Modeling Scheduling &Supervisory Control Integrated System With Hierarchical Extended Petri Nets

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1. Introduction

The materials, products and semi-finished product are always continuous, sometimes in batches in process industry. Most of the state variables of production processes are continuous too. Despite the material operated in finite quantities can be considered as a part in FMS, during the transport of material between two tanks or reactors, the discrete nature of the system disappear. Moreover, all the processes often have high randomcity and non-determinacy. So the effective operation of a processing based plant requires better integration of engineering function of the plant, especially scheduling and supervisory control function. There have been several papers addressing various forms of the integrated method [1,2], but no formal modeling, analysis and synthesis method is available for such an integration, which can ensure that any feasible schedule generated based on the scheduling level model can be successfully implemented on the plant for a variety of process plant.

In this paper, we try to propose such a method by means of Petri nets model. As an effective graphical modeling tool as well as a good mathematics analysis tool, Petri net has been proved to be a very popular tool with the industrial community. It can not only model the complex system within the single hierarchy, but also can model the system with different hierarchies. Chen H.X. et al[3] proposed hybrid Net condition/event system to model the integration of batch scheduling and control. J. Proth et al [4] introduced a class of Petri nets named controllable-output Petri nets that are reversible, live, and can be kept bounded. And it is used to model the manufacturing system integration. Andreu [5] extended the hierarchical approach in manufacturing system applications to process plants, where the possibility of using a hierarchical Petri nets based approach for describing the discrete aspects of batch systems was discussed. In [6] error identification and recovery for multilevel systems are studied based on a kind of Petri nets named Hierarchical time-extended Petri nets (H-EPNs). In this paper, a new kind of extended Petri nets named Hierarchical Extended Petri Nets (HEPNs) is proposed to model Scheduling & Supervisory Control Integrated System (SSCIS).

The structure of this paper is as follows: Scheduling &supervisory Control Integrated system is introduced in section 2. Then the definition and the evolution rules of Hierarchical Extended Petri Nets are discussed in section 3. In section 4, modeling process of SSCIP with HEPNs and the validation method of model properties are described in section 4 and section 5, respectively. Conclusion remarks are given in the last section.

2. Scheduling &supervisory Control Integrated System (SSCIS)

A process control system can be refined into four levels: planning, scheduling, supervisory control and local control. The scheduling level and the supervisory control level are the key factors to implement Computer Integrated

Process Systems (CIPS). The scheduling level addresses the route of operations in light of resource capacities of the process units. It receives process planners as its input and its task is to determine the allocation of tasks to devices and the sequence of operations so that the constraints of the system are met and performance criteria are optimized. The aim of supervision is to implement real-time scheduling and realize the co-ordination of sub-systems in terms of resource availabilities and actual states. Its task is to supervise the operations of process according to the schedule of production orders from the scheduling module.

The research on scheduling and supervisory control is still two irrelevant activities in the past. But in process industry the process time discussed in the scheduling of process industry can't be considered as constant, and it is decided on the base of supervision of the state variable of the production process, or else the scheduling results don't meet the production constraint and need to be modified very frequently. So the conception of scheduling & supervisory control integrated system (SSCIS), in which the scheduling and supervisory control of process system are considered in a uniform framework, is proposed to implement the real-time scheduling and online monitoring in process industry.

The description of SSCIP is as follows:

Given product recipes and limited resources, according to the result of the online supervisory control to production states, make certain the process sequences and transportation sequences and its corresponding beginning time and ending time so as to some performance or economical guideline optimal when satisfying the production constraints.

The function of SSCIS is to find out the process and transportation sequence of tasks on limited resources and the responding beginning and finishing time of each process to optimize the given performance objective. All the process must be under the constraint condition of given production receipts and limited resource (including the materiel, devices for production or transportation) and safety production and steady running of system. In the integrated system, discrete events coexist with continuous state variables and all the processes full of high randomicity and non-determinacy. This makes the modeling and analysis of system very difficult. In the next section, Hierarchical Extended Petri nets are introduced to model the SSCIP.

