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# The Basic Framework for Robot Applicability Enhancement of Nuclear Risk Management in Nuclear Power Plants

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## 1. Introduction

Beyond-design-basis external events such as the one having occurred at the Fukushima Daiichi Nuclear Power Plant typically pose considerable challenges to the plant personnel because of the harsh environments caused by the events (e.g., extreme terrains, high radiation, radioactive rubbles, high heat, and explosive environment). Therefore, remote response techniques by use of robotic systems [1] are needed to help the plant personnel cope with the extreme events. In this study the basic framework for enhancing robotic applicability to disaster management was developed using the analytic technique of Master Logic Diagram (MLD) and Goal-Tree Success-Tree (GTST).

## 2. Architecture for high robot performance of Accident Conditions in NPP

A Master Logic Diagram (MLD) [2] for robot performance was constructed in this study. The MLD shown in Fig. 1 delineates various attributes needed to achieve high robot performance in terms of major goals, functional goals, design goals, and support activities. The top goal representing high performance of robotic systems has been divided into five major goals: 1) high capability; 2) high efficiency; 3) high reliability; 4) high safety; and 5) high maintainability.

### *2.1. High Capability*

As shown in Fig. 1, high capability can be obtained through an optimum design program along with proper materials and workmanship. An important task in this regard is to perform a functional analysis for the robot being developed. Functional analysis is a fundamental tool of the robotic design process to explore new concepts and define their architectures. The robotic designer performs functional analysis to refine the functional requirements of the robot, to map its functions to physical components, to guarantee that all necessary components are listed and that no unnecessary components are requested and to understand the relationships between the constituent components. As functions of an engineering system generally can be hierarchically structured, it is often useful to develop a functional tree in a hierarchical and deductive fashion.

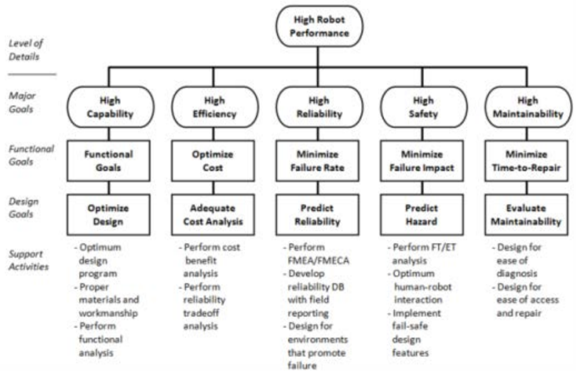


Fig. 1. Master Logic Diagram for high performance of robot systems

Another thing to notice in this regard is that a Goal-Tree Success-Tree (GTST) may be used as a structure in which goals and functions can be logically analyzed in an integrated manner, starting from a top objective, then to goals, subgoals, functions, and systems/components and human elements that help implement the functions. This GTST structure shown in Fig. 2 was used to analyze functions of the KAEROT_M2 robot developed by the KAERI's robotics team.

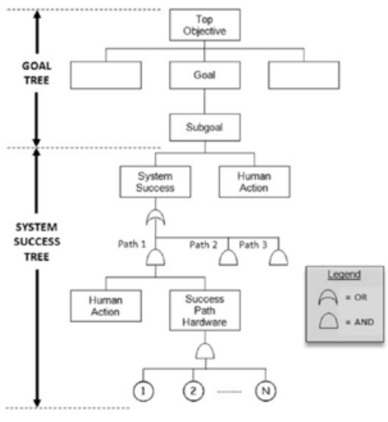


Fig. 2. Typical structure of a GTST model

### *2.2. High Efficiency*

Engineering systems such as robots should be developed as efficiently as possible in a manner to minimize fuel or energy consumed by the systems. The efficiency may be evaluated in terms of cost involved, and thereby, a cost-benefit analysis could be performed. Another relevant aspect in this regard is to optimize the reliability of the systems through reliability tradeoff analysis, as failure of the systems incurs significant cost in general.

