požadovaných nákladů ze všech zdrojů

Materiální náklady:

Požadované finanční prostředky na materiální náklady ve výši 5 tis. Kč budou určeny na nákup drobných kancelářských potřeb.

Cestovní náklady:

Cestovní náklady budou určeny na podporu spolupráce se zahraničními kolegy, tedy na financování aktivní účasti na významných konferencích a na krátké vzájemné návštěvy.
Konkrétně pak následující vědecké aktivity budou podporovány z cestovného (v celkové výši 55 tis. Kč) v roce 2015:
• aktivní účast na konferenci European Control Conference ECC 2015, Linz, Rakousko, 15-17.7.2015, 2015: 15 tis. Kč
• aktivní účast na konferenci 54th IEEE CDC (prosinec 2015): 30 tis. Kč
• pozvání zahraničního hosta (vědce) do Brna, jen částečně z navrhovaného projektu (kapesné a ubytování), asi 10 tis. Kč

Náklady na ostatní služby a nemateriální náklady:

Položka ostatních služeb a nemateriálních nákladů ve výši 15 tis. Kč je určena zejména na financování konferenčních poplatků. Konkrétně bude z této částky hrazen konferenční poplatek pro řešitele na European Control Conference ECC 2015: celkem asi 15 tis. Kč.

Zdůvodnění osobních nákladů pro jednotlivé osoby:

Plánované mzdy vycházejí z procentuálního úvazku na řešení grantového projektu a z platných mzdových tarifů v Matematickém ústavu AV ČR.

Pro první a druhý rok projektu:
Mgr. Jan Komenda, Ph.D. - 11 980 Kč (odpovídá částce 39 920 Kč/FTE, 30% úvazku, kategorie: řešitel)
Odpovídající částka na sociální a zdravotní pojištění a SF (FKSP) tedy činí asi 52 tis. Kč ročně a celkové osobní (mzdové) náklady jsou pak ve výši 196 tis. Kč ročně.

Pro třetí rok řešení projektu:
Mgr. Jan Komenda, Ph.D.- viz výše.
RNDr. T. Masopust, Ph. D. - 9 820 Kč (odpovídá částce 32 720 Kč/FTE, 30% úvazku, kategorie: B).
Odpovídající částka na sociální a zdravotní pojištění a SF (FKSP) tedy činí asi 94 tis. Kč a celkové osobní (mzdové) náklady jsou pak ve výši 356 tis. Kč v třetím roku projektu.

GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část B - osobní náklady

Uchazeč: **Matematický ústav AV ČR, v.v.i.**

Navrhovatel: **Mgr. Jan Komenda Ph.D.**

Registrační číslo: **15-02532S**

Osobní náklady pro uchazeče pro první rok řešení

Mzdy odborných pracovníků

Jméno	Příjmení	Pracovní úvazek na řešení (v % úvazku)	Požadavky na mzdy od GA ČR
Jan	Komenda	30 %	144

Mzdy technických a administrativních pracovníků

Souhrný pracovní úvazek technických a administrativních pracovníků (v % úvazku)	Požadavky na mzdy od GA ČR
0	0

Ostatní osobní náklady

(na základě dohod o provedení práce nebo dohod o provedení činnosti)

Jméno, příjmení, případně označení (s) u studenta	Požadavky od GA ČR

Předpokládané výsledky projektu

1a. článek v odborném periodiku impaktovaném (druh výsledku Jimp)	6
1b. článek v odborném periodiku obsaženém v databázi Scopus (druh výsledku Jsc)	1
1c. článek v odborném periodiku neimpaktovaném (druh výsledku Jneimp)	0
1d. článek v českém odborném recenzovaném časopise (druh výsledku Jrec)	0
2a. odborná kniha (druh výsledku B)	0
2b. kapitola v odborné knize (druh výsledku C)	0
3. článek ve sborníku (druh výsledku D)	12
4. patent (druh výsledku P)	0

GAČR

GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část D2 - bibliografie

Uchazeč: **Matematický ústav AV ČR, v.v.i.**

Navrhovatel: **Mgr. Jan Komenda Ph.D.**

Registrační číslo: **15-02532S**

Úplné bibliografické údaje o nejvýznamnějších výsledcích vědecké a výzkumné činnosti definovaných v aktuálně platné Metodice hodnocení výsledků výzkumu a vývoje

	Výsledek	kód druhu výsledku	Počet citací (bez autocitací) podle WOS	Impaktní faktor časopisu nebo kategorie ERIH	Počet citací v oborech NRRE	Časopis je zařazen v databázi SCOPUS
1	J. Komenda, J. H. Van Schuppen, B. Gaudin, H. Marchand. Supervisory Control of Modular Systems with Global Specification Languages. Automatica 44 (4), 2008, 1127-1134.	J_{imp}	8	2.919		Ano
2	J. Komenda, J. H. Van Schuppen. Modular Control of Discrete-Event Systems with Coalgebra. IEEE Transactions on Automatic Control 53 (2), 2008, 447-460.	J_{imp}	5	2.7118		Ano
3	J. Komenda, T. Masopust, J. H. Van Schuppen. Supervisory Control Synthesis of Discrete-Event Systems using a Coordination Scheme. Automatica 48 (2), 2012, 247-254.	J_{imp}	2	2.919		Ano
4	J. Komenda, J. H. Van Schuppen. Control of Discrete-Event Systems with Partial Observations Using Coalgebra and Coinduction Discrete Event Dynamic Systems-Theory and Applications 15 (3), 2005, 257-315.	J_{imp}	14	0.771		Ano
5	J. Komenda, T. Masopust, J. H. Van Schuppen. Synthesis of Controllable and Normal Sublanguages for Discrete-Event Systems using a Coordinator, Systems & Control Letters 60 (7), 492-502, 2011.	J_{imp}	4	1.667		Ano
6	J. Komenda, T. Masopust, J. H. Van Schuppen. On Conditional Decomposability, Systems & Control Letters 61 (12), 1260-1268, 2012.	J_{imp}	0	1.667		Ano
7	J. Komenda, S. Lahaye, J.L. Boimond .Supervisory Control of (max,+) automata: a behavioral approach Discrete Event Dynamic Systems 19 (4), 2009, 525--549.	J_{imp}	5	0.771		Ano
8	J. Komenda, J. H. Van Schuppen. Control of discrete-event systems with modular or distributed structure Theoretical Computer Science 388 (3), 2007, 199-226.	J_{imp}	0	0.489		Ano

