Application of Neuro-fuzzy System : A Literature Review

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Abstract

Traditional algorithmic approaches are not suitable for solving today's problems. Neuro-Fuzzy systems have recently become popular and promising choice among researchers in attempt to solve complex problems faced in any sector. The paper presents a brief review of most recent applications in agriculture and some other sector aimed at knowing future events in advance specifically employing neuro-fuzzy approach. The neuro-fuzzy systems designed and developed between 2000 and 2018 have been studied with the intention to explore the recent developments. Prominent applications in some wide-spread domains are considered with an outlook of their capabilities in respective domains.

Mathematics is considered as art of all arts and science of all sciences. Most of mathematical terms and functions are used in many other branches like engineering, robotics, physic s etc. One of these terms is Fuzzy Logic. This term has become more popular in mathematics and in other branches as in engineering, medical science, robotics etc. and even in households also. This paper presents the concept of fuzzy logic and its application in different branches. This study represents the use of fuzzy logic approach in chemical science, medical science, agriculture, political science, operations research, in environment science and in household. This paper represents that fuzzy logic approach has mainly three phases: fuzzification, rule or inference and defuzzification. The findings indicated that fuzzy logic is a wide approach rather than a mathematical logic and is applicable in many branches.

Key words:

Fuzzy logic application, Hybrid systems, Neural networks, Adaptive Neuro fuzzy Inference System (ANFIS).

1. Introduction

In recent years, numerous studies have been carried out which revealed the limitations of traditional methods in dealing with problems of today. The methods currently used in agriculture and other area are somewhere incapable of prediction of future events to act proactively due to vagueness and mass of the data or due to complexity of the problem. Everything cannot be represented precisely due to unavailability of proper information, lack of information or unclear information. It is evident that traditional computing methods are inefficient in such situations. A significant research contribution in finding solution to these problems has made companies to see a gradual shift from traditional methods to advanced systems. The reason behind the motivation is obvious; the common characteristics of problems of any fields like non-linear behavior, high degree of uncertainty, lack of precise knowledge etc. A variety of machine learning techniques are being developed for possible application into various fields to experience intelligent information systems.

The advancement of technology, success of upcoming methods and their acceptance has given way to modified methods in almost all areas. An emerging class of intelligent machines taking place of traditional methods consists of fuzzy logic and neural networks. Fuzzy logic provides a mathematical foundation for dealing with situations full of uncertainties by simulating human perception for understanding linguistic attributes while neural network mimics human beings in the process of learning, thinking and adaptation. A combination of these two techniques called neuro-fuzzy systems has the potential to get the advantages of both leaving behind their limitations. In a hybrid model, neural network learning algorithms are fused with fuzzy reasoning of fuzzy logic. Each of the components plays their own role; neural network determine the values of parameters while if-then rules are handled by fuzzy logic. A fuzzy inference system uses human expertise by storing required knowledge in its rule-base, and then performs fuzzy reasoning on the input to infer the overall output value.

Fuzzy logic and neural networks complement each other in developing intelligent systems. Neural networks form low-level computational structures and can deal with raw data while, fuzzy logic sits on a higher level and uses linguistic information. Looking from the other viewpoint, fuzzy systems lack the ability to learn and cannot adjust to a new environment, but neural networks can learn and generalize. A general problem with neural networks is that they are black box with number of hidden layers whose operation is opaque to user. Integrated together, the resultant neuro-fuzzy system can perform parallel computation and learn like neural networks and can represent human-like knowledge with explanation abilities of fuzzy systems making the overall system more transparent. Researchers from varied domains have attempted and relied on the use of hybrid neural network and fuzzy logic approach. A neuro-fuzzy system has input and output layers, and hidden layers representing membership functions and fuzzy rules, which learns to solve problems full of uncertainty. It is not possible to include all the applications on neuro-fuzzy hybridization, so we restrict the discussion to sciences domains like agriculture, computer science,

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environmental science, chemical science and household appliances.

The development of a fuzzy system with good performance is not an easy task. The problem of finding a correct membership functions and appropriate rules is frequently a tiring process of attempt and error. It leads to the idea of using learning algorithms to the fuzzy systems (Berenji, 1992). Neural networks that have efficient learning algorithms, had been presented as an alternative to automate or to support the development of tuning fuzzy systems. A neuro-fuzzy system is based on a fuzzy system which is trained by a learning algorithm derived from neural network theory. The extensive learning procedure operates on primitive information and causes only local modifications in the underlying fuzzy system (Berenji, 1992).

