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Integrated Reliability Estimation of a Nuclear Maintenance Robot including a Software

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1. Introduction

Conventional reliability estimation techniques such as Fault Tree Analysis (FTA), Reliability Block Diagram (RBD), Markov Model, and Event Tree Analysis (ETA) have been used widely and approved in some industries [1]. Then there are some limitations when we use them for a complicate robot systems including software such as intelligent reactor inspection robots. Therefore an expert's judgment plays an important role in estimating the reliability of a complicate system in practice, because experts can deal with diverse evidence related to the reliability and then perform an inference based on them. The proposed method in this paper combines qualitative and quantitative evidences and performs an inference like experts. Furthermore, it does the work in a formal and in a quantitative way unlike human experts, by the benefits of Bayesian Nets (BNs).

2. BN based integrated reliability estimation method

2.1 Advantages of Bayesian Net (BN)

BNs are graphs consisting of nodes (variables), arcs and a node probability table (NPT). The node represents a discrete random variable. The arcs represent a causal relationship between the variables [2]. The main advantage of the BN is to propagate consistently the impact of evidence on the probabilities of uncertain outcomes, by the rules of a probability. Another advantage is that the BN can enable us to make inferences which are much more precise than just using expressions such as “very likely,” “unlikely,” “slightly increases” and so on. Besides the BN also allows for both subjective probabilities and probabilities based on statistical data in a unified framework, thus in turn we can combine qualitative and quantitative measures in making inferences.

2.2 BN based integrated reliability estimation method

There is no generally accepted a single method which can handle all parts of a complicate system including software. Therefore it is useful to select a proper method for each part of the system and integrate them into a whole assessment model. In this light, we implemented this approach by utilizing the BN as shown in Fig. 1 which is the high level BN graph for reliability estimation for a nuclear robot including software. This BN model considers all aspects related to reliability of a system in the development cycle.

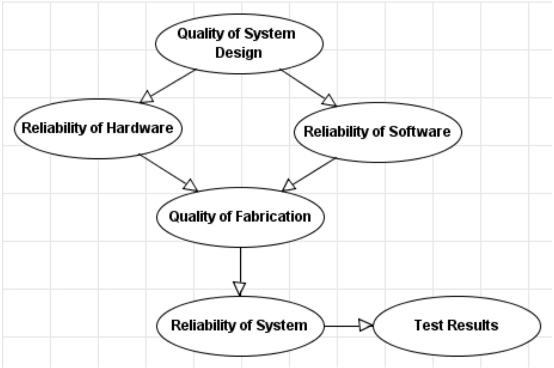

Fig. 1 High level BN graph for a robot's reliability

Conventional reliability assessment techniques are mostly analyzing method based on the failure rate of components which constitute a whole system. So these kinds of methods are not proper for considering errors in the design aspect such as embedded software in a system. The BN method can be one of the alternatives for this case. For a software part, there are many techniques for a reliability analysis. Some of them are testing, various reliability growth models, Bayesian Nets, and so on.

A robot's hardware usually consists of an electronic part and a mechanical part. The widely known methods for a component reliability of electronic parts are MIL-HDBK-217[3], Bellcore TR-332[4]. The reliability of hardware including electronic components can be calculated by using RBD, FTA, and simulation models.

The BN calculates value of a target node based on observed evidences. Therefore it is necessary to obtain the value of all observable nodes. These values can be obtained in a quantitative form (for example, test results or the reliability of hardware components) or a qualitative form (for example, expert's judgment about the quality of design team or the quality of design process).

By utilizing BN's benefits the proposed method can convert an expert's informal and quantitative evaluation process into a formal and quantitative process, and also overcome the conventional methods' limitations that could not consider an expert's qualitative judgments. The method can also obtain a quantitative conclusion by systemically combining all evidences (qualitative and quantitative) into one unified model.

2.3 Case study

The proposed method was applied to reliability assessment of a automated reactor inspection robot (RISYS) which was developed in Korea Atomic Energy Research Institute (KAERI).

RISYS consists of an underwater mobile robot (RIROB), a direction indicator system (LAPOS), and a main control computer. RIROB moves around on the inner wall of a reactor, and LASPO indicates RIROB's course with a laser beam. RIROB has a manipulator to maneuver a few ultrasonic transducers which are necessary for an inspection of welded parts of the reactor. The main control computer has several application programs which control RIROB and LASPO.

