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Research paper

Fuzzy Ponics: a Fuzzy Based System to Control Temperature, Relative Humidity, Electrical Conductivity and PH of Hydroponics

Armie E. Pakzad[1]*, Abbas Ali Pakzad[2]

[1]*Electronics and Communications Engineering Dept., De La Salle University Manila, Philippines*
[2]*School of Computer Studies, Arellano University Jose Abad Santos Campus, Pasay City, Philippines*
**Corresponding author E-mail: armie.pakzad@dlsu.edu.ph*

Abstract

Hydroponics is a process in which plants grow in a nutrient solution instead of soil. It is a controlled environment agriculture (CEA), which needs intensive controlling of the greenhouse environmental condition such as temperature and relative humidity (RH) along with electrical conductivity (EC) and pH of nutrient solution. A successful Hydroponics System (HS) depends on the way the greenhouse is maintained in terms of the environmental condition and the plant's nutrient uptake. This paper presents FuzzyPonics, a system which focuses on the application of fuzzy logic algorithm to automatically control the temperature and RH of the greenhouse, alongside EC and pH of the nutrient solution. The identified input parameters were classified accordingly, relative to predefined linguistic outputs and solutions. Sugeno-style of Fuzzy Inference System (FIS) and triangular membership functions were used. The results were simulated using the rule viewer of Matlab Fuzzy Logic Toolbox for six FIS and the proponents were able to get favorable results, which only showed that a fuzzy logic controller is a powerful tool to control the environmental condition and the nutrient solution's pH and EC of a hydroponics system.

Keywords: *Controlled Environment Hydroponics; Electrical Conductivity and pH; Fuzzy Logic; Hydroponics Temperature; Relative Humidity.*

1. Introduction

A number of researches in developing automated systems for agricultural application have been done. One of the well-liked topics in research related to agriculture is the development of automated soilless farming system. Hydroponics system (HS) or the so called soilless culture (SC) which allows crops to grow in a nutrient solution, earned its popularity for decades [6] due to its flexibility on growing wide variety of crops especially in a controlled environment [10], [8]. Since HS is considered as controlled environment agriculture (CEA), it is very important to maintain the environmental condition as well as the nutrients taken by the plants. With this, an automatic system that will monitor and control the foregoing parameters should be considered. Different approaches have been proposed for making an automated HS [1], [2], [4], [5], [6], [7], [9], [10]. Fuzzy logic is one of the advanced algorithms which has been applied in some papers [2], [6]. However, some authors' concentrated on the adjustment of pH and EC of the nutrient solution only [1], [2], [4], [5], [6] while others focused on controlling humidity and temperature [7]. This paper presents FuzzyPonics, a fuzzy logic design that will monitor and adjust the four important parameters in controlled environment Hydroponics namely, temperature, RH, pH and EC.

2. Literature review

This section presents concepts on hydroponics and the significant researches related to this study.

2.1. Hydroponics

HS is a process in which plants grow in a nutrient solution [1], [2]. Some growers use media which includes perlite, vermiculate, brick shards and wood fiber. Several techniques can be used to implement this practice such as EBB and Flow, Nutrient Film Technique (NFT) and Dynamic Root Flowing Technique (DRFT) to name a few [6], [2], [1]. In HS, plants grow faster because nutrients are delivered directly to the roots of the plants, thus promoting higher productivity in a short span of time [4], [5]. Compared to soil gardening, HS has less water consumption and plants are grown in a sterile environment, hence there is a lower chance of contamination. Moreover, it requires less space for growing and seasonal crops can be produced all year round [7].

2.2. Controlled environment agriculture

HS is a CEA where temperature and humidity are one of the primary factors to be considered for a successful crop production [9]. Different types of plants require diverse temperature and relative humidity ranges. Warm season crops like tomatoes, peppers, eggplants, beans, squash, melons and herbs grow best in the ideal range of 70°F - 80°F during daytime and 60°F - 70°F at night time. Cool season crops like broccoli, cabbage, lettuces, endive, peas, spinach, green onions, on the other hand can have optimum growth in 60°F - 70°F day temperature and 50°F - 60°F at night [3]. The use of oscillating fans and lighting equipment aids in the adjustment of the temperature whenever it falls out of the ideal range. Relative humidity (RH) is also an important aspect that should be controlled, if not, it can cause diseases that will affect the plant's development. A light cycle RH of 50% - 60% and a dark cycle RH of 60% - 70% are required for optimum plant growth [11]. The installation of humidifier and dehumidifier is a worthy solution to adjust RH of the garden.

