FUZZY CONTROLLER FOR INDOOR LIGHTING SYSTEM WITH DAYLIGHTING CONTRIBUTION

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ABSTRACT

Classic control systems, based on continuous dimming present some difficulties to adjust their performances to the rapid changes in daylight. Therefore, fuzzy control could be a better solution. The paper analyzes the possibility to implement this new technique in daylighting control and presents the structure of a fuzzy controller proposed by authors; its operation rules and the influence on the imposed value of the illuminance level are also studied.

I. INTRODUCTION

During the last three decades, the electricity consumption in indoor and outdoor lighting systems has continuously increased. That is why the implementation of sustainable energy development has addressed this sector as having an important potential regarding energy savings.

Energy-management controls provide energy saving through reduced illuminance or reduced time of use [1]. Advanced lighting control devices and systems can be used to reduce ongoing costs for the owner and thereby increase profitability and competitiveness. According to [2], lighting controls can reduce lighting energy consumption by 50% in existing buildings and by at least 35% in new construction.

The sustainable development concept has revived the interest for daylighting, i.e. for the use of daylight as a primary source of illumination in a space as any day lit area has very promising energy-saving opportunities. As daylight represents a dynamic source of lighting, electric lighting control systems will be needed to adapt the lighting systems to changing lighting conditions**.**

Classic control systems present some difficulties to adjust their performances to the rapid changes in daylight and to occupants' preferences. Taking into account these aspects, fuzzy control could be a better solution. The paper analyses the possibility to implement this new technique in daylighting control and presents the structure of a fuzzy controller proposed by authors; its operation rules and the influence on the imposed value of the illuminance level are also studied.

II. LİGHTİNG CONTROLS

Lighting controls, addressing controls for electric lighting, offer desired illuminance at appropriate times while reducing energy use and operating costs of lighting system. Energy-management controls provide energy saving through reduced illuminance or reduced time of use; a control system can also consider the physiological characteristics; for instance, a 20-year old person needs one-third less light than someone who is 60-years old (for the same task).

All lighting control systems are based on one of the following strategies:

- *Occupancy sensing,* in which lights are turned on and off or dimmed according to occupancy;
- *Scheduling,* in which lights are turned off according to a schedule;
- *Tuning,* in which power to electric lights is reduced to meet current user needs;
- *Daylight harvesting (daylighting control),* in which electric lights are dimmed or turned off in response to the presence of daylight;
- *Demand response,* in which power to electric lights is reduced in response to utility curtailment signals or to reduce peak power charges at a facility;
- *Adaptive compensation,* in which light levels are lowered at night to take advantage of the fact that people need and prefer less light at night than they do during the day.

These strategies can be accomplished by means of various control devices, but any lighting control system contains three major components: (1) a power controller, (2) a logic circuit and (3) a sensing device. The *sensing device* is capable to measure or to detect a physical parameter of interest (e.g., illuminance level) and to translate it into an electric signal (current or voltage); the *logic circuit* accepts this electric signal and, using a specific algorithm, converts it into an appropriate electric signal for the power controller; the *power controller* acts on artificial lighting source in order to obtain the proposed goal.

The sustainable development concept has revived the interest for daylighting; except for energy savings, daylighting provides an improved sense of well being. However, the huge attention of lighting designers for this technique is based on its energy saving potential: a daylighted building should need only minimal electric lighting during daylight hours, especially in sunny regions. Lighting controls can be used to dim or turn off electric lighting when bright sun makes the electric lighting unnecessary, and this can result in substantial savings, due to the reductions in both power demand and energy use. In addition, since ample daylight is often available during utility peak demand hours, daylight harvesting can reduce demand charges, particularly valuable if a “ratchet clause” is in effect.

There are at least two dimensions to daylight-responsive controls [4]: the control of the daylight input to the space, and the control of the electric lighting output. The first is critical for providing adequate quantity and quality of daylight in interior spaces; the second saves energy and improves the overall distribution of light when daylight is insufficient.

