

# Technical and Non-Technical Applications of Evolving Takagi-Sugeno-Kang Fuzzy Models

Radu-Emil Precup, *Senior Member, IEEE*, Stefan Preitl, *Senior Member, IEEE*,  
Claudia-Adina Bojan-Dragos, *Member, IEEE*, Mircea-Bogdan Radac, *Member, IEEE*,  
Alexandra-Iulia Szedlak-Stinean, *Member, IEEE*, Elena-Lorena Hedrea and  
Raul-Cristian Roman, *Student Member, IEEE*

**Abstract**—This paper presents a part of the results obtained by the Process Control group of the Politehnica University of Timisoara, Romania, in the field of evolving Takagi-Sugeno-Kang fuzzy models. These results concern the development of Takagi-Sugeno-Kang fuzzy models by incremental online algorithms for the description of the dynamics or static behavior of three technical and non-technical system applications, namely magnetic levitation systems, Anti-lock Braking Systems and automated translation.

**Index Terms**—Anti-lock Braking Systems; automated translation; evolving Takagi-Sugeno-Kang fuzzy models; magnetic levitation systems.

## REFERENCES

- [1] P. Angelov, *Evolving Rule based Models: A Tool for Design of Flexible Adaptive Systems*. Berlin, Heidelberg: Springer-Verlag, 2002.
- [2] M. Sayed Mouchaweh, A. Devillez, G. Villerman Lecolier, and P. Billaudel, "Incremental learning in fuzzy pattern matching," *Fuzzy Sets Syst.*, vol. 132, no. 1, pp. 49–62, Nov. 2002.
- [3] P. X. Liu and M. Q.-H. Meng, "Online data-driven fuzzy clustering with applications to real-time robotic tracking," *IEEE Trans. Fuzzy Syst.*, vol. 12, no. 4, pp. 516–523, Aug. 2004.
- [4] W. Wang and J. Vrbancik, Jr., "An evolving fuzzy predictor for industrial applications," *IEEE Trans. Fuzzy Syst.*, vol. 16, no. 6, pp. 1439–1449, Dec. 2008.
- [5] E. Lughofer, *Evolving Fuzzy Systems - Methodologies, Advanced Concepts and Applications*. Berlin, Heidelberg: Springer-Verlag, 2011.
- [6] D. Dovžan and I. Škrjanc, "Recursive clustering based on a Gustafson-Kessel algorithm," *Evolving Syst.*, vol. 2, no. 1, pp. 15–24, Mar. 2011.
- [7] E. Lughofer, "On-line assurance of interpretability criteria in evolving fuzzy systems - achievements, new concepts and open issues," *Inform. Sci.*, vol. 251, pp. 22–46, Dec. 2013.
- [8] R.-E. Precup, P. Angelov, B. S. J. Costa, and M. Sayed-Mouchaweh, "An overview on fault diagnosis and nature-inspired optimal control of industrial process applications," *Comput. Ind.*, vol. 74, pp. 75–94, Dec. 2015.
- [9] D. Kangin, P. Angelov, and J. A. Iglesias, "Autonomously evolving classifier TEDAClass," *Inform. Sci.*, vol. 366, pp. 1–11, Oct. 2016.
- [10] C. Za'in, M. Pratama, E. Lughofer, and S. G. Anavatti, "Evolving type-2 web news mining," *Appl. Soft Comput.*, vol. 54, pp. 200–220, May 2017.
- [11] D. Dovžan, V. Logar, and I. Škrjanc, "Implementation of an evolving Fuzzy Model (eFuMo) in a monitoring system for a waste-water treatment process," *IEEE Trans. Fuzzy Syst.*, vol. 23, no. 5, pp. 1761–1776, Oct. 2015.
- [12] J. Platt, "A resource allocating network for function interpolation," *Neural Comput.*, vol. 3, no. 2, pp. 213–225, June 1991.
- [13] S. H. A. Ali, S. Ozawa, T. Ban, J. Nakazato, and J. Shimamura, "A neural network model for detecting DDoS attacks using darknet traffic features," in *Proc. 2016 International Joint Conference on Neural Networks*, Vancouver, BC, Canada, 2016, pp. 2979–2985.
- [14] C.-F. Juang and C.-T. Lin, "An on-line self-constructing neural fuzzy inference network and its applications," *IEEE Trans. Fuzzy Syst.*, vol. 6, no. 1, pp. 12–32, Feb. 1998.
