FUZZY LOGIC: AN OVERVIEW OF DIFFERENT APPLICATION AREAS

RAMANDEEP KAUR and AMAR SINGH

School of Computer Applications
Lovely Professional University
Phagwara, India
E-mail: ramandeep.11629@lpu.co.in
         amar.23318@lpu.co.in

Abstract

Fuzzy logic is the primary component of soft computing. Fuzzy logics have the solution of each any every non-linear problem of this real world. Fuzzy sets are used to create the fuzzy logics and by using fuzzy logics we can design fuzzy experts systems. Among so many applications of fuzzy expert system, we have discussed few of them in our paper. In this paper we have discussed the basic concept of fuzzy sets and fuzzy logics. The components and working of any kind of expert system has been discussed diagrammatically. This paper also contains the different application area of fuzzy logic.

I. Introduction

The usability of fuzzy is going to increase day by day. The solutions which are given by fuzzy expert systems are very optimal and easy to use. The ease of using the fuzzy systems adds the importance of this in each and every field of life. Any kind of nonlinear problem can be solved by embedding fuzzy with any other technology or hardware problems.

Lotfi A. Zadeh and Dieter Klaua had introduced fuzzy sets in 1965. The classical notion of sets were further extended as fuzzy sets. Fuzzy sets are the classes of objects with a continuum of grade of membership. The membership grade from zero to one is allocated to each set of objects. The annotation of union, intersection, inclusion, complement etc. are extended to these kind of sets, moreover, the properties of the annotations are substantiate in fuzzy set domain [1].

Fuzzy set allows moderate calculation of membership of the components for a given set. It is portrayed with guide of membership function esteemed in the unit interim $[0, 1]$. Fuzzy is a set of two values (U, m) where U is universal set and $m : U \rightarrow [0, 1]$ is the membership function. The membership functions of fuzzy set $A = (U, m)$ is $m = \mu(A)$ [2].

Crisp sets and fuzzy sets both are the piece of the particular set theories, where fuzzy actualizes infinite-valued logic while crisp utilizes bi-valued. Fuzzy sets are used by fuzzy controllers and crisp sets are used by digital designs [3].

It could be incontrovertible fact currently that fuzzy logic is having the capability to solve the problems in different like industrial management, consume natural philosophy, management, medicine, skilled systems and data technology. It provides an easy way to get definite results from inaccurate and incomplete data. Like human beings fuzzy system can think and can take the decisions.

Instead of Boolean logic, fuzzy logics are utilized while designing any fuzzy logic expert framework. As such, a fuzzy expert system is a gathering of membership functions and principles that are used to reason about information. In contrast to expert system, which are for the most part symbolic reasoning engines, FES are arranged toward numerical preparing [4]. It is situated towards dealing with unverifiable or loose data and utilized in the spaces where the information factors don't have settled qualities [5]. Furthermore, In 2014 Xu, et al. has given one example of fuzzy expert system which can solve the incorrect and irrational problems faced while selecting the test cases at system level. The visible results demonstrate that defects detection rate can be essentially enhanced by utilizing this proposed method [6]. In 2015 Akhouayri, et al. has introduced one fuzzy principle based framework which can be used effectively to fill in as an arrangement of seismic events. This framework gives a nonlinear device to control the ambiguity and intricacy of information [7]. In 2016 Hettiarachchi, et al. have used a fuzzy system to limit the subjectivity, imprecision, furthermore, irregularity issues stood up to by the process for estimating the risk related with requirements [8]. In 2017 Katigari, et al. have intended a fuzzy expert system for diagnosing diabetic neuropathy. This system helps the experts to

spot the diabetes more quickly by using very basic parameters. General experts can utilize this framework in remote regions to enhance the care for patients with diabetes [9].

After this section, section II includes the components of fuzzy expert system and working of the fuzzy expert system. In section III, the review of different area of implementation of fuzzy system has been done. There are some applications where fuzzy has already implemented successfully for different reasons. For this purpose, the data is collected from the last few years. The last section IV contains the conclusion of the paper.

