

Modelling, analysis and control design of hybrid dynamical systems

Dominik Vošček, Anna Jadlovská, Dominik Grigľík*

This paper introduces a methodology for one of the challenges regarding cyber-physical systems, i.e. modelling and control design them as hybrid systems. The proposed methodology comprises modules with specific steps to accomplish the tasks. Specifically, the paper aims to utilize hybrid systems framework onto the chosen hydraulic hybrid system with complex dynamics to showcase different aspects of hybrid systems. The mathematical model was derived using hybrid automata framework and then transformed into the linear form either using Jacobi matrices or using linear approximations without Jacobi matrices. After that the system was validated and analysed and the control design utilizing piecewise linear-quadratic regulator optimal control was proposed. Furthermore, parameters of control algorithm were tuned using particle swarm optimization algorithm. The whole logic, system dynamics and constraints are implemented within MATLAB/Simulink simulation environment using s -functions. The proposed methodology can be implemented on the various types of cyber-physical systems as far as they can be described as hybrid systems.

Keywords: cyber-physical system, hydraulic hybrid system, methodology, particle swarm optimization, piecewise affine system, piecewise LQR optimal control.

1 Introduction

Cyber-physical systems (CPS), defined as an integration of physical processes with computation platforms, are an integral part of the phenomenon Industry 4.0. One of their complexity challenges stated in [1, 2] can be formulated as to model and control CPS within hybrid systems framework [3].

This paper focuses specifically on this challenge of CPS from modelling up to the control design as hybrid systems (HS) [4, 5]. The most convenient hybrid systems framework for such a task is hybrid automata (HA) which naturally deals with a continuous and discrete dynamics of hybrid systems [6]. However, such a mathematical representation is not appropriate for analysis and control design of CPS. For these tasks, different but equivalent mathematical representations were introduced, e.g. piecewise affine (PWA) systems [7].

There have been proposed several approaches to unify the procedure to model, analyse and design control algorithms for hybrid systems. Within mentioned procedures being one published in [8], however, this approach does not utilize analysis of the system in the open loop and during control synthesis no metaheuristic algorithms to tune control parameters were used. Another approach, published in [9], utilizes supervisory control of hybrid systems but omits the analysis part. Methodology utilizing modelling and diagnosis of hybrid systems was proposed in [10].

Goal of this article is to propose and introduce the unified methodology for the whole process from modelling

up to the control design and therefore cover all the steps to ensure proper design and analysis of CPS as a hybrid system. This process was partially introduced in [2, 11] and will be completed with regards to other research challenges. The methodology consists of several steps, namely determination of HA elements such as possible discrete modes and transitions between them, followed by assigning continuous dynamics to these modes. At this point it is possible to simulate and analyse the hybrid system.

After validation of the system, design control utilizing appropriate control algorithms can be implemented onto the hybrid system. Between the most used control algorithms for hybrid systems being model predictive control based on multiparametric optimization [12] and piecewise optimal linear quadratic (LQR) optimal control [13]. These methods were chosen as representatives of control algorithms for hybrid systems. However, there are many others such as semi-Markov mode switching for linear parameter-varying systems [14] or supervisory control [15].

While designing control law, a metaheuristic method for tuning control law parameters can be utilized. Between these metaheuristic methods belong e.g. particle swarm optimization (PSO) [16], artificial bee colony [17], ant colony optimization [18] or grey wolf optimization approach [19]. We have chosen PSO algorithm as a representative example for tuning control algorithm parameters. This algorithm was then applied onto all controllable discrete modes of the HS.

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Modelling Analysis And Design Of Hybrid Systems

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