A conformance relation for model-based testing of PLC

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Background

An example of non-invasive conformance test execution:

A conformance relation for model-based conformance testing of PLC - WODES'14
Claim

- Usual conformance relations are based on models of the implementation

- Conformance test is performed on a Programmable Logic Controllers (PLC)

- We claim to propose a conformance relation that takes into account the features of the PLC as the I/O scanning cycle
PLC I/O scanning cycle

Introduction

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Desynchronization phenomenon

Synchronous input changes can be detected as asynchronous events

Input signals sent to the PLC

Input signals read by the PLC

Input 1
Input 2

Input 1
Input 2

Inputs reading
Inputs reading

PLC cycle duration $T$
Assumptions

On the specification model:
• Non timed
• Mealy machine
• Complete and deterministic
• Without transient evolution (two following transitions that are not self-loop with the same input condition)
• States distinguishable by the output emission

On the test execution:
• All Input/Output changes are detected
• Test objective: Every transition has been crossed at least once
Example of specification model

2 inputs: \( V_I = \{ a, b \} \)

1 output: \( V_O = \{ o \} \)
Test sequence construction and execution

Test step

Transition to test:

Elementary test step: \( et = (s_1, a \cdot b, s_2, o) \)

- Remark: One test step test both the transition and the self-loop

\[
TS_{MIC} = ((s_1, \bar{a} \cdot \bar{b}, s_1, \bar{o}), (s_1, a \cdot b, s_2, o), (s_2, \bar{a} \cdot \bar{b}, s_2, o),
(s_2, a \cdot \bar{b}, s_1, \bar{o}), (s_1, a \cdot b, s_2, o), (s_2, \bar{a} \cdot b, s_1, \bar{o}))
\]
Test sequence construction and execution

Test sequence

[Provost, WODES’10]

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-Input-Change MIC</td>
<td>Minimal-length</td>
<td>Biased verdict possible (false negative)</td>
</tr>
<tr>
<td>Input 1</td>
<td></td>
<td></td>
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<tr>
<td>Input 2</td>
<td></td>
<td></td>
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<tr>
<td>Input 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-Input-Change SIC</td>
<td>No erroneous verdict</td>
<td>Test objective is not guaranteed</td>
</tr>
<tr>
<td>Input 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input 2</td>
<td></td>
<td></td>
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<tr>
<td>Input 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Aim:

- Being able to prevent biased verdict on MIC test sequences
Expected behavior

Initial situation:
- State $s_2$ active
- Input combination $a \cdot b$

Test step:
- $et = (s_2, \overline{a} \cdot \overline{b}, s_2, o)$

Expected sequence:
- $\sigma = ((a \cdot b, o), (\overline{a} \cdot \overline{b}, o), (\overline{a} \cdot \overline{b}, o), ...)$
Effective behavior

I/O observed outside the PLC

Expected sequence:

• \(\sigma = (a. b, o), (\bar{a} \cdot \bar{b}, o), (\bar{a} \cdot \bar{b}, o), \ldots\)

PLC read/updated sequence:

• \(\sigma = (a. b, o), (a. \bar{b}, \bar{o}), (a. \bar{b}, \bar{o})\)

Observed sequence:

• \(\sigma = (a. b, o), (\bar{a} \cdot \bar{b}, \bar{o}), (\bar{a} \cdot \bar{b}, \bar{o})\)
Idea

The observed sequence is not the expected one

However, this implementation conforms to the specification

It should not be rejected by the conformance relation.
Conformance relation (1)

Built from several observations for each test step

Let $e_{tc} = (s_b; I^j; s_c; O^j)$ be the current test step, Let
$e_{tp} = (s_a; I^i; s_b; O^i)$ be the previous test step.

The implementation conforms to the specification if for every test step one of these relations is verified:

1) Test of the firing of a transition
   • $O_{obs} = (O^i, O^j, O^j)$
   • Or
   • $O_{obs} = (O^j, O^j, O^j)$
Conformance relation (2)

2) Synchronous input changes read asynchroneously

- $O_{obs} = (O^i, O^k, O^{k+1}, O^{k+1})$
- Or
- $O_{obs} = (O^k, O^{k+1}, O^{k+1}, O^{k+1})$

Where:

- $O^k$ such as $\exists I^x \in I_M$ that verifies:
  - $(I^x \setminus I^i \cup I^i \setminus I^x) \subset (I^j \setminus I^i \cup I^i \setminus I^j)$
  - $\lambda(s_b, I^x) = O^k$
- $O^{k+1}$ such as $\exists s \in S_M$ that verifies:
  - $\delta(s_b, I^x) = s$
  - $\lambda(s, I^j) = O^{k+1}$
Example of a correct implementation

Initial situation:
- State $s_2$ active
- Input combination $a \cdot b$

Test step:
- $et = (s_2, \bar{a} \cdot \bar{b}, s_2, o)$

Expected sequence:
- $\sigma = (a \cdot b, o), (\bar{a} \cdot \bar{b}, o), (\bar{a} \cdot \bar{b}, o), ...$

Observed sequence:
- $\sigma = (a \cdot b, o), (\bar{a} \cdot \bar{b}, o), (\bar{a} \cdot \bar{b}, o), ...$
Conclusions and perspectives

Conclusion:

• To meet the test objective, it is not always possible to prevent MIC test steps
• Asynchronous reading of synchronous input changes cannot be ignored in the conformance relation
• A new conformance relation has been defined

Perspectives:

• Choice and implementation of a method to pursue test execution
• Adaptation to closed-loop validation methods
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