A Fuzzy Logic Controller Controls a Smart Lighting System for Energy Savings

電機3A 108601205 王佑恩

電機3A 109206532 王昱達

電機4A 108303517 張家豪

電機3A 109302025 盧欣靖

電機3A 109501510 林采玟

電機4A 108303526 劉亦修

TABLE OF CONTENTS

01

INTRODUCTION

INTRODUCTION

- ➢ From 2021 9th International Renewable and Sustainable Energy Conference
- ➢ Electric lighting consumes 20-40% of all electricity consumed in buildings
- ➢ Use fuzzy logic lighting control
- ➢ Reducing lighting energy consumption, and maintaining lighting comfort (Output)
- ➢ Taking into account the Daylight and the areas' real-time status

02
System Structure

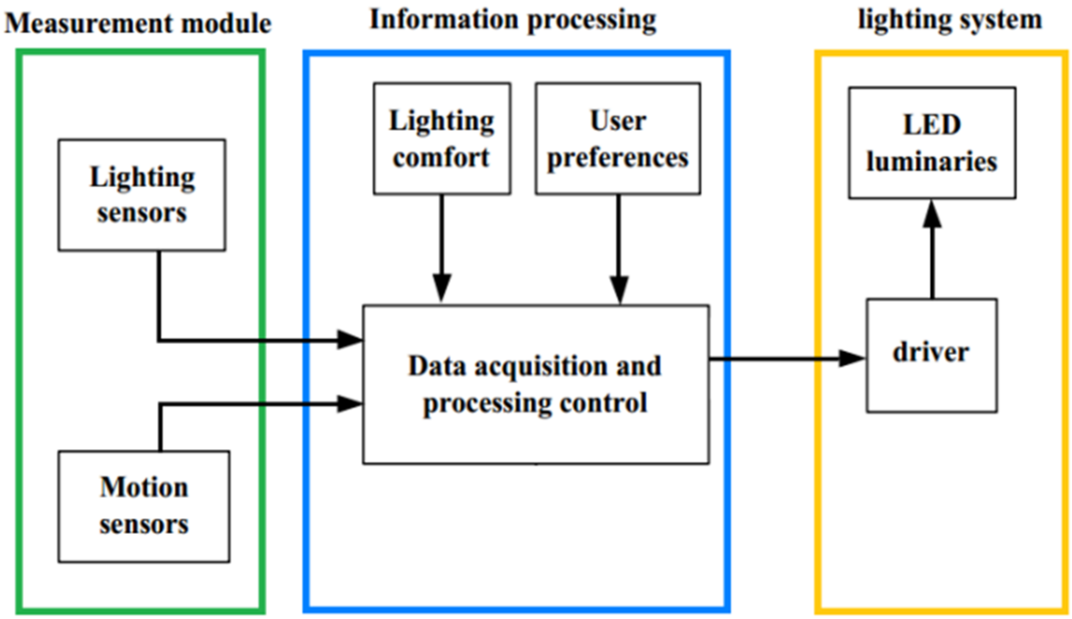


Figure 1. Lighting systems components

03

Goal Functions

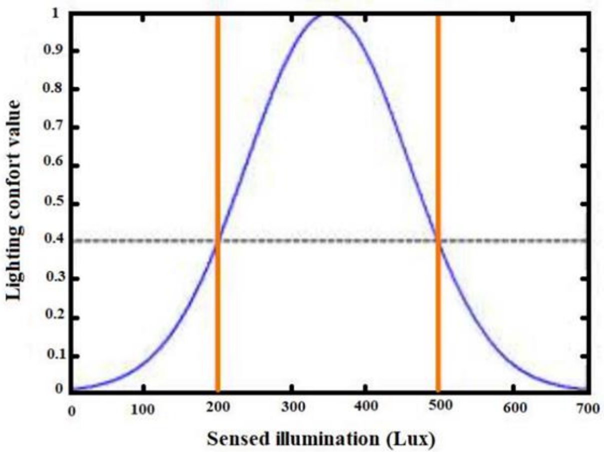


Figure 2. Lighting comfort level

1. Minimize Energy Consumption

$$\min E = \sum_{i=1}^{n} Dc_i \times P \times t$$

2. Maximize Comfort Value

$$\max Cf = \sum_{i=1}^{n} c_i$$

04

CONSTRAINTS

A. Constraints on Control

A. Lighting Comfort constraint

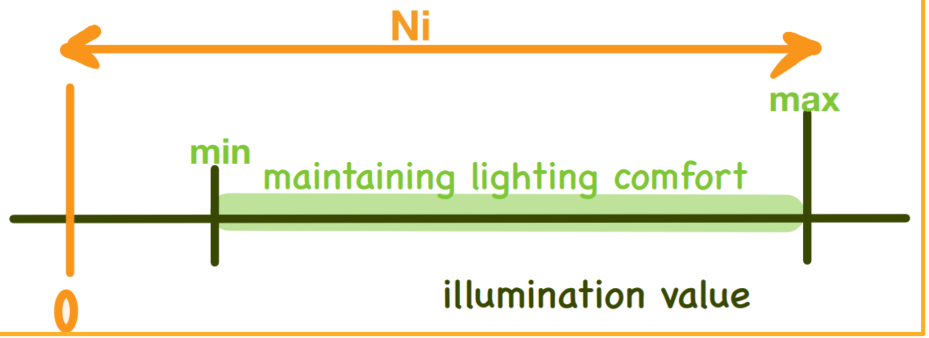
A. Constraints on Control

Daylight

- **Can not be controlled**, but can be measured.
- Can not provide adequate lighting values in the room.
- the lighting value is below the comfortable value. (based on Emax)

Illumination value：

$$0 \leq N_i \leq E_{\max}, \quad i = 1, \ldots, n$$



