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

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PLENARY TALK

***Abstract*—The development of myoelectric-based control systems for prosthetic hands includes several control techniques as on-off, proportional, direct, finite state machine, pattern recognition-based, posture and regression. These techniques are applied in the model-based control design framework, which requires accurate models of the human hand in order to tune the controllers. The human hand in such systems is a challenging biomedical process, namely a Multi Input-Multi Output (MIMO) nonlinear dynamical system, with the inputs represented by the myoelectric signals (MESs) and the outputs by several finger angles.**

The presentation starts with giving the prosthetic hand myoelectric-based control system structure. A set of evolving Takagi-Sugeno-Kang (TSK) fuzzy models, neural network models and simple linear models of the human hand dynamics, i.e. the finger dynamics, is next offered. These models will be used as reference models in myoelectric-based control systems. The inputs of this MIMO nonlinear system are the MESs obtained from eight sensors placed on human subject's arm, and the outputs are the flexion percentages that correspond to the midcarpal joint angles.

Proportional-Integral (PI) and cost-effective PI fuzzy controllers are designed and tuned. On the other-hand, since the process modeling might be difficult and also expensive for certain applications, data-driven model-free controllers became popular during the last two decades. The tuning of these controllers does not make use of process models. Some popular data-driven model-free controllers are discussed and exemplified for this biomedical process. Both data-driven model-free control (in terms of the controller parameter update laws) and evolving fuzzy modeling (in terms of incremental online identification algorithms) can be viewed as machine learning techniques.

The models and the controllers were tested on a dataset that covers approximately 450 s and the results are encouraging. The structure, the models, the controllers and the experimental results illustrated in this presentation belong to a relatively wide range of applications focused on the development of evolving TSK fuzzy models, Tensor Product-based model transformation, neural network models, model-based and data-driven model-free controllers, with different degrees of intelligence and learning included, obtained by the Process Control group of the Politehnica University of Timisoara, Romania.

SHORT BIO

Radu-Emil Precup (M'03–SM'07) received the Dipl.Ing. (with honors) degree in automation and computers from the "Traian Vuia" Polytechnic Institute of Timisoara, Timisoara, Romania, the Dipl. degree in mathematics from the West University of Timisoara, Timisoara, and the Ph.D. degree in automatic systems from the Politehnica University of Timisoara (UPT), Timisoara, Romania, in 1987, 1993, and 1996, respectively.

He is currently with UPT, Timisoara, Romania, where he became a Professor with the Department of Automation and Applied Informatics in 2000. He is also an Adjunct Professor within the School of Engineering, Edith Cowan University, Joondalup, WA, Australia, and an Honorary Professor with the Óbuda University, Budapest, Hungary. He is the author or coauthor of more than 300 papers. His current research interests include intelligent control systems and data-driven control.

Prof. Precup is a corresponding member of The Romanian Academy, a member of several Technical Committees (TCs) including IEEE ones, the IFAC TC on Computational Intelligence in Control and the TC12 on Artificial Intelligence of IFIP. He was the recipient of the Elsevier Scopus Award for Excellence in Global Contribution (2017), the "Grigore Moisil" Prize from the Romanian Academy, two times, in 2005 and 2016, for his contribution on fuzzy control and the optimization of fuzzy systems, the "Tudor Tănăsescu" Prize from the Romanian Academy in 2020 for his contribution on data-driven controller tuning techniques, and several best paper awards (2004–2021).

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 Intl. 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," *I. 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 Intl. 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 Intl. Conf. Syst. Theory 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 Intl. 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, LNCS, 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 Intl. 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 Intl. 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 Intl. 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] F. Hui, P. Payeur, and A.-M. Cretu, "Visual tracking of deformation and classification of non-rigid objects with robot hand probing," *Robotics*, vol. 6, no. 1, paper 5, Mar. 2017.

[29] R.-E. Precup, M. L. Tomescu, S. Preitl, E. M. Petriu, J. Fodor, and C. Pozna, "Stability analysis and design of a class of MIMO fuzzy control systems," *J. Intell. Fuzzy Syst.*, vol. 25, no. 1, pp. 145–155, Mar. 2013.

[30] 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.

[31] 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.

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

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

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

[35] R.-E. Precup and S. Preitl, "Development of fuzzy controllers with non-homogeneous dynamics for integral-type plants," *Electr. Eng.*, vol. 85, no. 3, pp. 155–168, Jul. 2003.

[36] 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.

[37] 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.

[38] R.-E. Precup, T.-A. Teban, and A. Albu, "Evolving fuzzy and neural network models of finger dynamics for prosthetic hand myoelectric-based control," in *Proc. 11th Int. Conf. Electron. Comput. Artif. Intell.*, Pitesti, Romania, 2019, pp. 1–8.

[39] 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.

[40] A. Albu, R.-E. Precup, and T.-A. Teban, "Results and challenges of artificial neural networks used for decision-making in medical applications," *Facta Univ. Ser. Mech. Eng.*, vol. 17, no 4, pp. 285–308, Dec. 2019.

[41] 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," *IEEE Trans. Instrum. Meas.*, vol. 69, no. 7, pp. 4625–4636, Jul. 2020.

[42] R.-E. Precup, R.-C. Roman, T.-A. Teban, A. Albu, E. M. Petriu, and C. Pozna, "Model-free control of finger dynamics in prosthetic hand myoelectric-based control systems," *Stud. Informat. Control*, vol. 29, no. 4, pp. 399–410, Dec. 2020.

[43] 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.

[44] 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.

[45] 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.

[46] 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.

[47] 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.

[48] 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.

[49] 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.

[50] 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.

[51] 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.

[52] A. Lucchini, S. Formentin, M. Corno, D. Piga, and S. M. Savaresi, "Torque vectoring for high-performance electric vehicles: a data-driven MPC approach," *IEEE Control Syst. Lett.*, vol. 4, no. 3, pages 725–730, Jul. 2020.

[53] M. Parigi Polverini, S. Formentin, L. Merzagora, and P. Rocco, "Mixed data-driven and model-based robot implicit force control: a hierarchical approach," *IEEE Trans. Control Syst. Technol.*, vol. 28, no. 4, pp. 1258–1271, Jul. 2020.

[54] R.-E. Precup, E.-L. Hedrea, R.-C. Roman, E. M. Petriu, A.-I. Szedlak-Stinean, and C.-A. Bojan-Dragos, "Experiment-based approach to teach optimization techniques," *IEEE Trans. Educ.*, vol. 64, no. 2, pp. 88–94, May 2021.

[55] E. Osaba, J. Del Ser, A. D. Martinez, J. L. Lobo, and F. Herrera, "AT-MFCGA: An adaptive transfer-guided multifactorial cellular genetic algorithm for evolutionary multitasking," *Inf. Sci.*, vol. 570, pp. 577–598, Sep. 2021.

[56] R.-E. Precup, C.-A. Bojan-Dragos, E.-L. Hedrea, R.-C. Roman, and E. M. Petriu, "Evolving fuzzy models of shape memory alloy wire actuators," *Rom. J. Inf. Sci. Technol.*, vol. 24, no. 4, pp. 353–365, Dec. 2021.