Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Bayesian Network based Reliability Model of a UGV for Remote-response in Nuclear Emergency Situation

Heung-seop Eom [a*], Kyungmin Jeong [a]
[a] *Fusion Technology Division, Korea Atomic Energy Research Institute, Daejeon, Korea*
[*] *Corresponding author: ehs@kaeri.re.kr*

1. Introduction

UGVs are appealing for Urban Search and Rescue (USAR) and Modern military Operations in Urban Terrain (MOUT) [1]. They can also be useful for nuclear emergency situation for similar reasons, thus some of UGVs are utilized for various purposes in Fukushima NPPs in Japan [2]. But current UGVs are far from commonplace because they have shown a noticeable lack of reliability in real field conditions [1]. Therefore, in order to use UGVs for nuclear emergency situations there are two important problems to be solved: One is development of reliable UGVs and another is a proper method to evaluate reliability of those developed UGVs correctly.

This paper presents a Bayesian Network (BN) based UGV reliability assessment model which covers the whole development life-cycle of a UGV. It models faults insertion and elimination process during a development phase, and then integrates all development phases to get the final number of faults. The checklist method is used to gather the input data for the BN model. The objective of this paper is to present the quantitative reliability assessment method that will be applied to various UGVs for remote-response in nuclear emergency situations.

2. A BN Model for Reliability Assessment of a UGV

As there are so many uncertain factors related to reliability estimation of a UGV, it can't be correctly estimated just by testing or conventional analytical methods such as Fault Tree Analysis, Reliability Block Diagram, and Markov analysis [3]. Thus it is reasonable to consider some methods which can cover uncertain factors including expert's subjective judgments [4]. A Bayesian Network is a graphical probabilistic model that is especially well-suited in decision-making area that require us to consider multiple pieces of uncertain evidence involving causal relationships. For this reason we used Bayesian Network to model reliability assessment of a UGV. The proposed BN model can cover the whole development life-cycle of the UGV, and can assess all the factors affecting reliability of the UGV in each development phase. The BN model also assesses qualitative and quantitative factors related to reliability in systematic and consistent way.

2.1 Reliability Assessment Process of a UGV through a Development Life-cycle

The life-cycle of a UGV consists of many phases. Among them, only the following five phases are considered in this paper because reliability of the UGV after the validation phase is of interest.

- User requirements phase
- System requirement phase
- Design and components development phase
- Integration phase
- Validation (Acceptance Testing) phase

At each development phase in the UGV development life-cycle, development activities and V&V activities are performed. During the development activities in each phase a number of faults are inserted, and during the V&V activities some portion of inserted faults are eliminated. The number of remaining faults in the output from each development phase (for example, system requirement specification, design specification, etc.) is calculated in this way, and the fault numbers in the validation phase becomes the one directly used for the calculation of reliability of the UGV. Finally, the number of faults in the validation phase and the operational environment are combined in a probabilistic way to estimate quantitative reliability of the UGV.

2.2 Some Important Variables affecting Fault Number Calculation in each Development Phase

In the proposed BN model, some important variables affecting the number of faults occurring in each development phase are functional characteristics, process characteristics, and V&V characteristics. Functional and process characteristics decide the number of faults inserted by development activities, and V&V characteristics decide the number of faults eliminated by V&V activities.

The functional characteristics consist of accuracy, functionality, reliability, robustness, safety, security, consistency, and timing [5]. The process characteristics consist of completeness, consistency, correctness, style, traceability, unambiguity, and verifiability [5]. The operational environment affects the calculation of UGV reliability along with remaining faults at the validation phase.

2.3 Graph of the BN Model

The BN graph represents the qualitative part of the model and Fig. 1 shows the process of fault insertion, elimination, and the calculation of remaining faults in a development phase. The node 'function characteristics' and the node 'process characteristics' decide the number of faults inserted in the current development phase and the number of inserted faults are represented in the node 'faults inserted'. The node 'V&V characteristics' decides the number of faults eliminated by V&V and the number is represented in the node 'faults eliminated by V&V'. The node 'faults after V&V' is the result of [the value of 'faults inserted' minus the value of 'faults eliminated by V&V'].

