Using a soft computing method for impedance modelling of li-ion battery current

Mohammad (Behdad) Jamshidi*
Young Researchers and Elite Club, Kermanshah Branch,
Islamic Azad University, Kermanshah, Iran.
E-mail: bmj.jmd@gmail.com
*Corresponding Author

Rouzbeh Farhadi
Department of Electrical Engineering, Malard Branch,
Islamic Azad University, Malard, Iran.
E-mail: rouzbeh.farhadi@yahoo.com

Morteza Jamshidi
Young Researchers and Elite Club, Kermanshah Branch,
Islamic Azad University, Kermanshah, Iran.
E-mail: jamshidi.azad.un@gmail.com

Zahra Shamsi
Department of Electrical Engineering, Arak Branch,
Islamic Azad University, Arak, Iran.
E-mail: shamsi.zahra@yahoo.com

Seyedfoadin Naseh
Department of Electrical Engineering, Kermanshah Branch,
Islamic Azad University, Kermanshah, Iran.
E-mail: cyrus.pnu@gmail.com

Abstract: Using the soft computing as a powerful tool for modelling of complex systems is highly regarded. Adaptive neuro fuzzy inference system is one of the best methods of soft computing which identifies and models non-linear systems. In this paper, complex impedance behaviours of li-ion batteries are studied by adaptive neuro fuzzy inference system. To present an approach for modelling and identification of electrochemical systems is purposed. This method can be improved to reach the most accurate model of the batteries. In the presented work, complex current is modelled as the main important element of the batteries in impedance state. Modelling results showed that this method can have acceptable output for impedance modelling the batteries.

Keywords: Electrochemical; impedance modelling; li-ion battery; soft computing; complex systems, systems engineering, ANFIS.

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Biographical notes: Mohammad (Behdad) Jamshidi received the associate degree in electrical engineering from Shamsipour Technical and Vocational College, Tehran, Iran, in 2005, the B.S. degree in electrical engineering from University of Applied Science and Technology, Shiraz, Iran, in 2008, and the M.S. degrees in mechatronic engineering from Islamic Azad University of South-Tehran (IAU-ST), Tehran, Iran, in 2011.From 2010 to 2016, he was a Research Assistant with the Young Researchers and Elite Club. From 2012 to 2017, he was a Full-Time Faculty Member with the Electrical Engineering Department, Islamic Azad University of Kermanshah (IAU-KSH). He is the author more than 50 articles, inventions, and research projects. His research interests systems engineering, nonlinear systems, and soft computing. Mr Jamshidi awards and honours include the team member of design and build the HOMA Electric Vehicle at Sharif University of Technology in 2010, Distinguished Alumni Mechatronics Engineering at IAU-ST in 2011, the Best Professor Award of Researcher at IAU-KSH in 2014, second place of AUV League at Feira Cup at Amirkabir University of Technology in 2016, and several other awards of national and international robotics competitions.

