A Fault Propagation Model of Embedded Systems Based on Fault Association *

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Abstract - According to the characteristics of the hardware associated with software in embedded systems, this paper defined a new Fuzzy Petri Nets, and presented a model of embedded systems based on the Fuzzy Petri Nets according to the new definition. Finally, an example showed the specific modeling method and fault propagation process, illustrated the validity of the model.

Index Terms - embedded systems, Fuzzy Petri Nets, Fault association, fault propagation

1. Introduction

With the development of information technology, embedded systems obtained more and more applications. In many complex embedded systems, especially in such a complex system of aerospace systems, including spacecraft, launch vehicles and launch their facilities and equipment. These systems high degree of automation, complex structure, both inside and outside the system related to each other, close combination of hardware and software the synergistic action together to complete the task. The event of failure, especially common failure, will produce incalculable results, even disastrous results. Therefore, the safety and reliability of the aerospace embedded systems is extremely important, the fault diagnosis technology has important military and economic significance.

Fault diagnosis is to research the relationship between the failure modes and failure characteristics failure mechanism analysis. But difficult to use a precise mathematical model due to the relationship between the Aerospace and system complexity, failure modes and characterized in that the performance of some fault condition is inherently fuzzy, and not with a simple result of the "fault" to express, In addition, a variety of complex systems failure phenomenon and the cause of the malfunction is not a simple one-to-one relationship, some kind of failure phenomenon may be caused by more than one cause of the malfunction.

Due to the failure of the generation and propagation of a typical dynamic behavior of the process, many scholars have proposed dynamically generated fuzzy mathematical theory and Petri nets combine to describe the phenomenon of failure process the respective fault Petri net is defined and in the corresponding field of fault diagnosis within applications [1-4].

In this paper, the hardware and software closely related embedded systems fault propagation mechanism is proposed based on Fuzzy Petri Nets embedded system fault propagation model. The paper is organized as follows: In Section 2, I give a new definition of Fuzzy Petri Nets and the fault propagation model on the basis of the new definition, In Section 3, I present the fault propagation model based on Fuzzy Petri Nets in embedded systems considering the impact of hardware associated with software, The application of the model is illustrated in the Section 4, Finally, some conclusions are presented in Section 5.

2. Fault propagation model based Fuzzy Petri Nets

Based on the fault propagation model of Fuzzy Petri Nets can be a good description of the system state and behavior change, reflecting the fault propagation characteristics and propagation behavior, describing the fuzzy relationship between fault features and fault mode, clearly reflect the failure of the generation, development and impact [5].

2.1 The definition of Fuzzy Petri nets

Definition1: Fuzzy Petri Nets fault propagation model is 8-tuple $\Omega = (P, T, A, I, O, \alpha, \beta, \mu)$ where P and T are called places and transitions.

The Non-empty finite set of places nodes $P = \{P_1, P_2, \dots\dots, P_m\}$ is expressed in round in the Fuzzy Petri nets.

The Non-empty finite set of transitions nodes $T = \{T_1, T_2, \dots\dots, T_n\}$ is expressed in short-term in the Fuzzy Petri nets.

The $P \cap T = \emptyset$, $P \cup T \neq \emptyset$ condition must been meet between P and T.

The set $A = (P \times T) \cup (P \times T)$ is a directed Arc set of $P \rightarrow T$ and $T \rightarrow P$.

The parameter $I = [r_{ij}]_{m \times n}$ is an $m \times n$ matrix which means that the relationship from P_i to T_j.

The parameter $O = [\rho_{ij}]_{m \times n}$ is an $m \times n$ matrix which means that the relationship from T_j to P_i.

The parameter α is the proposition real degree fuzzy value, represented by token in the place, Equivalents the history prior probability of proposition occurrence.

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The parameter β is the fuzzy value which the transition is fired probability, being decided by the experts given probability and system operation information.

The parameter μ is the transition credibility from a place to post-place, when the firing conditions are met, Equivalents the history prior probability.

What transition is fired means that the system dynamic behavior changing from one place to another place, but the premise of the proposition does not disappear after the transition being fired.

2.2 The fault propagation model based Fuzzy Petri Nets

Definition 2: Given a node $y \in \Omega$, $*_y = \{x|(x,y) \in A\}$ is the preset of y, while $y^* = \{z|(y,z) \in A\}$ is the post-set of y.

System fault propagation Fuzzy Petri Nets consist of the subsystem fault Fuzzy Petri Nets, subsystem fault propagation Fuzzy Petri Nets is composed of the most basic fault propagation model. We define four basic fault propagation modes: sequential propagation mode, concurrent propagation mode, AND gate propagation mode, OR gate propagation mode. Various propagation modes is shown in Fig. 1 – Fig. 4, where α_i is the proposition real degree fuzzy value, represented by token in the place, equivalents the history prior probability of proposition occurrence, β_i is the fuzzy value which the transition is fired probability, being decided by the experts given probability and system operation information, μ_i is the transition credibility from a place to post-place, equivalents the history prior probability.

