Fault Injection for AUTOSAR Systems: Challenges and Solution

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Fault injection and AUTOSAR

- Fault injection is the deliberate introduction of faults in a target system.
- Critiware has a long lasting experience with fault injection:
  - commodity software;
  - operating systems;
  - middleware platform;
  - hardware;
  - ...

But what can be done with AUTOSAR?
Automobiles are increasingly incorporating a large amount of Electronic Control Units (ECUs)

Some vehicles contain up to 70+ ECUs

Variety of functionalities:
- navigation devices
- audio devices
- dynamic stability control
- anti-lock breaking systems
- ...
Cost of electronics and software can amount to 40% of a vehicle's overall cost.

Issues found in vehicles after release can also have considerable cost:

- Toyota*: recall issued between 2009-2010 after several vehicles experienced unintended acceleration problems.

Background and rationale

- ECU traditional development approaches
  - developer-dependent
  - proprietary architectures for both HW and SW
  - low maintainability
  - low reusability
  - high cost of ownership
  - ...

[Image of a car crash test]
AUTOSAR® - AUTomotive Open System ARchitecture

“Driven by the advent of innovative vehicle applications, contemporary automotive E/E architecture has reached a level of complexity which requires a technological breakthrough in order to manage it satisfactorily and fulfill the heightened passenger and legal requirements.”

“To achieve the technical goals modularity, scalability, transferability and re-usability of functions AUTOSAR® will provide a common software infrastructure for automotive systems of all vehicle domains based on standardized interfaces for the different layers in the architecture.”

from AUTOSAR® web site
ISO 26262 is a functional safety standard tailored from the IEC 61508 relating to automotive systems

ISO 26262 provides automotive SW development guidance
- a tailored safety lifecycle including management, development, production, operation, service and decommissioning
- a risk-based approach for defining Automotive Safety Integrity Levels (ASILs)
- a means to specify safety requirements using ASILs to reach an acceptable residual risk
- activities for validation and confirmation measures
- ...

AUTOSAR and ISO26262
The role of fault injection

ISO-26262 and Fault Injection

• Explicitly mentioned in the standard for all three levels:
  • System Level
  • Hardware Level
  • Software Level
• Highly recommended for the highest criticality levels of the life cycle
• Same as saying mandatory
The role of fault injection

ISO-26262 and Fault Injection

• System Level

Table 4 — Correctness of implementation of system design specification and technical safety requirements

<table>
<thead>
<tr>
<th>Methods</th>
<th>ASIL</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1a Requirements-based test(^a)</td>
<td>++</td>
<td>++</td>
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<tr>
<td>1b Fault injection test(^b)</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>1c Back-to-back test(^c)</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
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</tbody>
</table>

\(^a\) A requirements-based test denotes a test against functional and non-functional requirements.

\(^b\) A back-to-back test compares the responses of the test object with the responses of a simulation model to the same stimuli, to detect differences between the behaviour of the model and its implementation.
The role of fault injection

ISO-26262 and Fault Injection

- **does not** provide a **clear guidance** for performing fault injection
- **does not** mandate **where** the fault campaigns must be performed
- hardware? software? ...
- **does not** provide guidance on the fault model definition
  - **what** to inject? (SW faults, bit-flip ...)

*It is the responsibility of the safety engineering team to plan, implement and execute the fault injection campaigns in order to comply with the standard!*
Fault injection in AUTOSAR is challenging:

- no specific fault injection support/interface
- implementations are proprietary
- sparse error-handling mechanisms
- mixed-criticality components involved in the error recovery
- ...

**Objective:** to exercise safety and error handling mechanisms implemented **across all the layers** of an AUTOSAR system in a **minimally-intrusive way**
Error models

• Used in the specification of error handling mechanisms
• Cover the behavioural specification of error manifestation as a consequence of a fault activation

• There are five error categories defined in the specifications:
  1. Data flow errors
  2. Program flow errors
  3. Access errors
  4. Timing errors
  5. Asymmetric errors
Several, well-established, handling mechanisms are permitted either at the BSW or SWC level. Examples:

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Description</th>
<th>Imp. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plausibility Checks</td>
<td>Predicates defined on a set of variables to determine their validity at runtime</td>
<td>SWC</td>
</tr>
<tr>
<td>Execution Sequence Monitoring</td>
<td>Detecting deviations from the correct execution path which could be on the level of individual statements, or block of code.</td>
<td>SWC/BSW</td>
</tr>
<tr>
<td>Voting</td>
<td>Consolidate values of redundant units by voting</td>
<td>SWC</td>
</tr>
<tr>
<td>Agreement</td>
<td>Components interact/exchange messages in order to reach a decision</td>
<td>SWC</td>
</tr>
<tr>
<td>Checksums and Codes</td>
<td>Adding redundant info to data values to increase data consistency, e.g., digital signature or encryption/decryption data</td>
<td>SWC/BSW</td>
</tr>
</tbody>
</table>
AUTOSAR error handling

- Concept of **Error Information Path**, defined for each error, specifies information paths for each error that typically point out stages like polling, detection, notification and recovery.
AUTOSAR error handling

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Fault injection is crucial to validate the role of each element within an error path!
Fault injection requirements

- Should not assume availability of APIs or hooks.
- Should exercise system-wide features.
- Should be minimal intrusive.
- Should trigger error information paths.
Injection performed at **microcontrollers level**: it aims to trigger error-handling mechanisms across different AUTOSAR layers
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A possible solution

How to inject? **CDD-based solution**: access to microcontrollers layer and RTE

- corruption of the status, behaviour, or content of the µCs through the CDD (communication-related, WatchDog Timer, or NVRAM-related).
A possible solution

Fault-injection control & monitoring
A possible solution

Leveraging the memory partition feature
Example: CAN Bus OFF

A CAN Bus Off error is emulated when there is a CAN communication channel loss.

1- RTE.Call( CDD.FI-COM-Module, activate(CAN.BUS.OFF) )
2- CDD.FI-COM-Module.activate(CAN.BUS.OFF)
3- BUS_OFF = True
Example: CAN Bus OFF

Despite injection is conducted at HW level, error handling is spread across different components and AUTOSAR layers.
Conclusion

• There is a need for a flexible fault injection approach for AUTOSAR with the ability to assess the spread error-handling mechanisms.

• A minimally-intrusive, (i.e., no change in the BSW) CDD-based fault injection framework for AUTOSAR that also benefits from memory partitioning was presented and it is believed to be promising.

• Open issues:
  • fault-model;
  • cost-effectiveness;
  • temporal intrusiveness;
Related publications


CRITICAL Software Technology for an Evolutionary Partnership (CRITICAL-STEP), Marie Curie Industry-Academia Partnerships and Pathways (IAPP) number 230672, within the context of the EU Seventh Framework Programme (FP7).

http://www.critical-step.eu