- [15] M. Prasad, C.-T. Lin, D.-L. Li, C.-T. Hong, W.-P. Ding, and J.-Y. Chang, "Soft-boosted self-constructing neural fuzzy inference network," *IEEE Trans. Syst., Man, Cybern.*, vol. 47, no. 3, pp. 584–588, Mar. 2017.
- [16] S. G. Tzafestas and K. C. Zikidis, "NeuroFAST: On-line neuro-fuzzy ART-based structure and parameter learning TSK model," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 31, no. 5, pp. 797–802, Oct. 2001.
- [17] S. G. Tzafestas and K. C. Zikidis, "NeuroFAST: high accuracy neuro-fuzzy modeling," in *Proc. 2002 IEEE International Conference on Artificial Intelligence Systems*, Geelong, Australia, 2002, pp. 228–235.
- [18] N. K. Kasabov and Q. Song, "DENFIS: Dynamic Evolving Neural-Fuzzy Inference System and its application for time-series prediction," *IEEE Trans. Fuzzy Syst.*, vol. 10, no. 2, pp. 144–154, Apr. 2002.
- [19] L. S. Riza, C. Bergmeir, F. Herrera, and J. M. Benitez, "Learning from data using the R package "FRBS"," in *Proc. 2014 IEEE International Conference on Fuzzy Systems*, Beijing, China, 2014, pp. 2149–2155.
- [20] F.-J. Lin, C.-H. Lin, and P.-H. Shen, "Self-constructing fuzzy neural network speed controller for permanent-magnet synchronous motor drive," *IEEE Trans. Fuzzy Syst.*, vol. 9, no. 5, pp. 751–759, Aug. 2002.
- [21] N. Wang and M. J. Er, "Self-constructing adaptive robust fuzzy neural tracking control of surface vehicles with uncertainties and unknown disturbances," *IEEE Trans. Control Syst. Technol.*, vol. 23, no. 3, pp. 991–1002, May 2015.
- [22] P. Angelov and D. Filev, "An approach to online identification of Takagi-Sugeno fuzzy models," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 34, no. 1, pp. 484–498, Feb. 2004.
- [23] M. Moshtaghi, J. C. Bezdek, C. Leckie, S. Karunasekera, and M. Palaniswami, "Evolving fuzzy rules for anomaly detection in data streams," *IEEE Trans. Fuzzy Syst.*, vol. 23, no. 3, pp. 688–700, June 2015.
- [24] E. Lughofer and E. P. Klement, "FLEXFIS: A variant for incremental learning of Takagi-Sugeno fuzzy systems," in *Proc. 14<sup>th</sup> IEEE International Conference on Fuzzy Systems*, Reno, NV, USA, 2005, pp. 915–920.
- [25] B.-K. Xie and S.-J. Lee, "A modified scheme for all-pairs evolving fuzzy classifiers," in *Proc. 2014 International Conference on Machine Learning and Cybernetics*, Lanzhou, China, 2014, vol. 2, pp. 573–578.
- [26] M. Pratama, S. G. Anavatti, P. Angelov, and E. Lughofer, "PANFIS: A novel incremental learning machine," *IEEE Trans. Neural Netw. Learn. Syst.*, vol. 25, no. 1, pp. 55–68, Jan. 2014.
- [27] R.-E. Precup, S. Preitl, C.-A. Bojan-Dragos, M.-B. Radac, A.-I. Szedlak-Stinean, E.-L. Hedrea, and R.-C. Roman, "Evolving Takagi-Sugeno fuzzy modeling applications of incremental online identification algorithms," in *Proc. XIII International SAUM Conference on Systems, Automatic Control and Measurements*, Niš, Serbia, 2016, pp. 3–10.

Radu-Emil Precup, Stefan Preitl, Claudia-Adina Bojan-Dragos, Mircea-Bogdan Radac, Alexandra-Iulia Szedlak-Stinean, Elena-Lorena Hedrea and Raul-Cristian Roman are with the Department of Automation and Applied Informatics, Politehnica University of Timisoara, Bd. V. Parvan 2, 300223 Timisoara, Romania (e-mails: radu.precup@upt.ro, stefan.preitl@upt.ro, claudia.dragos@upt.ro, mircea.radac@upt.ro, alexandra-iulia.stinean@aut.upt.ro, elena.constantin@student.upt.ro, raul-cristian.roman@student.upt.ro).

