Unifying Control and Verification of Cyber-Physical Systems (UnCoVerCPS)

WP6 Dissemination and Exploitation

D6.4 – Second Report on Dissemination and Exploitation

WP6	**D6.4 – Second Report on Dissemination and Exploitation**
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Short Description	This document is the second report on dissemination and exploitation of the Horizon 2020 project UnCoVerCPS (grant agreement number 643921). It covers the dissemination and exploitation strategy and activities during the first 30 months of the project (January 2015 — June 2017). An updated version will be published in December 2018, i.e. upon conclusion of the project.
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Contents

1 Introduction

This document is the second report on dissemination and exploitation of the Horizon 2020 project UnCoVerCPS (grant agreement number 643921). It covers the dissemination and exploitation strategy and activities during the first 30 months of the project (January 2015 - June 2017). An updated version will be published in December 2018, i.e. upon conclusion of the project.

Dissemination mainly aims at publishing and spreading the scientific and technical achievements of the project to demonstrate the value of the project and to stimulate future research. Dissemination is achieved by means of publications in journals and presentations at conferences, via workshops, lectures, seminars, etc. Target audiences of dissemination activities include academia, industry, government bodies and the general public. Key dissemination platforms for UnCoVerCPS have been the Cyber–Physical Systems Week (CPSWeek) conferences in 2015 (Seattle, WA), 2016 (Vienna), and 2017 (Pittsburgh, PA). Numerous members of the consortium attended the conferences and presented papers. Goran Frehse was co-organizer of the 20th ACM Int. Conf. Hybrid Systems: Computation and Control (HSCC), the leading conference on foundations of cyber-physical systems. Matthias Althoff and Goran Frehse organized workshops on Applied Verification for Continuous and Hybrid Systems (ARCH'15, ARCH'16, ARCH'17). The workshops included the presentations of tools, including tool evaluations, industrial experience reports, and proposals for new, industrially relevant benchmark problems. The presented benchmark problems will be adopted by the UnCoVerCPS project, going forward, to further improve its toolchain and to validate its tools and results against. The proceedings of the 2015, 2016 and 2017 workshops have been published and are available at http://easychair.org/publications/volume/ARCH15, http://easychair.org/publications/volume/ARCH16, and http://easychair.org/publications/volume/ARCH17.

An important aspect of the dissemination activities in UnCoVerCPS is around open source software tools. Software tools for system synthesis and verification developed within the UnCoVerCPS project are made available under open source licenses so that third parties can apply these tools to their particular problems and/or contribute to further developments of the tools and methods. The consortium also hopes to receive feedback from users for further improvement of the tools and for future research directions. Key tools in UnCoVerCPS are SCADE Suite, commercially available from Esterel, CORA, developed at TUM, and SpaceEX from UJF. As part of the UnCoverCPS project, new versions of these tools have been released in 2015 and 2016. Further, the integration of CORA and SpaceEx into a consolidated tool for

hybrid systems verification is ongoing.

Exploitation includes all measures for creating commercial value from the project results such as to strengthen competitiveness and create and secure jobs in the domain of cyber–physical systems in Europe. Exploitation can include the development or improvement of products or services, the creation of new businesses or business units, protection and exploitation of intellectual property, or the improvement of processes in organizations in order to increase efficiency or quality. Based on the horizontal UnCoVerCPS approach, three of the four industrial partners in the UnCoVerCPS consortium (Bosch, GE, R.U. Robots) mainly pursue an exploitation route around the application of project results and tools to vertical applications in their respective industries (automotive, avionics, smart grids, human–robot interaction in food assembly), with the aim to enable more cost– and time–efficient design, development, and verification of safety–critical cyber–physical systems. In all four industries, different regulatory and legislative regimes are applicable with regards to systems safety. UnCoVerCPS also aims at addressing and/or influencing these regulatory regimes and ensuring that systems developed with the UnCoVerCPS approach will ultimately be certifiable in the respective industries. The fourth industrial partner, Esterel, will mainly focus on deployment of horizontal tools for cyber–physical systems design and verification that are applicable across multiple industries and applications.

2 Dissemination and Exploitation Management

Dissemination and exploitation activities in UnCoVerCPS are bundled in work package WP6, led by Politecnico di Milano. The UnCoVerCPS consortium strongly believes that dissemination and exploitation is the joint responsibility of all consortium members. We have therefore widely distributed the tasks and responsibilities in such a way that most of the partners have a relevant responsibility for at least one task, deliverable, or milestone related to dissemination and exploitation. Obviously, multiple project partners contribute to each task, deliverable and milestone.

The responsibilities of the project partners are detailed in the table below.

Responsibility	**Description**	**Owner**	**Month**	**Status**
Task 6.1	Project website setup and maintenance	TU Munich	Continuous	
Task 6.2	Data and knowledge management	Tecnalia	Continuous	
Task 6.3	Workshop and summer schools	Politecnico di Milano	Continuous	
Task 6.4	Educational activities	TU Munich	Continuous	
Task 6.5	Exploitation	RU Robots	Continuous	
Deliverable 6.1	Website setup	TU Munich	3	Completed
Deliverable 6.2	First version of data management plan	TU Munich	6	Completed
Milestone 31	First version of internal exploitation plan	RU Robots	6	Completed
Deliverable 6.3	First dissemination and exploitation report	GE	12	Completed
Milestone 32	Presentation of results at a European event	GE	24	Completed[1]
Deliverable 6.4	Second dissemination and exploitation report	GE	30	Completed
Deliverable 6.5	Final version of data management plan	TU Munich	48	
Deliverable 6.6	Final dissemination and exploitation report	GE	48	

[1] Computing and CPS, June 2016, Brussels

3 Dissemination Report

3.1 Dissemination Plan

The objectives of the UnCoVerCPS dissemination activities are:

- to reach out to a large set of target groups via a broad spectrum of dissemination channels;
- to become an integral and visible part of the international cyber–physical systems research community;
- to provide academic services such as organizing workshops and special sessions at conferences; to implement structures that allow open-access to scientific results, software tools, and benchmarking examples.

A summary of the dissemination activities influenced or driven by UnCoVerCPS and their number are listed in the table below. More details can be found in the respective sections.

Activity	**Number**	**References**
Workshops	10	Section 3.4
Conference papers	62	Section 3.5
Journal articles	24	Section 3.6
Teaching activities	15	Section 3.8
Master theses supervised	16	Section 3.8
Bachelor theses supervised	3	Section 3.8

Key elements of dissemination include a project website which is continuously kept up to date, scientific publications, open source releases of software tools, and educational activities. The website is also used for information and document exchange within the consortium. An important aspect of the UnCoVerCPS project is that it spans across multiple technical disciplines as illustrated in Figure 1 below.

It involves aspects from the area of cyber–physical systems and embedded systems, in particular cyber–physical systems with strict requirements in terms of safety. It also involves the broad discipline of systems theory, including system dynamics and stochastic systems, and the design and analysis of system controls. This discipline is sometimes also referred to as “cybernetics”. And finally it touches upon multiple application domains related to the four use cases considered in the project, namely power systems, automotive, power generation and robotics. In particular for the robotics and automotive use cases, an important aspect is the modelling of human capabilities and human behaviour as well as the interaction between

humans and machine in safety–critical contexts. This multi–disciplinary nature of the project is considered in the dissemination strategy of this project. We aim at reaching all relevant communities with our dissemination activities, including cyber–physical systems, controls, automotive and power systems.

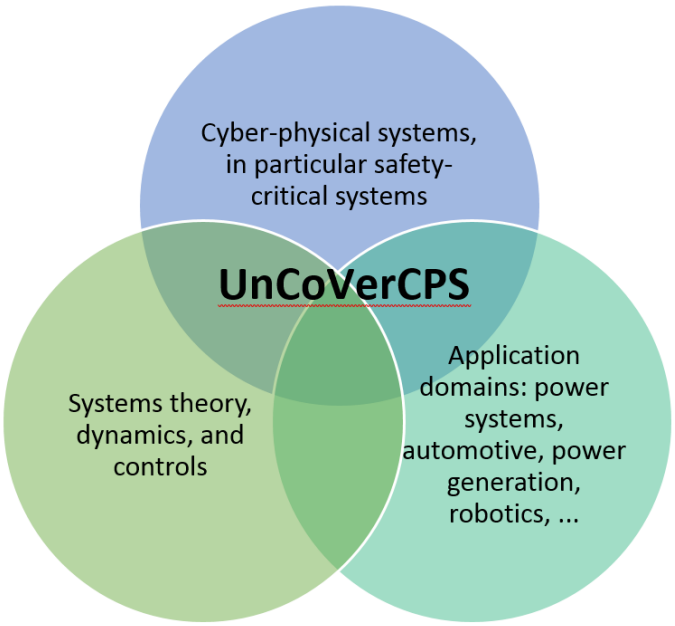


Figure 1: Multidisciplinary nature of the UnCoVerCPS project.

3.2 Project Website

The central platform of the UnCoVerCPS dissemination activities is the project website at http://cps-vo.org/group/UnCoVerCPS. It contains up–to–date information on the consortium members, publications, events, etc. as well as a platform for internal information and document sharing among the consortium members. Figure 2 below shows a screenshot of the homepage of the website. The website is continuously updated throughout the lifetime of the project.

