A Multi-Paradigm Modeling Approach for Hybrid Dynamic Systems

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Outline

I. Introduction

II. Petri-Net Based Framework

III. Example: A Rapid Thermal Process

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I. Introduction

- Why do we have modeling and simulation?
  - Modeling is a way of representing our knowledge about structure and behavior of systems and further answering questions about them via the simulation (Mosterman and Vangheluwe, 2002).

Traditional System Modeling

- Time-driven, continuous variable systems (CVS)
  - Differential/Difference equations.
- Event-driven, discrete event systems (DES)
  - Finite state automata or Petri nets (Cassandras and S. Lafortune, 1999; Zhou and Jeng, 1998)
- Both are to reduce the complexity for presenting real systems.

Issues in Traditional System Modeling

- Most practical systems have both the time-driven and event-driven dynamics and form the so-called **hybrid dynamic systems (HDS).**
- Relative literature (special issues) on HDS
  - Antsaklis and Nerode, "Hybrid control systems: An introductory discussion to the special issue," IEEE Trans. Automat. Contr., 1998.
  - Morse et al, "Introduction to the special issue on hybrid systems," Automatica, 1999.
  - Antsaklis and Lemmon, "Introduction to the special issue," J. Discrete Event Dynamic Syst, 1998.

Modeling Approaches for HDS

- **Integrate Continuous and Discrete Models**
  - Extend CVS to include event-driven dynamics
    - Linear piece-wise systems (Branicky et al, 1998)
  - Extend DES to include time-driven dynamics
    - Hybrid automata (Lygeros, 2003), Hybrid Petri nets (David and Alla, 1994), Hybrid Statechart (Lee and Hsu, 2002).
    - Commercial Software: MATLAB Simulink with Stateflow (Harman and Dabney, 2001), VHDL-AMS (Bakalar and Christen, 1999).

Motivations

- Simultaneously dealing with the discrete and continuous variables is very difficult.
- Their mathematical backgrounds are completely different: event-driven vs. time-driven dynamics.
- Most of the existing HDS modeling approaches result in a unified, but more complicated and unnatural model.
- Design engineers cannot be allowed to use their preferred domain models.

II. Petri-Net Based Framework

- PN-Based Approach
  - Use Petri net (PN) to model the event-driven dynamics
  - Use the Differential/Difference equations to model the time-driven dynamics
  - Define the interfaces for model communications

Advantages of Using PN

- Graphic representation.
- More compact representation.
- A structured model of DES dynamics.
- Mathematical support (reachability, invariant, reduction, siphon/trap, and simulation; Zhou and Jeng, 1998).
- PN family (Stochastic PN, Colored PN, CTPN, Automation PN…etc)
- A large body of existent tools and software for PN analysis and design. http://www.daimi.au.dk/PetriNets/tools/