II. Components and Working of Fuzzy Expert System

A fuzzy expert system will be portrayed with the assistance of a diagram as shown in figure 1. Every fuzzy expert system is having 4 main components:

1. Fuzzification

2. inference engine

3. knowledge base

4. defuzzification module.

1. Fuzzification Module: Fuzzification is the way toward changing a real scalar incentive into a fuzzy value. Fuzzy Linguistic Variables are utilized to speak to characteristics crossing a specific range. In this module.

I. The data is received from input device in the form of crisp sets.

These input sets are transforms to the fuzzy input (linguistic variables) and these converted variables are transferred to the next phase.
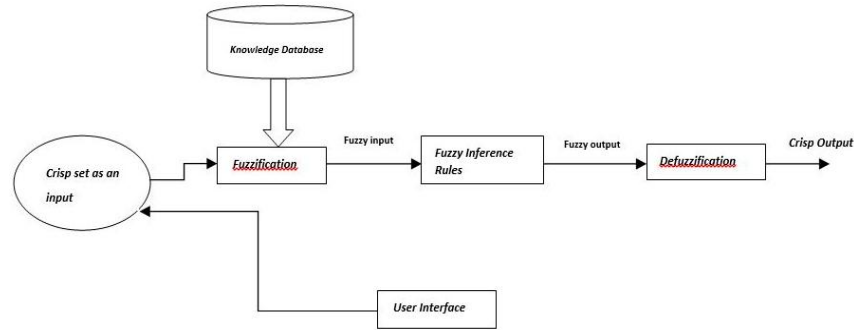
Figure 1. Block diagram of Fuzzy Expert System.

(2) Knowledge Base Module:

It holds the knowledge of the application domain and the procedural knowledge. It contains the data base and linguistic (fuzzy) control rule base.

I. All the supporting data related to linguistic control rules is provided by this module.

II. A rule base portrays the control objectives and control approach of the area expert by set of linguistic control rules.

(3) Inference Engine:

Like human brain, this module is having the capability to take the decisions. Under this module the output is mapped with every input by using expert rules already stored on the database.

(4) Defuzzification Module:

Fuzzy output (linguistic variables) from the previous module has been sent to this module for defuzzification process. The defuzzification process will convert the fuzzy output to the crisp set and further send this crisp set to the user interface.

III. Literature Review of Fuzzy Application Areas

Fuzzy logics provides the way to solve complex and non-linear problems easily and effectively. There are so many applications of fuzzy logics in the real world. Some of these applications we have discussed in this paper. The two extensive software systems utilize this fuzzy system to design the test plans.

Image Processing: Image processing is the m research area for the researchers in the field of computer science engineering. The researchers always try to find out the best solutions by using the fuzzy logic to extract the useful information from the given input as an image or a video. Time to time the researchers used fuzzy logic control system for solving the different kind of image processing problems in different areas. In 2011 Bhatia, et al. has introduced one new face detection technique by using two different models. Takagi-Sugeno (T-S) fuzzy model and Hue Saturation and Value (HSV) color models are used to locate the faces on the image [10]. In 2016, Bhagavathi S. L. and Thomas Niba S. have discussed the fuzzy logic system which will help in the detection of RBC (Red blood cell count) and WBC (White blood cell count) from blood samples. They used the blood smear image to process it in the MATLAB for further digital processing [11]. In 2018, Pragalath, et al. has used the fuzzy logic-decision making tool with image processing algorithm, which is used for identifying the damaged plane and measure the deterioration for scaling the civil grounds [12]. In 2018 Wang, et al. has introduced a self-evolving fuzzy cerebellar model articulation controller (IRSFCMAC) classifier which can solve the problems of face recognition. Findings of given algorithm shows that the proposed IRSFCMAC classifier has the capability to detect the face in a better way than the others [13]. Table 1.1 shows the fuzzy logic tools which can be used in image processing.

