A behavior model for IEC 61499 function blocks

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Plan

• Context
• IEC 61499 standard concepts
• Problematic
  – Model of FB behavior
  – Temporal interoperability property
• Contributions
  – Addition of some semantics to the standard
  – Proposition of modeling approach
  – Proposition of an offline scheduling approach
• Conclusion and future works
Context

• Validation and design of Embedded Real Time Systems
  – Functional properties
  – Extra-functional properties

• Component based approaches
  – Composition at Run Time
  – Composition at Off-line (at design time)

• Function Blocks
  – IEC 61131.3
  – IEC 61499
The IEC 61499 concepts

- **Function Block**
  - **Interface**
    - Data inputs / Outputs
    - Event inputs / Outputs
  - **Implementation**
    - Head
      - The Execution Control Chart (ECC)
    - Body
      - Algorithms: the FB functionalities
      - Internal data

- **Device**
  - Processing unit(s), sensor(s), actuator(s), network interface(s)
  - Resource(s): logic execution unit(s)

- **Control application = FBs network distributed on**
  - One or several resources

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The ECC behavior

- **Selects** one of the simultaneous occurrences.
  ⇒ All the others occurrences are lost
- **Activates** the algorithms sequence
- **Waits** for the resource scheduler
- **Emits** the corresponding output event(s) at the execution end

```
ALGORITHM INIT IN ST
XOUT := 0.0
DT := TIME_TO_REAL(CYCLE);
END_ALGORITHM.

ALGORITHM MAIN IN ST
IF NOT HOLD THEN
  XOUT := XOUT + XIN*DT;
END_IF;
END_ALGORITHM;
```
Problematic

- The selection mechanism is not clear in the standard
  - What is the meaning of simultaneous occurrences???
  - How can we perform the selection policy???

- The loosing phenomena is a very critical problem
  - How can we characterize such problem???
  - How can we avoid such problem??
Enrich the standard IEC 61499

- Input events characterizations
- Proposition of a FB behavior model
  - Priority rules
  - Not ambiguous
  - Optimal
- Proposition of an offline scheduling strategy
  - Temporal interoperability constraints
  - Optimal Scheduler model
    - Idling / Non-Idling
    - Deterministic
  - Regular events flow inside a Control Application
Problem 1

The selection mechanism is not clear in the standard

Contribution

A FB behavior model
The proposed FB behavior model

- A FBj characterization
  - $n$ event inputs: $EX_1, \ldots, EX_n$
  - $m$ event outputs: $EXO_1, \ldots, EXO_m$. $m \leq n$
  - $n$ algorithms: $Alg_{(j,1)}, \ldots, Alg_{(j,n)}$
    - $BCET(Alg_{(j,i)})$: Best Case Execution Time
    - $WCET(Alg_{(j,i)})$: Worst Case Execution Time

- Modeling approach
  - Timed Automata formalism

- Simultaneous occurrences $EX_i, EX_j$
  $\Rightarrow t(EX_i), t(EX_j)$ between two selection operations

- Event inputs selection mechanism
  - A unique priority for each event input
  - The event input selection policy
    - Memorization of the highest priority event occurred from the last selection
The event input model

Selection mechanism

- **priority**(EXi): the priority level of the event input EXi
- **WHP** (Waiting Highest Priority)
  - Variable storing the highest priority of events occurred from the last selection
  - Initialized to n (the event inputs number)
- An event occurs on EXi
  - **If** WHP ≤ priority(EXi) **Then** the occurrence is lost
  - **Else**
    - WHP := priority(EXi)
    - All the other input occurrences are discarded
    - The state machine waits the ECC
The ECC model

• Selection of an input occurrence
• Interaction with the Scheduler
• Emission of the corresponding output occurrences

The resource model

• Periodic Offline scheduling stored in the array sched

![Diagram of the ECC model]

![Diagram of the resource model]
Problem 2

The loosing phenomena is a very critical problem

Contribution
temporal interoperability properties
Input events characterizations

- **FBj input events characterization**
  - $EX_1$, $EX_2$, …, $EX_n$
  - **Periodic** event $EX_i$: $Of(EX_i)$, $P(EX_i)$, $G(EX_i)$

- **Definition:** The longest worst case execution time in $FB_j$

  $$WCET_{\text{MAX}}(FB_j) = \max_{i \in [1,n]} \{WCET(Alg_{(j,i)})\}$$

- **Definition:** $PW(FB_j)$: the scheduler worst waiting time in $ECC_j$

- **Definition:** The worst $ECC_j$ activation period

  $$AP(FB_j) = PW(FB_j) + WCET_{\text{MAX}}(FB_j)$$
Temporal interoperability property (1)

• **The schedulability condition 1**
  The scheduling policy avoids loosing occurrences for the function block FB if it respects the condition

\[ \forall i = 1..n, \forall j = 1..n, \forall k, m \text{ integers such as } (Ex_i,k) \neq (Ex_j,m) \]

\[ PW(FB) < | Of(EX_i) + (k \cdot P(EX_i)) - Of(EX_j) - (m \cdot P(EX_j)) - G(EX_j) | - WCET_MAX(FB) \]

• **N.B:** If \( i = j \) and \( m = k-1 \)

\[ | P(EX_i) - G(EX_i) | > AP(FB) \]
Output events characterizations

- The output event EXOi
  - $O_f(\text{EXOi}) = O_f(\text{EXk}) + \text{Minexec}(j,k)$
  - $P(\text{EXOi}) = P(\text{EXk})$
  - $G(\text{EXOi}) = G(\text{EXk}) + 2.\text{PW}(\text{FB}) + \text{WCET}_{\text{MAX}}(\text{FB}) + (\text{WCET}(\text{Alg}(j,k)) - \text{Minexec}(j,k))$

- Periodic output event EXOi : $G(\text{EXOi}) \leq P(\text{EXOi})$

- Non-Idling policy: Minexec = BCET
- Idling policy: Minexec = WCET
Temporal interoperability property (2)

Regular Output events flows

• **The schedulability condition 2**

To obtain a periodic output event, the scheduling policy has to respect the condition:

\[ \forall EXi \text{ input periodic event of FB.} \]

\[ PW(FB) \leq \frac{1}{2} \cdot (P(Exi) - G(Exi) - WCET_MAX(FBj) - WCET(Alg(j, i)) + Minexec(j, i)) \]
• Conclusion
  ➢ We completely specify a FB behavior
    • Time aspects
    • Priority semantic
    • Simultaneity semantic
    • A model in order to verify
      – Functional properties
      – Extra functional properties
  ➢ We specify the temporal interoperability inside a FBs network
    • Offline scheduling policy
    • A resource scheduler model
    • Schedulability conditions to guarantee such interoperability

• Future works
  ➢ Propose other policies for the loosing phenomena problem
    • (m, k) condition
  ➢ Automatic generation of a safe offline scheduling
  ➢ Extend our model to take into account
    • Several resources in one or more devices
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TRIO project

http://www.loria.fr/equipes/TRIO/

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