R.-E. Precup, T.-A. Teban and A. Albu, Evolving Fuzzy and Neural Network Models of Finger Dynamics for Prosthetic Hand Myoelectric-based Control, 11th International Conference on Electronics, Computers and Artificial Intelligence ECAI 2019, Pitesti, Romania, 2019.

Evolving Fuzzy and Neural Network Models of Finger Dynamics for Prosthetic Hand Myoelectric-based Control

Radu-Emil Precup, Teodor-Adrian Teban and Adriana Albu
Department of Automation and Applied Informatics
Politehnica University of Timisoara
Timisoara, Romania
radu.precup@upt.ro

KEYNOTE SPEECH

***Abstract*—This paper first presents a structure for prosthetic hand myoelectric-based control systems (MBCSs). A set of evolving Takagi-Sugeno fuzzy and neural network models of the human hand dynamics, i.e., the finger dynamics, is next offered. These models will be used as reference models in structures of MBCSs. The inputs of the models are the myoelectric signals obtained from eight sensors placed on human subject's arm, and the outputs of these models are the flexion percentages of midcarpal joint angles. Elements of model-based fuzzy control are included. This plenary keynote paper is supported by authors' recent papers on modeling in the framework of prosthetic hand myoelectric-based control.**

Keywords—evolving Takagi-Sugeno fuzzy, flexion percentages of midcarpal joint angles, myoelectric-based control systems, neural network models

SELECTED REFERENCES

[1] P. Geethanjali, "Myoelectric control of prosthetic hands: state-of-the-art review," *Med. Dev. Evid. Res.*, vol. 9, pp. 247–255, Dec. 2016.

[2] J.-H. Wang, H.-C. Ren, W.-H. Chen, and P. Zhang, "A portable artificial robotic hand controlled by EMG signal using ANN classifier," in *Proc. 2015 IEEE Int. Conf. Inform. Autom.*, Lijiang, China, 2015, pp. 2709–2714.

[3] Z.-J. Xu, Y.-T. Tian, and L. Yang, "sEMG pattern recognition of muscle force of upper arm for intelligent bionic limb control," *J. Bionic Eng.*, vol. 12, no. 2, pp. 316–323, Apr. 2015.

[4] H.-X. Cao, S.-Q. Sun, and K.-J. Zhang, "Modified EMG-based handgrip force prediction using extreme learning machine," *Soft Comput.*, vol. 21, no. 2, pp. 491–500, Jan. 2017.

[5] Y. Guo, G. R. Naik, S. Huang, A. Abraham, and H. T. Nguyen, "Nonlinear multiscale maximal Lyapunov exponent for accurate myoelectric signal classification," *Appl. Soft Comput.*, vol. 36, pp. 633–640, Nov. 2015.

[6] C.-G. Yang, J.-S. Chen, Z.-J. Ju, and A. S. K. Annamalai, "Visual servoing of humanoid dual-arm robot with neural learning enhanced skill transferring control," *Int. J. Humanoid Robot.*, vol. 15, no. 2, pp. 1–23, Apr. 2018.

[7] T.-A. Teban, R.-E. Precup, T. E. Alves de Oliveira, and E. M. Petriu, "Recurrent dynamic neural network model for myoelectric-based control of a prosthetic hand," in *Proc. 2016 IEEE Int. Syst. Conf.*, Orlando, FL, USA, 2016, pp. 1–6.

[8] T.-A. Teban, R.-E. Precup, E.-C. Lunca, A. Albu, C.-A. Bojan-Dragos, and E. M. Petriu, "Recurrent neural network models for myoelectric-based control of a prosthetic hand," in *Proc. 22nd Int. Conf. Syst. Theor. Control Comput.*, Sinaia, Romania, 2018, pp. 603–608.

[9] 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 Int. Conf. Fuzzy Syst.*, Vancouver, BC, Canada, 2016, pp. 72–77.

[10] R.-E. Precup, T.-A. Teban, E. M. Petriu, A. Albu, and I.-C. Mituletu, "Structure and evolving fuzzy models for prosthetic hand myoelectric-based control systems," in *Proc. 26th Mediter. Conf. Control Autom.*, Zadar, Croatia, 2018, pp. 625–630.

[11] R.-E. Precup, T.-A. Teban, A. Albu, A.-I. Szedlak-Stinean, and C.-A. Bojan-Dragos, "Experiments in incremental online identification of fuzzy models of finger dynamics," *Rom. J. Inform. Sci. Tech.*, vol. 21, no. 4, pp. 358–376, Dec. 2018.

[12] M. Tabakov, K. Fonal, R. A. Abd-Alhameed, and R. Qahwaji, "Fuzzy bionic hand control in real-time based on electromyography signal analysis," in *Comput. Coll. Intell. ICCCI 2016*, N. T. Nguyen, L. Iliadis, Y. Manolopoulos, and B. Trawiński, Eds. Cham: Springer, Lecture Notes in Computer Science, vol. 9875, pp. 292–302, 2016.

