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Online Diagnosis based on Chronicle Recognition of a Coil Winding Machine

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ABSTRACT

This paper falls under the problems of the diagnosis of Discrete Event System (DES) such as coil winding machine. Among the various techniques used for the on-line diagnosis, we are interested in the chronicle recognition and fault tree. The Chronicle can be defined as temporal patterns that represent system possible evolutions of an observed system. Starting from the model of the system to be diagnosed, the proposed method based on the P-time Petri net allows to generate the chronicles necessary to the diagnosis. Finally, to demonstrate the effectiveness and accuracy of the monitoring approach, an application to a coil winding unit is outlined.

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1. INTRODUCTION

Industrial systems need to be monitored online to avoid critical situations. Our study concerns Discrete Event Systems (DES), especially the diagnosis of their failures. In this context, we propose the chronicles as formalism for interpreting events to diagnose DES as manufacturing systems.

A chronicle is composed of a set of events and a set of temporal constraints linking a pair of events. Over the past decade, this formalism has been used and / or extended by various authors, particularly for failures diagnosis [1-4].

It was also operated by Telecom operators for fault diagnosis in telecommunications networks [5] or for the diagnosis of web service failures [6], [7].

Lately, to deal with the time aspects inherent to the chronicles, Gougam [8] propose an automated translation of chronicles into a set of Labeled Time Petri Nets with Priorities. The diagnosability analysis is then performed on the state class graph of these nets and consists in determining whether the recognition of a chronicle is exclusive or not.

González [9] proposes a diagnostic approach based on chronicles and modular temporized analysis. In fact, each fault is associated with a set of chronicles and each chronicle recognizes fault signature which is obtained from the state diagnoser associated to the finite state automata defined for each process module.

Developments presented in this paper are devoted to distributed monitoring of discrete event systems and deals with the problem of the distributed detection of a failure symptom in manufacturing job-shops with time constraints. P-time Petri nets are used for modelling. Among the various techniques used for the distributed monitoring, we are interested in the chronicle recognition.

This paper is organised as follows. The next section begins by presenting the coil winding machine. P-time Petri nets are used as a modelling tool. The third section presented the chronicle formalism and shows how chronicles are applied to intrusion detection. We conclude in section 4, by an application of the online diagnosis to a coil winding unit. Finally, conclusions of this work are given.

2. Modelling of coil winding machine

2.1 P- time Petri net

Definition 1 [10]: The formal definition of a P-time Petri net (Rp) is given by a pair: < R; IS>, where:

– R is a marked Petri net,

– IS : P $\rightarrow Q^+ \times (Q^+ \cup \{+\infty\})$

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

IS_i defines the static interval of staying time of a mark in the place p_i (Q^+ is the set of positive rational numbers). A mark in the place p_i is taken into account in transition validation when it has stayed in p_i at least a duration a_i and no longer than b_i. After the duration b_i the token will be dead.

2.2 Presentation of coil winding machine

Winding machines are used heavily in textile manufacturing, especially in preparation to weaving where the yarn is wound on to a bobbin. In our study, the obtained bobbins are used for the production of fishing nets, figure 1. Once the winding is completed, the operator intervenes to evacuate the full bobbins before being stored.