Multiple Models in Hybrid Control Systems

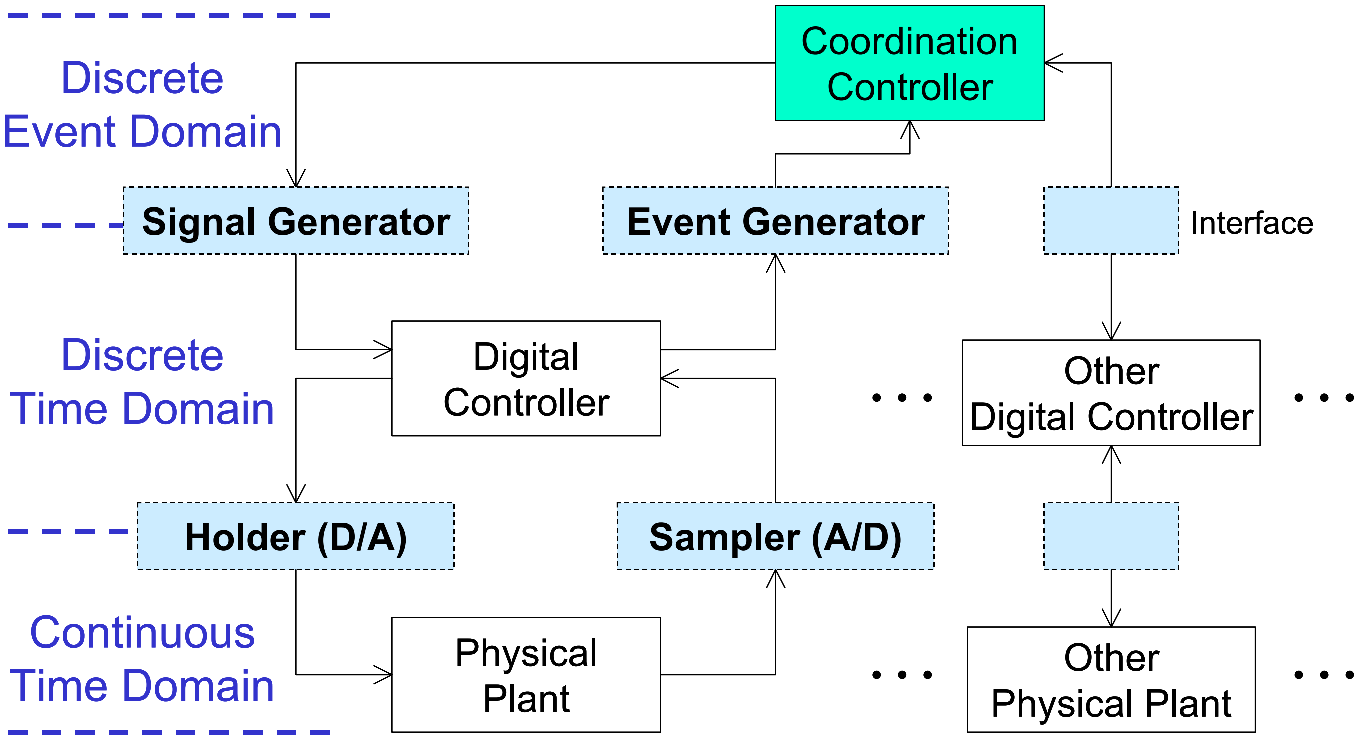


Fig. 1. Multiple domains in hybrid control systems.

