Continuous and Hybrid Petri Nets:
The GISED perspective

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The present report is written after some requests following the presentations in the tutorial in honor of Prof. Laura Recalde, *Continuous Petri Nets: Expressivity, Analysis and Control of a Class of Hybrid Systems* (a satellite event of the 30th *International Conference on Applications and Theory of Petri Nets*, Paris, June 23, 2009). It provides a structured view of works on this topic produced by members of the GISED (*Grupo de Ingeniería de Sistemas de Eventos Discretos*, Instituto de Investigación en Ingeniería de Aragón and Dept. de Informática e Ingeniería de Sistemas, Universidad de Zaragoza), with cooperation of colleagues of different research centers.

When an article is a revised/extended version of an older one, we keep in the main list the most complete and recent. Nevertheless, the reference of the previous version is given in a footnote.

1. General perspectives

Three of the following articles correspond to keynote speeches, the last to an invited contribution to a Spanish journal. Usually they are not only tutorial/survey.

[SR02][1] M. Silva and L. Recalde: "Petri Nets and Integrality Relaxations: A view of Continuous Petri Net Models". *IEEE Transactions on Systems, Man and Cybernetics.* November, 2002. Vol. 32 (4): 314-327.

[SR04][2] M. Silva and L. Recalde: "On fluidification of Petri Nets: from discrete to hybrid and continuous models", *Annual Reviews in Control* 28: 253-266, 2004. (Invited.)

[SR05] M. Silva and L. Recalde: "Continuisation of Timed Petri Nets: From Performance Evaluation to Observation and Control". In G. Ciardo and Ph. Darondeau (eds.), *Applications and Theory of Petri Nets*, Springer-Verlag, LNCS 3536: 26-47, 2005. (Keynote speech)

[SR07] M. Silva and L. Recalde: "Redes de Petri continuas: Expresividad, Análisis y Control de una clase de sistemas lineales conmutados", *Revista Iberoamericana de Automática e Informática Industrial (RIAI),* 4(3): 5-33, Julio 2007. (Invited)

2. Autonomous models (I): Analysis and verification

[RTS99] L. Recalde, E. Teruel and M. Silva: "Autonomous continuous P/T systems". *Application and Theory of Petri Nets'99,* LNCS 1639: 107-126, Springer-Verlag, Berlin, 1999.

[JRS03] J. Júlvez, L. Recalde and M. Silva: "On reachability on autonomous continuous Petri Net Systems", *Applications and Theory of Petri Nets'03*, Springer-Verlag, LNCS 2679: 221-240, 2003.

3. Autonomous models (II): State estimation and fault diagnosis

[CGMRSS07] M.P. Cabasino, A. Giua, C. Mahulea, L. Recalde, C. Seatzu and M. Silva, "State Estimation of Petri Nets by Transformation", *IEEE Conf. on Automation Science and Engine*ering (CASE), pp.194 -199, Arizona, September, 2007.

[MSCRS09] C. Mahulea, C. Seatzu, M. P. Cabasino, L. Recalde, and M. Silva: "Observer Design for Untimed Continuous Petri Nets", *American Control Conference* (ACC), St. Louis, Missouri, June 2009.

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[1] [SR00] M. Silva and L. Recalde: "Réseaux de Pétri et relaxations de l´intégralité: Une vision des Réseaux Continues". *IEEE/CNRS Colloque International Francophone d'Automatique* (CIFA), pp. 1-14, Lille, Septembre, 2000. (Conférence Plénière)

[2] [SR03] M. Silva and L. Recalde: "On fluidification of {Petri} net models: from discrete to hybrid and continuous models", In Procs. *IFAC Conference on Analysis and Design of Hybrid Systems, ADHS03*, Saint-Malo, France, June, 2003, pp. 9-20. (Keynote speach)

[SMCS09] C. Seatzu, C. Mahulea, M. P. Cabasino, and M. Silva: "Fault diagnoser design for untimed continuous Petri nets", *IEEE Multi-conference on Systems and Control*, Saint Petersburg, July 8-10, 2009.