- [28] R.-E. Precup, H.-I. Filip, M.-B. Radac, C. Pozna, C.-A. Dragos, and S. Preitl, "Experimental results of evolving Takagi-Sugeno fuzzy models for a nonlinear benchmark," in *Proc. 2012 IEEE 3<sup>rd</sup> International Conference on Cognitive Infocommunications*, Kosice, Slovakia, 2012, pp. 567–572.
- [29] R.-E. Precup, H.-I. Filip, M.-B. Radac, E. M. Petriu, S. Preitl, and C.-A. Dragos, "Online identification of evolving Takagi-Sugeno-Kang fuzzy models for crane systems," *Appl. Soft Comput.*, vol. 24, pp. 1155–1163, Nov. 2014.
- [30] R.-E. Precup, E.-I. Voisan, E. M. Petriu, M.-B. Radac, and L.-O. Fedorovici, "Implementation of evolving fuzzy models of a nonlinear process," in *Proc. 12<sup>th</sup> International Conference on Informatics in Control, Automation and Robotics*, Colmar, France, 2015, vol. 1, pp. 5–14.
- [31] R.-E. Precup, E.-I. Voisan, E. M. Petriu, M.-B. Radac, and L.-O. Fedorovici, "Gravitational search algorithm-based evolving fuzzy models of a nonlinear process," in: *Informatics in Control, Automation and Robotics*, J. Filipe, K. Madani, O. Gusikhin, and J. Sasiadek, Eds. Cham: Springer International Publishing, Lecture Notes in Electrical Engineering, vol. 383, pp. 51–62, 2016.
- [32] R.-E. Precup, T.-A. Teban, T. E. Alves de Oliveira, and E. M. Petriu, "Evolving fuzzy models for myoelectric-based control of a prosthetic hand," in *Proc. 2016 IEEE International Conference on Fuzzy Systems*, Vancouver, BC, Canada, 2016, pp. 72–77.
- [33] R.-E. Precup, M.-B. Radac, E. M. Petriu, R.-C. Roman, T.-A. Teban, and A.-I. Szedlak-Stinean, "Evolving fuzzy models for the position control of twin rotor aerodynamic systems," in *Proc. 2016 IEEE 14<sup>th</sup> International Conference on Industrial Informatics*, Poitiers, France, 2016, pp. 237–242.
- [34] R.-E. Precup, C.-A. Bojan-Dragos, E.-L. Hedrea, M.-D. Rarinca, and E. M. Petriu, "Evolving fuzzy models for the position control of magnetic levitation systems," in *Proc. 2017 IEEE Conference on Evolving and Adaptive Intelligent Systems*, Ljubljana, Slovenia, 2017, pp. 1–6.
- [35] R.-E. Precup, C.-A. Bojan-Dragos, E.-L. Hedrea, I. D. Borlea, and E. M. Petriu, "Evolving fuzzy models for anti-lock braking systems," in *Proc. 2017 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications*, Annecy, France, 2017, pp. 1–6.
- [36] A. Tenescu, R.-E. Precup, and N. Minculete, "Evolving fuzzy models for automated translation," *Acta Polyt. Hung.*, vol. 14, no. 2, pp. 27–46, Apr. 2017.
- [37] S. Preitl and R.-E. Precup, "On the algorithmic design of a class of control systems based on providing the symmetry of open-loop Bode plots," *Scientific Bulletin of UPT, Transactions on Automatic Control and Computer Science*, vol. 41 (55), no. 2, pp. 47–55, Dec. 1996.
- [38] R.-E. Precup and S. Preitl, "Popov-type stability analysis method for fuzzy control systems," in *Proc. Fifth European Congress on Intelligent Technologies and Soft Computing*, Aachen, Germany, 1997, vol. 2, pp. 1306–1310.
- [39] I. Škrjanc, S. Blažič, and D. Matko, "Direct fuzzy model-reference adaptive control," *Int. J. Intell. Syst.*, vol. 17, no. 10, pp. 943–963, Oct. 2002.
- [40] P. Baranyi, D. Tikk, Y. Yam, and R. J. Patton, "From differential equations to PDC controller design via numerical transformation," *Comput. Ind.*, vol. 51, no. 3, pp. 281–297, Aug. 2003.
- [41] K. Veszprémi and K. Lamár, "Accuracy analysis of digitally implemented field orientation of induction motor drive," in *Proc. 15<sup>th</sup> International Conference on Electrical Drives and Power Electronics*, Podbanské, Slovakia, 2003, pp.497–502.
- [42] Č. Milosavljević, B. Peruničić-Drazenović, B. Veselić, and D. Mitić, "A new design of servomechanism with digital sliding mode," *Electr. Eng.*, vol. 89, no. 3, pp. 233–244, Jan. 2007.
- [43] F. G. Filip, "Decision support and control for large-scale complex systems," *Annual Rev. Control*, vol. 32, no. 1, pp. 61–70, Apr. 2008.
- [44] D. Antić, M. Milojković, Z. Jovanović, and S. Nikolić, "Optimal design of the fuzzy sliding mode control for a DC servo drive," *Strojniški vestnik – J. Mech. Eng.*, vol. 56, no. 7–8, pp. 455–463, Dec. 2010.
- [45] S. Nikolić, D. Antić, B. Danković, M. Milojković, Z. Jovanović, and S. Perić, "Orthogonal functions applied in antenna positioning," *Adv. Electr. Comput. Eng.*, vol. 10, no. 4, pp. 35–42, Dec. 2010.
- [46] J. Vaščák and K. Hirota, "Integrated decision-making system for robot soccer," *J. Adv. Comput. Intell. Informat.*, vol. 15, no. 2, pp. 156–163, Mar. 2011.