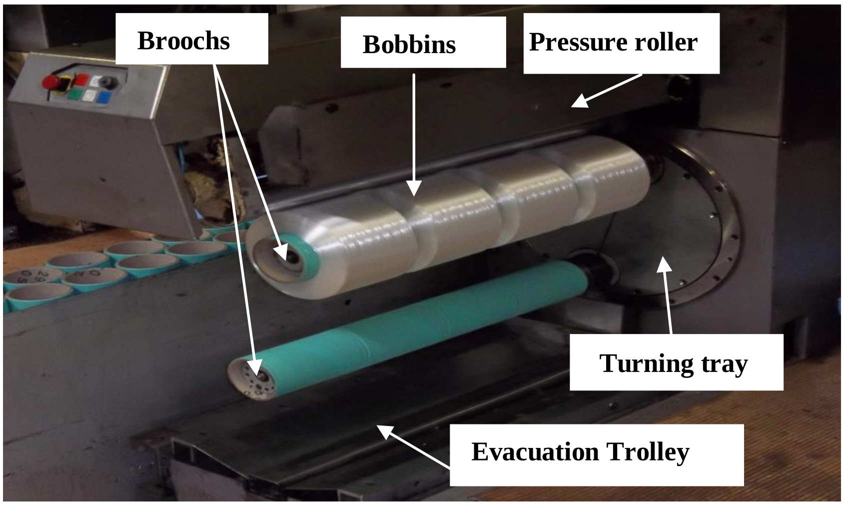


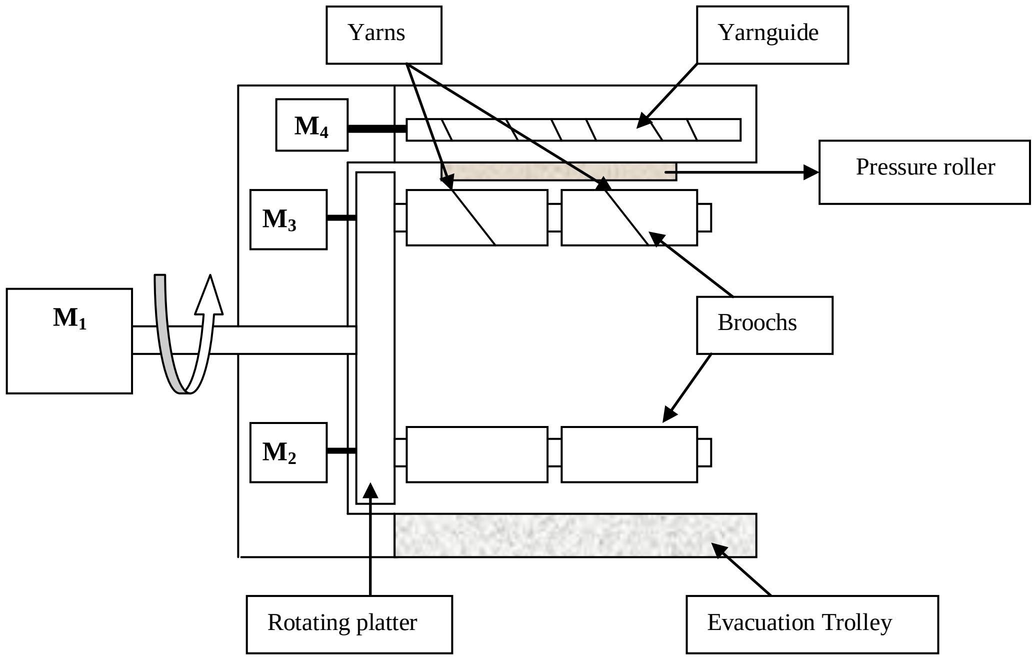
Figure 1. Winding machine

The winder is responsible for winding the nylon filament, and evacuates the full bobbins. Once the winding operation is completed, the coils deviate from the pressure roller and the servo motor “M1” provides the inversely of the two brooches, figure 2. The lever arm is responsible for cutting the yarn. The full bobbins are then discharged by an evacuation trolly and a new winding operation is started, figure 2.

2.3 Modeling of winding machine

In the studied workshops, a time interval is associated to each operation ($[a_i, b_i]$ with *u.t*: unit time). Its lower bound indicates the minimum time needed to execute the operation and the upper bound fixes the maximum time to not exceed otherwise the quality of product is deteriorated.

Figure 3, shows a P-time Petri net (G) modeling the production unit. The obtained G is used to study the supervision of the winding unit. The full set time intervals of operations “IS_i” and effective sojourn time “q_{ie}”, are summarized in table 1 (u.t: unit time second). The full set time intervals of clamping, winding, cutting and unloading are computed using the CPLEX 12.5 on a computer with Intel (R) at 2.16 GHz and 2 Go RAM.



M1 : servo-motor ; **M2** , **M3** :Brooch motors; **M4** : Yarnguide motor

Figure 2. Components of the winding machine

Table 1. Full sets of time intervals

Place	Operation	Task	IS_i	q_{ie}
P1	Op1	**Clamping empty cones**	IS_1=[1, 11]	**q_{1e}= 5**
P2	Op2	**Winding**	IS_2=[6600,7200]	**q_{2e}=6780**
P3	Op3	**Yarn cutting**	IS_3=[2, 5]	**q_{3e}= 3**
P4	Op4	**Brooch inversion**	IS_4=[1, 3]	**q_{4e}= 2**
P5	Op5	**Motor braking**	IS_5=[8, 13]	**q_{5e}= 9**
P6	Op6	**Evacuation**	IS_6=[10, 17]	**q_{6e}= 16**

In the studied workshop, the operations have temporal constraints which must be imperatively respected. The violation of these constraints can induce some catastrophic consequences. Therefore, the considered monitoring approach uses the additional information provided by the knowledge of interval constraints and allows detecting a failure symptom when a constraint is violated.

