IJE TRANSACTIONS A: Basics Vol. 27, No. 1, (January 2014) 113-122

International Journal of Engineering

Journal Homepage: www.ije.ir

Using Interval Petri Nets and Timed Automata for Diagnosis of Discrete Event Systems (DES)

L. Mhamdi[a]*, H. Dhouibi[a], Z. Simeu-Abazi [b], N. Liouane[a]

[a] UR ATSI D. Génie Electrique de L'ENIM, Monastir - Tunisie
[b] Grenoble-INP / UJF-Grenoble 1 / CNRS, G-SCOP, Grenoble, 46, avenue Félix Viallet -38031- France

PAPER INFO

Paper history:
Received 10 June 2013
Received in revised form 27 August 2013
Accepted 14 September 2013

Keywords:
Modeling
Petri Nets
Interval Constraint Petri Nets
Timed Automata
Robustness

ABSTRACT

A discrete event system (DES) is a dynamic system that evolves in accordance with the abrupt occurrence, at possibly unknown irregular intervals, of physical events. Because of the special nature of these systems, different tools are currently used for their analysis, design and modeling. The main focus of this paper is the presentation of a new modeling approach of Discrete Event Systems. The proposed approach is based on hybrid model which combines Interval Constrained Petri Nets (ICPN) and Timed Automata. These tools allow us to evaluate, respectively, the quality variations and to manage the flow type disturbance. An example analysis illustrates our approach.

doi: *10.5829/idosi.ije.2014.27.01a.14*

1. INTRODUCTION

Discrete event systems is an area of research that is developing within the interstices of computer, control and communication sciences [1]. The basic direction of research addresses issues in the analysis and design of distributed intelligent systems operating within real time constraints. In view of the relatively long history of prior approaches to discrete event control design (notably discrete event system simulation, and analysis via Petri nets, starting in the 1960s, and investigations via stochastic models, including perturbation analysis from the early 1970s). Consequently a suitable model, rich in analytical properties, is necessary to synthesize the needed controller. Petri net is being widely accepted by the research community for modelling and simulation of DES. The modeling formalism of discrete event systems is suitable to represent man-made systems such as manufacturing, telecommunication, transportation and logistics systems [2-5]. The literature suggests different modeling techniques for DES such as automata [6], Petri-nets [7], or algebraic state space models [8-11].

The aim of this paper is to explain the use of hybrid tool which combines Interval Constrained Petri Nets (ICPN) and timed Automata. ICPN is a sub-class of High Level Petri Nets with Abstract Marking (AM-HLPN) [12-14]. ICPN model allows us to model and guarantee a constraint on any parameter of a manufacturing process. In our case, it has been used to model the flux of material flow for regulating the quality of tobacco. Timed automata is a tool for the modelling and verification of real time systems [15, 16]. A timed automata is essentially a finite automata (FSM), extended with real-valued variables. Such an automata may be considered as an abstract model of timed systems. This expressive modelling tool offers the possibilities of model analysis like verification, controller synthesis and also faults detection and isolation to model manufacturing systems whose activity times are included between a minimum and a maximum value. We use it for modelling the discrete parts of system command. Both tools are applied to a robustness control for regulation systems and for description of dynamical system.

*Corresponding Author Email: lotfienim@yahoo.fr (Mhamdi. L)

In this paper, first, the process is presented. The following section describes ICPN and gives some basic notions on the timed automata which is used in the modeling step. Then, the ICPN mode which describes the material flow is built. This tool presents a complement to the P-temporal Petri nets [12]. Therefore, the robust control laws of this model are proven to use production data information of manufacturing production systems. Then, we use the timed automata model to describe the control law. Finally, when the global model of the process is completely defined, we present an application to tobacco manufacturing to illustrate our approach. Finally, a conclusion is presented with some perspectives.

2. MATHEMATICAL MODEL

The problem which lays in the cigarette transformation and production systems is depended on the weight of the manufactured units.

Indeed, from a quality point of view, a cigarette which is too heavy has a difficult drawing, and a light cigarette gives the consumer the impression of bad quality, because its extremities are not well filled and can easily fray. From a point of view of cost, the excess quantity of tobacco in a cigarette is considered as a loss and can cause blockage due to stuffing in the circuit of the tube formation.

For a given cigarette, the weight depends on six parameters: the compactness (C) of the tobacco, the level (H) of the supplying conveyor, the trimmer setting (E), the tobacco density (d), the module (m), and the length (l) of the cigarette. The evolution of these parameters is proper to the typology of the considered cigarette fabric.

The compactness (C) of the tobacco is a parameter of the system entry to be considered. Its value depends essentially on the raw material. Its variation is random and its distribution can be modeled by a normal law (according to the production statistical data). The level of tobacco varies depending on the compactness and has to be in a given range to guarantee the good functioning of the system. This level is a variable that depends on the tobacco flow, a parameter which must be supervised in order to maintain an optimal density.

This flow is controlled in two steps: at the moment of filling the distributor by a control C_1 and at the moment of driving tobacco on the conveyor by a control C_2.

