FUZZY LOGIC SIMULATION USING SUGENO-STYLE FOR SCHOOL DIMMING LIGHTING SYSTEM

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ABSTRACT

This study involves the fuzzy logic concept for designing an automatic dimming system. The input parameters of the study will be the luminance of the environment and the room illumination needed for a specified area. The output of the system will be the variable lux, which will be compared from the given input. Input parameters will be categorized as VD (Very Dark), D (Dark), F (Fair), B (Bright), and VB (Very Bright). The output parameters, on the other hand, are to be classified as VL (Very Low), L (Low), M (Moderate), H (High) and VH (Very High). The luminance of the environment will be acquired by using a light sensing circuit. The standard of illumination will be based on IIEE standards. The study uses Sugeno-style of fuzzy inference system and triangular membership functions. The study is purely simulation using MATLAB Fuzzy Logic toolbox and Fuzzylite. The goals of the study are to describe the fuzziness of the dimming lighting system, to provide a fuzzy logic design, and to simulate and to compare the results using two simulations.

Keywords: *diming lighting system; fuzzy logic; Fuzzylite; Matlab Fuzzy Logic toolbox; Sugeno-style.*

INTRODUCTION

Dimming Lighting System

In previous years, men are satisfied with just manually operating lighting fixtures as "ON and OFF", but with the help of technology advancement it is now capable of dimming itself by means of programming, sensors and automation. Automation has been achieved by various means including mechanical, hydraulic, pneumatic, electrical, electronic, and they are usually in combination used to simplify our day to day activity [1].

Dimming lighting systems are not used often due to its higher initial costs [2]. A dimming lighting system provides convenience to its user and efficiency to the system by giving the correct amount of light needed. It also provides energy management control which reduces the energy consumption. According to [3], an efficient lighting control can save as much as 50% on existing buildings and 35% on the construction. This leads to the study of the proponents to emphasize the advantage of having a dimming lighting system.

Fuzzy Logic Algorithm

In problems that we encounter in our daily life, most of time the solutions cannot be answered by just simply "yes" or "no". There are uncertainties that cannot be solved using direct formulation. This is meant to be solved by the Fuzzy logic. The concept of Fuzzy logic was introduced by Professor LoftiZadeh, a professor of University of California. Professor Zadeh explained that people need systems that are capable of doing flexible control. He elaborated that if interference or noise can take part of membership degrees and utilized by the system, it will be more effective [4].

Fuzzy logic algorithms are used in many applications like dimming system, street light control, and in microcomputers [5] [6]. Fuzzy logic algorithm is easier to understand and calculates faster than the Proportional Integral Derivative (PID) systems [7]. In due course, the proponents decided to utilize fuzzy logic algorithm to design a dimming lighting system.

In this work, the procedure of lighting control system design was focused on fuzzy logic simulation where this process intended to have inputs to be fuzzified and defuzzified to produce crisp output. In this process, the last phase of Fuzzy Logic System operation is to defuzzify the fuzzy output sets by determining a value from membership function and compute for the crisp output using weighted average [7].

Objectives of the Study

Generally, the proponents aim to design and simulate a dimming system using a fuzzy algorithm that is capable of controlling the luminance of lighting fixtures based on the amount light present in a given area. Specifically, this research endeavors to:

- Design a fuzzy logic algorithm, which can be used as a basis for an automatic dimming system;
- Present the fuzzy logic rules derivation for the dimming lighting system;
- Develop a model for the variable output lux using MATLAB toolbox and Fuzzylite; and,
- Verify the performance of the system using the abovementioned simulations.

METHODOLOGY

Tools and Techniques

In this study, the proponents will use the Sugeno style of fuzzy inference system (FIS) technique in developing the system. Compared to Mamdani type FIS, Sugeno FIS is more computationally efficient and appealing in control systems, which requires flexibility and optimization. Sugeno FIS simplifies the deffuzification process. It makes use of the averaging technique to produce the crisp output as shown in Figure 2.1. Mamdani FIS is mostly used in decision support applications while Sugeno FIS is preferred in system design [8].