[SCMS09] C. Seatzu, M. P. Cabasino, C. Mahulea and M. Silva: "New results for fault detection of untimed continuous Petri nets", *48th IEEE Conference on Decision and Control* (CDC), Shanghai, December 16-18, 2009.

4. Timing net models: Server's semantics, related formalisms and expressivity

[RS01][3] L. Recalde and M. Silva: "Petri Nets Fluidification Revisited: Semantics and Steady State". In *Modelling and Control of Hybrid Dynamical Systems,* Special Issue of *JESA* (J. Zaytoon, S. Engell, S. Kowaleweski, eds.), vol 35 (4): 435-449, Hermes, 2001.

[JRS01] E. Jiménez, L. Recalde and M. Silva: "Forrester Diagrams and Continuous Petri Nets: A comparative View", *8th IEEE Int. Conf. on Emerging Technologies and Factory Automation* (ETFA´01), Antibes, pp. 85-94, October 2001.

[JJRS04] E. Jiménez, J. Júlvez, L. Recalde and M. Silva, "Relaxed Continuous Views of Discrete Event Systems: considerations in Forrester Diagrams and Petri Nets", *Int. Conf. on Systems, Man and Cybernetics (SMC 2004),* pp. 4897-4904, La Haya, 2004.

[SR03] M. Silva and L. Recalde: "Unforced continuous Petri nets and positive systems". *On Positive Systems: Theory and Applications,* POSTA'03, LNCIS 294: 55-62. Springer-Verlag, September, 2003.

[HRS06] S. Haddad, L. Recalde, and M. Silva. On the computational power of Timed Diferentiable Petri nets. In *4th Int. Conf. On Formal Modeling and Analysis of Timed Systems* (E. Asarin and P. Bouyer, eds.), FORMATS 2006, *LNCS* 4202: 230-244, Paris, 2006.

[RHS07] L. Recalde, S. Haddad and M. Silva, "Continuous Petri Nets: Expressive Power and Decidability Issues", *Int. Symposium on Automated Technology for Verification and Analysis,* ATVA 2007, LNCS 4762, pp. 362-377, Kyoto, Japan, octubre 2007.

[VRS08] C.R. Vázquez, L. Recalde and M. Silva: "Stochastic Continuous-State Approximation of Markovian Petri Net Systems". In Proceeding of the *47th IEEE Conference on Decision and Control* (CDC), 901-906, Cancún, December, 2008.

[VS09] C.R. Vázquez and M. Silva: "Hybrid Approximations of Markovian Petri nets". *3rd IFAC Conference on Analysis and Design of Hybrid Systems*, ADHS'09, Zaragoza, September 2009.

[MRS09] [4] C. Mahulea, L. Recalde, and M. Silva: "Basic Server Semantics and Performance Monotonicity of Continuous Petri Nets", *Discrete Event Dynamic Systems: Theory and Applications* (to appear), 2009-10.

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[3] [RS00] L. Recalde and M. Silva: "Petri Nets Fluidification Revisited: Semantics and Steady State". *APDM´2000*. Dortmund, pp. 279-286, September 2000.

[4] [MRS06] C. Mahulea, L. Recalde and M. Silva: "On performance monotonicity and basic servers semantics of continuous Petri nets". In IEEE Procs. of the *Int. Workshop on Discrete Event Systems,* WODES'06, pp. 345-351, Ann Arbor, Michigan, July, 2006.

5. Timed net models (I): Analysis and verification

[JRS05][5] J. Júlvez, L. Recalde and M. Silva "Steady-state performance evaluation of continuous mono-T-semiflow Petri nets", *Automatica* Vol. 41(4): 605-616, 2005.

[JRS06][6] J. Júlvez, L. Recalde and M. Silva, "Deadlock-freeness analysis of Continuous mono-T-semiflow Petri Nets. *IEEE Transactions on Automatic Control,* 51(9): 1472-81, 2006.

[KMBRS08] M. Kloetzer, C. Mahulea, C. Belta, L. Recalde, and M. Silva: "Formal analysis of timed continuous Petri nets". In *47th IEEE Conference on Decision and Control (CDC)*, Cancún, México, December, 2008.