Celkové počty výsledků definovaných v aktuálně platné Metodice hodnocení výsledků výzkumu a vývoje za posledních 5 let

1a. článek v odborném periodiku impaktovaném (druh výsledku Jimp)	7
1b. článek v odborném periodiku obsaženém v databázi Scopus (druh výsledku Jsc)	1
1c. článek v odborném periodiku neimpaktovaném (druh výsledku Jneimp)	1
1d. článek v českém odborném recenzovaném časopise (druh výsledku Jrec)	0
2a. odborná kniha (druh výsledku B)	0
2b. kapitola v odborné knize (druh výsledku C)	3
3. článek ve sborníku (druh výsledku D)	19

4. patent (druh výsledku P)	0
5. užitný nebo průmyslový vzor (druh výsledku F)	0
6. poloprovoz, ověřená technologie, odrůda, plemeno (druh výsledku Z)	0
7. prototyp, funkční vzorek (druh výsledku G)	0
8. poskytovatelem realizovaný výsledek (druh v výsledku H)	0
9. specializovaná mapa (druh výsledku L)	0
10. certifikovaná metodika a postup (druh výsledku N)	0
11. software (druh výsledku R)	0
12. výzkumná zpráva obsahující utajované informace podle zvláštního právního předpisu (druh výsledku V)	0

Celkový počet citací včetně autocitací na všechny práce podle Web of Science	**64**
H-index podle Web of Science	**5**

GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Část E

Uchazeč:	**Matematický ústav AV ČR, v.v.i.**
Navrhovatel:	**Mgr. Jan Komenda Ph.D.**
Registrační číslo:	**15-02532S**

Údaje o běžících, navrhovaných a ukončených projektech navrhovatele

Projekty v současné době podporované

Poskytovatel / název programu:	**MŠMT**
Reg. č./ zařazení do CEP	**LH13012**
Panel	-
Nezkrácený název projektu	**Víceúrovňové Supervizní Řízení**
Celková výše podpory pro uchazeče nebo spoluuchazeče	**1337**
Doba řešení od-do (roky)	**2013-03-01 - 2015-12-31**
Pracovní úvazek:	**20**
Název instituce, která podporu přijímá:	**Matematický ústav AV ČR, v.v.i.**
Role:	**řešitel**
Vztah k podávanému návrhu:	**Projekt MŠMT spolupráce s Univerzitami v Ann Arboru a v Detroitu (USA), kde studujeme víceúrovňové supervizní řízení systémů s explicitní modulární strukturou. Projekt je na rozdíl od podávaného návrhu zaměřen na čistě logické automaty s danou součinovou strukturou a nestudujeme v něm problematiku opožděných a ztracených komunikací. Na projektu pracuje Jan Komenda se spolupracovníkem Tomášem Masopustem.**

V současné době nejsou žádné projekty navrhované

Přehled hodnocení grantových projektů GA ČR ukončených v posledních třech letech, u kterých byl navrhovatel řešitelem nebo spoluřešitelem:

Registrační číslo	Hodnocení
P103/11/0517	dosud nehodnoceno

Czech Science Foundation – Part PD1 (Brief CV)

Applicant: Jan Komenda

Date and place of birth: August 18, 1971, Dačice, Czech Republic

CONTACT Institute of Mathematics, Czech Academy of Sciences
Žižkova 22, 616 62 Brno, Czech Republic, E-mail: komenda@ipm.cz, komenda@math.cas.cz

Education:

M.Sc. (Mathematics) - Faculty of Sciences, Masaryk University, Brno (1994)
Ph.D. (Control theory ad computer science) - Université de Franche-Comté, Besançon, France (1999)
Ph.D. (Mathematics) Faculty of Sciences, Masaryk University, Brno (2000)

Employment:

May 1999- April 2001: postdoctoral researcher at Mathematical Institute of Czech Academy of Sciences, branch in Brno, Czech Republic
May 2001-August 2003: postdoctoral researcher at CWI Amsterdam, The Netherlands

September 2003-present: researcher at the Institute of Mathematics, Czech Academy of Sciences, branch in Brno, Czech Republic

Short positions or long visits abroad:

2000 research stay at ENSMM, Laboratoire d'Automatique de Besançon, France, (1 month)
2002 research stay at University of Illinois at Urbana-Champaign (UIUC), USA, (1 month)

2006 invited lecturer at University of Angers , France, (3 months)

2007, 2012 invited lecturer at University of Angers , France, (1+1 months)

Scientific activities:

