Towards an FDIR Software Fault Tree Library for Onboard Computers
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Outline

- FDIR Analysis with Fault Trees
- Problem Statement
- FDIR Software Fault Tree Library
- Dependability Quality Model
- Use Case: MMX
- Results
- Conclusion
Fault Detection, Isolation and Recovery

FDIR

Even well designed systems cannot avoid the existence of faults

- But not every fault is a failure
- FDIR tries to prevent faults from turning into failures
Fault Detection, Isolation and Recovery

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![Diagram](image.png)
On-Board Computing in Space

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- But: Space is a harsh environment
  - Radiation effects
  - Limited room for human intervention
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Need FDIR to provide stable operation

How to plan and assess the FDIR concept in the design phase?
Modeling the F in FDIR

Fault Model

Relationship between basic faults and how they lead to failures

- Failure Modes and Effects Analysis (FMECA)
- Reliability Block Diagrams
- Markov Modeling
- **Fault Tree Analysis (FTA)**
- ... and many more
Basics of Fault Trees

Fault Tree

How do faults propagate through components?

- Propagation model using gates (AND, OR, SPARE, PAND, etc.)
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Diagram:
- OnBoard-Computer
- Top-Level-Event / Feared Event
- Gates
- CPU
- Memory
- Memory1
- Memory2
Basics of Fault Trees

Fault Tree

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Fault Trees and RAMS

Fault Model

Mathematical Model

RAMS Metrics

Figure: Fault Tree Evaluation
Problem Statement

Fault trees provide great analysis benefits but...

- also require a lot of modeling effort!
- need to be redone mostly from scratch for each new system!
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Can we develop..

- a generic FDIR software library
- generic fault tree models for FDIR Software library?
- a methodology to easily generate fault trees incorporating calls to the library?
FDIR Software Library

Application

FDIR Parameter Pool

FDIR Routines Configuration

Onboard Monitoring Service (12)

Event Action Service (19)

Custom PUS FDIR Configuration Management Service

Custom Callback

Plausibility Check

Voter

Checkpointing

Alert

Figure: FDIR C++ Library Architecture
Fault Tree Generation

Figure: Generation process with DFT model and service library models.
Fault Tree Generation

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Fault Tree Generation

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Figure: Quality mode using factor-criteria-metric model (Based on ECSS)
Implementation - Virtual Satellite 4 FDIR

Virtual Satellite

- Model Based Systems Engineering tool
- FDIR Extension supporting Model-Based Fault Tree Analysis
- https://github.com/virtualsatellite
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Figure: Excerpt of the library in VirSat
Mission

- Martian Moon eXploration (Phobos)
- Carries rover exploration with various payloads
- Limited communication windows and delays: High degree of autonomy required
- Single OBC based on COTS components
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Figure: Artist impression of the MMX rover on Phobos (credit: CNES)
**Services**

**Feared Events**

- Loss of Position Service
- Loss of Obstacle Detection Service
Services

Feared Events

- Loss of Position Service
- Loss of Obstacle Detection Service

Applications

- **Rectification**: Reverses lens distortions
- **Depth Image Computation**: Computes disparity image and depth image
- **Visual Odometry**: Measures rover’s egomotion
- **Obstacle Detection Algorithm**: Utilizes camera images and depth images to detects obstacles and terrain features
Basic Events

Main Events

- Short mission duration (50 days): Focus on short-term effects rather than long-term accumulation effects
- Main focus: Single-Event Effects (SEE)
## Basic Events

### Main Events

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### Main Hardware Components for Analysis

- **Processing Logic (PL):**
  - Sub-Components: BRAM, CRAM
  - SEE/day: 3.21
- **Processing System (PL):**
  - Sub-Components: OCM, D-CACHE, ALU, FPU, Peripheral
  - SEE/day: 8.22E-02
Bare Fault Tree Model

Figure: Bare fault tree model without FDIR
Summary of Evaluation Results

Experiment Setup

- Defined (sensible) configurations of increasing complexity
- FT size, configuration costs, MTTF, and reliability after 50 days
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**Results**

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Results

- Could answer the question if simpler configurations would suffice (sadly: No)
- Generated fault trees with \(~100\) nodes
- Reduced modeling effort by 80\% for most complex configuration
Conclusion

Recap

- Separated software fault model (Bare model) and mitigation fault models (Fault Tree Library)
- Reusable
- Achieved significant reduction on modeling effort
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Towards the future

- Automatic optimization of configurations? Constraints defining what a "sensible" configuration is?
- Coupling with code generation
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Thank You!! Questions?