- [47] J.-S. Chiou and S.-H. Tsai, "Stability and stabilization of Takagi-Sugeno fuzzy switched system with time-delay," *Proc. Inst. Mech. Eng., Part I, J. Syst. Control Eng.*, vol. 226, no. 5, pp. 615–621, May 2012.
- [48] R.-E. Precup, M.-B. Radac, M. L. Tomescu, E. M. Petriu, and S. Preitl, "Stable and convergent iterative feedback tuning of fuzzy controllers for discrete-time SISO systems," *Expert Syst. Appl.*, vol. 40, no. 1, pp. 188–199, Jan. 2013.
- [49] L. Horváth and I. J. Rudas, "Active knowledge for the situation-driven control of product definition," *Acta Polyt. Hung.*, vol. 10, no. 2, pp. 217–234, Apr. 2013.
- [50] Č. Milosavljević, B. Peruničić-Drazenović, and B. Veselić, "Discrete-time velocity servo system design using sliding mode control approach with disturbance compensation," *IEEE Trans. Ind. Informat.*, vol. 9, no. 2, pp. 920–927, May 2013.
- [51] J. V. Ramos and A. Dourado, "On line interpretability by rule base simplification and reduction," in *Proc. European Symposium on Intelligent Technologies, Hybrid Systems and Their Implementation on Smart Adaptive Systems EUNITE 2004*, Aachen, Germany, 2004, pp. 1–6.
- [52] L. Aires, J. Araújo, and A. Dourado, "Industrial monitoring by evolving fuzzy systems," in *Proc. Joint 2009 IFSA World Congress and 2009 EUSFLAT Conference*, Lisbon, Portugal, 2009, pp. 1358–1363.
- [53] D. Martín, R. Del Toro, R. Haber, and J. Dorronsoro, "Optimal tuning of a networked linear controller using a multi-objective genetic algorithm and its application to one complex electromechanical process," *Int. J. Innov. Comput. Informat. Control*, vol. 5, no. 10 (B), pp. 3405–3414, Oct. 2009.
- [54] R.-E. Precup, R.-C. David, E. M. Petriu, S. Preitl, and M.-B. Radac, "Novel adaptive charged system search algorithm for optimal tuning of fuzzy controllers," *Expert Syst. Appl.*, vol. 41, no. 4, pp. 1168–1175, Mar. 2014.
- [55] R.-E. Precup, M.-C. Sabau, and E. M. Petriu, "Nature-inspired optimal tuning of input membership functions of Takagi-Sugeno-Kang fuzzy models for anti-lock braking systems," *Appl. Soft Comput.*, vol. 27, pp. 575–589, Feb. 2015.
- [56] O. Arsene, I. Dumitrache, and I. Mihu, "Expert system for medicine diagnosis using software agents," *Expert Syst. Appl.*, vol. 42, no. 4, pp. 1825–1834, Mar. 2015.
- [57] A. Moharam, M. A. El-Hosseini, and H. A. Ali, "Design of optimal PID controller using NSGA-II algorithm and level diagram," *Stud. Informat. Control*, vol. 24, no. 3, pp. 301–308, Sep. 2015.
- [58] E. Osaba, E. Onieva, F. Dia, R. Carballedo, P. Lopez, and A. Perallos, "A migration strategy for distributed evolutionary algorithms based on stopping non-promising subpopulations: A case study on routing problems," *Int. J. Artif. Intell.*, vol. 13, no. 2, pp. 46–56, Oct. 2015.
- [59] K. W. Derr and M. Manic, "Wireless sensor networks - node localization for various industry problems," *IEEE Trans. Ind. Informat.*, vol. 11, no. 3, pp. 752–762, June 2015.
- [60] J. K. Tar, J. F. Bitó, and I. J. Rudas, "Contradiction resolution in the adaptive control of underactuated mechanical systems evading the framework of optimal controllers," *Acta Polyt. Hung.*, vol. 13, no. 1, pp. 97–121, Jan. 2016.
- [61] F. Gaxiola, P. Melin, F. Valdez, J. R. Castro, and O. Castillo, "Optimization of type-2 fuzzy weights in backpropagation learning for neural networks using GAs and PSO," *Appl. Soft Comput.*, vol. 38, pp. 860–871, Jan. 2016.
- [62] K. Michail, K. M. Deliparaschos, S. G. Tzafestas, and A. C. Zolotas, "AI-based actuator/sensor fault detection with low computational cost for industrial applications," *IEEE Trans. Control Syst. Technol.*, vol. 24, no. 1, pp. 293–301, Jan. 2016.
- [63] S. B. Ghosn, F. Drouby, and H. M. Harmanani, "A parallel genetic algorithm for the open-shop scheduling problem using deterministic and random moves," *Int. J. Artif. Intell.*, vol. 14, no. 1, pp. 130–144, Mar. 2016.
- [64] Q. Qin, S. Cheng, Q. Zhang, L. Li, and Y. Shi, "Particle swarm optimization with interswarm interactive learning strategy," *IEEE Trans. Cybern.*, vol. 46, no. 10, pp. 2238–2251, Oct. 2016.
- [65] D. Azar, K. Fayad, and C. Daoud, "A combined ant colony optimization and simulated annealing algorithm to assess stability and fault-proneness of classes based on internal software quality attributes," *Int. J. Artif. Intell.*, vol. 14, no. 2, pp. 137–156, Oct. 2016.
- [66] A. Fakharian and R. Rahmani, "An optimal controlling approach for voltage regulation and frequency stabilization in islanded microgrid