A neuro-fuzzy system can be viewed as a 3-layer feed forward neural network. The first layer represents input variables, the middle (hidden) layer represents fuzzy rules and the third layer represents output variables. Fuzzy sets are encoded as (fuzzy) connection weights (Berenji, 1992). It is not necessary to represent a fuzzy system like this to apply a learning algorithm to it. However, it can be convenient, because it represents the data flow of input processing and learning within the model. The first studies of the neuro-fuzzy systems date of the beginning of the 90"s decade, with Jang, Lin and Lee in 1991, Berenji in 1992 and Nauck from 1993 etc. The majority of the first applications were in process control. Gradually, its application spread for all the areas of the knowledge like, data analysis, data classification, imperfections detection and support to decision-making, etc

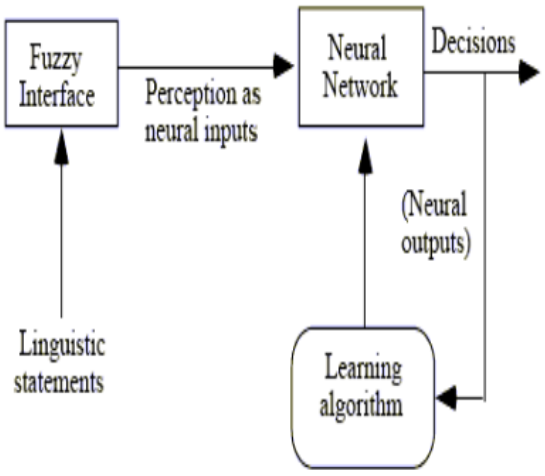

Fig. 1 Model of Fuzzy Neural Systems (Aparna et al, 2012).

Fuzzy logic is a mathematical term, used by many researchers in different fields at different periods of time. A great change has been occurred by the use of fuzzy logic. Due to the use of fuzzy logic many things has become easier and this has helped to save time, money and energy. Fuzzy logic was first time proposed by Lotti Zadeh in 1965. Before Zadeh many efforts were done in this field by many researchers like Plato, Hegel, Marx, Lukasiewicz etc.[1]. Some of them gave three valued logic and some of them gave four valued or five valued logic, which are the extension of Boolean logic, which accepts only two values true or false (0 or 1).

Lotti Zadeh in his work "Fuzzy sets" described mathematics as fuzzy sets and fuzzy logic. Before the introduction of fuzzy logic, mathematics is confined only to two conclusions that is true or false (0 or 1). But fuzzy logic has extended this range to the real numbers (0, 1). This paper presents the concept of fuzzy logic and a brief review of its application in different fields. This study represents that how fuzzy logic has been applied in different fields and how its use make the things and concepts easier.

Fuzzy logic is very useful for various people who involved in research and development including several engineers like mechanical, electrical, civil, aerospace, chemical, agricultural, computer, biomedical, environmental, industrial, geological, and mechatronics. It also includes mathematicians, computer software developers, medical researchers, natural scientists, social scientists, business analysts, public policy analysts, and jurists. Actually, the applications of fuzzy logic, once supposed to be an ambiguous mathematical curiosity, can be establish in various engineering and scientific works (Zadeh, 2008). Fuzzy logic has been used in several applications such as air conditioners, facial pattern recognition, washing machines, antiskid braking systems, vacuum cleaners, transmission systems, knowledge-based systems for multi objective optimization of power systems, soil testing prediction, control of subway systems and unmanned helicopters, weather forecasting systems, medical diagnosis and treatment plans, models for new product pricing or project risk assessment, and stock trading. Fuzzy logic has been effectively used in various fields such as power engineering, control systems engineering, image processing, robotics, industrial automation, consumer electronics, and optimization (Zadeh, 2008).

2. Concept of Fuzzy Logic

Boolean logic accepts only two values true or false (0 or l). In this one can talk about low or high. It does not say anything between them that is it does not take the concept of medium. This can be done by the more extended concept that is by fuzzy logic as it takes values [O, l]. Because of this concept one can talk about low, high and medium and also about very low, very high also. So it is the extended version of Boolean logic (Renu, 2017).

