https://doi.org/10.31256/Dy3Sk6W

Risk assessment and navigation of a wheeled mobile robot in nuclear applications

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***Abstract*—Robots used for nuclear decommissioning often fail prematurely due to the extreme conditions encountered. Generally, the robots are deployed with a human-in-the-loop operator to intervene if problems occur. However, in some of the most critical situations, the response time of the operator is too slow to prevent an incident. In such cases, if the robot is capable of assessing the risk present with a given operation or path, it could take an appropriate action until an operator can assess the situation and decide on an action to take, or could calculate and proceed with an alternative action. This raises two important research questions: how can the robot assess risks and how can the risks be incorporated into the robot's architecture? This paper addresses these two issues. We propose a navigational framework based on risk-assessment where a wheeled-mobile robot is able to assess risks like radiation, temperature, battery power and collision. These risks are calculated at different levels of the framework depending on the nature of the risks. We use the Conditional Value at Risk (CVaR) metric for measuring the risk value. Preliminary results have shown that the risk-based robots have longer mission times compared to robots without risk-assessment.**

***Index Terms*—nuclear robots, risk, navigation, radiation, temperature.**

I. Introduction

The main challenge in a nuclear environment is that it is highly unstructured. During decommissioning operations, the environment is unknown with potentially extreme radiation and temperatures, as well as caustic and chemical hazards. Working in such conditions with limited knowledge is both - hazardous and physically demanding for humans. Such environments also affect the robots, making them fail prematurely before the mission completion, reducing the robot lifespans. Such robot failure causes huge monetary losses, additional nuclear debris and can also block paths for other robots in the future to navigate. For such scenarios, recovering the robot or in other words, avoiding robot failure is more important than the reliability of the mission.

II. Literature Review

In recent years, remote handling robots have achieved considerable amount of success using digital twin technologies, internet of things, symbiotic systems, etc. On the other hand, the risk-aware [4] and reliability-aware systems are on the rise with advanced AI algorithms in recent times. Robots are

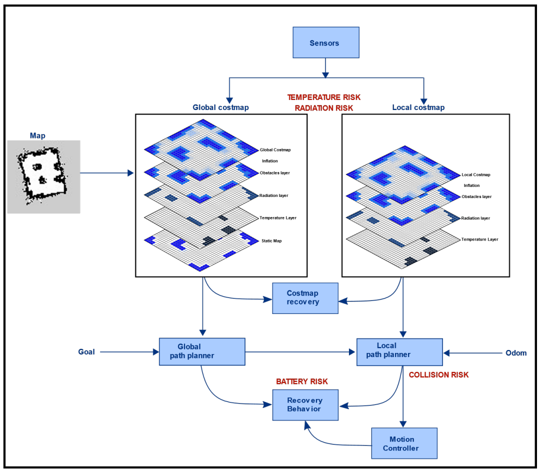

Fig. 1. Single robot risk-based navigation

able to account for uncertainty, failure risks, risk bounds, etc. with respect to the environment and apply such information for decision-making [2], [3]. Planning under uncertainty and uneven terrain navigation using Partially Observable Markov Decision Processes and Model Predictive Controls have proved to be a huge success in recent years [5], [6].

In this short paper, we focus on the different types of risks that a mobile robot can encounter on a nuclear decommissioning operation and how it can assess the risk. We propose a risk-based navigational framework which we use to assess four different types of risks - radiation, temperature, collision and battery using CVaR. The paper is organized as follows: In the next section III, we detail the risks and its metrics with our methodology followed by preliminary results in section IV and future work in the section V.

III. Risk Assessment

Risk is defined as the product of severity of an event and the probability of the occurrence of the event. Sometimes, the frequency of exposure of the event (F) is also included.

$$Risk = P \times S \times F \tag{1}$$

The severity of an event is not quantifiable and hence, it is difficult to quantify risk. However, recently, researchers have used many methods [7], [8] to assess risk. In this paper, we consider four risks for the robot to assess.

1) Environmental risks like radiation and temperature as they are critical in a nuclear environment.
2) Battery risk - so the robot can navigate back to the exit/entry point based on the environment and odometry.
3) Collision risk is important due to the constrained environment.

. Communication risk is ignored for now as the robot is always tethered and assumed that there is no communication loss. We define two criteria for robots to assess risks. Firstly, according to [1], in order to quantify the risk value, Conditional Value-at-Risk (CVaR) is the appropriate metric as it captures the expected cost of the tail risk past a given probability threshold. So, one can dynamically change severity of risk depending on a number of factors like mission goals, user-preferences, etc. Secondly, we consider the risk threshold values for risks like - radiation, temperature and battery are similar to the risk perception by humans. Radiation and temperature risks can be perceived by the robots based on the previous exposure values and can be measured. Same way, battery risks can be attributed based on the lower threshold value of the battery and the discharge rate. And the collision risk is based on the CVaR value of the distance of the robot from the nearest obstacle.

The four risks are integrated in the navigational framework as shown in figure 1. The radiation and temperature values are converted to their corresponding risk values based on the robot's present state. Since radiation is cumulative and temperature is dissipative, this is also considered as dynamic costs and are embedded in the costmaps of the robot navigation [9]. This framework is termed the ISRA (internal state-based risk assessment) mission. The battery risk values are also converted to a risk value based on the CVaR threshold value with respect to the discharge rate of the battery and the odometry distance from the entry/exit point. The collision risk is also calculated based on the distance CVaR threshold value.

IV. Results and Discussion

The risk-based navigational framework is run on Ubuntu 18.04 with ROS Melodic - Navigation stack. Preliminary results showed that the robot was able to run missions more safely by avoiding risk-areas of radiation and temperature and avoided navigational commands when the battery level went low. In figure, 2, the robot with radiation risk was able to keep the radiation at a low level. A video of one of the experiment runs can be seen at https://youtu.be/iUFOOIbQk7k.

V. Conclusion

In this paper, we briefly explain the different risks involved in a nuclear environment for robots. We show a navigational framework based on risks like radiation, temperature, battery and collision risk that is used for safe navigation of the mobile robot. Initial results have been successful for single robots and future work will involve employing multiple mobile robots for such scenarios as shown in figure 3.

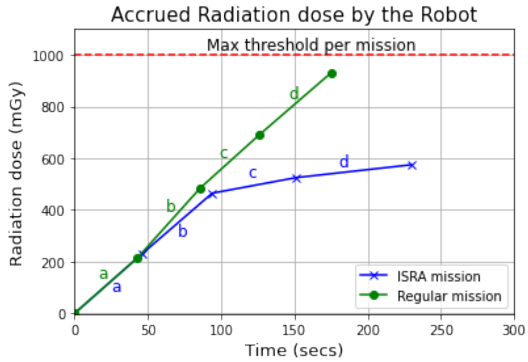

Fig. 2. The radiation dose accrued by the robot while navigating between start and end goals - with and without ISRA is demonstrated here.

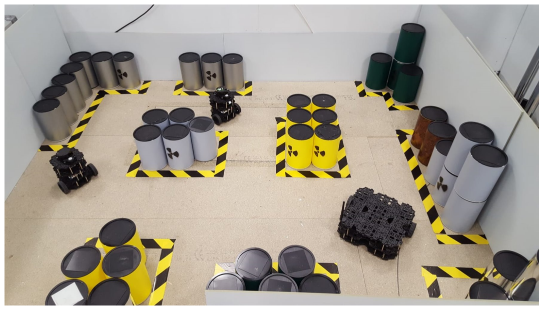

Fig. 3. Present work - multiple robots

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