The control C_1 maintains the level of tobacco in the girdle (tobacco reservoir). The level must be kept between a minimum n_1 under which the machine stops, locking the tobacco, and a maximum level n_2 over which there is a need for supply. The control C_2 regulates the level of tobacco (H) on the conveyor.

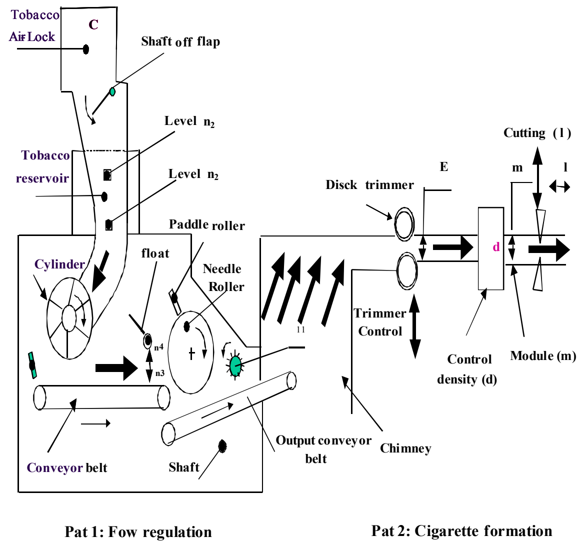

Figure 1. The manufacturing system

It must be kept between a minimum level n_3 under which the tobacco driving cylinder stops, locking tobacco, and a maximum level n_4 over which the tobacco driving cylinder stops. The trimming is adjustable by a mechanical system which the operator can manipulate in order to adjust the quantity of tobacco in the cigarettes. In conclusion, the cigarette transformation consists of two stages (Figure 1).

- **Flow Regulation:** To obtain a homogeneous density of the tobacco. This density depends on the compactness of the tobacco (C), the level (H) of tobacco on the conveyor and the quantity of tobacco trimmer (E) such as:

$$d = \alpha \times C \times H_1 \times H_2 \times E \tag{1}$$

were:
C: compactness in g/mm^3, where C Є $[C_{min}, C_{max}]$;
H1: level of tobacco in the reservoir in mm, where H_1 Є $[H_{1min}, H_{1max}]$;
H_2: level of tobacco on the conveyor in mm, where H_2 Є $[H_{2min}, H_{2max}]$;
E: trimmer of tobacco flow, where E Є $[E_{min}, E_{max}]$;
α : is a constant value.

- **Cigarette Formation:** this stage consists of enveloping the bundles of tobacco obtained, by the cigarettes paper. The tobacco band is obtained with a diameter (m) and is cut into sections of length (l) of a cigarette to get the consumption unit. Consequently, the cigarette weight can be written:

$$P = km^2.l.d \tag{2}$$

m: diameter of the cigarettes in mm.
l: length in mm.
d:density in g/mm^3.

k: constant value (π/4).

Obviously, the variation of one of these parameters provides a variation of the weight. In this work we are interested on the first stage. Our goal is to maintain the density within the specified limits by changing the setting parameters (C, H and E), while they have to remain in a valid range.

3. MATRIX GEOMETRIC SOLUTION

Several classes Petri networks have been developed, each trying to describe a "view" of production systems, their design and conduct. Among those classes, we include models that integrate the dimension of time [17-21]. The extension covers the modeling systems whose behaviour depends on an explicit time values. The resulting model can treat problems related to the analysis and evaluation of performance through the analytical methods. Consequently, Petri nets have been used to model various kinds of dynamic event-driven systems like computers networks [22], communication systems [23, 24], manufacturing plants [25-27], command and control systems [28], real-time computing systems [29, 30], logistic networks [31] and workflows [32-34] to mention only a few important examples. The study of the workshops with temporal or non temporal constraints contains a singular problem which occurs when one is in the presence of a synchronization mechanism. We choose the Petri nets (Intervals Constrained Petri Nets) and the timed automata as modelling tools. In fact, these tools are known as being powerful tools of modelling of Discrete Event Systems.

3. 1. Interval Constrained Petri Nets

ICPN are introduced to extend the application [35, 36] field of P-Time PN by proceeding to a functional abstraction of the parameter associated places. Furthermore, introducing a new formalism is an opportunity to review the initial definition. Thus, we present in an unequivocal manner the marking as a multi-set. In the same way, the transmission of a quantity conveyed by a token is represented explicitly.

3. 1. 1. Definition

An ICPN is a t-uple $< R, m, IS, D, Val, Val_0, X, X_0 >$ where:

- R is a marked PN
- m is an application associating token to places:

Let Va be a set of rational variables.

Let V be a non empty set of formulas to use a variables of Va.

Let μV be a multiset defined on V. $m: P \rightarrow \mu V$

$p \in P \rightarrow m(p)$, where $m(p)$ is a place marking. We note M the application: $M: P \rightarrow N$ (set of positive integer)

$p \rightarrow Card(m(p))$

$IS: P \rightarrow R \cup \{-\infty, +\infty\} \times R \cup \left(Q^{+} \cup \{-\infty, +\infty\}\right)$

defines the intervals associated to places. R is the set of real numbers.

