COST Action IC1404: Multi-Paradigm Modelling for Cyber-Physical Systems

http://www.mpm4cps.eu/



Proceedings of the 5th Workshop of the MPM4CPS COST Action

November 24-25, 2016 • Malaga, Spain

Hans Vangheluwe, Vasco Amaral, Holger Giese, Jan Broenink, Bernhard Schätz, Alexander Norta, Paulo Carreira, Miguel Goulão, Antonio Vallecillo, Tanja Mayerhofer (Eds.)

Technical Report No. ITI16/02
Departamento de Lenguajes y Ciencias de la Computación.
Universidad de Málaga.

Copyright © 2016 for the individual papers by the papers' authors. Copying permitted for private and academic purposes. This volume is published and copyrighted by its editors.

Editors:

Hans Vangheluwe
University of Antwerp (Belgium)

Vasco Amaral
Universidade Nova de Lisboa (Portugal)

Holger Giese
Hasso-Plattner-Institut für Softwaresystemtechnik GmbH (Germany)

Jan Broenink
University of Twente (Netherlands)

Bernhard Schätz
fortiss GmbH (Germany)

Alexander Norta
Tallinn University of Technology (Estonia)

Paulo Carreira
Universidade de Lisboa (Portugal)

Miguel Goulão
Universidade Nova de Lisboa (Portugal)

Antonio Vallecillo
Universidad de Málaga (Spain)

Tanja Mayerhofer
TU Wien (Austria)

Table of Contents

Preface I

Foundations

Modeling Mobility Using Dynamic Topology Models 1–21
Fernando J. Barros

Engineering Hybrid Modelling Languages 22–34
Sadaf Mustafiz, Cláudio Gomes, Bruno Barroca, Hans Vangheluwe

Real-Time MDE: An Overview 35–46
Moussa Amrani, Pierre-Yves Schobbens

Novel Verification Paradigms for Nonlinear Hybrid Automata 47–55
Eva M. Navarro López

Usability Driven Development with Usability Software Engineering Modeling Environment (USE-ME) 56–75
Ankica Barišić

Automated Analysis of Traceability in Cyber-Physical Systems (Tool Demonstration) 76–92
Ferhat Erata, Bedir Tekinerdogan

Techniques

A Hybrid Master (Discrete-Event and Discrete-Time) for Functional Mockup Interface ... 93–100
Vincent Albert

Adding Uncertainty and Units to Quantity Types in Software Models 101–110
Loli Burgueño, Tanja Mayerhofer, Antonio Vallecillo, Manuel Wimmer

Integrating Uncertainty Modelling with Use Case Modelling to Discover Unknowns 111–117
Tao Yue, Shaukat Ali, Man Zhang

Model-Driven Testing of Cyber-Physical Systems with the Explicit Consideration of Uncertainty (U-Testing) 118–123
Shaukat Ali, Man Zhang, Tao Yue

Separation of Concerns in Continuous Time Hierarchical Co-Simulation 124–130
Cláudio Gomes, Joachim Denil, Bart Meyers, Hans Vangheluwe

Modeling of Cooperation Behavior in Flexible Vehicle Platoon Based on Hybrid Automaton and Predicitive Analysis 131–142
Lejla Banjanovic-Mehmedovic

Introduction to Physical-Systems Modelling with Bond Graphs (Tutorial) 143–159
Jan F. Broenink

Application Domains

Architecting the Next Generation of Vehicles 160–174
Patrizio Pelliccione

Innovative Designs through Topological Design Space Exploration 175–191
Mike Nicolai

Simulation and Design-Time Analysis of the Smart Grid in the Czech Republic 192–195
Barbora Buhnova

A Multi-Domain Approach to Design of CPS in Special Education: Issues of Evaluation and Adaptation (Paper) 196–205
Maya Dimitrova, Anna Lekova, Snezhanka Kostova, Chavdar Roumenin, Milena Cherneva, Aleksandar Krastev, Ivan Chavdarov

