Mechatronics 24 (2014) 1262–1268

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Technical note

Current configuration detection in hybrid systems: Application to a conjunction–disjunction mechatronics system

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ARTICLE INFO

Article history:
Received 21 December 2012
Accepted 28 September 2014
Available online 22 October 2014

Keywords:
Hybrid mechatronic systems
Petri nets
Configuration detection
Observer design

ABSTRACT

This paper deals with the problem of detecting the current configurations of hybrid mechatronic systems, where the evolution of the discrete part is governed by a Petri net. The considered class of systems may have several subsystems, with different dimensions, evolving at the same time. The current configurations are detected using an observer based on the descriptor system theory. It is shown that the evolution of the discrete dynamics can be formulated as a descriptor system. Necessary and sufficient conditions are derived in order to guarantee the uniqueness of the reconstruction of the discrete state of the system. The proposed observer is applied to a mechatronic system to show the effectiveness of the proposed approach.

1. Introduction

A large number of mechatronic systems are modeled using hybrid models, which include discrete and continuous behavior. These systems combine hydraulic, mechanical and electronic technologies associated with a computer control. The latter allows to control the operation modes and to develop the safety functions. Mechatronics systems are characterized by their high complexity, which makes the modeling challenging. Indeed, the simplest mechatronic system is composed of a set of subsystems of different natures [9]. In mechatronic systems, the continuous variables represent physical measurable quantities, such as pressure and volume, while discrete configurations represent the state of the logical control of the system and, can be associated with normal or dangerous operation. Therefore, it is often required to detect the current configuration of this type of systems. In general, this problem is always solved using estimation techniques such as observers-based methods.

Unlike continuous estimation problem for hybrid systems, discrete state estimation problem has received less attention and only few results are available. In particular, Baglietto et al. [3], address the active mode detection problem for a class of switched systems in the presence of unknown noises and assuming the knowledge on the continuous state. An approach to estimate the discrete state of a class of a multi-robot system using basic lattice theory is addressed in [5]. In [15], a method based on the theory of sliding mode is presented to construct the discrete state for a class of nonlinear switched systems assuming that the continuous state is available for measurement, where it was proven that the time needed for reconstructing the discrete state can be made arbitrarily small by sufficiently increasing a certain observer tuning parameter. Another work based sliding mode technics is presented in [19] for a class of switched mechanical systems to estimate both discrete and continuous state.

Similarly, for Discrete Event Systems (DES), the problem of detecting the active mode has also received considerable attention from researchers in recent years. In [17], the detection of the active mode, or the so-called current-location of a system was presented from partial observation of the system state and the events. A similar problem was addressed in [16] assuming only the observation of a subset of the events. For DES modeled by Petri Nets (PN), the estimation of the state is usually not unique when only observations of events are available, because the information can be very limited. In this case, the estimation is represented by a set of consistent states in which the system may be. An algorithm was given by Giua and Seatzu [7], to estimate the actual marking of the PN based on the observation of the transitions firings. We can also cite other estimation methods that are based on labeled PN with silent

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http://dx.doi.org/10.1016/j.mechatronics.2014.09.012
0957-4158/

or undistinguishable transitions [8], interpreted PN [13], generalized PN [4], partially observed PN [18].

In this paper, we focus on the detection of the current configuration in Hybrid Mechatronic Systems (HMS) at a given instant, where the evolution of the discrete part is governed by a PN. This class may have several subsystems evolving at the same time with different dimensions and it is characterized by switching laws that can depend on the continuous states and/or external events. Assuming that some switching conditions are known (for example, the condition of switching dependent on known external inputs, output or measured states of the system), some modes are detected. The remaining switching conditions are represented by the unknown inputs. The detected modes (some places of the PN) are considered as measured modes by the proposed observer in order to obtain the full discrete states estimation.

The main idea is based on writing the evolution of the token in a PN by state equations similar to the equations used for descriptor systems. By using the theory of descriptor systems, a characterization of observability of the discrete part of the HMS is presented and an unknown input (UI) observer is proposed to detect the configuration of the HMS at a given instant. Necessary and sufficient conditions of the existence and convergence of the proposed observer are given. The performance of the proposed approach is assessed through a simple mechatronic system.

The main differences with respect to our previous works in this framework are: (i) Unlike former studies which consider only one active subsystem, in this work we consider the case of several subsystems evolving at the same time, (ii) a novel algebraic characterization of observability, called causal observability is presented and (iii) the proposed observer ensures that the current state is uniquely and exactly reconstructed at a given instant.

The proposed observer may be useful for an optimal positioning of the sensors. In addition, this approach can be extended to the fault diagnosis of this type of systems on one hand, and can be used for monitoring and for implementing supervisory control on the other hand.

2. Problem formulation and notations

In this section, we consider the class of hybrid dynamical systems (HDS) defined by a hybrid state where the continuous part is described by difference or differential equations and the evolution of the discrete part is governed by a PN. This class represents the more general case of HDS because it may have several subsystems evolving at the same time with different dimensions. This class is often found in industrial systems such as HMS.

Before introducing the considered class of HMS, we recall basic definitions of PN used in this paper.

