SMART ENERGY MANAGEMENT AND LOW-POWER DESIGN OF EMBEDDED SYSTEMS ON ALGORITHMIC LEVEL FOR SELF-POWERED SENSORIAL MATERIALS AND ROBOTICS

A Contribution from Behavioural High-Level Synthesis and Advanced Artificial Intelligence Algorithms

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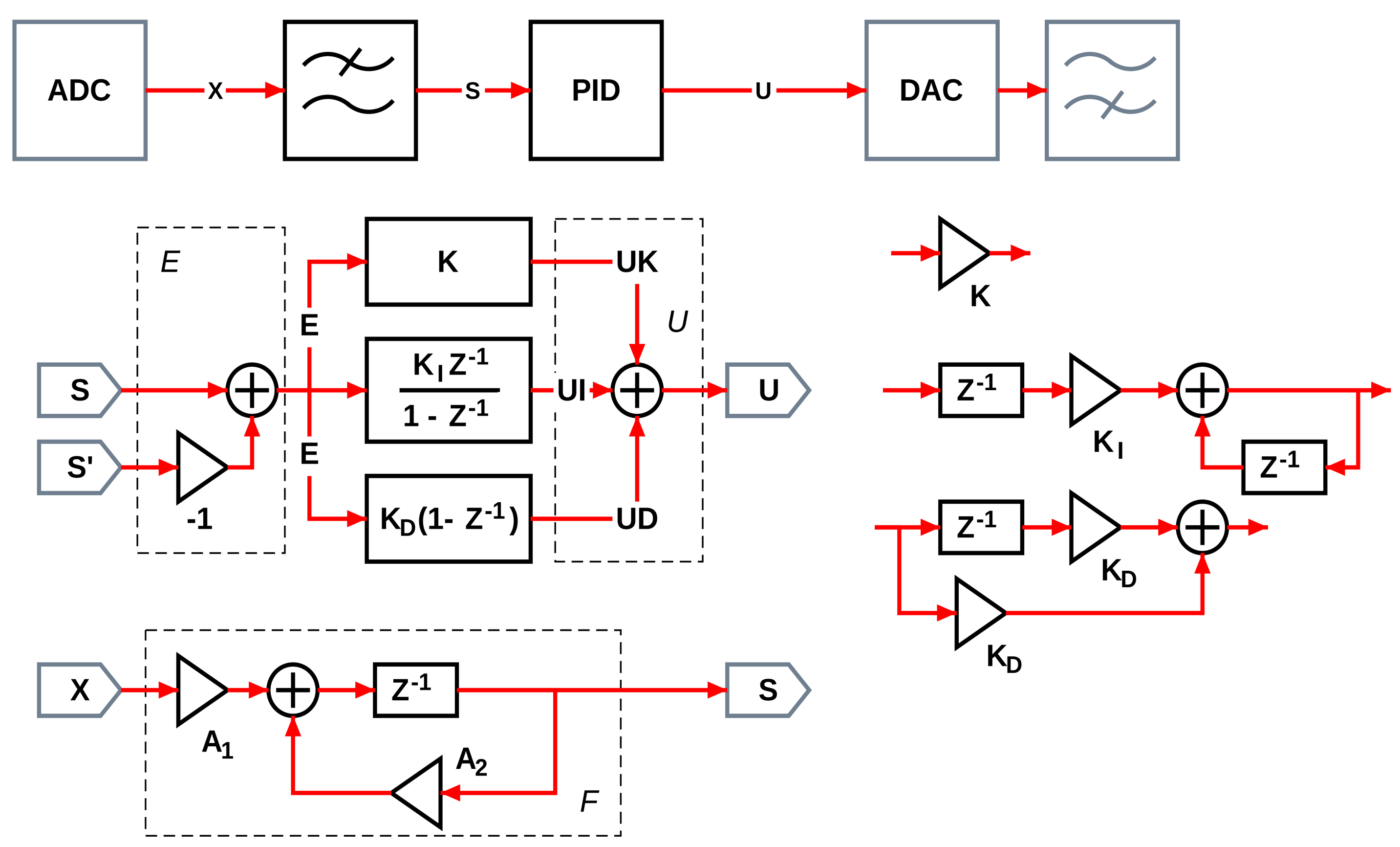
ENERGY-AWARE DESIGN FLOW FOR EMBEDDED SYSTEMS