- Talks at many (>30) international conferences and University seminars abroad (>20)
- Investigator of the postdoc grant GA ČR 201/03/P077, NWO (Dutch organization for scientific research) project Coalgebra and Control (COCON): 2001-2003, EU Esprit LTR project Control and Computation, ISO-2001-33520, 2003, and GAAV KJB 100190609 (2006-2008), GA ČR 103/11/0517.
- Local responsible of 7th FP EU.ICT project DISC (DIstributed Supervisory Control), N. 224498 (2008-2011) at the Institute of Mathematics, Czech Academy of Sciences
- Reviewer for many journals: e.g. Discrete Event Dynanic Systems: Theory and Applications, Automatica, European Journal of Control, IEEE Transactions on Automatic Control, Mathematics of Control, Systems and Signals, Information Sciences, Linear Algebra and its Applications and for several control conferences (IEEE CDC, ECC, ACC and IFAC conferences).
- Associated editor of Automatica (since December 2009)
- Member of several Ph.D. committees and two habilitation thesis committees, IFAC TC 1.3
- International Program Committee (IPC) member of IEEE/IFAC Workshop on Discrete-Event Systems (WODES) 2006, WODES 2008, WODES 2010, WODES 2012, Modélisation des Systèmes Réactifs (MSR) 2009, 2011, Conference on Analysis and Design of Hybrid Systems (ADHS) 2012, European Control Conference (ECC) 2013, MSR 2013, ECC 2014, WODES 2014

Czech Science Foundation – Part C

Project Description

Applicant: Jan Komenda
Project Title: Modular and Decentralized Control of Discrete-Event and Hybrid Systems with Communication

1. Introductory motivation

In this research program we propose to investigate new methodologies for decentralized supervisory control of large discrete-event systems (DES), especially those that do not benefit from an a priori modular structure in a form of synchronized product of local subsystems. DES are dynamical systems with discrete state spaces and event-driven dynamics meaning that the state changes are not governed by differential or difference equations but rather by asynchronous occurrences of discrete events. This is a typical feature of technological systems often referred to as man-made systems. The emergence of networked embedded systems and sensor/actuator networks stimulated further development of supervisory control of DES, in particular hierarchical, distributed and decentralized control of large scale DES. These arise in technological systems either directly or as a result of various discretization techniques for more complex hybrid (cyber-physical) systems, which are characterized by the coexistence of both event driven dynamics of the discrete part and continuous-time dynamics of the continuous part. Typical examples of models for cyber-physical systems are timed and hybrid automata. The former model allows only for trivial continuous dynamics using variables called clocks, while the latter model supports general (including nonlinear) continuous dynamics.

Many control problems for hybrid systems are the so-called safety control problems in which inclusion of the system behavior in a prescribed behavior called safety specification is to be guaranteed. It is then natural to apply discretization of timed and hybrid automata and recast the original hybrid control problem as a supervisory control problem. There is an inherent problem with the very large complexity of verification and control problems for DES coming from real-word systems such as embedded systems and in particular those stemming from discretization of timed or hybrid automata.

Decentralized control with several controllers receiving each only part of the observations and controlling only part of the events is a possible approach. Since a reasonable solution to decentralized control may not exist without communication between controllers, coordination control has been proposed as a form of decentralized control with supervisors communicating via coordinators for modular DES in the form of synchronous product of local automata.

The main motivation of this research proposal is to further develop multi-level coordination control so that it can be applied to decentralized supervisory control with communicating local controllers based on modular overapproximation. Both purely logical (Boolean) automata as well as those obtained as a result of a discretization applied on a given timed or hybrid automaton will be considered in this project. This is motivated by the fact that in the case of timed automata, discretizations (known as regional or zone Boolean automata) do not preserve the modular structure of large timed automata, which are often represented by the synchronous product of local (component) timed automata. More precisely, the synchronous product of discretized local timed automata yields a different result than the discretization of the large timed automaton defined as the product of local ones. It is to be expected that discretization of hybrid automata does not preserve the modular structure either.

In order to face this serious issue new computationally efficient approaches to decentralized supervisory control will be proposed based on multi-level coordination control with hierarchical structure of subsystems and coordinators on different levels. We will compare computational complexity of two methods of multi-level coordination control: the top-down approach and the bottom-up approach, both applied to decentralized supervisory control. The contribution of this project will then provide new solutions to decentralized supervisory control of large automata without a priori known modular structure in the form of a synchronized product of smaller automata. The proposed approaches to decentralized control will be implemented in the open-source software package libFAUDES developed by researchers from the University of Erlangen.

2. State of the art

2.1 Supervisory control of logical automata

Supervisory control theory has been proposed [RW 89] as a formal approach for control of logical automata with partial transition functions that aims to solve the safety issue (avoidance of forbidden states given by control specifications) and nonblockingness (avoidance of deadlocks) that rise in nowadays technological systems. If control specifications are given informally, software engineers must translate them into control software manually. This is a time-consuming and an error prone process, and moreover, the produced software needs to be verified using model checking techniques. Due to the growing complexity of technological systems the risk of a human error is so high that the design of supervisory controllers has to be automated. The ultimate goal of supervisory control is to develop formal theory that enables an automated synthesis of controllers that are correct by construction so that further verification is not needed. More concretely, given a control specification describing required behavior of the system, one has to construct a supervisor that observes a subset of events (yielding a possibly partial information about the state of the plant) and selects actuators, that can control the execution of some controllable events in order to meet the prescribed specification language, which specifies a property of the system such as certain states must be forbidden. The specification language is achieved by running another automaton (supervisor) in parallel with the original system so that the specified property is met by the parallel composition of the plant with its supervisor. Not every specification language can be exactly achieved, because there are uncontrollable events that cannot be prevented from happening by any supervisor and unobservable event whose occurrences cannot be monitored directly by the sensors. Therefore, properties called controllability and relative closedness have been introduced as necessary and sufficient conditions on a specification to be exactly achieved by the closed-loop (controlled) system. Moreover, if the controller has only partial access to the events of the system (only part of the events are observable), the additional property of observability is needed for a specification to be exactly achieved by the closed-loop (controlled) system.

