Intelligent Daylight Panel Control System based on Fuzzy Control for Green Buildings

T. C. Kuo, *Member, IAENG*, J. S. Lin, Y. Takeuchi, and Y. J. Huang, *Member, IAENG*

Abstract—**This paper proposes an intelligent daylight panel control system based on fuzzy control theory for green buildings. The goal of this research is to automatically modulate sunlight efficiently and to enhance the quality of interior illuminations, thus reducing the need for artificial lighting and conserving energy. Daylight panels are typically installed on the outside of windows. By applying the proposed fuzzy controller, the reflection angle of daylight panels could be adjusted and optimized so that interior illuminative quality is improved and energy-saving is achieved at the same time.**

Index Terms—**daylight panel, intelligent control, fuzzy control.**

I. INTRODUCTION

Because of growing eco-awareness nowadays, illuminative equipments play an important role for energy saving. Guiding the natural light into the building through windows could be the most immediate, simplest, and economical approach. It becomes very important to acjieve an efficient technique to ease the load of indoor artificial illumination.

The trend of illumination design globally is to improve illumination quality and to conserve energy simultaneously. A good illumination design not only enhances environmental illuminative quality and reduces uncomfortable feelings caused by the dazzling light, but also establishes a harmonious and safe visual environment and effectively decreases the electricity required for lighting fixtures, and thus fulfills both design goals: illumination quality and energy conservation [1-6].

Fixing the daylight panel on windows is a usual method to observe daylight, however, the efficiency of daylight guiding is not guaranteed because of changing positions and angles of the sun. Among intelligent control techniques, fuzzy control is effective, robust, and can be found in various applications. One advantage of designing a controller based on fuzzy logic is that the dynamics of the controlled system need not be fully elaborated. Basically, fuzzy control is a human knowledge based design methodology which is driven by fuzzy membership functions and fuzzy rules. The fuzzy set theory is initiated by Zadeh [7]. So far, fuzzy control techniques have been successfully applied to many fields, such as servo systems, biped robots, permanent-magnet brushless AC drives, hybrid electric vehicle, and so on [8-15]. In this paper, we proposes an intelligent controller technique to adjust the reflection angle of daylight panel to provide optimized daylight guidance, which can improve indoor illumination quality and conserve energy.

II. CONTROL METHODOLOGY

The solar energy has been studied in recent years due to its cleanness and persistence. Because solar radiant energy is inexhaustible, free, and easy to obtain, it has become an affordable, effective, and energy-saving method for illumination. Thus, the energy consumed by artificial lighting could be saved.

A. Design of the micro-structured daylight panels and its optical theory

The design of micro-structured daylight panels is shown in Fig. 1. The phenomenon of refraction, reflection, scattering, and absorbing when the light passes through the microstructure is investigated. By changing the geometric structure, depth, and angle of horizontal groove, the distribution of light running through the microstructure panel could be controlled. After that, micro-structured molds are created using ultra-precision manufacturing process. The micro-structures panel usually is used to apply to backlight for liquid crystal display panel [16]. The indoor illumination quality could be improved if the lighting angle on the microstructure is manipulated effectively. As shown in Fig. 2, when the elevation angle of sunlight is higher, the radiation light (blue solid line) incidents at the EF surface on the microstructure, and then refracts into base materials. After the refraction, light is reflected by the GH surface and incident into the IJ surface, and then refracts again and goes away from the base materials.

When the elevation angle of sunlight is lower or scattering (red solid line), the radiation light incidents into the microstructure surface KL, refracts, and then penetrates through base materials and incident into the surface of glass window; after that, the light is refracted by the glass and then penetrates through the glass surface. Angle a represents the surface internal included angle above the microstructure daylight panel. Angle b indicates the surface bevel angle above the microstructure daylight panel. Angle c is the

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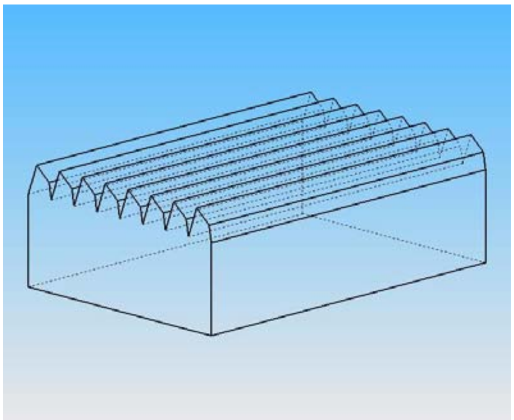

Fig. 1. Structural model design.

