A Fault-Tolerant On-Board Computer For CubeSat Based-On Hybrid Architecture

Jérémy Delaporte, Florent Swingedouw, Cyrille Dromas, Thierry Capitaine

Laboratoire des Technologies Innovantes (LTI - EA3899)
Université de Picardie Jules Verne (UPJV)
80000 Amiens, France

Institut Supérieur des Sciences et Techniques (INSSSET/UPJV)
48, rue Raspail
02100 Saint Quentin, France
1. Institut Supérieur Des Sciences Et Techniques (INSSET - UPJV)

2. Space Environment – Effects On Electronic And Consequences

3. On-Board Computer For CubeSat
   1. Architecture And Mitigation Techniques
   2. Our Approach : Secure_ODB Project

4. Functional And Validation Tests
   1. Test Facilities
   2. Injection Faults Based-On JTAG Interface
   3. QB50 Project

5. Conclusion And Perspectives
Embedded System

Constraints

- Mass
- Cost
- Energy Consumption
- Performances
- Reliability Level
- Environmental
- Plug And Play (Modularity)
- Maintainability
- Memory
- ...

Architectures Design
Embedded Systems And Reliability

Constraints

Embedded Systems

Consequences

Radiations
Temperatures
Thermal
Transfert

Space
Environment

Constraints B.A
Constraints B.B
Constraints B.C

Environment B

Constraints C.A
Constraints C.B
Constraints C.C

Environment C

Effects

SEUs
0 -> 1
1 -> 0

SELs

Human
Economical
Political

...
**Space Environment Effects And Consequences On \( \mu \text{C} \)**

**Effects**
- Single Event Effects
  - Single Event Upsets (SEUs) => Soft Errors And Non-destructive
  - Single Event Latchups (SELs) => Hard Errors And “Destructive”
  - Single Event Burnout (SEBs) => Hard Errors And “Destructive”
  - ... See [1]

**Consequences**
- Destruction of components
- Corruption of data

Mitigation techniques

“The goal of a fault-tolerant computer is to provide safety and liveness, despite the possibility of faults.” Fault-Tolerant Architecture, Daniel Sorin – 2009

Error Detection: REDUNDANCY

<table>
<thead>
<tr>
<th>TYPE OF REDUNDANCY</th>
<th>BASIC IDEA</th>
<th>SINGLE EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical (spatial)</td>
<td>Add redundant hardware</td>
<td>Replicate a module and have the two replicas compare their results</td>
</tr>
<tr>
<td>Temporal</td>
<td>Perform redundant operations</td>
<td>Run a program twice on the same hardware and compare the results of the two executions</td>
</tr>
<tr>
<td>Information</td>
<td>Add redundant bits to a datum</td>
<td>Add a parity bit to a word in memory</td>
</tr>
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</table>

The use of detection techniques implies the system to be:

- More expensive
- Less performances
- Need more memory
On-Board Computer For CubeSat

General architecture

NanoMind A712C Block Diagram
(GOMSPACE)
Our approach: Secure_ODB project (1/3)

1. Real-time overview of internal resources
   1. What is working or not
   2. Flash/RAM State
   3. Statistical information on errors
   4. ...

2. Estimation of threat based on environment sensing: radiation & t° sensors (Need a calibration)

3. Dynamique reprogramming or reconfiguration of the Software Processing Unit
On-Board Computer For CubeSat

Our approach: Secure_ODB project (2/3)

Interfaces

- ARM Cortex-M3 Based µC (NXP LPC1788)
- Boot loader in ROM Memory
- FreeRTOS

Controller
Software Processing Unit

• Less performances than Software Processing Unit
• Reliable

Must be protected against energetic particles strikes (Radiation)
On-Board Computer For CubeSat

Our approach: Secure_ODB project (3/3)

Top view
On-Board Computer For CubeSat

Our approach: Secure_ODB project (3/3)

CubeSat Kit Bus Connector

CAN Transceiver

Controller & µC Supervisors

JTAG

µSD Socket

EEPROM/FRAM* Memories

Controller Interface

RTC Battery

Cortex-M3 Based µC

[Image of a computer board with labeled components]
On-Board Computer For CubeSat

Our approach: Secure_ODB project (3/3)

Bottom view
On-Board Computer For CubeSat

Our approach: Secure_ODB project (3/3)

External Flash Memories

External RAM Memories
Functional And Validation Tests

Test Facilities

- Brookhaven National Laboratory SEUTF (heavy ion)
- Lawrence Berkeley Labs 88" Cyclotron (heavy ion)
- Texas A & M University Cyclotron (heavy ion)
- Paul Scherrer Institute (heavy ion)
- University of California at Davis Crocker Nuclear Lab (proton)
- Indiana University Cyclotron (proton)
- ...
Functional Tests And Validation

Controller <-> Software Processing Unit

RAM <-> Flash

JTAG-Based Injection Fault System

Random

Script
QB50 project

“QB50 has the scientific objective to study in situ the temporal and spatial variations of a number of key constituents and parameters in the lower thermosphere (90-320 km) with a network of about 40 double CubeSats, separated by a few hundred kilometres and carrying identical sensors.”

- Launch scheduled in 2015
• On-Board Computer (Prototype 1) has just been done
  • Functional tests will be perform next weeks
  • Validation tests (QB50 or Facility tests)

• Definitive choice of the controller (doctor) : CPLD, μC 8-bits, other ?

• Contact Marquette University => Similar hardware architecture

• Questions ?