[13] M. Tabakov, K. Fonal, R. A. Abd-Alhameed, and R. Qahwaji, "Bionic hand control in real-time based on electromyography signal analysis," in *Trans. Comput. Coll. Intell. XXIX*, N. T. Nguyen and R. Kowalczyk, Eds. Cham: Springer, LNCS, vol. 10840, pp. 21–38, 2018.

[14] X. Zhou and P. Angelov, "Real-time joint landmark recognition and classifier generation by an evolving fuzzy system," in *Proc. 2006 IEEE Int. Conf. Fuzzy Syst.*, 2006, Vancouver, BC, Canada, pp. 1205–1212.

[15] X. Zhou and P. Angelov, "Autonomous visual self-localization in completely unknown environment using evolving fuzzy rule-based classifier," in *Proc. 2007 IEEE Symp. Comput. Intell. Secur. Def. Appl.*, Honolulu, HI, USA, 2007, pp. 131–138.

[16] R. D. Baruah and P Angelov, "Evolving local means method for clustering of streaming data," in *Proc. 2012 IEEE Int. Conf. Fuzzy Syst.*, Brisbane, QLD, Australia, 2012, pp. 1–8.

[17] P Angelov, "Outside the box: an alternative data analytics framework," *J. Autom. Mob. Robot. Intell. Syst.*, vol. 8, no, 2, pp. 29–35, Apr. 2014.

[18] P. Angelov, I. Škrjanc, and S. Blažič, "Robust evolving cloud-based controller for a hydraulic plant," in *Proc. 2013 IEEE Conf. Evolv. Adapt. Syst.*, Singapore, 2013, pp. 1–8.

[19] S. Blažič, I. Škrjanc, and D. Matko, "A robust fuzzy adaptive law for evolving control systems," *Evolv. Syst.*, vol. 5, pp. 3–10, Mar. 2014.

[20] D. Leite, R. M. Palhares, V. C. S. Campos, and F. A. C. Gomide, "Evolving granular fuzzy model-based control of nonlinear dynamic systems," *IEEE Trans. Fuzzy Syst.*, vol. 23, no. 4, pp. 923–938, Aug. 2015.

[21] E. Lughofer and M. Pratama, "Online active learning in data stream regression using uncertainty sampling based on evolving generalized fuzzy models," *IEEE Trans. Fuzzy Syst.*, vol. 26, no. 1, pp. 292–309, Feb. 2018.

[22] P. Wide, E. M. Petriu, and M. Siegel, "Sensing and perception for rehabilitation and enhancement of human natural capabilities," in *Proc. 2010 IEEE Int. Works. Robot. Sens. Env.*, Phoenix, AZ, USA, 2010, pp. 75–80.

[23] 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.

[24] N. Kasabov, "ECOS: A framework for evolving connectionist systems and the eco learning paradigm," in *Proc. 5th Int. Conf. Neural Inf. Proc.*, Kitakyushu, Japan, 1998, pp. 1222–1235.

[25] 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.

[26] J. V. Ramos and A. Dourado, "On line interpretability by rule base simplification and reduction," in *Proc. Eur. Symp. Intell. Technol. Hybrid Syst. Impl. Smart Adapt. Syst.*, Aachen, Germany, 2004, pp. 1–6.

[27] T. Niemueller, S. Zug, S. Schneider, and U. Karras, "Knowledge-based instrumentation and control for competitive industry-inspired robotic domains," *Künst. Intell.*, vol. 30, no. 3–4, pp. 289–299, Oct. 2016.

[28] E. Osaba, R. Carballedo, F. Diaz, E. Onieva, A. Masegosa, and A. Perallos, "Good practice proposal for the implementation, presentation, and comparison of metaheuristics for solving routing problems," *Neurocomput.*, vol. 271, pp. 2–8, Jan. 2018.

[29] R. Radiša, N. Dučić, S. Manasijević, N. Marković, and Ž Ćojbašić, "Casting improvement based on metaheuristic optimization and numerical simulation," *Facta Univ. Ser. Mech. Eng.*, vol. 15, no. 3, pp. 397–411, Jul. 2017.

[30] R.-E. Precup and R.-C. David, *Nature-Inspired Optimization Algorithms for Fuzzy Controlled Servo Systems*. Oxford, UK: Butterworth-Heinemann, Elsevier, 2019.

[31] P. Korondi, H. Hashimoto, and V. Utkin, "Discrete sliding mode control of two mass system," in *Proc. 1995 IEEE Int. Symp. Ind. Electron.*, Athens, Greece, 1995, pp. 338–343.

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

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

[34] C. Pozna, R.-E. Precup, J. K. Tar, I. Škrjanc, and S. Preitl, "New results in modelling derived from Bayesian filtering," *Knowl.-Based Syst.*, vol. 23, no. 2, pp. 182–194, Mar. 2010.

[35] Á. Takács, L. Kovács, I. J. Rudas, R.-E. Precup, and T. Haidegger, "Models for force control in telesurgical robot systems," *Acta Polyt. Hung.*, vol. 12, no. 8, pp. 95–114, Dec. 2015.