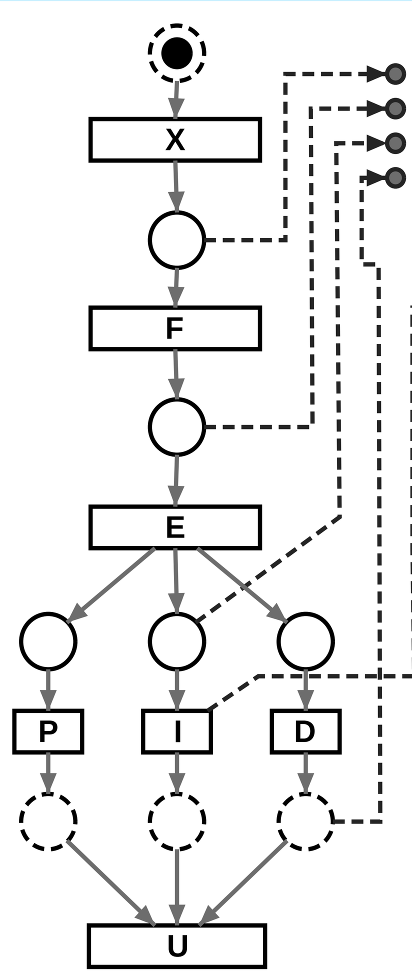
- ☞ Today there is an increasing demand for miniaturized smart sensors embedded in sensorial materials.
- ☞ With increasing miniaturization and sensor-actuator density, decentralized network and data-processing architectures are preferred, but energy supply is still centralized. *Advanced smart low-power design methodologies and applications are required.*
- ☞ A new design methodology focuses on 1. smart energy management at runtime and 2. application-specific System-On-Chip (SoC) design at design time contributing to low-power systems on both algorithmic and technological level.

Figure 1. Composition and modelling of a feedback-controlled system with signal flow diagrams. This example implements a PID controller used for example in actuator position control, consisting of sensor signal acquisition (ADC), filtering, and an error controller with a proportional, integral, and differential sub-controller [3].



- ➤ Data processing systems are modelled using signal flow diagrams (see **Figure 1.**) **[2]**.
- ➤ This initial specification is used to derive 1. a multi-process programming model, and 2. a hardware model for a System-On-Chip design on Register-Transfer level.
- ➤ The signal flow diagram is first transformed into a S/T Petri Net representation (**Figure 2.**). The **Petri Net** is used 1. to derive the communication architecture, and 2. to determine an initial configuration for the communication network.
- ➤ The Petri Net is mapped to sequential processes performing functional operations and channels providing the inter-process communication.
- ➤ Finally, a RTL SoC design is synthesized **[1]** and the circuit activity is analyzed regarding different algorithms and complexity (**Figure 4.**).

Figure 2. Mapping of the signal flow diagram to a Petri Net and mapping of Petri Net to communication channels and sequential processes using the ConPro programming language.




```
channel c_x:int[12] with model=buffered;
channel c_s:int[12] with model=buffered;
channel c_e1,c_e2,c_e3:int[12] ...
channel c_u1,c_u2,c_u3:int[12] ...
```

```
process p_i:
begin
  reg t1,t2,z1,z2: int[DATAWIDTH4];
  always do
  begin
    t1 <- c_e2;
    t1 <- z1, z1 <- t1;
    t1 <- t1 * KI;
    t1 <- t1 asr 4;
    t2 <- t1 + z2,
    z2 <- t2;
    c_u2 <- t2;
  end;
end;
```

ENERGY MANAGEMENT AT RUNTIME

- ☞ Smart energy management is performed spatially at runtime by a behaviour-based or state-action-driven selection from a set of different (implemented) algorithms classified by their demand of computation power, and temporally by varying data-processing rates (*based on previous activity analysis*).

Definition 1. Constraints net relations satisfying quality of service and minimizing power consumption to be fulfilled at runtime. Some values are derived from circuit activity analysis.

```
VARS = {Runtime,Rate,Level,Energy,Power,Error}
Runtime = {LOW=1,MED=2,HIGH=3}, Error = {0,5,10,100}, Lev-
el = {LOW=1,HIGH=1.5} ,
Rate = {1,5,10,50,100} , ...
Runtime > 0, Energy > 0, Rate > 0
Energy ≥ (Power*Runtime)/2
Power ≥ (Level*Rate)/4
Error ≤ (Level+Rate)/2
```