$p_i \rightarrow IS_i = [a_i, b_i]$ with $0 \leq a_i \leq b_i$

D is an application that associates to each pair (place, token) a rational variable $q(q \leq b_i)$. This variable corresponds to a modification of the associated value of a token in a place.

$D: m(p) \times P \rightarrow Va$

$\forall i,\ 1 \leq i \leq n,\ \ n = card(P)$. Let k be a token, $k \in m(p_i)$.

$k \rightarrow q_i |\ a_i \leq q_i \leq b_i$, where a_i, b_i are rational values fixed by IS

X is an application that assigns to each variable a value. $X: Va \rightarrow Q$; $va \rightarrow u \in Q$; X sets the qi.

X_0 defines the initial values of variables.

Val associates to each token a formula of values in Q. Val is an application of set of the tokens $m(p)$ in V: $m(p) \rightarrow V\ \ ((k \in m(p)) \rightarrow v \in V$, where k is a given token.

Val_0 defines to initial formulas associated to tokens.

A mark in the place p_i is taken into account in transition validations when it has reached a defined value between a_i and b_i. When the value is greater than b_i the mark is said to be dead. Logically, in the firing of an upstream transition, tokens are generated in the output places and their associated variables are equal to:

$$Val(K) + qi(K) \tag{3}$$

The signification of q and Val (k) are intentionally not fixed in order to provide a general model. As an example with P-time PN there is the following relation:

$$Val(K) + qi(K)\text{; Where t represent time,} \tag{4}$$

In ICPN the application, X is not mathematically imposed. We will meet, for example, applications where q parameters represent weight variations of cigarettes. In this case, parameter values associated to pairs (place, token) are independent.

3. 1. 2. State Definition

A state E is defined by a t-uple $< m, D, Val, X >$ where:

m, D, Val and X are the above defined applications D and m assign a variable $qi(k)$ to each token k in a place pi.

A token k of the place pi can take a part in the validation of output transitions if:

$qi(k) \in [a_i, b_i]$, where $[a_i, b_i]$ is the static interval associated to the place pi. This token k dies when:

$qi(k) > b_i$

X is an application which provides a value for each variable of V. Actually, X defines the real value of each q.

When X is not defined, there exists a way to make the model evolve. Furthermore, some mathematical properties may be outlined. It is the mathematical abstraction.

3. 1. 3. Computing the Next Step There are two different ways of reaching a state from a given one. The first solution is to use the evolution of associated variables. The second one is the transition firings. The following two definitions correspond to these two possibilities of evolution.

Definition 1: A state $E'(m', D', Val', X')$ is accessible from another state $E(m, D, Val, X)$ according to associated variable evolution if and only if:

1- m'=m, and

2- $\forall$j a token in p_i: $q'_i(j) = q_i(j) + \Delta q_i(j)$, $a_i \le q'_i(j) \le b_i$

where $[a_i, b_i]$ is the static interval of the place p_i. The possibility of reaching $q'_i(j)$ depends generally on the coupling with other q evolutions. This particular aspect is not presented here.

Definition 2: A state $E'(m', D', Val', X')$ is accessible state from another state $E(m, D, Val, X)$ by the firing transition t_i if and only if:

1- t_i is validated from E,

2- $p \in P,\ \ m'(p) = m(p) - \Pr e(p, t_i) + Post(p, t_i),$

$\Pr e(p, t_i)$ Corresponds to the weight of the output arcs from p to t_i, $Post(p, t_i)$ corresponds to the weight of the input arcs from t_i to p.

3- Tokens that remain in the same place keep the same associated value between E and E'.

The newly created tokens take null values for the q counter associated to their new places. The value allocated to the token k' by Val is:

$Val(k') = Val(k) + q(k)$ .Where k is a token that is in an input place p_j of t_i and consumed to fire t_i.

The previous firing rule allows computing states and accessibility-relationships. The set of the firing sequences from an initial state specifies the PN behavior as well as sets of accessible markings or validated firing sequences in the case of Autonomous PN.

3. 2. The Timed Automata The fault diagnosis problem in DES is generally solved by using the model-based approach. In other words, an algorithm for fault detection and isolation will analyze and compare the model with the observed behavior. The timed automata is a well suited tool for modelling all the evolutions of a DES.

Timed automata is a tool for modelling and verification of real time systems [15, 16]. A timed automata is essentially a finite automata (FSM), extended with real-valued variables. Such an automata may be considered as an abstract model of timed systems. This expressive modelling tool offers the possibilities of model analysis like verification, controller synthesis and also faults detection and isolation. In the original theory of timed automata, it is a finite state extended with a set of real-valued variables modelling clocks. Constraints on the clock variables are used to restrict the behavior of timed automata, and conditions are used to enforce progress properties. A simplified version, namely Timed Safety Automata, is introduced in to specify progress properties using local invariant conditions. Due to its simplicity, a Timed Safety Automata has been adopted in several verification tools for timed automata. Using timed automata, this system is described in a qualitative and quantitative way. This is illustrated by an example on the Figure 2, where the qualitative parameters represent the sequence of events while quantitative ones relate to temporal parameters.