[VMMRS08] C.R. Vázquez, A.M. Mangini, A.M. Mihalache, L. Recalde and M. Silva: "Timing and deadlock-freeness in Continuous Petri nets", *17th IFAC World Congress,* pp. 3186-3191*,* Seoul, July, 2008.

6. Timed net models (II): Observability and observers

[JJRS04] J. Júlvez, E. Jiménez, L. Recalde and M. Silva: "On Observability in Timed Continuous Petri Net Systems", *International Conference on the Quantitative Evaluation of Systems (QEST)*, pp. 60-69, Twente, September, 2004.

[MRS05] C. Mahulea, L. Recalde and M. Silva: "Optimal observability for continuous Petri Nets", *16th IFAC World Congress*, Praga, July, 2005.

[MCGS07] C. Mahulea, M.P. Cabasino, A. Giua and C. Seatzu, "A State Estimation Problem for Timed Continuous Petri nets", *IEEE Int. Conference on Decision and Control* (CDC), 2007.

[JJRS08][7] J. Júlvez, E. Jiménez, L. Recalde and M. Silva, "On observability and design of observers in timed continuous Petri net systems", *IEEE Transactions on Automation Science and Engineering*, 5(3): 532-537, 2008.

[MRS09][8] C. Mahulea, L. Recalde, and M. Silva: "Observability of continuous Petri nets with infinite server semantics". *Nonlinear Analysis: Hybrid Systems* (to appear).

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[5] [RJS02] L. Recalde, J. Júlvez and M. Silva: "Steady State Performance Evaluation for Some Continuous Petri Nets". In *Procs.* of *b´02,* the *IFAC World Congress*, Barcelona, July 2002.

[6] [JRS02] J. Júlvez, L. Recalde and M. Silva, "On deadlock-freeness analysis of autonomous and timed continuous mono-T-semiflow nets", *Proc. of the 41st Conference on Decision and Control* (CDC), pp. 781—786, Las Vegas, 2002.

[7] [JJRS04] J. Júlvez, E. Jimenez, L. Recalde and M. Silva: "Design of Observers for Timed Continuous Petri Net Systems", In *Procs. of the IEEE International Conference on Systems, Man and Cybernetics (SMC 2004),* La Haya, pp. 1678-1685, 2004.

[8] [MRS08] C. Mahulea, L. Recalde, and M. Silva: "Observability of Timed Continuous Petri Nets: A Class of Hybrid Systems". Procs. of the *17th IFAC World Congress*, Seoul, Korea, July 2008.

7. Timed net models (III): Controllability and sampling

[JJRS05] E. Jiménez, J. Júlvez, L. Recalde and M. Silva: "On Controllability of Timed Continuous Petri Net Systems: the Join Free Case", *44th IEEE Conference on Decision and Control (2005 Joint CDC-ECC)*, pp. 7645—7650, 2005.

[MGRSS06] C. Mahulea, A. Giua, L. Recalde, C. Seatzu and M. Silva: "On Sampling Continuous Timed Petri Nets: Reachability 'Equivalence' Under Infinite Servers Semantics". *2nd IFAC Conf. on Analysis and Design of Hybrid Systems,* ADHS'06, Alghero, June 7-9, pp. 37-43, 2006.

[VRRS08] C.R. Vázquez, A. Ramírez, L. Recalde and M. Silva: "On Controllability of Timed Continuous Petri Nets", *Hybrid Systems: Computation and Control*, LNCS 4981: 528-541, Springer, 2008.

[MRRS08][9] C. Mahulea, A. Ramírez-Treviño, L. Recalde, and M. Silva, "Steady state control reference and token conservation laws in continuous Petri net systems", *IEEE Transactions on Automation Science and Engineering*, 5(2): 307-320, 2008.

8. Timed net models (IV): Control issues

[JBRS04] J. Júlvez, A. Bemporad, L. Recalde and M. Silva: "Event-Driven Optimal Control of Continuous Petri Nets", *43rd IEEE Conference on Decision and Control (CDC), pp.* 69—74, December, 2004.