3.3 Project Flyer

The UnCoVerCPS project has published a flyer as a double–sided A4 sheet with key program facts (Figure 3 below). The flyer can be downloaded via the project website (Dissemination). A total of 1,250 of high–quality printouts of the flyer have been produced and are being distributed by all of the consortium partners on conferences, workshops, etc. The flyer contains information on the technical mission of the project, the partners, the use cases and contact information. Its main goal is to raise interest in and awareness of the project, and direct interested parties to the project website for more details.

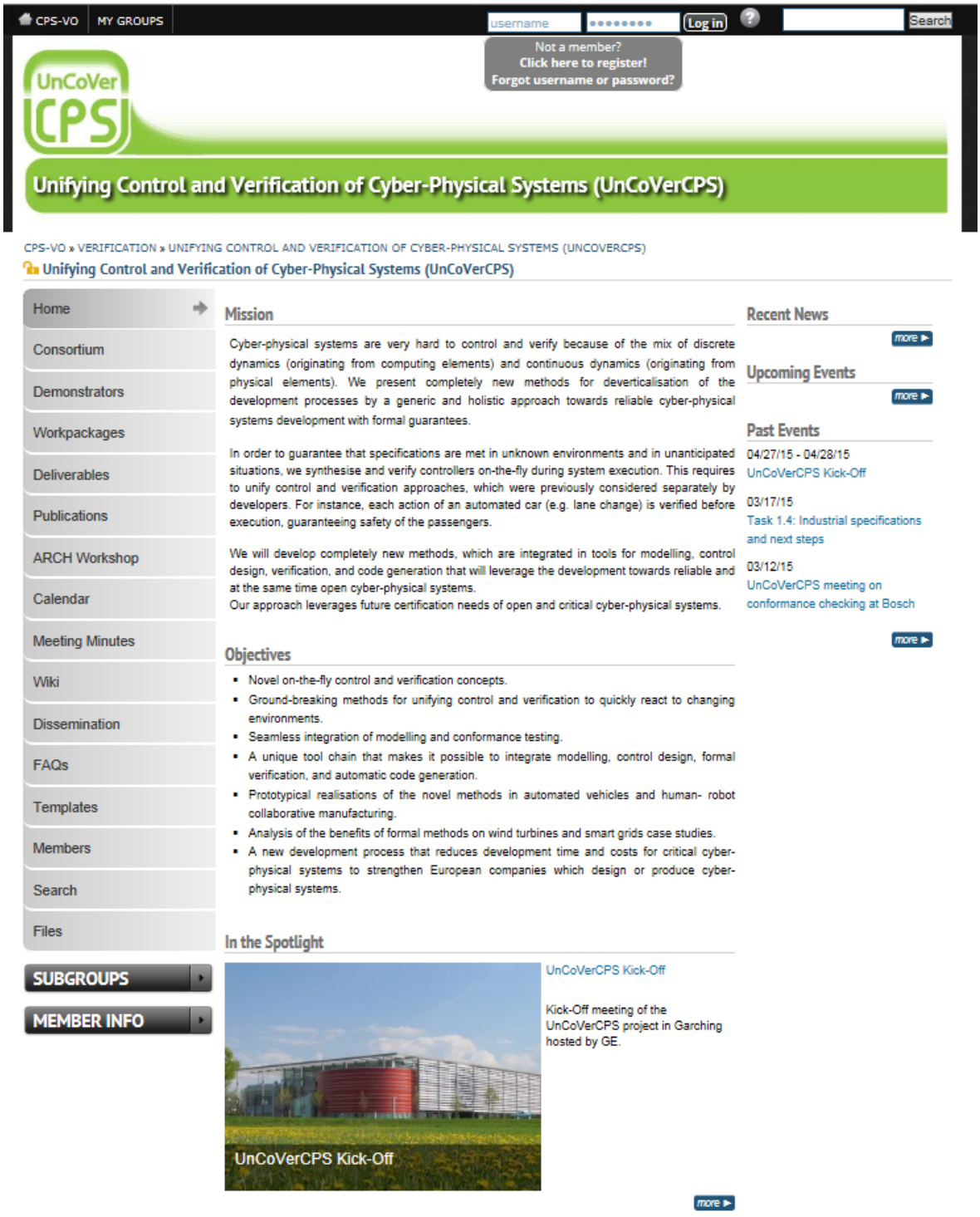


Figure 2: Screenshot of the homepage of the UnCoVerCPS website (http://cps-vo.org/group/UnCoVerCPS), captured on May 4, 2015.

MISSION STATEMENT

UnCoVerCPS provides methods for a faster and more efficient development process of safety- or operation-critical cyber-physical systems in (partially) unknown environments.

Cyber-physical systems are very hard to control and verify because of the mix of discrete dynamics (originating from computing elements) and continuous dynamics (originating from physical elements).

We present completely new methods for de-verticalisation of the development processes by a generic and holistic approach towards reliable cyber-physical systems development with formal guarantees.

In order to guarantee that specifications are met in unknown environments and in unanticipated situations, we synthesise and verify controllers on-the-fly during system execution. This requires to unify control and verification approaches, which were previously considered separately by developers. For instance, each action of an automated car (e.g. lane change) is verified before execution, guaranteeing safety of the passengers.

We will develop completely new methods, which are integrated in tools for modelling, control design, verification, and code generation that will leverage the development towards reliable and at the same time open cyber-physical systems. Our approach leverages future certification needs of open and critical cyber-physical systems.

CONSORTIUM

Technische Universität München (TUM) - *Coordinator*
Germany

Université Joseph Fourier Grenoble 1 (UJF)
France

Universität Kassel (UKS)
Germany

Politecnico di Milano (PoliMi)
Italy

GE Global Research Europe
Germany

Robert Bosch GmbH
Germany

Esterel Technologies
France

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Germany

Tecnalia
Spain

R.U.Robots Limited
United Kingdom

UnCoVer CPS

Unifying Control and Verification of Cyber-Physical Systems

UnCoVerCPS

More information about the project is available online.
Please visit **http://cps-vo.org/group/UnCoVerCPS**

The UnCoVerCPS Consortium acknowledges financial support by the European Commission under grant number 643921.

HORIZON 2020

OBJECTIVES

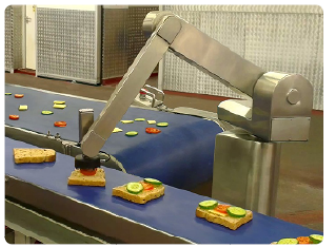
- Novel on-the-fly control and verification concepts.
- Ground-breaking methods for unifying control and verification to quickly react to changing environments.
- Seamless integration of modelling and conformance testing.
- A unique tool chain that makes it possible to integrate modelling, control design, formal verification, and automatic code generation.
- Prototypical realisations of the novel methods in automated vehicles and human-robot collaborative manufacturing.
- Analysis of the benefits of formal methods on wind turbines and smart grids case studies.
- A new development process that reduces development time and costs for critical cyber-physical systems to strengthen European companies which design or produce cyber-physical systems.

 Version 1.5

DEMONSTRATORS

Automated Vehicles

Wind Turbines



Human-Robot Collaboration

Smart Grids

Figure 3: UnCoVerCPS flyer.

3.4 Workshops

Matthias Althoff (TUM) and Goran Frehse (UJF) organized workshops on Applied Verification for Continuous and Hybrid Systems ("ARCH") as part of CPSWeek 2015, 2016, and 2017 (http://cps-vo.org/group/ARCH). CPSWeek (Cyber–Physical Systems Week) is the leading annual international conference for cyber–physical systems, under technical sponsorship of IEEE, ACM (Association for Computing Machinery) and others. Under one umbrella, it brings together multiple conference, workshops and tutorials on different aspects of cyber–physical systems research, including embedded systems, hybrid systems, real–time systems, and sensor networks. Bosch sponsored CPSWeek 2017 as platinum sponsor.

The **ARCH'15** workshop took place as part of CPSWeek 2015 in Seattle, WA, from April 13–16, 2015. A total of 15 contributions were presented on benchmarks, tools, and experience reports. Many consortium members attended CPS week and this particular workshop. Bosch sponsored the best tool result award at ARCH. The awarded contribution by Chuchu Fan, Parasara Sridhar Duggirala, Sayan Mitra, and Mahesh Viswanathan presented significant "Progress on Powertrain Verification Challenge with C2E2".

The **ARCH'16** workshop took place as part of CPSWeek 2016 in Vienna, Austria, from April 11-14, 2016. Eight benchmark contributions and six tool contributions were presented, including three contributions from the UnCoVerCPS project. Also in 2016, Bosch sponsored the best tool award which went to Stanley Bak, Sergiy Bogomolov and Christian Shilling for their tool "Hypy", a phython library for high–level hybrid systems analysis which is capable of running several hybrid systems analysis tools, such as SpaceEx, Flow, dReach, and HyCreate, parsing their output, and modifying the models based on the output.

The **ARCH'17** workshop took place in Pittsburgh, PA, on April 17, 2017, co–located with CPSWeek 2017. Proceedings will be made available via EasyChair Publications. During the workshop, results from a friendly competition on verification of continuous and hybrid systems in different categories, and applied to different benchmark problems, were presented.

Maria Prandini co-organized with Kostas Margellos a workshop on "Distributed and Stochastic Optimization and Applications" at the European Control Conference, that took place in Aalborg, Denmark from June 29 to July 1, 2016 (http://www.ecc16.eu/workshops.shtml). The European Control Conference aims to bring together academic and industrial professionals in the field of systems and control, and to promote scientific cooperation and exchanges within the European Union and between Europe and other parts of the World. The workshop provided a concise, yet complete, exposition to the topic of distributed and stochastic optimization. A diverse group of internationally recognized researchers, affiliated with outstanding

institutions in Europe and in the United States, were brought together to expose the workshop attendees to cutting edge research on the field as well as to present new vistas on the field. Olaf Stursberg from Universität Kassel delivered a presentation on "Model predictive control for jump Markov linear systems."