Table 1. Tools used in image processing.

Tools Available	Purpose
Fuzzy UPWELL [14]	This tool is committed to the completely programmed and unsupervised exact division of upwelling pictures. [14].
Mandelias 2013 [14]	This tool is for the programmed picture division consolidating fuzzy subjective maps and wavelet change [14].

Robotics: This section of the paper describes the significance of fuzzy logic in the area of robotics. Robots are highly versatile machines capable of incredible motions, but are simply too difficult to use and hard to setup. A Fuzzy Logic Based Control for Autonomous Mobile Robot Navigation

technique was proposed by Omrane, et al. in 2016. The author used two fuzzy logic controllers in the robot i.e. navigation fuzzy controller to enhance the navigation performances and second fuzzy controller is used to avoid the obstacles. This fuzzy logic controller can utilized for the implementation on an intelligent wheelchair to help the elderly or disabled people to perform the navigation task [15].In 2017 Akmal, et al. have designed one fuzzy logic controller which is employed as a controller to stabilize the two wheeled EV3 lego robot through Simulink-Matlab simulation. [16]. In 2018 Azar, et al. the researchers have discovered a theoretical and sensible implementation of a fuzzy algorithmic program methodology to manage a mobile manipulator path coming up with employing a real-time vision system trailing. To meet high execution reaction and hearty security of the stage route, a fuzzy logic controller is planned with practical compels [17]. In 2017 Chen, et al. has designed the fuzzy logic controller by which the robot can avoid obstacles the robot consists of many ultrasonic sensors to detect the obstacles and the decisions are taken by the proposed fuzzy logic controller [18].

Management: To manage the things in banks, business or any kind of field the fuzzy logic is playing very important role. In 2015 Mazlum, et al. has invented fuzzy PERT and Fuzzy CPM techniques, which can be used in fuzzy project handling. Online internet branches can use these techniques to improve the quality of the projects. The authors have tested these fuzzy techniques to check the performance [19]. Kłosowski, et al. presented the concept of selecting staff for production tasks with the employment of fuzzy logic. This Mamdani-type fuzzy deduction technique was utilized to structure a controller whose undertaking was to help the basic leadership process. A simulation model of a discrete assembling framework with an executed fuzzy controller was produced [38]. In 2017 a three dimensional framework was introduced, which will help to estimate the risk related with the large scale business projects. The given risk modeling framework is validated by conducting a survey [20]. In 2018 (Choy, et al.) another experiment goes for keeping up high administration nature of long term care services suppliers by setting up a learning based framework to upgrade the administration nature of nursing homes and the execution of its nursing staff consistently. In this case study an intelligent case-based knowledge management system is produced by joining fuzzy logic and case-based reasoning (CBR) [21].

Agriculture: Under this area the fuzzy logic techniques are used to enhance the fertility and to analysis the environmental parameters like light, temperature and humidity which can affect the crops. In 2016 (Hernández-Vera, et al.) in a Mexican coffee company, a fuzzy logic based expert system was created to strengthen basic decision making on the kind of creation process thinking about factors for example, weight, pellets, green aspect and the level of minor and major abandons, this data got from organoleptic examination. A Mandani-Fuzzy logic model to wind up a help apparatus for choosing the most fitting procedure on a dry factory as indicated by client necessities and all together to manage the production of coffee by avoiding delays in production. The potential advantage of the model could avoid stoppage of production by the non-attendance of a specialist who can settle on a choice about the procedure to be performed and cost decrease produced by reprocessing [22]. In 2017 (Heidari M. and Khodadadi H.) natural nursery conditions are made by utilizing three actuators like Heater, piezoelectric transducer and fans. The adjustments in moistness and within a small greenhouse temperature are accepted as the outputs of the system. In addition, greenhouse model shows recognizable proof is performed dependent on the acquired real information through MATLAB framework identification tool kit. Consequently, fuzzy logic self-tuning PID controller is intended for this reason and the execution of the controller in the atmosphere control of the farming greenhouse is contrasted and PID controller [23]. In 2018 (Kurniasih, et al.) the writers have directed an examination to decide the results of potential Bulurejo town dependent on criteria, like the potential in the field of agriculture, field of extensive cattle and domesticated animals and poultry utilizing fuzzy logic strategy. As the results of this, the utilization of fuzzy logic method in deciding the potential estimation of the town as per the criteria has been effectively settled, with the goal that the fuzzy logic method is appropriate for the count of the indexed lists from the potential of Bulurejo town [24].