Fuzzy means not well known or not clear enough. Fuzzy logic is a proposition that may be true or false or have an intermediate true value. It is formed to handle the concept of partial truth. Degree of truth is represented by membership function. A membership function on a set X is any function from X to a real unit interval [O, l]. The value 0 represents the false value, lrepresents truth value and the value between 0 and l represents partial truth. One of the major advantages of fuzzy logic is that it resembles with human reasoning. In this linguistic variables are used to reduce complexity (Renu, 2017).

3. Fuzzy Logic Control

Fuzzy logic controller proceeds in three steps. First step is fuzzification. In this crisp variable is converted in fuzzy variable. In second step some rules are set up in the form of If -Then and inference system works. The third step is defuzzification. In this resulting fuzzy output is converted back into crisp variable (Poonam, 2017).

4. Existing Applications of Fuzzy Logic and ANFIS

4.1 In Chemical Science

Fuzzy logic has been used in chemical science. Davidson and Hayward (2003) considered many examples based on use of fuzzy logic. The study of Almardy used a fuzzy control system to apply current to a series of anodes to protect a long buried pipeline and also to minimize power used to protect the pipeline (Hayward, 2003). The study showed that for this he set up a fuzzy control system with 126 rules and got output by adjusting the output membership functions. Adroer et al found fuzzy error, the difference between the desired and actual pH, in controlling pH of flowing waste water (Hayward, 2003). The fuzzy technique implemented by Adroer et al found that for acceptable pH control with a small mixer could be provided with a short residence time. Thus the study shows that the fuzzy logic has great contribution in chemical science (Renu, 2017).

4.2 In Healthcare Industry

Fuzzy logic has been used in healthcare industry. Biomedicine is seemed as branch of science but more than science, it is an art. because it uses human knowledge, experience and skills to diagnosis and treatment of diseases. Biomedical systems are intrinsically non linear, time varying and have time delay. To regulate the blood pressure in case of open heart patients a real time fuzzy control drug delivery system has been tried in 1980s [l O]. The study of Davidson and Hayward (2003) represented that Warren et al presented a decision support system for automating the application of clinical practice guidelines based on fuzzy method. The study shows that the test report yields likelihood estimates rather than confirmation of presence or absence of disease and in fuzzy method, likelihood estimates can be handled as membership values and used as such in fuzzy inference model. Thus the study shows that the fuzzy logic has great contribution in health industry (Renu,2017).

4.3 In Agriculture

Philomine (2015) studied the use of fuzzy logic in agriculture. The paper represent s application of fuzzy logic in pest management. disease management. and weed management in developing expert system for various crops and to study and analyze soil. The paper "Design and development of Fuzzy Expert System for Integrated Disease management in Finger Millets" identified diseases as Immune, highly resistant, resistant. moderately resistant. susceptible and highly susceptible. The expert system use fuzzification and defuzzification process to reason out otherwise done only by agricultural scholars or by experienced farmers. The study of paper "Integrated pest management system using fuzzy expert system" showed three inputs in fuzzy logic approach based on pest like number of pests, size of pests, damages to pests. A fuzzy based expert system "Design and development of expert system for potato crop" analyzed the soil condition using fuzzy membership function. Thus the study shows that fuzzy logic approach has great contribution in agriculture (Renu, 2017).

4.4 In Computer Science

A Fuzzy Preprocessing Module for Optimizing the Access Network Selection in Wireless Networks proposed by Kaleem et al (2013). The main objective of this paper was to presents the implementation and design of a fuzzy multi principles based on Vertical Handoff Necessity Estimation (VHONE) pattern which determines the appropriate time for VHO, however considering the quality and continuity of the currently developed service and the end user's satisfaction also. This scheme was proposed to regulate the proper time for an upcoming handoff in order to preserve the quality and the continuity of the current session. Numerous parallel fuzzy logic controls were exploited with multiple constraints measured from the modern Point of Attachment to determine the necessity of vertical handoffs.

A Soft Computing Approach to Crack Detection and Impact Source Identification (CDISI) with Field Programmable Gate Array Implementation proposed by Dixit and Singh (2012). The objective of this paper was to report on determinations to develop a computerized CDISI procedure and to communicate a technique such that the

proposed technique can be certainly implemented on a chip. The CDISI fuzzy implication system is developed by using toolbox of fuzzy logic MATLAB. A VLSI circuit for CDISI is industrialized on basis of fuzzy logic prototype using Verilog, a hardware description language. The Xilinx ISE WebPACK9.1i is used for design, implementation, synthesis, and verification. The Crack Detection and Impact Source Identification (CDISI) field programmable gate array (FPGA) execution is done by using Xilinx's Spartan 3 FPGA. Analysis of Adaptive Fuzzy Technique for Multiple Crack Diagnosis of Faulty Beam Using Vibration Signatures is proposed by Dash (2013). The main objective of this paper was to discuss the multi crack detection of the configuration using fuzzy Gaussian technique.