Education

How to Exploit an Experience Gained in CPS Related Projects for Master Students Training Program in ERASMUS+ Project 206-221
Anatolijs Zabašta, Nadezda Kuņicina, Oksana Nikiforova, Andrejs Romanovs

Preface

In virtually any area of human activity, Cyber-Physical Systems (CPS) are emerging. CPS are truly complex, designed systems that integrate physical, software and network aspects. To date, no unifying theory and no systematic design methods, techniques and tools exist for such systems. Individual mechanical, electrical, network or software engineering disciplines only offer partial solutions. Multi-paradigm Modelling (MPM) proposes to model every part and aspect of a system explicitly, at the most appropriate level(s) of abstraction, using the most appropriate modelling formalism(s). Modelling language engineering, including model transformations, and the study of their semantics, are used to realize MPM. MPM is seen as an effective answer to the challenges of designing CPS.

The COST Action IC1404: Multi-Paradigm Modelling for Cyber-Physical Systems (MPM4CPS) aims to promote foundations, techniques and tools for multi-paradigm modelling for cyber-physical systems, and to provide educational resources to both academia and industry. This will be achieved by bringing together and disseminating knowledge and experiments on CPS problems and MPM solutions.

The fifth MPM4CPS workshop took place on November 24-25, 2016 in Malaga, Spain. The program comprised presentations of MPM4CPS COST Action members discussing their work on foundations, techniques, application domains, and education in MPM4CPS, as well as joint work meetings. These proceedings collect the presentations given at the workshop. They cover many different aspects of multi-paradigm modelling for cyber-physical systems including, but not limited to

- foundations of MPM4CPS including
  - language engineering,
  - model transformations,
  - verification paradigms,
  - traceability;
- techniques in MPM4CPS including
  - co-simulation,
  - uncertainty modelling,
  - model-driven testing,
  - predictive analysis;
- application domains of MPM4CPS in the
  - automotive industry,
  - aviation industry,
  - smart grids,
  - robotics;
- education in MPM4CPS.

We would like to thank the presenters contributing their work to the MPM4CPS COST Action. Furthermore, we would like to thank Antonio Vallecillo, Loli Burgueño and Tanja Mayerhofer for organizing the workshop.

December 2016

A Multi-Domain Approach to Design of CPS in Special Education: Issues of Evaluation and Adaptation

Maya Dimitrova, Anna Lekova, Snezhanka Kostova, Chavdar Roumenin, Milena Cherneva, Aleksandar Krastev and Ivan Chavdarov

Institute of Systems Engineering and Robotics, Bulgarian Academy of Sciences, Akad. G. Bonchev Str., Bl. 2, POB 79

Email: dimitrova.iser@gmail.com

Abstract The paper presents a multi-domain approach to design of Cyber-Physical-Systems, especially in special education. The domains of game design for education and the control systems design are merged into the domain of novel educational technology design. The approach is tested within the recent EEA Grant project of Bulgaria and Norway "METEMSS: Methodologies and technologies for enhancing the motor and social skills of children with developmental problems". A formalized model is proposed to account for the nature and direction of the incremental game transformation based on the preferences of the individual child. The results provided statistically significant difference in the desired direction of game change. Examples with humanoid and non-humanoid educational robots are discussed with relevance to the topic of COST Action IC1404 WG3 Application Domains.

Keywords: Cyber-Physical Systems, multi-domain modeling, game design and evaluation, special education

1 Introduction

The concept of Cyber-Physical Systems (CPS) is being introduced to account for technical devices with certain adaptive, sensing and reasoning abilities with a varying degree of autonomous behavior within networked environments (briefly named Internet-of-Things) – with or without the human in the information and control loop [1, 2, 3]. Seven types of CPS are most often discussed in the working documents of the EU [4, 5] (first 7 rows of Table 1). To them 3 additional, but none less important, can be proposed as emerging and rapidly acquiring influence in present day society - under No 8-10 of Table 1.

Environmental robotics includes swarm robots, robots intended to replace bees in the field, growing robots like trees, robotic fish intended to collect the underwater

pollution especially in bay areas of big cities and underwater cleaning of ship corpuses. Two such robotic systems are currently being developed under the FET Proactive funding scheme of the EC – 2015-2018: FLORA ROBOTICA and subCULTron [6].