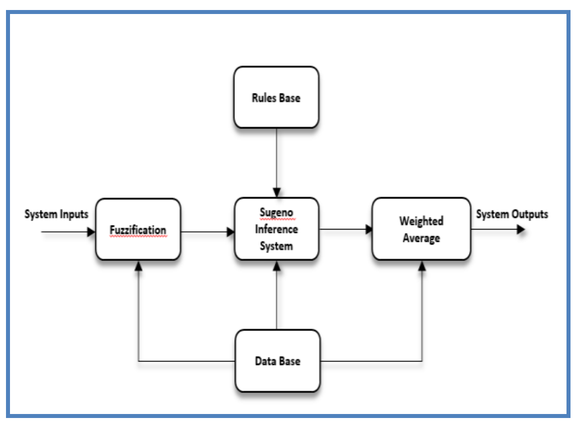

Figure 2.1 Fuzzy Logic Process

Figure 2.1 shows the fuzzy logic process in producing the crisp output. At first, the process requires system inputs from the user which will be fuzzified by the system to determine its linguistic classification. After the fuzzification process, the inputs will be evaluated using Sugeno FIS base on the given standards (Refer to Table 2.2). When the inputs are already evaluated, it will undergo defuzzification using weighted average to give the system outputs.

Based on Figure 2.1, the system inputs are needed for the system process. These are the following:

1. *Illuminance of the environment* – Environment light was considered for the reduction of light, which will be produce d by the system. The measurement of environment light is important so that we can harvest and utilize daylight that is most of the time present in a classroom.

2. *Area illumination* – To give the correct amount of light produced by the system, it is essential to determine the amount of light present in the area.

3. *Recommended level of illumination* – The proponents will based their standards on *IIEE-ELI Manual of practice on efficient lighting [9].* Diverse levels of illumination are required on different areas. The proponents subjected school areas for the research. The table shows the recommended illumination for the given areas.

Table 2.1 Recommended Output lux for School Vicinities

Area	Recommended lux output
Laboratories	750 lux
Lecture Rooms	750 lux
Library	750 lux
Drafting room	1600 lux
Gymnasium	540 lux

In constructing the membership functions for the necessary input and output parameters, the proponents defined the linguistic classification of inputs based on the levels of brightness as shown in Table 2.2.

Table 2.1 Levels of Input and Output Parameters

INPUTS	
CONDITIONS	**DESCRIPTION/DEFINITION**
Very Dark (VD)	State of an area when it have the smallest amount or close to zero lux present (0 lux - 299 lux)
Dark (D)	State of an area when it have small amount of lux present, but not close to zero (300 lux - 699 lux)
Fair (F)	State of an area when it have an enough lux present (700 lux - 800 lux)
Bright (B)	State of an area when it have high amount of lux present (801 lux - 1500 lux)
Very Bright (VB)	State of an area when it have very high amount of lux present (1501 and above lux)
OUTPUTS	
CONDITIONS	**DESCRIPTION/DEFINITION**
Very Low (VL)	The system will give a very low amount of lux (200 lux - 399 lux)
Low (L)	The system will give a very low amount of lux (400 lux - 699 lux)
Moderate (M)	The system will give a moderate amount of lux (700 lux - 800 lux)
High (H)	The system will give a high amount of lux (801 lux - 1500 lux)
Very High (VH)	The system will give a very high amount of lux (1501 and above lux)

Fuzzy Associative Memory (FAM) matrix was used to create the rules for the system. FAM is a good method in storing and representing fuzzy rules [10]. The output values of the FAM matrix are determined based on the membership functions set by the proponents with respect to its x and y coordinates. Considering that we have two input parameters and we have five classifications (shown in the hierarchical structure depicted in Figure 2.2), we will have 25 possible combinations. The following are samples of output values of the

FAM matrix with respect to its input parameters.