Education: The use of fuzzy logic techniques is very popular to find out the new ways to evaluate the performance and to find out the reasons of low performance of the student as well as faculty member. In 2015 (Deliktas D. and Ustun O.) an incorporated methodology of fuzzy MULTIMOORA and multi choice conic programming is introduced to think about the criteria in

picking the best understudies and characterize the ideal assignments among the predefined projects to expand both the aggregate inclination esteem and aggregate positioning worth. The fuzzy MULTIMOORA is used to determine the rankings of the students [25]. In 2017 (Al-Samarraie, et al.) the study intends to decide the key components influencing understudies' and teachers' duration fulfillment with e-learning in the advanced education setting. So as to recognize the elements that affect e-learning continuation in advanced education foundations, a methodical survey of the writing was led. To investigate the information gathered from 9 educators and 38 understudies Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) method was used. A few distinctive causal connections between the variables recognized from the two understudies' and instructors' perspectives were likewise distinguished and used to frame a solitary perspective [26]. In 2018 (Pazil, et al.) the four main considerations which are based on the physical aspect, socio-emotional, spiritual, and intellectual of preschool kids are used to evaluate the performance of the student. This paper displays a technique to move forward these four factors by examining the execution of individual understudies in Malaysia. The ponder centers around 17 preschools in Johor which comprise of five chose schools in the year 2015. The entire information from the four perspectives are isolated into different extents. The fuzzy logic system is used to perform the same. It has been demonstrated that the execution of the five chose schools is effective in their procedure of learning [27].

Home Appliances: In many home appliances like television, washing machines, microwaves and refrigerators the fuzzy logic techniques has been used to provide the advancement in the field. In 2015 (Dovydaitis, et al.) one paper promotes a feeling that a lot of electronically controlled keen things must be intellectualized utilizing human-type thinking. It has discussed a tale approach and new calculations for the various leveled fuzzy preparing, retraining, and self-training for intellectualized home situations. Imperativeness and effectiveness of the proposed philosophy was tried and reproduced on a specific virtual software/hardware framework. The demonstrating performed for the working put light control in conditions near genuine home condition affirmed the conceivable viable productivity of the examined system [28]. In 2017 (Collotta M. and Pau G.) an Artificial Neural

Network (ANN) called BluHEMS is introduced to manage the energy utilization conditions. This system is used to forecast the home energy usage at various occasions of the day or on various days of the week. Matlab and NS-2 simulations are used to test the system and to check the performance of the proposed system [29]. Today almost all well-known companies like Philips, LG, Samsung etc. are using fuzzy for their products. Given picture 1.1 shows the same [30].

LG Washing Machine   Fuzzy Logic Based Rice Cooker

Image 1.1. Fuzzy Logic Based Products.