The sequential propagation mode: that is a cause of the fault led to a failure mode. As Fig. 1 shown below, the place P_1 has got failure and its real degree fuzzy value is α_1, the transition T_1 being fired probability value of is β_1, the credibility of the change from the place P_1 to the place P_2 is μ_1, So the place P_2 will got failure and its real degree fuzzy value

$$\alpha_2 = \alpha_1 \times \beta_1 \times \mu_1.$$

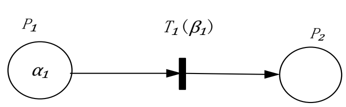

Fig. 1 sequential propagation mode

The concurrent propagation mode: that is a cause of the fault led to multiple failure modes. As Fig. 2 shown below, the place P_1 Fault, and its real degree fuzzy value is equal to α_1, the transition T_1 being fired probability value of is β_1, the credibility of the change from the place P_1 to the place P_2, P_3, P_4 all is μ_1, So the place P_2, P_3, P_4 will got failure and the real degree fuzzy value

$$\alpha_2 = \alpha_3 = \alpha_4 = \alpha_1 \times \beta_1 \times \mu_1.$$

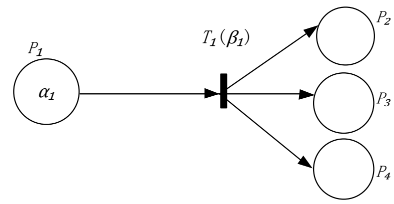

Fig. 2 concurrent propagation mode

The AND gate propagation mode: That more than one Fault causes a failure mode. As Fig. 3 shown below, There are Failure in the place P_1, P_2 and P_3, and the real degree fuzzy value all is equal to α_1, the transition T_1 being fired probability value of is β_1, the credibility of the change from the place P_1, P_2, P_3 to the place P_4 all is μ_1, So the place P_4 will got failure and the real degree fuzzy value

$$\alpha_4 = min(\alpha_1, \alpha_2, \alpha_3) \times \beta_1 \times \mu_1.$$

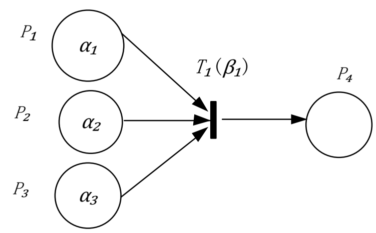

Fig. 3 AND gate propagation mode

The OR gate propagation mode: One of the fault cause can result in a failure mode. As Fig. 4 shown below, The Failure in the place P_1, P_2 and P_3, is equal to $\alpha_1, \alpha_2, \alpha_3$ respectively, the transition T_1, T_2, T_3 being fired probability value of is $\beta_1, \beta_2, \beta_3$ respectively, the credibility of the change from the place P_1, P_2, P_3 to the place P_4 is μ_1, μ_2, μ_3, So the place P_4 will got failure and the real degree fuzzy value

$$\alpha_4 = max(\alpha_1 \times \beta_1 \times \mu_1, \alpha_2 \times \beta_2 \times \mu_2, \alpha_3 \times \beta_3 \times \mu_3).$$

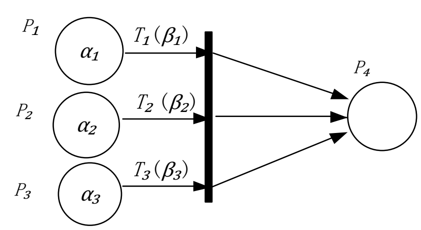

Fig. 4 OR gate propagation mode

3. The fault propagation mode of Embedded systems hardware associated with software based Fuzzy Petri Nets

In fact, the firing of transition doesn't result in the movement of information in the place, but derivative of the fault information, fault information can be shared and superimposed. When the firing conditions are met, and the transition has not been fired, the system will be changed. The

Firing of the transition is relevant to the proposition state in its preset and its own circumstances. The Fault information sharing and superimposed present the concurrent Fault. About the hardware associated with software Closely for embedded systems, it is assumed that the proposition, the place, and the transition can be hardware devices, can also be a software system, the entire system is not particularly divided into software systems and hardware systems, but treated the same. This Fault propagation model based Fuzzy Petri Nets can be a good simulation of fault propagation mechanism for embedded systems. Considering the proposition status in the place and the transition, I give a fault-propagation algorithm that can calculate the real degree fuzzy value of the post-set when the real degree fuzzy value of the preset is given.