4.5 In Soil Science

Fuzzy inference systems were used as alternative to statistical tool for developing predictive models to estimate the needed parameters which have been successfully applied to solve different problems in soil applications (Mcbratney et al, 1997). Aali et al, (2009) used an ANFIS for estimation of saturation percentage of soils collected from Boukan region in the north-western part of Iran. Percent clay, silt, sand and organic carbon were used as inputs. The results showed that ANFIS model can be used for reasonable estimation of saturation percentage values of soils. Bektas and Ozgan (2010) developed a model using ANFIS technique to predict the particle diameter of soil for different cases without the need for a test. The quantities of the sodium hexametaphosphate and the hydrometer reading times were used as inputs in the model. Test results and predicted outcomes were compared and high correlations were obtained. Sezer et al, (2010) employed an ANFIS to predict sand permeability and the result was very significant (Saad et al, 2014).

In comparison with nonlinear multiple regression analyses results, it was revealed that ANFIS structure was comparatively successful in the prediction of the permeability utilizing particle shape and grain size distribution information. The measurement of the natural radionuclides concentration in a soil can be influenced by the fractions of the grain size of the soil (Bisht et al, 2011). Hashemi Jokar (2018) proposed modeling unsaturated soils shear strength using Adaptive Neuro fuzzy inference system. This study was compared with other methods and ANFIS method outperform other methods. Tiwari (2017) proposed modelling of infiltration of soil using ANFIS. Results suggests that Gaussian membership function of ANFIS works better. Al-Sulaiman (2015) applyed an ANFIS for prediction of unsaturated soil hydraulic conductivity (ku). The unsaturated hydraulic conductivity of soil (ku) is one of the most principal parameters in the study of water movement in the soil. The result shows that ANFIS gives better modelling.

Mokarram (2017) proposed the prediction of soil fertility for wheat cultivation. In this study, three method was used for the prediction and ANFIS gives better prediction. Saad and Hemed (2014) proposed the prediction of soil fractions (sand, silt and clay) in surface layer based on natural radionuclides concentration in the soil using ANFIS. ANFIS prediction was rated the best compared to other method. Abdulwahed (2015) proposed modelling of sodium adsorption ratio of the soil using ANFIS. The result of this study shows the effectiveness of the ANFIS for the modelling. Rahnema (2018) proposed the prediction of effective stress parameter of unsaturated soils using ANFIS. The study reveals that ANFIS prediction was the best compared to other methods.

4.6 In Operations Research

In operations research we deal about the problems which are related to optimization. Operations research helps to maximize profit and to minimize cost of production or cost of transportation etc. Fuzzy logic can be helpful in operations research also. By the use of fuzzy logic transportation cost can be minimized. Pappis and Mamdani (1977) [2] applied fuzzy logic in operation research techniques successfully. The study shows the use of fuzzy logic to control an intersection of two one way streets. Teodorovic and Kalie (1996) used fuzzy logic to choose the mode of transportation in order to minimize travel cost and travel time [2]. Fuzzy logic is helpful in traffic control also. Jarkko and Esko (2003) had applied fuzzy logic to minimize waiting time and risk of collisions during traffic signals [2]. In this way the study represents the use of fuzzy logic in operations research. Thus fuzzy logic has great contribution in operations research (Renu, 2017).

4.7 In Household

Nowadays, many home appliances are being upgraded using fuzzy logic to save time and money. Fuzzy logic system is used in many home appliances like washing machine, vacuum cleaner and in air conditioner etc. Tiryaki and Kazan's dish washer using fuzzy logic and Alhanjouri and Alhaddad's optimize wash time of washing machine using fuzzy logic are the main studies based on fuzzy logic. After that many researchers worked on this in order to reduce washing time and the less consumption of time and water. The study of the paper "Washing machine using fuzzy logic" (2014) shows the use of fuzzy logic in washing machine. The study represents that four input variables and five output variables are set up together with eighty one rules to define relationship among these variables. Some other researchers used sensors in washing machine for linguistic inputs which are type of clothes,

type of dirt, mass of clothes etc. These control the linguistic output that is wash time, spin time and rinse time etc. The study shows the use of fuzzy logic in air conditioner s and in air coolers also. The study of the paper "Application of Fuzzy Logic in Daily Life" (2017) showed that the design work of the room cooler may consist of more than one input and output values. The paper considered two input variables: temperature and humidity and three output variables: cooler fan speed, water pump speed and exhaust fan speed. Using these, fuzzy logic was applied to get the optimal result. Thus fuzzy logic has great contribution in household also (Renu, 2017).