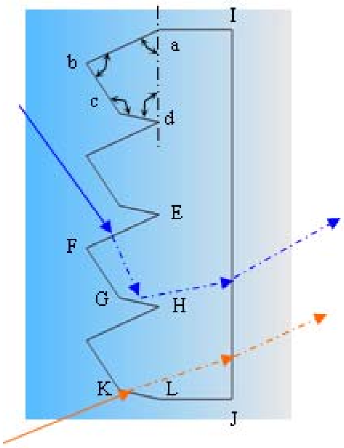

Fig. 2. Incident light on structural panel section view.

surface bevel angle below the microstructure daylight panel, and angle d is the surface internal included angle below the microstructure daylight panel.

The incident light from sun is shown in solid lines in Fig. 2. Incident light transmits within the microstructure following the theorems of refraction and reflection. Let the included angle formed between the incident light and surface of normal be the incident angle when the light encounters the structural surface. If the incident angle is smaller than critical angle, the light will deflect out of the structural surface, so that the effect of light control could be achieved. Suppose that when the included angle of normal, which is between the incident angle and microstructure panel, is greater than 42°, reflection happens. The dashed lines in Fig. 2 indicate the behavior routine of light after being refracted or reflected. The difference is that the incident light refracts from the first surface by the microstructure daylight panel, and reflects while passing through the second surface. So the angle of outgoing light is controlled and guided indoor through the modulation cause by the inclination below the second surface.

As shown in Fig. 3, the guiding light angle on the ceiling would be different after microstructure modulation when incident angle changes (provided that other conditions remain unchanged). Therefore, the microstructure modulated daylight design must consider the influence caused by incident light angle and projection guiding light angle during indoor environmental illumination analysis.

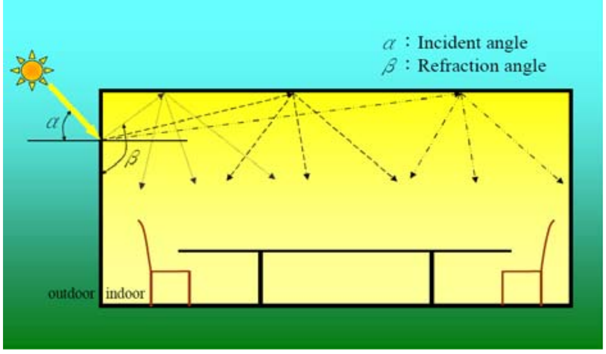

Fig. 3. Microstructure modulated daylight panel.

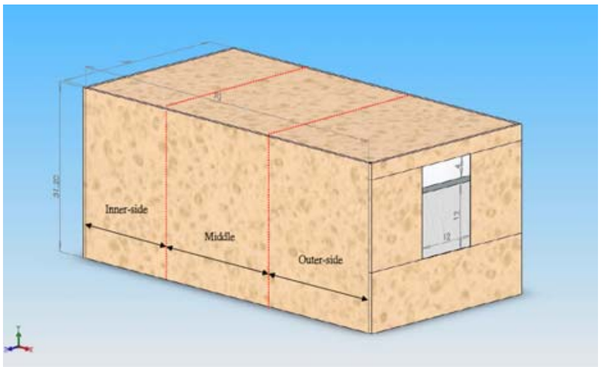

Fig. 4. The indoor designing model for light guiding.

B. Daylight modulated panel in the office

Consider the offices in subtropical region. Typically, we assume that the workspace has a dimension of 7 meters in length, 3.6 meters in width, and 3 meters in height. In the simulation, the dimension will be shrunk to one hundredth. We designate the upper part of the window (roughly quarter of the window area) for daylight incidence, and place the daylight panel into double-glazed window filled with argon. The refraction of sunlight caused by the daylight panel is simulated and analyzed. Figure 4 shows the model we use for simulation, including the dimensions of the office, window, and daylight panel. The standard size of simulation models is listed in Table 1, including the office model, the dimensions of window and microstructure daylight panel. Figure 5 illustrates the daylight panel window and the definition of daylight incident angle α and refraction angle β.

