Control Synthesis of Nonlinear Sampled Switched Systems using Euler's Method

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In this paper, we propose a symbolic control synthesis method for nonlinear sampled switched systems whose vector fields are *one-sided Lipschitz*. The main idea is to use an approximate model obtained from the *forward Euler method* to build a guaranteed control. The benefit of this method is that the error introduced by symbolic modeling is bounded by choosing suitable time and space discretizations. The method is implemented in the interpreted language Octave. Several examples of the literature are performed and the results are compared with results obtained with a previous method based on the Runge-Kutta integration method.

1 Introduction

As said in [10], in the methods of symbolic analysis and control of hybrid systems, the way of representing sets of state values and computing reachable sets for systems defined by ordinary differential equations (ODEs) is fundamental (see, e.g., [2, 14]). An interesting approach appeared recently, based on the propagation of reachable sets using guaranteed Runge-Kutta methods with adaptive step size control (see [6, 17]). In [10] such guaranteed integration methods are used in the framework of *sampled switched systems*.

Given an ODE of the form $\dot{x}(t) = f(t, x(t))$, and a *set* of initial values X_0, a symbolic (or "set-valued") integration method consists in computing a sequence of approximations $(t_n, \tilde{x}_n)$ of the solution $x(t; x_0)$ of the ODE with $x_0 \in X_0$ such that $\tilde{x}_n \approx x(t_n; x_{n-1})$. Symbolic integration methods extend classical *numerical* integration methods which correspond to the case where X_0 is just a singleton $\{x_0\}$. The simplest numerical method is Euler's method in which $t_{n+1} = t_n + h$ for some step-size h and $\tilde{x}_{n+1} = \tilde{x}_n + h f(t_n, \tilde{x}_n)$; so the derivative of x at time t_n, $f(t_n, x_n)$, is used as an approximation of the derivative on the whole time interval. This method is very simple and fast, but requires small step-sizes h. More advanced methods coming from the Runge-Kutta family use a few intermediate computations to improve the approximation of the derivative. The general form of an explicit s-stage Runge-Kutta formula of the form $\tilde{x}_{n+1} = \tilde{x}_n + h \Sigma_{i=1}^{s} b_i k_i$ where $k_i = f(t_n + c_i h, \tilde{x}_n + h \Sigma_{j=1}^{i-1} a_{ij} k_j)$ for $i = 2, 3, \ldots, s$. A challenging question is then to compute a bound on the distance between the true solution and the numerical solution, i.e.: $\|x(t_n; x_{n-1}) - x_n\|$. This distance is associated to the *local truncation error* of the numerical method. In [10], such a bound is computed using the *Lagrange remainders* of Taylor expansions. This is achieved using *affine arithmetic* [27] (by application of the Banach's fixpoint theorem and Picard-Lindelöf operator, see [23]). In the end, the Runge-Kutta based method of [10] is an elaborated method that requires the use of affine arithmetic, Picard iteration and computation of Lagrange remainder.

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Table of Contents Synthesis Of Optimum Nonlinear Control S

1. Understanding the eBook Synthesis Of Optimum Nonlinear Control S
    - The Rise of Digital Reading Synthesis Of Optimum Nonlinear Control S
    - Advantages of eBooks Over Traditional Books
2. Identifying Synthesis Of Optimum Nonlinear Control S
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an Synthesis Of Optimum Nonlinear Control S
    - User-Friendly Interface
4. Exploring eBook Recommendations from Synthesis Of Optimum Nonlinear Control S
    - Personalized Recommendations
    - Synthesis Of Optimum Nonlinear Control S User Reviews and Ratings
    - Synthesis Of Optimum Nonlinear Control S and Bestseller Lists
5. Accessing Synthesis Of Optimum Nonlinear Control S Free and Paid eBooks
    - Synthesis Of Optimum Nonlinear Control S Public Domain eBooks
    - Synthesis Of Optimum Nonlinear Control S eBook Subscription Services
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