The problem of automata analysis is considerably more difficult in the timed case compare to the discrete case: in the discrete case, one deals with classical regular languages which have robust closure properties. The timed automata tool [37, 38] is defined as a finite state machine with a set of continuous variables that are named clock. These variables evolve continuously in each location of the automata, according to an associated evolution function. As long as the system is in one state Li, the clock xi is continuously incremented. Its evolution is described by $\dot{X} = 1$. The clocks are synchronized and change with the same step. An invariant is associated to each state. It corresponds to the conditions needed to remain in the state. The number of clocks depends on the parallelism in the system. The automata can stay in one state as long as the invariant condition is checked.

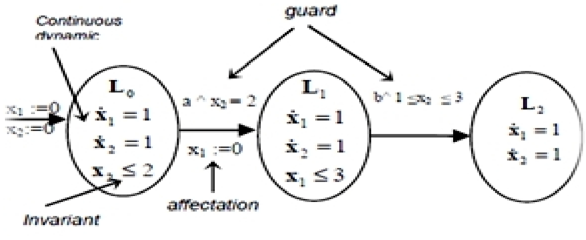

Figure 2. Example of Timed Automata

Each transition of an automata is conditioned by an event or temporization called "guard" and its execution determines the discrete evolution of the variables according to its associated assignment.

Let us consider the timed automata given in Figure 2. This automata has two clocks x_1 and x_2. The continuous evolution of time in this model is represented by $\dot{X}=1$ and the labeled arcs in the graph represent the model of discrete evolution. The guard in each arc is a transition labelling labeling function that assigns firing conditions with the transitions of the automata. The affectation is a function that associates with each transition of the automata one relation that allows actualizing the value of continuous state space variables after the firing of a transition. The invariant in the state L_0 and L_1 are $x_2 \leq 2$ and $x_2 \leq 3$, respectively. The initial state of this system is represented by an input arc in the origin state (L_0). In the dynamic model, active clocks are found in each state. A graphical interpretation of the timed automata is the automata graph (Figure 2).

3. 3. Modelling Process with ICPN It is possible to construct a RdP model of a shop in order to study the different laws of order while simulating the statistical distribution of the orders on the diameter [39].

However, it is necessary to assume that the synthesis of the model is subject to mistakes and approximations. In the best of the cases, we can recover on the model the outputs of the shop for various values of the parameters. However, the data corresponding to the real outputs of the shops are available. Then it is possible to calculate the tolerances of the parameters directly on statistics of the shop. These last results will be logically more correct than those that integrate the imperfections ensuing of the modelling phase.

Note that these parameters in Equation (1) (d, C, E, H) are related to each others. Obviously, the variation of one of these parameters provides a variation of the weight. When it is outside the validity range, the production has to be rejected, or the machine blocks. Our objective is to make sure that the permitted tolerance concerning the weight of the cigarettes will be respected by controlling H_1, H_2 and E parameters. It must belong to a predefined range The aim of the controller is to maintain the density specification by changing the setting levels H_1 and H_2, whereas they have to remain in a valid range.

We consider the variations of a parameter are always very small in contrast to its setting value. Consequently, the above relation may be approximated by the following one doing a first order linearization [40]. A first step develops nonlinear relation (1). This gives the relations (5) which describes the behavior of the process around a reference state.

$$\Delta d = \alpha_1 \Delta C + \alpha_2 \Delta H_1 + \alpha_3 \Delta H_2 + \alpha_4 \Delta E \quad (5)$$

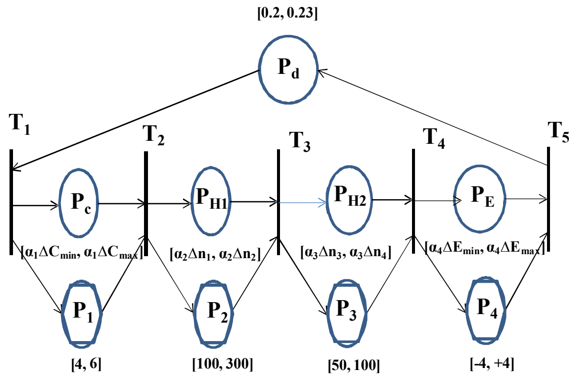

Figure 3. Validity intervals of the ICPN model

With α_i (i: 1...4) are constant values, where:

$\alpha_1=\alpha H_1H_2E$, $\alpha_2=\alpha C\ H_2E$, $\alpha_3=\alpha C\ EH_1$, $\alpha_4=\alpha C\ H_1H_2$ and C, H_1, H_2, E, d are the target values.

Figure 3 describes model ICP of the process of Figure 1. To construct this global model with validity ranges, simulation of the real production data was performed.

The target values are: d = 0.22, E = 7.9, C = 5, H_1 = 300 and H_2 = 100.