Fluorescent lighting is the light source generally used with electric lighting controls and fluorescent lamps with a color temperature within 3,000-4,500°K are most likely to be in agreement with the color temperature of daylight

The daylighting control is based on continuous dimming techniques that allow users to adjust lighting levels over a wide range of lighting output and offer far more flexibility than step-dimming controls. As continuous dimming follows the daylight pattern very closely, it is often more acceptable to occupants, and can produce higher energy savings, particularly in areas with highly variable cloud cover. Continuous dimming also responds to changes in light output due to dirt depreciation on fixtures and lamps, and lamp lumen depreciation due to lamp aging.

Continuous dimming is achievable using either analog or digital ballasts. Analog dimming systems are established and common, while digital dimming systems are relatively new to the industry. Both provide the essential function of controlling the lamp output based on input from a control device. In analog dimming the controller varies the control signal sent to the electronic ballast in order to maintain the desired level. The range of dimming is specific to the type of dimming ballast: 1 or 5 percent of full output for “architectural dimming” ballasts and 5 or 10 percent for “energy management dimming” ballasts.

Digital provides a higher degree of granularity of control capability, such as ability to individually address and group the ballasts, gain feedback information from ballasts, manage a variety of zones and scenes, and provide a lighting system that can easily accommodate changes over time.

If the methods used to measure the daylight contribution are considered, daylighting controls may be closed loop or open loop systems [6]. *Closed loop systems* measure the combined lighting from all lighting sources, including daylight and the controlled electric light. Based on this feedback, the control device raises or lowers the electric lights to obtain the desired luminance level. *Open loop systems* have photocells that are designed to measure only incoming daylight, not the controlled lighting’s contribution to the space. In an open loop system, the controller proportionately dims the electric lights based on an estimated daylight contribution; this contribution is measured at start-up.

III. FUZZY LOGİC AND DAYLİGHTİNG CONTROL

Daylight is a dynamic source of lighting and the variations in daylight can be quite large depending on season, location or latitude, and cloudiness. Different skylight levels can be found under the same sunlight conditions, and, even when the sky pattern remains the same, the range of solar illuminances may increase as a result of a momentary turbidity filter or scattering of particles over the sun. In consequence, any prediction system has to be flexible to allow for the multivariate changes that characterize the combination of sunlight and skylight [5].

In recent years, the control technology has been well developed and has become one of the most successful tools in the industry. However, due to above mentioned aspects, traditional control systems, based on mathematical models, have shown their limits as daylighting energy-management controls. Taking into account the random pattern of potentially available daylight and rapid change of its characteristics, fuzzy control has proved to be a more convenient solution.

A. Fuzzy Control

Fuzzy logic is a computational paradigm originally developed in the early 1960’s and represents a natural, continuous logic patterned after the approximate reasoning of human beings. It allows for partial truths and multivalued truths, and is therefore especially advantageous for problems that cannot be easily represented by mathematical modelling because data is either unavailable, incomplete, or the process is too complex. The real-world language used in fuzzy control enables engineers to incorporate ambiguous, approximate human logic into computers and technical applications. Using linguistic modeling, as opposed to mathematical modelling, greatly simplifies system design and modification.

There is a fundamental difference between fuzzy control and conventional control: conventional control starts with a mathematical model of the process and controllers are designed based on the model; fuzzy control, on the other hand, starts with heuristics and human expertise (in terms of fuzzy *IF-THEN* rules) and controllers are designed by synthesizing these rules. For practical problems where the mathematical model of the control process may not exist, or may be too "expensive" in terms of computer processing power and memory, a system based on empirical rules may be more effective and, consequently, the fuzzy control is most useful.

B. Fuzzy Controllers

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensors or other inputs, such as switches, thumbwheels, and so on, to the appropriate memberships functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value [7].

