A Modeling Approach of System Reliability Based on Statecharts

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Abstract

The paper puts forward a modeling approach of system reliability based on statecharts. Firstly, it analyzes the limitation of current reliability modeling approach, and introduces the elements and characters of statecharts. Then, it sets forth reliability modeling approach of state-independent system and state-dependent system. In the end, it reviews the modeling approach of system reliability based on statecharts. System reliability model based on statecharts is a universal modeling approach which can resolves the system reliability dynamics, depict the system reliability vividly combining the other reliability modeling methods.

1. Introduction

Reliability model is an abstract, mathematical and graphical representation of the system reliability. At present the common reliability models are: the reliability model of the portfolio, Markov models, Petri net models, Monte Carlo simulation model [1-3]. Lack of reliability models for existing, this paper attempts to provide a more general framework of the reliability model: system reliability model based on statecharts to better compensate for the lack of current models.

2. Statecharts

In 1987, Harel [4] based on finite state machine theory proposed statecharts (state diagram) theory, statecharts is a discrete state transition system describes the graphical model. 20 years later, statecharts
have been widely used, such as in UML[5] and SysML, statecharts describing the system dynamic behavior is the important part; in Matlab Stateflow toolbox, statecharts has been further improved. You can respond to the complex system modeling and simulation; in Labview statecharts also have applications.

2.1 Characters of Statecharts

Discrete event system is actually a state machine framework with the model. However, the actual control, DES (Discrete Event System) by the number of concurrently running components. The main disadvantage of the state machine is that it can not model the parallel activities and collaboration. Therefore, as part of the increase in the composite system, the state machine model with exponentially growing number of states. Exponential growth in the state of state machine modeling framework is a fatal drawback, most of the complexity of the algorithm into a linear relationship with the state.

In order to reduce the complexity of state machine model, while retaining its advantages, Harel proposed statecharts modeling framework, extending the functionality of a state machine, which greatly enhanced its modeling capabilities, a state machine with, depth, radio co- mechanisms and other advanced statecharts. For example, a. State by the level of the parent state and sub-state, achieving a depth. b. State can be run concurrently to achieve parallelism. c. At all levels of the state diagram of the structure, the transfer can occur, so concise description. Harel’s statecharts can be short, as follows:

Statecharts= state machine+ depth+ orthogonality+radio

2.2 Elements of Statecharts

Statecharts is a language described complex reaction system behavior in graphical form. Its main elements are described below [6].

As in the conventional state transition diagrams, state is the basic component elements of statecharts. However, the state can be embedded in the parent state, so the state has a hierarchy. There are two types of the parent state: " with" and "exclusive or". The former describes the state of concurrency; which the state can be refined. If the system is in "with", a certain parallel to all the sub-state. That is, the state is divided into several parts with dashed lines. If the system is in "exclusive or", must be in either sub-state.

State through the transfer interaction, composed of three parts: event, condition and action. State diagram transfer labels the following syntax:

\[ \alpha[C]/\beta \]

\( \alpha \) is the event of the trigger transfer; \( \beta \) is the action performed after the transfer. Events and conditions that are input, the action is the output. Conditions by the logic and relational operators, comprising variables and special conditions in \( \text{(X)} \) (that is in state \( X \)), en () (that events of enter the state \( X \)).

3. Reliability Modeling of State-Independent System Based on Statecharts

3.1 Modeling Steps

Modeling with statecharts specific steps:

1) The establishment of parts of the state diagram

   Usually we only consider the "normal" and "failure" two states.

2) The establishment of the system state diagram

   The key part is to determine the status and system status is part of the logic expression. The solution is to first establish a combination of system reliability model; then combined according to the system
reliability model, to get the system structure function; Finally, the system structure function into parts of the state and system state logic expressions.

3.2 Build the Logic Expression

In order to define the system structure function, so that

\[ X_i = \begin{cases} 
1 & \text{Component } i \text{ normal} \\
0 & \text{Component } i \text{ failure}
\end{cases} \quad (1) \]

System structure function:

\[ \Psi (X_1, X_2, \ldots, X_n) = \begin{cases} 
1 & \text{System } i \text{ normal} \\
0 & \text{System } i \text{ failure}
\end{cases} \quad (2) \]

3) Series systems

For series systems, the system structure functions:

\[ \Psi (X_1, X_2, \ldots, X_n) = X_1 X_2 \cdots X_n = \min[X_1, \ldots, X_n] = X_1 \cap \cdots \cap X_n \quad (3) \]

4) Parallel systems

For parallel systems, the system structure functions:

\[ \Psi (X_1, X_2, \ldots, X_n) = 1 - (1 - X_1)(1 - X_2)\cdots(1 - X_n) \]
\[ = \max[X_1, \ldots, X_n] = X_1 \cup \cdots \cup X_n \quad (4) \]

5) \( K/n \) (G) voting system

Voting system is a redundant system, in engineering practice has been widely used. System composed of several units, as long as there are K or more than K units normal, the system is normal, to put such a system is called: " take K in to n good (K-out-of n: Good) voting system." denoted by \( K/n \) (G) system.

For \( K/n \) (G) systems, the system structure functions:

\[ \Psi (X_1, X_2, \ldots, X_n) = \begin{cases} 
1 & \text{if } \sum_{i=1}^{n} X_i \geq k \\
0 & \text{if } \sum_{i=1}^{n} X_i < k
\end{cases} \quad (5) \]

6) \((K to r)/n \) (G) voting system

In n units, there are K to r units normal, the system normal. If normal number of units is less than K or greater than r \( (r > k) \) then the system is unormal. For example, multi-processor system, if all n sets of processors, less than K sets to work, the system computing power is too small; if more than r units simultaneously, then the utility equipment (e.g. bus) can not hold so much data volume, and thus the system efficiency is very low. It can be considered normal K to r sets of processors, the system is normal, or system failure. Similar situation exists in any capacity with a fixed computer networks.