In this model the places P_c, P_{H1}, P_{H2} and PE denote respectively the compacity, the level of tobacco in reservoir, the level tobacco on conveyor belt and tobacco trimmer. The places P_1, P_2, P_3 and P_4 present, respectively, the constraints associated to P_c, P_{H1}, P_{H2} and P_E. These places are considered as "places test" to maintain the specification of the above parameters, that obviously describe the ICPN tobacco flow.

3. 4. Verification of the Robustness of the ICPN Model (Definition [41]) The robustness of a system is defined by its capacity to maintain the specified characteristics facing variations (expected or unexpected). The robustness of a system can be divided in two classes:

- A passive robustness when the objectives are kept without modification of the control.
- An active robustness when the objectives are kept through a computation (in real-time) of a new control.

This study deals with the passive robustness of the process with regard to the perturbations at its entry because of variations of the compactness of the tobacco. The operating objective is to maintain the specifications on the parameters: C, E and H. For this, the Petri-Net model has been simulated using the intervals of Figure 1, in same [36]. Under these conditions we can conclude that our model is robust shown in Figure 4 which represents the variation of tobacco density.

3. 5. Modelling with Timed Automata In this work we model the control part of the system (Figure 1) using timed automata. Then we use the approach developed by Lunze [42]. These approaches are based on principle of state and events by integrating the time. At first, we consider that the production sequence is as following:

The system starts from a known initial state. Firstly, the shaft-off flap open; the tobacco flows into the reservoir. After duration time of t_1, the level n_2 is reached, then the drive motor rotates at low speed and the cylinder begins to rotate and the tobacco flows on the conveyor belt. After duration time of t_2 the level n_4 is reached and the machine goes to the nominal speed. As the level in the reservoir and on the conveyor are respectively greater than n_1 and n_3 the system is functioning normally.

The control C_1 maintains the level H_1 of tobacco in the girdle (tobacco reservoir). The level must be kept between a minimum n_1 under which the machine stops, locking tobacco, and a maximum level n_2 over which there is a need for supply.

The control C_2 regulates the level of tobacco (H_2) on the conveyor. It must be comprised between a minimum level n_3 under which the tobacco-driving cylinder stops, locking tobacco, and a maximum level n_4 over which the tobacco-driving cylinder stops.

The control C_3 regulates the trimmer (E). A trimmer motor (M) consists of an electrodynamics motor whose output shaft is mechanically linked to the trimmer disks through a quadrant gear. By driving the trimmer disks, the tobacco rod weight can be adjusted.

This kind of motor allows carrying out rapid and precise movements. Due to a position transducer (T) integrated in the motor, the trimmer disks position is controlled in closed control loop. Data from the scanning unit is processed in the electronic rack, which sends a correction command to the trimmer if the cigarette is outside of the user's defined tolerances. The control sequence is then the following:

S_0: is the initial position when the machine is initialized.

S_1: the shaft-off flap open the tobacco flows into reservoir.

S_2: After time t_1 the cylinder begins to rotate and the tobacco flows on the conveyor belt.

S_3: After an additional time t_2 the machine reaches its first speed.

S_4: After an additional time t_3 the machine reaches its nominal speed.

The proposed approach deals with time analysis of timed automata. The principle of modelling task is to follow the control sequence. Then, let us start building the state space model of the system. We use the levels in reservoir and on the conveyor (two states for each: LOW and HIGH). This leads to four states for the timed automation, which correspond to all the possibilities for the levels of tobacco.

- ✓ State L_1L_2 (n_1n_3) denotes LOW level in both parts.
- ✓ State L_1H_2 (n_1n_4) denotes LOW level in reservoir and HIGH level on the conveyor.
- ✓ H_1L_2 (n_2n_3) denotes HIGH level in reservoir and LOW level on the conveyor.
- ✓ H_1H_2 (n_2n_4) denotes HIGH level in reservoir and HIGH level on the conveyor.

4. APPLICATION: DESIGNS OF EXPERIMENTS

Figure 4 describes the global model of the process of Figure 1.To construct this global model with validity intervals, a new modelling tool has used ICPN in order to evaluate the variations of the quality of tobacco and Timed Automata to manage the flow type disturbance.

Thus, when the model is built, it is possible to describe the constraints on the quality parameters which are required for manufacturing of products in accordance with the specifications.

This model allows setting the system functioning around a target state. Another policy is to control the workshop while following the evolution of the parameters in the course of time in order to compensate for the fluctuations. Note that in this global model we added places representing optimal states "SM_1, SM_2 and SM_3" process operating.