3. Hierarchical Extended Petri Nets(HEPNs)

3.1 The definition of HEPNs

A Hierarchical Extended Petri nets is defined as HEPNs=$<P, T, Pre, Post, C, E, \{S_{ij}, (f_{ij}, X_{ij}, U_{ij}, Z_{ij}, X_{ij0}, O_{ij}), p_i \in P\}, M_0,>$ where $P=P_r \cup P_P \cup P_s$ is a finite set of places with $|P|=n$, where P_r is the resource places sets, P_p is the process places sets, and P_s is the subnets place sets. T is a finite set of transitions with $|T|=m$, $P \cap T=\phi$ and $P \cup T \neq \phi$, $Pre(p, t)$ is a function that defines on the directed arcs from a place to a transition, and $Post(p, t)$ is a function that defines on the directed arcs from a transition to a place. C is color sets defined on place, transition or directed arcs. E is the event sets connected to the firing of the transition, which can be classified as internal event and external event. $\{S_{ij}, (f_{ij}, X_{ij}, U_{ij}, Z_{ij}, X_{ij0}, O_{ij}), p_i \in P\}$ is the variable defined on the process place p_i, where S_{ij} is the identifier vector of the corresponding color C_i defined on the process place p_i, which can be equal to one or zero. $(f_{ij}, X_{ij}, U_{ij}, Z_{ij}, X_{ij0}, O_{ij})$ is the continuous time model of the corresponding color C_j defined on the process place p_i, where f_{ij} is the module function of the color C_j on the process place p_i, that is, the vector field of the state variables corresponding to the color C_j on the process place p_i, X_{ij} is the state variables set of the evolution function f_{ij}, U_{ij} is the control variable set of f_{ij}, Z_{ij} is the domain of C_{ij}, X_{ij0} is the initial state of f_{ij}, and O_{ij} is the objective state set of f_{ij}. The detail definition sees [7]. M_0 denotes the initial marking of the net.

Some notations are further introduced as follows.

(1) *Internal Event* are more of a predictable nature and can be quantified by means of stochastic or discrete firing times, they may be due to the beginning or completion of an process, or an input data; while *External Events* occur sporadically and can not be quantified, they may be due to an occurrence of a random external event required firing a transition or an operator interruption. The transitions whose firing

is caused by the internal event is called *Internally Driven Transitions,* and the transition whose firing is trigged by the external event is called and *Externally Driven Transitions*.

(2) Every sub-net place has its corresponding sub-HEPNs, in which at least a source place and a sink place exist.

(3) The tokens in HEPNs are classified Consumable tokens and Reusable tokens. Consumable Tokens are tokens that generated within the net and represent objects in movement, message transfer, etc., within the net and are brought into and taken out of existence. Reusable tokens are tokens that represent reusable system resource, buffer areas, etc., and are part of the initial system description.

3.2 Evolution rule of HEPNs

3.2.1 Enabling condition

As with the classical PN theory, all transitions that have their input places marked are considered enabled and are potentially fireable. But in HEPNs, the enabling of transitions is a two-step process as defined below:

Place enable: this means that if all the input places to a HEPNs transition are appropriately marked then the transition is considered enable.

Events enable: the state changes are primarily derived by the occurrence of internal or external events.