Supervisory control is based on the algebraic theory of formal languages and automata theory for DES represented by automata and their extensions, but also on linear algebra for DES represented by Petri Nets [SB 01], [BA 92], and [GSB 04]. It appears that complex concurrent systems are typically built in a compositional way as synchronous or asynchronous compositions of smaller components. A major problem is that the computational complexity of the centralized supervisory control design is often considered prohibitive, because the global system has an exponential number of states in the number of components. Therefore, a modular approach to the supervisory control of DES modeled by products of finite automata has been introduced in [WR 88] that aims at compositional (local) control synthesis. The system is composed of local components (subsystems) that run concurrently (in parallel), i.e. the global system is the synchronous product of local components. Modular supervisory control of DES has been further developed by many authors, notably in [WL 02] structural conditions are derived for local computation of (global) supremal controllable sublanguages. In practice, specification languages are not decomposable, but are rather defined over the global alphabet, which means that global specification languages are much more relevant than local specification languages. The case of global specifications has been considered in [GM 04]. As is shown therein, it is sometimes possible to exploit the modular structure of the plant and to avoid the manipulation with the global plant. Using a structural condition, called global mutual controllability, requirement that all shared events have to controllable has been weakened in [KvS 08b] to the assumption that events shared by two or more local subsystems must have the same controllability status in all these subsystems. Under these assumptions it is still possible to compute the optimal supervisor locally, i.e. without having to construct the global plant language. The modular approach has been generalized to partially observed systems in [KvS 08a], where necessary and sufficient conditions for local control synthesis to equal global control synthesis are presented.

However, some systems do not benefit from explicit modular structure in the form of a product of concurrent components. Decentralized supervisory control has been proposed in [CV 88], and further developed in [RW 92] and [YL 02]. It is simply based on the distribution of overall actuator and sensor capabilities among several local control agents called supervisors, which is motivated by decreasing computational complexity. Each supervisor can issue its own control decision on enabling or disabling of an event based on its own (partial) observation of the system behavior, which is formally given as a natural projection of the system's behavior. The global control action of the decentralized control architecture is then given by a fusion rule on the local control actions. There are many different control policies that are based on two elementary ones, namely the conjunctive and permissive (C&P) policy, and the disjunctive and antipermissive (D&A) policy. For any such a decentralized control architecture, a corresponding notion of coobservability has been proposed, which together with controllability and relative closedness form necessary and sufficient conditions to achieve a specification as the resulting behavior of the closed-loop system.

An interesting approach to ensure coobservability of a specification is to extend locally observable events by communication among local supervisors. There are decentralized control problems that cannot be solved without enriching locally observable events via communication. Decentralized control with communicated supervisors, where an occurrence of transitions visible to one supervisor can be communicated to other supervisors, has been studied in [BL 00] and [RR 00]. A more recent approach based on synchronization vector and communication language is presented in [RC 11] with several other recent references on the topic. Nowadays, there exist more advanced architectures of decentralized supervisory control, such as with conditional decision (inferencing) [YL 04] or even multi-level inferencing [TK 08].

Almost all results available in the literature provide existence results, and there are only a few papers providing constructive results, namely, how to compute a controllable and coobservable sublanguage of a specification that fails to satisfy these properties. It is considered as a computationally difficult problem, but the existence of a set of local supervisors that enforce the safety specification (meaning that the behavior of the controlled system is included in the specification) is still decidable when nonblockingness is not required unlike the general problem. If the marked language of the controlled system has to be included in the specification and nonblockingness is required, then the existence of local supervisors has been shown undecidable in [Th 05] and [Tr 04].

The term coordinator has first appeared in the DES literature in [LW 90]. Coordination control approach has been recently developed for modular DES, cf. [KMvS 12]. Coordination control may be seen as a reasonable trade-off between a purely decentralized (modular) control synthesis, which is in some cases unrealistic, and a global control synthesis, which is naturally prohibitive for high complexity reasons. It is useful in the general case, where conditions for local control synthesis to equal global control synthesis are not satisfied and/or the composed system is blocking. The concept of a coordinator is useful for both safety and for nonblockingness in [KMvS 14]. The complete closed-loop then consists of the coordinator, its supervisor, and the local supervisors for the subsystems. Necessary and sufficient condition, called conditional controllability, for control synthesis using the coordination control architecture has been studied in [KMvS 12] together with a procedure for computation of the supremal conditionally controllable sublanguage of a given specification. We have also extended coordination control for non prefix-closed specification languages [KMvS 14] and partial observations [KMvS 11]. Multi-level coordination control with existential results for the top-down architecture has been presented in [KMvS 13]. However, coordination control has only been developed for automata with explicit modular (concurrent) structure, which is missing in decentralized control that deals with monolithic plants. Note that an extension of coordination control to the general framework of decentralized control is also needed for supervisory control of timed automata, because untiming abstraction (known as region automata) does not preserve the concurrent structure.

An important issue of supervisory control is to take into account communication delays and losses of communication. It is natural that communication among supervisors as well as information flow between observers and supervisors and between supervisors and actuators induces delays and losses. Typically, supervisors may not observe the occurrence of an event until after some delay. More seriously, the message may be damaged or lost so that a supervisor may never see its content, i.e. the occurrence of an event. In the same way, a control decision of the supervisor may not reach the plant in time for an effective control. Until recently, it has been commonly adopted that the communication between a plant and its supervisor is instantaneous or it is so fast that delays do not affect control decisions and can be neglected. The author of [L 14] was the first to assume that there are delays and losses in both parts of the supervisory control loop: in communication from the plant to the supervisor, which is for sensing (observation), and in the communication from the supervisor to the plant, which is for actuating (control). It is assumed therein that these communications may be delayed or lost.

