Advanced methods for recurrent hierarchical systems modeling. Application to producer-consumer distributed energy production systems

Eugen Minca*, Daniel Racoceanu**, Veronica Stefan*, Ryad Zemouri***

*Faculty of Electrical Engineering, Valahia University, 18 Unirii Av.0200, Targoviste, Romania (minca@valahia.ro, vstefan@valahia.ro)
**French National Research Center, IPAL (UMI CNRS, NUS, I2R-A*STAR, U1F), Fusionopolis, Singapore (daniel.racoceanu@ens2m.fr)
***Ryad Zemouri, Laboratoire d’Automatique du CNAM, 21 Rue Pinel, 75013 Paris, France (Ryad.Zemouri@paris.ensam.fr)

Abstract—A new tool for non-autonomous hierarchical systems modelling is proposed in this article. This tool is used for the modelling of monitoring functions and integrates the fuzzy logic in the temporal aspect of the events occurrence. The tool is also suited for the development of the hierarchical and distributed typologies structures and in modelling of recurrent functions. The proposed hierarchical systems are structured on hierarchical levels. On each level there are events with equal probabilities of occurrence/detection. The proposed typologies ensure a recurrent behaviour to the horizontal firing of the networks, which allows the detection of the occurrence/persistence of the monitored external events. In this context, the Recurrent Synchronized Fuzzy Petri Nets (PNetSinFREC) are well adapted to detection/decision modelling of the functions by a temporized fuzzy transition approach in hierarchical systems.

Keywords - fuzzy detection; fuzzy logic; fuzzy reasoning; Temporized Petri nets

I. INTRODUCTION

Uncertain knowledge associated to the systems monitoring of the discrete events requires specific reasoning and modeling methods adapted to a logic different from the traditional one [1], [2], [3], [4]. Hierarchical systems [5] have been for many years a practical solution to approach complex, large-scale systems.

Between modeling tools, Fuzzy Petri nets are the most appropriate for discrete events description using a fuzzy knowledge base. A complete state of the art of the various Fuzzy Petri Net (PNetF) approaches was published by Cardoso [6].

The various types of logics (traditional, linear and fuzzy) used in the description of the systems, generate two main categories of PNetF models: the first class of models is represented by the Fuzzy Expert Systems. In this case, PNetF is interfaced by the supervised system by information arrived from sensors and represents the equivalent of a fuzzy controller for a discrete events system [7], [8]. Another class of application modeled by the PNetF is that which express the inaccuracy or the fuzzy knowledge [9], [10]. This last type of PNetF models a physical system by applying linear logic [6], [8] to the resource transformation level. Generally, PNetF use traditional logic [11], [12], [4] at the level of the sentences semantics. Our contribution is situated in the first class of PNetF.

To modelize the survey function, an extension of PNetF [13], [14], [15] is used. This integrates in a temporal aspect the moment of the defect appearance in the supervised system. The Supervised Fuzzy Petri net PNetSinF [16], [17] is dedicated to the modeling of a fuzzy logical rule basis that follows from the logical expression tree of failures (ADD), a priori identified in the supervised system. The PNetSinF tool models the reunion or the intersection of the logical reasoning, respecting the specifically concepts of fuzzy logic [1], [2]. The analysis offers refined information at the level of each defect, transferring signals from the temporary synchronized defects. PNetSinF highlights the characteristics of certain critical points which materialize the critical path in the strategy of the forecast function.

The limit of this tool is the network operational mode: the external signals arrive and validate the transitions simultaneously. Even if the external event occurs at a given moment, it is injected into the network at the moment when they are read by the detection interface. The proposed tool has an asynchronous running in respect of the signals’ apparition moment, this providing an error in the evaluation in time of parameters (characterizing the fuzziness of the produced defaults which are based on the variation in time of the parameters.

In this respect, we propose another tool - Recurrent Synchronized Fuzzy Petri Net (PNetSinFREC). PNetSinFREC describes the operational mode of the non autonomous systems treated on a hierarchical basis. Their functioning is conditioned by some external events and by the time. One proposes a tool which can quantify the external conditional relations via the receptive transitions to the external events. In the same time, by the fuzzy approach, one refines the external information considering the temporal window where the event is going to occur.