1 Introduction

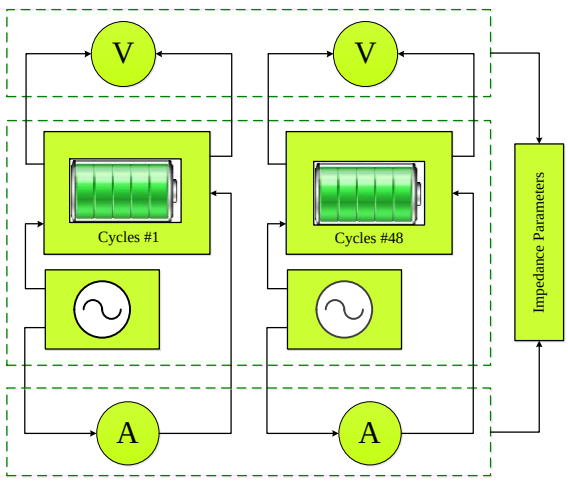
Soft Computing (SC) is set of new computational technique in software engineering, manmade brainpower, machine learning and numerous other application zones implies. To demonstrate and solve the problems of nonlinear systems, SC is extremely used as a new computational techniques which can predict complex behaviours of the systems. (Mansouri and Hamednia, 2015; Huang, 2016). Fuzzy logic, neural networks and expert systems create combined methods for modelling the hybrid systems. Adaptive Neuro Fuzzy Inference System (ANFIS) is one of the most important methods that is extract from combination of Artificial Neural Network (ANN) and fuzzy systems. (Liu and Zhang, 2015; Shamshirband et al., 2016; G. Chen et al, 2016). ANFIS consists of a fuzzy expert framework with a source information base. Neural systems gain from preparing information blunders and are effective sending of such answers for issues. Today, ANFIS for researcher is as a known technique to model, to identify, to analyse the nonlinear systems. To access of a good result with using SC methods, it is not important the studied system has what types such electrical, chemical, mechanical (Jamshidi et al., 2012). For example, to approximate of damage or develop in environmental studies that have biological nature, SC has been the most commonly used by experts (Mohammadi et al., 2013). Recognizable proof framework that uses a particular technique for displaying the framework therefore of down to earth testing happens. Displaying of getting a relationship amongst information and yield framework so that if a comparable info flag is connected to the framework and reproduction models, yield of the principle framework and models are practically indistinguishable (Ning et al., 2006; Inoue et al., 2001). Battery applications have pervaded our lives today at each level, from little Bluetooth headsets to cameras, mobile phones and portable PCs to half breed and electric vehicles (Saha and Goebel, 2009). Lithium batteries give the most noteworthy vitality thickness, nickel-cadmium batteries twofold the accessible vitality. They don't have to totally release and higher streams can be utilized to charge and release without harm to the battery. While releasing a potential drop a bit, soften up period don't require batteries and memory don't know about the issue (Guo et al., 2015; Bartram and Mahadevan, 2012;

Fergus, 2010). Lithium-ion can be sensing by the use of electrical and chemical sensor at the environment easily (Taherpour et al., 2015; Jamshidi et al., 2016). Batteries frame a center segment of many machines and are as a rule basic to the prosperity and utilitarian capacities of the general framework (Saha et al., 2007). Electrochemical impedance spectroscopy (EIS) is a developed and helpful device in portraying electrochemical frameworks (Greenleaf et al., 2014). The impedance spectroscopy technique measures the battery impedance by testing the voltage response with a small AC current applied to the battery (Ehsani et al., 2009; Du et al., 2014). A spectroscopy is made out of the impedance information separated from various recurrence streams (Du et al., 2014). To expand helpfulness, comparable circuit demonstrating has been utilized to give physical or phenomenological portrayals of watched electrochemical conduct (Greenleaf et al., 2014). The members in the electrochemical responses in a lithium-particle battery are the negative and positive cathodes with the electrolyte giving a conductive medium to Lithium-particles to move between the terminals (Amatucci et al., 1996; Wang, 2013).

2 Case study: li-ion battery current

System includes of a battery dataset that is downloaded from the Prognostics Data Repository (PCoE) of NASA (Prognostics, 2016). PCoE is a source of technique data sets which are used by some research centres and universities. In this paper, the experiments on li-ion batteries is applied for ANFIS model. This data set is the result of a research work has been done by B. Saha and K. Goebel in 2007. In this part, methods of extracting data from the system under study is described. Data used in this paper includes current of battery in the first cycle and 48th cycle in impedance status. Figure 1 shows block diagram of the experimental data lithium batteries. Of course, this step was performed in the laboratories of NASA and the schematic for better understanding of the data used is shown. According to the data of discharge per cycle are stored as a time series. This time series is used as input and target signal at the artificial neural network.

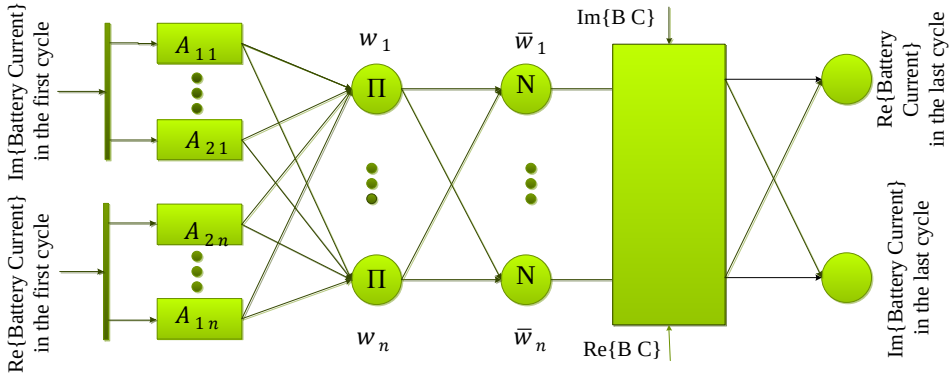
Figure 1 Block diagram of the experimental data