system,” *Control Eng. Appl. Informat.*, vol. 18, no. 4, pp.107–114, Dec. 2016.

[67] R.-E. Precup, M.-C. Sabau, C.-A. Dragos, M.-B. Radac, L.-O. Fedorovici, and E. M. Petriu, “Particle swarm optimization of fuzzy models for anti-lock braking systems,” in *Proc. 2014 IEEE Conference*

*on Evolving and Adaptive Intelligent Systems*, Linz, Austria, 2014, pp. 1–6.

[68] SAE, Surface Vehicle Recommended Practice, [http://www.apex-translations.com/documents/sae\\_j2450.pdf](http://www.apex-translations.com/documents/sae_j2450.pdf), 2001.





ETRAN

Society for Electronics, Telecommunications, Computers,  
Automatic Control and Nuclear Engineering

## CERTIFICATE

**Radu-Emil Precup**  
**„Technical and Non-Technical Applications  
of Evolving Takagi-Sugeno-Kang  
Fuzzy Models”**

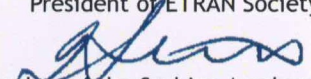
An invited presentation presented  
in the Section of Automation (AUI)  
at the 4<sup>th</sup> International Conference - IcETran 2017

Chairman of Programme Committee



Dr. Predrag Petković

President of ETRAN Society



Dejan Popović, member of the Serbian Academy of Sciences and Arts

Kladovo  
07.06.2017.