The domain of CPS for creativity, art, social communication/media and companionship deal with the entertainment industry where robotic performance is comparable to the human one – in composing music, painting, performing music or dancing and in simulating human-to-human communication in the social media [e.g. 7, 8].

Table 1. Classification of Cyber-Physical Systems

No	Cyber-Physical Systems
1.	Disabled People
2.	Healthcare
3.	Agriculture & Food Supply
4.	Manufacturing
5.	Energy & Critical Infrastructures
6.	Transport & Logistics
7.	Community Security & Safety
8.	*Environmental Robotics*
9.	*Creativity, Art, Social Communication/media and Companionship*
10.	***Education & Pedagogical Rehabilitation***

The education & pedagogical rehabilitation frameworks have emerged recently but have been employed widely for implementing information and robotic technology in clinics and special education [e.g. 9, 10, 11]. A promising case is the Wizard of Oz experimental framework for the analysis of the human response to the performance of the robot [12].

We witness the emergence of a new ontology, so-called 'rob-ontology' with a special application domain being education. Currently robots are being used as part of the subject "informatics" (i.e. computer science) or in extra-curriculum lessons. Our view is that the moment of introducing robots at school is late – at the age of 12 or older - whereas almost all above mentioned robotic systems and platforms are designed for little children. If we populate the child's environment with robots from the age of 3, this will help feel comfortable with technology from a very early age, very much in the same way as smartphones and laptops have already done. This will also open workplace for technicians, engineers, software developers and multidisciplinary teams, including psychologists and special education teachers, at kindergarden and school and will give examples of highly skilled jobs to the children. The educators will learn technical and programming skills to operate the robotic platforms.

The robots will assist the teachers in the process by exhibiting cognitive and social skills in an amusing learning environment. The process of implementing robotic technology at school is to be gradual – from simple to more complex behaviors of the robot. The schools that decide not to implement robotics will be at disadvantage with the others, so **legal regulation** will be necessary to **promote** the new trend with using robot assistants to the teacher. Parents can be informed and attracted to the idea by pointing out the possibilities that robots can demonstrate regarding shaping their children's interests.

In general, all these 10 groups of CPS encompass the large, domain specific developments of robotic systems that are implemented in practice to this moment or are currently being designed. But in terms of the internal ontological specificity of the CPS, or the robots under consideration, the following taxonomy/categorization of robots is proposed along the dimension of the level of involvement of the human in defining, controlling or predicting the behavior of the robot from the lowest human involvement to the highest: **Autonomous CPS, Semi-autonomous CPS** and **Assistive CPS**. The latter are technological platforms (networked software and hardware, e.g. Aldebaran's NAO [13]) for design of scenarios of robot behavior. The main applications of the assistive CPS are: education, pedagogical rehabilitation, mental health, playing games, socializing (as well as in other domains).

One possible application of assistive CPS is presented further in the present paper. The domains of game design for education and the control system design are merged into the domain of novel educational technology design (Fig. 1).



Fig. 1. Multi-domain approach towards the process of game design in special education

The approach is implemented within the recent EEA Grant project of Bulgaria and Norway "METEMSS: Methodologies and technologies for enhancing the motor and social skills of children with developmental problems" (2015-2016) [14].

2 A Formal Model of the Design Process of Assistive CPS in Special Education

The proposed evolving design of games for children with special needs describes the transition from one experiment in real-life conditions to another, not just from pilot to real-life testing, which is the main specificity of the current approach. The pilot testing in the laboratory is denoted as Experiment 0 in Fig. 2.