PN-Based Framework

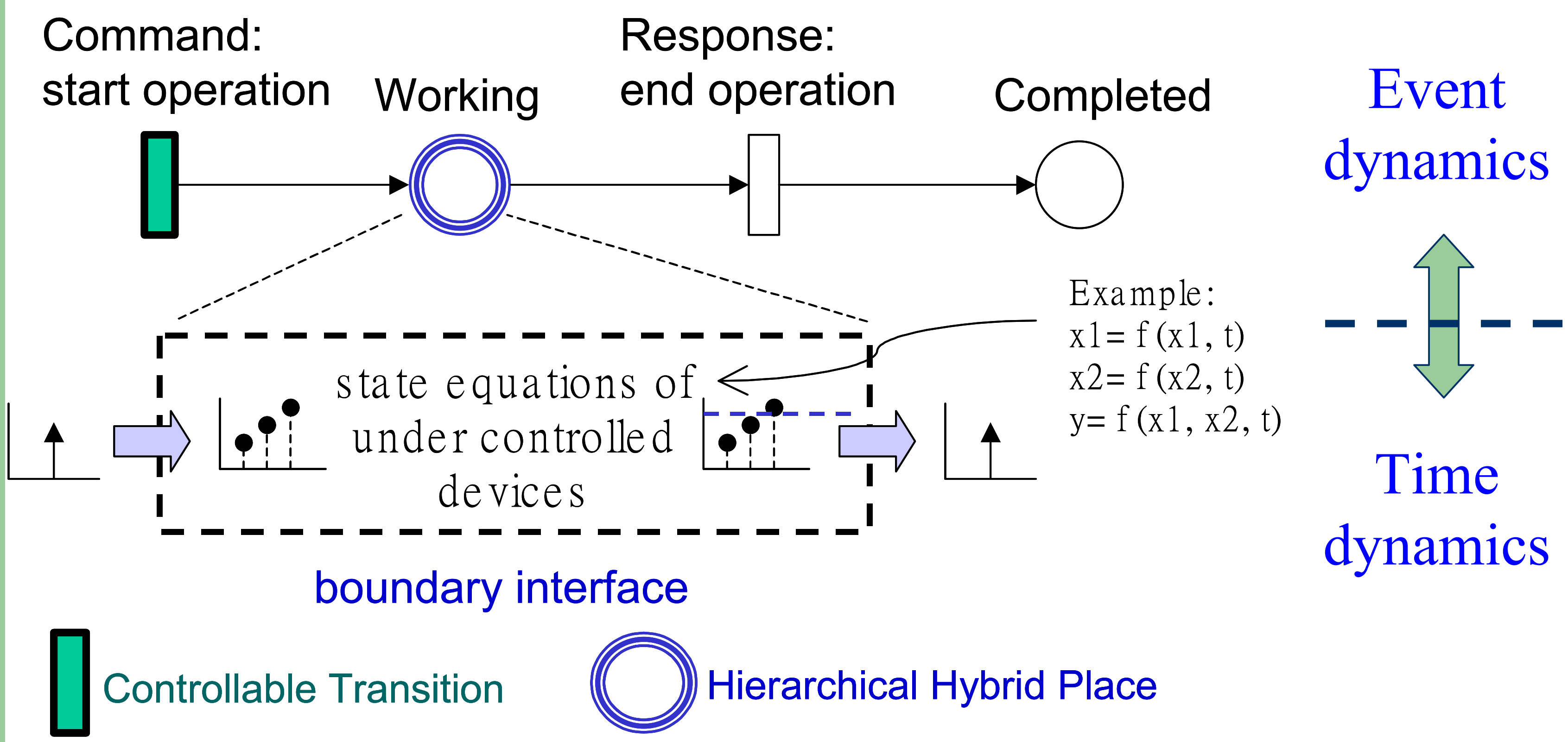


Fig. 2. Modeling the continuous dynamics within a Petri net via a hierarchical way.

Comparison: Hybrid Petri Net (David & Alla, 1994)