Let C(P) and C(T) denotes respectively the color set of place set P and transition set T, $C(p_i)=\{c_{i1}, c_{i2}, \ldots, c_{il_i}\}$, $l_i=|C(p_i)|$ is the number of color of place p_i, $C(t_j)=\{c'_{i1}, c'_{i2}, \ldots, c'_{il_i}\}$, $l_j'=|C(t_j)|$ is the color number of transition t_j, $pre(p,t)(c,c')$ denotes the mapping relation function from the color c on place p to the color c' on transition t, $post(p,t)(c',c)$ denotes the mapping relation function from the color c' on transition t to the color c on place p, $m(p)(c)$ denotes the marking related to color c on place p, ${}^o t_j$ and t_j^o be the sets of predecessors and successors, respectively, of the transition t_j ,

Definition 2: A transition t_j is enabled related to color c'_{jn} iff

(1)The corresponding event(internal or external) is created;

(2) The marking of the pre-place of t_j meets the following:

When p_i is a resource place, its marking must greater than or equal to the weight of the corresponding arc. That is $\forall p_i \in P_c \cap t_j$, there is $m(p_i)(c_{ih}) \geq pre(p_i, t_j)(c_{ih}, c_{jn}')$.

When p_i is a process place, except the above condition, the identifier vector of the corresponding color must be equal to one, that is $S_{ih}=1$.

When p_i is a subnet place, the marking of its sink place of the subnet must greater than or equal to the weight of the corresponding arc.

3.2.2 The firing rule of HEPNs

Supposing that the transition t_j related to color c'_{jn} is enable, then after firing, the following changes of the marking of the place in HEPNs will happen:

$\forall p_i \in t_j^o$

$$m'(p_i)(c_{ih}) = m(p_i)(c_{ih}) - post(p_i, t_j)(c_{ih}, c_{jn}')$$

When p_i is a process place, the corresponding identifier vector is also set to zero at the same time. When p_i is a subnet place, the marking change of place means the marking change of the sink place of the sub-HEPNs corresponding to the place p_i.

$\forall p_i \in {}^o t_j$

$$m'(p_i)(c_{ih}) = m(p_i)(c_{ih}) + pre(p_i, t_j)(c_{ih}, c_{jn}')$$

When p_i is a process place, the corresponding identifier vector is also set to zero at the same time. When p_i is a subnet place, the marking change of place means the marking change of the resource place of the sub-HEPNs corresponding to the place p_i.

4. Modeling SSCIP with HEPNs

The sub-net places defined in the HEPNs model allow for the stepwise refinement of the system modeling process. SSCIS is a classical hierarchy structure which includes three level such as scheduling level, supervisory control level and process level, so the top-down modeling method is used. Initially, the operations and events are defined at the macro level, that is, the operation and events related to scheduling problem are modeled with place or transition defined on HEPNs according to the optimal objective. Once macro operations, that is, subnet place, have been defined, they can be refined into a sequence of micro operations joined with different transitions depending on the level of required detail. So the sub-nets places used in the higher level can be institute by a sub-HEPNs. In the modeling of SSCIS, sub-nets places mainly include the production process which is continuous, dis-continuous, or in batches. The process monitoring and failure diagnoses are always modeled by sub-net places. Then an implicit hierarchical structure of the system resources is created by the definition of sub-net places. A resource at the lower level is not visible at the higher level. At last the initialization of the nets model are considered. This is an important aspect of the use of HEPNs in system modeling and analysis. Tokens representing system resources at a lower level are localized, and if they do not affect the net behavior at a higher level of system, they are neglected in a higher system analysis.

5. The validation Method of Model Properties

Owing to subnet place is introduced in HEPNs, and every subnet place has its corresponding sub-HEPNs, a bottom-up approach can be used to verify the properties of the hierarchical system. First the lowest level sub-nets are proven to satisfy the necessary properties. Then, interacting sub-nets if present at that level are considered. Subsequently, the properties of the next higher level sub-net are proven and so on, until the properties of the entire net are proven. During the model process of SSCIP with HEPNs, the properties such as reachability, schedulablity and liveness are needed to verify using this bottom-up method.

6. Conclusion remarks

In this paper, scheduling &supervisory control Integrated system is introduced firstly, then a new kind of Petri nets model named Hierarchical Extended Petri nets, in which scheduling and supervision can be model in a uniform framework, is proposed to model the integrated system. The model definition and its evolution rule are described in detail. At last the modeling method and the validation method of the model properties are discussed in brief.

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