This article can be cited as R.-E. Precup, Nature-inspired optimization algorithms applied to fuzzy control, fuzzy modeling, mobile robots and optical character recognition, Proceedings of IEEE 9th International Symposium on Applied Computational Intelligence and Informatics (SACI 2014), Timisoara, Romania, DOI: 10.1109/SACI.2014.6840046, 2014.

NATURE-INSPIRED OPTIMIZATION ALGORITHMS APPLIED TO FUZZY CONTROL, FUZZY MODELING, MOBILE ROBOTS AND OPTICAL CHARACTER RECOGNITION

Radu-Emil Precup

Department of Automation and Applied Informatics, Politehnica University of Timisoara
Bd. V. Parvan 2, RO-300223 Timisoara, Romania
E-mail: radu.precup@upt.ro

Abstract

The plenary talk deals with the presentation of several applications of nature-inspired optimization algorithms (NIOAs) obtained by the Process Control group of the Department of Automation and Applied Informatics with the Politehnica University of Timisoara, Romania. The algorithms include Simulated Annealing (SA), Particle Swarm Optimization (PSO), Gravitational Search Algorithms (GSAs), Charged System Search (CSS), hybrid and adaptive versions. Aspects concerning the design and tuning of Mamdani and Takagi-Sugeno fuzzy controllers with dynamics focused on proportional-integral fuzzy controllers (PI FCs) and the general formulation of Takagi-Sugeno fuzzy models are first discussed. The optimal tuning of fuzzy controllers is carried out by the definition of optimization problems with the tuning parameters of the fuzzy controllers defined as vector variables, and with objective functions expressed as the weighted sums of functions that depend on the (absolute or squared) control error and of the output sensitivity functions of the state sensitivity models with respect to process parametric variations. The NIOAs minimize the objective functions to achieve optimal fuzzy control systems with reduced parametric sensitivity, and optimal PI-FCs for nonlinear servo systems are offered. The NIOAs are next applied to the optimal tuning of the parameters of Takagi-Sugeno fuzzy models for Anti-lock Braking Systems and for magnetic levitation systems. Initial Takagi-Sugeno fuzzy models of the process are derived on the basis of the modal equivalence principle by placing a set of linearized process models at several operating points in the rule consequents. The vector variables in the optimization problems are a part of the parameters of the input membership functions. The NIOAs are inserted in optimal path planning algorithms for mobile robots. The multi-objective optimization is considered as the NIOAs use two to four objective functions to generate optimal trajectories for mobile robots in static environments while avoiding collisions with the obstacles and danger zones that might exist in the environment. The NIOAs solve the optimization problems by minimizing the objective functions, producing optimal collision-free trajectories in terms of minimizing the length of the paths and also assuring that the generated trajectories are at a safe distance from the danger zones. Some details on the implementation of training algorithms for convolutional neural networks in

This article can be cited as R.-E. Precup, Nature-inspired optimization algorithms applied to fuzzy control, fuzzy modeling, mobile robots and optical character recognition, Proceedings of IEEE 9th International Symposium on Applied Computational Intelligence and Informatics (SACI 2014), Timisoara, Romania, DOI: 10.1109/SACI.2014.6840046, 2014.

optical character recognition (OCR) applications are discussed. The training algorithms involve NIOAs in combination with the popular back-propagation in order to achieve performance improvements by avoiding local minima. A comparison between our training algorithms is carried out and illustrated in terms of the analysis of convergence, computational cost and accuracy for a benchmark problem specific to OCR applications.

References (selected)

[1] J. Kennedy and R. C. Eberhart, "Particle swarm optimization," in *Proc. IEEE Int. Conf. Neural Networks (ICNN'95)*, Perth, Australia, 1995, pp. 1942–1948.

[2] J. Kennedy and R. C. Eberhart, "A new optimizer using particle swarm theory," in *Proc. 6th Int. Symp. Micro Machine and Human Science*, Nagoya, Japan, 1995, pp. 39–43.

[3] 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 "Politehnica" University of Timisoara, Romania, Transactions on Automatic Control and Computer Science*, vol. 41 (55), pp. 47–55, Dec. 1996.

[4] P. Baranyi, P. Korondi, H. Hashimoto, and M. Wada, "Fuzzy inversion and rule base reduction," in *Proc. IEEE International Conference on Intelligent Engineering Systems (INES'97)*, Budapest, Hungary, 1997, pp. 301–306.

[5] 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 (EUFIT'97)*, Aachen, Germany, 1997, vol. 2, pp. 1306–1310.