3 Adaptive neuro-fuzzy inference system

In this approach, samples of the input signal and output by the sampler, computer numerical values they have placed. It is very important that input should be applied to the system during the test. For someone who only thinks to identify extreme changes in the input trigger system is the ideal all frequencies. But in most physical systems of such input signal is not permitted and may damage the system or its application is not possible. These numbers are stored in the computer. After storing numbers, we have two vectors, one vector input and one output vector. The modelling is to obtain a relationship between the input and output of the system, so that if a similar input signal is applied to the system and simulation models the main system output and models are almost identical. Block diagram of the ANFIS model data is shown in figure 2. As shown in figure 2, first complex signal is broken to Re and Im, then enter the model as inputs.

Figure 2 Block diagram of the ANFIS model



4 Results and simulation

In this paper, modelling battery current as one of the impedance parameters in the li-ion batteries is selected. The battery current is an important parameter for managing energy and increasing quality control of these devices. The most important innovation in this work is using ANFIS with separated inputs. Since, there is complex function here so the soft computing methods such as ANFIS cannot achieve to the best result with ordinary ways. In fact, here we are involved with a complex phenomenon. This point was considered less in previous work. So complex function must be definable as a real function for using the soft computing environments. To model the battery current based on ANFIS, three stages are considered. Firstly, the battery current as a complex variable has to separate to two parts: image part and real part, because ANFIS cannot process the inputs which have complex entity. Secondly, these separated inputs are applied to ANFIS as two independent variable. Since, the proposed study is modelling of impedance behaviours, so the obtained model is built based on numbers of primary cycles and secondary cycles as inputs and outputs respectively. In the third part, ANFIS is started for training, testing and evaluating of data which was applied to it. This stage is done by

ANFIS option in the Fuzzy Toolbox of MATLAB. Results of simulation is illustrated in the next parts. Figures 3 and 4 show the surface function between inputs and targets. The surface function is one of the important index for displaying relationship between different variables of tanning operations in ANFIS. In the figures the relationship of inputs and outputs are shown clearly. The graphs illustrate which ANFIS model could determine to find dependency between of the concerned variables. Here, input 1 and input 2 are image part of battery current and real part of battery current respectively. A flat surface determine a good training state and a nonlinear surface determine a bad training.

Figure 3 Relationship between inputs and target as surface function

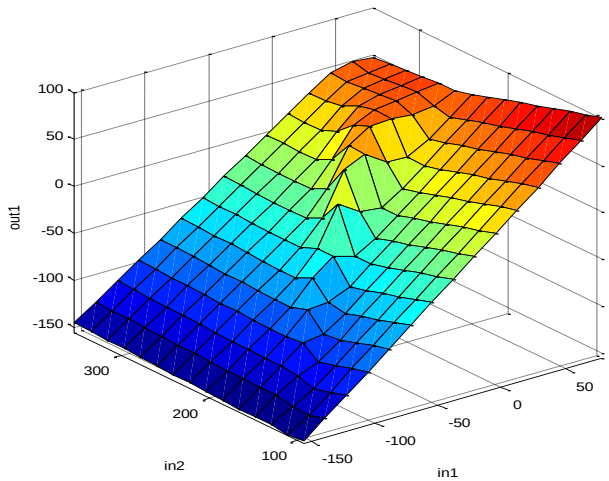
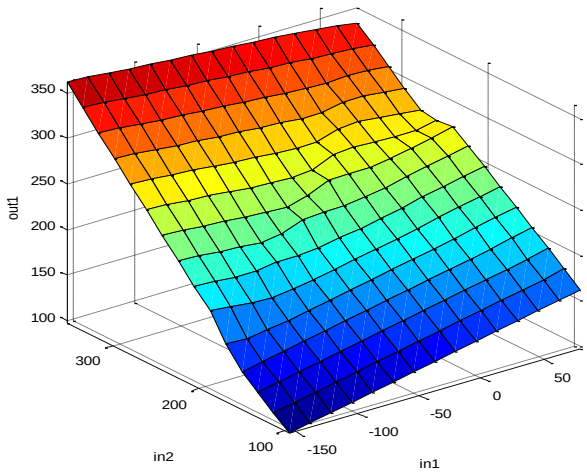