2.1 Supervisory control of hybrid and timed automata

Hybrid (sometimes called cyber-physical) systems combine event triggered discrete-event dynamics with time triggered dynamics driven by differential equations, a standard model for continuous time systems. Typical examples of hybrid models are hybrid automata (HA) [HK 95] that combine the traditional finite automata with continuous dynamics of the physical world. HA are finite automata extended with continuous variables that evolve either continuously in time or have discontinuous jumps whenever a discrete event occurrs. In hybrid automata, sets of differential equations and algebraic equations specify dynamics of the system at each discrete location, and finite automata specify discrete changes of dynamics of the system from one set of equations to another. This model is useful for describing systems that interact with the physical world such as embedded systems encountered in many technological systems. When a hybrid automaton stays in a location, variables are updated continuously according to the differential equations until a discrete transition is taken or the invariant condition of the location is violated. A discrete transition can be taken whenever the associated condition (guard) is true. When the transition is taken from one location to another, the differential equations belonging to the new destination become effective immediately, and the variables continuously evolve according to those new equations.

Timed automata (TA) of Alur and Dill [AD94] form an important subclass of hybrid automata in which all continuous variables are clocks meaning they have derivatives equal to 1. TA are finite-state machines endowed with a set of continuous variables called clocks that operate like stopwatches and measure the time that has elapsed since their last reset. Still it is a very general model for timed DES because clocks can be read and their values are used in definitions of discrete transitions upon which some specified clocks are reset to zero. State reachability is decidable for this sub-class (unlike general HA), which makes TA an important formalism for verification. For real-time discrete event systems both discrete and dense time models have been studied, where dense time models are more popular, because they are more accurate than discrete time models.

It is well known that timed automata have finite bisimulation quotients under so-called region equivalence relations on clock vector values. The quotient automata are finite automata known as region automata. Similar discretization techniques have been proposed for hybrid systems in [AH 00]. Unfortunately, TA also suffer from undecidability results [AD 94] that have been established for several fundamental problems such as checking of equality and inclusions of their behaviors (timed languages) or checking universality, while non emptiness and reachability are decidable. Moreover, TA are not closed under complementation and there does not exist a terminating determinization procedure for nondeterministic TA. Supervisory control has been extended to timed automata using a game-theoretical approach, where the existence of a controller corresponds to the existence of a winning strategy of the game [AMPS 98] and it is based on corresponding region automata.

Conceptually much simpler models of timed systems are (max,+) automata, proposed by Gaubert in [Gau 95]. Nondeterministic (max,+) automata model an important class of TDES, exhibiting both synchronization of tasks and resource sharing (choice) phenomena. (Max,+) automata are weighted automata with weights (multiplicities interpreted as duration of events) in the so called (max,+)-semiring. We have studied their supervisory control in [KLB 09a], where it is shown that for control problems the use of nondeterministic (max,+) automata is very limited, because rational (finite state) controllers can essentially be obtained only for plants modeled by deterministic (max,+)-automata. It is however known that not all (max,+)-automata have equivalent deterministic ones. This has serious consequences in supervisory control of (max,+)-automata and interval automata, which are weighted automata in a semiring of real intervals. The results of [LM 06] and [KLB 09a] imply that nondeterministic representations of concurrent (multi-clock) timed systems are not very useful for supervisory control of weighted automata, because rational controllers cannot be obtained. This is a major motivation for developing new techniques for determinization of weighted automata.

We have introduced deterministic synchronous product in [KLB 09b] over an extended alphabet that may contain sequences of original events. This product has been applied to modular control of synchronous products of (max,+)-automata using the coalgebraic framework in [KLB 12]. Sufficient conditions have been presented under which closed-loop behavior with local control equals closed-loop behavior with computationally expensive global control.

However, these results cannot be generalized to global specifications that are not decomposable and direct extension to coordination control of weighted automata is also not straighforward due to the fact that there might not exist finite state observer (projected) automata for (max,+)-automata. This is related to the determinization issue of (max,+)-automata: for a non deterministic (max,+)-automaton there does not always exit a finite state deterministic one having the same behavior [LM 06].

We have proposed in [LKB 14] synchronous product of deterministic (max,+)-automata, which are nondeterministic (max,+)-automata capable of modeling many realistic real-time systems such as asynchronous circuits and represent a reasonable trade-off between expressive power and tractability. This result of this product is better suited for determinization, which is currently under investigation.

3. Main goals of the project and our solution approach.

The main goal of this project is to propose efficient methods for decentralized supervisory control of large systems that do have an a priori modular structure in a form of synchronized product of local subsystems. It will be based on application of multi-level coordination control to decentralized supervisory control with communicating controllers. This will bring new constructive results to decentralized supervisory control of purely logical, but also timed and hybrid systems for which discretizations do not preserve their modular structure.

3.1 Logical systems

The main idea of this project is that the initial problem of decentralized control will be transformed into a coordination control problem owing to modular over-approximation according to natural projections on events observable by local supervisors. This way efficient constructive techniques of multi-level coordination control with hierarchical structure of subsystems and coordinators on different levels will help to compute a controllable and co-observable sublanguage of the specification language. However, we have only developed coordination control based on the notion of conditional decomposability that is related to standard (conjunctive and permissive) coobservability and can hopefully be further refined. For instance, it is mentioned above that conditional (inference based) architectures have been proposed for decentralized supervisory control. It is clear that these architectures will require an updated form of the coordination control of modular system that should be developed first so that it can be applied to these inference based architectures. In particular, we will find a new notion of conditional decomposability that will correspond to inference coobservability (under mild conditions imposed on locally controllable and observable event sets) in a similar way as decomposability is related to standard coobservability.