The system structure function:
n continuous K voting system

n continuous K system need to be considered more failure modes and logic expressions complex, for example here to illustrate the specific methods. For example, "4 continuous 2" system, if the components 1, 2 failure, or components 2, 3 failure, 3, 4 failure, the system failure. So, from a normal to fault state transition label conditions: \[(\text{in} (\text{c1.off}) \& \& \text{in} (\text{c2.off})) \lor (\text{in} (\text{c2.off}) \& \& \text{in} (\text{c3.off})) \lor (\text{in} (\text{c3.off}) \& \& \text{in} (\text{c4.off}))\]; Similarly to normal from a fault condition the transfer of the label’s criteria: \[! ((\text{in} (\text{c1.off}) \& \& \text{in} (\text{c2.off})) \lor (\text{in} (\text{c2.off}) \& \& \text{in} (\text{c3.off})) \lor (\text{in} (\text{c3.off}) \& \& \text{in} (\text{c4.off})))\].

complex systems

For complex systems (such as fault tree, network systems and hybrid systems) can be the first of its analysis, the minimal cut sets and minimal path sets [7]. By the minimal cut sets and minimal path sets can get the system structure function, the system structure function can be converted to a function, can also be converted to a logic operation. All the minimal path is \(P_1, ..., P_m\), minimal cut sets for the \(c_1, ..., c_l\). The failures of the structure function is:

\[
\Psi (X_1, X_2, ..., X_n) = \bigcap_{j=1}^{m} \bigcup_{i \in c_j} X_i
\]

or

\[
\Psi (X_1, X_2, ..., X_n) = \bigcup_{j=1}^{m} \bigcap_{i \in c_j} X_i
\]

4. Reliability Modeling of State-Dependent System Based on Statecharts

State-dependent system is more complex, traditional reliability modeling approach is to use Markov models and Petri net models. Here are some typical state-related system reliability model.

4.1 Load Sharing System

Load sharing system, composed of two components in parallel. If one component fails, the other components due to take on more load, the failure rate increases.

Figure 1. Load sharing system reliability model

Figure 1 is based on the statecharts of the load sharing system reliability model. Figure 1 c1 and c2 represent the two components, sys that system, they are parallel state. c1 and c2 have three states: on1
(half load normal), on2 (full load normal), off (fault); sys has two states: on (normal), off (failure). c1, c2, sys the initial state is the normal state; when c1 fault, if c2 is a normal state in a semi-load to full load normal state; until c1 and c2 are failures, system failures.

4.2 Cold Reserve System

Reserve system is the number of units as spare parts, and work can replace the failed unit work to improve system reliability. Cold reserve is a reserve unit in the process does not work without fault, the length of the reserve unit’s work life is not affected. Figure 2 is based on the statecharts of the cold storage system reliability model. C1 and c2 that figure in two parts, sys that system, they are parallel state. c1 and c2 have three states: on (normal), wait (stand), off (fault); sys has two states: on (normal), off (failure). c1, sys the initial state is normal, c2 initial state to standby state; after a failure when c1, c2 into the normal state based on conditions; until c2 failure, system failure.

Figure 2. Cold reserve system reliability model

4.3 Warm Reserve System

Warm reserve its unit will fault in the storage period, but it's failure rate is less than the failure rate, which ranged between cold reserve and hot reserve.

Figure 3 is the warm reserve system reliability model based on statecharts. Figure 3 and Figure 2 is basically the same, only increased the state wait to state off the transfer, and the events f2 and f4. The implication is that when the components c1 and c2 in stand-by state, you may fail, thus describes the unit in the storage period will fail.

Figure 3. Warm reserve system reliability model

4.4 Cold Reserve System consider the transition failure

In practical problems, the cold reserve system switch may malfunction, which is good or bad switch affect the system reliability is an important factor. In practice, the switch is good or bad, and its impact on the system may have a variety of different types. Now consider two different types:
5. Example

Here, an example to illustrate the system reliability model to establish a general method. Figure 6 shows the block diagram of a system reliability model [7], we can learn from the figure S, B, C form a reserve system with a switch, we here assume that the system is cold reserve system, when the system switches S failure, system failure immediately; also reserve system with a switch in series with the a is the relationship.

First, we will re-division of this system, dividing the result shown in Figure 7. This system of "dynamic" part and "static" part separated. Then, switch the cold belt reserve system reliability model. Finally, construct the series system reliability model. The results shown in Figure 8.
6. Conclusion

This paper discusses the system reliability modeling based on statecharts. This approach has many advantages: First, to describe the dynamics of the system state and concurrency. Second, it could describe the impact of maintenance on system reliability. The third is a comprehensive. System reliability based on statecharts modeling to fully draw on other modeling approaches, while also building a common framework for reliability modeling. Fourth, easy to translate into reliability simulation model. Fifth, do not appear Markov models and Petri net model of the sharp increase in the number of states, and more convenient for large and complex system-level modeling.

In short, the system reliability model based on statecharts is a general reliability model framework, this approach can solve the problem of dynamic modeling system reliability, reliability modeling can be way before the combined reliability of the system carry out a more detailed description of the simulation can be used as a conceptual model of system reliability, high engineering value.

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