Figure 4 Relationship between inputs and target as surface function



Figures 5 to 8 are shown comparing between target and output model. In this figures, the horizontal axis and the vertical axis show the frequency and image or real part of battery current respectively. As shown in the figures, whatever the graphs closer to each other the obtained answers will be more accurate. Figure 5 illustrates the best response of ANFIS output than real target among all graphs because graphs are almost completely overlapping. These figures show the right model for modeling signals.

Figure 5 Comparing between target and output model

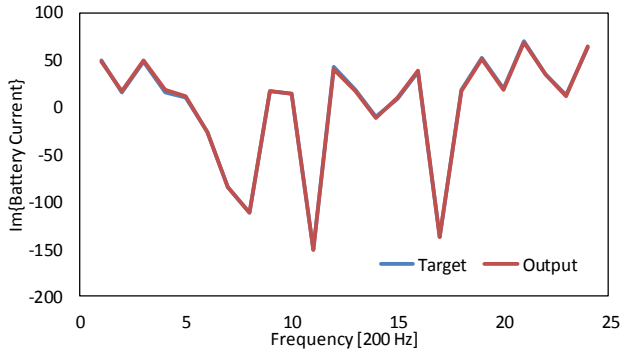


Figure 6 Comparing between target and output model

Figure 7 Comparing between target and output model

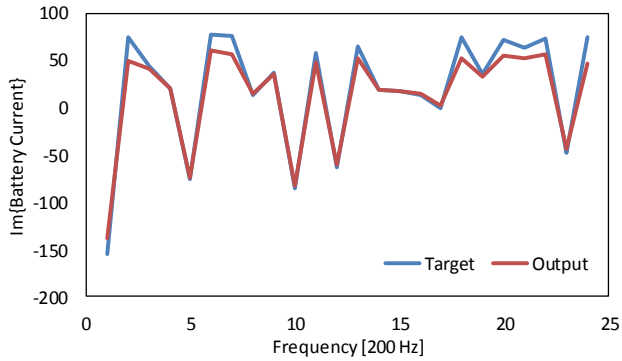
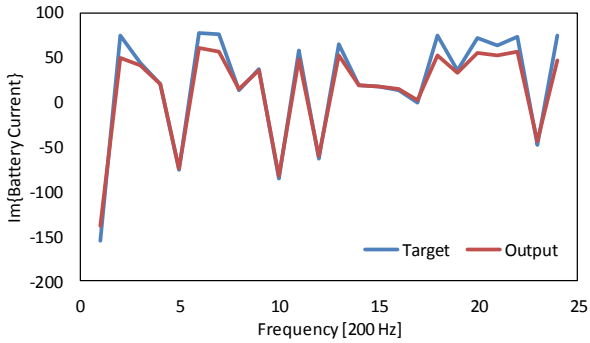


Figure 8 Comparing between target and output model.



The last stage in the modelling and system identification model is evaluation and validation. Identify methods that were used in a lot of assumptions about the system was considered (Jamshidi et al., 2014; Jamshidi and Nikjoo, 2014). One way to choose the right model or a model, is different sets of models are evaluated to determine which ones perform better. The mathematical relationship between the input and output of a system, say a mathematical model. In the experimental model parameters do not have individual values obtained through separate tests and the physical laws governing them are written. Equally important, it is the choice of model structure and grade. Select the type of structure model based on nonlinear effects in the system, and physical parameters based on prior knowledge of it. The second issue is the choice of the model. In this approach, samples of the input signal and output by the sampler, computer numerical values they have placed. After testing a series of numbers that have nothing to do with the nature of what they are and what they are single. For example, temperature or pressure. In an experimental model, our art is that a mathematical model or equation differential between the two vectors graceful. After modelling and system identification, evaluating the model arises. Evaluation model means that the model is good or bad is this and what measure of good or bad there.