Maria Prandini and Axel Busboom organized a workshop on "Verification and Control of Cyber–physical Systems: Theory and Application" as part of the 55^{th} IEEE Conference on Decision and Control in Las Vegas, NV, from December 12–14, 2016 (http://cdc2016.ieeecss.org/workshops.php#w06, http://home.deib.polimi.it/prandini/CDC16_CPS_workshop.htm). CDC is a premier scientific and engineering conference dedicated to the advancement of the theory and practice of systems and control. The workshop comprised eight presentations from high–profile speakers from industry and academia. It started with application–driven presentations from several domains (road freight transport, intelligent robots, autonomous systems, automated vehicles) and went on to talks on verification, testing, safe control design and supervisory control. Two presentations were given by PI's from the UnCoVerCPS consortium: Matthias Althoff reported on "Self–verification of automated vehicles" and Olaf Stursberg spoke about "Controller synthesis for probabilistic cyber–physical systems using reachable set computation."

Several consortium members attended the SafeTRANS Industrial Day in Renningen, Germany, on May 20, 2015. The topic of the workshop was "Modelling of Context and Environment for Verification and Testing of Highly Autonomous Systems". SafeTRANS ("Safety in Transportation Systems") is a German competence cluster combining research and development expertise in the area of complex embedded systems in transportation systems. It drives research in human centred design, in system and software development methods for embedded systems, as well as in safety analysis – for avionics and rail -– and its integration in certification processes.

Several consortium members attended the ARTEMIS Co–Summit in Berlin, Germany, on March 11–12, 2015 (https://artemis-ia.eu/co-summit-2015/index.html) and represented the UnCoVerCPS project with an exhibition booth. ARTEMIS is a European industry association in embedded and cyber–physical systems. The over 180 members include industry, SME's, universities and research institutes. ARTEMIS is responsible for the Strategic Research Agenda (SRA) on embedded and cyber–physical systems.

Matthias Althoff participated in a podium discussion on the International Scientific Conference on Mobility and Transport (mobil.TUM 2015) in Munich, Germany, from June 30 – July 1, 2015. The title of the podium was "Cyber physical transport systems - ITS on the move towards the Internet–of–Things".

Matthias Althoff also gave two presentations at the BMW workshop "We live innovations – dialogue Munich" which was held in Munich, Germany, from July 13–15, 2015:

- Provably correct collision avoidance systems
- Formalisation of traffic rules for defending against liability claims in automated driving

Olaf Stursberg gave an invited talk entitled "On optimization–based control of switched uncertain systems" at the MOBOCON Symposium Optimization and Control of Uncertain Systems in Dortmund, Germany, from September 15–16, 2015. He also delivered an invited presentation on "Robust stabilization of power grids with larger shares of renewable energy" at the 3$^{\text{rd}}$ JST-NSF-DFG-RCN workshop "Distributed energy management systems: frontiers of multimodal energy systems" which was held in Heidelberg, Germany, from May 23–26, 2016.

UnCoVerCPS consortium members also gave a presentation at the ARTEMIS Technology Conference 2015 in Turin, Italy, on October 6–7, 2015 (https://artemis-ia.eu/calendar/402-artemis%20technology%20conference%202015.html).

Matthias Althoff further held two invited talks on workshops at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2015) which was held in Hamburg, Germany, from September 28 to October 2, 2015:

- "Determining the nonexistence of evasive trajectories for collision avoidance systems," part of the 7$^{\text{th}}$ Workshop on Planning, Perception and Navigation for Intelligent Vehicles.
- "Safety Control of Robots," part of the workshop Robotic Co–workers: Methods, Challenges and Industrial Test Cases.

Additionally, he gave a talk on "Provably Safe Maneuvers of Automated Vehicle" at the Artemis Technology Conference, Turin, Italy. October 2015, and presented in the following workshops:

- "The UnCoVerCPS Approach Towards Certifiable Human-Robot Co-Existence" in Smart Cyber-Physical Systems Concertation Event, Brussels, Belgium, 31.01.2017
- "Self-Verification of Automated Vehicles" at the Workshop Verification and Control of Cyber-physical Systems: Theory and Applications, Las Vegas, USA, 11.12.2016
- "Safe Human-Robot Co-Existence through Online Verification" at the Workshop *PUMA* graduate school, St.Martin, Austria, 12.10.2016

- "Online Verification of Cyber-Physical Systems" at the International Symposium on Networked Cyber-Physical Systems, Garching, Germany, 19.09.2016
- "Safe Human-Robot Co-Existence through Online Verification" at the GlobalTech Alliance Robotic Workshop, Munich, Germany, 22.05.2016
- "Unifying Control and Verification of Cyber-Physical Systems" at the ARTEMIS Spring Event, Vienna, Austria, 14.04.2016
- "Self-Certification of Cyber-Physical Systems" Industry talk, TÜV Süd GmbH, Garching, Germany, 31.03.2016
- "Safe Human-Robot Co-Existence through Online Verification" Industry talk, Robert Bosch GmbH, Renningen, Germany, 14.03.2016

Goran Frehse participated in a podium discussion at the French "Assises de l'Embarquée", a major industrial forum on embedded systems, on Nov. 29, 2016 (the event is reported at http://www.assisesdelembarque.fr/assises-de-lembarque-2016). The title of the discussion was "Simulating Cyber-Physical Systems: Which gains for the Industry?"

Jens Oehlerking held an invited presentation at the final colloquium of the transregional research collaborative AVACS: "Specification models, testing and verification in industrial practice", Oldenburg, Germany, October 2, 2015.

Maria Prandini was/is a co–organizer of the following invited sessions:

- "New developments in stochastic systems, control and their applications" at the 54th IEEE Conference on Decision and Control (CDC), Osaka, Japan, December 2015.
- "Coordination and communication issues in energy networks" at the American Control Conference, Boston, US, July 2016.
- "Challenges for optimization and control in power systems and networks" at the American Control Conference, Boston, US, July 2016.
- "Advances in control, game theory, and identification for stochastic systems" at the 55th IEEE Conference on Decision and Control, Las Vegas, US, December 2016.
- "Multi-agent and networked systems" at the IFAC World Congress, Toulouse, France July 2017

Maria Prandini delivered

- a plenary talk on "A big-data approach to decision making under uncertainty" at the 2016 International Conference on Control, Automation, and Systems (ICCAS 2016)
- a seminar on "Randomized methods for decision making in presence of uncertainty" at TUM on May 20, 2016 and Oxford University on September 7, 2016
- an invited presentation on "Distributed optimization over networks: application to multi-building energy" at the workshop Optimization techniques for hybrid dynamical systems: from theory to applications (OptHySYS) organized in Trento, January 9–11, 2017,
- a seminar on "Distributed optimization over networks and its application to multi-building energy management" at TUM on May 2, 2017.

Jens Oehlerking gave an invited talk at the 2nd Workshop on Monitoring and Testing of Cyber-Physical Systems, held at CPSWeek in Pittburgh on April 21, 2017, titled "Experiences in Testing and Verification".

Bastian Schürmann gave an invited talk on "Convex Interpolation Control with Formal Guarantees for Disturbed and Constrained Nonlinear Systems" as part of the seminar series of the Field Robotics Center at Carnegie Mellon University, Pittsburgh, USA in July 18, 2016. He also gave a talk on "Formale Reglersynthese mittels konvexer Kombinationen" at the Regelungstechnisches Kolloquium in Boppard, Germany on February 18, 2016. He was invited to present this talk again at the Dresden Colloquia on Automation Technology of the Fraunhofer Institute for Transportation and Infrastructure Systems (IVI) and the Technical University of Dresden, Germany on October 24, 2016.

3.5 Conference Papers

Many conference papers have already been published in the context of the UnCoVerCPS project. Pivotal conferences for the consortium were CPSWeek 2015, 2016, and 2017, where the UnCoVerCPS consortium also organized dedicated workshops. The papers published and submitted by UnCoVerCPS to date are listed in Appendix A.

3.6 Journal Articles

A total of 15 journal articles resulting from the UnCoVerCPS project has been accepted for publication. In addition, several journal articles have been submitted or prepared for submission. The journal articles published and submitted by UnCoVerCPS to date are listed in Appendix B.

3.7 Upcoming Conferences and Journals Considered for Paper Submissions

Below we provide a — not necessarily exhaustive – list of upcoming conferences and journals that we will consider for paper submission and presentation:

- CPSWeek 2018, Porto, dates to be announced.
- European Control Conference 2018, Limassol, Cypurs, June 13–15, 2018.
- 2018 American Control Conference (ACC 2018), Milwaukee, WI, June 27–29, 2018.
- 57^{th} IEEE Conference on Decision and Control (CDC 2018), December 17–19, 2018, Florida.