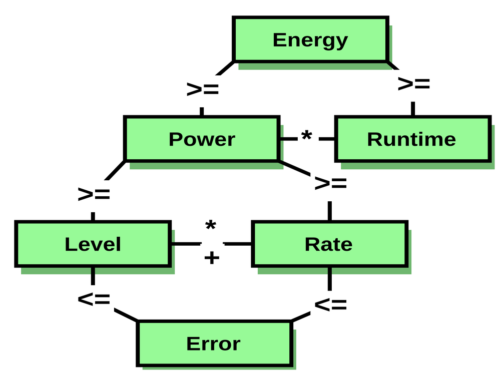
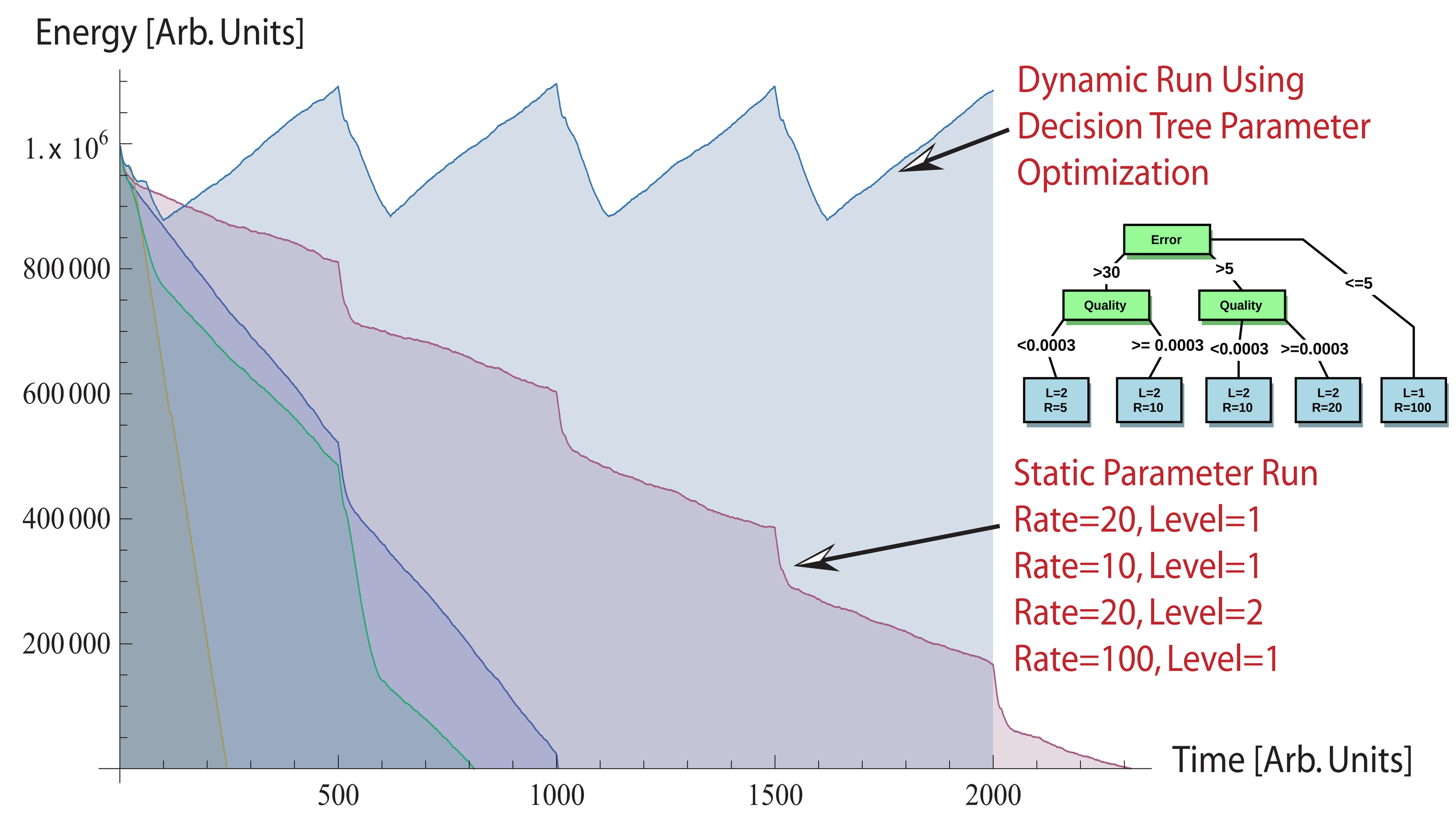
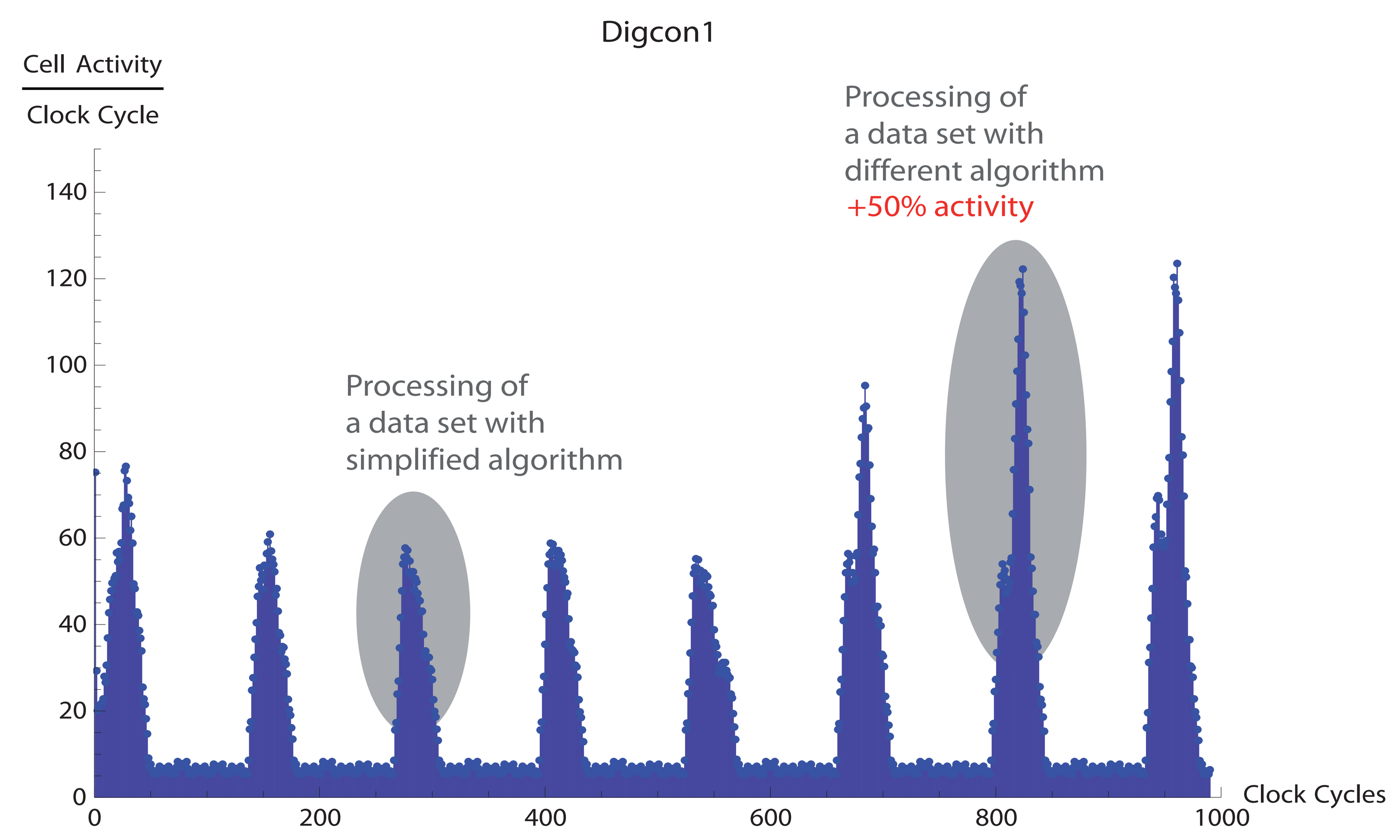