Important factors in the design of RISYS are requirement complexity, design team quality, design complexity, design method quality, design process quality, resource constraints. These factors were used as nodes (variables) in the design-stage BN as shown in Figure 2.

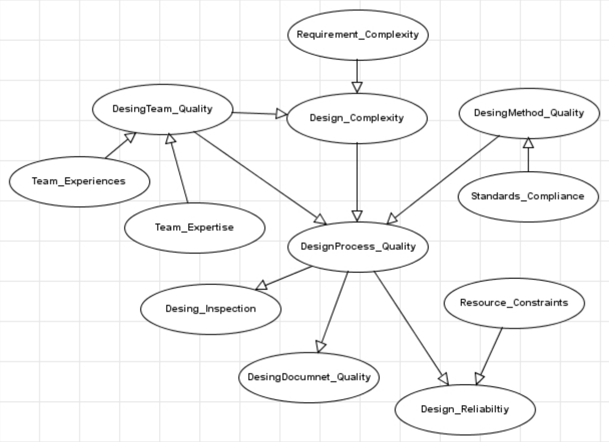

Fig. 2 BN graph for the design stage of RISYS

Part count analysis method and part stress analysis method in MIL-HDBK-217 [3] were used to calculate reliability of the electronic part of RISYS hardware, and FTA method was used to calculate the mechanical part of the RISYS hardware. Base time for the calculation of a failure rate is one million hours. An example of reliability data of the electronic part is shown in Table 1, and Figure 2 is the top level FTA for the reliability calculation of the hardware of RIROB.

Table 1 Reliability of the RIROB hardware by MIL-HDBK-217 (Environment NS-Naval Sheltered, Temperature: 30.0 C)

Assembly name	Part #	Qty	Failure Rate	MTBF
Controller	Sub #1	1	106.105	9,425
Capacitor		1	2.890	345,961
Connector		1	90.909	11,000

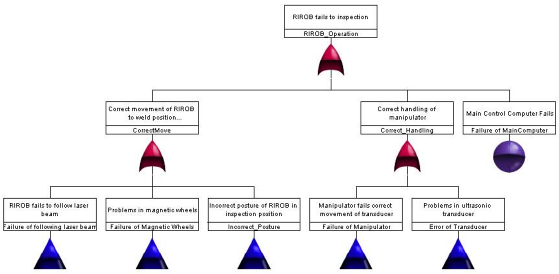

Fig. 3 FTA of RIROB hardware

Most frequently occurring events (gates) in the FTA were failure of RIROB main control board, failure of motor driver board, and failure of encoder board.

The reliability of software was estimated by the BN based on evidences. First we identified important factors relevant to reliability of software, and constructed a BN graph with those factors. Input (evidence) values for software part of the BN were mostly prepared by experts. Historical data in Table 2 were used in assigning the probabilities to high level nodes of the BN. Table 2 is the failure distribution of the electronic systems derived from the historical data [5].

Table 2 Failure distribution of the electronic systems (unit %)

<table>
<tr><td rowspan="5">Reliability of final product (100)</td><td rowspan="4">Reliability of prototype (74.7)</td><td rowspan="3">Reliability of design (37.4)</td><td>Design process quality (17)</td></tr>
<tr><td>Resource constraints (3.4)</td></tr>
<tr><td>Software adequacy (17)</td></tr>
<tr><td colspan="2">Reliability of hardware (37.3)</td></tr>
<tr><td colspan="3">Product adequacy (25.3)</td></tr>
</table>

As computation of the BN is a very intricate process, one should use a proper computer tool for a practical size BN. In this paper, we used tool "AgenaRisk" [6] to calculate the BNs of RISYS. The value of the target node in the BN is 86.82%, and this number means that 'probability of {less than 1 failure} during {100 operating hours of RISYS} is 0.8065. The reliability of RISYS considering the field test results, which is 74.36%, was lower than that of without considering the field test result. This is due to the condition of the field test environment which was much worse than the normal operation environment.

3. Conclusions

The proposed method can combine diverse evidences relevant to reliability of a complicate robot. Therefore it can overcome some limitations in conventional reliability analysis methods. A case study was carried out to verify the feasibility of the method and the results were promising. The limitation of the method is that the construction of BNs for design aspects requires a lot of experts' subjective judgments (probability), so it is necessary to develop a proper technique that can convert qualitative information into probabilities.

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