Error regression for train, test, and evaluation data is shown in figure 9. In statistical models, regression analysis is a statistical process used to estimate relationships between variables. It includes many techniques for modelling and analysis of certain variables unique focus on the relationship between the dependent variable when the independent variable and one or more. In particular, regression analysis helps to understand how each of the independent variables and the dependent variable and the other independent variables with constant changes. Most used regression analysis to estimate the conditional expectation of the dependent variable given the independent variables is equal to the average value of the dependent variable when the independent variables are fixed. Basic knowledge of statistics for the study and use of knowledge and understanding of concepts and subject to its application. So mention a few points of difference and how to properly use these two indicators is necessary. (Girlich, 1999; Wikipedia, 2016b; Bland, 1996). Standard Deviation (SD): square root of the sample variance, is a measure of dispersion around their average describes the sample data. Provided that the survey sample is required to describe the data (Gorard, 2005). Regression analysis was used extensively to predict. In certain circumstances this analysis to derive the excellent relations between

independent and dependent variables can be used. However, this can lead to incorrect or false relations, so caution is recommended.

Figure 9 Response for the ANN model

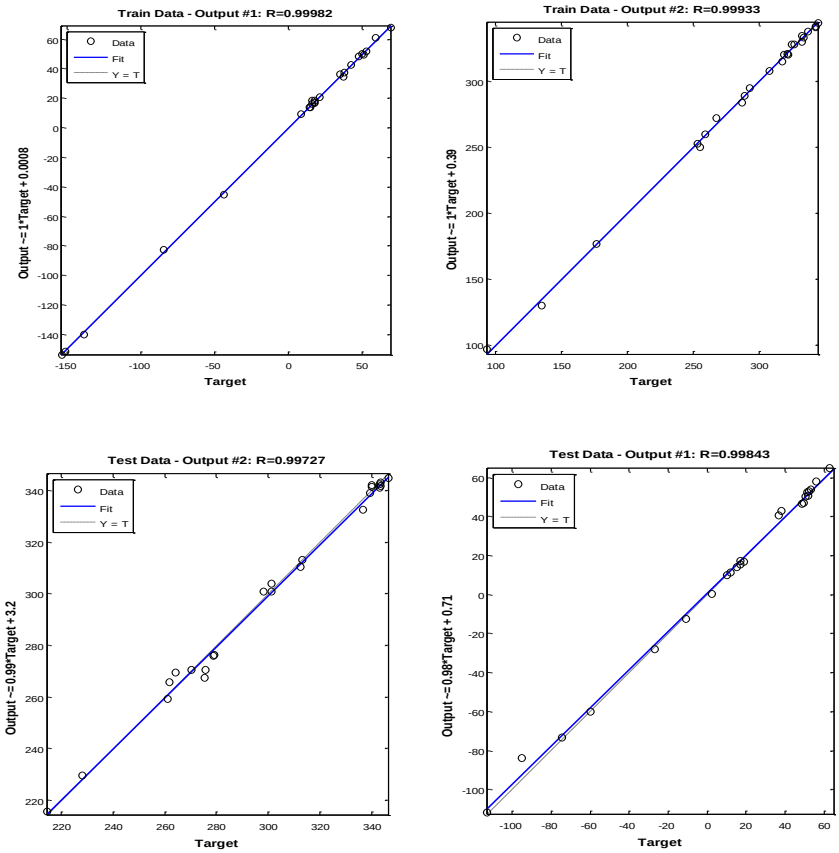
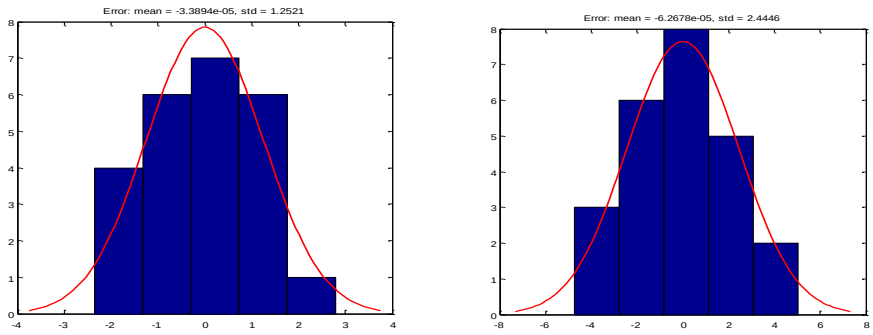