### *2.3. High Reliability*

High reliability of a robot system can be achieved by minimizing the failure rate of the system. To minimize the failure rate, the system reliability should be somehow predicted. The reliability of a robot can be designated through a probability (i.e., probabilistic approach), or deterministically. The deterministic approach such as Failure Mode and Effect Analysis (FMEA), Failure Mode Effect and Criticality Analysis (FMECA), seeks to understand how and why an item fails, and how it can be designed and tested to prevent such failures from occurrence or recurrence. On the other hand, the probabilistic approach seeks to assess the item's ability in terms of the reliability.

Robotic failures are often regarded as occurring due to these four categories of failures [3]: (1) random component failures, (2) software failures, (3) human errors, and (4) systematic hardware faults. Of these, human errors are due to personnel who design, manufacture, test, operate and maintain a robot. Some of the reasons for the occurrence of human error are poor equipment design, task complexity, poorly written maintenance and operating procedures, poor training, improper tools, and adverse working environment (e.g., high heat, inadequate lightening). Systematic hardware faults are those failures which happen because of unrevealed mechanisms present in the robot design. Reasons such as peculiar wrist orientations and unusual joint-to-straight-line mode transition may lead the robot not to carry out a certain task or execute specific parts of a program.

Reliability database (DB) for robotic components is under development at KAERI. FMEA was recently conducted for a robotic system at KAERI.

### *2.4. High Safety*

As any other industry, the robot industry is not immune to accidents. Dhillon [3] points out that there have been many robot-related accidents over the years, fatal and nonfatal. The largest proportion of major injuries or deaths seems to occur due to human factors, for example: (a) workers taking chances rather than following the prescribed procedures fully; (b) workers often forgetting about hazards associated with a robot during normal or abnormal conditions; and (c) workers becoming preoccupied and self-satisfied. Therefore, 'High Safety' is identified as one of the major goals for 'High Robot Performance' in Fig. 1. Also as human factors are important in maintaining robot safety, optimizing human-robot interaction to the possible extent is important as indicated in the figure.

In order to achieve high safety, risk analysis should be carried out to understand the hazards associated with the robot. One of the most comprehensive methods to perform risk analysis is Probabilistic Safety Analysis (PSA), or alternatively called Probabilistic Risk Analysis (PRA), where the combination of Fault Trees (FT) and Event Trees (ET) is typically used to identify potential accident scenarios [4]. The FT/ET technique will be used at KAERI for robotic systems particularly requiring safe implementation.

### *2.5. High Maintainability*

Since some components of robots may fail, maintenance actions are needed to avoid or minimize failure, and also return them to service following failure. Maintenance to avoid or minimize failure is called 'preventive maintenance', and maintenance to restore failed equipment 'corrective maintenance'. In addition, 'predictive maintenance' may be performed when failure can be predicted somehow, e.g., in the case where robot systems equipped with sophisticated electronic components and sensors are capable of being programmed to predict when a failure might happen and to alert the concerned maintenance personnel.

The users of robots have to devise a sound maintenance program, otherwise their unscheduled downtime may increase beyond limit, consequently defeating the purpose of robot applications. In order to achieve high maintainability, the time-to-repair should be minimized as indicated in Fig. 1. In addition, maintainability could be enhanced by designing for ease of diagnosis, and ease of access and repair. Ways to upgrade maintainability could be devised by evaluating maintainability in the design stage.

## 3. Concluding Remarks

The basic framework discussed herein shall be used by the KAERI's robotics team as a fundamental framework in enhancing the applicability of disaster robots in the hazardous environment caused by extreme events.

## REFERENCES

[1] B. Siciliano and O. Khatib (Ed.), "Springer Handbook of Robotics," Springer-Verlag Berlin Heidelberg, 2008.
[2] M. Modarres, M. Kaminskiy, and V. Krivtsov, Reliability Engineering and Risk Analysis – A Practical Guide, Marcel Dekker, 1999.
[3] B.S. Dhillon, "Robot Reliability and Safety," Springer-Verlag, New York, 1991.
[4] K. Khodabandehloo, "Analyses of Robot Systems Using Fault and Event Trees: Case Studies," Reliability Engineering and System Safety, Vol. 53, 1996.