Health Care: Diagnosing any disease in medical field is very difficult for a medical expert. They need to perform different task for find out the cause of problem. To help the medical experts so many fuzzy expert systems have been introduce till date In 2015 Gayathri, et al. has introduced one fuzzy expert system to detect the risk of breast cancer. The main motive of this system to reduce the time for diagnosing the breast cancer. Mamdani is used to evaluate the results for the same [31]. In 2016 (Chanamool, et al.) the researchers proposed an application of utilizing Fuzzy FMEA, meant to build up the type of prioritization and evaluation on the failures for the working procedure in emergency by examine and recognizing proof of the failures as indicated by the philosophy of Failure Mode and Effects Analysis (FMEA). Besides, the prioritization and evaluation of the issues are enhanced with the usage of Fuzzy technique. The emergency department can easily adopt this application [32]. In 2017 (Singh, et al.) To quantify the SQ (Service Quality) of four hospitals of Punjab state in India, an incorporation of Fuzzy set theory and SERVQUAL approach has been done. The researchers have utilized Fuzzy Analytical Hierarchy Process to discover the need of every measurement and sub-measurement of medicinal services SQ traits. It is also

utilized for positioning the best hospital from the patient viewpoint [33]. In 2018 Soltani, et al. has introduced one new fuzzy expert system to diagnose the glaucoma disease which can affect the eyes and damage them very badly. A fuzzy logic based classification algorithm, is recommended to govern the patient's conditions like age, race, family history etc. On the basis of these conditions the doctors can take decision about the cause of glaucoma and take some necessary steps for treating the same [34].

Software Engineering: Developing any software or any application is very important and difficult task. Fuzzy logic is playing a vital role in the field of software engineering to solve the problems of software development process. In 2015 Ahlawat, et al. has invented one technique for estimating the cost and efforts in the software development process. They integrate the Constructive Cost Model (COCOMO) with the fuzzy logic. The investigated study explains the process of implementing the fuzzy logic with given model to estimate the size, efforts and cost drivers of any project. Four membership functions are used to estimate the efforts while developing a software [35]. In 2017 Yadav, et al. has proposed one model by using fuzzy logic, which can help to predict the defects in the requirement analysis phase of SDLC. They implement this model on twenty projects to test the usability of the same. The results of this validation process are satisfactory [36]. In 2018 (Hsieh, et al.) a fuzzy risk impact rating (FRIR) was produced for deciding the level of risk in a New Software Development (NSD) as indicated by risk attributes related with the task, for example, authoritative condition, clients, prerequisites, complexity, group, planning and control. The FRIR is made out of qualities conceivable evaluations and relating seriousness levels, and is accumulated utilizing fuzzy weighted average. The testing of the given application confirms that the fuzzy logic based risk assessment model can proficiently help administrators in managing equivocalness, imprecision, and multifaceted nature in NSD risk assessment [37].

IV. Conclusion

In this paper the fuzzy sets, fuzzy logics and fuzzy expert systems have been reviewed. From this detailed survey we have found the importance of using fuzzy for any nonlinear kind of problem. This is also observed that the

fuzzy utilizes the limited resources like time and money very well. Matlab is used to test and implements the fuzzy experts systems easily. The optimal solutions of any problem in any field of life can be taken by implementing fuzzy sets. The fuzzy is already implemented successfully in the field of robotics, banking, education, software engineering, image processing, and mechanics, medical etc. and so on. The results of these implementations are remarkable. It has been observed that there are some areas like automation of software testing, agile testing automation and criminal physiology, where we need to implement the fuzzy expert systems to find out the solutions of existing problems.

References

[1]   L. A. Zadeh, Fuzzy sets, Information and control, 1965 June 8; 8(3): 338-53.

[2]   https://en.wikipedia.org/wiki/Fuzzy_set [Accessed on 9th Feb 2019].

[3]   https://techdifferences.com/difference-between-fuzzy-set-and-crisp-set.html [Accessed on 4th Feb 2019].

[4]   http://www.austinlinks.com/Fuzzy/expert-systems.html [Accessed on 26th Jan 2019].

[5]   S. Thaker and V. Nagori, Analysis of Fuzzification Process in Fuzzy Expert System. Procedia Computer Science 2018 Dec 31; 132:1308-16.

[6]   Z. Xu, K. Gao, T. M. Khoshgoftaar and N. Seliya, System regression test planning with a fuzzy expert system, Information Sciences, 2014, Feb. 20;259:532-43.