Figure 10 shows the standard deviation of the model. The standard deviation of the dispersion index that shows how much the average value are average data. If the standard deviation of a set of data is close to zero, a sign that the data are close to the average and dispersion little while large standard deviation indicates considerable scatter data. The standard deviation equal to the square root of the variance. The standard deviation in statistical analysis is also used to determine confidence. In scientific studies, usually with data from more than two standard deviations is considered as outliers and analysis, are removed.

One of the main goals of this paper, the modelling parameters was mixed with soft computing approach. In the paper, modelling for complex parameters by separating real and imaginary parts of the simulation were used in lithium ion batteries. This section uses a different measure of the accuracy of the models was discussed. This method as a new method of modelling complex parameters could well be alternative analytical methods. Because analytical methods required a lot of knowledge in the field of battery.

Figure 10 Standard deviation of the model



5 Conclusion

In this paper, adaptive neuro fuzzy inference system is used as a soft computing method for modelling complex current of li-ion in the impedance state. The used technique is an experimental technique which using data mining of the battery signals models and approximates the impedance behaviours. The purpose approach has high speed and simple to model the nonlinear systems. Since electrochemical systems such li-ion battery are combination of several nature which contain electrical, mechanical, chemical, and thermo dynamical, application of analytical methods cannot be useful to achieve the clear model so soft computing techniques will be powerful here. After the simulation of reached models with real system responses, results were acceptable for modelling the current. The method used in this research can be used to model other dynamic systems similar. One of the advantages of this method are very high precision of the analytical method. A limitation of this method of modeling, models of the system is the input and output signals, this means that if the system is not stimulated so well or do not accurately measure signals derived models will be wrong.

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References

Amatucci G., Tarascon J. and Klein L. (1996) 'Coo2, the end member of the li x coo2 solid solution', *Journal of the Electrochemical Society* 143: 1114-1123.

Bartram G. and Mahadevan S. (2012) 'Prognostics and health monitoring in the presence of heterogeneous information', *Proc. Annual. Conference. Prognostic. Health Management Society*.

Bland J. M. A., D.G. . (1996) 'Statistics notes: measurement error', *BMJ*.

Du J., Liu Z. and Wang Y. (2014) 'State of charge estimation for Li-ion battery based on model from extreme learning machine', *Control Engineering Practice* 26:11-19.

Ehsani M., Gao Y. and Emadi A. (2009) 'Modern electric, hybrid electric, and fuel cell vehicles: fundamentals, theory, and design ': CRC press.

Fergus J. W. (2010) 'Recent developments in cathode materials for lithium ion batteries', *Journal of Power Sources* 195: 939-954.

Girlich H.-J. (1999) 'Hausdorffs Beiträge zur Wahrscheinlichkeitstheorie', *Felix Hausdorff zum Gedächtnis.* Springer, 31-70.

Goebel B. S. a. K. (2007) 'Battery Data Set'. NASA Ames Research Center, Moffett Field, CA: NASA Ames Prognostics Data Repository

Gorard S. (2005) 'Revisiting a 90-year-old debate: the advantages of the mean deviation', *British Journal of Educational Studies* 53: 417-430.

Greenleaf M., Li H. and Zheng J. (2014) 'Application of physical electric circuit modeling to characterize Li-ion battery electrochemical processes', *Journal of Power Sources* 270: 113-120.

Guo J., Li Z. and Pecht M. (2015) 'A Bayesian approach for Li-Ion battery capacity fade modeling and cycles to failure prognostics', *Journal of Power Sources* 281:173-184.