2.3. Hydroponics nutrient solution

HS uses a formulated nutrient mix added to water to fertilize plants. It is a mixture of water and six basic elements: Nitrogen, Potassium, Sulphur, Phosphorus, Calcium and Magnesium [4], [5]. This solution is contained in a reservoir and delivered directly to the roots of plants with the use of a pump. The plant growth depends primarily on the concentration of the nutrient solution distributed to the crops on a specified time interval or schedule. The solution's pH and electrical conductivity are very significant in the success of crop production [1]. The nutrient solution's pH describes how acidic or basic a solution can be and determines how plants and other organisms interact with different nutrients. It can be measured using a pH meter. For most plants grown hydroponically, the ideal pH is 5.5 - 6.5. However, different ranges vary on the type of plants to be grown. EC or conductivity factor (CF) on the other hand, indicates the salinity of a nutrient solution that is the ratio of total nutrients to the amount of water. Consistent monitoring of EC is vital in HS so that it can be regularly adjusted to a suitable range. The plants nutrient uptake affects the value of EC hence, making it lower. It can be adjusted by adding nutrients to the solution. On the contrary, when there is too little amount of water in the solution due to evaporation, EC increases, thus adding the right amount water to the solution will adjust it to the appropriate level. Then again, adjusting the pH and EC of the nutrient solution is not an easy task and requires skill to meet the proper requirements of the said parameters. Exact values must be used in order to fine-tune the solution. [4], [5].

2.4. Related researches

Several researches have been conducted about hydroponics. The following are some of the most recent and significant to this study.
Reference [1] developed an arduino – based system which utilized the NFT prototype. The system used a proximity sensor as a water level detector, total dissolved solids (TDS) sensor to monitor the EC of the nutrient solution and a servo motor that aids in automatic water delivery when the water level drops to the minimum level. It also automatically added nutrients when the solution concentration is below 800 parts per million (ppm).
Reference [2] used fuzzy logic to control the electrical conductivity and pH of the hydroponic system. The experiment was conducted using a DRFT technique. The experiment used a nutrient solution control system which was composed of four part controls

- Solution 1 that drain alkaline (pH up) to increase pH
- Solution 2 that drain acid (pH down) to decrease pH
- Solution 3 that drain Stock A to increase EC
- Solution 4 that drain Stock B to increase EC

EC and pH sensors were used to monitor EC and pH levels integrated to the system which helped in the adjustment of these two parameters to achieve the desired range. Fuzzy logic method was used to determine which solution would be added to adjust the two parameters. However, temperature and relative humidity controls were not taken into consideration in this study. Successful crop production using HS must include these parameters.
Reference [4] introduced an arduino-based system for adjusting pH and EC by using linear regression. EC and pH measurement tools were used to monitor EC and pH levels respectively. The system computed the required amount of solutions to be added in order to reach the ideal levels of EC and pH.
Reference [6] presented a fuzzy inference system (FIS) grading unit and a genetic algorithm technique that uses this FIS grading technique to control the hydroponics nutrient solution. A virtual HS setup was developed in LabView with a nutrient solution monitoring unit. The experiment was only limited to pH and EC controls and did not include the environment control.
Reference [7] worked on a sensor-based automatic control mobile application for HS. The system used temperature, humidity and light intensity sensors to monitor and control the HS environment. The application also included functions for planning, managing and harvest data recording.

2.5. Lacking in the approaches

A successful crop production in HS needs intensive monitoring and controlling of four parameters such as temperature, RH, pH and EC. As mentioned in section B of the literature review, warm and cool season crops have different temperature and RH requirements. Also, daytime and night time temperature and RH should be maintained. None of the preceding studies considered all these parameters. Researches [1], [2], [4], [5], [6] were limited to the adjustment of EC and pH of the nutrient solution, while [7] was aimed at controlling temperature and RH only for a particular crop. This paper focused on controlling the four important parameters for an effective HS namely, temperature, RH, for both warm and cool season crops and the nutrient solution's pH and EC. It also included light and dark cycle environmental assessment for both warm and cool season crops.