A. Constraints on Control

Illumination value

considering
- m (LED luminaries)
- n (room area)

$$L = X \times Dc + N$$

extending

$$\begin{bmatrix} L_1 \\ \cdot \\ \cdot \\ \cdot \\ L_n \end{bmatrix} = \begin{bmatrix} X_{11} & \cdot & \cdot & \cdot & X_{1m} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ X_{n1} & \cdot & \cdot & \cdot & X_{nm} \end{bmatrix} \times \begin{bmatrix} Dc_1 \\ \cdot \\ \cdot \\ \cdot \\ Dc_m \end{bmatrix} + \begin{bmatrix} N_1 \\ \cdot \\ \cdot \\ \cdot \\ N_n \end{bmatrix} = \begin{bmatrix} Le_1 \\ \cdot \\ \cdot \\ \cdot \\ Le_n \end{bmatrix} + \begin{bmatrix} N_1 \\ \cdot \\ \cdot \\ \cdot \\ N_n \end{bmatrix}$$

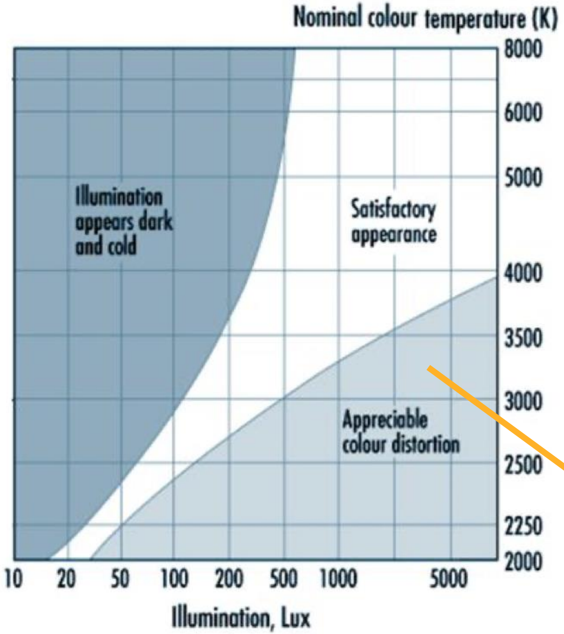
Total contribution of every luminaries in each room area n

\+

Contribution of daylight in each room area n

B. Lighting comfort constraint

Comfort diagram



Lighting comfort parameter

- ➢ Color temperature
- ➢ Illumination

*electric lamps

- ➢ Daylight white: 6000k
- ➢ Neutral white: 4000k
- ➢ Warm white: 3000k

Low level of illumination, low color temperature

B. Lighting comfort constraint

Lighting comfort constraints

$$\begin{cases} E_{\min} \le E_i \le E_{\max}, & i = 1, \dots, n \\ th \le c_i \le 1, & i = 1, \dots, m \end{cases}$$

room(1), room(2), ……, room(n)

lamp, candle, ……, light bulb
(total m luminaries)