3.8 Teaching Activities

Consortium members have created new teaching material and taught a number of related courses:

- Goran Frehse: French Summer School MACS, organized by GT MOSAR and SDH, Bourge, France, June 16–17, 2015 (http://jdjnmacs2015.sciencesconf.org/resource/page/id/3).
- Goran Frehse: SyDe Summer School on Modelling and Verification of Cyber–Physical Systems, Bremen, Germany, September 9–11, 2015 (http://www.informatik.uni-bremen.de/syde/index.php?summerschool-21).
- Goran Frehse: AVACS Summer School, Oldenburg, Germany, September 30-–October 2, 2015 (http://www.avacs.org/autumn2015/).
- Goran Frehse: DigiCosme Spring School, organized by ENSTA, Paris, France, May 12, 2016 (https://www.ensta-paristech.fr/fr/actualites/retour-sur-la-spring-school-digicosme-2016)
- Matthias Althoff: TUM Summer Seminar on Cyber–Physical Systems, June 8, 2015 (http://www6.in.tum.de/Main/TeachingSs2015SeminarCyberPhysicalSystems).
- Matthias Althoff: Improvements made to regular TUM lecture on Cyber–Physical Systems (http://www6.in.tum.de/Main/TeachingSS2015CyberPhysicalSystems).
- Matthias Althoff: Seminar Cyber–Physical Systems, 17 participants (http://www6.in.tum.de/Main/TeachingWs2015SeminarCyberPhysicalSystems).

- Olaf Stursberg: Course on "Discrete Event Systems and Control Theory," University of Kassel, summer semesters 2015, 2016, 2017.
- Olaf Stursberg: Course on "Hybrid Control Systems," University of Kassel, winter semester 2015/2016.
- Olaf Stursberg: Course on "Hybrid and Networked Control Systems," University of Kassel, winter semester 2016/2017.
- Olaf Stursberg: Course on "Adaptive and Predictive Control," University of Kassel, winter semesters 2015/2016 and 2016/2017.
- Olaf Stursberg: Course on "Optimal Control," University of Kassel, summer semesters 2016, 2017.
- Jens Oehlerking: Guest Lecture at TUM, "Specification models for cyber–physical systems in industrial practice," Garching, Germany, July 14, 2015.
- Maria Prandini: PhD course on hybrid systems at Politecnico di Milano, June 15–19, 2015 (http://home.deib.polimi.it/prandini/hybrid-systems.htm).
- Maria Prandini: PhD course on hybrid systems at Lund University, October 5–8, 2015 (http://www.control.lth.se/Education/DoctorateProgram/hybrid-systems.html).
- Maria Prandini (lecturer): Mini–Symposium on "Stochastic Control: Computational Approaches to Large–Scale Problems," in SIAM Conference on Control and its Applications, Paris, July 8–10, 2015.
- Maria Prandini (co–organizer and lecturer): Mini–Symposium on "Stochastic Systems and Applications," in SIAM Conference on Control and its Applications, Paris, July 8–10, 2015.
- Joshué Manuel Pérez Rastelli: Lectures on "Standards for Automobiles," François Rabelai University (Tours, France), January–February, 2017.
- Joshué Manuel Pérez Rastelli: Lectures on "Digital enfironment and road — ITS applications," François Rabelai University (Tours, France), January–February, 2017.
- Maria Prandini (organizer and lecturer), Olaf Stursberg (lecturer), Goran Frehse (lecturer): PhD course on hybrid systems at Politecnico di Milano, February 20–24, 2017 (http://home.deib.polimi.it/prandini/Hybrid_Systems_2017.html).

- Matthias Althoff: "TUM Winter School: How to Guarantee Safety of Cyber-Physical Systems?", Garching, Germany, 06.02.2017
- Matthias Althoff: "Seminar Cyber-Physical Systems (WS 2016/17, SS 2017)"
- Matthias Althoff: "Proseminar Bahnplanung für autonome Fahrzeuge (SS 2017)"
- Matthias Althoff: "Master-Praktikum/Lab Course Safe Human-Robot Co-Existence (SS 2017)"
- Matthias Althoff: "Vorlesung Cyber-Physical Systems (2015-now)"
- Bastian Schürmann and Matthias Althoff: Practical course "Path Planning and Tracking Control for Autonomous Driving" (SS 2016)

Maria Prandini co-organized with Sergio Grammatico, Kostas Margellos, and Giuseppe Notarstefano a tutorial on "Cooperative and noncooperative decision making in multi-agent systems: An operator theoretic perspective" as part of the IFAC 2017 World Congress in Toulouse, France, July 9–14, 2017 (https://www.ifac2017.org/workshops-and-tutorials). Motivated by applications in energy and transportation networks, this tutorial presents a mathematical framework to analyse and design distributed decision making in multi-agent systems seeking convergence to cooperative or noncooperative equilibria.

One Ph.D. student at Bosch, Hendrik Röhm, is supervised by Matthias Althoff from TUM on topics related to UnCoVerCPS.

GE Global Research has supervised two student interns as part of the UnCoVerCPS project: Dipankar Maity, Ph.D. student at University of Maryland, and Matei Catalin Moldoveanu, MEng student at University of Sheffield.

Bosch also supervised one student intern as part of the project.

Some **PhD theses** related to UnCoVerCPS topics have been supervised in the context of the project to date:

1. R. Vignali: Automatic verification and input design for dynamical systems: an optimization-based approach to the detection of non-influential inputs. PhD in Information Technology - Area: Systems and Control. Politecnico di Milano, 2016.
2. G. Manganini: Optimal control of large scale stochastic hybrid systems with a finite control space. PhD in Information Technology - Area: Systems and Control. Politecnico di Milano, 2016.

3. L. Deori: A Model Predictive Control approach based on randomized methods to aircraft motion control. PhD in Information Technology - Area: Systems and Control. Politecnico di Milano, 2016.

4. Leonhard Asselborn: Probabilistic control of stochastic hybrid systems based on reachability analysis. Universität Kassel, 2015-2016.

5. Damian Kontny: Control of systems with time–varying constraints by using homotopy methods. Universität Kassel, 2015-2017.

6. Zonglin Liu: Controlling distributed systems with uncertain interaction. Universität Kassel, 2015-2017.

Several **Master's theses** have been supervised in the context of the UnCoVerCPS project to date:

1. Petio Dimitrov: Distributed allocation of a shared energy storage system. Automation and Control Engineering, Politecnico di Milano, 2015.

2. Caterina Brocchini: A chance–constrained approach to the quantized control of a heat ventilation and air conditioning system with prioritized constraints, Politecnico di Milano, 2015.

3. Wuqiang Sun: Algorithms for the identification of the parameters of nonlinear vehicle–dynamic models, DLR, 2015.

4. Joao de Campos Salvado: Contingency planning for automated vehicles in urban traffic, DLR, 2015. [Task 5.3]

5. Friderike Meier: Adaptive control of linear systems with time–varying constraints. Control and System Theory, Universität Kassel, 2015.

6. Maximilian Müller: Cooperation of autonomous cars by auction–based control. Control and System Theory, Universität Kassel, 2015.

7. Zonglin Liu: Optimization of multi–agent Markov decision processes using game theory. Control and System Theory, Universität Kassel, 2015.

8. Mohammad K. Daaboul: Cooperative control of quadcopters considering obstacles and coupling. Control and System Theory, Universität Kassel, 2017.

9. Fabio Belluschi: Energy management of a multi-building system via distributed optimization. Automation and Control Engineering, Politecnico di Milano, 2016.

10. Vedad Causevic: Optimal energy management in a multi-building set-up via distributed stochastic optimization. Automation and Control Engineering, Politecnico di Milano, 2016.

11. Cigdem Yazili: Cost optimization for vehicle-to-grid application. Automation and Control Engineering, Politecnico di Milano, 2016.

12. Stefano Mutti: A novel distributed approach to power control in wireless cellular networks. Automation and Control Engineering, Politecnico di Milano, 2016.

13. Zhou Huang: Modelling of driving situations and verification of collision freedom for an automated vehicle model, Bosch/Karlsruhe Institute for Technology (KIT), 2016.

14. Florian Grötzner: Automated Construction of Maneuver Automata for Autonomous Vehicles with Formal Guarantees, Technische Universität München, 2017.

15. Niklas Kochdumper: Improvements and Extensions for the Convex Interpolation Control Algorithm, Technische Universität München, 2017.

16. Moritz Klischat: Formal Set-Based Control as a Safety Net for Unverified Controllers, Technische Universität München, 2017.

17. Gerardo Lopez Alonso: Set-Based Optimal Control with Formal Guarantees for Robotic Manipulators, Technische Universität München, 2017.

18. Sudishna Sthapit: A Client-Software Architecture for Interactive Modeling of Cyber-Physical Systems, Univ. Grenoble Alpes, 2017

Several **Bachelor's theses** have been supervised by members of the consortium:

1. Ute Schiehlen: Formally correct vehicle prediction on road networks. Robotics and Embedded Systems, TUM, 2015.

2. Natalie Reppekus: Representation of reachable sets in human–robot interaction with a view to online safety control. Robotics and Embedded Systems, TUM, 2015.

3. Hannes Rewald: Auction–based mechanisms for intelligent control of autonomous cars. Control and System Theory, Universität Kassel, 2015.

4. Jannik Hahn: Design of LPV–controllers for wind turbines contributing to grid stabilization. Control and System Theory, Universität Kassel, 2016.

3.9 Liaisons with Other EU Projects

UnCoVerCPS was represented in several collaboration and liaison events, in particular:

- the collobration workshop "Advanced Computing and Cyber–Physical Systems 2017," jointly organized by DG CONNECT and HiPEAC, which took place in Brussels on June 14, 2016,
- the Digital Innovation Forum (DIF), organized by ARTEMIS–IA and ITEA, which took place in Amsterdam on May 10–11, 2017.