The modeling of the monitoring discrete events system can be done by means of various Petri nets (Pn) types (ordinary Pn, high level Pn), making the assumption that the possible defects are known a priori and modeled by specific mechanisms (for example by “the watchdog” [18]). Our approach takes into account a modeling with a temporized Petri net at the transitions level.
II. RECURRENT SYNCHRONIZED FUZZY PETRI NETS

We propose a type of Fuzzy Petri net inspired by work of Chen in [11] and Minca in [13], [14], [16] and [17] adapted to the need of modeling the supervision functions. The approach proposed by Minca, has some limits in respect of the temporal synchronizing of the detection system model. This consideration is important due to the fuzzy approach which is based on the temporal description of the information “default occurrence”.

The model of Chen is adapted to the modeling of static logical informational bases. This approach is not entirely satisfactory for the dynamic monitoring.

It is in this direction that we propose the Recurrent Synchronized Fuzzy Petri nets as an extension of the PNFD. To model the functions of detection/diagnosis we define a fuzzy model able to integrate the moment of appearance of the events in the supervised system. The proposed tool defines, by its own network structure:

- synchronized relations with the external events, which means that certain transitions of the model are associated and fired by the supervised external events.
- repeated inspection of the events occurring. This is realized by the hierarchical structure itself, which allows the repetition of the signals acquisition sequences by a number of times dependent of the sequence position in the supervising system hierarchy.

A. Tool definition

Recurrent Synchronized Fuzzy Petri nets are defined as a n-pair

$$PNSinFREC = (PNSinF,n)$$

where:

- $PNSinF$ the Synchronized Fuzzy Petri Net
- $n$ the degree of recurrence

$$PNSinF = \langle P,T,E,I,O,w,F,Sinc,D,M_0 \rangle$$

Where:

- $P = \{p_1, p_2, \ldots, p_n\}$ the set of places;
- $T = \{t_1, t_2, \ldots, t_m\}$ the set of transitions;
- $E = \{E_1, E_2, \ldots, E_n\}$ the set of external events;
- $F : T \rightarrow T$ the place’s input function;
- $O : P \rightarrow T$ the place’s output function;
- $w : (P \times T) \cup (T \times P) \rightarrow \{1, 2\}$ the arch’s weight function; the weight of the places input arches on the last layer is 2 and 1 in the rest.
- $F(t) : T \rightarrow [0, 1]$ the associative function that establishes a credibility value $\mu = F(t)$ that is time variable for each transition $t_i \in T$. $\mu$ represents the truth degree of the sentence corresponding to the transition. The moment $t$ corresponds to the moment $t_i \in \delta$ when the external event $E_i$ will be received by the modeled system.

$\text{Sinc} : T \rightarrow E \cup e$ is an application on the set of transitions and has values on the set of events $E$ united with the $e$ event which is permanent. If a transition has not an external event $E$ associated, it is considered that it has associated the event $e = \text{event with permanent appearance.}$

$D = \{d_1, d_2, \ldots, d_n\}$ is the set of associated times to the external events that represent a temporal window to their receptions. These periods of time represent the same times of associated temporizations to the external events synchronized transitions.

$M_0$ is the initial marking of the network.

PNetSinFREC are suited to the conventional and distributed hierarchical supervising systems. Both are describing the hierarchical structure of the detection function and the recurrent effective detection of the supervised events (defaults occurrence).

The hierarchical structure is generated by the probability of the supervised events occurrence. An event with a low probability is placed on the lower levels and has a high recurrence degree in its detection. Events with higher detection probability are placed on superior hierarchical levels and have a limited recurrence of the detection function. Since, we propose two types of hierarchical systems which have different recurrence of the detection depending on the information acquisition strategy. The monitoring system can wait an event to be produced (Fig. 1) and in this case the network validates the corresponding states of the level. The monitoring system succeeds the states $\{0, n\}$ since an $a \text{ priori}$ order of the events is established (Fig. 2).

![Detection Modeling in Distributed Systems Using PNetSinFREC](image-url)
In both of the hierarchical structures, the nucleus of the PNSinF is represented. By definition, the arcs corresponding to the last level states have the weight [2] and [1] in rest. Every PNSinF models a default detection function and can contain synchronized transitions with the supervised external events. For this reason, every PNSinF contains a single place on the last level states. For this reason, every PNSinF contains a single place on the last level states.