*Consider lighting comfort

- E_{min} : lower limit of illumination
- E_{max} : upper limit of illumination
- E_i : total illumination value in room i
- th: least intensity of light visible to the eyes
- Ci: level of lighting comfort for user

B. Lighting comfort constraint

Main objectives

- ➢ To decrease energy usage
- ➢ To meet the lighting needs of the users

Objective functions(Take daylight into consideration)

$$\begin{cases} \min E = \sum_{i=1}^{n} Dc_i \times P \\ \max Cf = \sum_{i=1}^{m} c_i \end{cases}$$

E: overall energy consumption
n: rooms
DCi: duty cycle of all LEDs
P: luminary power consumption

Cf: lighting comfort
Ci: level of lighting comfort for the user
M: luminaries

B. Lighting comfort constraint

Objective functions

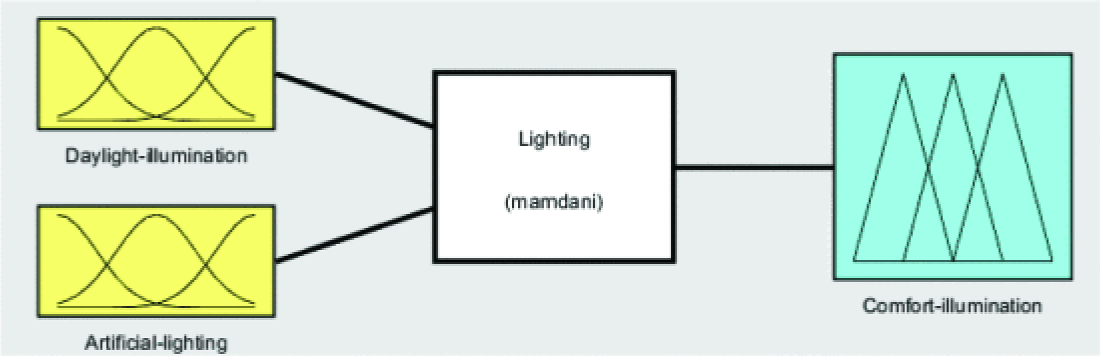
$$\begin{cases} \min E = \sum_{i=1}^{n} Dc_i \times P \\ \max Cf = \sum_{i=1}^{m} c_i \end{cases}$$

Minimize energy consumption

$$\begin{cases} \min E = \sum_{i=1}^{n} Dc_i \times P \\ E_{\min} \leq E_i \leq E_{\max}, \quad i = 1, \ldots, n \end{cases}$$

B. Lighting comfort constraint

Fuzzy Logic controller for the lighting system



- ➢ Resilient
- ➢ Easy to construct

Lighting comfort

- ➢ A subjective measure of user’s contentment
- ➢ Difficult to categorize accurately with boundaries

05

THE DESIGNED FUZZY LOGIC CONTROLLER

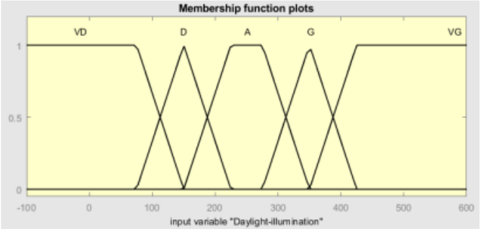
A. Fuzzification

B. Inference

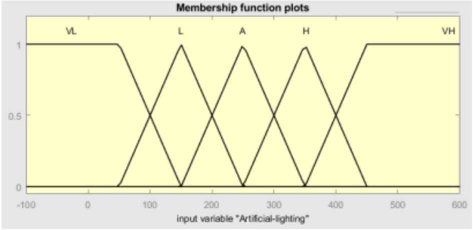
C. Defuzzification

A. Fuzzification

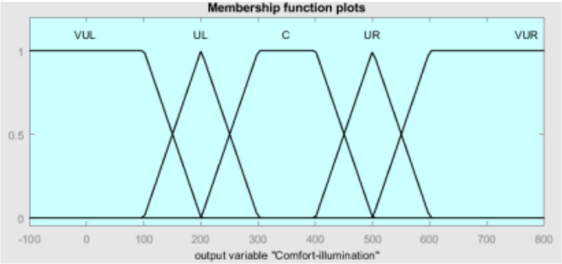
- ➢ 2 Inputs : DI and AL (DI:Daylight illumination ranks AL:Artificial lighting ranks)
- ➢ 1 output : CI (CI:comfort illumination ranks)
- ➢ The definition(ranks) of figures are based on the EN 12464-1 standard
- ➢ Each Variable defines five fuzzy subsets