If *Environment Illumination* is <very bright> and *Area Illumination* is <very bright>

Then the output light will be<Very Low>

If *Environment Illumination* is <very dark> and *Area Illumination* is <very dark>

Then the output light will be<Very High>

If *Environment Illumination* is <fair> and *Area Illumination* is <bright>

Then the output light will be<Moderate>

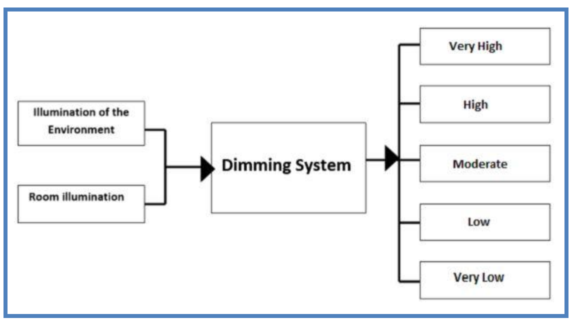

Figure 2.2 Hierarchical Structure of Dimming Lighting System

The Adaptive Neuro Fuzzy Inference System (ANFIS) approach was used to determine the fuzziness of the system. Since ANFIS is integrated in MATLAB, the proponents can easily do the simulation using the MATLAB fuzzy logic toolbox. To determine the viability of results, it will be compared with the data obtained using fuzzylite. Similar to commonly used Matlab Fuzzy Logic toolbox, fuzzylite is a fuzzy logic control library which can be used for fuzzy logic simulations [11]. Comparing the results of two different simulators will ensure that the fuzzy system provides reliable results.

RESEARCH DESIGN

Fuzzy Inference System (FIS)

FIS activates the FAM rules in generating fuzzy output. It maps the given inputs to its corresponding crisp output using defuzzification process. This mapping provides basis for decision-making. The input(s) and output(s) are modeled as membership functions (MFs). The environmental light, which can be obtained and detected by light sensors, will be used as input variable x (i.e. Illumination of the Environment) and y (i.e. Room Illumination). **Figure 3.1** and **Figure 3.2**depicts the input variables using triangular functions. The output variable (see Figure 3.3) is the linguistic classification of illumination that is needed by the room to reach the illumination standard. The fuzzy set of the output variable is inferred by max-min composition where the VH is the maximum output of illumination and the VL is the minimum. The fuzzy relation describes the desired control action. The fuzzy set of the output variable is defuzzified to deliver a crisp numerical value by the centroid-of-area method [11]. The proponents used Fuzzy Logic Matlab Toolbox and Fuzzy Lite in simulating the system shown in figures 3.1 to 3.5.

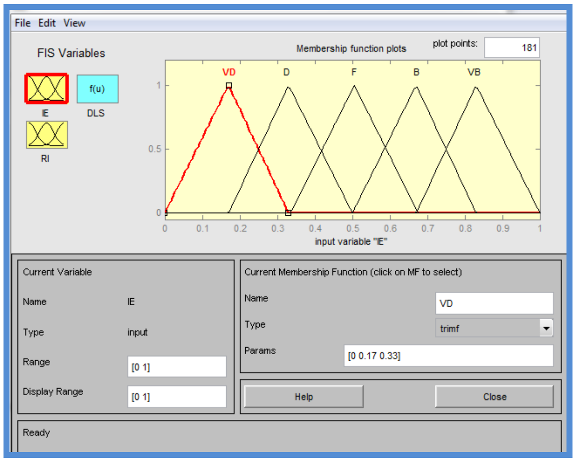

Figure 3.1: MF of Illumination of the Environment (IE)

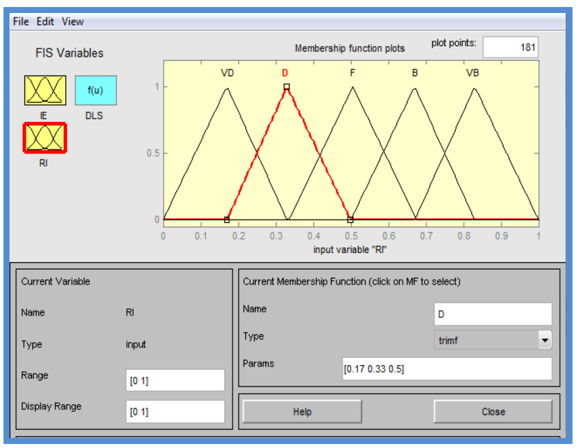

Figure 3.2: MF of Room Illumination (RI)