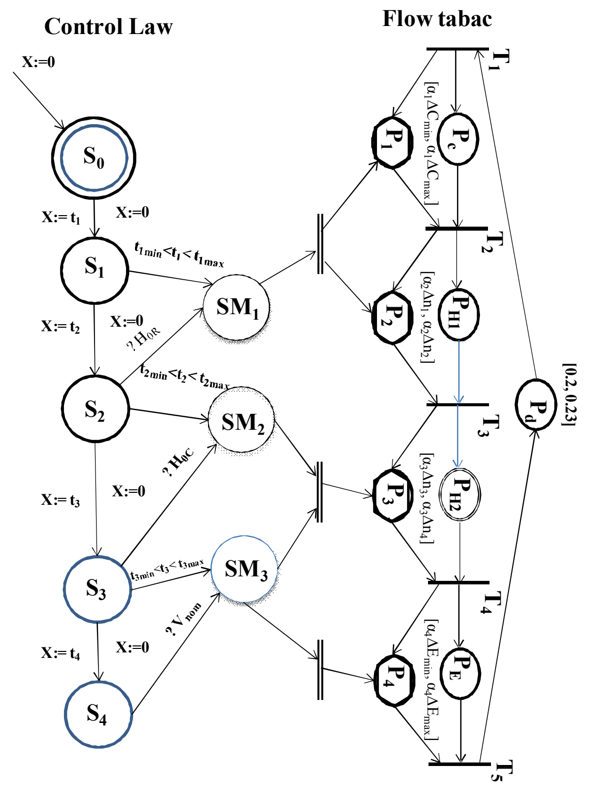

Figure 4. Global ICPN model with command (flow-quality)

4. 1. Control Maintaining Constant Density The effective value of parameters can be calculated with polynomial algorithms [43]. This can be done because the above algorithm is only based on the structural properties of P-time Petri Net. In this case, it has been shown that under some particular assumptions, the property may be extended to ICPN [44].

4. 2. Computing the Robust Control Finally, when the ICPN model of the process is completely defined, it is possible to analyze the structural properties. It has been proven that most of the structural properties of P-time PN can be extended to ICPN [45, 46]. An internal robustness analysis of the ICPN model of the presented process is published in [13].

Finally, using the information from production data, a computing methodology has been applied in order to build the valid intervals of the ICPN model.

This approach uses only a sub-part of the information, because we only want to find critical tests which are needed for the designs of experiments applied in the production data.

An observation of the tobacco processing by different units during one month has resulted in picking out the variations of the output measures: compacity, trimmer and the tobacco density.

Figures 5 and 6 represent, respectively, the variation of trimmer tobacco and density. It has plotted control limits that present regulation boundaries, which are managing boundaries, and a centreline gained by calculating average arithmetic value of the measurement samples. In our case, the measured values are within control limits and then the process is under control.

A centreline (CL) represents the mathematical average of all the samples plotted.
UCL and LCL present respectively the upper and lower statistical control limits that define the constraints of common cause variations.

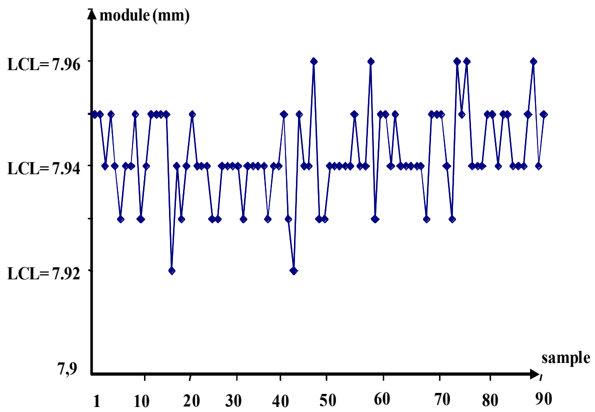

Figure 5. Variation of trimmer tobacco (E)

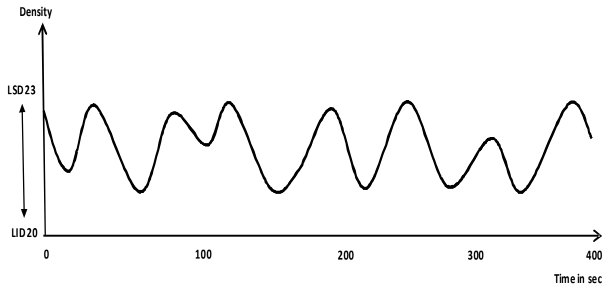

Figure 6. Variation of density

5. CONCLUSION

In this paper, a methodology of design and modelling of control laws is adopted. We have modelled using the ICPN tool which presents a functional abstraction of the P-temporal Petri Nets, constraints subjected on flow and quality parameters while integrating the margins of robustness. The goal is to satisfy qualitative and quantitative needs of the market.

It is to be noted that the presented data are real production data of an existing workshop. The proposed methodology is therefore validated by a large set of data, and it provides an interesting industrial efficiency for the considered case study.

The next step in our work is the model checker. It means to verify if all faulty states in the dynamic model are reachable, or it is necessary to add some other sensors to isolate the faults.