[36] R.-E. Precup, T.-A. Teban, A. Albu, A.-B. Borlea, I. A. Zamfirache, and E. M. Petriu, "Evolving fuzzy models for prosthetic hand myoelectric-based control using weighted recursive least squares algorithm for identification," in *Proc. 2019 IEEE Int. Symp. Robot. Sens. Environ.*, Ottawa, ON, Canada, 2019, pp. 164–169.

[37] D. Hladek, J. Vascak, and P. Sincak, "Hierarchical fuzzy inference system for robotic pursuit evasion task," in *Proc. 2008 6th Int. Symp. Mach. Intell. Informat.*, Herľany, Slovakia, 2008, pp. 273–277.

[38] C. Pozna and R.-E. Precup, "Aspects concerning the observation process modelling in the framework of cognition processes," *Acta Polyt. Hung*., vol. 9, no. 1, pp. 203–223, Mar. 2012.

[39] H. Costin and S. Bejinariu, "Medical image registration by means of a bio-inspired optimization strategy," *Comput. Sci. J. Moldova*, vol. 20, no. 2, pp. 178–202, Jun. 2012.

[40] R.-E. Precup, T. Haidegger, S. Preitl, B. Benyó, A. S. Paul, and L. Kovács, "Fuzzy control solution for telesurgical applications," *Applied and Computational Mathematics*, vol. 11, no. 3, pp. 378–397, Sep. 2012.

[41] H. Costin, "Fuzzy rules-based segmentation method for medical images analysis," *Int. J. Comput. Communic. Control*, vol. 8, no. 2, pp. 196–206, Apr. 2013.

[42] 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.

[43] I.-D. Borlea, R.-E. Precup, F. Dragan, and A.-B. Borlea, "Centroid update approach to K-means clustering," *Adv. Electr. Comput. Eng.*, vol. 17, no. 4, pp. 3–10, Dec. 2017.

[44] L. Nyulászi, R. Andoga, P. Butka, L. Főző, R. Kovacs, and T. Moravec, "Fault detection and isolation of an aircraft turbojet engine using a multi-sensor network and multiple model approach," *Acta Polyt. Hung.*, vol. 15, no. 2, pp. 189–209, Apr. 2018.

[45] Z. C. Johanyák, "Fuzzy rule interpolation based model for student result prediction," *J. Intell. Fuzzy Syst.*, vol. 36, no. 2, pp. 999–1008, Apr. 2019.

[46] 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, no. 2, pp. 149–156, Jan. 2006.

[47] R.-E. Precup and S. Preitl, "Stability and sensitivity analysis of fuzzy control systems. Mechatronics applications," *Acta Polyt. Hung.*, vol. 3, no. 1, pp. 61–76, Mar. 2006.

[48] P. Angelov and D. Filev, "On-line design of Takagi-Sugeno models," in *Fuzzy Sets and Systems – IFSA 2003*, T. Bilgiç, B. De Baets, and O. Kaynak, Eds. Berlin, Heidelberg, Lecture Notes in Computer Science, vol. 2715, pp. 576–584, 2003.

[49] P. Angelov, J. Victor, A. Dourado, and D. Filev, "On-line evolution of Takagi-Sugeno fuzzy models," *IFAC Proc. Vol.*, vol. 37, no. 16, pp. 67–72, Sep. 2004.

[50] I. Škrjanc, S. Blažič, and O. E. Agamennoni, "Interval fuzzy modeling applied to Wiener models with uncertainties," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 35, no. 5, pp. 1092–1095, Oct. 2005.

[51] C. Pozna and R.-E. Precup, "Plausible reasoning in modular robotics and human reasoning," *Acta Polyt. Hung.*, vol. 4, no. 4, pp. 133–147, Dec. 2007.

[52] E. Horváth, C. Pozna, and R.-E, Precup, "Robot coverage path planning based on iterative structured orientation," *Acta Polyt. Hung.*, vol. 15, no. 2, pp. 231–249, Apr. 2018.

[53] C. Pozna, R.-E. Precup, and P. Földesi, "A novel pose estimation algorithm for robotic navigation," *Robot. Auton. Syst.*, vol. 63, pp. 10–21, Jan. 2015.

[54] R.-E. Precup, S. Preitl, K. J. Burnham, and B. Vinsonneau, "Virtual reference feedback tuning approach to fuzzy control systems development," *IFAC Proc. Vol.*, vol. 40, no. 8, pp. 123–128, May 2007.

[55] 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.

[56] 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.

[57] R.-E. Precup, S. Preitl, A. Gräser, and M. Mihajlov, "Approach to optimization problems with controller and reference model tuning," *IFAC Proc. Vol.*, vol. 40, no. 18, pp. 721–726, Sep. 2007.

[58] S. Preitl and R.-E. Precup, "Points of view in controller design by means of Extended Symmetrical Optimum method," *IFAC Proc. Vol.*, vol. 36, no. 18, pp. 95–100, Jul. 2003.