The definition of the algorithm [6]:

(1) Input Matrix $I = [r_{ij}]_{m\times n}$ is an $m \times n$ matrix which means that the relationship from P_i to T_j where

$$r_{ij} = \begin{cases} 1 & \text{if } P_i \text{ is the input of } T_j \\ 0 & \text{if } P_i \text{ isn't the input of } T_j \end{cases}$$

$i = 1,2,\dots.m,\ j = 1,2,\dots n,$

(2) $\mu = [\mu_1, \mu_2, \dots \mu_n]$ means the credibility of the change from the place to its post-place,

(3) Output Matrix $O = [\rho_{ij}]_{m\times n}$: is an $m \times n$ matrix, which means that the relationship from P_i to T_j and the credibility of the change from the place to its post-place where

$$\rho_{ij} = \begin{cases} \mu_j & \text{if } P_i \text{ is the output of } T_j \\ 0 & \text{if } P_i \text{ isn't the output of } T_j \end{cases}$$

$i = 1,2,\dots m,\ j = 1,2,\dots n,$

(4) $\alpha_k = [\alpha_{1k}, \alpha_{2k}, \dots \alpha_{mk}]^T$ means the proposition real degree fuzzy value in the place,

(5) $\beta = [\beta_1, \beta_2, \dots \beta_n]^T$ means the fuzzy value which the transition is fired probability,

(6) The Addition Operator $\oplus$: If A, B, C all is $m \times n$ matrix, $A \oplus B = C$, then $c_{ij} = \max(a_{ij}, b_{ij})$,

(7) The Multiplication Operator $\otimes$: If A, B, C is $m \times p$, $p \times n$, $m \times n$ matrix respectively, $A \otimes B = C$, then $c_{ij} = \max_{1\le k\le p}(a_{ik} \cdot b_{kj})$,

(8) Neg Operator: If γ is a m-dimensional vector, then $neg(\gamma) = 1_m - \gamma$, 1_m is a m-dimensional vector whose element all is 1.

Fault propagation algorithm is as follows:

Step 1 Given all preset and post-set of every transition,

Step 2 Given the initial value α_0, the transition firing probability fuzzy value β and the credibility μ,

Step 3 Given the Input Matrix I and the Output Matrix O,

Step 4 Calculate $\alpha_{k+1} = \alpha_k \oplus \{O \otimes [neg(I^T \otimes neg(\alpha_k))] \otimes \beta\}$

Step 5 If $\alpha_{k+1} \neq \alpha_k$, then $k = k + 1$, repeat step 4, else $\alpha_{k+1} = \alpha_k$, fault propagation is over.

4. Application Examples

An example about the Fault Petri nets of a control subsystem of space system [7] illustrates the fault propagation model based Fuzzy Petri Nets and fault propagation. Known the place P_3 Fault, the proposition fuzzy value is 0.96, the initial state is as follows Fig. 5 - (a) below, all changes occur following status shown in Fig. 5 - (b).

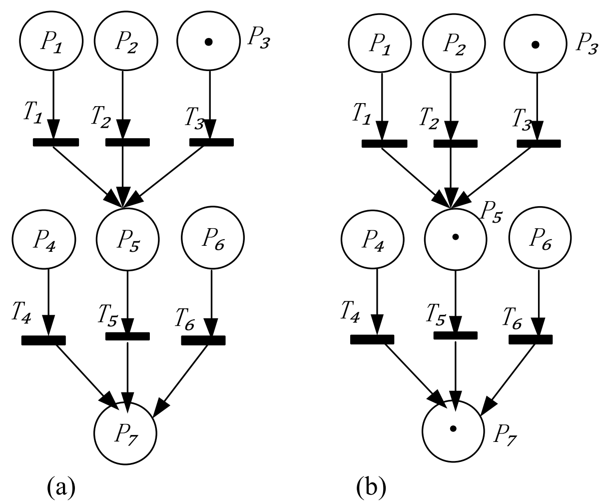

Fig. 5 A Fuzzy Petri Net of the fault propagation model for a controlling subsystem

The steps of the algorithm:

Step1 Given preset and post-set of the transition, shown TABLE 1.

TABLE 1 Preset and Post-set of the Transition

transition	preset	Post-set
T_1	P_1	P_5
T_2	P_2	P_5
T_3	P_3	P_5
T_4	P_4	P_7
T_5	P_5	P_7
T_6	P_6	P_7

Step2 Given

$\alpha_0 = (0,0,0.95,0,0,0,0)^T$, $\beta = (0.75,0.67,0.85,0.94,0.78,0.89)^T$

$\mu = (0.96,0.98,0.94,0.97,0.93,0.95)$.

Step3 Calculate the Input Matrix I and Output Matrix O.

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$O = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0.96 & 0.98 & 0.94 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.97 & 0.93 & 0.95 \end{bmatrix}$$

Step4 Calculate

$\alpha_1 = (0,0,0.95,0,0.893,0,0)$.

Step5

$\alpha_1 \neq \alpha_0$,then Calculate

$\alpha_2 = (0,0,0.95,0,0.893,0,0) = \alpha_1$.

Finally we arrive the goal place P_7 which is an OR gate propagation mode, so the eventual fault propagation path to P_7 is:

$P_3 \rightarrow P_5 \rightarrow P_7$.

5. Conclusions

Because of the complex structure of the embedded system, the hardware and software are linked closely together, the failure propagation mode is diverse, not sure of the cause of the fault, the propagation model based on Fuzzy Petri Net is applied to the fault propagation of the complex system in the paper, by an example, I prove the usefulness of fault propagation model based on Fuzzy Petri Net propagation algorithm, as well as its visual features.

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