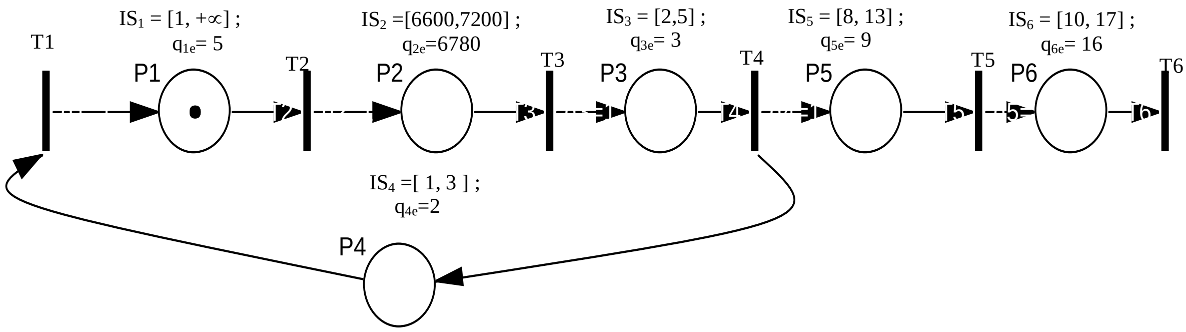


Figure 3. Winding unit modeled by a P-time Petri net

3. Chronicle formalism

Chronicles provide a formalism for monitoring manufacturing systems with time constraints. They are constituted of a set of events, linked toghter by time constraints, whose occurrence may depend on the context. The chronicle recognition is based on time which is a fundamental formalism. This is in contrast with classical expert systems, which base their reasoning on rules and knowledge base.

3.1 Basic definition

Preliminary definitions, useful for the rest of this paper, are given in order to explain the distributed detection principles.

Definition 2 [11]: An event is a stimulus to which the system can react by a state change. An event can occur after a message sent by the process at the beginning or at the end of any operation. There are two types of events:

– **Mandatory events**. Mandatory events are the main events of a chronicle. The arrival of all the mandatory events is necessary for recognizing chronicles.
– **Forbidden events**. In case of forbidden event occurrence during the time window corresponding to the time constraints, the chronicle will not be recognized.

Definition 3 [11]: An occurrence date is the time corresponding to an event issued from the process. Let O be the occurrence function which associates to each event "e_i" its occurrence date $O(e_i)$, then:

$$O: E \rightarrow Q^+$$
$$e_i \rightarrow O(e_i)$$

Where, Q^+ is the set of positive rational numbers and E is the set of events ($e_i \in E$).

Definition 4: A constraint is a relationship expressed by a duration between events occurrences. Two types of constraints can be distinguished:

– *Local constraints* link events dated by a same site,
– *Global constraints* link events dated by different diagnosers.

3.2 Time constraint verification

The problem induced by the chronicle recognition is the verification of a global constraint.

Let us denote by $\Delta \in [\delta_m, \delta_M]$; where $\delta_m, \delta_M \in Q^+$) are the delay bounds existing between the different sites. The problem to be solved can be summarized as follows:

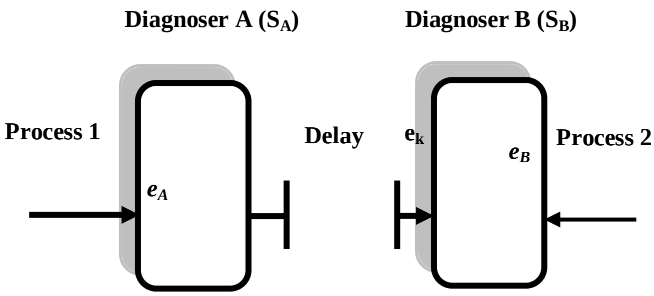


Figure 4. Operating delay between diagnosers

Given, figure 4:

– the global constraint $C_{B,A}$ linking e_B to e_A,
– the occurrence dates of e_B and e_k on the site S_B,
– the bounds δ_m and δ_M of the transmission delay from S_A to S_B.