[7]   E. S. Akhouayri, D. Agliz, D. Zonta and A. Atmani, A fuzzy expert system for automatic seismic signal classification, Expert Systems with Applications, 2015, Feb. 15; 42(3):1013-27.

[8]   C. Hettiarachchi, H. Do and B. Choi, Risk-based test case prioritization using a fuzzy expert system, Information and Software Technology, 2016, Jan. 31; 69:1-5.

[9]   M. R. Katigari, H. Ayatollahi, M. Malek and M. K. Haghighi, Fuzzy expert system for diagnosing diabetic neuropathy, World Journal of Diabetes 2017, Feb. 15; 8(2): 80.

[10]   A. Bhatia, S. Srivastava and A. Agarwal, Face detection using fuzzy logic and skin color segmentation in images, In 2010 3rd International Conference on Emerging Trends in Engineering and Technology 2010 Nov 19 (pp. 225-228). IEEE.

[11]   S. L. Bhagavathi and S. T. Niba, An automatic system for detecting and counting rbc and wbc using fuzzy logic, ARPN Journal of Engineering and Applied Sciences, 2016; 11(11):6891-4.

[12]   H. Pragalath, S. Seshathiri, H. Rathod, B. Esakki and R. Gupta, Deterioration Assessment of Infrastructure Using Fuzzy Logic and Image Processing Algorithm, Journal of Performance of Constructed Facilities, 2018 Feb 2;32 (2): 04018009.

[13] J. G. Wang, S. C. Tai and C. J. Lin, The application of an interactively recurrent self-evolving fuzzy CMAC classifier on face detection in color images, Neural Computing and Applications, 2018 Mar 1;29(6): 201-13.

[14] https://sci2s.ugr.es/fss#FSS%20for%20Specific%20Application%20Purposes%20-%20Solving%20Specific%20Problems%20of%20Image%20Processing [Accessed on 15th March 2019].

[15] H. Omrane, M. S. Masmoudi and M. Masmoudi, Fuzzy logic based control for autonomous mobile robot navigation, Computational Intelligence and Neuroscience, 2016; 2016.

[16] M. A. Akmal, N. F. Jamin and N. A. Ghani, Fuzzy logic controller for two wheeled EV3 LEGO robot, In Systems, Process and Control (ICSPC), 2017 IEEE Conference on 2017 Dec 15 (pp. 134-139). IEEE.

[17] A. T. Azar, H. H. Ammar and H. Mliki, Fuzzy Logic Controller ith Color Vision System Tracking for Mobile Manipulator Robot, In International Conference on Advanced Machine Learning Technologies and Applications 2018 Feb. 22 (pp. 138-146). Springer, Cham.

[18] C. H. Chen, C. C. Wang, Y. T. Wang and P. T. Wang, Fuzzy Logic Controller Design for Intelligent Robots, Mathematical Problems in Engineering, 2017.

[19] M. Mazlum and A. F. Güneri, CPM, PERT and project management with fuzzy logic technique and implementation on a business, Procedia-Social and Behavioral Sciences, 2015 Dec 2; 210: 348-57.

[20] Y. E. Hawas and M. T. Al-Nahyan, A Fuzzy-Based Approach to Estimate Management Processes Risks, In The Application of Fuzzy Logic for Managerial Decision Making Processes 2017 (pp. 73-84). Springer, Cham.

[21] K. L. Choy, K. Y. Siu, T. S. Ho, C. H. Wu, H. Y. Lam, V. Tang and Y. P. Tsang, An intelligent case-based knowledge management system for quality improvement in nursing homes, VINE Journal of Information and Knowledge Management Systems, 2018 Feb 12;48(1):103-21.

[22] B. Hernández-Vera, A. A. Aguilar Lasserre, M. Gastón Cedillo-Campos, L. E. Herrera-Franco and J. Ochoa-Robles, Expert System Based on Fuzzy Logic to Define the Production Process in the Coffee Industry, Journal of Food Process Engineering, 2017 Apr; 40(2):e 12389.