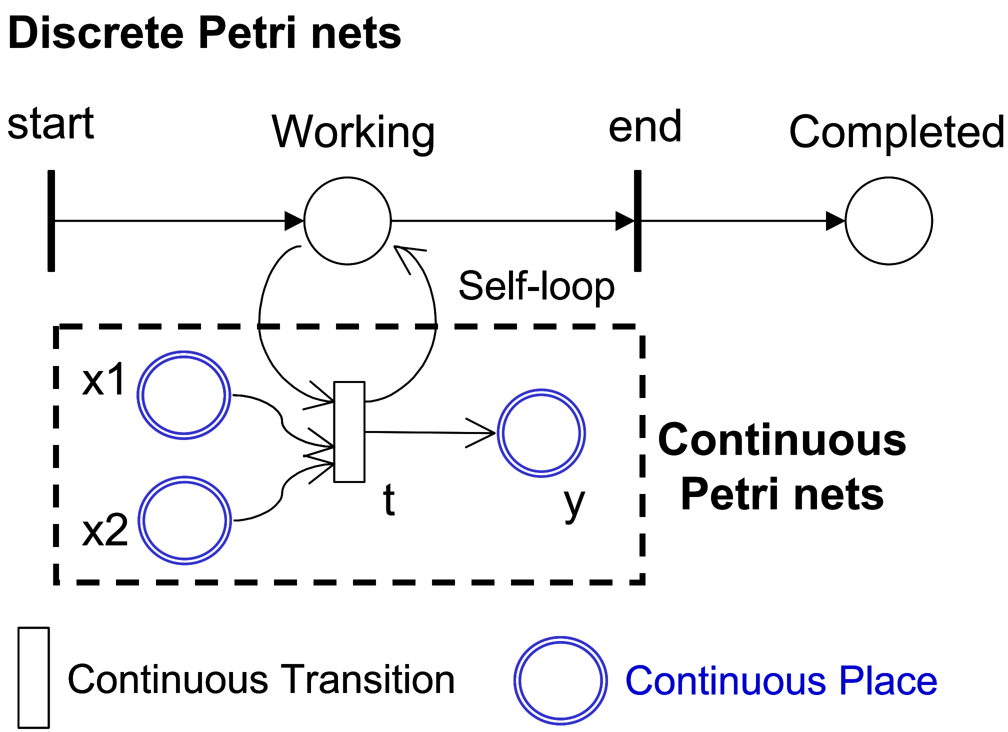


Fig. 3. Hybrid Petri net (with a net structure to model continuous dynamics).

Discrete-Event & Discrete-Time Models

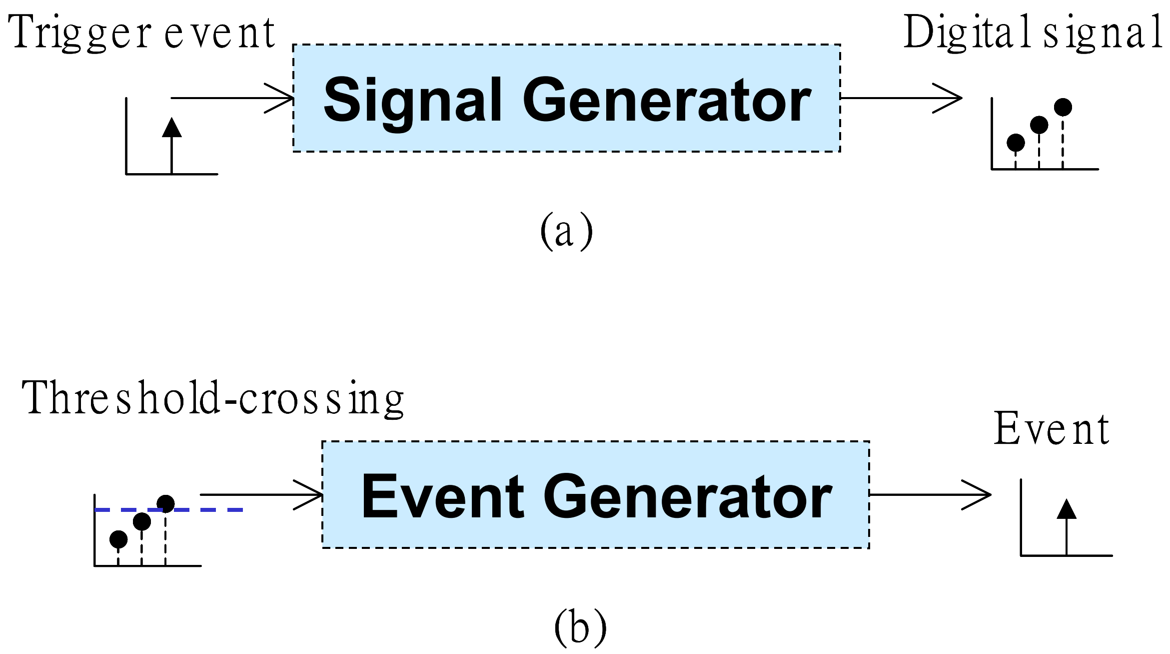


Fig. 4. Interfacing devices in high level: (a) signal and (b)event generators.