3. Methodology

This section presents the design considerations which include the hierarchical structure of the hydroponics control system, environmental conditional assessments and the simulation results of FuzzyPonics.

3.1. Design Consideration

This section presents the six fuzzy inference systems designed and created by the proponents for hydroponics control system. The model presented was based from identified experts and standards. The proponents made use of triangular membership function for input parameters and singleton for output membership function. Fig. 1 to 3 illustrate the input parameters considered for each Fuzzy Inference System (FIS) and its corresponding outputs with respect to pre-defined linguistic classifications.

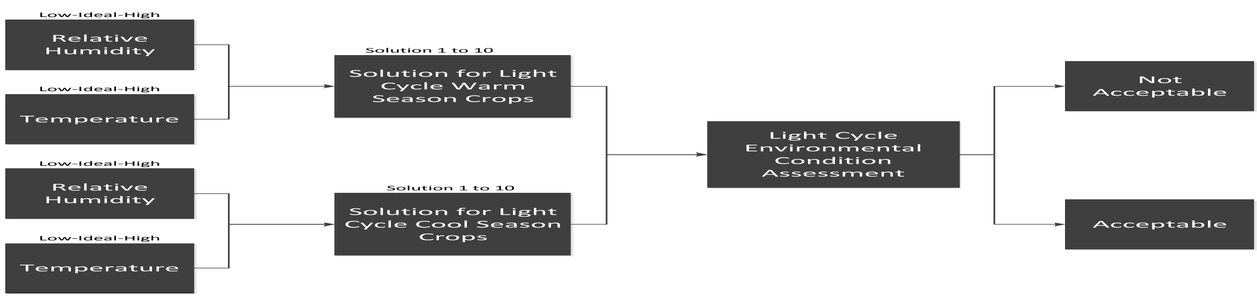

Fig. 1: Hierarchical structure of hydroponics control system for the relative humidity and temperature for light cycle warm and cool season crops.

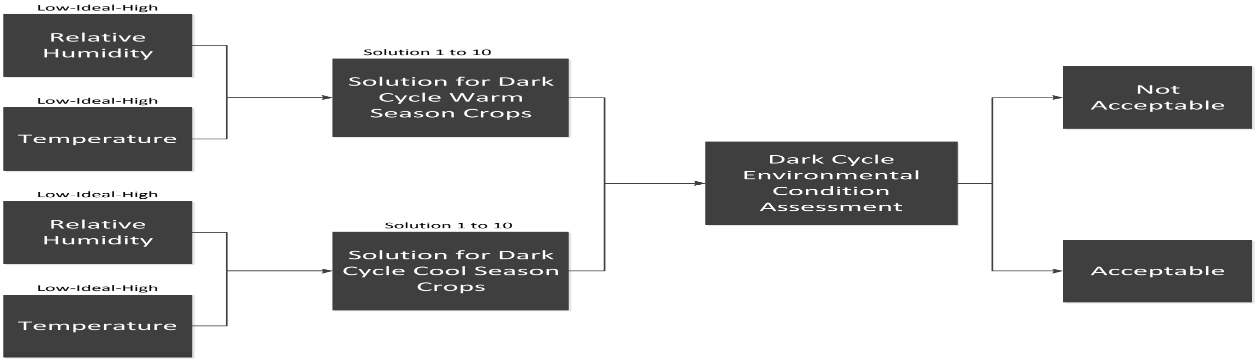

Fig. 2: Hierarchical structure of hydroponics control system for the relative humidity and temperature for dark cycle warm and cool season crops.