Once a more general coordination control framework is developed, it will be extended to the multi-level setting with hierarchical structure of groups of subsystems and their coordinators and applied to decentralized control by using modular overapproximation. This overapproximation consists in replacing the plant with the synchronous product of its projection to alphabets of local supervisors. The obtained constructive results will provide new types of communication protocols, where groups of subsystems communicate via coordinators on different layers of the hierarchy. We will compare computational complexity of two complementary approaches to multi-level control: top down approach and bottom-up approach. In the top-down approach the coordination control design starts at the top level by computing first a coordinator on the high level and by (conditionally) decomposing the specification in the top-down manner. Then a coordinator is computed for each group on the low level. Finally, at the bottom level local supervisors must be computed for all individual subsystems combined with the group coordinators. Unlike the bottom-up approach no supervisors are needed on the upper levels of the hierarchy, because the specification has been decomposed in the top-down manner with coordinators on different levels so that safety will be guaranteed.

In a complementary, bottom-up approach, the computations proceed from the low lovel to the high level, where the partial results computed at the low level are reused. Both bottom-up and top-down approaches have then their advantages and inconvenients and these will be compared with the emphasis to their application to decentralized control. Since it is well known that no (globally) optimal solutions to decentralized control exist in general, the optimality will be investigated with respect to the associated coordination control problems, where optimal solutions exist.

We will take into account communication delays and losses of communication. In the centralized setting with a single supervisor these issues are quite well understood, but it is still not the case in modular and decentralized control. It is our plan is to incorporate robust solutions to these issues into our approach based on multi level coordination control of modular and decentralized DES.

Last but not least, the proposed approaches to decentralized control will be implemented in the open-source software package libFAUDES, where our preliminary results on coordination control with one central coordinator are already implemented. Firstly, the extension of coordination control to the multi-level setting with both bottom-up and top-down approaches will be implemented and then the corresponding constructive approches to decentralized control will lead to software tools for computation of decentralized supervisors.

3.2 Decentralized control of timed and hybrid automata

Concerning timed and hybrid automata, the literature on their model checking is abundant, but there are little works on supervisory control of timed and hybrid automata, especially on their decentralized control. Since it does not seem possible to develop decentralized control for general timed automata directly (we have done this only for the class of (max,+)-automata in [KLB 12]), we will apply decentralized control on corresponding region automata. The only implementable approach to control of TA is based on their discretizations using well known region construction. Control of TA with complete observations is decidable, even though the size of region automata grows exponentially with the number of clocks and the greatest time constant used in guards and resets. This renders centralized control of little practical interest for large TA. Moreover, large scale timed automata are represented as synchronous products of many smaller timed automata, where the number of clocks is often quite large. Unfortunately, discrete abstractions of timed automata (known as region or zone Boolean automata) do not preserve the synchronous product. Indeed, synchronous product of discretized local timed automata yields a different result than discretization of the large timed automaton defined as the product of local ones. It is to be expected that discretization of hybrid automata does not preserve the modular structure either.

Hence, modular and coordination control we have developed (and are further developing) for logical automata cannot be applied directly. Instead we rely on the application of coordination control to decentralized control of monolithic plant. In fact, what still remains from the modular structure after the discretization of a modular timed automaton is the distribution of events into local events of local timed automata (modules). It is then natural to create a modular structure on the discretized (region) automaton based on overapproximation by the synchronous product to these local events. Note that controllability of a solution computed for this overapproximation will not be lost, because controllability with respect to the overapproximation clearly implies controllability with respect to the original region automaton without the modular structure that has in general smaller language. Once we have created an auxiliary modular structure the decentralized control problem will be transformed into a coordination control problem. In order to achieve a maximum saving on computational complexity two generalizations of coordination control developed earlier in the project will be applied: the multi-level coordination control with hierarchical structure of subsystems and coordinators and the novel framework based on the notion of conditional decomposability corresponding to inference conjunctive and permissive coobservability.

We will also investigate decentralized supervisory control of large automata stemming from discretizations of hybrid automata, which will be useful for some control problems for hybrid systems, where safety (avoidance of dangerous states) is the main issue.

Finally, it is our plan to continue the investigation of weighted automata and to apply new modeling paradigms based on the nondeterministic synchronous product of [LKB 14] to their supervisory control. As we have mentioned, supervisory control can only be efficient for deterministic plant models, and therefore, we will investigate new algorithms for determinization of (max,+) and interval automata that will enable us to compute natural projections and to introduce the corner stones of the coordination control: conditional decomposability and conditional controllability directly on timed behaviors: formal power series. As a first step towards this goal we have derived a language based sufficient condition for determinization of (max,+)-formal power series. This condition is known in Petri net literature as bounded fairness. A future approach is to impose this condition on the original (max,+) automaton by restricting the system's behavior so that bounded fairness holds (and determinization can be done) on the restricted system.

4. International cooperation and impact of the research project

The applicant has established scientific cooperation with several research teams in Europe, North America, and Turkey. The longstanding scientific cooperation with Prof. J. H. van Schuppen from TU Delft (formerly CWI, The Netherlands) on the topic of control of logical DES has been very fruitful as well as the cooperation with Prof. J.L. Boimond and his team from Univesity of Angers (France) on control of timed DES. Recently, new cooperation has been established with Prof. S. Lafortune from University of Michigan (Ann Arbor, USA) and Prof. F. Lin from Wayne State University (Detroit) on the topic of modular DES.

The plan is to further develop the existing cooperations and to restart cooperation with Dr. Hervé Marchand (INRIA Rennes) on modular control and with Prof. K. Schmidt (Cankaya University, Turkey) on hierarchical control (the results of hierarchical control are needed in coordination control) and to create new cooperations with other teams that are highly active in control of DES and hybrid systems, in particular with Prof. J. Raisch (TU Berlin) and Prof. G.J. Pappas (University of Pennsylvania), experts in discretizations of hybrid systems and their supervisory control.