The internal structure of a fuzzy controller contains the following four basic components:

- Fuzzification unit: converts the crisp input variables into fuzzy ones so that they are compatible with the fuzzy set representation of the process state required by the inference unit.
- Knowledge base, consisting on two parts: a rule base that describes the control actions and a database that contains the definition of the fuzzy sets representing the linguistic terms used in the rules.
- Inference unit: generates fuzzy control actions applying the rules in the knowledge base to the current process state.
- Defuzzification unit: converts the fuzzy control action generated by the inference unit into a crisp value that can be used to drive the actuators.

C. Daylighting Fuzzy Control

The daylighting fuzzy control uses a fuzzy controller as the logic circuit of the lighting control and continuously electronic dimming ballasts controlled by low-voltage analog signals as power controllers. The ballast receives a signal from the control device and subsequently changes the current flowing through the lamp, thereby achieving a gradual controlled reduction in lamp output. The characteristics of the control signal affect the duration and extent of the change in current and subsequent lamp output. Most commercially available dimming ballasts for operation of these lamps are electronic rapid-start or programmed-start ballasts, and all linear lamps operated by these ballasts feature bi-pin bases typical of rapid-start lamps. As the sensing device, different types of photo-sensitive devices, commercially available, can be implemented.

For the studied room (20x10 m), the indoor pendant-mounted lighting system, designed by DIALUX software package, consist of 35 luminaires containing two 54WT16 linear fluorescent lamps. They are mounted in seven rows of five pieces, parallel to the daylit side of the room, and assure an average illuminance level of 500 [lx].

An important task consists in the proper selection of control zones; a control zone is a group of luminaires or individual lamps within luminaires that are controlled by one signal. The goal in creating a control zone is to define an area that receives a consistent amount of daylight at any given time and has consistent light level requirements.

In our case, taking into account the windows head height, the pattern of the daylight is presented in Fig. 1; accordingly, four control zones parallel to the short side of the room have been identified.

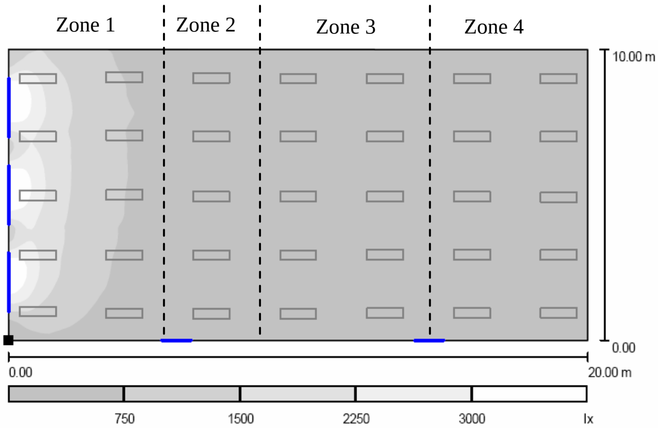

Figure 1. Daylighting of the room

IV. RESULTS AND DISCUSSION

The proposed daylighting fuzzy control uses four sensing devices (an occupancy/motion sensor and three photosensors), continuously electronic dimming ballasts for every luminaries aiming the control of the electric lighting output, and a fuzzy controller; the three photosensors are placed in the control zones 1, 2 and 4. Figure 2 presents the control algorithm for the proposed control system, implemented into a fuzzy controller.

Until *a person is present*
    if *illuminance is between 500 and 550 lux*
        then *hold constant all lamp parameters*
        else *use the fuzzy controller for lighting control*
after 5 min turn off all lamp.

Figure 2. Algorithm for daylighting fuzzy control

A. Fuzzyfication

The input linguistic variables of the fuzzy controller are the level of the illuminance measured by the three photosensors while the output variables are the level of the DC control signal sent to electronic ballasts in the four control zones. Every linguistic variable has five fuzzy values with triangular or trapezoid membership functions, as follows:

- For input variables – Figure 3: *D* – dark; *HD* – half dark; *M* – half; *HL* – half light; *L* – light;
- For output variables – Figure 4: *VL* – very low; *L* – low; *M* – medium; *H* – high; *VH* – very high.