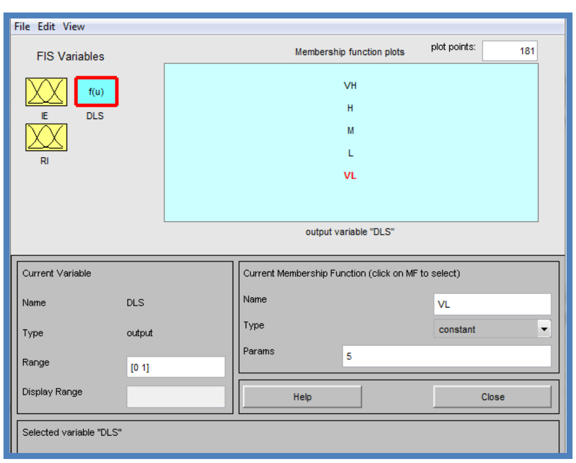

Figure 3.3: MF of Output Variable (Crisp Outputs) for dimming reference

Similar to Matlab Fuzzy Logic Toolbox, Fuzzy Lite was used for testing and comparison purposes. The input and output membership functions used in Matlab were also used in fuzzylite. Upon finishing the fuzzy model in fuzzylite, the proponents make use of the same inputs injected in Matlab, so as to check the reliability of the system. *Refer to* ***Figure 3.4*** *and* ***Figure 3.5*** *for this illustration.*

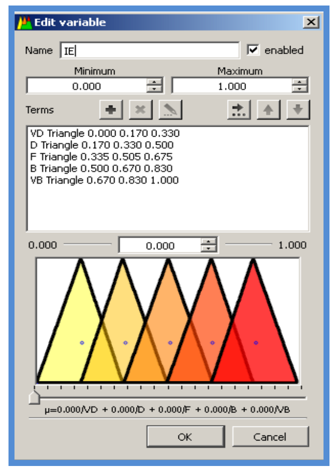

Figure 3.4 FuzzyLite Illumination of Environment

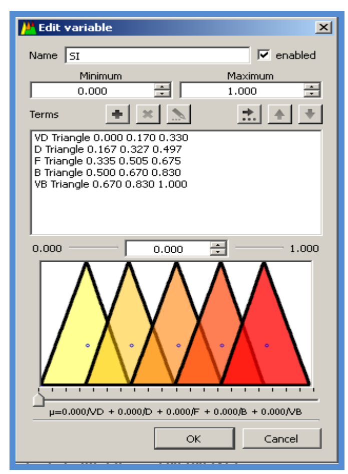

Figure 3.5 FuzzyLite Room Illumination (RI)

The proponents set the ranges of the output membership function (MF) in determining the light intensity needed by the room (shown in **Table 3.2**).

Table 3.2 Linguistic Classification of Membership Functions

Linguistic Classification	
Level	Range
Very High	4.41 to 5.00
High	3.91 to 4.40
Moderate	2.91 to 3.91
Low	1.91 to 2.90
Very Low	1.00 to 1.90

The fuzzy rule base consists of a collection of fuzzy IF-THEN rules. The proponents constructed rules stated as follows:

Rule 1: IF x(IE is VD) an y(SI is VD) then z(DLS) = VH

Rule 2: IF x(IE is VD) an y(SI is D) then z(DLS) = VH

Rule 3: IF x(IE is VD) an y(SI is F) then z(DLS) = H

Rule 4: IF x(IE is VD) an y(SI is B) then z(DLS) = H

Rule 5: IF x(IE is VD) an y(SI is VB) then z(DLS) = M

Rule 6……n

These rules tabulated in FAM matrix were realized in Matlab using Rule Editor as shown in Figure 3.6.