Figure 3. System simulation (from Figure 1.) with different runtime behaviours using a decision tree which can be retrieved by machine learning methods. Parameters: Data-processing rate={1,5,10,20,100}, Algorithmic level={P:1,PID:2}



- ➤ Using advanced methods from the **artificial intelligence** area enables dynamic adaption of smart sensors and actuators at runtime.
- ➤ Definition **1** shows a **constraints net** approach performing energy managament at runtime.
- ➤ **Figure 3.** shows simulation results of a system using **decision tree** and machine learning approaches to optimize the runtime behaviour.

Figure 4. SoC cell activity correlates strongly with computation and signal/data flow. The first five results are computed only with the P controller; after obtaining the fifth result value U, the I and D computational blocks are switched on.



REFERENCES

[1] S. Bosse, *Hardware Synthesis of Complex System-on-Chip-Designs for Embedded Systems Using a Behavioural Programming and Multi-Process Model*, Proceedings of the 55th IWK - Internationales Wissenschaftliches Kolloquium, Session C4, Ilmenau, 13 - 17 Sept. 2010

[2] T. Behrmann, C. Zschippig, M. Lemmel, S. Bosse, *Toolbox for Energy Analysis and Simulation of self-powered Sensor Nodes*, Proceedings of the 55th IWK - Internationales Wissenschaftliches Kolloquium, Session A3, Ilmenau, 13 - 17 Sept. 2010

[3] R. Isermann, *Digital Control Systems*, Springer, 1989

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