System for detection and isolation of failures using Interpreted Petri Nets (IPN)

Sistema para detección y aislamiento de fallas utilizando Redes de Petri Interpretadas (RPI)

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Abstract	Resumen
<p>Interpreted Petri Nets (IPN) allow the analysis of Discrete Event Systems (DES) to guarantee the detection of failures in a fast, efficient, and safe way. The objective of this research is the design of an Interpreted Petri Net for the detection of failures in a water supply system. The IPN allows us to identify two types of failures, permanent failures and control failures. The first are inherent to the system and are those that make impossible the functionality of the system. The second refers to those that are inherent to the user and are those failures that do not meet the given specifications. Detecting failures in a system allows the improvement of the operation in such a way that it is more efficient. In this manner, it is possible to design reliable systems which can work properly. In this research, an algorithm was designed for the sensors involved in the system using Interpreted Petri Nets. The detection of failures as main objective is achieved through the implementation of a previously designed IPN. By implementing a programming code in MATLAB®, it was possible to observe its simulated behavior in the system. The input parameters used assume a behavior. Objective: Analyze and implement a mathematical model to automatically detect failures in a system, based on a polynomial algorithm according to the methodology proposed in Matlab®. Methodology: Algorithms were used to characterize the area of influence of the failure in the IPN of the system, from which the implementation in Matlab® showed minimal T-semiflows that do not share any transition with the structure where the failure is located. Therefore, if the problem of linear programming has a solution then the system will be not diagnosable. In this case, if the system is modeled by parts, it is possible to find those parts that are diagnosable and therefore implement the methodology, in this way a module model will be obtained in which the failure detection can be performed. Contribution: Characterization of the diagnosticability property and use of algorithms in MATLAB® to analyze the property of systems designed by IPN. Identify failure occurrence modeled in a system using IPN in MATLAB® for failure monitoring.</p> <p>Diagnosticability, Discrete Event Systems, Interpreted Petri Nets</p>	<p>Las Redes de Petri Interpretadas (RPI) permiten analizar Sistemas de Eventos Discretos (SED), para garantizar la detección de fallas de una manera rápida, eficiente y segura. El objetivo de esta investigación es el diseño de una Red de Petri Interpretada para la detección de fallas en un sistema de abastecimiento de agua. Las RPI nos permiten identificar dos tipos de fallas, las fallas permanentes y las de control. Las primeras son inherentes al sistema, es decir aquellas que imposibilitan la funcionalidad del sistema. La segunda se refiere a aquellas que son inherentes al usuario, es decir, aquellas fallas que no cumplen con las especificaciones dadas. Detectar las fallas en un sistema permite mejorar el funcionamiento de tal manera que sea más eficiente. De esta manera es posible realizar el diseño de sistemas confiables al funcionamiento adecuado. En esta investigación se realizó el diseño de un algoritmo de los sensores involucrados en el sistema utilizando redes de Petri Interpretadas. La detección de fallas como objetivo principal se logra a través de la implementación de una RPI diseñada previamente, la cual mediante la implementación de código de programación en MATLAB®, fue posible observar su comportamiento simulado en el sistema. Los parámetros de entrada utilizados suponen un comportamiento. Objetivo: Analizar e Implementar un modelo matemático para detectar automáticamente fallas en un sistema, basándose en un algoritmo polinomial acorde a la metodología propuesta en Matlab®. Metodología: Se utilizaron algoritmos para caracterizar el área de influencia de la falla en la RPI del sistema, a partir de los cuáles la implementación en Matlab®, mostró T-semiflujos mínimos que no comparten alguna transición con la estructura en donde se encuentra la falla. Por tanto, si el problema de programación lineal tiene solución entonces el sistema será No diagnosticable. En este caso si el sistema es modelado por partes es posible encontrar las partes que son diagnosticables y por tanto implementar la metodología en esas partes, de este modo se obtendrá un modelo por módulos en el cuál se puede realizar la detección de fallas. Contribución: Caracterización de la propiedad de diagnosticabilidad y utilización de algoritmos en MATLAB® para analizar la propiedad de sistemas diseñados mediante RPI. Identificar ocurrencia de falla modelada en un sistema mediante RPI en MATLAB® para monitoreo de las fallas.</p> <p>Diagnosticabilidad, Sistemas de eventos discretos, Redes de Petri interpretadas</p>

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Introduction

Systems are now increasingly complex and require being able to control more specifications in different environments, proving to have levels of high performance. F. Basile and G. Tomassi (2008) monitor system failure states and are based on an online algorithm which estimates the markings of observable transitions without determining the property of diagnosability. In addition, M. Dotoli et al. (2009) considered Discrete Event Systems (DES) with unexpected behavior as caused failures, which are included in a Petri Network (RP) model as uncontrollable transitions.

Algorithms based on mathematical structures using Interpreted Petri Nets (IPN), are a diagnostic method and with software that supports monitoring, like MATLAB®, we can determine online within our system where failures occur. The diagnosis and detection of failures allows us to improve the systems to make them more efficient; if a prototype is carried out, reliable operation can be achieved before its implementation.

Materials and methods

Algorithms were used to characterize the area of influence of the failure in the IPN of the system, from which the implementation in Matlab® showed minimum T-semiflows that do not share any transition with the structure where the failure is located. Therefore, if the linear programming problem has a solution, then the system will be non-diagnosable. In this case, if the system is modeled by parts, it is possible to find the parts that are diagnosable and thus implement the methodology in those parts; in this way, a module model will be obtained in which failure detection can be performed.