[6] S. Preitl and R.-E. Precup, *Introducere în conducerea fuzzy a proceselor*. Bucharest: Editura Tehnica, 1997.

[7] R.-E. Precup and S. Preitl, *Fuzzy Controllers*. Timisoara: Editura Orizonturi Universitare, 1999.

[8] S. Preitl, Z. Preitl, and R.-E. Precup, "Low cost fuzzy controllers for classes of second-order systems," in *Prep. 15th IFAC World Congress*, Barcelona, Spain, 2002, paper 416, pp. 1–6.

[9] I. Dumitrache and M. Dragoicea, "Intelligent techniques for cognitive mobile robots," *Control Eng. Appl. Informat.*, vol. 6, pp. 3–8, Jun. 2004.

[10] L. Horváth and I. J. Rudas, *Modeling and Problem Solving Methods for Engineers*. Burlington, MA: Academic Press, Elsevier, 2004.

[11] R.-E. Precup, S. Preitl, M. Balas, and V. Balas, "Fuzzy controllers for tire slip control in anti-lock braking systems," in *Proc. IEEE International Conference on Fuzzy Systems (FUZZ-IEEE 2004)*, Budapest, Hungary, 2004, vol. 3, pp. 1317–1322.

[12] I. Škrjanc, S. Blažič, and O. E. Agamennoni, "Identification of dynamical systems with a robust interval fuzzy model," *Automatica*, vol. 41, pp. 327–332, Feb. 2005.

[13] R.-E. Precup and S. Preitl, "PI and PID controllers tuning for integral-type servo systems to ensure robust stability and controller robustness," *Electr. Eng.*, vol. 88, pp. 149–156, Jan. 2006.

This article can be cited as R.-E. Precup, Nature-inspired optimization algorithms applied to fuzzy control, fuzzy modeling, mobile robots and optical character recognition, Proceedings of IEEE 9th International Symposium on Applied Computational Intelligence and Informatics (SACI 2014), Timisoara, Romania, DOI: 10.1109/SACI.2014.6840046, 2014.

[14] R.-E. Precup and S. Preitl, "Stability and sensitivity analysis of fuzzy control systems. Mechatronics applications," *Acta Polyt. Hung.*, vol. 3, pp. 61–76, Mar. 2006.

[15] S. Preitl, R.-E. Precup, J. Fodor, and B. Bede, "Iterative feedback tuning in fuzzy control systems. Theory and applications," *Acta Polyt. Hung.*, vol. 3, pp. 81–96, Sep. 2006.

[16] R.-E. Precup, M. L. Tomescu, and S. Preitl, "Lorenz system stabilization using fuzzy controllers," *Int. J. Comput. Commun. Control*, vol. 2, pp. 279–287, Sep. 2007.

[17] M. L. Tomescu, S. Preitl, R.-E. Precup, and J. K. Tar, "Stability analysis method for fuzzy control systems dedicated controlling nonlinear processes," *Acta Polyt. Hung.*, vol. 4, pp. 127–141, Sep. 2007.

[18] R.-E. Precup and S. Preitl, "PI-fuzzy controllers for integral plants to ensure robust stability," *Inf. Sci.*, vol. 177, pp. 4410–4429, Oct. 2007.

[19] G. Hermann, "Robust convex-hull based algorithms for straightness and flatness determination," *Acta Polyt. Hung.*, vol. 4, pp. 111–120, Dec.2007.

[20] T. Orlowska-Kowalska and K. Szabat, "Damping of torsional vibrations in two-mass system using adaptive sliding neuro-fuzzy approach," *IEEE Trans. Ind. Informat.*, vol. 4, pp. 47–57, Feb. 2008.

[21] Z. C. Johanyák and S. Kovács, "Polar-cut based fuzzy model for petrophysical properties prediction," *Scientific Bulletin of "Politehnica" University of Timisoara, Romania, Transactions on Automatic Control and Computer Science*, vol. 57 (67), pp. 195–200, Dec. 2008.

[22] R.-E. Precup, S. Preitl, B.-I. Ursache, P. A. Clep, P. Baranyi, and J. K. Tar, "On the combination of tensor product and fuzzy models," in *Proc. IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR 2008)*, Cluj-Napoca, Romania, 2008, vol. 2, pp. 48–53.

[23] D. Hládek, J. Vaščák, and P. Sinčák, "Hierarchical fuzzy inference system for robotic pursuit evasion task," in *Proc. 6th International Symposium on Applied Machine Intelligence and Informatics (SAMI 2008)*, Herľany, Slovakia, 2008, pp. 273–277.