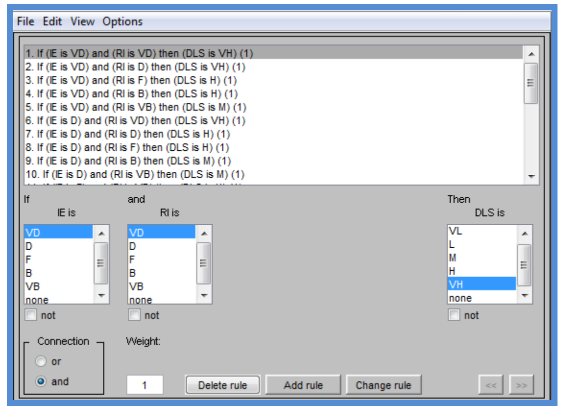

Figure 3.6 Matlab Fuzzy Logic Toolbox Ruling

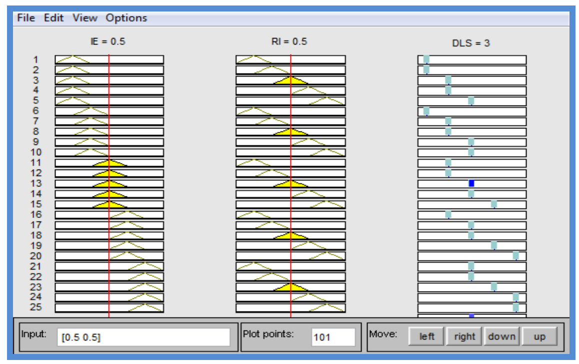

Figure 3.7 Matlab Fuzzy Logic Toolbox Simulation

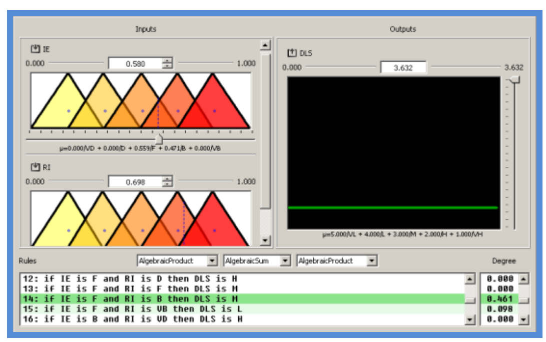

Figure 3.8 FuzzyLite Output Response and Linguistic Classification

The simulation in **Figure 3.8** shows that the results obtained using fuzzylite is likely equal to the results obtained using Fuzzy Logic Toolbox. The output linguistic class of fuzzyLite is the same with Matlab Fuzzy Logic, they both give Moderate (M) classification. The actual inputs are 1218 and 1047 and their given normalized inputs are .58 and .698 for Illumination of Environment (IE) and Room Illumination (RI) respectively. The bit difference of the two is that the fuzzylite gives a membership degree that is not exactly the same as what was obtained using Matlab fuzzy logic. These are just some of the inputs used for testing. *Refer to Section 4 for complete set of simulation results.*

The proponents make use of the variables x, y, and z for input 1, input 2, and output respectively. Output is represented by Linguistic classification Very High (VH), High (H), Moderate (M), Low (L) and Very Low (VL). Consequent pair of Linguistic Classification stated by the rules is tabulated to be the truth table for outputs. For instance, IF *x* is VL (1) and *y* is VL (1) THEN *z* is VH (5) (see Table 3.6).

Table 3.6: The Fuzzy Rules for the Dimming Lighting System

Count	Weights	Illumination of the Environment	Standard Room Illumation	Dimming Lighting System (Classified Value)	Dimming Lighting System (Linguistic Class)
0	w1	5	5	5.00	VL
1	w2	5	4	4.50	VL
2	w3	5	3	4.00	L
3	w4	5	2	3.50	M
4	w5	5	1	3.00	M
5	w6	4	5	4.50	VL
6	w7	4	4	4.00	L
7	w8	4	3	3.50	M
8	w9	4	2	3.00	M
9	w10	4	1	2.50	H
10	w11	3	5	4.00	L
11	w12	3	4	3.50	M
12	w13	3	3	3.00	M
13	w14	3	2	2.50	H
14	w15	3	1	2.00	H
15	w16	2	5	3.50	M
16	w17	2	4	3.00	M
17	w18	2	3	2.50	H
18	w19	2	2	2.00	H
19	w20	2	1	1.50	VH
20	w21	1	5	3.00	M
21	w22	1	4	2.50	H
22	w23	1	3	2.00	H
23	w24	1	2	1.50	VH
24	w25	1	1	1.00	VH

EXPERIMENTS, COMPARISON AND ANALYSIS OF RESULTS

In this study, the proponents conducted two different fuzzy logic simulations using Matlab Fuzzy Logic Toolbox and FuzzyLite for the dimming lighting system. The proponents conducted 20 trials to check the reliability of the two applications and determine their crisp outputs as shown in **Table 4.1.**

Table 4.1 Measure of Relationship between Matlab Fuzzy Logic ToolBox and FuzzyLite