Very Dark (VD), Dark (D), Average (A), Good (G), and Very Good (VG)



Very Low (VL), Low (L), Average (A), High(H), and Very High (VH)



Very Uncomfortable Left (VUL), Uncomfortable Left (UL), Comfortable (C), Uncomfortable Right (UR), and Very Uncomfortable Right (VUR)

A. Fuzzification

➢ The SFS-EN 12461-1:2011 standard

· The minimum required illuminance levels for the task area and its surroundings

· Illuminance in the surrounding areas must be no less than a third of the illuminance in the immediate vicinity of the task area

· The illuminance uniformity value must be no less than 0.4 in the immediate vicinity and no less than 0.1 in the background

Illuminance in the task area E_{task} (lx)	Illuminance in the immediate vicinity of the task area (lx)
≥ 750	500
500	300
300	200
200	150
150	E_{task}
100	E_{task}
≤ 50	E_{task}

Colour appearance	Correlated colour temperature T_{CP}
warm	under 3,300 K
neutral	3,300 K to 5,300 K
cold	over 5,300 K

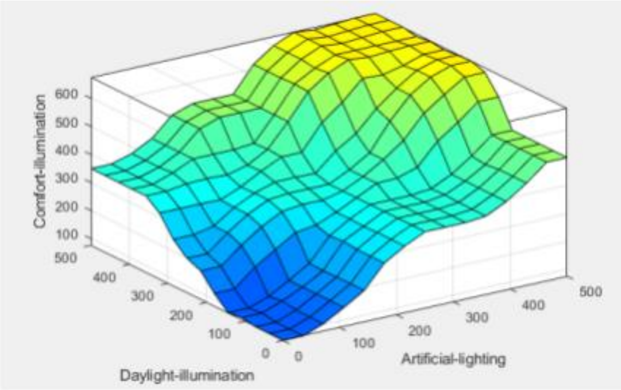
Reference[1] : https://www.ensto.com/downloads/tools/lighting-guide/the-indoor-lighting-standard-sfs-en-12464-12011/

B. Inference

➢ Mamdani technique

- A method to create a control system by synthesizing a set of linguistic control rules obtained from experienced human operators
- Output of each rule is a fuzzy set.
- Well-suited to expert system applications (where the rules are created from human expert knowledge, ex : medical diagnostics)

Daylight illumination	Artificial Lighting				
	VL	*L*	*A*	*H*	*VH*
VD	VUL	UL	C	C	UR
D	VUL	UL	C	C	UR
A	UL	C	C	UR	VUR
G	C	C	UR	VUR	VUR
VG	C	UR	UR	VUR	VUR



C. Defuzzification

- Defuzzification is the process of obtaining a single number from the output of the aggregated fuzzy set. It is used to transfer fuzzy inference results into a crisp output.
- In our case, we use the most popular technique, which is the centroid method (COG: center of gravity). The defuzzified output COG can be written as:

$$CI = \frac{\sum_{i=a}^{b} \mu_A(CI_i).\,CI_i}{\sum_{i=a}^{b} \mu_A(CI_i)}$$

- Where CI is the comfortable illumination value, $\mu_A(CI_i)$ is the ith term's activation degree, and CI_i is the centroid position.

C. Defuzzification

- ➢ In this work, the Fuzzy controller for controlling the lighting comfort of a room (building area) was built using the Mamdani inference system, as discussed earlier.