[24] F.-G. Filip and K. Leiviskä, "Large-scale complex systems," in *Springer Handbook of Automation*, S. Y. Nof, Ed. Berlin, Heidelberg: Springer-Verlag, pp. 619–638, 2009.

[25] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "GSA: A gravitational search algorithm," *Inf. Sci.*, vol. 179, pp. 2232–2248, Jun. 2009.

[26] R.-E. Precup, M. L. Tomescu, and S. Preitl, "Fuzzy logic control system stability analysis based on Lyapunov's direct method," *Int. J. Comput. Commun. Control*, vol. 4, pp. 415–426, Dec. 2009.

[27] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "BGSA: binary gravitational search algorithm," *Nat. Comput.*, vol. 9, pp. 727–745, Sep. 2010.

[28] S. Blažič, D. Matko, and I. Škrjanc, "Adaptive law with a new leakage term," *IET Control Theory Appl.*, vol. 4, pp. 1533–1542, Sep. 2010.

[29] J. Vaščák and L. Madarász, "Adaptation of fuzzy cognitive maps – a comparison study," *Acta Polyt. Hung.*, vol. 7, pp. 109–122, Sep. 2010.

[30] E. Masehian and D. Sedighizadeh, "Multi-objective PSO-and NPSO-based algorithms for robot path planning," *Adv. Electr. Comput. Eng.*, vol. 10, pp. 69–76, Nov. 2010.

This article can be cited as R.-E. Precup, Nature-inspired optimization algorithms applied to fuzzy control, fuzzy modeling, mobile robots and optical character recognition, Proceedings of IEEE 9th International Symposium on Applied Computational Intelligence and Informatics (SACI 2014), Timisoara, Romania, DOI: 10.1109/SACI.2014.6840046, 2014.

[31] L. Tang and X. Wang, "An improved particle swarm optimization algorithm for the hybrid flowshop scheduling to minimize total weighted completion time in process industry," *IEEE Trans. Control Syst. Technol*., vol. 18, pp. 586–592, Nov. 2010.

[32] R.-E. Precup, L.-T. Dioanca, E. M. Petriu, M.-B. Radac, S. Preitl, and C.-A. Dragos, "Tensor product-based real-time control of the liquid levels in a three tank system," in *Proc. 2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2010)*, Montreal, ON, Canada, 2010, pp. 768–773.

[33] S. Mirjalili and S. Z. M. Hashim, "A new hybrid PSOGSA algorithm for function optimization," in *Proc. IEEE Int. Conf. Computer and Information Application*, Tianjin, China, 2010, pp. 374–377.

[34] A. Sánchez Boza, R. Haber-Guerra, and A. Gajate, "Artificial cognitive control system based on the shared circuits model of sociocognitive capacities. A first approach," *Eng. Appl. Artif. Intell.*, vol. 24, pp. 209–219, Mar. 2011.

[35] E. Hashemi, M. Ghaffari Jadidi, and N. Ghaffari Jadidi, "Model-based PI-fuzzy control of four-wheeled omni-directional mobile robots," *Robot. Auton. Syst.*, vol. 59, pp. 930–942, Nov. 2011.

[36] R.-E. Precup, R.-C. David, E. M. Petriu, S. Preitl, and M.-B. Radac, "Gravitational search algorithms in fuzzy control systems tuning," in *Proc. 18th IFAC World Congress*, Milano, Italy, 2011, pp. 13624–13629.

[37] R.-E. Precup, R.-C. David, E. M. Petriu, S. Preitl, and A. S. Paul, "Gravitational search algorithm-based tuning of fuzzy control systems with a reduced parametric sensitivity," in *Soft Computing in Industrial Applications*, A. Gaspar-Cunha, R. Takahashi, G. Schaefer, and L. Costa, Eds. Berlin, Heidelberg: Springer-Verlag, Advances in Intelligent and Soft Computing, vol. 96, pp. 141–150, 2011.

[38] S. M. Islam, S. Das, S. Ghosh, S. Roy, and P. N. Suganthan, "An adaptive differential evolution algorithm with novel mutation and crossover strategies for global numerical optimization," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 42, pp. 482–500, Apr. 2012.

[39] R.-E. Precup, M. L. Tomescu, M.-B. Radac, E. M. Petriu, S. Preitl, and C.-A. Dragos, "Iterative performance improvement of fuzzy control systems for three tank systems," *Expert Syst. Appl.*, vol. 39, pp. 8288–8299, July 2012.