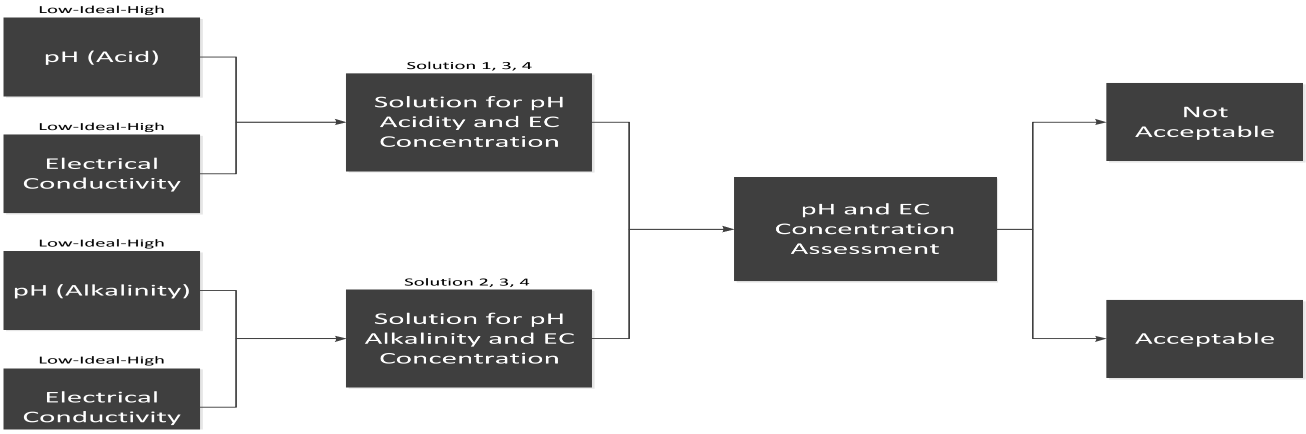

Fig. 3: Hierarchical structure of hydroponics control system for the pH and electrical conductivity of the nutrient solution.

3.1.1. Light cycle environmental condition assessment

There are two identified input parameters for light cycle environmental assessment for warm season crops namely: Relative Humidity and Temperature. The values for triangular membership functions for "Relative Humidity" with respect to its linguistic classifications are: [44 44.5 49] for low; [50 55 60] for ideal and [61 65.5 70] for high respectively. While, the values for triangular membership functions for "Temperature" with respect to its linguistic classifications are: [60 64.5 69] for low; [70 75 80] for ideal and [81 85.5 90] for high respectively. On the other hand, for cool season crops, the values for triangular membership functions are: [40 49.5 59] for low; [60 65 70] for ideal and [71 75.5 80] for high respectively. Table 1 shows the 9 fuzzy rules generated for two input parameters with three identified classifications. In obtaining the consequent, the proponents based their decision making from previous researches and pre-defined standards. The output parameters are classified into ten solutions: Solution 1 Humidifer ON, Solution 2 Humidifer OFF, Solution 3 Demudifier ON, Solution 4 Demudifier OFF, Solution 5 Lighting equipment ON, Solution 6 Lighting equipment OFF, Solution 7 Oscillating fan ON, Solution 8 Oscillating fan OFF, Solution 9 Cooling System ON and Solution 10 Cooling System OFF. The numerical values were used for presenting the output membership function using singleton/spike.

Table 1: Fuzzy Associative Memory (FAM) Matrix for Light Cycle Environmental Condition

SN	Weights	Relative Humidity	Temperature	Solution (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
1	w1	low	High	1, 0, 0, 0, 0, 0, 0, 0, 1, 0
2	w2	low	Low	1, 0, 0, 0, 1, 0, 1, 0, 0, 0
3	w3	low	Ideal	1, 0, 0, 0, 0, 1, 0, 1, 0, 1
4	w4	Ideal	High	0, 1, 0, 1, 0, 0, 0, 0, 1, 0
5	w5	Ideal	Low	0, 1, 0, 1, 1, 0, 1, 0, 0, 0
6	w6	ideal	Ideal	0, 1, 0, 1, 0, 1, 0, 1, 0, 1
7	w7	High	High	0, 0, 1, 0, 0, 0, 0, 0, 1, 0
8	w8	High	Low	0, 0, 1, 0, 1, 0, 1, 0, 0, 0
9	w9	high	Ideal	0, 0, 1, 0, 0, 1, 0, 1, 0, 1

3.1.2. Dark cycle environmental condition assessment

There are two identified input parameters for dark cycle environmental assessment for warm season crops namely: Relative Humidity and Temperature. The values for triangular membership functions for "Relative Humidity" with respect to its linguistic classifications are: [40 49.5 59] for low; [60 65 70] for ideal and [71 75.5 80] for high respectively. While, the values for triangular membership functions for "Temperature" with respect to its linguistic classifications are: [40 49.5 59] for low; [60 65 70] for ideal and [71 75.5 80] for high respectively. On the other hand, for cool season crops, the values for triangular membership functions are: [40 44.5 49] for low; [50 55 60] for ideal and [61 65.5 70] for high respectively. In obtaining the consequent, the proponents based their decision making from previous researches and pre-defined standards. The output parameters are classified into ten solutions similar to light cycle environmental condition assessment as elicited in Table 1.

