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# Analysis of Fault Tolerant Control Methods for Nuclear Radiation Detection Robot

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***Abstract:*** Dual-redundant systems represent a widely employed fault-tolerant technology aimed at enhancing the reliability and fault tolerance performance of nuclear radiation detection robots. In this study, with a specific focus on nuclear radiation detection robots, we introduce a comprehensive fault-tolerant control scheme achieved through an analysis of the fault detection and handling methodologies inherent in dual-redundant systems. This scheme encompasses fault detection approaches spanning the processing layer, interface layer, and peripheral device layer, all accompanied by their respective fault-handling strategies. By conducting an exhaustive examination of fault detection and handling within dual-redundant systems, the reliability and fault tolerance capabilities of nuclear radiation detection robots can be significantly advanced.
***Keywords:*** Nuclear Radiation Detection Robot; Dual-Redundant System

## Introduction

Nuclear radiation detection robots are widely employed for safety monitoring and rescue missions in environments subjected to nuclear radiation. However, due to the extreme nature of their operational conditions and the risks posed by radiation, these robots are susceptible to various faults, resulting in performance degradation or even complete malfunction. In order to enhance the reliability and fault tolerance performance of nuclear radiation detection robots, dual-redundant systems have found extensive application in this field. This paper primarily analyzes the fault detection and handling methods of dual-redundant systems, aiming to provide a comprehensive fault-tolerant control scheme.

## 1. Introduction to Dual-Redundant System Design

The dual-redundant system is a fault-tolerant technical approach achieved by incorporating redundant robots. In the context of nuclear radiation detection robots, a dual-redundant system typically consists of two robots with identical functionalities, ensuring continuous task execution through real-time communication and data exchange. During the system design phase, factors such as synchronization of redundant robot positions, state transitions, and switching strategies need to be taken into account to facilitate seamless transitions in the event of faults.

## 2. Fault Detection Methods of Dual-Redundant Systems

### 2.1 Fault Detection Methods at the Processing Layer

In the dual-redundant system of nuclear radiation detection robots, the processing layer holds critical significance, as it is responsible for tasks such as data processing, decision-making, and control. To detect faults in the processing layer, various approaches can be employed to monitor the consistency of output results between the two robots. A commonly used fault detection method is based on state estimation. By utilizing sensors to gather environmental information and estimating robot states, a comparison of the states of the two robots can be made. Significant disparities in the state estimation results between the two robots might indicate a potential malfunction in one of them.

Another fault detection method is based on data consistency. This method involves monitoring the consistency of output data between the two robots to determine the presence of faults. Data fusion techniques can be employed to compare and merge the output data from both robots. If inconsistencies are identified, it could imply that one of the robots has encountered a malfunction.

## 2.2 Interface Layer Fault Detection Methods

The interface layer plays a crucial role in dual-redundant systems, facilitating communication and data exchange between robots. To detect faults in the interface layer, appropriate methods are required to ensure the availability of communication links and the integrity of data transmission. One commonly used fault detection method is heartbeat monitoring. In a dual-redundant system, communication link availability can be assessed by periodically sending heartbeat signals. When one robot fails to receive a heartbeat signal from the other, it can infer a communication link fault and initiate corresponding error correction measures. Additionally, data verification methods can be employed to detect faults in the interface layer. By adding validation information to data packets, such as checksums or CRC checks, data integrity during transmission can be ensured. The receiving end can validate received data packets based on this verification information to determine if transmission errors have occurred.

## 2.3 Peripheral Device Layer Fault Detection Methods

The peripheral device layer encompasses the interactive components of nuclear radiation detection robots with the environment, including sensors and actuators. To detect faults in the peripheral device layer, various fault detection methods can be applied to ensure sensor data accuracy and normal actuator operation. One commonly used method is data consistency detection. Detecting faults in the peripheral device layer can involve comparing sensor data obtained by the two robots for consistency. Noticeable discrepancies in sensor data between the two robots might indicate a malfunction in the sensors of one robot. Another fault detection method is redundant sensor fusion. By utilizing multiple redundant sensors to gather environmental information and fusing their data, sensor data accuracy and reliability can be enhanced. If significant disparities are identified between the fused data and data from a specific robot, it could imply a sensor fault in that robot.

# 3. Fault Handling Methods of Dual-Redundant Systems

## 3.1 Fault Detection and Switching

When a fault occurs in one of the robots within the dual-redundant system, timely intervention is essential to ensure uninterrupted system operation and task completion. A commonly employed fault handling method is fault detection and switching. The system can detect faults in real-time by monitoring key parameters and states, and automatically switch to an alternate robot for task execution.

During the fault detection phase, the system monitors the state of the faulty robot and compares it with the state of the backup robot. If a significant disparity is observed between the states of the faulty robot and the backup robot, the system identifies a fault occurrence and triggers the switching mechanism. Various methods can be utilized for switching, such as decision algorithms and switching rules. Decision algorithms determine the optimal switching approach based on system objectives and constraints, ensuring performance and reliability. Switching rules consist of predefined strategies and guidelines, directing the system's switching operations during different fault scenarios.

While conducting switching operations, the system must consider task continuity and data consistency. Techniques such as data redundancy and state synchronization can be employed to ensure data transmission and synchronization throughout the switching process. Additionally, fault recovery algorithms and fault tolerance mechanisms can be employed to mitigate the impact of potential faults on system performance.

## 3.2 Fault Diagnosis and Repair

In addition to fault detection and switching, dual-redundant systems also require fault diagnosis and repair processes to identify the root causes of faults and restore normal system operation. Fault diagnosis involves determining the reasons and locations of faults, while repair involves corrective actions to fix and recover from faults. During the fault diagnosis phase, various fault diagnostic techniques can be employed to aid in pinpointing the causes of faults. This includes methods such as fault code analysis, sensor data analysis, state monitoring, and fault pattern recognition. By analyzing fault symptoms and relevant data, the scope of the fault can be narrowed down, and the specific fault cause can be determined.

Once the fault is identified, the system needs to undertake repair operations to rectify the fault. This might involve steps like replacing faulty components, repairing damaged parts, or reconfiguring system parameters. Repair operations should adhere to relevant repair procedures and operational standards to ensure the effectiveness of repairs and the safety of the system. Furthermore, dual-redundant systems can also implement preventive maintenance measures to reduce the occurrence of faults. Preventive maintenance includes activities like regular inspections, maintenance, and component updates to ensure normal system operation and reliability.

# 4. Conclusion

In conclusion, this paper comprehensively analyzed the fault detection and handling methods of dual-redundant systems for nuclear radiation detection robots. In terms of fault detection, methods for the processing layer, interface layer, and peripheral device layer were extensively discussed. Concerning fault handling, appropriate strategies were proposed for different levels of faults. By judiciously applying fault-tolerant control methods offered by the dual-redundant system, the reliability and fault tolerance performance of nuclear radiation detection robots can be enhanced, ensuring their seamless operation in complex environments.

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