11th International Conference on Electronics, Computers and Artificial Intelligence ECAI 2019, 27-29 June 2019, Pitesti, Romania

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

Plenary speaker: Radu-Emil Precup
Co-authors: Teodor-Adrian Teban and Adriana Albu
Department of Automation and Applied Informatics, Politehnica University of Timisoara
Bd. V. Parvan 2, 300223 Timisoara, Romania
radu.precup@upt.ro, adrian.teban@student.upt.ro, adriana.albu@upt.ro

ABSTRACT

The development of myoelectric-based control systems for prosthetic hands includes several approaches: on-off control, proportional control, direct control, finite state machine control, pattern recognition-based control, posture control, and regression control. All these approaches are considered in the model-based control design framework, which requires accurate models of the human hand. The human hand in such systems is a multi-variable nonlinear dynamical system, with the inputs represented by the myoelectric signals (MESs) and the outputs by finger angles at various joints.

The concept of evolving fuzzy (rule-based) controllers was coined by P. Angelov back in 2001 and further developed in his later works. These controllers are related to evolving Takagi-Sugeno (T-S) fuzzy models, for which the rule bases are computed by a learning process, namely continuous online rule base learning. Constructing virtual state-space process models from input-output data samples can be carried out in this regard. Several techniques associated with T-S fuzzy and neural network models can be used to learn the controllers for this virtual process.

This paper starts with presenting structures for prosthetic hand myoelectric-based control systems. A set of evolving T-S 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 myoelectric-based control systems. The inputs of this 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.

The structure, models and experimental results given in this presentation belong to a relatively wide range of applications of incremental online identification algorithms focused on the development of evolving T-S fuzzy models, Tensor Product-based model transformation and neural network models and obtained by the Process Control group of the Politehnica University of Timisoara, Romania. Implementation details concerning the incremental online identification algorithms will be given.

The models were tested on a dataset that covers approximately 450 s and the results are encouraging. The system and model responses and performance indices indicate that past samples of the output increased the performance of the 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 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-Dragoş, "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 *Computational Collective Intelligence. ICCCI 2016*, N. T. Nguyen, L. Iliadis, Y. Manolopoulos, and B. Trawiński, Eds. Cham: Springer, Lect. Notes Comput. Sci., 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 *Transactions on Computational Collective Intelligence XXIX*, N. T. Nguyen and R. Kowalczyk, Eds. Cham: Springer, Lect. Notes Comput. Sci., 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, no. 1, pp. 3–10, Mar. 2014.

[20] 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.

[21] 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.

[22] 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.
[23] 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.
[24] 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.
[25] 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.
[26] 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.
[27] 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.
[28] J. V. Ramos and A. Dourado, “On line interpretability by rule base simplification and reduction,” in *Proc. Eur. Symp. Intell. Technol. Hybrid Syst. Their Implem. Smart Adapt. Syst.*, Aachen, Germany, 2004, pp. 1–6.
[29] S. Hochreiter and J. Schmidhuber, “Long short-term memory,” *Neural Comput.*, vol. 9, no. 8, pp. 1735–1780, Nov. 1997.
[30] F. A. Gers, J. Schmidhuber, and F. Cummins, “Learning to forget: continual prediction with LSTM,” *Neural Comput.*, vol. 12, no. 10, pp. 2451–2471, Oct. 2000.
[31] J. Saadat, P. Moallem, and H. Koofigar, “Training echo state neural network using harmony search algorithm,” *Int. J. Artif. Intell.*, vol. 15, no. 1, pp. 163–179, Mar. 2017.
[32] J. G. Hincapie and R. F. Kirsch, “Feasibility of EMG-based neural network controller for an upper extremity neuroprosthesis,” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 17, no. 1, pp. 80–90, Feb. 2009.
[33] R. N. Khushaba, A. Al-Ani, and A. Al-Jumaily, “Orthogonal fuzzy neighborhood discriminant analysis for multifunction myoeletric hand control,” *IEEE Trans. Biomed. Eng.*, vol. 57, no. 6, pp. 1410–1419, June 2010.
[34] G. W. Favieiro and A. Balbinot, “Adaptive neuro-fuzzy logic analysis based on myoelectric signals for multifunction prosthesis control,” in *Proc. 2011 Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Boston, MA, USA, 2011, pp. 7888–789.
[35] A. Balbinot, A. S. Júnior, and G. W. Favieiro, “Decoding arm movements by myoeletric signal and artificial neural networks,” *Intell. Control Autom.*, vol. 4, no. 1, pp. 87–93, Feb. 2013.
[36] H.-J. Liu and K.-Y. Young, “Upper-limb EMG-based robot motion governing using empirical mode decomposition and adaptive neural fuzzy inference system,” *J. Intell. Robot. Syst.*, vol. 68, no. 3, pp. 275–291, Dec. 2012.
[37] M. Borghetti, E. Sardini, and M. Serpelloni, “Sensorized glove for measuring hand finger flexion for rehabilitation purposes,” *IEEE Trans. Instrum. Meas.*, vol. 62, no. 12, pp. 3308–3314, Dec. 2013.
[38] Z. Ma, P. Ben-Tzvi, and J. Danoff, “Hand rehabilitation learning system with an exoskeleton robotic glove,” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 24, no. 12, pp. 1323–1332, Dec. 2016.
[39] I. Dumitrache, N. Constantin, and M. Drăgoicea, *Retele neurale: identificarea si conducerea proceselor*. Bucharest: Matrix Rom, 1999.
[40] A. Alique, R. E. Haber, R. H. Haber, S. Ros, and C. Gonzalez, “Neural network-based model for the prediction of cutting force in milling process. A progress study on a real case,” in *Proc. 15th IEEE International Symposium on Intelligent Control*, Patras, Greece, 2000, pp. 121–125.
[41] M. Wagarachchi and A. Karunananda, “Optimization of artificial neural network architecture using neuroplasticity,” *Int. J. Artif. Intell.*, vol. 15, no. 1, pp. 112–125, Mar. 2017.