Is it possible to establish if the occurrence date $O(e_A)$ satisfies the global constraint $C_{B,A}$?

We have:

$$d_{B,A} \leq O(e_B) - O(e_A) \leq f_{B,A} \quad \text{(Eq. 1)}$$

and

$O(e_B) - O(e_k) + O(e_k) - O(e_A) = \Phi + \Delta$.

As $\delta_m \leq \Delta \leq \delta_M$, we obtain:

$$\Phi + \delta_m \leq O(e_B) - O(e_A) \leq \Phi + \delta_M \quad \text{(Eq. 2)}$$

with $\Phi \in]-\infty, +\infty[$.

The verification of the interval constraint consists, by means of the measurable duration Φ, of looking for the durations $O(e_B) - O(e_A)$ that verify both [Boufaied et al. 2005]:

$$\begin{cases} d_{B,A} \leq O(e_B) - O(e_A) \leq f_{B,A} \\ \Phi + \delta_m \leq O(e_B) - O(e_A) \leq \Phi + \delta_M \end{cases}$$

In order to quantify the set of possible durations $\Phi \in \Re$ ($\Re$ is the universe of discourse), a graphical representation of real values allowing to verify the constraint $C_{B,A}$ is proposed (Figure 5).
Considering a bounded delay, the possibility to check a time constraint belongs to [0, 1]. Consequently the verification of time constraints is fuzzy. These results make it possible to highlight zones of certainty for the detection function.

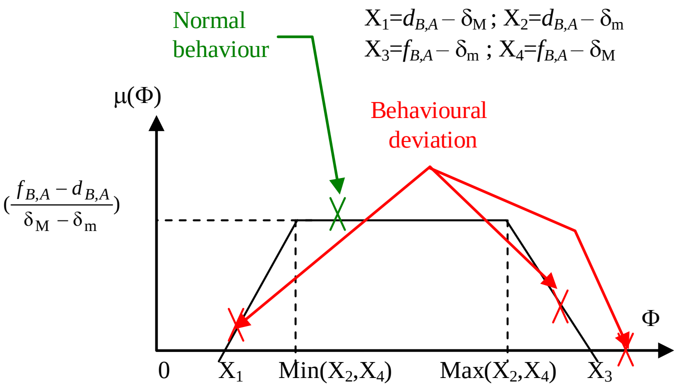


Figure 5. Possibility function for an interval constraint with $X_1 \geq 0$, $X_2 \geq 0$, $X_3 \geq 0$ and $X_4 \geq 0$

