COST IC1404 WG4

Y1 and Y2 Technical Report WG4.2

CPS profile - Systematic Search

2016

Authors

Vasco Amaral (NOVA-LINCS, FCT/UNL PT), Paulo Carreira (INESC-ID, IST/UL PT), Miguel Goulão (NOVA-LINCS, FCT/UNL PT), Goran Martinović (University Osijek), Lejla Banjanovic-Mehmedovic (University of Tuzla)

Document History

Version	Date	Who	What
V0.1	25/11/2016	VA	Document Created
V0.2	29/12/2016	PC	Corrections and formatting

Introduction

The current report presents the work done in the scope of IC1404's Workgroup 4 (activity of year 1, 2015 and year 2, 2016), with the specific task force dedicated to doing a systematic search in digital libraries to compile information regarding CPS teaching with respect to the following items:

- Courses on CPS engineering offered inside the EU
- Courses on CPS engineering offered outside the EU
- List of topics/syllabus taught to the CPS engineers
- Reference books on CPS engineering

The ultimate goal of this exercise is to serve as input information to the task force that is going to define the CPS engineer's different profiles that are the baseline for the proposal of a Master course (Erasmus) formed by IC 1404's University members.

Methodology

The results presented in this document are the outcome of a systematic reading of the hits obtained by using a search engine (Google). Due to the difficulty of analysing and comparing the results of using different languages, it was only considered courses taught in English. After compiling the results in raw, the task force systematically reviewed the courses and topics and properly categorized them removing repetition. Fig. 1 presents the steps of the methodology followed.

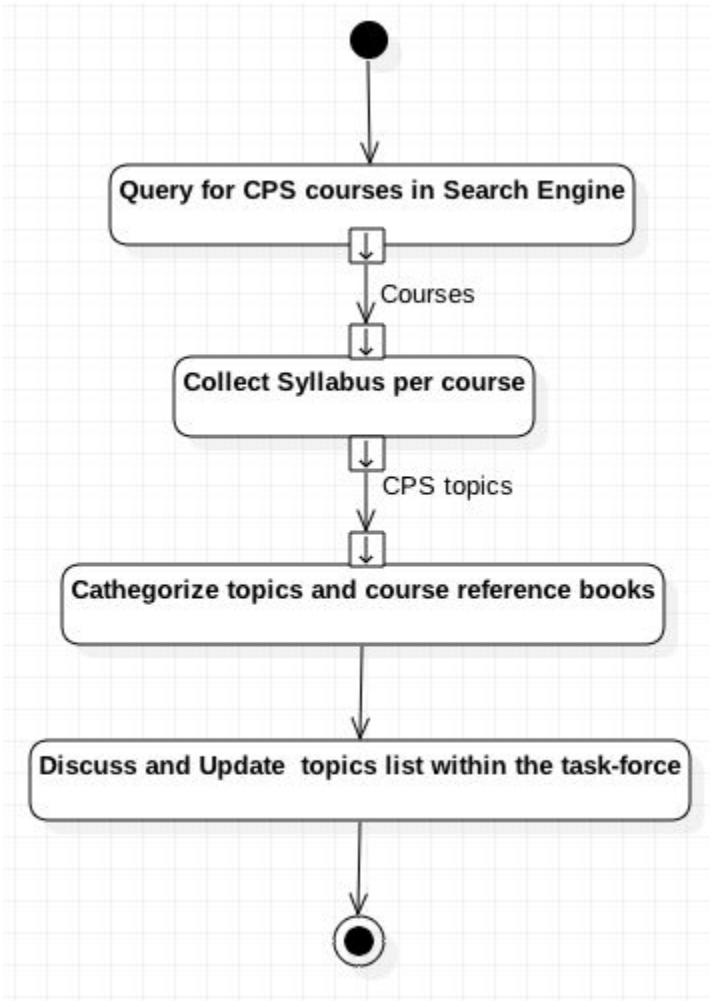

Fig. 1 - Activity diagram depicting the Systematic Search methodology

Results

Non- European CPS courses

Canada:

ECE720T5, **Cyber-Physical Systems**, University of Waterloo, Rodolfo Pellizzoni,

https://ece.uwaterloo.ca/~rpellizz/ECE720T5-2014.php

USA:

Foundations of Cyber-Physical Systems,CMU, André Platzer,
http://www.cs.cmu.edu/~aplatzer/course/fcps16.html

CMPE142, **Introduction to Cyber-physical Systems**, Ricardo Sanfelice,
https://hybrid.soe.ucsc.edu/cmpe142-2014

CIS 541, **Embedded and Cyber Physical Systems**, Insup, Lee
http://www.seas.upenn.edu/~lee/10cis541/

CS 8803 O07, Cyber-Physical Systems Security, Georgia Tech, Raheem Beyah,
https://www.omscs.gatech.edu/cs-8803-special-topics-cyber-physical-systems

(Mini-course) Cyber-Physical Systems, Georgia Tech, Dr. Guy Boy (Florida Institute of Technology and NASA),Dr. Eric Feron (Decision and Control Lab, Georgia Institute of Technology), Pierre-Loïc Garoche (ONERA, Office National d'Etudes et Recherches Aérospatiales),Emmanuel Grolleau (LIAS, ISAE-ENSMA, Institut Supérieur de l'Aéronautique et de l'Espace – Ecole Nationale Supérieure de Mécanique et d'Aérotechnique), Marilyn Wolf (Embedded Systems Lab, Georgia Institute of Technology),
https://cps-course.ensma.fr/

EECS 571, **Principles of Real-Time Embedded Systems**, University of Michigan, Kang G. Shin,
http://www.eecs.umich.edu/courses/eecs571/lectures/lecture2-intro-of-CPS.pdf

EEL 6935, **Cyber-Physical Systems**, University of Florida, Dr. Xiaolin (Andy) Li,
http://www.andyli.ece.ufl.edu/teaching/cps/

COMP 451 001, Design and Analysis of Cyber-Physical Systems, RICE, Robert S. Cartwright, Michael Fagan,
https://courses.rice.edu/admweb/!SWKSCAT.cat?p_action=COURSE&p_term=201520&p_crn=24313

(Online) Berkley, Edward Lee, Jeff Jensen, Sanjit Seshia
https://www.coursetalk.com/providers/edx/courses/eecs1491x-cyber-physical-systems-2?search_index=5

CSE 40437/60437, **Social Sensing and Cyber-Physical Systems**, Univ. Notre Dame, Dong Wang,
http://www3.nd.edu/~dwang5/courses/spring15/

ESE-534, **Cyber Physical Systems**, Stony Brook University, Shan Lin,
https://www.stonybrook.edu/commcms/electrical/graduate/course_syllabi/2016_fall/ese543.pdf

EECS 227, **Cyber-Physical System Design**, Univ. of California - Irvine, Mohammad Abdullah Al Faruque,
http://plaza.eng.uci.edu/course/eecs/227/outline/2013-2014

ECE 8803A, **Computational Aspects of Cyber-Physical Systems**, Georgia Tech,
http://www2.ece.gatech.edu/research/labs/esl/classes/8803/index.html

CS557, **Cyber-Physical Systems: Networking and Algorithms**, IIT,
http://www.cs.iit.edu/~xli/cs557/intro.htm

COMP 451, **Design and Analysis of Cyber-Physical Systems**, Rice University,
https://courses.rice.edu/admweb/!SWKSCAT.cat?p_action=COURSE&p_term=201520&p_crn=24313

CMPE149, **Introduction to Cyber-Physical Systems**, UC Santa Cruz,
https://hybrid.soe.ucsc.edu/cmpe142-2014

ECE 7855, **Large Scale and Cyber-Physical Systems**, The Ohio State University,
https://ece.osu.edu/sites/ece.web.engadmin.ohio-state.edu/files/uploads/courses/syllabi/7855.pdf

CSE40437/60437, **Social Sensing and Cyber-Physical Systems**, Notre Dame University,
http://www3.nd.edu/~dwang5/courses/spring15/

Comp 790-062, **Cyber-Physical Systems Information**, University of North Carolina at Chapel HIll, James H. Anderson,
http://www.cs.unc.edu/~anderson/teach/comp790c/

European CPS courses

Phd. Program:

PhD in Networked Interactive Cyber Physical Systems, Portugal, IST/CMU
http://www.m-iti.org/netsys

Security and limitations of Cyber-physical Systems, Sweden, Linkopings University
http://www.control.isy.liu.se/student/graduate/Cyberphysical2015/