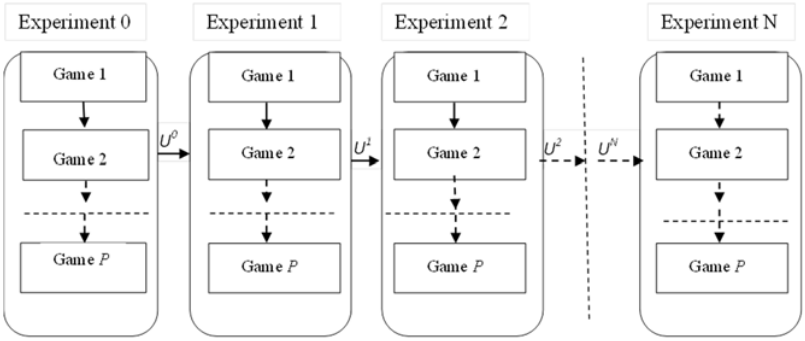


Fig. 2. A systems approach to the representation of the process of game testing in the evolving design framework

Consider the process of training motor and social skills of children using evolving game design. Children play games consecutively, either individually, or in groups (figure 2). The assessment of the game is made based on the set of averaged scores given by the teachers at the end of each game and at the end of each experiment along several game dimensions. After each experiment and in case of unsatisfactory result, improvements are being made in the games. These improvements in the games after each experiment are considered the manipulated process variables in terms of the control vector $\boldsymbol{U^k}$.

$$\boldsymbol{U^k} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \in \boldsymbol{\mathcal{R}^2},\ k = 1,2,\dots,N \tag{1}$$

is a 2-dimensional vector representing 2 types of possible improvements of the games after the *k*-th experiment, $k = 1,2,\dots, N$:
- adding a new function/functionality to the game - u_1;
- adding new elements to the construction of the game - u_2.
The process terminates when the game has no further capacity for improvement.

Let's denote the state after the *i*-th game from *k*-th experiment by $\boldsymbol{x}(\boldsymbol{Game_i^k})$. After completion of the k-th experiment, if the result is not satisfactory from a designer point of view, we make improvements in the games. The improvements can be of both types - u_1, u_2 - from the described above, or only one, in the opinion of the experts. These improvements are assumed the control actions on the process of enhancing the trained skills of children, playing the games, within the proposed model. Therefore, the initial value of the *k*+1-st experiment is determined by a non-homogeneous linear system described by

$$\boldsymbol{x}(\boldsymbol{Game_1^{k+1}}) = \boldsymbol{x}(\boldsymbol{Game_p^k}) + \boldsymbol{BU^k},\ k = 1,2,\dots,N, \tag{2}$$

where $\boldsymbol{U^k}$ is the control variable from the *k*-th to *k*+1-st experiment.

Matrix $\boldsymbol{B} \in \boldsymbol{\mathcal{R}^{m\times 2}}$ consists of coefficients, reflecting the individual *m* number of skills of the participating children, as described by their teachers in the children's profiles. The detailed description of the model is presented in [15].

3 Types of Games Included in the Evolving Game Design Framework

The developed games within the METEMSS framework are intended for use in motor, cognitive and social skills training. Games of type I use Kinect sensor for 3D interaction within a virtual environment via gestures (Fig. 3).



Fig. 3. A child, playing game called "Flipper", hitting virtual balls to reach a target on the screen

Type II are games with humanoid robot NAO. The interaction with a humanoid robot is always very emotional (Fig. 4, right).



Fig. 4. A child playing basketball with NAO humanoid robot.

Type III are games with nonhumanoid robots – "Minion" doll with robotic arm (figure 5) and a walking robot called BigFoot (figure 6). The CPS implementing non-humanoid robots were designed at ISER-BAS especially for the project METEMSS with the assistance of the Departments of Medico-social sciences and Logopedics of the South West University, Bulgaria.



Fig. 5. A Minion doll with anthropomorphic robotic hand

A Minion doll was equipped with an anthropomorphic robotic hand designed with 3D printing technology and controlled by a Kinect sensor (Fig. 5, right). The doll imitates the gestures of the child. As a reward, a song is played when the child is attentive to the game. The observed effect was of assisting the development of the social skills via the robotic technology – both humanoid and non-humanoid by creating an entertaining and amusing environment in the special school [16].