A PN is a graphical and mathematical modeling tool applicable to many systems and formally defined by a 5-tuple $PN = (\mathcal{P}, \mathcal{T}, Pre, Post, P_0)$ where $\mathcal{P} = \{p_1, p_2, \ldots, p_n\}$ is a finite non empty set of n places; $\mathcal{T} = \{t_1, t_2, \ldots, t_m\}$ is a finite non empty set of m transitions (with $\mathcal{P} \cap \mathcal{T} = \emptyset$); $Pre: \mathcal{P} \times \mathcal{T} \longrightarrow \{0, 1\}$ is the input incidence mapping; $Post: \mathcal{T} \times \mathcal{P} \longrightarrow \{0, 1\}$ is the output incidence mapping and P_0: is the initial marking.

A marking (i.e., net state) is a vector $P \in \mathbb{N}^n$. Intuitively, the ith entry of P describes the number of tokens in the place p_i. If $p = p_i \in \mathcal{P}$, then $P(p)$ will denote the ith entry of P.

Given a PN, a transition t is enabled at marking P iff $P \geqslant Pre(., t)$. An enabled transition t may fire, and its firing removes $Pre(p, t)$ tokens from each input place p and adds $Post(t, p')$ tokens to each output place p'.

Graphicaly, places are represented by circles, transitions by bars, and tokens by black dots, as shown in Fig. 1. For more details about the basic notions of PNs, the reader can refer to [14]. The

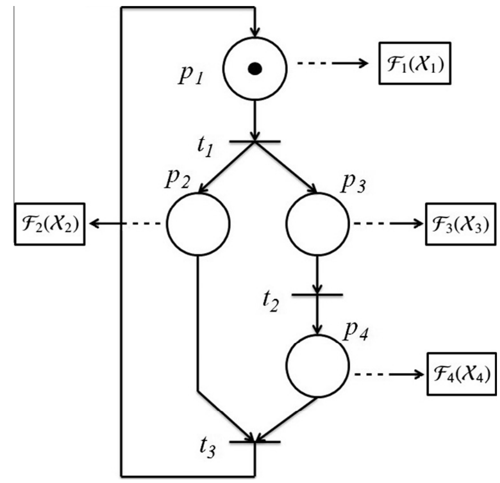

Fig. 1. Interaction between discrete and continuous parts.

marking vector of the PN P_k is given by a state equation similar to that used for discrete dynamical systems [14,4,1]:

$$P_{k+1} = P_k + \mathcal{W} T_{k+1}, \tag{1}$$

where $P_k \in \mathbb{N}^n$ is the marking vector of places, $T_k \in \mathbb{N}^m$ is the firing vector at time instant k (i.e. its ith entry is one if the transition t_i is fired at time instant k), $\mathcal{W}$ is the incidence matrix of the net, defined as $\mathcal{W} = Post - Pre$.

The considered class of HMS in this work is described as follow:

$$\dot{\mathcal{X}} = \mathcal{Q}\mathcal{F}(\mathcal{X}), \tag{2}$$

with $\mathcal{X}$, $\mathcal{F}(\mathcal{X})$ and $\mathcal{Q}$ are respectively the continuous state vector, the continuous dynamics vector and the location matrix defined as:

$$\mathcal{X} = \begin{bmatrix} \mathcal{X}_1 \\ \mathcal{X}_2 \\ \vdots \\ \mathcal{X}_n \end{bmatrix}, \quad \mathcal{F}(\mathcal{X}) = \begin{bmatrix} \mathcal{F}_1(\mathcal{X}_1) \\ \mathcal{F}_2(\mathcal{X}_2) \\ \vdots \\ \mathcal{F}_n(\mathcal{X}_n) \end{bmatrix} \textit{and} \quad \mathcal{Q} = \begin{bmatrix} q_1 & \underline{0} & \underline{0} & \underline{0} \\ \underline{0} & q_2 & \underline{0} & \underline{0} \\ \underline{0} & \underline{0} & \ddots & \underline{0} \\ \underline{0} & \underline{0} & \underline{0} & q_n \end{bmatrix},$$

with $\bar{0}$ is a matrix of appropriate dimension and the dimensions of the subsystems can be different and are defined by $l_i = dim(\mathcal{X}_i)$, then:

$$\dim(\mathcal{X}) = \sum_{i=1}^{n} \dim(\mathcal{X}_i) = \sum_{i=1}^{n} l_i.$$

The system (2) is rewritten as the following:

$$\begin{cases} \dot{\mathcal{X}}_1 = q_1 \mathcal{F}_1(\mathcal{X}_1) \\ \dot{\mathcal{X}}_2 = q_2 \mathcal{F}_2(\mathcal{X}_2) \\ \vdots \\ \dot{\mathcal{X}}_n = q_n \mathcal{F}_n(\mathcal{X}_n) \end{cases}, \tag{3}$$

with: q_i is a zero square matrix or an identity matrix i.e. $q_i \in \{\bar{0}_{l_i}, I_{l_i}\}$,

$$\mathcal{X}_i = \begin{bmatrix} x_{i1} & x_{i2} & \cdots & x_{il_i} \end{bmatrix}^T \quad \text{and}$$
$$\mathcal{F}_i(\mathcal{X}_i) = \begin{bmatrix} f_{i1}(\mathcal{X}_i) & f_{i2}(\mathcal{X}_i) & \cdots & f_{il_i}(\mathcal{X}_i) \end{bmatrix}^T,$$

where i is the index of the active mode, it takes its value in a finite set of indices $i \in \{1, \ldots, n\}$ where n is the number of continuous subsystems and also the number of places in the PN. This latter represents the different configurations of the HDS. The interaction between the discrete and the continuous part is done in the same way as in a hybrid automaton model type. To each configuration