Discrete-Time & Continuous-Time Models

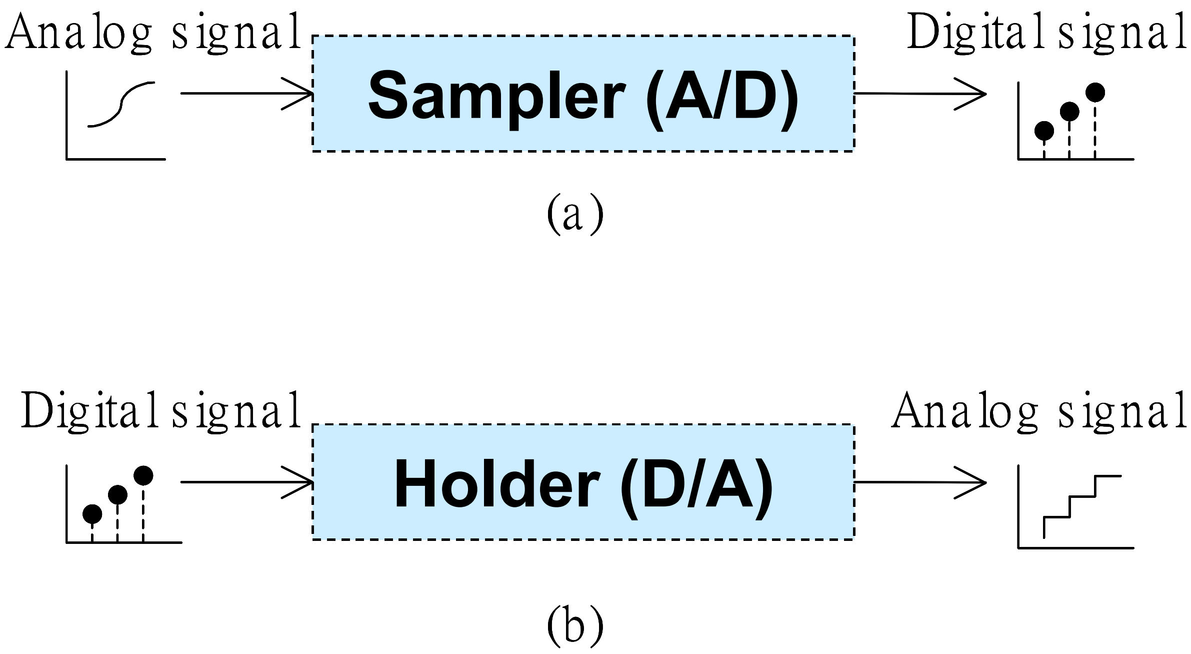


Fig. 5. Interfacing devices in low level: (a) sampler and (b) holder.