Figure 1 RP modules of each component of the water supply system

The IPN model includes two permanent failures f1 and f2, represented respectively by transitions t6 and t7. When constructing a corresponding reachability graph (see Fig. 2) it is observed that the occurrence of a definite indeterminate cycle can occur where transitions t4 and t5 can be triggered to infinity, while f2 was triggered, thus avoiding detection.

Figure 2 Reachability tree of the IPN to be modeled

Diagnostic Property Calculation

In this section we proceed to show the diagnosis analysis, in this case a water supply system of an extruder machine is proposed.

- Components: I considered the water supply system, consisting of: Water tank (T), pump (B) and cistern (C). Each component has a specific task which obeys certain operating conditions.
- Mode of operation: The T component supplies water only while the water tank is half full with cold water.

The Petri Red incidence matrix in its normal behavior is as follows:

$$C^N = \begin{bmatrix} -1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & -1 & -1 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & -1 & 0 & -1 \\ 0 & 0 & 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

Which represents the structure of the network. The matrix that represents the relationship between the places and the sensors is given as follows:

$$\varphi^N = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \quad (1.2)$$

The product of $\varphi^N C^N$ allows analyzing the property of event-detectability of the system, which is presented in the following matrix.

$$\varphi^N C^N = \begin{bmatrix} -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} \quad (1.3)$$

It can be seen that the IPN of the water supply system is event-detectable, that is, that the system is able to observe the events, so algorithms will be applied to analyze the property of diagnosability.

The problems of linear programming are evaluated in such a way that:

- The positive P-semifluxes are obtained, this is the conservative part.
- P-semiflows that contain the places of risk.
- The minimum T semiflow that does not share transitions with previously calculated siphons.

In this way, it is said that if transitions are not shared with the previously calculated siphons, then the system will be diagnosable; otherwise if the system shares transitions with another or with any of the siphons, this means that it can be triggered to infinity and, consequently, the failure will not be detected, therefore it will not be diagnosable.

Risk locations are necessary as system inputs so that the algorithm can characterize each transition and say what P-semifluxes are related to.

This is how we get the following calculations:

Solving the first linear programming problem PPL1 for failure f1, f2 and f3 we have:

$$\begin{aligned} PPL_1 = Y_{conservativo} &= [1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 0] \\ PPL_1 = Y_{conservativo} &= [0 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0] \\ PPL_1 = Y_{conservativo} &= [1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 0 \quad 0] \end{aligned} \quad (1.4)$$

This means that the place of risk p4 is associated with failure f1, p5 is associated with failure f2 and p1 is associated with failure f3. Now, the second problem of linear programming is applied taking as input the Yconservative solution that will get as a result:

$$\begin{aligned} PPL_2 = Y_{general} &= [0 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0] \\ PPL_2 = Y_{general} &= [0 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0] \\ PPL_2 = Y_{general} &= [1 \quad 1 \quad 1 \quad 0 \quad 0 \quad 0 \quad 0] \end{aligned} \quad (1.5)$$

Which are the minimum P- semifluxes to which the transitions are related: f1, f2 and f3 respectively; it can be seen that p4 and p5 are associated to the same p-semiflow that belongs to the behavior of the pump and the temperature sensor and p1 belongs to the p-semiflow related to the operation of the water tank, so we can conclude that f1 and f2 represent failures in the pump and f3 represents a failure in the tank.

Finally, the linear programming problem PPL3 is applied, which for f1, f2 and f3 generates the following solutions:

$$\begin{aligned} PPL_3 &= [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0] \\ PPL_3 &= [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0] \\ PPL_3 &= [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0] \end{aligned} \quad (1.6)$$

Therefore, f1, f2 and f3 are always related to all normal behavior.

Thus, the system in question is diagnosable, and no failure is triggered in an infinite sequence.

Results

Once it is known that the IPN is diagnosable, then, it is guaranteed that if failures occur, they will be detected and located in a finite time. The algorithm guaranteed the detection and isolation of failures in line, from the demanded resource where the failure occurred. The implementation of the proposed case study analyzed in Matlab® was carried out to determine the structural conditions that define whether it is diagnosable or not. The diagnosability of the system implies the existence of a monitoring model, such that it allows the simulator to detect failures. The monitoring process is a tool that helps in this proposal to simulate the online behavior of the evolution of the real behavior of the system. In fig. 3 a failure detection and isolation scheme is observed. Once the Petri Network meets all the diagnostic properties that were characterized to say that an IPN is diagnosable, it is possible to detect permanent and operational failures that occur online in a finite time. The importance of this scheme is that it is possible not only to know the failures, but also to isolate them and to know to which set of failures each one belongs.

Figure 3 Diagnostic Scheme

For this particular case, the operating conditions are available and it was analyzed to determine the structural conditions that define whether it is diagnosable or not. For this purpose an algorithm was first used that defines the diagnostic property implemented in MATLAB and from which the following results were obtained:

Figure 4 First result of the IPN analysis, it is true that an event has been detected

Figure 5 Analysis of the IPN; all the necessary conditions for the system to be diagnosable are met

Conclusions

The occurrence of a failure in the analysis of a monitored system can be controlled in an automated manner and corrective maintenance can be implemented before it occurs.

The Matlab® program allows visualization and simulation in a practical way for the user, since the inputs of different operating sequences can be introduced, each one being analyzed before the failures occur and the set to which they belong, thus making an analysis of the sensitive elements in real time.

With the results obtained, the algorithm guarantees the detection and isolation of failures in line, giving certainty that the system will detect the failures without user interaction and the system will know the demanded resource where the failure has occurred.

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