Consortium members have formed an informal liaison with INTO-CPS, a Horizon 2020 project (grant agreement number 644047) working on an integrated tool chain for model–based design of cyber–physical systems. Both projects are obviously highly synergistic, as UnCoVerCPS requires as a prerequisite the ability to do model based design of its systems, all the way from requirements to hardware and software implementations. On the other hand, UnCoVerCPS provides the tools and methods for controller synthesis and verification which, in return, will be required by INTO-CPS, in particular in the case of stochastic and/or hybrid systems.

UnCoVerCPS has also established an informal liaison with Smart-E, a Marie Curie ITN under FP7 (http://smart-e-mariecurie.eu/). Smart-E works on training for early stage researchers and experience researchers in the area of advanced robotics to ensure a sustainable manufacturing sector in Europe. The consortium involves a team of experts in a broad range of areas, including embodied intelligence, soft robotics, compliant robotics, smart materials, safety and human–machine interaction, autonomous systems, dexterous end effectors and statistics. TUM and R.U. Robots are members in Smart-E and will help ensure that UnCoVerCPS results will be applied in Smart-E for certified human–robot interaction. Smart-E researchers, on the other hand, will provide a modular robot for experiments within UnCoVerCPS for testing of on–the–fly control design and verification.

A third liaison has been established with the FP7 Support Action for Vehicle and Road Automation, VRA. VRA shares interests with UnCoVerCPS in the application area of vehicle automation and allows participants to share expertise and cooperate at a European and international level. It aims at maintaining an active European network of experts and stakeholders in the area of vehicle and road automation, contributing to EU-US-JPN international collaboration, identifying deployment needs for the different domains in vehicle and road automation, and at promoting European research through an innovative set of dissemination tools. UnCoVerCPS is represented in VRA and the associated discussion group

iMobility Forum (iMF) via DLR. This allows us to directly contribute ideas and results developed in UnCoVerCPS, such as online verification for automated driving, to the discussion groups. An official affiliation of DLR with the VRA network is currently being finalized.

DLR has further participated in the standardisation meeting within the EU FP7 call 10 on June 30, 2015, which was dedicated to vehicle–to–vehicle (V2V) standardisation. Results of these discussions, as well as other projects such as AutoNet2030 and iGame, are considered with the UnCoVerCPS Task 5.3 (Automated Driving). The standardisation meeting also included standards for the use cases and testing methodologies which are relevant to UnCoVerCPS Task 6.5 (Exploitation). In addition, DLR has presented the UnCoVerCPS project at the iMF Automation Working Group (AWG) meeting on July 1, 2015 at ERTICO Brussels and contributed ideas of UnCoVerCPS to an iMF AWG white paper.

3.10 Liaisons with Industry Organizations and Competence Clusters

ARTEMIS–IA is a non–profit association for the area of embedded and cyber–physical systems in Europe. It represents its members — industry, SME's, universities and research institutes — in the ECSEL Joint Undertaking. ARTEMIS–IA continuously promotes the research and innovation interests of its members to the European Commission and the public authorities of the participating states. It continues the work of the European Technology Platform ARTEMIS and is therefore responsible for the ARTEMIS Strategic Research Agenda (SRA) on Embedded and Cyber–Physical Systems which reflects the research and innovation needs in industry. The association aims at a coordinated, pan-European strategy. GE Global Research and Bosch are members.

Further, Bosch is a long–term member of Safetrans (see Section 3.4).

RUR has held a first meeting with the Health & Safety Laboratory (the research and solution development arm of the UK Health and Safety Executive) to discuss the project approach in relation to safety legislation trends as applied to human–robot interaction. It is intended to follow up this contact once the specific project approach is confirmed.

Dissemination activities to promote UnCoVerCPS results in the automotive sector

Tecnalia is an active member of several European Automotive platforms, such as the European Green Vehicles Association (www.egvi.eu, EGVIA), where a specific "Automated Driving Roadmap" has been launched in the frame of the European Road Transport Research Advisory Council (www.ertrac.org, ERTRAC) in July 2015, and it is being deployed.

UnCoVerCPS results will be spread in different events, such as the annual meeting of European Automotive Research Partners Association (www.earpa.eu, EARPA). These events are attended by the main stakeholders involved in the vehicle automation supply chain (OEM's, Tier1 & Tier2's, integrators and infrastructure agents). Thanks to them it will be possible to gain specific feedback about the use of UnCoVerCPS results and to review the project Exploitation Plan, taking into account the opinion of potential users present in these dissemination events.

3.11 International Academic Exchange Activities

The UnCoVerCPS project has also contributed to the attraction of several professors in cyber-physical systems for international exchange stays: Prof. Anca Muscholl from the Laboratoire Bordelais de Recherche en Informatique at Université Bordeaux received a three–year Hans Fischer Senior Fellowship from TUM. Prof. Marco Caccamo from the Department of Computer Science at University of Illinois at Urbana–Champaign received a three–month stipend at TUM as a TÜV Süd Foundation Visiting Professor.

An international collaboration was also initiated between TUM and the Robotics Institute at Carnegie Mellon University (CMU). As part of this collaboration, a TUM student, Robert Lösch, will write his Master thesis in collaboration with John M. Dolan, Principal System Scientist at CMU.

4 Exploitation Report

4.1 Exploitation Plan

UnCoVerCPS will enable faster time to market in the design of controls for safety-critical cyber–physical systems, and hence yield a significant competitive advantage over traditional approaches consisting of manual control algorithm design and verification by means of time–intensive and error–prone manual testing. As part of the project, four use cases are studied in detail (wind turbine controls, automated vehicles, smart grids, and human–robot collaboration); however, it should be obvious that the technology has a much wider range of potential applications in automotive, manufacturing, aerospace, construction, energy and many other industries. Figure 4 below shows the anticipated timeline for bringing the innovations developed in UnCoVerCPS to market. It visualized both the four vertical applications as well as the horizontal research on methodologies and application–agnostic tool chain development.

While the exploitation path of the industrial partners will either be geared towards one or

more of the specific use cases (GE, Bosch, RUR) or on the development of world–class tools (Esterel); the academic partners pursue an open source strategy for academic exploitation and dissemination by means of granting open access to all tools developed under the UnCoVerCPS umbrella.

As a result of the first project review in Brussels in February 2016, it was decided to prematurely wrap up the wind energy use case, and instead to reinforce collaboration between the project partners on the automated vehicles, smart grids, and human–robot collaboration use cases. A corresponding amendment to the grant agreement was initiated on November 14, 2016, and closed on January 16, 2017.

4.2 Bosch Exploitation Plans and Activities

Bosch Mobility Solutions *Bosch Mobility Solutions* is the largest Bosch Group business sector. In 2014, its sales came to €33.3bn, or 68% of total group sales. This makes the Bosch Group one of the leading automotive suppliers. The Mobility Solutions business sector combines the group's expertise in three mobility domains – automation, electrification, and connectivity – and offers its customers integrated mobility solutions. Its main areas of activity are injection technology and powertrain peripherals for internal combustion engines, diverse solutions for powertrain electrification, vehicle safety systems, driver–assistance and automated functions, technology for user–friendly infotainment as well as vehicle–to–vehicle and vehicle–to–infrastructure communication, repair–shop concepts, and technology and services for the automotive aftermarket. Bosch is synonymous with important automotive innovations, such as electronic engine management, the ESP anti–skid system, and common–rail diesel technology.

Robert Bosch GmbH targets to leverage the UnCoverCPS tool chain to efficiently develop new technologies and services (i) with decreased development costs and (ii) with shorter development times to bring products and services faster to the market. Bosch's main interest for exploitation is the UnCoVerCPS tool chain for efficiently developing new and safe technologies and services.

Bosch Mobility Solutions has a total revenue for embedded control units of approximately €6bn; this translates to sales of about 150 million embedded control units per year. The development cost for these embedded control units can be estimated to about €1bn. We estimate that leveraging the UnCoVerCPS tool chain, we can save two development iterations for a software function; this corresponds to at least 30% of development cost. Assuming 5% of software functions are safety–critical and amenable to the UnCoVerCPS toolchain, we can save at least €15m.

The application domain of interest for Bosch is automated driving and in particular the aspect of verified safety of vehicle dynamics. Hence, we focus on the results from the application of the UnCoVerCPS toolchain to the automated driving use case in task 5.3. To this end, we discuss with the mobility business unit applications of UnCoVerCPS to internal pre-development projects in the con-text of automated driving. In the following, we discuss how such an internal pre–development project may progress along the activities in UnCoVerCPS.