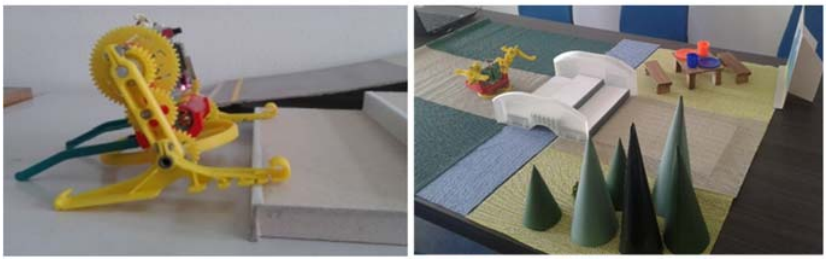


Fig.6 . Remotely controlled non-humanoid robot BigFoot in an imaginary environment

The walking robot BigFoot was placed in a social context – in a scene with buildings, trees, animals - and the task of the children was to remotely control its movements left-right, up-down, to reach a certain goal. It trains learning of colors, shapes and directions (figure 7).



Fig. 7. A child remotely controlling the movement of the walking robot BigFoot

We have called the approach *Evolving design* of games for children with special learning needs. It consists of the following steps:

- Conducting Experiment 0 in the laboratory (piloting);
- Conducting Experiment 1 in real life settings;

- Analysis and recommendations for evolution of the game design;
- Game modifications;
- Conducting Experiment 2 in real life settings;
- Evaluation of the change in *quantitative* terms.

Examples of the proposed game modifications between 2 successive experiments as elements of vector $\mathbf{U}^k$ are the following. Changing the interface of a game is an example of u_1. The laptop from Fig. 6 was replaced with a joystick, so that the robot and its control are within the eye view of the child. Example of u_2 is adding a constructive element in the game (adding a holding platform to the Walking robot) as presented in Fig. 8, following the child's request.

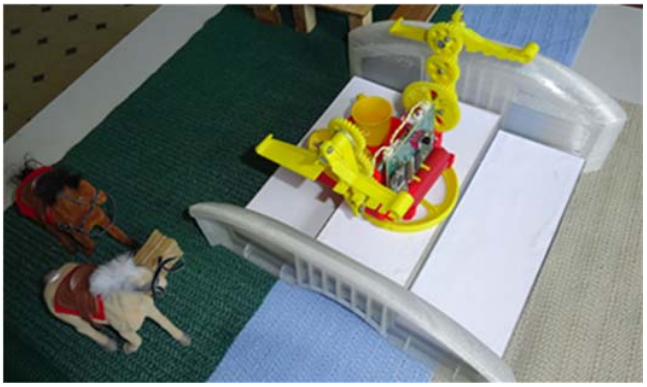


Fig. 8. Adding a holding platform to the Walking robot from Experiment 1 to Experiment 2

Adding a holding platform to the Walking robot on child's request makes the game design participative.

4 Issues of Evaluation and Adaptation: Main Hypotheses

The main hypotheses for the quantitative comparison of the games were the following:

H1. Games with bigger change in their design from experiment 1 to experiment 2 will be given scores by the teachers in the expected direction for positive change.

H2. Games with overall positive scores for improved design will score positively for both *motivation* and *interest* of the children.

In total 73 filled in questionnaires were collected from the teachers in both experiments. These consisted in 9 Likert scales along dimensions like "role for cognitive/social/motor development", "interest of the child", "motivating role of the

game", etc. [15]. Four of the games produced subsequent testing according of the model and were used to validate the hypotheses - „Flipper", „Forms and Shapes", „Walking Robot BigFoot" and „Minion Doll with Robotic Hand". These 4 games were used to test hypotheses 1 and 2.

The results regarding H1 were the following: The 2-factor ANOVA did not reveal main effect of the factor "Game", nor of the factor "Experiment", however revealed significant interaction between the factors, $F(3, 56) = 3.70$, $p = 0.017$, which was expected, meaning that scores of games behaved differently in different conditions. The overall scores of the teachers of the games Walking Robot and Minion Doll were higher after experiment 2 in comparison with experiment 1, unlike the other 2 games, therefore supporting H1.