Cognitive Cyber-physical Systems: from theory to practice, Italy, Politecnico de Milano

http://roveri.faculty.polimi.it/teaching/cognitive-cyber-physical-systems-from-theory-to-practice/

MSc. Program:

Cyber-Physical Systems (CPS), Germany, University of Freiburg

https://www.informatik.uni-freiburg.de/studies/furtherinformation/concentrationCPS

Master in Cyber-Physical and Embedded Systems (MCPES), Switzerland, USI Lugano
http://www.mcpes.usi.ch/course-descriptions.htm

Cyber-Physical System Fundamentals, Germany, TU Dortmund
http://ls12-www.cs.tu-dortmund.de/daes/en/lehre/english-courses/ss15-cyber-physical-system-fundamentals.html

CyberPhysical Systems, Sweden, HALMSTAD UNIVERSITY
http://www.hh.se/sitevision/proxy/3010.html/svid12_70cf2e49129168da015800067326/752680950/se_proxy/utb_kursplan.asp;jsessionid=3CCF56E94B5D7991E79509D19D8A6F48?kurskod=DA8003&revisionsnr=1&format=pdf&lang=EN

MSc. Courses:

Autonomous and Vehicle Dynamics and Control, United Kingdom, Cranfield University

https://www.cranfield.ac.uk/courses/taught/autonomous-vehicle-dynamics-and-control

INF5910CPS - Cyber physical systems, Norway, University of Oslo
http://www.uio.no/studier/emner/matnat/ifi/INF5910CPS/

Embedded Systems: Cyber-Physical Systems stream, Netherlands, Technische University of Eindhoven
https://educationguide.tue.nl/programs/graduate-school/masters-programs/embedded-systems/curriculum/cyber-physical-systems-stream/

DTEK2016 Cyber Physical Systems, Finland, University of Turku

https://nettiopsu.utu.fi/opas/teaching/course.htm?id=9492

BSc. Courses:

Human Interactions with Cyber-Physical , Sweden, Lulea University

http://www.ltu.se/edu/course/D00/D0022E/D0022E-Manniska-maskin-interaktion-for-cyber-fysikaliska-system-1.124779?kursView=kursplan&l=en

Certification Programs:

Cyber-Physical Systems for Intelligent Robotics (CPS-IR), Germany, RWTH Aachen University

https://www.academy.rwth-aachen.de/en/index/education-formats/cyber-physical-systems-for-intelligent-robotics-cps-ir

CPS Education Topics based on course syllabus

Logics and Proof Calculi for Hybrid Systems
- Differential Dynamic Logic dℒ
- Differential-Algebraic Dynamic Logic DAL
- Differential Temporal Dynamic Logic dTL

Automated Theorem Proving for Hybrid Systems
- Deduction Modulo Real Algebra and Computer Algebra
- Computing Differential Invariants as Fixed points

Case Studies and Applications in Hybrid Systems Verification
- European Train Control System
- Air Traffic Collision Avoidance
- First-Order Logic and Theorem Proving
- Differential Equations
- Hybrid Automata

Introduction to cyber-physical systems
- Discrete Event Systems
- Continuous Event Systems

Models of physical systems
- Hybrid systems in biology
- Multibody systems
- Multi-domain/Multi-physics, e.g. electrical-hydraulic
- Physical Models
- CAD modeling

Software Design, Modeling and Analysis
- Specification languages

Simulation of physical systems and introduction to models of cyber components
- Model-based testing

Modelling and Simulation
- Modelica-UML-SysML
- Discrete systems
- Finite-state machines
- Formalisms: Causal Block Diagrams (CBDs)
- Formalisms: Petri Nets
- Formalisms: Statecharts
- Formalisms: Event-Scheduling Discrete-Event
- Formalisms: Discrete-EVent System Specification (DEVS)
- Formalisms: (Forrester) System Dynamics
- Formalisms: Hybrid DAE (Modelica)
- From Data to Information using Ontology-based Modelling of Semantics

Models of interfaces
- Cyber-physical systems models as interconnections.