3.1.3. pH Acidity and electrical conductivity assessment

There are two identified input parameters for pH Acidity and Electrical Conductivity assessment namely: pH and Electrical Conductivity. The values for triangular membership functions for “pH” with respect to its linguistic classifications are: [0 2.45 4.9] for acid high; [5 5.2 5.4] for acid low and [5.5 6 6.5] for ideal respectively. While, the values for triangular membership functions for “Electrical Conductivity” with respect to its linguistic classifications are: [0 0.895 1.79] for low; [1.8 1.85 1.9] for ideal and [1.91 1.955 2] for high respectively. Table 2 shows the 9 fuzzy rules generated for two input parameters with three identified classifications. The output parameters are classified into four solutions: Solution 1 drain alkaline (pH up) to increase pH, Solution 2 drain acid (pH down) to decrease pH, Solution 3 drain Stock A to increase EC and Solution 4 to drain Stock B in order to increase EC.

Table 2: Fuzzy Associative Memory (FAM) Matrix for pH Acidity and Electrical Conductivity

SN	Weights	pH (Acid)	EC	Solution (1, 3, 4)
1	w1	Acid High	High	1/ON, 3/OFF, 4/OFF
2	w2	Acid High	Low	1/ON, 3/ON, 4/ON
3	w3	Acid High	Ideal	1/ON, 3/OFF, 4/OFF
4	w4	Acid High	High	1/OFF, 3/OFF, 4/OFF
5	w5	Acid High	Low	1/OFF, 3/ON, 4/ON
6	w6	Acid High	Ideal	1/OFF, 3/OFF, 4/OFF
7	w7	Ideal	High	1/OFF, 3/OFF, 4/OFF
8	w8	Ideal	Low	1/OFF, 3/ON, 4/ON
9	w9	Ideal	Ideal	1/OFF, 3/OFF, 4/OFF

3.1.4. pH Acidity and electrical conductivity assessment

There are two identified input parameters for pH Alkalinity and Electrical Conductivity assessment namely: pH and Electrical Conductivity. The values for triangular membership functions for “pH” with respect to its linguistic classifications are: [5.5 6 6.5] for ideal; [6.6 7.55 8.5] for alkaline low and [8.6 11.3 14] for alkaline high respectively. While, the values for triangular membership functions for “Electrical Conductivity” are the same with that of number 3. Table 3 shows the 9 fuzzy rules generated for two input parameters with three identified classifications. The output parameters are classified into four solutions similar to pH acidity and electrical conductivity assessment as elicited in Table 2.

Table 3: Fuzzy Associative Memory (FAM) Matrix for pH Alkalinity and Electrical Conductivity

SN	Weights	pH (Alkaline)	EC	Solution (2, 3, 4)
1	w1	High	High	2/ON, 3/OFF, 4/OFF
2	w2	High	Low	2/ON, 3/ON, 4/ON
3	w3	High	Ideal	2/OFF, 3/OFF, 4/OFF
4	w4	Low	High	2/OFF, 3/OFF, 4/OFF
5	w5	Low	Low	2/OFF, 3/ON, 4/ON
6	w6	Low	Ideal	2/OFF, 3/OFF, 4/OFF
7	w7	Ideal	High	2/OFF, 3/OFF, 4/OFF
8	w8	Ideal	Low	2/OFF, 3/ON, 4/ON
9	w9	Ideal	Ideal	2/OFF, 3/OFF, 4/OFF

3.2. Simulation results

The six FISs were simulated using rule viewer of Matlab Fuzzy Logic Toolbox. The proponents tested the results using random selection of weights from pre-defined fuzzy rules. Random values were tested and crisp output was obtained and compared with set rules. As observed, the output obtained using rule viewer is consistent with FAM matrix for each inference system. It is confident to say that the proponents were able to get accurate simulation results, refer to Tables 4 to 9.