The development of new efficient approaches to supervisory control of discrete-event and hybrid systems with their implementation in new or existing tools is a very important task of research community in discrete event and hybrid systems. These systems and supervisory control problems can be encountered in wide infrastructures or manufacturing organizations. Possible application domains are among others: supervisory control and verification of high-tech systems (e.g. complex printers, avionic systems), hierarchical control of road networks; coordination control of autonomous vehicles. Our approach also allows for updating controllers in a modular way when changes occur in these infrastructures, but still guaranteeing correct operation (safety) of the whole system. The results we are planning to develop should contribute to the application of supervisory control techniques by offering scalable methods and algorithms based on decentralized and coordination control architectures for both logical and real-time systems.

5. Time schedule of the project

The project is planned for the duration of three years. During the first year (2015) multi-level coordination control developed just before the project started (2013-2014) will be further developed and applied to the decentralized control of logical automata without product structure. In particular, results on robustness of multi-level coordination control with respect to communication delays and losses will be established. Multi-level coordination control will be extended to the case of partial observations, where local supervisors on the bottom level and supervisors for coordinators on different levels of the hierarchy can observe only proper subsets of their respective event sets. Computational complexity and resulting closed-loop languages of both top-down and bottom-up approaches will be compared. At the same time, determinization of (max,+) and interval-weighted automata will be studied and newly obtained results on determinization will be applied to synthesizing controllers for these automata.

Second year will be mostly spent on generalizing coordination control framework to cope with inference based decentralized control and the new obtained results on coordination control will be applied to decentralized control of plants without modular structure. Concretely, computation of sublanguages of specification languages that are controllable and inference coobservable will be investigated. Optimality (maximal permissiveness) with respect to coordination control framework will be studied, especially in the case of partial observations, where no results on optimality of our coordination control approach are known at all.

The third year will be devoted to the application of the results of the first two years to the supervisory control of timed and hybrid automata based on modular overapproximation of their discretizations. Constructive solutions to the decentralized supervisory control problems obtained during the first two years will be applied to these modular overapproximation (with synchronous product structure). New results on multi-level coordination control of modular DES and the constructive results on decentralized control will be implemented in libFAUDES.

There are no formal delivrable documents planned for this project, but publication at prestigious conferences and in the top journals specified below describing the above planned results will play the role of delivrables. The estimated number of publications is given at a different part of this proposal. The expected distribution of the publications is four conference publications (D) every year, during the first year one, second year two and the third year three journal publications (Jimp). One publication in a Scopus journal (Jsc) is expected during the third year. Another type of delivrable is to extend the functionalities of the coordination control plug-in that is now part of libFAUDES to multi-level coordination control and to decentralized control.

6. Justification of financial means

The research team is formed by the applicant (main investigator) and his local collaborator Dr. Tomáš Masopust who is currently on leave in Germany, but he will work during the third year. Both researchers have gained necessary qualification and experience in the field during their postdoctoral stays abroad and subsequent longstanding international cooperations.

The requested budget is composed of personal costs for Jan Komenda (0.3 full time equivalent, while the remaining 0.7 fte will be paid by the Institute of Mathematics of the Academy of Sciences) and travel costs to be used for strengthening our international cooperation and dissemination of results at conferences that will be very important for a successful run of the project. For the third year, Dr. T. Masopust will join the team and help among others with software implementation (0.3 fte). The financial support of this proposal will cover travel costs for conferences and part of the exchanges (in the form of short scientific work visits) with colleagues from leading foreign institutions. The dissemination of the research results among the members of the scientific community will be made mainly by participation in conferences and workshops and publication in the relevant top quality journals. In particular, we plan to participate in the following meetings: IEEE Conference on Decision and Control (CDC), European Control Conference (ECC), IFAC Workshop on Discrete Event Systems (WODES) and publish in the following journals: Automatica, IEEE Transactions on Automatic Control, Systems and Control Letters, Discrete Event Dynamical Systems: Theory and Applications.

References

[AD 94] R. Alur and D. Dill. A theory of timed automata. Theoretical Computer Science, 126(2):183-235, 1994.

[AH 00] R. Alur, T.A Henzinger, G. Lafferriere, G.J. Pappas. Discrete abstractions of hybrid systems. Proceedings of the IEEE 88(7), 971–984, 2000.

[AMPS 98] E. Asarin, O. Maler, A.Pnueli, J. Sifakis. Controller Synthesis for Timed Automata. In IFAC Symposium on System Structure and Control, 469-474, Elsevier, 1998.

[BA 92] F. Baccelli, G. Cohen, G.J. Olsder and J.P. Quadrat. Synchronization and linearity-An algebra for discrete event systems. New York, Wiley, 1992.

[BL 00] G. Barrett and S. Lafortune. Decentralized supervisory control with communicating controllers. IEEE Trans. on Automatic Control, 45, pp. 1620-1638, 2000.

[CL 08] S.G. Cassandras and S. Lafortune. Introduction to Discrete Event Systems, 2nd edition, Springer 2008.

[CV 88] R. Cieslak, C. Desclaux, A.Fawaz, and P. Varayia. Supervisory Control of a Class of Discrete Event Processes. IEEE Trans. Automatic Control, 33:249-260, 1988.

[GA 95] S. Gaubert. Performance evaluation of (max,+)-automata. IEEE Trans. on Automatic Control, Vol. 40, N 12, 1995.

[GM 04] B. Gaudin, H. Marchand. Modular Supervisory Control of a class of Concurrent Discrete Event Systems, Proceedings Workshop on Discrete Event Systems, WODES'04, pp. 181-186, 2004.

[GSB 04] A. Giua, C. Seatzu, F. Basile, "Observer-based state feedback control of timed Petri nets with deadlock recovery," IEEE Trans. on Automatic Control, Vol. 49, No. 1, pp. 17-29, Jan 2004.