G. Chen et al "Fuzzy System and Data Mining", Frontiers in Artificial Intelligence and Applications, IOS Press, Vol. 281, pp.1-168, 2016.

Huang H.-C. (2016) 'Fusion of Modified Bat Algorithm Soft Computing and Dynamic Model Hard Computing to Online Self-Adaptive Fuzzy Control of Autonomous Mobile Robots', *IEEE Transactions on Industrial Informatics* 12: 972-979.

Inoue T., Sasake T., Immamura N., Yoshida H. and Mizutani M. (2001) 'NASA Aerospace Battery Workshop', *Huntsville, Alabama*.

Jamshidi M. B., Jahangiri Q., Manesh R. E., Azimi S., Darvishi H. and Nemati B. (2012) 'Identify and simulation a furnace of steam boiler based on a new fuzzy modeling approach', *International Journal of Computer Science (IJCSI)* 9: 452-458.

Jamshidi M. B. and Nikjoo M. (2014) 'Economic Evaluation of the Application of Wireless Sensor Networks in Intelligent Management of Environmental Crises', *Journal of Middle East Applied Science and Technology (JMEAST)*: 573-577.

Jamshidi M. B., Sharafi M. A. and Shababi R. (2014) 'Optimization Electrical Energy Consumption by using Smart Grid', *Journal of Middle East Applied Science and Technology (JMEAST)*: 655-659.

Jamshidi M., Rezaei O., Rezaei Belverdi A., Malekian S. and Rezaei Belverdi A. (2016) 'A highly selective fluorescent chemosensor for Mg2+ ion in aqueous solution using density function theory calculations', *Journal of Molecular Structure (JMS)*, 111–115.

Liu Y. and Zhang Y. (2015) 'Iterative local ANFIS-based human welder intelligence modeling and control in pipe GTAW process: a data-driven approach', *IEEE/ASME Transactions on Mechatronics* 20: 1079-1088.

Mansouri B. and Hamednia Y. (2015) 'A Soft Computing Method for Damage Mapping Using VHR Optical Satellite Imagery', *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 8: 4935-4941.

Mohammadi A., Mohammadi Azam S., Hasanifard G., Rahmanzadeh H., Jamshidi M. B. and Manesh R. E. (2013) 'Management Estimates the Amount of Damage to Wetlands Caused by Various Environmental Threats Based on Fuzzy Logic', *Interdisciplinary Journal of Contemporary Research In Business* 5: 161.

Ning G., White R. E. and Popov B. N. (2006) 'A generalized cycle life model of rechargeable Li-ion batteries', *Electrochimica acta* 51: 2012-2022.

Prognostics N. A. (2016) ' Prognostics Data Repository'. NASA Ames Research Center, Moffett Field, CA: NASA Ames Prognostics Data Repository

Petković, D., Shamshirband, S., Anuar, N. B., Sabri, A. Q. M., Rahman, Z. B. A., & Pavlović, N. D. (2016). Input displacement neuro-fuzzy control and object recognition by compliant multi-fingered passively adaptive robotic gripper. Journal of Intelligent & Robotic Systems, 82(2), 177-187.

Saha B. and Goebel K. (2009) 'Modeling Li-ion battery capacity depletion in a particle filtering framework', *Proceedings of the annual conference of the prognostics and health management society*. 2909-2924.

Saha B., Poll S., Goebel K. and Christophersen J. (2007) 'An integrated approach to battery health monitoring using Bayesian regression and state estimation', *2007 IEEE Autotestcon*. IEEE, 646-653.

Taherpour A A., Rezaei O., Shahri Z., Jalilian J., Jamshidi M. and Zolfaghar N., (2015) 'First principles studies of electronic and optical properties of helium adsorption on Sc-doped BN monolayer', *Journal of the Iranian Chemical Society (JICS)*, 1983–1990.

Wang J. (2013) 'The interfacial effects on the conductive performance of the composite films based on materials with electron and ionic conductors', *Composite Interfaces* 20: 661-671.

Wikipedia. (2016b) 'Standard deviation', *Available at: https://en.wikipedia.org/wiki/Standard_deviation*.