4.8 In Environment Science

Fuzzy logic can be applied in Environment science also. It has been successfully used in detection of natural tragedies like flood and in environment change etc. A review of the paper "Prediction of flood detection system Fuzzy logic approach" (2014) showed that fuzzy logic model using If - Then rules for the prediction of flood detection system based on Mamdani approach is very helpful. In this paper water level and climate conditions are used as input and control action is used as output and total twenty five rules are set up for the process of prediction of flood. Due to fuzzy logic it has become possible to make vehicles better, more efficient and safer to save climate. Thus fuzzy logic has great contribution in environment science (Renu, 2017).

Table 2: Applications of Fuzzy Logic (Yager, 2007)

S.No	Product Name	Role of Fuzzy Logic
1	Air Conditioner	Prevents overshoot undershoot temperature oscillation and consumers less on off power
2	Anti-lock Brakes	Controls brakes in hazardous cases based on car speed and acceleration and on wheel speed and acceleration
3	Auto Engine	Controls fuel injection and ignition based on throttle setting, oxygen content, cooling water temperature, RPM, fuel volume, crank angle, knocking and manifold pressure
4	Auto Transmission	Select gear ratio based on engine load, driving style and road conditions
5	Chemical Mixer	Mixes chemicals based on plant conditions
6	Cruise Control	Adjusts throttle setting to set the speed based on car speed and acceleration
7	Dishwasher	Adjusts cleaning cycle and rinse and wash strategies based on the number of dishes and on the type and amount of food encrusted on the dishes
8	Dryer	Converts load size, fabric type and flow of hot air to dry times and strategies
9	Elevator Control	Reduces waiting time based on passenger
10	Factory Control	Schedule tasks and assembly line strategies
11	Golf Diagnostic System Health	Selects golf club based on golfer’s physique and swing
12	Management	Over 500 fuzzy rules track and evaluate an employee’s health and fitness
13	Humidifier	Adjusts moisture content to room conditions
14	Iron Mill Control	Mixes inputs and set
15	Kiln Control	temperatures and times Mixes cement
16	Microwave Oven	Sets and tunes power and cooking strategy
17	Palmtop Computer	Recognizes handwritten kanji characters
18	Paper Industry	Pulp production
19	Plasma Etching	Sets etch time and strategy
20	Refrigerator	Sets defrosting and cooling times based on usage. A neural network learns the user’s usage habits and tunes the fuzzy rules accordingly.
21	Rice Cooker	Sets cooking time and method based on steam, temperature and rice volume
22	Shower System	Suppresses variations in water temperature
23	Still Camera	Finds subject anywhere in the frame, adjusts autofocus
24	Stock Trading	Manages portfolio of Japanese stocks based on macroeconomic and microeconomic data
25	Television	Adjusts screen color and texture for each frame and stabilizes volume based on viewer’s room location
26	Translator	Recognizes, translates word in pencil size unit
27	Toaster	Sets toasting time and heat strategy for each bread type
28	Vacuum Cleaner	Sets motor suction strategy based on dust quantity and floor type
29	Video Camcorder	Adjusts autofocus and lighting
30	Washing Machine	Adjusts washing strategy based on sensed dirt level, fabric type, load size and water level. Some models use neural networks to tune rules to the user’s tastes.

5. Conclusion

Fuzzy logic is an extension of two valued logic or Boolean logic. In this mainly three steps are used fuzzification, inference system and defuzzification. It can be easily taught by using fuzzified educational methods. So it is appropriate to use multivalued fuzzy logic rather than two valued logic. This paper presents a brief overview of fuzzy logic and its applications in different fields. Very less is covered and more are there, that means this paper presents just an overview on fuzzy logic and its applications. But it has a lot of applications that has been discovered and are realized these days. A lot are left that are to be discovered still. The paper reviews neuro fuzzy system, Sfuzzy logic concept and its application in chemical science, in healthcare industry, in agriculture. In operations research,

in household and in environment science. Thus fuzzy logic has become a helping hand not only in mathematics, but in many other branches also.