The PNSinF tool is well adapted for the modeling of the logical rules as well as for the modeling of the resources. In both cases, the network has different operating rules. Various structures of Petri nets are possible for modeling (Figures 4 a, b, c).

Figure 2. Detection modelling in hierarchical systems using PNetSinFREC

Figure 4. a) Modelling the logical rule \( p_1 \land p_2 \rightarrow p_4 \); b) Modelling the logical rule \( p_1 \land p_2 \rightarrow p_3 \land p_2 \rightarrow p_4 \); c) Modelling the logical rule \( (p_1 \rightarrow p_4) \lor (p_2 \rightarrow p_3) \lor (p_4 \rightarrow p_5) \)

B. Fuzzy aspect in the PNSinF for the modeling of the logical rules. Operational mode

Each transition corresponds to a fuzzy rule and is associated to a function \( \mu_j = F(t) \) which describes the moment of possible firing. The function represents the membership function of the fuzzy variable \( t \) to the fuzzy set defined by the linguistic variable "appearance of event \( E_i \)". Being variable in time, the value of credibility \( \mu \) of the rule modeled by the transition prints to each rule a dynamic credibility character. The interval \([0 \ d_j]\) represents the entire analyzed period and at the same time the interval of temporization associated to transitions.

Even the event occurs in the temporal window \([0 \ d_j]\), the transition firing will be done after the duration \( d_j \). During the interval \([t \ d_j]\), the token of the place \( p_i \) represents the reserved token in the place, thus it is not available for firing any other transition.

In our approach, the next operators are considered: \( T(U,v) = \min(U,v) \) and \( \perp(U,v) = \max(U,v) \), as well as the operator \textit{modus ponens} generalizad \( T_{probablistic}(U,v) = U \cdot v \).

For the structures presented in Fig. 4., the evolution of marking is natural but, the fuzzy values associated to the tokens of the next places are determined according to the following definitions:

Fig. 2., a) \( \alpha_0 = \min(\alpha_t, \alpha_t) \cdot \mu_j \)  \hspace{1cm} (3)

Fig. 2., b) \( \alpha_0 = \alpha_2 = \alpha_4 = \min(\alpha_t, \alpha_t) \cdot \mu_j \)  \hspace{1cm} (4)

Fig. 2., c) \( \alpha_0 = \max(\alpha_t, \alpha_t, \alpha_t, \alpha_t) \cdot \mu_j \)  \hspace{1cm} (5)

To exploit the proposed tool in an efficient way, we present the basic principles of the evolution analysis for such a network. For this, we will focus our study on the transitions and more precisely on the transitions with concurrent places.

Figure 3. Marking evolution in the PNSinF a) initial marking b) network marking with temporal window \( d_i \)
Sentence 1: If a transition has not an external event $E$ associated, it is considered that it has associated the event $e = m$ event with permanent appearance. The associated function, will be the constant function $F(t) = 1$

Sentence 2: If a transition has not a temporization $d$ associated, it is considered that its duration is null thus the marking after firing will be an unstable marking.

Sentence 3: If the next logical rule is modeled $d_1 \land d_2 \ldots \land d_k \rightarrow d$ or $(d_1 \rightarrow d_k) \lor (d_2 \rightarrow d_k) \ldots \lor (d_l \rightarrow d_k)$ the logical variable $d_t$ will take the fuzzy associated value: $\alpha_k = \min(\alpha_1, \alpha_2, \ldots, \alpha_l)$; $\mu_j = \max(\alpha_1, \mu_1, \alpha_2, \mu_2, \ldots, \alpha_l, \mu_l)$

C. Marking and fuzzy parameters evolution in the PNetSinFREC networks

By definition, one considers that the arches corresponding to the places located on the last layer, having the weight, and $r$ represents the recurrence degree. On the level of each PNetSinFREC network, after each recurrence, the corresponding markings are:

\[
M_0 = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_k \end{bmatrix}, \quad M_n = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_k \end{bmatrix}, \quad M_{n+1} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_k \end{bmatrix}
\]

For the last level of the PNSinF network, the marking of the places located on the last level is

\[
2^n + 2^k + 2^n = 2^n \cdot 2^n
\]

for the $2^{n+1}$ places, located on each level of recurrence.