The results regarding H2 were the following: Two-way ANOVA did not reveal main effect of game on the scores and no interaction, but revealed main effect of Experiment for the games Walking Robot BigFoot and Minion Doll with Robotic Hand, in teacher's assessment of children's interest and motivation, $F(1, 28) = 4.77$, $p = 0.038$. Both evaluations of children's *motivation* and *interest* in the modified games after experiment 2 were significantly higher for these 2 games than after experiment 1, therefore supporting hypothesis 2.

5 Conclusion

The proposed system model for evaluation of the process of design of games is an effective instrument of the evolving design of games for children with special needs. The evolving design describing the transition from one experiment in real-life conditions to another, not just from pilot to real-life testing, is the main specificity of the current approach. It can be applied to predict the direction of game evolution in quantitative terms. The attitudes of the children towards the modified games are well reflected in the teachers' scores along several dimensions. The multi-domain approach is applicable in other educational scenarios and fulfills the role of bringing technology closer to children and assisting the teachers in their profession.

Acknowledgments This work was supported in part by the Financial Mechanism of EEA under Grant D03-90/15.05.2015 for project "METEMSS: Methodologies and technologies for enhancing the motor and social skills of children with developmental problems" of Bulgaria and Norway (2015-2016).

References

[1] http://sparc-robotics.eu/wp-content/uploads/2014/05/H2020-Robotics-Multi-Annual-Roadmap-ICT-2016.pdf

[2] https://eu-robotics.net/cms/upload/downloads/ppp-documents/SRA2020_SPARC.pdf

[3] http://cyberphysicalsystems.org/

[4] http://www.europarl.europa.eu/RegData/etudes/STUD/2016/563501/EPRS_STU(2016)56350_EN.pdf
[5] http://www.europarl.europa.eu/RegData/etudes/STUD/2016/563501/EPRS_STU(2016)563501(ANN)_EN.pdf
[6] http://ec.europa.eu/programmes/horizon2020/en/news/first-future-and-emerging-technologies-fet-proactive-projects-under-horizon-2020-framework
[7] Zappi, V., Pistillo, A., Calinon, S., Brogni, A. and Caldwell, D.G. (2012). Music expression with a robot manipulator used as a bidirectional tangible interface. EURASIP Journal on Audio, Speech, and Music Processing (SpringerOpen), Special Issue on Music Content Processing by and for Robots, 2012:2, 1-11.
[8] Calinon, S. Epiney, J., Billard, A. A humanoid robot drawing human portraits. Proceedings of the IEEE-RAS International Conference on Humanoid Robots (HUMANOIDS 2005)
[9] http://www.aliz-e.org/
[10] http://monarch-fp7.eu/
[11] http://www.dream2020.eu/
[12] http://www.ri.cmu.edu/pub_files/2009/3/steinfeld_hri2009.pdf
[13] https://www.ald.softbankrobotics.com/en/cool-robots/nao
[14] http://www.iser.bas.bg/metemss/en/index.html
[15] Lekova, A., Dimitrova, M., Kostova, S., Stancheva-Popkostadinova, V., Davidrajuh, R., Roumenin, Ch., Chavdarov, I., Botzova, R., Andreeva, A., Krastev, A., Nikolov, V., and Ryan, D. An evolving design of technologies for enhancing the development of motor and social skills: Issues of methodology and experimentation, *IEEE Transactions on Man-Machine Systems* (unpublished)
[16] Dimitrova, M., Lekova, A., Chavdarov, I., Kostova, S., Krastev, A., Chavdar Roumenin, C., Stancheva, V., Andreeva, A., G. Kaburlasos, V.G., Pachidis, T. A Multidisciplinary Framework for Blending Robotics in Education of Children with Special Learning Needs. *Proc. International Association for Blended Learning Conference*, IABL 2016, Kavala, Greece, pp. 152-155. http://iabl.org/a-multidisciplinary-framework-for-blending-robotics-in-education-of-children-with-special-learning-needs/