III. Example: A Rapid Thermal Process

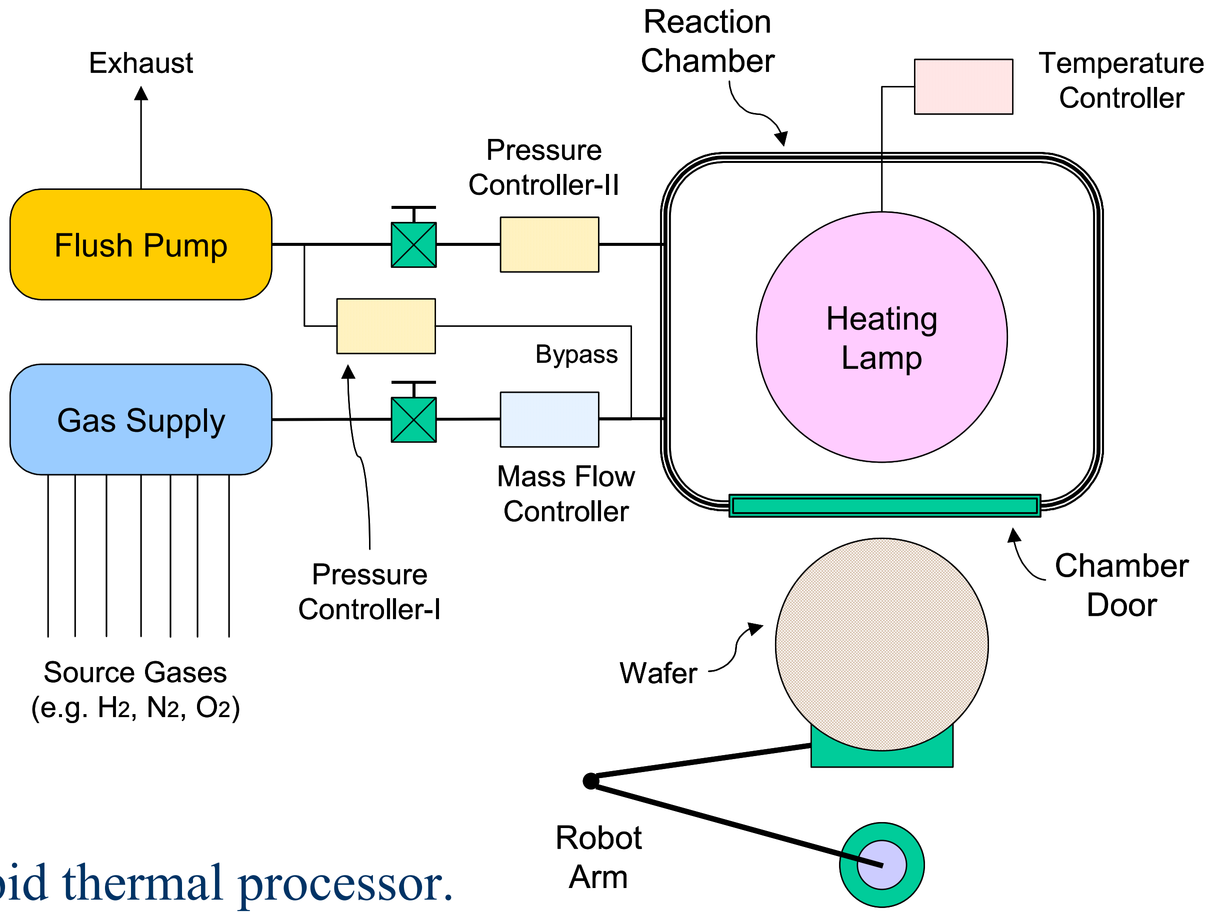


Fig. 6. A rapid thermal processor.

A Hydrogen Baking Process

Step 1) Load the raw wafer.

Step 2) Close the chamber door.

Step 3) Open the gas valve to supply gases with a desired gas flow rate and pressure of 2.8 liters per minute (lpm) and 0.5 Torr, respectively.

Step 4) Close the gas valve.

Step 5) Turn on the heating lamp to bake the wafer with a desired baking temperature and time of 1000°C and 4 seconds, respectively.

A Hydrogen Baking Process (cont'd)

Step 6) Turn off the heating lamp.

Step 7) Turn on the flush pump with a desired pressure of less than 0.05 Torr.

Step 8) Turn off the flush pump.

Step 9) Open the chamber door.

Step 10) Unload the processed wafer.