Embedded Systems

- Embedding programming
- Mobile computing (Mobile Platforms like iOS and Android, applications...)
- Multi Core embedded applications design
- Optimizing embedded applications
- Adaptation mechanisms in embedded system
- Designing embedded hardware, software and algorithms

Design of system on chip

- Microelectronics, FPGA soc
- Reprogrammable systems

Rapid Prototyping

Verification

- Invariants.
- Attractivity.
- Stability.
- Temporal logic
- Robustness.
- Run-time verification

Real-time systems

- Virtualization, real-time VM
- Software design languages and methods, addressing the software real-time aspects CPS (RTOS, AADL, software life-cycle, co-design, multitasking, programming, schedulability analysis)
- Multicore real-time scheduling
- Real-time interfaces and compositional scheduling
- Programming timing constraints
- TTA, Timed observation in distributed systems
- Reconfigurations, Mode change protocols
- Real-time scheduling

Verification

- Hardware verification
- Formal verification of control software
- Formal methods for specification and analysis (UPPAAL)
- Formal methods to analyze critical software: model checking, abstract interpretation, Deductive methods
- Specificities of control software: control laws, safety architecture
- Model level analysis: synchronous languages, model checking algorithms, invariant Computations
- Source level analysis
- Industrial experiences
- Computation of sound numerical invariants: the floating point issue

Architecture description

- language (AADL)
- Industrial Network Design and Architecture

Analysis of stream processing systems

CPS maintenance

Security

Security and trust management of CPS
Privacy
Hacking Industrial Control Systems
cybersecurity
Information Security

Networks

Mobile computing
Localization and LBS
Context aware emerging applications and services in IoT
Optimization and analysis approach in protocols performance evaluation
Routing in wireless sensor networks
Radio Frequency Identification (RFID) key components and systems
Industrial Network Protocols
Wireless sensor networks: architectures, protocols and techniques
Peer-to-Peer Networks
Concurrency: Theory and Practice
Medium access control in wireless sensor networks
Localization in wireless/mobile sensor networks
Data aggregation and fusion in wireless sensor networks
Clustering schemes in wireless sensor networks
Anti-collision mechanisms and medium access protocols in RFID systems
Wireless/wired/hybrid technological solutions and architectures for cyber-physical systems

Clouds and IOT

Mobile Clouds
parallel computing

Distributed Systems

Grid and cloud computing
Advanced Communication Middlewares
Architecture of distributed systems
Computational aspects of cyber-physical system design (CPS architecture, networked control system, distributed embedded system, design methodology)
Sensing and Fusion
Wireless sensor networks
Industrial Internet of Things (IoT) for pervasive computing
Interplay sensing and actuators in cyber physical system
From measurements to smart sensors

Intelligent Systems

Cognitive (model-free) learning and adaptation mechanisms
Decision Procedures
Multi-agent Systems.
Decision Making using Expert Systems and Machine Learning
Adaptive Task Planning
Cognitive (model-free) learning and adaptation mechanisms
Emotional cognitive mechanisms for cyber-physical systems
From smart objects to intelligent cyber-physical systems

Control Theory

Stability analysis of hybrid systems

Controller design and synthesis

Introduction to Industrial Control Systems And Operations

Hardware in the loop simulation

Feedback-based resource management in computer systems

User Interfaces

Introduction to Human-Computer Interaction, theories and Paradigms

From automation to tangible interactive objects: distributing cognitive functions among Humans and systems

Fundamental theories, concepts, tools and techniques in the field of Human Computer Interaction

User Interface design and evaluating the appropriateness of the designed UI.

Methods for quality control and quality evaluation of the User Interfaces.

The usefulness criteria of computer systems, and the role of HCI in increasing such system level usefulness.

Systems and Manipulation: How the system is manipulated through its interface. Direct and Indirect manipulation

How to use the gained knowledge in a real-world scenario, by designing and developing UIs for Computer-based cyber-physical systems

Digital signal processing

Digital automation

Nanosystems: devices and design

System Design and Management

Mobile Social Networks

Robotics

Path planning in robotics

Cloud of Robots/CPS

Mobile Robotics for In-Factory Logistics

Big Data

Data Analytics in Production Systems

Complexity Theory

Problem Complexity and Complexity Reduction

CPS Applications

Smart Energy Harvesting and Management

Intelligent Transport Systems

Advanced Manufacturing Systems

Video health monitoring

Generic language technology

The specification (e.g. spatial-temporal logics)

The analysis (e.g. symbolic and stochastic model checking)

Co-modeling, Co-simulation, FMI

Hybrid systems

Probabilistic hybrid systems

Stochastic hybrid systems

Hardware and energy issues

Adopted Reference Books

Andre Platzer, **Logical Analysis of Hybrid Systems: Proving Theorems for Complex Dynamics**, Springer-Verlag Berlin Heidelberg, ISBN 978-3-642-14508-7, DOI: 10.1007/978-3-642-14509-4, 2010.