[GMRSS06] A. Giua, C. Mahulea, L. Recalde, C. Seatzu and M. Silva: "Optimal control of continuous Petri nets via model predictive control", *8th Int. Workshop on Discrete Event Systems,* WODES'06, Ann Arbor, Michigan, pp. 235-241, July 2006.

[GMRSS08] A. Giua, C. Mahulea, L. Recalde, C. Seatzu and M. Silva: "Properties of continuous Petri nets controlled via model predictive control". In the *9th International Workshop on Discrete Event Systems*, WODES'08, Gothenburg, Sweden, May 2008.

[MGRSS08][10] C. Mahulea, A. Giua, L. Recalde, C. Seatzu, and M. Silva: "Optimal model predictive control of Timed Continuous Petri nets". *IEEE Transactions on Automatic Control*, 53(7): 1731 - 1735, August 2008.

[XRS08][11] J. Xu, L. Recalde and M. Silva: "Tracking Control of Join-Free Timed Continuous Petri Net Systems under Infinite Servers Semantics", *Journal of Discrete Event Dynamic Systems*, 18(2): 263 – 283, June 2008.

[XRS08] J. Xu, L. Recalde and M. Silva, "Tracking Control of Timed Continuous Petri Net Systems under Infinite Servers Semantics", *IFAC World Congress,* Seoul, July, 2008.

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[9] [MRRS05] C. Mahulea, A. Ramírez-Treviño, L. Recalde and M. Silva: "Steady State Control, Zero Valued Poles and Token Conservation Laws in Continuous Net Systems". *Control of Hybrid and Discrete Event Systems* (Colom, Sreenivas and Ushio, eds.), Miami, June, 2005.

[10] [GMRSS06] A. Giua, C. Mahulea, L. Recalde, C. Seatzu, and M. Silva: "Optimal control of timed continuous Petri nets via explicit MPC. *On Positive Systems: Theory and Applications (POSTA'06).* LNCIS 341: 383-390, Springer-Verlag, September, 2006.

[11] [XRS06] J. Xu, L. Recalde and M. Silva: "Tracking control of Join-Free timed continuous Petri Net Systems". In *Preprints of the 2nd IFAC Conf. on Analysis and Design of Hybrid Systems,* ADHS'06, Alghero, pp. 30-36, June 7-9, 2006.

[VS09] C.R. Vázquez and M. Silva: "Performance Control of Markovian Petri Nets via Fluid Models: A Stock-Level Control Example". In Procs. of the *5th IEEE Conference on Automation Science and Engineering* (IEEE CASE), Bangalore, August 2009. (Session ***In Memoriam* of prof. Laura Recalde:** *Advances in Petri Net theory*.)

[AJMS09] H. Apaydin-Ozkan, J. Júlvez, C. Mahulea and M. Silva: "An Efficient Heuristics for Minimum Time Control of Continuous Petri nets", *3rd IFAC Conference on Analysis and Design of Hybrid Systems*, ADHS'09, Zaragoza, September 2009.

[VS09] C.R. Vázquez and M. Silva: "Piecewise-Linear Constrained Control for Timed Continuous Petri Nets". *48th IEEE Conference on Decision and Control* (CDC), Shanghai, December, 2009.

9. Miscelanea

[JB05] J. Júlvez, R. Boel: "Modelling and controlling traffic behaviour with continuous Petri nets", *16th triennial World congress of the International Federation of Automatic Control* (IFAC2005), Prague, July 2005.

[RMS06] L. Recalde, C. Mahulea, and M. Silva, Improving analysis and simulation of continuous Petri nets. In 2*nd IEEE Conference on Automation Science and Engineering*, *CASE'06,* pages 7–12, Shanghai, China, October 2006.

[MMVRS07] A.M. Mangini, A. Mihalache, C.R. Vázquez, L. Recalde and M. Silva, "A hierarchy of Petri net systems", Technical Report, Diciembre, 2007.