PN Model

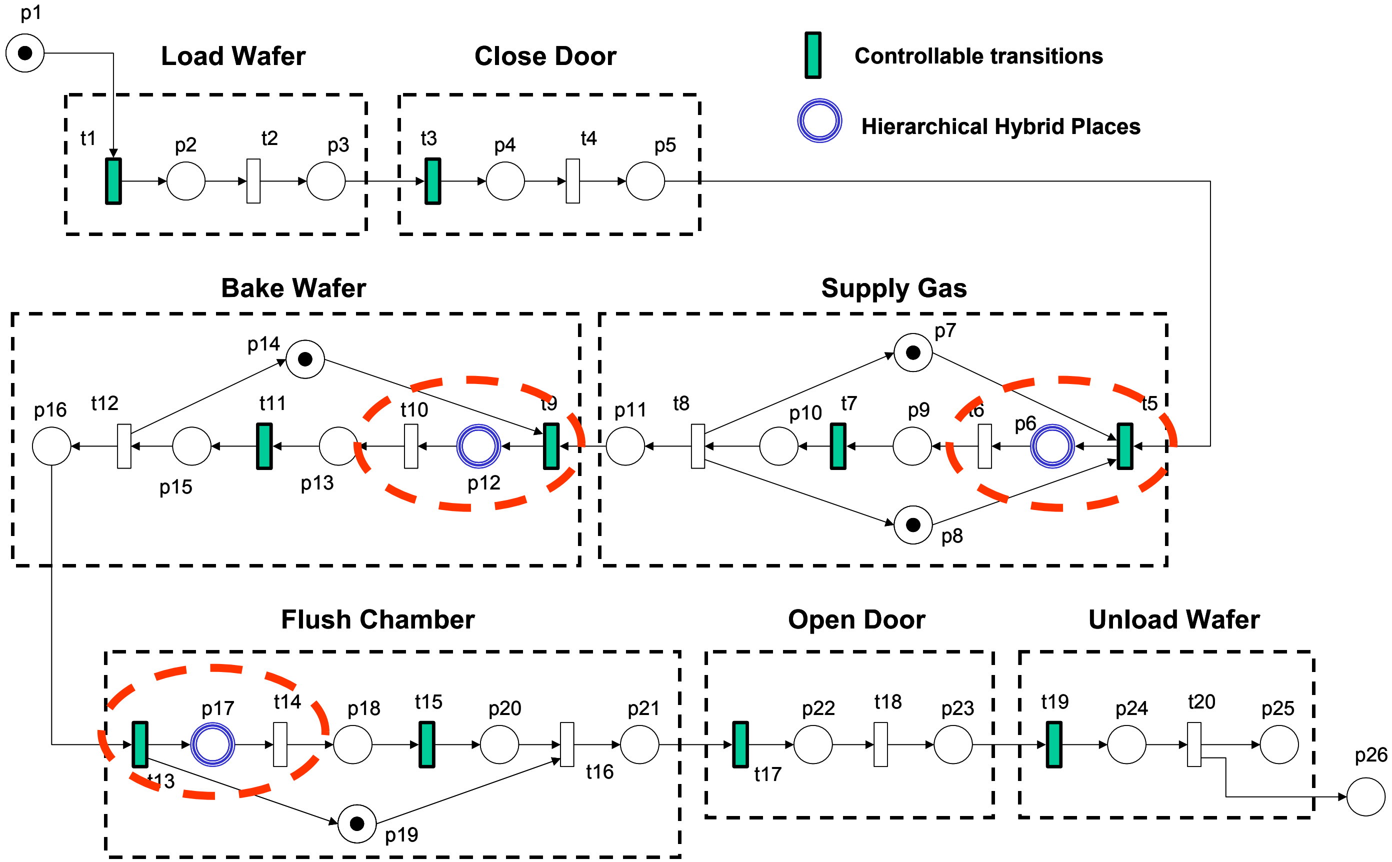
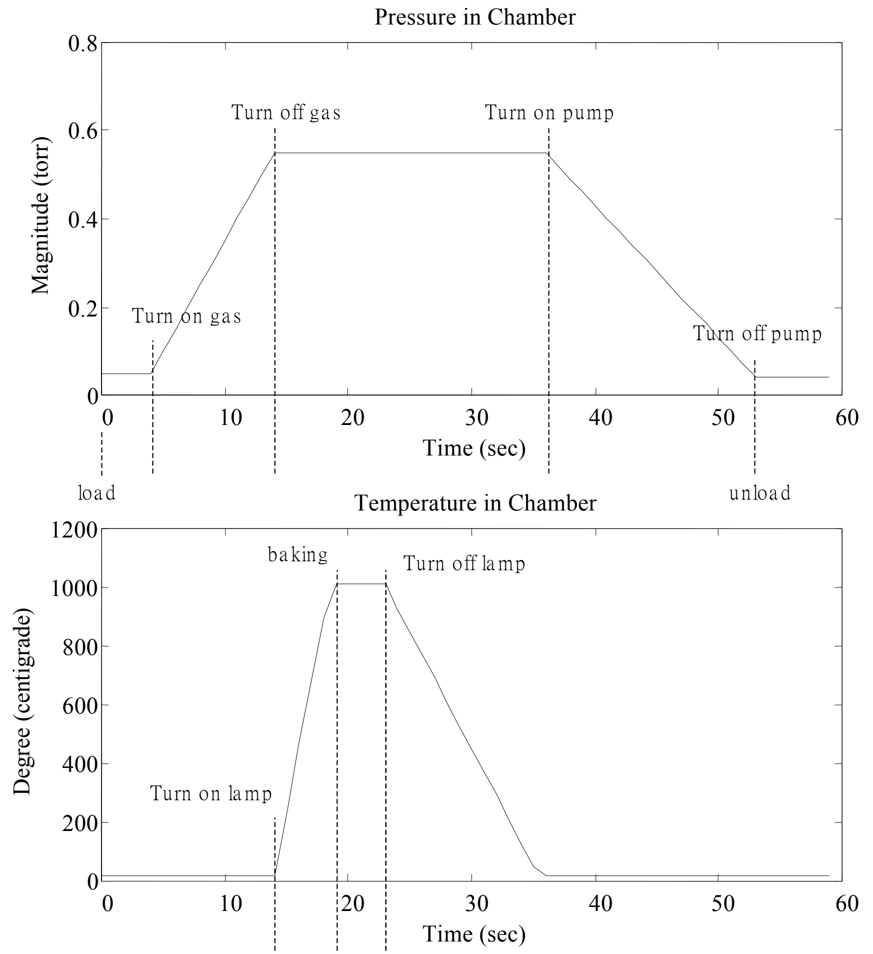