Rajeev Alur, **Principles of Cyber-Physical Systems**, THE MIT PRESS, ISBN: 9780262029117, 2015.

C. M. Krishna, Kang G. Shin, **Real Time Systems**, McGraw-Hill series in computer science, ISBN: 9780070701151, 2010.

Cesare Alippi, **Intelligence for Embedded Systems**, Springer International Publishing, ISBN: 978-3-319-05277-9, DOI: 10.1007/978-3-319-05278-6, 2014.

Edward A. Lee, Sanjit A. Seshia, **Introduction to Embedded Systems: A Cyber-Physical Systems Approach**, Second Edition, MIT Press, ISBN 978-0-262-53381-2, 2017.

Suh, S.C., Tanik, U.J., Carbone, J.N., Eroglu, A. (Eds.), **Applied Cyber-Physical Systems**, Springer-Verlag New York, ISBN: 978-1-4614-7335-0, DOI: 10.1007/978-1-4614-7336-7, 2014.

Junichi Suzuki, Pruet Boonma, Shingo Omura, Toshimi Munehira (Eds), **Cloud-integrated Cyber-Physical Systems (Internet of Things)**, 1st ed., Springer-Verlag, ISBN-10: 3319022814, 2016.

A.J. van der Schaft, J.M. Schumacher, **An Introduction to hybrid dynamical systems**, Lecture Notes in Control and Information Sciences, Vol. 251, Springer-Verlag, London, 174 pp., ISBN: 9781846285424, 2000.

A.J. van der Schaft, J.M. Schumacher, **An Introduction to hybrid dynamical systems**, Lecture Notes in Control and Information Sciences, Springer-Verlag, London, 192 pp., ISBN: 9781447139157 2014.

Daniel Liberzon, **Switching in Systems and Control**, Birkhäuser Boston, ISBN: 978-1-4612-6574-0, DOI:10.1007/978-1-4612-0017-8, 2003.

Wayne Wolf, **High-Performance Embedded Computing**, Morgan Kaufmann, ISBN: 9780123694850, 544 pp., 2006.

John Lygeros, **Lecture Notes on Hybrid Systems**, University of Patras, ENSIETA 2-6/2/2004. http://robotics.eecs.berkeley.edu/~sastry/ee291e/lygeros.pdf

E. A. Lee, P. Varaiya, **Structure and Interpretation of Signals and Systems**, Addison-Wesley, ISBN-10: 0201745518, 2002.

Song & Rawat & Jeschke & Brecher, **Cyber-Physical Systems, 1st Edition: Foundations, Principles and Applications**, Academic Press, ISBN :9780128038017, 2016.

Jeff C. Jensen, Edward A. Lee, and Sanjit A. Seshia, **An Introductory Lab in Embedded and Cyber-Physical Systems**, http://LeeSeshia.org/lab, First Edition v1.70, 2015.

Peter Marwedel, **Embedded System Design: Embedded Systems Foundations of Cyber-Physical Systems**, Springer Netherlands, ISBN: 978-94-007-0256-1, DOI: 10.1007/978-94-007-0257-8, 2011.

Siddhartha Kumar Khaitan, James D. McCalley, Chen Ching Liu (Eds.), **Cyber Physical Systems Approach to Smart Electric Power Grid**, Springer-Verlag Berlin Heidelberg, ISBN: 978-3-662-45927-0, 2015.

Alan Dix, **Human–Computer Interaction**, Pearson Education, 3rd Edition , 834 pp., ISBN-13: 978-0-13-046109-4, 2004.

Related Bibliography

Walid Taha, Robert Cartwright, Roland Philippsen, Yingfu Zeng: Developing A First Course on Cyber-Physical Systems. WESE 2014: 6:1-6:8