The software named TracePro is utilized to simulate the improvement of illumination after installing daylight panel. In this simulation, the working time of the daylight panel is assumed to be from 8 a.m. to 5 p.m., and simulate different deflection angles of daylight panel ranged from 0° to 60° with steps of 20°. The middle and inner-side area of indoor illumination can be improved if the daylight panel is tilted to a specific angle according to the elevation angle. From the simulation results, we found the best referral value of elevation angle is 41° when daylight panel is not tilted; the best referral value of elevation angle changed to 52.9° when the daylight panel is tilted 20°; the best referral elevation angle is 51.5° if daylight panel tilted to 40°; finally, the best referral elevation angle is 39.4° provided the daylight panel tilted 60°.

Table 1: Model size

Model size	Length (mm)	Width (mm)	Height (mm)
Office	70	36	30
Window		12	17
Daylight panel		12	4

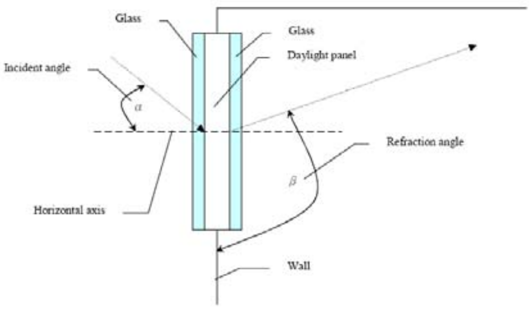

Fig. 5. Daylight refraction.

III. FUZZY DEFLECTION ANGLE CONTROL OF THE DAYLIGHT PANEL

The proposed fuzzy controller uses a set of fuzzy rules and linguistic variables to capture knowledge and experience of domain experts in the control system. A basic fuzzy system, which provides a systematic procedure for transforming a set of linguistic rules into a nonlinear mapping, comprises four principal components: fuzzifier, fuzzy rule base, fuzzy inference engine, and defuzzifier [17-18] as shown in Fig. 6.

Fuzzy modeling can be interpreted as a qualitative modeling scheme that describes system behavior using fuzzy quantities, i.e. fuzzy sets or fuzzy numbers. In a fuzzy set, each element in the universe of discourse is associated with a membership value between 0 and 1, which indicates the degree of membership of the element in the fuzzy set. If U is the universe of discourse and the input space, and its elements are denoted by x. Then, a fuzzy set A in U can be represented by a membership function $\mu_A(x)$, which is the degree of membership of x belonging to the fuzzy set A. The transformation of real-valued inputs to its membership degree is known as fuzzification. In general, membership functions of geometrical shapes such as triangular and trapezoidal are used for reservoir operation applications when the standard deviation of the variable is not large.

The fuzzy set primarily constitutes union and intersection operations [9]. Let A and B be two fuzzy sets in the universe of discourse U, and $\mu_A(x)$ and $\mu_B(x)$ are the membership functions of fuzzy sets A and B, where $\mu_A \in [0,1]$ and $\mu_B \in [0,1]$. The union and intersection operations of the fuzzy sets A and B are respectively given as

$$\mu_{A \cap B} = \min[\mu_A(x), \mu_B(x)]$$

$$\mu_{A \cup B} = \max[\mu_A(x), \mu_B(x)]$$

Fuzzy rules are then formed, which provide necessary connections between the input and output fuzzy sets. They are represented by means of fuzzy *IF-THEN* rules of the following general form:

IF antecedent proposition *THEN* consequent proposition.

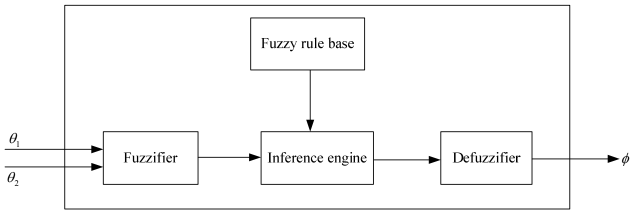

Fig. 6. Fuzzy control block diagram.

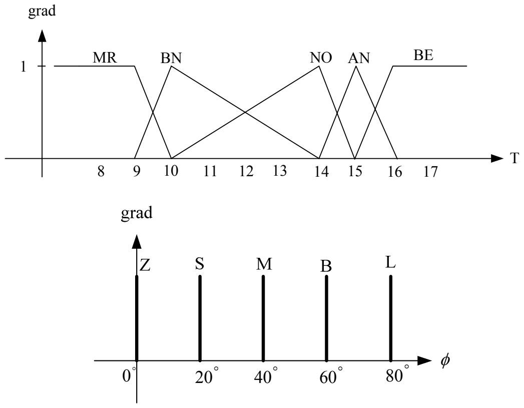

Fig. 7. The membership function.