Trials	Board Predictive Assessment Input Parameters		Input Values		Crisp Output (Matlab Fuzzy Logic Toolbox)	Crisp Output (Fuzzy Lite)	Linguistic Classification	True Error	% Relative Approximate Error
			lux	Normalized					
1	DLS	IE	483	0.23	1.84	1.842	Very High	0.002	0.108577633
		RI	684	0.456					
2	DLS	IE	655.2	0.312	2.35	2.355	High	0.005	0.212314225
		RI	855	0.57					
3	DLS	IE	1218	0.58	3.63	3.632	Moderate	0.002	0.055066079
		RI	1047	0.698					
4	DLS	IE	882	0.42	3.39	3.386	Moderate	0.004	0.118133491
		RI	1185	0.79					
5	DLS	IE	1386	0.66	2.91	2.914	Moderate	0.004	0.13726836
		RI	990	0.33					
6	DLS	IE	1050	0.5	3	3	Moderate	0	0
		RI	930	0.62					
7	DLS	IE	924	0.44	1.8	1.799	Very High	0.001	0.055586437
		RI	361.5	0.24					
8	DLS	IE	525	0.25	2.75	2.75	High	0	0
		RI	1125	0.75					
9	DLS	IE	1596	0.76	3.54	3.538	Moderate	0.002	0.056529112
		RI	735	0.49					
10	DLS	IE	1680	0.8	2.81	2.813	High	0.003	0.106647707
		RI	150	0.1					
11	DLS	IE	1575	0.75	4.97	4.969	Very Low	0.001	0.020124774
		RI	1230	0.82					
12	DLS	IE	1365	0.65	4.17	4.17	Low	0	0
		RI	1080	0.72					
13	DLS	IE	1428	0.68	3.58	3.577	Moderate	0.003	0.083869164
		RI	885	0.59					
14	DLS	IE	1995	0.95	5	5	Very Low	0	0
		RI	1050	0.7					
15	DLS	IE	273	0.13	1.7	1.71	Very High	0.01	0.584795322
		RI	675	0.45					
16	DLS	IE	714	0.34	1.39	1.405	Very High	0.015	1.067615658
		RI	345	0.23					
17	DLS	IE	525	0.25	1.85	1.855	Very High	0.005	0.269541779
		RI	675	0.45					
18	DLS	IE	1155	0.55	3.11	3.114	Moderate	0.004	0.128452152
		RI	855	0.57					
19	DLS	IE	1785	0.85	5	5	Very Low	0	0
		RI	1050	0.7					
20	DLS	IE	903	0.43	2.19	2.195	High	0.005	0.227790433
		RI	585	0.39					

The results obtained from Matlab fuzzy logic toolbox were compared with the results obtained from the FuzzyLite. The proponents computed the true error and the percent approximate error of crisp outputs for two metrologies. It was realized that the two output values were the same and the linguistic classifications were met, based from the specified range that was assigned by the proponents from Table 2.1. The 20 trials were conducted to cater five linguistic classifications and the highest true error obtained was **0.015**. It could be analyzed that the highest obtained true error (highlighted in red) is negligible; it still fits same "Very High" linguistic classification. In general, Matlab Fuzzy Logic Toolbox and FuzzyLite are correlated with each other in terms of the desired linguistic classification that can be used in dimming lighting system.

CONCLUSIONS

In this paper, the study showed that the fuzzy-based system for dimming lighting system is simple, reliable and effective. The novelty of this paper is the simulation and comparison of two handy fuzzy based programs. The obtained crisp outputs of two metrologies were compared to check the reliability of the system. The outputs were analogous with each other due to its similar rules and membership functions (constructed by the proponents). The results gathered by the proponents were credible and reliable, because regardless of the simulator used, the linguistic classifications will always be the same. The crisp outputs of the two simulators will only have bit or negligible difference.The paper presents a purely simulation model, which employs fuzzy logic for automatic classification of dimming lighting system. Both programs (Matlab fuzzy logic toolbox and Fuzzylite) provide accurate results that can be used on dimming lighting system. It could be concluded that both Matlab fuzzy logic toolbox and Fuzzylite can be used as an effective, handy and powerful tool to simulate fuzzy logic algorithms.

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