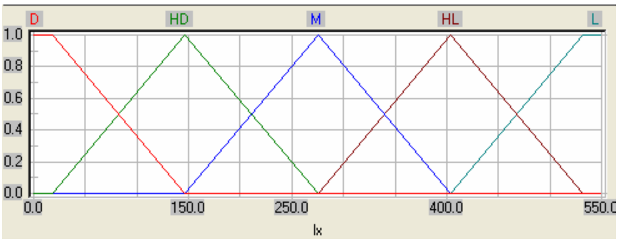

Figure 3. Input variables fuzzyfication

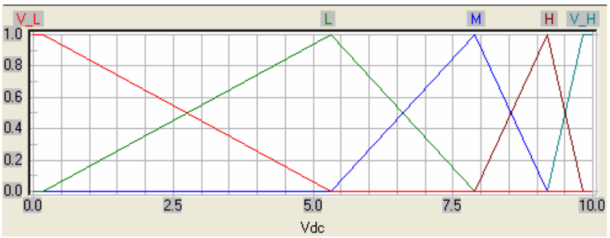

Figure 4. Fuzzyfication of output variables

B. Knowledge base

The knowledge base used by the control system is presented in Table 1 where μ_i (i=1…4) represents the membership functions for the DC control signals corresponding to the four control zones.

Table 1

IF			Then			
A	**B**	**C**	μ_1	μ_2	μ_3	μ_4
D	D	D	V_H	V_H	V_H	V_H
D	D	HD	V_H	V_H	V_H	V_H
D	D	M	V_H	V_H	V_H	V_H
...	...	...	...	...	....	...
L	L	L	V_L	V_H	V_L	V_L

The processing stage invokes each appropriate rule and generates a result for each of them, then combines the results of the rules; this mechanism was implemented by the *max-min* inference method.

C. Defuzzyfication

The results of all rules that have fired are defuzzified to a crisp value by the *centroid* method and gives different crisp values of DC control signals corresponding to each control zone. Simulated results have been obtained by FuzzyTech tool.

The illuminance levels provided by the proposed fuzzy control system are presented in Figure 5 and highlight a good quality of illumination combined with a significant energy saving.

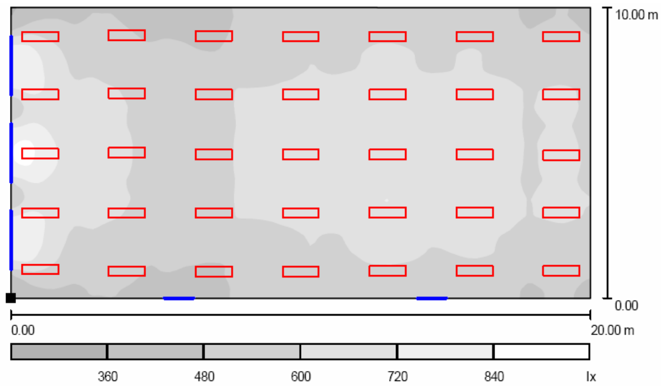

Figure 5. Combined artificial and daylighting with fuzzy controller

V. CONCLUSION

Daylighting has a very promising energy-saving potential and became an attractive alternative to conventional indoor electric lighting systems. Classic control systems, based on continuous dimming, present some difficulties to adjust their performances to the rapid changes in daylight depending on season, location or latitude, and cloudiness.

Taking into account these aspects, fuzzy control could be a better solution in implementation of daylighting, an issue that cannot be easily represented by mathematical modeling because data is unavailable, incomplete, or too complex.

The proposed system uses four sensing devices (an occupancy/motion sensor and three photosensors), continuously electronic dimming ballasts for every luminaries aiming the control of the electric lighting output, and a fuzzy controller. Data obtained by simulation proved the correctness of the proposed solution.

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