[40] R.-E. Precup, C.-A. Dragos, S. Preitl, M.-B. Radac, and E. M. Petriu, "Novel tensor product models for automatic transmission system control," *IEEE Syst. J.*, vol. 6, pp. 488–498, Sep. 2012.

[41] Y. Zhong and L. Zhang, "Remote sensing image subpixel mapping based on adaptive differential evolution," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 42, pp. 1306–1329, Oct. 2012.

[42] A. Tuncer and M. Yildirim, "Dynamic path planning of mobile robots with improved genetic algorithm," *Comput. Electr. Eng.*, vol. 38, pp. 1564–1572, Nov. 2012.

[43] Z. C. Johanyák and O. Papp, "A hybrid algorithm for parameter tuning in fuzzy model identification," *Acta Polyt. Hung.*, vol. 9, pp. 153–165, Dec. 2012.

[44] R. Diao and Q. Shen, "Feature selection with harmony search," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 42, pp. 1509–1523, Dec. 2012.

This article can be cited as R.-E. Precup, Nature-inspired optimization algorithms applied to fuzzy control, fuzzy modeling, mobile robots and optical character recognition, Proceedings of IEEE 9th International Symposium on Applied Computational Intelligence and Informatics (SACI 2014), Timisoara, Romania, DOI: 10.1109/SACI.2014.6840046, 2014.

[45] I. Chaari, A. Koubaa, H. Bennaceur, S. Trigui, and K. Al-Shalfan, "smartPATH: A hybrid ACO-GA algorithm for robot path planning," in *Proc. 2012 IEEE Congress on Evolutionary Computation (CEC 2012)*, Brisbane, QLD, Australia, 2012, 8 pp.

[46] 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, pp. 188–199, Jan. 2013.

[47] Y. Maldonado, O. Castillo, and P. Melin, "Particle swarm optimization of interval type-2 fuzzy systems for FPGA applications," *Appl. Soft Comput.*, vol. 13, pp. 496–508, Jan. 2013.

[48] Y. Zhang, D.-W. Gong, and J.-H. Zhang, "Robot path planning in uncertain environment using multi-objective particle swarm optimization," *Neurocomput.*, vol. 103, pp. 172–185, Mar. 2013.

[49] S. Formentin, A. Karimi, and S. M. Savaresi, "Optimal input design for direct data-driven tuning of model-reference controllers," *Automatica*, vol. 49, pp. 1874–1882, Jun. 2013.

[50] R.-C. David, R.-E. Precup, E. M. Petriu, M.-B. Radac, and S. Preitl, "Gravitational search algorithm-based design of fuzzy control systems with a reduced parametric sensitivity," *Inf. Sci.*, vol. 247, pp. 154–173, Oct. 2013.

[51] D. Yazdani, B. Saman, A. Sepas-Moghaddam, F. Mohammad-Kazemi, and M. R. Meybodi, "A new algorithm based on improved artificial fish swarm algorithm for data clustering," *Int. J. Artif. Intell.*, vol. 11, pp. 193–221, Oct. 2013.

[52] M. Z. Ali, K. Alkhatib, and Y. Tashtoush, "Cultural algorithms: emerging social structures for the solution of complex optimization problems," *Int. J. Artif. Intell.*, vol. 11, pp. 20–42, Oct. 2013.

[53] M.-B. Radac, R.-E. Precup, E. M. Petriu, S. Preitl, and C.-A. Dragos, "Data-driven reference trajectory tracking algorithm and experimental validation," *IEEE Trans. Ind. Informat.*, vol. 9, pp. 2327–2336, Nov. 2013.

[54] P. Angelov, I. Škrjanc, and S. Blažič, "Robust evolving cloud-based controller for a hydraulic plant," in *Proc. IEEE Symposium Series on Computational Intelligence (SSCI 2013)*, Singapore, 2013, pp. 1–8.

[55] C. Purcaru, R.-E. Precup, D. Iercan, L.-O. Fedorovici, E. M. Petriu, and E.-I. Voisan, "Multi-robot GSA- and PSO-based optimal path planning in static environments," in *Proc. 9th Int. Workshop on Robot Motion and Control (RoMoCo'13)*, Wasowo, Poland, 2013, pp. 197–202.

[56] D. Wijayasekara, O. Linda, M. Manic, and C. Rieger, "Mining building energy management system data using fuzzy anomaly detection and linguistic descriptions," *IEEE Trans. Ind. Informat.*, vol. 10, pp. 1829–1840, June 2014.