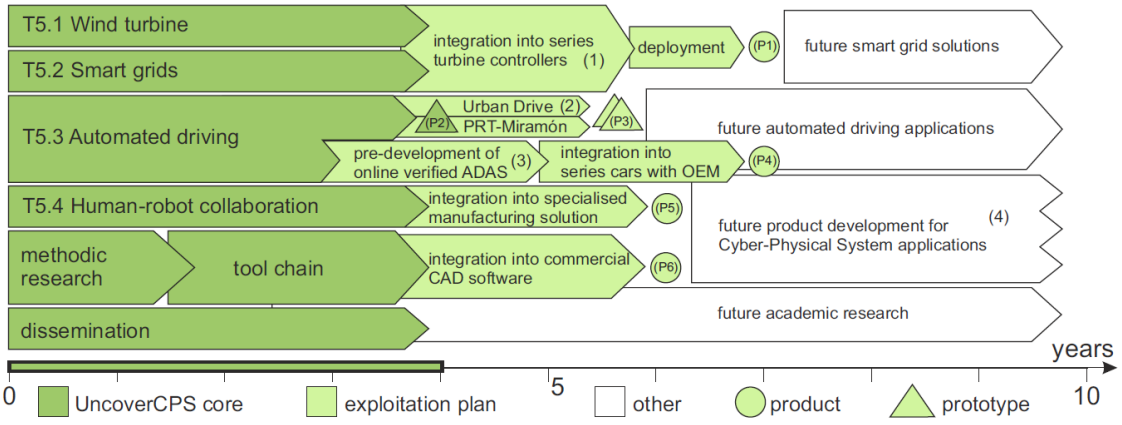


Figure 4: UnCoVerCPS exploitation timeline.

The pre–development phase in Figure 4 (3) for an advanced driver assistance systems (ADAS) with safety guarantees will begin in parallel to our project. Assuming successful technology transfer from academic to industry partners, a pre–development phase of two to four years can be expected. Product and series development in cooperation with an original equipment manufacturer (OEM) will integrate the functions into a real vehicle, taking approximately another two years. The optimal outcome is to bring an advanced driver assistance system to the market as shown in Figure 4 (P4), which has greater flexibility and is better able to adapt to varying traffic situations due to on–the–fly verification.

In order to bring UnCoVerCPS methods to fruition within Bosch, contacts to the relevant players in the field of highly automated driving have been established. This includes the business unit *Chassis Systems and Control*, which is responsible for the automated driving use case and acts as a contact to the relevant OEMs. It is envisioned that the maneuver automaton concept, as developed on the UnCoVerCPS AD use case can also be used to support the planning software of automated vehicles within the business unit, provide a selection of safe maneuver options in a given situation. In addition, a contact to the regulatory organization TÜV Süd has been established, with the goal of a letter or certification of the UnCoVerCPS approach by an additional external body. Feedback by TÜV Süd has been very positive so

far, and there has been a strong interest in the UnCoVerCPS methods. Talks with TÜV Süd are ongoing at this point in time, with meetings between Bosch, TÜV Süd, and TUM.

Robotics at Bosch Since its foundation in 2013 as a subsidiary of the Robert Bosch GmbH, the *Robert Bosch Start-up GmbH* has acted as an incubator for start-ups within the Bosch group. Among the startups that have been established is *Zenoway*, which is active in the field intralogistic robotics. In the business sector *Bosch Industrial Technology*, the business unit *Drive and Control Technology*, in cooperation with the *Bosch Engineering GmbH*, is also working on intralogistics solutions. The products of these two units within the Bosch group are mobile robots which need to interact safely with humans in their environment.

In the field of mobile robots, safe interaction between robots and humans is paramount and regulated by norms such as ISO 13482, ISO 13855, or European Machinery Directive 2006/42/EC . In this field, online reachability analysis is a promising approach to arrive at human behavior predictions that are less conservative than the state of the art, enabling less conservative motion planning that is still safe.

Through the course of UnCoVerCPS, we established connections to robotics researchers within Bosch, who act as contact persons to these start-ups, working, among other topics, on norm-compliant safety verification of mobile robots. In cooperation with Prof. Althoff, we conducted a study applying UnCoVerCPS online verification methods to a mobile robot prototype with promising results. In particular, we conducted conformance testing on pedestrian models and used reachability analysis for online prediction of pedestrian behavior. The results showed that the robot can maneuver in large groups of people significantly more efficiently than state-of-the-art approaches. We expect this work to be continued in parallel to and after the conclusion of UnCoVerCPS with the goal of including UnCoVerCPS methods in mobile robots of the Bosch group.

4.3 GE Exploitation Plans and Activities

General Electric (GE) is a widely diversified industrial conglomerate with eight globally operating industrial businesses: Power, Renewable Energy, Oil & Gas, Aviation, Healthcare, Transportation, Energy Connections and Lighting. In all of these businesses, cyber–physical systems are playing an ever–increasing role, either as systems or components that GE markets, or as tools that GE or its customers use in manufacturing, operations, and maintenance of complex systems. GE has coined the terms “Industrial Internet” and “Brilliant Machines” to describe its conviction that the combination of embedded intelligent controls, advanced sensing and cloud connectivity will be a disruptive trend across many industries that unlocks

huge opportunities to increase efficiency, safety, performance, and reduce operational cost. The expectation is that industrial assets as diverse as aircraft, distributed energy systems, locomotives, or intelligent, interactive lighting systems will have increasing capabilities to:

1. Observe, i.e. sense and process sensor data into information
2. Orient, i.e. put the observed information into context
3. Decide, based on the information and context
4. Act, i.e. close the control loop

At the same time, many of the industrial assets that GE makes, maintains or operates, are highly safety–critical in nature. This is obviously true for avionics such as flight management systems or FADEC's[2] controlling jet engines, but it also holds for locomotives, wind turbines, medical imaging systems, power plants or subsea oil production systems where a failure or an incorrect decision of the control system could cause severe damage to property, the environment or even human life. In most industries GE operates in, regulatory and certification requirements are in place to ensure the appropriate level of safety.

In areas such as embedded software for avionics, the cost of validation and verification already accounts for 40-50% of overall software engineering cost. This number increases further as the system complexity and autonomy advance. GE has put substantial effort into developing integrated tool chains for the validation and verification of complex embedded software systems all the way along the V–model, i.e. from high–level requirements engineering all the way to overall system validation. These tool chains, however, are only applicable to pure software systems which can be modelled as discrete systems. They cannot be readily transferred to systems where the embedded controller interacts with a physical system whose dynamics and disturbances are continuous or hybrid in nature.

When UnCoVerCPS was launched, GE's exploitation interests were focused around two areas: wind turbine controller design and verification, and applications of the "automated driving" use case to avionics, in particular human factors engineering and reduced crew operations.

The first UnCoVerCPS review in February 2016 marked an important pivot point for GE: Based on feedback from the project reviewers as well as internal feedback received from the different GE businesses, it was decided to wrap up the wind turbine use case after completing the tasks on conformance testing. Instead it was decided to focus on the automated driving use case, and to add collaboration with Politecnico di Milano on smart grid controls. Below,

[2]Full Authority Digital Engine Control

we detail the status of exploitation and interaction between GE Global Research and the respective GE businesses in the three application areas.

4.3.1 Wind Turbine Conformance Testing

The original intent was to apply techniques for unified controller design and verification to wind turbine rotor controls. The UnCoVerCPS team has been in regular communication with GE Renewable Energy in Salzbergen, Germany, and kept the business updated about progress in the project. Based on this, the potential applicability of UnCoVerCPS tools to this particular application seems to be rather far out in the future.

However, the business is highly interested in adopting methods for reachset conformance testing that some partners in the UnCoVerCPS consortium (Bosch, TUM) have developed. GE Renewable Energy uses high–fidelity aero–elastic and structural dynamics modelling tools such as FAST, Flex5, ADAMS, BLADED in its structural and aerodynamic design, controller design as well as system certification. The expectation is that the fidelity of such tools is high enough so that a system that can be shown to comply with the IEC 61400 series of standards in the simulation tools, with sufficient safety margins will also be safe in reality. Among many other safety measures, simulations of design load cases specified in IEC 61400-1 are run against the simulation tools in SIL[3] or HIL[4] types of tests. These include normal turbine operation, including start–up and shut–down, normal power production, but also dynamic wind events, extreme wind conditions, failure cases such as control failures or yaw errors. For each of these events, compliance of the turbine design with resulting fatigue load and ultimate load limits is verified. There is, however, a remaining uncertainty with regards to the fidelity of the models under all conditions, in other words, an uncertainty whether it is correct to assume that a turbine design that is safe is the simulated environment is also safe in the real world. This remaining uncertainty needs to be mitigated by appropriate safety margins in the turbine design.

The conformance testing work done in UnCoVerCPS is geared towards guaranteeing transference of safety properties between a model and the actual system, and towards establishing best practices for selection of test cases for conformance testing. These techniques could be used by GE Renewable Energy to establish conformance between a real wind turbine and the respective modelling tools, to reduce the number of tests that need to be run on the real turbine, and to reduce any excessive safety margins in the turbine design.

Likewise, the work can be applied to establish conformance between the above mentioned

[3] Software–in–the–loop

[4] Hardware–in–the–loop

high fidelity simulation environments, and simplified, reduced–order models that are used, for example, for designing model–based control algorithms.

Work on conformance testing applied to wind turbine models in collaboration with Bosch and TUM is currently ongoing.

4.3.2 PV Plant Prediction and Optimization

As one of the outcomes of the first UnCoVerCPS review, a collaboration between GE and Politecnico di Milano (PoliMi) was initiated, regarding work that Polimi had done on the smart grid use case. In this use case, a hybrid, distributed energy system is considered which comprises several modalities of power generation and energy storage and is characterized by stochastic uncertainty, e.g. with regards to renewable generation and to loads.

As part of UnCoVerCPS, this work by Polimi which had originally been verified against simulation models, was ported to and verified on a smart grid test rig on the GE Global Research premises in Munich, Germany. To this end, a researcher from Polimi spent several months at GE Global Research. The test rig comprises a rooftop photovoltaic (PV) installation, battery storage, a grid interface, and programmable three–phase load simulators. The objective of the prediction and control algorithms developed by Polimi – adapted to this particular test rig – is to optimize overall cost of operations, taking into account time–varying energy prices, physical constraints such as battery storage properties, as well as stochastic properties of PV generation and energy demand.

