Fault Tolerance in Spacecrafts

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Abstract

Motivation: Our fascination with space exploration drives this project, aiming to ensure high reliability in extreme and remote environments. Developing a fault-tolerant system for spacecraft is critical for maintaining mission continuity despite subsystem failures, minimizing human intervention, and safeguarding astronaut safety. Historical mission challenges, such as Apollo 13 and the James Webb Space Telescope, emphasize the need for robust fault-tolerant systems in future missions.

Problem Statement: The goal of this project is to design a multi-layered digital circuit-based fault diagnosis and recovery system. This system will employ a hierarchical approach, where subsystems are organized into levels based on their criticality to the spacecraft's mission. A level-by-level verification ensures that critical subsystems are diagnosed and recovered efficiently to minimize mission disruption.

System Architecture:

- **Level 1: Base Layer**
  - *Subsystems:* Advanced Sensors, Data Acquisition and Analysis, Advanced Materials, Device Failure Physics, *Thermal Regulation*.
  - The system will first focus on diagnosing and recovering these subsystems to ensure the spacecraft's baseline functionality. One subsystem in this level is crucial but uncorrectable; if this subsystem fails, the mission will terminate immediately. Passing Level 1 is mandatory for the mission to proceed to the next level.
- **Level 2: Functional Module Implementation Layer**
  - *Subsystems:* Power Status Monitoring, Attitude Control, Load Monitoring, Measurement Control, *Communications Integrity*.
  - If Level 1 is passed, this layer ensures that subsystems crucial for spacecraft stability, control, and communication are fully operational. One subsystem in this layer is uncorrectable, and if it fails, the mission will terminate.
- **Level 3: Task Goal Implementation Layer**
  - *Subsystems:* Fault Detection, Fault Isolation, Fault Prediction, Health Assessment, Repair Planning.
  - This final level assesses and ensures fault detection and health management systems are functioning. The same condition applies—one uncorrectable subsystem must pass, and failure will lead to mission termination.
- **Non-Critical Subsystems:** These subsystems, although not essential for the core spacecraft operations, can be monitored and toggled based on the user's discretion. In an ideal operational scenario, all non-crucial subsystems are turned off to conserve resources. Failures in non-crucial subsystems are tolerated.

Mission Termination Conditions:

- If any crucial subsystem, particularly the uncorrectable ones in each level, fails to recover, the mission will terminate immediately.
- Progression to the next level occurs only if all crucial subsystems in the current level are functional. Failure to pass any level results in mission termination.
- For the mission to succeed, all levels must be passed.

Features:

- A layered approach ensures that **critical subsystems** are prioritized in diagnosis and recovery, minimizing the overall recovery time.
- Built-in error detection mechanisms ensure system self-correction without human intervention.
- Users can decide whether to activate non-crucial subsystems, with the ideal scenario being that these subsystems are turned off.
- A predefined recovery plan ensures the mission continues only if all subsystems in every level pass, and the mission will terminate upon any critical failure.

Key components:

•Basic Logic gates

• MUX(2x1)

• Shifters

• D-Flip Flops

•LEDs

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