III. APPLICATIONS

A. Application of the PNetSinFREC in monitoring of a distributed system for production/consume from renewable energy with photovoltaic solar panels

Since the proposed modelling tool is oriented to the monitoring functions modelling, in particular for the modelling of the defaults occurrence in complex systems (the detection function), for modelling of the decision function in modular systems an application is forward proposed.

The application described in this section is integrated in a research project, PROMES [19] dedicated to the renewable energy resources, precisely to the development of these alternatives energy sources.

One considers a hierarchical monitoring renewable energy which produces/consume renewable energy (Fig. 5).

Renewable energy includes: photovoltaic solar energy, thermal solar low temperature, thermal solar energy high temperature, wind energy, hydraulic power or hydroelectricity, geothermic, biomass itself composed by wood energy, biogas and bio-fuels. The proposed modular system has solar panels in fixed structures that are inclined by different gradients $\gamma$ and an azimuth of $40^0$ (Fig. 5, places P11, P12, P13). The hierarchical system (Fig. 8) is a whole of repetitive modular structures, grouped by the geographical location in which they are placed. The geographical location contributes with a correction factor depending by the global solar radiation density flow $I_g$ [W/m²]. The two factors: the variable inclination angle of the solar panel and the geographical location, influence the efficiency of the modular system collector as is shown in the Fig. 7.

The decisional system optimizes the production/consuming energy from renewable alternative sources regarding the price of the energy in national network different day moments.

![Figure 6. Inclination angle of the solar collectors](image1)

![Figure 7. Efficiency of the solar collector](image2)

Figure 5. Modelling of the monitoring intelligent system using PNSinF
TABLE I.
FUZZY VALUES OF THE CONVERSION EFFICIENCY IN THE DISTRIBUTED SYSTEM

For the day moments characterized by an energy deficit, the system (Fig. 5: \( P_{11} + P_{12} + P_{13} \)) will supply with "green" energy the national network, where:

- \( E_c \) = energy demands of the consumers;
- \( E_r \) = national network energy;
- \( p_r \) = the highest priority level in monitoring/ control system.
- \( E_{vi} \) = "green- energy" furnish by the \( i \)th producer.

The demand energy \( E_c \) can be provided by the modular structures (\( P_{11}, P_{12}, P_{13} \)) or can be assured directly from the national energy network \( P_{10} \). If the price of the renewable energy is lower than that from the national network, in the period in which decision is taken, then the decisional system connects the modular structures of renewable energy and the overflow is sent to a battery \( P_{10} \).

The functioning of the hierarchical system is conceived on decisional levels. The energy demand can be cumulative satisfied, so as modular structures from adjacent levels are connected as energy producer until the necessity is entirely covered from the renewable alternative energy.

If the need is to cover the demand from modular producer structures placed in the same geographic site, then the energy level \( i \) is connected and the demand is satisfied.

If the costs are high, the monitoring system interrupts the hierarchical levels with alternative energy and consequently the subsystems became producer/consumer state. The aspect of intelligence is integrated by the fuzzy modeling of the temporal window of physical parameters who condition the conversion efficiency (Table 1: the conversion efficiency of a single panel and of the hole modular structure are remaining constant on each hierarchical level and are accordingly to the formulas (2), (3) and (4)). The function \( \text{Sinc} : T \rightarrow E \cup e \) ensures the selective hierarchical command that synchronize the transitions when an associated extern event appears (external decision).
the other hand the quantitative/qualitative aspects - that make the distinctions between the subsystems in the modeling process - aren’t completely, with all their aspects taken into account. Therefore it remains an open problem for the future research in this area of interest: the object oriented Petri nets.

**REFERENCES**


**CONCLUSIONS**

In this article we proposed a new tool named **Recurrent Synchronized Fuzzy Petri Net**. It was shown that this tool is well adapted for the modeling of the logical rules which describe the hierarchical monitoring (detection/decision) systems. It was particularized on the modeling of the systems’ hierarchies by a fuzzy temporal approach. Our study starts from the assumption that the monitoring system is modeled by temporal PNet (PNetT). The paper proposes an adaptive technique dedicated to the hierarchical systems modeling. On