Fig. 7. PN model of the RTP system.

Table I. Notations for the PN model in Fig. 7

Place	Description	Transition	Description
p1	Raw wafer buffer	t1	Cmd: start loading wafer
p2	Loading wafer	t2	Re: end loading wafer
p3	Loading wafer completed	t3	Cmd: start closing chamber door
p4	Closing chamber door	t4	Re: end closing chamber door
p5	Closing chamber door completed	t5	Cmd: start opening gas valve
p6	Opening gas valve	t6	Re: end opening gas valve
p7	Mass flow controller ready	t7	Cmd: start closing gas valve
p8	Pressure controller-I ready	t8	Re: end closing gas valve
p9	Opening gas valve completed	t9	Cmd: start turning on heating lamp
p10	Closing gas valve	t10	Re: end turning on heating lamp
p11	Closing gas valve completed	t11	Cmd: start turning off heating lamp
p12	Turning on heating lamp	t12	Re: end turning off heating lamp
p13	Turning on heating lamp completed	t13	Cmd: start turning on flush pump
p14	Temperature controller ready	t14	Re: end turning on flush pump
p15	Turning off heating lamp	t15	Cmd: start turning off flush pump
p16	Turning off heating lamp completed	t16	Re: end turning off flush pump
p17	Turning on flush pump	t17	Cmd: start opening chamber door
p18	Turning on flush pump completed	t18	Re: end opening chamber door
p19	Pressure controller-II ready	t19	Cmd: start unloading wafer
p20	Turning off flush pump	t20	Re: end unloading wafer
p21	Turning off flush pump completed		
p22	Opening chamber door		
p23	Opening chamber door completed		
p24	Unloading wafer		
p25	Unloading wafer completed		
p26	Processed wafer buffer		

Fig. 8. Pressure and temperature in one cycle processing.



IV. Conclusion

- We have presented a Petri net-based framework to model the hybrid dynamic systems.

- **Future Work**
  - From a idea/concept, to a methodology, even to a theory…

Q & A

Thanks for your time and attention!

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