References

[1] Aali, K.A., Parsinejad, M. and Rahmani, B. (2009) Estimation of Saturation Percentage of Soil Using Multiple Regression, ANN and ANFIS Techniques. Computer and Information Science, Vol 2, No 3, pp 127-136.

[2] Baharom AS, ldris Z, lsa SSM, Nazir M, Ahamed Khan (2014). Prediction of Flood Detection System: Fuzzy Logic Approach, International Journal of Enhanced Research in Science Technology and Engineering. Vol 3, No l, pp 335-339.

[3] Bektas, S. and Ozgan, E. (2010) Adaptive Neuro Fuzzy Inference System for Estimating Particle Diameter of Soils in Micro Structure for Varying Quantities of Sodium Hexametaphosphate. Scientific Research and Essays, 5, 782-789.

[4] Harmanjit Singh, Gurdev Singh, Nitin Bhatia (2012). Election Results Prediction System Based on Fuzzy Logic, International Journal of Computer Applications. (0975-8887). Vol 53, No 9, pp 30-37.

[5] Hayward, Davidson (2003). Fuzzy Logic Application, Analyst. Vol 128 pp 1304-1306.

[6] Kumar, P., Kumar, D., Jaipaul, A. and Tiwari, K. (2012) Evaporation Estimation Using Artificial Neural Networks and Adaptive Neuro-Fuzzy Inference System Techniques. Pakistan Journal of Meteorology, 8, 81-88.

[7] Lee K. C. and Lee H.H 2004 'Network-based fire detection system via controller area network for smart home automation'. Transactions on consumer electronics. Vol 50, No. 4, PP. 1093-1100.

[8] Mcbratney, A.B. and Odeh, I.O.A. (1997) Application of Fuzzy Sets in Soil Science: Fuzzy Logic, Fuzzy Measurements and Fuzzy Decisions. Geoderma, 77, 85-113.

[9] Mustafa Demetgul, Osman Ulkir, Tayyab Waqar (2014). Washing Machine using Fuzzy Logic, Automation. Control and Intelligent Systems. Vol 2, No 3, pp 27-32.

[10] Philomine Roseline TN, Ganesan, Clarence Tauro JM (2015). A study of Applications of Fuzzy Logic in Various Domains of Agricultural Sciences. International Journal of Computer Applications (0975 -8887). pp 15-18.

[11] Poonam Gupta (2017). Application of Fuzzy Logic in Daily Life. International Journal of Advanced Research in Computer Science. Vol 8, No 5, PP 1795-1800.

[12] Preeti Kaushik (2014). Applications of Fuzzy Logic in Operation Management Research. International Journal of Scientific and Research Publications. Vol 4, No10, pp 1-6.

[13] Priyanka Kausha, Neeraj Mohan, Parvinder Sandhu S (2010). Relevancy of Fuzzy Concept in Mathematics. Internationa Journal of Innovation, Management and Techno logy. Vol l, No 3, PP 312-315.

[14] Renu Makkar (2017). Application of fuzzy logic: A literature review. International journal of statistics and applied mathematics. Vol 3, No 1, pp 357-359.

[15] Saad Hamed, Wahby, M., Al-Sulaiman, M., Al-Saqer, S. and Aboukarima, A. (2012) Application of Artificial Neural Networks to Predict Natural Soil Radionuclides Concentrations in Some Saudi Agricultural Soils. Archives Des Sciences, Vol 65, 196-206.

[16] Suliman, A.S. and Post, D.F. (1988) Relationship between Soil Spectral Properties and Sand, Silt, and Clay Content of the Soils on the University of Arizona Maricopa Agricultural Centre. Proceedings of Hydrology and Water Resources in Arizona and the Southwest, 16 April 1988, Tucson, Arizona (Arizona-Nevada Academy of Science, Tucson Arizona), 18, 61-65.

[17] Ying H (2000). Fuzzy System Technology: A Brief Overview, IEEE Circuit s and System Society Newsletter. Vol 11, No 3, pp 28-37.

[18] Zadeh L A, 2008 'Is there a need for fuzzy logic?' information Sciences, Vol 178, No 13, PP. 2751-2779.