This work is highly relevant for GE Energy Connections, in particular with regards to the ability to improve forecasting and provide better dispatchability of utility–scale photovoltaic plants. Polimi and GE are currently discussing a bilateral follow–on collaboration to fuse the stochastic forecasting algorithms with sensor information and/or meteorological data.

4.3.3 Unmanned Aerial Vehicles

GE's interest in Unmanned Aerial Vehicles (UAV's) is twofold:

- For GE Aviation System, a leading provider of navigation and guidance systems for commercial aircraft, the rapidly growing market of unmanned aviation is an obvious adjacency to their current business.

- For many of GE's industrial businesses which sell large and complex industrial assets and services around these assets, UAV's offer enormous potential to optimize and automate inspection and repair tasks, especially tasks which would be risky or dangerous to perform manually.

Navigation and Guidance systems are today verified by first establishing conformance between the real system and a high–fidelity model by means of extensive flight test, similar to the conformance testing for wind turbines described above. Then, a huge number of verification runs are performed against this high–fidelity model, e.g. in SIL or HIL tests.

There is enormous potential in automated synthesis and verification of such algorithms, either in an off–line fashion, or on–the–fly, for example in collision avoidance scenarios. We are in regular communication with the interested GE businesses, in particular with GE Aviation Systems with whom we review UnCoVerCPS at least once per month and who also internally co–fund the project. We are adopting results and tools from other project partners working on the automated driving use case (Bosch, Tecnalia, TUM, UJF) to a number of scenarios relevant to these businesses. The challenges are very similar to the automated driving use case, including collision avoidance scenarios with or without vehicle–to–vehicle or vehicle–to–infrastructure communication, with the obvious difference of the third dimension and very different kinematic and dynamic vehicle models.

4.4 R.U. Robots Exploitation Plans and Activities

R.U. Robots Limited (RUR) develops specialised solutions for human–robot collaborative manufacturing and plans to integrate on–the–fly verification methods developed in UnCoVerCPS into food assembly robots collaborating with human workers. The food industry is Europe's largest manufacturing sector. 99.1% of the food industry is made up of SME's that generally have an extremely poor take up of automation. Food assembly, in particular, is very much a labour intensive task partly due to the uncertain nature of the products being handled, but mainly due to the requirements for ultraflexibility — in certain cases with entire product changes every 15 minutes. One aspect of ultra–flexibility that arises is the need to mix people and robots on a single line (robots cannot do all tasks cost effectively) and then the need for operatives to work in close proximity to robots. Current guidelines for safety of robots at work prevents uncaged robots, except in special circumstances.

The UncoverCPS approach and toolset promises to provide a way to address this issue of safety under close, collaborative working between robots and people. In order to address the exploitation potential of these results, RUR will undertake five distinct actions, namely:

1. Tracking and discussing standards and legislative issues.
2. An implementation–options study regarding the incorporation of the UnCoverCPS results in product options.
3. A market study of the potential exploitation routes.

4. Promotion of the UnCoVerCPS tool to the wider robotics community.

5. Final exploitation plan.

Tracking and discussing standards and legislative issues

In order to utilise the UnCoVerCPS approach it is necessary that it is implemented in a way that is consistent with safety legislation and regulations. As an SME, RUR has very limited capability to effectively influence standards and legislation. That is why much of the activity will involve tracking current movements in standards and legislation and then assessing how the UnCoVerCPS approach can be made consistent with these. Currently there is much interest in collaborative working between people and robots and there is a current ISO Tech Committee (184) that is looking at safety standards for robots with capabilities beyond those of a standard industrial robot. There is currently a draft standard (ISO / TS15066) which specifically addresses collaborative working between humans and robots. RUR will investigate in which ways this standards work would permit or cause difficulties for the UnCoVerCPS approach in order to influence the way that we try and implement it within the project.

Second, RUR has opened dialogue with the UK Health & Safety laboratory which looks at future requirements for legislation and certification in order to investigate the trends in safety approaches that may be conducive to the use of UnCoverCPS technologies.

Third, RUR will try to influence others in the community (see "Promotion" below) and convince them of the benefits of the UnCoverCPS approach with a view to getting longer term influence on such things as standards.

An implementation–options study regarding the incorporation of the UnCoverCPS results in product options

The aim of the implementation–options study is to evaluate the ways that the UnCoVerCPS approach could be implemented and the effect that different approaches would have upon the necessary hardware and software systems that would need to be included within robots developed by RUR. It is unlikely that UnCoverCPS will be a simple add–on or wrapper but more likely that it will involve architectural changes to the system. One of the critical areas that will have a large difference is the type and number of sensors utilised and their need to themselves being safety certified. The primary output of this study will be a first order cost assessment of various approaches that can then be used in the market study to determine the cost options for the robot system.

A market study of the potential exploitation routes

Although food assembly is the primary target for RUR's GRAIL robot system, there is potential for it to also be exploited in other markets. One of the potential difficulties of the food assembly market is the extreme price sensitivity for capital purchases and the low rate of acceptance of new technologies. It may therefore be possible to implement the combination of GRAIL robot, with UnCoverCPS technologies in markets other than food assembly. This study will aim to identify those potential markets and to evaluate the price sensitivity and potential sales volumes for those markets. This work will feed the final exploitation plan work by RUR.

Promotion of the UnCoVerCPS tool to the wider robotics community

An important part of the exploitation work is the adoption of the UnCoverCPS approach by potential end users and other robot suppliers. The latter is because if RUR is the only supplier using the approach then it is unlikely to get widespread acceptance as a suitable safety approach within the robotics community.

Therefore RUR will firstly work with end user groups such as the UK Food Engineering and Manufacturing Group to hold seminars and contribute to workshops in order to raise the awareness of the food industry of the benefits of the UnCoVerCPS tool chain in allowing automation with the required flexibility to the industry. As well as raising awareness it would be intended to use these events to elicit feedback from the industry as to the potential uses such a system could perform.

In addition RUR will use its position as a well networked European robotics firm to inform the rest of the European robotics industry about the UnCoVerCPS approach and its potential benefits. This would be done in conjunction with organisations such as euRobotics AISBL, EUnited Robotics and the British Automation and Robotics Association. The aim would be to get a critical mass of interested companies that could firstly provide feedback on potential uses of the approach but also be able to exert any necessary influence over future standards work.

Exploitation Plan

The final work undertaken by RUR would be the production of an exploitation plan with respect to the use of the UnCoVerCPS approach within the robotics industry. This work, as well as informing RUR's own post–project exploitation activities, will feed directly into deliverable 6.5.3.

4.5 Esterel Exploitation Plans and Activities

Esterel Technologies, as a subsidiary of ANSYS, Inc, is in charge of the development of the virtual system paradigm with the goal to aggregate multi-physics simulation and embedded software controllers. Our solutions can be applied to various domains such as Aerospace & Defence (A&D), Automotive, Railway Transportation, Industry and Energy. System complexity is increasing, in particular in the cyber–physical systems class. This is particularly true in Automotive with Advanced Driver Assistance Systems (ADAS), but also in A&D systems requiring a high safety level and for which on–line failure prediction is key. Esterel Technologies expects to get a better understanding of the needs of real application cases from the UnCoVerCPS project. Leveraging these applications and the cooperation with research partners, the SCADE and Simplorer toolsets will be improved.

The automotive use case offers two opportunities. The first one is related to the development of the controller in charge of the trajectory selection. The second one, although not directly related to cyber–physical systems, is vehicle–to–vehicle communication, which could be also a good example of the use of SCADE tools for protocols. In that context, a trajectory tracking controller and a first communication controller have been implemented in SCADE by DRL and Tecnalia. This is the first steautomotive demonstrator for the UnCoVerCPS toolchain. This work has been presented at the ASWC[5] 2016 [3].

The Scade language has been extended with hybrid constructs allowing for a complete mix of discrete and continuous parts. This work is a continuation of research work leading to the implementation into an industrial prototype [2]. Tp of the automotive demonstrator for the UnCoVerCPS toolchain. This work has been presented at the ASWC[6] 2016 [3].

The Scade language has been extended with hybrid constructs allowing for a complete mix of discrete and continuous parts. This work is a continuation of research work leading to the implementation into an industrial prototype [2]. The continuous part is integrated in the textual form of the Scade language and a dedicated library allows for its use within the graphical environment. The addition of the hybrid support within Scade also permit to import a FMU[7] in both model-exchange or co-simulation flavours. This integration extends the simulation capability as a complex physical model can be imported to provided an environment for the software controller.

Ongoing work is considering the interoperability between the SCADE and SpaceEx. An analysis of the semantics of the languages supported by the two tools has been performed.

[5] Ansys Automotive Simulation World Congress

[6] Ansys Automotive Simulation World Congress

[7] Functional Mock-Up Unit, see `https://www.fmi-standard.or`

From that analysis and with the automotive case as an example the flow using the two tools will be derived.