For a given input, one or more of the rules are activated, depending on the way in which the membership functions are defined. A crisp output is obtained through the process of defuzzification by aggregating all the rules that have been activated for a given input. This is usually done with suitable defuzzification criteria such as centre of gravity or mean of the maximums.

The fuzzy rules are:

IF T is MR *THEN* ϕ is Z
IF T is BN *THEN* ϕ is S
IF T is NO *THEN* ϕ is M
IF T is AN *THEN* ϕ is B
IF T is BE *THEN* ϕ is L

where T is the input variable of fuzzy controller representing time; and ϕ is the output variable of fuzzy controller representing the deflection angle of daylight panel. Five terms, {MR, BN, NO, AN, and BE}, are assigned as input linguistic variables and denote {Morning, Before Noon, Noon, Afternoon, and Before Evening}. The output linguistic variables are {Z, S, M, B, L}, which denote {Zero, Small, Medium, Big, and Large}. The membership function of input variable and output fuzzy variable are shown in Fig. 7. In this paper, the Mamdani fuzzy inferences system is used as a reasoning procedure, and the center of gravity method is used as the defuzzification method.

In this paper, we use Matlab to simulate the proposed fuzzy controller. The sampling time is set to 30 minutes, and simulation results of deflection angle of daylight panel with fuzzy controller are shown in Fig. 8. For example, when at 10 am the angle of the window and the daylight panel is 20°. Fuzzy controllers can automatically change the deflection angle of daylight panel every 30 minutes. This intelligent control method can improve the deflection angle of daylight panel.

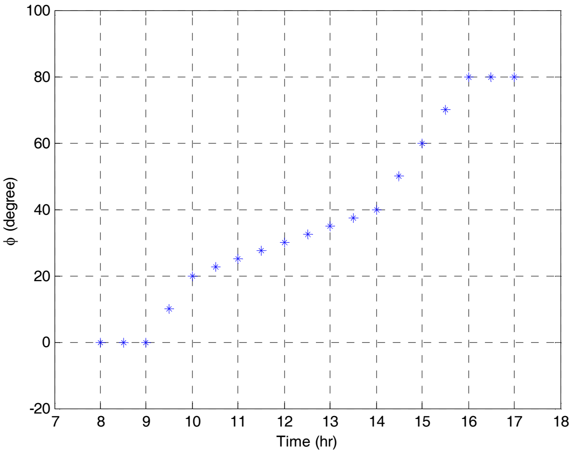

Fig. 8. Simulation results with fuzzy controller.

We then use TracePro again to verify if the results obtained from fuzzy Control simulations really improve the illumination quality. We take three data points: 9 A.M, 11 A.M, and 5 P.M., where the angles obtained from fuzzy control simulations are 0°, 25°, and 80° respectively. The results are shown in Table 2 where the data show that inner-side illumination quality is improved, and thus the performance of fuzzy control is clearly seen. If one performs brute-force TracePro simulations for these angles, it will take 15 hours to complete all the process. However, using fuzzy control module in Matlab, the simulation could be done in one minute. The time required for software simulations are reduced significantly.

IV. CONCLUSION

To modulate daylight effects efficiently and to enhance the quality of interior illuminations simultaneously, this study not only improves the structure of the daylight panel, but also proposes a control technique for the deflection angle control of the daylight panel at all the day time. Since fixing daylight panel on window is usually used, but it is an inefficient way to observe daylight because the sunlight changes position and angle all the time while illuminating on the daylight panel. Therefore, the proposed method in this paper is particularly useful, which utilizes a fuzzy controller to control the deflection angle of daylight panel and improve its function of guiding light. By using Matlab to simulate the proposed fuzzy controller, the simulation of controlling the deflection angle of daylight panel is successfully carried out, and it confirms the practicability of proposed method. Moreover, the time required by software simulation could be significantly reduced.

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Table 2: Validation of fuzzy control simulation results (unit: Lux)

Time of the day	Examining area	Outer-side	Middle	Inner-side
	Elevation angle			
9	41	24.0	58.9	77.2
11	62.3	42.2	48.7	247.3
17	12.9	24.4	44.2	123.9

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