4. Distributed monitoring of the winding unit

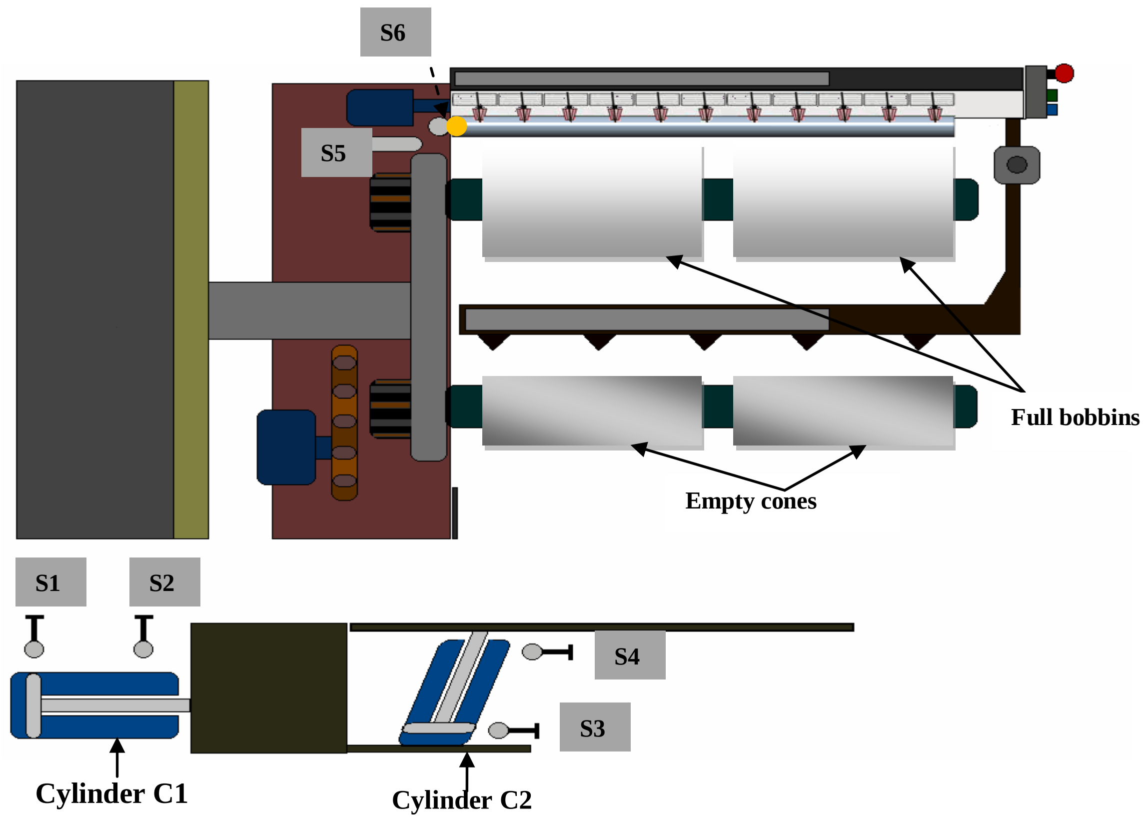


Figure 6. Example of production monitoring

4.1 Principle

The monitoring of the winding machine is done by observing the set of events. Therefore, we associate a diagnose, figure 6, to each event and the detection function is distributed on these different sites (set of sensors and resources):

e_{S1} : Retracting of the pneumatic cylinder C1 (Sensor S1).
e_{S2} : Extending of pneumatic cylinder C1 (Sensor S2).

e_{S3} : Retracting of the pneumatic cylinder C2 (Sensor S3).
e_{S4} : Extending of pneumatic cylinder C2 (Sensor S4).
e_{S5} : End of brooch inversion (Sensor S5).
e_{S6} : End of winding operation (Sensor S6).

Let us suppose that we want to monitor the duration between the two events, e_{S6} (the ending of winding operation) and e_{S1} (the end of unloading operation), figure 6.
To monitor this duration, it is necessary to check the timing constraint linking the occurrences of the two events e_{S6} and e_{S1}.

This timing constraint is a global one, therefore the verification of this constraint can be done through the measure of the operating (clamping, Winding, cutting and inversion) and evacuation durations associated to the intermediate events. As previously mentioned, the global constraint to compute is an interval constraint type defined by a constraint $C_{S6,\,S1}$:

$$d_{S6,\,S1} \leq O(e_{S6}) - O(e_{S1}) \leq f_{S6,S1}$$

with:

$$d_{S6,\,S1} = \sum_{i=1}^{6} a_i$$

$$f_{S6,S1} = \sum_{i=1}^{6} b_i$$

According to time intervals (figure 3), the minimum time ($d_{S6,\,S1}$) granted to the production of winding bobbins is 6622 *u.t* whereas the maximum time ($f_{S6,S1}$) is 7249 *u.t.*
When operating and evacuation durations are included in the mentioned intervals, the production cycle proceeded well. When the interval constraints are exceeded, it is possible that the time granted to the manufacture of bobbins has been delayed; consequently a failure symptom can be detected. We are going to express that in the following.

4.2 Scenario: Delay of brooch inversion operation

In the winding unit, the detection monitors the system evolutions through the verification of time constraints.
Let us suppose that:
$\Phi_{es1\rightarrow es5} = \Phi_{Op1} + \Phi_{Op2} + \Phi_{Op3}$; where Φ_{Op1}= 9s; Φ_{Op2}= 7193s and Φ_{Op3}= 4s;

Let us suppose that the operating durations associated to the brooch inversion is 52 seconds (Φ_{Op4} = 52s). It is sure that the coils evacuation operation will be delayed (Delay of production cycle) (Figure 7), according to the measured duration $\Phi_{es1\rightarrow es5}$ and to unloading durations of empty bobbins ($\Delta \in [10, 17]$). Consequently, the global constraint ($C_{S6,\,S1}$) is violated**.** The results, Figure 7, highlight areas of certainty for the detection function: as the constraints traduce a normal functioning of the monitored system, a low degree of possibility ($\mu_{\Phi es1\rightarrow es5}$= 0) induces the detection of a failure symptom and the possibility that the winding cycle will be delayed. So the chronicle recognition allows detecting a failure servo motor M1 allowing the brooch inversion.