4.6 DLR Exploitation Plans and Activities

DLR plans to incorporate results and methods from UnCoVerCPS into ongoing research projects and future demonstrations such as Urban Drive which strives to realise fully automated passenger vehicles in urban areas by 2020. By reducing the risk of technical failure, safety verification is a key enabler for automated driving. DLR will integrate on–the–fly verification techniques developed in UnCoVerCPS into its Urban Drive roadmap. We have started this process by replacing the trajectory tracking controller of the automated vehicle by a controller developed in SCADE Suite. We will derive correctness properties for this controller using the CORA toolbox. A combinatorial search algorithm for contingency manoeuvre planning has been developed which makes use of on–the–fly verification principles and builds on the correctness properties derived for the underlying SCADE Suite trajectory tracking controller. In addition to safeguarding the automated vehicle operation in UnCoVerCPS and in future projects, the newly developed control systems serve as demonstrators for the UnCoVerCPS paradigms, the application in the development process and as an example for the UnCoVerCPS toolchain.

4.7 Tecnalia Exploitation Plans and Activities

Exploitable result of UnCoVerCPS project: Tecnalia autonomous and collaborative vehicle demonstrator

In the framework of UnCoVerCPS project, Tecnalia, as Technological Research Center, will use the project results for further private and collaborative research activities. The most valuable result for Tecnalia is the autonomous vehicle demonstrator, which will be able to perform safe collaborative manoeuvres at the end of UnCoVerCPS project.

The exploitation activities to be developed involving the mentioned result are described in the following paragraphs.

Fostered research activities in Spain on road automation thanks to the new legislation in the frame of automated driving

In November 2015 a new instruction 15/V–113 was launched by the Spanish DGT (Dirección General de Tráfico), directly related to the Ministry of Internal Affairs of Spain. The denomination of this new instruction is “Authorization trials or research studies with automated

vehicles driving on roads open to general traffic". This very challenging approach accelerates the market take–up of Road Automation and opens a broad environment field for fostering Spanish research activities on Automated Driving, where Tecnalia's collaborative autonomous and collaborative vehicle demonstrator resulting from UnCoVerCPS project will be deployed. New business opportunities for Tecnalia are framed in research project activities such as the following ones:

- New private contracts for implementing UnCoVerCPS project results into different urban vehicle types developed by Spanish industrial companies, spin-offs and SME's, such as MASER, LARRAIOZ, MONDRAGON AUTOMOCION and others.
- AIRPORTS "Airport Improvement Research on Processes & Operations of Runway, TMA & Surface". Spanish Collaborative project where the vehicle demonstrator will be further developed for airport areas.

Use of Tecnalia autonomous and collaborative vehicle demonstrator after UnCoVerCPS project for further European research

Tecnalia will look for new business opportunities in the research and industrial community, spreading its development activities thanks to the use of the resulting autonomous vehicle of UnCoVerCPS into new collaborative projects in the frame of the ERTRAC "Automated Driving Roadmap", in running and future projects such as the following ones:

- IOSENSE "Flexible FE/BE Sensor Pilot Line for the Internet of Everything": ECSEL Innovation Project, starting at the end of 2015.
- MOB-ON-PARKS "Mobility Plans Based on Integrated Staff Management for Technology Parks": European proposal in the frame of LIFE Program 2014–2020 for environment and climate action.
- New proposal to be launched in January 2016 within the H2020-ART-2016-2017 calls, specifically on ART-04-2016. Safety and end–user acceptance aspects of road automation in the transition period.

OEM's and Tier1's from the automotive sector specially focused on Road Automation will gain access to UnCoVerCPS results through these collaborative projects with Tecnalia.

4.8 Open Source Software Releases

Two of the central tools which are developed and improved within UnCoVerCPS are SpaceEx (http://spaceex.imag.fr) and CORA (http://www6.in.tum.de/Main/SoftwareCORA). New

versions of these tools have been released throughout 2015 and 2016.

SpaceEx and CORA apply different technologies to perform reachability analysis. Reachability and safety verification is particularly challenging for continuous and hybrid systems due to the complexity of representing and computing with continuous sets of states.

The development of SpaceEx was spawned by recent progress in finding efficient data structures and algorithms for reachability computation. Reach set approximations are efficiently computed for continuous linear dynamics with hundreds of variables. Its wrapping–free algorithm is particularly efficient when zonotopes or support functions are used as set representations. The underlying model in SpaceEx is a composition of hybrid automata, including extensions such as hierarchy and templates. The tool allows the development of heterogeneous analysis methods, such as using different set representations in different parts of the state space, or at different levels of refinement, or combining symbolic computation with simulation. The SpaceEx analysis tool is available as a virtual machine server that can be run locally in a protected environment, with a web–based frontend. It is also available as a command line tool for experienced users. In addition there is a Java–based model editor for the creation and modification of SpaceEx model files. All three components are released under the GPLv3 license. SpaceEx is made available by Verimag, which is a research institution affiliated with the University Joseph Fourier in Grenoble. Multiple updates of the SpaceEx components have been released throughout 2015 with contributions from the UnCoVerCPS project.

The Continuous Reachability Analyser (CORA) is a collection of MATLAB classes for the formal verification of cyber–physical systems using reachability analysis. A less efficient algorithm is used based on abstracting the original dynamics to linear differential inclusions. The advantage of this algorithm is that it can also be applied to nonlinear differential equations and even to nonlinear differential–algebraic equations. This is particularly important for industrial applications, a vast majority of which involve nonlinear systems. CORA is designed in such a way that representations can be exchanged without the need to modify the code for reachability analysis. Since the toolbox is based on MATLAB, its installation and use is platform independent. A major new release ("CORA 2015") was published in 2015, with contributions from the UnCoVerCPS project.

Another update CORA version was released 2016 which, among others, includes the following new features:

- CORA no longer requires the MATLAB toolbox INTLAB for interval arithmetic. Instead it contains an own implementation of interval arithmetic, making CORA independent of the commercial INTLAB tool.

- Unit tests have been added to ensure that functionality is maintained after major software changes. The unit tests can also be used as guiding examples to set up own verification problems.
- It is no longer required to implement all systems as hybrid automata in order to the method *reach* for computing the reachable set. The method is now also applicable to purely continuous systems.
- Auxiliary files, such as the Lagrange remainder, now contain the name of the model and are no longer overwritten when changing the investigated model.
- To shorten to the code without compromising functionality, we have integrated the class *intervalhull* into the new class *interval*, and the classes *vehicleSys* and *vehicleSys_td* into the existing class *nonlinearSys*.
- Faster plotting of reachable sets thanks to a new routine from Daniel Heß at DLR.
- The 2015 version only contained a single example (bouncing ball). The new version contains at least one example for each implemented category of dynamic systems.
- Many unused or prototypical files have been removed, and the code has been decluttered for various functions.

A new release of CORA is scheduled for 2018.

UnCoVerCPS also aims at the integration of CORA and SpaceEx which is an ongoing effort. A student at TUM, Evgeny Agamirzov, has worked on porting MATLAB based CORA algorithms to C++ such as to enable integration into SpaceEx. In 2016, we have finished transferring the zonetope toolbox from CORA to SpaceEx. As a result, computation times in SpaceEx could be substantially reduced. The results of this are documented in [1].

Ongoing integration efforts include:

- Importing SpaceEx models into CORA.
- Transferring the nonlinear reachability analysis toolbox from CORA to SpaceEx.
- Computing Taylor models in CORA which should provide sharper results for the set–based evaluation of nonlinear functions compared to the currently implemented interval arithmetic.

4.9 IP Strategy

The protection of Intellectual Property has not been a central element for the UnCoVerCPS project to date; the focus has instead been on an open–source approach. This is due to the fact that the industrial partners will typically benefit from applying the developed tools and methods to faster design and verification of cyber–physical systems. This will give them a competitive advantage. However, the industrial partners will continuously revisit the IP strategies with regards to the respective use cases and file patent applications where appropriate.

5 Summary and Outlook

This report has described the dissemination and exploitation activities of UnCoVerCPS for the period of January 2015 to June 2017, as well as plans for the remainder of the project duration. Core elements of dissemination to date have been:

- numerous conference publications,
- workshops organized by the UnCoVerCPS project, in particular the ARCH'15, ARCH'16, and ARCH'17 workshops as part of Cyber–Physical Systems Week, and the workshop "Verification and Control of CPS: Theory and Applications" as part of CDC 2016,
- open source software releases, in particular CORA and SpaceEx,
- participation in collaboration and liaison events, e.g. "Advanced Computing and CPS 2016" and "Digital Innovation Forum" in 2017
- the UnCoVerCPS web site and flyer,
- teaching activities.

The ARCH workshops have not only raised awareness of UnCoVerCPS in the relevant scientific and industrial communities, but also provided the consortium with valuable input in the form of industrially relevant benchmark problems that the UnCoVerCPS toolchain will be evaluated against. In particular, in ARCH'17 a competition takes place, where tools are evaluated against benchmark problems, and compared to each other.

Besides significant improvements and open–source releases of CORA and SpaceEx, TUM and UJF have commenced a joint activity towards integration of both tools. To this end, CORA algorithms are in the process of being ported to C++ for integration into SpaceEx.

The consortium expects tool chain integration activities to continue throughout 2017 and 2018.

Commercial exploitation activities are ongoing, both horizontally with regards to tools (Esterel, TUM, UJF, Universität Kassel) and vertically with regards to a wide range of safety–critical CPS applications (Bosch, GE, R.U. Robots, Politecnico di Milano, DLR, Tecnalia). Commercial exploitation is expected to gain more momentum, going forward, and will also take into consideration regulatory and legislative aspects from the individual application domains.

Appendix A: Conference papers published and submitted in the context of UnCoVerCPS

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Appendix B: Journal papers published and submitted in the context of UnCoVerCPS

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