Table 4: Simulation Results for Light Cycle Environmental Assessment (Warm Season Crops)

Trials	Light Cycle (Warm Season Crops)	Input Values	Crisp Output (Matlab Fuzzy Logic Toolbox)	Solution
1	Relative Humidity	41	2	SOL 2
	Temperature	61		
2	Relative Humidity	48	2	SOL 2
	Temperature	65		
3	Relative Humidity	53	6	SOL 6
	Temperature	71		
4	Relative Humidity	62	7	SOL 7
	Temperature	83		
5	Relative Humidity	68	7	SOL 7
	Temperature	89		

Table 5: Simulation Results for Light Cycle Environmental Assessment (Cool Season Crops)

Trials	Light Cycle (Cool Season Crops)	Input Values	Crisp Output (Matlab Fuzzy Logic Toolbox)	Solution
1	Relative Humidity	41	2	SOL 2
	Temperature	41		
2	Relative Humidity	48	2	SOL 2
	Temperature	58		
3	Relative Humidity	53	6	SOL 6
	Temperature	66		
4	Relative Humidity	62	7	SOL 7
	Temperature	72		
5	Relative Humidity	68	7	SOL 7
	Temperature	79		

Table 6: Simulation Results for Dark Cycle Environmental Assessment (Warm Season Crops)

Trials	Dark Cycle (Warm Season Crops)	Input Values	Crisp Output (Matlab Fuzzy Logic Toolbox)	Solution
1	Relative Humidity	42	2	SOL 2
	Temperature	43		
2	Relative Humidity	57	2	SOL 2
	Temperature	57		
3	Relative Humidity	69	6	SOL 6
	Temperature	67		
4	Relative Humidity	72	7	SOL 7
	Temperature	74		
5	Relative Humidity	79	7	SOL 7
	Temperature	79		

Table 7: Simulation Results for Dark Cycle Environmental Assessment (Cool Season Crops)

Trials	Dark Cycle (Cool Season Crops)	Input Values	Crisp Output (Matlab Fuzzy Logic Toolbox)	Solution
1	Relative Humidity	42	2	SOL 2
	Temperature	41		
2	Relative Humidity	57	2	SOL 2
	Temperature	48		
3	Relative Humidity	69	6	SOL 6
	Temperature	58		
4	Relative Humidity	72	7	SOL 7
	Temperature	62		
5	Relative Humidity	79	7	SOL 7
	Temperature	68		

Table 8: Simulation Results for pH Acidity and Electrical Conductivity Assessment

Trials	Planting Factors	Input Values	Crisp Output (Matlab Fuzzy Logic Toolbox)	Solution
1	pH (Acid)	1.3	2	SOL 2
	Electrical Conductivity	0.5		

2	pH (Acid)	3.44	2	SOL 2
	Electrical Conductivity	1.5		
3	pH (Acid)	5.2	6	SOL 6
	Electrical Conductivity	1.82		
4	pH (Acid)	5.3	7	SOL 7
	Electrical Conductivity	1.92		
5	pH (Acid)	5.7	7	SOL 7
	Electrical Conductivity	1.98		

Table 9: Simulation Results for pH Alkalinity and Electrical Conductivity Assessment

Trials	Planting Factors	Input Values	Crisp Output (Matlab Fuzzy Logic Toolbox)	Solution
1	pH (Alkaline)	6.8	2	SOL 2
	Electrical Conductivity	0.5		
2	pH (Alkaline)	8.3	2	SOL 2
	Electrical Conductivity	1.5		
3	pH (Alkaline)	6.3	6	SOL 6
	Electrical Conductivity	1.82		
4	pH (Alkaline)	8.8	7	SOL 7
	Electrical Conductivity	1.92		
5	pH (Alkaline)	13.4	7	SOL 7
	Electrical Conductivity	1.98		

4. Conclusion

In this work, the proponents created six Sugeno-style fuzzy inference systems for light and dark cycle environmental condition assessments for warm and cool season crops, and pH and Electrical Conductivity concentration assessments using triangular and Singleton input and output membership functions respectively. The parameters considered for light and dark cycle environmental condition assessments are Relative Humidity and Temperature, the input membership functions were classified in three linguistic terms. There were 9 fuzzy rules to assess the environmental condition into 10 defined solutions. Ergo, the parameters considered for planting factors are pH and electrical conductivity, the input membership functions were classified using [2]. Similarly, there were 9 fuzzy rules generated to assess into three solutions. The results were simulated using the rule viewer of Matlab Fuzzy Logic Toolbox for three FIS and the proponents were able to get favorable results. The proponents suggest simulation in actual prototype set-up using any high-level programming language for faster and convenient analysis.

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