6. REFERENCES

1. K., I., " Recent developments in discrete event systems", ***International Journal of Engineering***, Vol. 5, No. 1&2, (1992), 25-32.
2. Caillaud, B., "Synthesis and control of discrete event systems", Springer, (2002).
3. Delgado-Eckert, E., "Reverse engineering time discrete finite dynamical systems: A feasible undertaking?", ***PloS one***, Vol. 4, No. 3, (2009), e4939.
4. Zhou, M. and Di-C, F., "Petri net synthesis for discrete event control of manufacturing systems", (1993).
5. Kumar, P. R. and Varaiya, P. P., "Discrete event systems, manufacturing systems, an communication networks", ***Mathematics and Its Applications, Springer Verlag***, Vol. 73, (1995).
6. Aho, A. and Ullman, J., Introduction to automata theory, languages and computation., Addison-Wesley, Reading, MA. (1979)
7. Murata, T., "Petri nets: Properties, analysis and applications", ***Proceedings of the IEEE***, Vol. 77, No. 4, (1989), 541-580.
8. Delgado-Eckert, E., "Boolean monomial control systems", ***Mathematical and Computer Modelling of Dynamical Systems***, Vol. 15, No. 2, (2009), 107-137.
9. Germundsson, R., "Symbolic systems: Theory, computation and applications", Department of Electrical Engineering, Linköping University, (1995).

10. Plantin, J., Gunnarsson, J. and Germundsson, R., "Symbolic algebraic discrete systems theory-applied to a fighter aircraft", in Decision and Control, Proceedings of the 34th IEEE Conference on, Vol. 2, (1995), 1863-1864.

11. Reger, J. and Schmidt, K., "A finite field framework for modelling, analysis and control of finite state automata", ***Mathematical and Computer Modelling of Dynamical Systems***, Vol. 10, No. 3-4, (2004), 253-285.

12. Dhouibi, H., Dutilleul, S. C., Nabli, L. and Craye, E., "Using interval constrained petri nets for regulation of quality", in Large Scale Complex Systems Theory and Applications. Vol. 9, (2010), 192-198.

13. Yim, P., Lefort, A. and Hebrard, A., "System modelling with hypernets", in Emerging Technologies and Factory Automation, ETFA'95, Proceedings., INRIA/IEEE Symposium on, IEEE. Vol. 1, (1995), 37-47.

14. Collart Dutilleul S., Dhouibi, H. and E.Craye., "Internal robustness of discret event system with interval constraints in repetitive functioning mode", in ACS, Miedzyzdroje Poland., (2003), 353-361.

15. Nabli, L., Telmoudi, A. J. and M'hiri, R., "Modeling and analysis of a robust control of manufacturing systems: Flow-quality approach", ***International Journal of Computer, Information, and Systems Science, and Engineering***, Vol. 2, No. 1, (2008).

16. Alur, R. and Dill, D. L., "A theory of timed automata", ***Theoretical Computer Science***, Vol. 126, No. 2, (1994), 183-235.

17. Ramchandani, C., "Analysis of asynchronous concurrent systems by timed petri nets", (1974).

18. Sifakis., J., "Use of petri nets for performance evaluation, measuring modeling and evaluating computer systems", Hollande, (1977).

19. Merlin, P. M., "A study of the recoverability of computing systems", (1974).

20. Khansa, W., Aygalinc, P. and Denat, J.-P., "Structural analysis of p-time petri nets", in CESA'96 IMACS Multiconference: computational engineering in systems applications. (1996), 127-136.

21. Diaz, M., "Vérification et mise en oeuvre des réseaux de petri", Hermès Science Publications, (2003).

22. Marsan, M. A., Balbo, G. and Conte, G., "Performance models of multiprocessor systems", (1986).

23. Merlin, P. and Farber, D., "Recoverability of communication protocols--implications of a theoretical study", ***Communications, IEEE Transactions on***, Vol. 24, No. 9, (1976), 1036-1043.

24. Wang, J., "Charging information collection modeling and analysis of gprs networks", ***Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on***, Vol. 37, No. 4, (2007), 473-481.

25. Venkatesh, K., Zhou, M. and Caudill, R. J., "Comparing ladder logic diagrams and petri nets for sequence controller design through a discrete manufacturing system", ***Industrial Electronics, IEEE Transactions on***, Vol. 41, No. 6, (1994), 611-619.

26. Zhou, M. C. and DiCesare, F., "Adaptive design of petri net controllers for error recovery in automated manufacturing systems", ***Systems, Man and Cybernetics, IEEE Transactions on***, Vol. 19, No. 5, (1989), 963-973.

27. Desrochers, A. A. and Al-Jaar, R. Y., "Applications of petri nets in manufacturing systems: Modeling, control, and performance analysis", IEEE press Piscataway (NJ NJ), Vol. 70, (1995).

28. Andreadakis, S. K. and Levis, A. H., Synthesis of distributed command and control for the outer air battle., DTIC Document. (1988)

29. Mandrioli, D., Morzenti, A., Pezze, M., Pietro, P. and Silva, S., "A petri net and logic approach to the specification and verification of real time systems", ***Formal Methods for Real-Time Computing***, (1996), 135-165.

30. Tsai, J. J. P., Jennhwa Yang, S. and Chang, Y.-H., "Timing constraint petri nets and their application to schedulability analysis of real-time system specifications", ***Software Engineering, IEEE Transactions on***, Vol. 21, No. 1, (1995), 32-49.