The node 'fault from previous development phase' represents the number of remaining faults in the product of the previous development phase. The node 'previous faults eliminated by V&V' represents the number of previous faults eliminated by V&V activities in the current development phase. The node 'previous faults after V&V' represents the number of remaining faults in the previous product (output from the previous development phase) after V&V activities. Finally, the node 'remaining faults in current development phase' represents the number of remaining faults in the output at the end of the current development phase, and it is the sum of the node 'faults number after V&V' and the node 'previous faults after V&V'. The value of the node 'Remaining faults in current development phase' becomes the value of the node 'fault from previous development phase' in the next development phase BN.

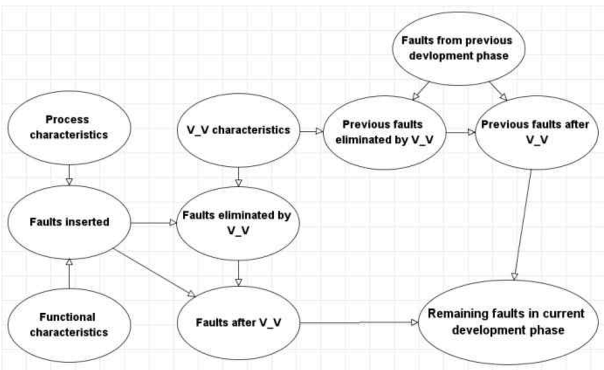

Fig. 1. The BN graph representing faults insertion/elimination process in a development phase

2.4 Quantitative reliability of a UGV in the BN Model

Unlike earlier development phases, there are not 'functional characteristics, and 'process characteristics' nodes in the validation phase, because main activities in the validation phase is testing (Fig. 2). As described in the previous section, the number of remaining faults in the validation phase and a UGV's operational environment decides reliability of the UGV. The node 'Faults from integration phase' is the number of faults included in the previous development phase (Integration phase) and the node 'V&V characteristics in validation phase' represents the quality of V&V activities in the validation phase, which are necessary for calculation of the number of remaining faults in the validation phase. Then quantitative reliability of the UGV is estimated by combining these two variables; 'Remaining faults in Validation phase' and 'Operational environment' as shown in Fig. 2.

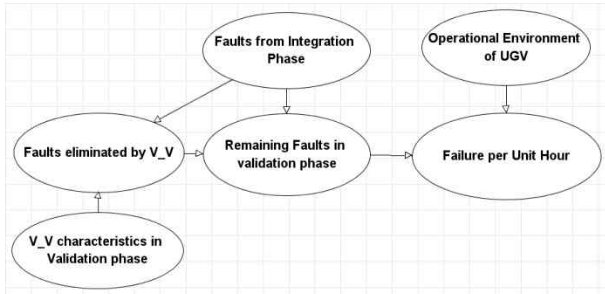

Fig. 2. The BN graph of the validation phase representing the process of UGV reliability estimation.

Table 1 is the node probability table (NPT) of the node 'Failure per Unit Hour' which is used to calculate reliability of the UGV.

Table I: NPT of the Reliability Node

Node name	NPT
Failure per Unit Hour	Type: ***Binomial distribution*** *Trials: Remaining Faults in Validation,* *Success: Operational Environment*

3. Summary and Discussion

A BN based reliability assessment model for a UGV is presented. It models faults insertion and elimination process in development phases through the whole life-cycle, and reflects specific features (such as development quality, V&V quality, a development life-cycle, and subjective expert's judgments) required for correct reliability assessment of UGVs.

Subjective expert's judgment derived from expert elicitation plays important role in the proposed BN model, and aggregation of experts' opinion is also an important part for making the good BN reliability model of UGVs.

REFERENCES

[1] J. Carson and R. Murphy, How UGVs Physically Fail in the Field, IEEE Transactions on Robotics, Vol.21, No.3, p.423, 2005.

[2] H. S. Eom, J. W. Cho, K. M. Jeong, Some Reliability Considerations of UGVs for Remote-response in Nuclear Emergency Situation, Transactions of the Korean Nuclear Society Spring Meeting, May 30-31, 2013, Gwangju, Korea.

[3] Phuoc-Nguyen, Nguyen-Huu, Joshua Titus, Reliability and Failure in Unmanned Ground Vehicle (UGV), GRRC Technical Report 2009-01, University of Michigan, 2009.

[4] Norman Fenton, Martin Neil, Risk Assessment and Decision Analysis with Bayesian Networks, CRC Press, New York, 2013.

[5] Guidance on Software Reviews for Digital Computer-based Instrumentation and Control Systems, NUREC-0800, Standard Review Plan: Branch Technical Position 7-14, NRC.