[HK 95] T.A. Henzinger, P.W. Kopke, A. Puri, and P. Varaiya. What's decidable about hybrid automata? In Proceedings of the 27th Annual Symposium on Theory of Computing, pages 373-382. ACM Press, 1995.

[KvS 08a] J. Komenda and J. H. van Schuppen, Modular Control of Discrete-Event Systems with Coalgebra. IEEE Trans. on Automatic Control. Vol. 53, N. 2 (2008), pp. 447-460.

[KvS 08b] J. Komenda and J. H. van Schuppe, B. Gaudin, and H. Marchand. Supervisory Control of Modular Systems with Global Specification Languages. Automatica. Vol. 44, N. 4 (2008), pp. 1127-1134.

[KMvS 11] J. Komenda, T. Masopust, and J. H. van Schuppen. Synthesis of controllable and normal sublanguages for discrete-event systems using a coordinator, Systems Control Lett., vol. 60, no.7, pp. 492-502, 2011.

[KMvS 12] J. Komenda, T. Masopust, and J. H. van Schuppen. Supervisory control synthesis of discrete-event systems using a coordination scheme, Automatica, vol. 48, no. 2, pp. 247–254, 2012.

[KMvS 13] J. Komenda, T. Masopust, and J. H. van Schuppen. Multilevel coordination control of modular DES, Proceedings 52nd IEEE Conference on Decision and Control (CDC 2013), IEEE Press, 2013, pp. 6323-6328.

[KMvS 14] J. Komenda, T. Masopust, and J. H. van Schuppen. Coordination control of discrete-event systems revisited, Discrete Event Dynamic Systems, to appear in 2014.

[KLB 09a] J. Komenda, S. Lahaye, and J.-L. Boimond. Supervisory Control of (max,+) automata: a behavioral approach. Discrete Event Dynamic Systems, vol. 19, N4, pp. 525-549, Springer 2009.

[KLB 09b] J. Komenda, S. Lahaye, and J.-L. Boimond. Le produit synchrone des automates (max,+). JESA (Journal Européen des Systèmes Automatisés), vol. 43, pp. 1017-1032, 2009.

[KLB 12] J. Komenda, S. Lahaye, and J.-L. Boimond. Decentralized Control of Product (max+)-automata using Coinduction. Proceedings of the 11th International Workshop on Discrete Event Systems (WODES 2012), Guadalajara, Mexico, pp. 122-127, 2012.

[KLB 13] J. Komenda, S. Lahaye, and J.-L. Boimond, Séquentialisation du comportement des réseaux de Petri temporisés, Journal Européen des Systèmes Automatisés, 47/1-3, pp.139 154, 2013.

[L 14] F. Lin. Control of networked discrete event systems: dealing with communication delays and losses, SIAM Journal of Control and Optimization, to appear.

[LKB 14] S. Lahaye, J. Komenda, and J.-L. Boimond. Compositions of (max+)-automata. Proceedings of the 11th Workshop on Discrete Event Systems (WODES 2012), Guadalajara, Mexico, pp. 61-66, 2012. Extended version to appear in Discrete Event Dynamic Systems.

[LM 06] S. Lombardy and J. Mairesse. Series which are both Max-plus and Min-plus Rational are Unambiguous, RAIRO - Theoretical Informatics and Applications, vol. 40, pp. 1-14, 2006.

[LW 90] F. Lin and W. M. Wonham, Decentralized control and coordination of discrete-event systems with partial observation, IEEE Transactions on Automatic Control, 35(12), pp. 1330-1337, 1990.

[RR 00] S. L. Ricker and K. Rudie. Know means no: Incorporating knowledge into discrete-event control systems. IEEE Trans. Automat. Control, 45(9):1656–1668, 2000.

[RC 11] S. L. Ricker and B. Caillaud. Mind the gap: Expanding communication options in decentralized discrete-event control. Automatica, Volume 47, Issue 11, pp. 2364-2372, 2011.

[RW 89] P.J. Ramadge and W.M. Wonham. The Control of Discrete-Event Systems. Proc. IEEE, 77:81-98, 1989.

[RW 92] K. Rudie and W.M. Wonham. Think Globally, Act Locally: Decentralized Supervisory Control, IEEE Trans. on Automatic Control, Vol. 37, N 11, pp. 1692-1708, 1992.

[SB 01] G. Stremersch and R.K. Boel: Decomposition of supervisory control problem for Petri nets, IEEE Trans. on Automatic Control, 46, September 2001, pp.1490-1496.

[Th 05] J. G. Thistle. Undecidability in decentralized supervision. Systems and Control Letters, 54(5):503–509, 2005.

[TK 08] S. Takai and R. Kumar. Synthesis of inference-based decentralized control for discrete event systems. IEEE Trans. Automat. Control, 53(2):522534, 2008.

[Tr 04] S. Tripakis. Undecidable problems of decentralized observation and control on regular languages. Inform. Process. Lett., 90(1):21–28, 2004.

[WL 02] K.C. Wong and S. Lee. Structural Decentralized Control of Concurrent Discrete-Event Systems. European Journal of Control, 0:1-15, 2002.

[WR 88] W.M. Wonham and P.J. Ramadge. Modular supervisory control of discrete-event processes, Mathematics of Control, Signal and Systems, 1:13-30, 1988.

[YL 02] T.S. Yoo, S. Lafortune. General Architecture for Decentralized Supervisory Control of Discrete-Event Systems. Discrete Event Dynamic Systems: Theory and Applications, 12, pp. 335-377, 2002.

[YL 04] T. S. Yoo and S. Lafortune. Decentralized Supervisory Control with Conditional Decisions: Supervisor Existence, IEEE Trans. on Automatic Control. Vol. 49, 11, pp. 1886-1904, 2004.