[23] M. Heidari and H. Khodadadi, Climate control of an agricultural greenhouse by using fuzzy logic self-tuning PID approach, In Automation and Computing (ICAC), 2017 23rd International Conference on 2017 Sep 7 (pp. 1-6). IEEE.

[24] J. W. Jang, H. Heo, J. W. Bang, H. G. Hong, R. A. Naqvi, P. H. Nguyen, D. T. Nguyen, M. B. Lee and K. R. Park, Fuzzy-based estimation of continuous Z-distances and discrete directions of home appliances for NIR camera-based gaze tracking system, Multimedia Tools and Applications, 2018 May 1:1-31.

[25] D. Deliktas and O. Ustun, Student selection and assignment methodology based on fuzzy MULTIMOORA and multichoice goal programming, International Transactions in

Operational Research, 2017, Sep. 24(5): 1173-95.

[26] H. Al-Samarraie, B. K. Teng, A. I. Alzahrani and N. Alalwan, *E*-learning continuance satisfaction in higher education: a unified perspective from instructors and students, Studies in Higher Education, 2018 Nov 2; 43(11): 2003-19.

[27] N. S. Pazil, N. Mahmud, S. H. Jamaluddin, U. H. Mazlan and A. A. Rahman, The Evaluation of Performance and Quality of Preschool Using Fuzzy Logic Approach, In Proceedings of the Second International Conference on the Future of ASEAN (ICoFA) 2017–Volume 2 2018 (pp. 101-111). Springer, Singapore.

[28] J. Dovydaitis, R. Jasinevicius, V. Petrauskas and A. Vrubliauskas, Training, retraining, and self-training procedures for the fuzzy logic-based intellectualization of IoT&S environments, International Journal of Fuzzy Systems, 2015 Jun 1;17 (2): 133-43.

[29] M. Collotta and G. Pau, An innovative approach for forecasting of energy requirements to improve a smart home management system based on BLE, IEEE Transactions on Green Communications and Networking, 2017 Mar; 1(1): 112-20.

[30] https://www.courts.com.sg/philips-hd3038-fuzzy-logic-rice-cooker-1-8l-ip061943 [Accessed on 17th March 2019]

[31] B. M. Gayathri and C. P. Sumathi, Mamdani fuzzy inference system for breast cancer risk detection, In 2015 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC) 2015 Dec 10 (pp. 1-6). IEEE.

[32] N. Chanamool and T. Naenna, Fuzzy FMEA application to improve decision-making process in an emergency department, Applied Soft Computing, 2016 Jun 1; 43: 441-53.

[33] A, Singh and A. Prasher, Measuring healthcare service quality from patients' perspective: using Fuzzy AHP application, Total Quality Management & Business Excellence. 2017 Mar 10:1-7.

[34] A. Soltani, T. Battikh, I. Jabri and N. Lakhoua, A new expert system based on fuzzy logic and image processing algorithms for early glaucoma diagnosis, Biomedical Signal Processing and Control, 2018 Feb 1;40:366-77.

[35] Ahlawat, Deepak & Chawla, Rshma. (2015). software development effort estimation using fuzzy logic framework : An implementation. Ijacte, ird India. 4. 15-21.

[36] H. B. Yadav and D. K. Yadav, Early software reliability analysis using reliability relevant software metrics, International Journal of System Assurance Engineering and Management, 2017, Dec. 1; 8(4): 2097-2108.

[37] M. Y. Hsieh, Y. C. Hsu and C. T. Lin, Risk assessment in new software development projects at the front end: a fuzzy logic approach, Journal of Ambient Intelligence and Humanized Computing, 2018 Apr 1;9(2): 295-305.

[38] G. Kłosowski, A. Gola and A. Świć, Application of fuzzy logic in assigning workers to production tasks, In Distributed Computing and Artificial Intelligence, 13th International Conference 2016 (pp. 505-513). Springer, Cham.