Some Reliability Considerations of UGV for Remote-response in Nuclear Emergency Situation

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1. Introduction

Robots can do many helpful things human can't or don't want to do in emergency situation like Fukushima Daiichi nuclear power plant (NPP) disaster. UGV (Unmanned Ground Vehicle) is a type of robot and most frequently used one for search and rescue operation in emergency situation. Therefore, in Fukushima disaster, a number of different UGVs, such as Packbots, Warriors, Quince, and Survey Runner, are used for monitoring, collecting data, inspection, and cleaning up. In utilizing UGVs in a nuclear emergency situation, one of serious problems is reliability of UGVs which is not sufficient yet for required mission completion. In this paper we surveyed failures and reliability of field UGVs and draw some important reliability considerations of UGVs for remote-response in a nuclear emergency situation. We think that the findings in this study will be helpful for developers or researchers of UGVs for nuclear emergency situations.

2. Failures and Reliability of UGVs in the Field

The major results from notable studies about failures and reliability of field UGVs are described in this section. Only field cases are included and laboratory level tests are excluded. Part of failure causes in the Fukushima case is not known yet clearly, so there is some assumption in them. Though Toshiba's robot in Fukushima case is quadruped (not a UGV type), we included it in this survey because it is being used in the real nuclear emergency case.

2.1 Findings in CRASAR' Study [1]

The Center for Robot-Assisted Search and Rescue (CRASAR) study includes data from 13 cases. Total of 28 different UGV models from 7 manufacturers are considered in this study. UGVs are used in Urban Search and Rescue or military field applications. More than 2100 hours, over 500 of which is field work, of UGV operation have been recorded. The study used a new taxonomy to categorize failures based on the cause (physical or human), its impact, and its repairability. Important statistics are derived from the field data analysis and presented using the taxonomy.

Remarkable results in this study are;

- Average MTBF of surveyed UGVs is about 6 hours.
- Availability of surveyed UGVs is less than 50%.
- In rescue operation of World Trading Center disaster, one-third of operation time is in failure mode such as track slipping, camera occluded.
- Average MTBF of military UGVs is less than 20 hours.
- Reliability is proportional to the maturity of platform.
- A state of the art of UGV cannot be expected to complete an entire shift without incident - 6 hours for Urban Search and Rescue and 20 hours for military mission.
- The most common sources of failure in modern robotic systems are custom-built by hand and increasingly complex components such as control and effectors system.
- The most reliable components in modern robotic systems are simple (power components) and/or mass-produced (sensors).

2.2 Failures of robots in Fukushima NPPs case [2]

In late October 2011, Japanese Quince robot No.1, developed by Chiba Institute of Technology, was sent in to check on a thermal reading and the radiation levels. While roaming around somewhere on the third floor of the reactor, all contact was lost. It turns out that the robot worked exactly as it was designed to but it was stopped by a faulty cable. In July 2012, Tepco used a robot "Survey Runner" to take radiation, visual and sound data in torus room of reactor 3. Human worker opened the door of the torus room to let the robot enter, it went around clockwise, but the communication was interrupted at the manhole located at the South-East of torus room. Tepco assumes the cable might have been damaged on the way, and also loss of battery power.

In November 2012, Toshiba developed a robot to investigate Fukushima NPPs. The robot is remote-controlled, radiation-resistant quadruped and has a child robot (UGV type) for investigation. On 12/12/2012, Tepco attempted investigation using Toshiba's robot. While investigating the vent pipe area in the Unit 2 reactor building, it fell over when it stepped up the stairway and stopped by the wall behind. On 12/18/2012, Tepco carried out another investigation using the same robot, and a arm failure occurred because of sensor error. On 12/21/2012, the same robot was sent to the Unit 2 reactor building for vent pipe inspection. This time, a coil winding machine attached to the quadruped robot failed, so the cable was cut to retrieve the quadruped robot and child robot was discarded. In summary, failures in Fukushima case are 3 communication cable troubles, 1 power loss, and 2 effectors (legs and arms of robot) problems. It seems that complication of the terrain in the reactor building brought out many cable problems.

2.3 Reliability Information from Other Studies [3]

Two studies on UGVs used in a museum are carried out. The first one “Sage” was conducted at the Carnegie Museum of Natural History. Total number of operation days is 174 and the MTBF of Sage was 97 hours. In the second study, Robot-X, which is an autonomous and a tour guide application, achieve a MTBF of 20.9 hours. Total run time of Robot-X is 2,447 hours and there are 117 failures during operation.

3. Reliability Considerations of Future UGVs

Based on the findings from reliability studies in section 2 and particularity of nuclear emergency situation, we deduced some reliability considerations of UGV for nuclear emergency situation. Those considerations are classified according to life-cycle of UGV for research and development.

- Requirement phase
  - Need of sufficient effort to draw realistic operation environment and scenario of UGV].
  - Requirement specification should be derived from the realistic environment and scenario of UGV.
  - Strengthen maintenance-related requirements for fast and easy field repair.
- Design phase
  - Additional use of design methodology for improving reliability, such as fault-tolerant techniques, redundant design, simple design.
  - Design for easy repair of components for fast field maintenance, such as modularity.
- Manufacturing phase
  - Minimization of custom built by-hand.
  - Use of proven (mass-product) components.
  - Adoption of proven manufacturing procedure.
- Validation phase
  - Testing of UGV in the condition similar to real operation environments.
  - Use of good test plans and practices.
  - Use of realistic assessment method under the insufficient data necessary for the assessment.
  - Inclusion of qualitative expert’s judgment in a formal way, such as reliability modeling by Bayesian Net [4, 6].
- Operation phase
  - Sufficient operator training and proper manuals to reduce human error in operation and maintenance.
  - systematic acquisition of failure data in the field. For example, automated black-box data collection, like those used on airplanes, which record usage and failure data of UGVs.
- Overall phase
  - Minimization of human error throughout the development life-cycle of a UGV. For example, Use of Verification and Validation (V&V) methodology which is obligatory for development of safety-critical software in NPPs. [5, 6].
  - Concentrative study on vulnerable area of UGVs in reliability aspect, such as human-robot interaction.

4. Conclusions

We studied failures and reliability of UGVs used in search/rescue, military, and nuclear field by literature survey. The results showed that a state of art field UGVs can't be expected to complete an entire mission without failures, which leads to needs of reliability improvement of them. Though part of failure data from the surveyed studies were not enough detailed to get reliability matrix, some meaningful insights were found through analysis. Based on these insights, we draw some important considerations for reliability improvement of UGVs for an NPP emergency situation, and those reliability considerations are classified according to life-cycle of a UGV for developers and researchers. Finally, there were not reported failures related to radiation environments in surveyed literature, but radiation-tolerant control boards and sensors are easily anticipated in a NPP emergency situation. Therefore studies about the radiation-tolerant design and the use of radiation-tolerant components also should be considered for high reliability of UGVs for a NPP application.

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