- ➢ Figure 5. Fuzzy relation for the first input DI

- ➢ The fuzzy control rules

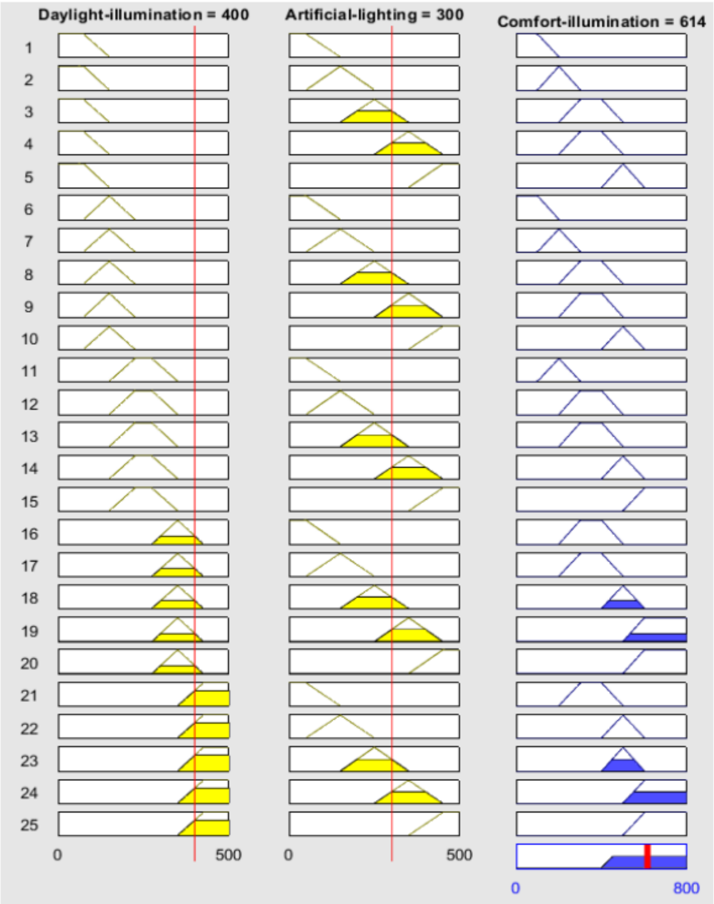


Figure 9. The switch output for comfort illumination when DI=400 Lux and AL=300Lux

C. Defuzzification

- According to figure 9, the comfort illumination is at 614 Lux, which is a value that is beyond the user's comfort, so in this case, the PID controller (fig 10) controls the artificial lighting in a way to decrease the comfort illumination until it reaches the maximum limit value set by the user.

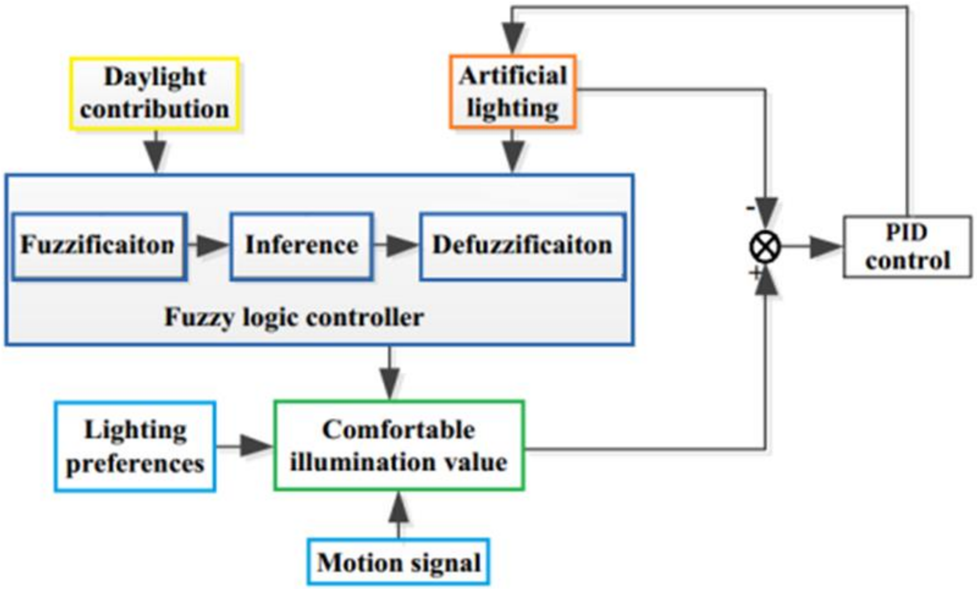


Figure 10. Fuzzy logic controller diagram

06

CONCLUSION

CONCLUSION

- ➢ The two key factors in creating a lighting system are saving lighting energy and fulfilling the user's lighting comfort
- ➢ Significant energy savings can be realized based on varied lighting choices
- ➢ The perspective of this work is to integrate this application into an intelligent smart home system with IoT
- ➢ Expensive

THANKS!