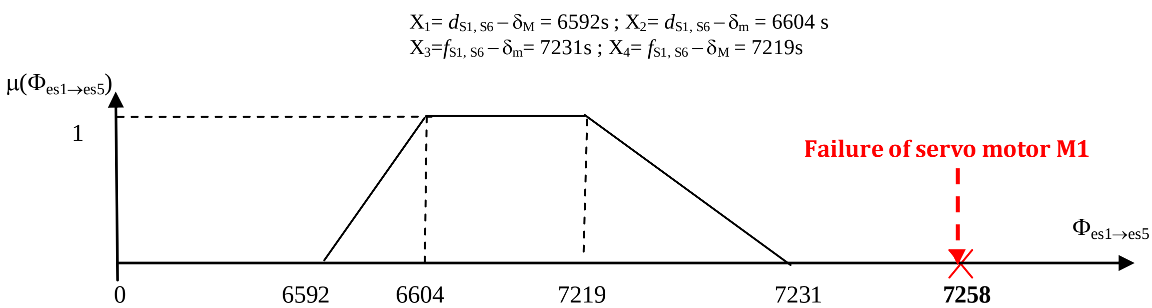


Figure 7. Possibility function considering $\Phi_{es1\rightarrow es5}$

When a symptom of an abnormal functioning is claimed by the chronicle mechanism, it is imperative to localize the failure by using fault tree as a modeling tool, figure 8.

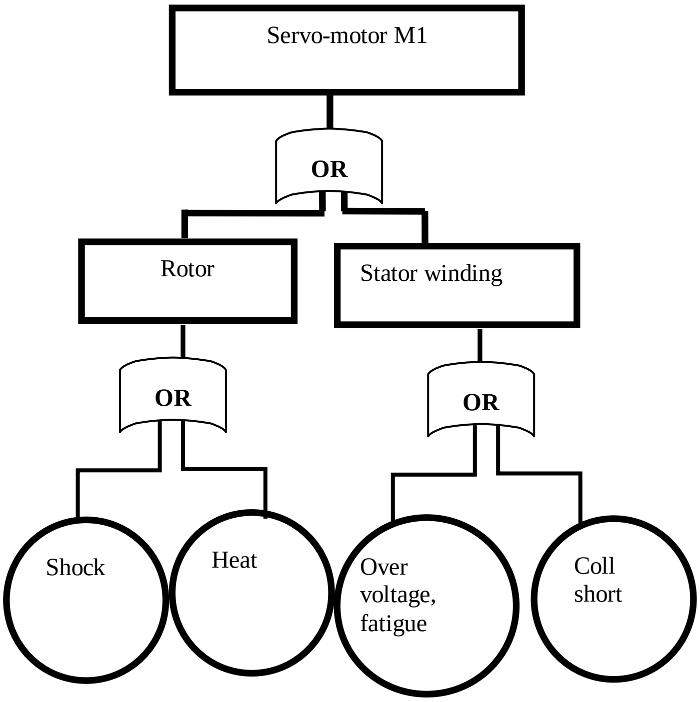


Figure 8. Fault tree associated to servo motor M1

5. Conclusion

The diagnosis has become an essential function for the safe control of industrial systems particularly in the context of online monitoring. In this study, we investigate the diagnosis of manufacturing system with time constraints. We propose a method based on chronicle recognition and fault tree.

The problem of the distributed recognition, in manufacturing workshop, of sub-chronicles through the verification of local and global time constraint has been pointed out. This recognition is based on time constraint verification performed with a possibility measure. The results obtained in the illustrative example are promising. They show that the distributed detection improves the prevention of violation of constraints by performing an early diagnosis.

Finally a comparative study based upon several cases should be developed. A comparison with the proposed monitoring architecture and results with the works using the Causal Time Signature (CTS), should also be considered.

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Pr Anis M'halla was born in Mahdia, Tunisia in 1980. He obtained the Ph.D. degree in automatic and computer science from EC-Lille in 2010. Professor at "Ecole Nationale d'Ingénieurs de Monastir "since 2020. His research interests include robustness and supervision of multi-product job-shops with time constraints.