31. Van Landeghem, R. and Bobeanu, C.-V., "Formal modelling of supply chain: An incremental approach using petri nets", in 14th European Simulation Symposium and Exhibition: Simulation in Industry–Modeling, Simulation and Optimization (ESS, Proceedings), Citeseer. (2002), 323-327.

32. Chuangl, L., Yangl, Q., Fengyuanl, R. and Marinescuz, D. C., "Performance equivalent analysis of workflow systems", in Engineering and Deployment of Cooperative Information Systems: First International Conference, EDCIS, Beijing, China, September 17-20,. Proceedings, Springer. Vol. 2480, (2002), 64.

33. Motameni, H., A.Movagar and Amiri, M. F., "Mapping activity diagram to petri net: Application of markov theory for analyzing non-functional parameters", ***International Journal of Engineering, Transactions B: Applications***, Vol. 20, No. 1, (2007).

34. Lindemann, C., "Performance modelling with deterministic and stochastic petri nets", ***ACM SIGMETRICS Performance Evaluation Review***, Vol. 26, No. 2, (1998), 3.

35. NABLI, L. and DHOUIBI, H., "Using interval constrained petri nets for regulation of quality: The case of weight in tobacco factory", ***International Journal of Intelligent Control and Systems***, Vol. 13, No. 3, (2008), 178-188.

36. H., D., S., C. D. and E., N. L. C., "Using interval constrained petri nets for reactive control design", ***The International Journal Manufacturing Systems and Production (IJMSP)***, Vol. 9, No. 3-4, (2008), 217-228.

37. Bengtsson, J. and Yi, W., Timed automata: Semantics, algorithms and tools, in Lectures on concurrency and petri nets., Springer. (2004) 87-124.

38. Sava, A. T., Sur la synthèse de la commande des systèmes à évènements discrets temporisés., Institut National Polytechnique de Grenoble-INPG.(2001)

39. Klajnmic, H., "Intervalles de confiances et intervalles de tolérance", ***EDF recherche et développement***, (2002).

40. Dhouibi, H., Dutilleul, S. C., Craye, E. and Nabli, L., "'computing intervals constrainted petri nets: A tobacco manufacturing application,'", in IMACS conference, Paris., (2005), 440-446.

41. S., C. D., Dhouibi, H. and Craye, E., Internal robustness of discret event system with interval constraints in repetitive functioning mode, in *ACS*.: Miedzyzdroje, Poland. (2003)

42. Lunze, J. and Schroder, J., "Sensor and actuator fault diagnosis of systems with discrete inputs and outputs", ***Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on***, Vol. 34, No. 2, (2004), 1096-1107.

43. Khansa, W., Denat, J.-P. and Collart-Dutilleul, S., "P-time petri nets for manufacturing systems", in International Workshop on Discrete Event Systems, WODES. Vol. 96, (1996), 94-102.

44. Collart Dutilleul, S., Dhouibi, H. and Craye, E., "Tolerance analysis approach with interval constrainted petri nets", in ESMc conference, Paris. (2004).

45. Pillet, M., Appliquer la maîtrise statistique des processus., Éditions d'Organi. (1995)

46. Jerbi, N., Collart, D., Craye, E. and Benrejeb, M., "Robust control of multi-product job-shops in repetitive functioning mode", in Systems, Man and Cybernetics, IEEE International Conference on,. Vol. 5, (2004), 4917-4922.

Using Interval Petri Nets and Timed Automata for Diagnosis of Discrete Event Systems (DES)

L. Mhamdi[a], H. Dhouibi[a], Z. Simeu-Abazi [b], N. Liouane[a]

[a] *UR ATSI D. Génie Electrique de L'ENIM, Monastir - Tunisie*
[b] *Grenoble-INP / UJF-Grenoble 1 / CNRS, G-SCOP, Grenoble, 46, avenue Félix Viallet -38031- France*

P A P E R I N F O

Paper history:
Received 10 June 2013
Received in revised form 27 August 2013
Accepted 14 September 2013

Keywords:
Modeling
Petri Nets
Interval Constraint Petri Nets
Timed Automata
Robustness

چکیده

سیستم رویدادگسسته (DES) یک سیستم پویاست که احتمالاً با وقوع ناگهانی وقایع فیزیکی ناشناخته در فواصل نامنظم، تکامل می‌یابد. به دلیل ماهیت ویژه این سیستم ها، در حال حاضر از ابزارهای مختلف برای تجزیه و تحلیل، طراحی و مدل‌سازی آنها استفاده می‌شود. تمرکزاصلی این مقاله ارائه روش مدل‌سازی سیستم‌های رویداد گسسته است. روش ارائه شده مدل ترکیبی از فاصله‌ی محدود پتری شبکه‌ها (ICPN) و آتوماتای به‌هنگام (timed automata) است. این ابزار به ما اجازه می‌دهد تا به ارزیابی تغییرات کیفیت و مدیریت نوع اختلال جریان بپردازیم. تحلیل این رویکرد را با یک مثال نشان می‌دهیم.

doi: *10.5829/idosi.ije.2014.27.01a.14*