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A Self-Adaptative and Smart System for Blinds Control

Guillemin A.
Morel N.

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A SELF-ADAPTIVE AND SMART SYSTEM FOR BLINDS CONTROL

A. Guillemin; N. Morel

Laboratoire d'Energie Solaire et de Physique du Bâtiment, EPFL, CH-1015 Lausanne

ABSTRACT

A shading device controller using fuzzy logic has been developed. It is splitted into two parts depending on the user presence. When the user is present, priority is given to visual comfort, and when he is absent, priority is given to thermal aspects (heating/cooling energy saving). Some MATLAB® simulations allow comparing different variants of the controller. An adaptation process using Genetic Algorithms is explained. This leads to a controller that is able to adapt to the user behaviour and to the room characteristics.

RÉSUMÉ

Un contrôleur de stores à logique floue a été développé. Il est divisé en deux parties. Lorsque l'utilisateur est présent, le contrôleur cherche à obtenir des conditions visuelles optimales et lorsqu'il est absent, le contrôleur ne s'occupe que de considérations thermiques (économie d'énergie de chauffage ou refroidissement). Des simulations avec MATLAB® permettent de comparer différentes variantes du contrôleur. Un processus d'adaptation qui utilise les algorithmes génétiques est présenté. L'algorithme de contrôle finalement obtenu s'adapte automatiquement au comportement de l'utilisateur ainsi qu'aux caractéristiques du local.

1. INTRODUCTION

Advanced installations for indoor climate control in buildings offer nowadays very promising possibilities to improve the building energy management system (BEMS): climate, building type, spaces, control, management methods and national regulations can be taken into account for design, manufacture, engineering, commissioning and maintenance processes.

In the frame of the EDIFICIO project, the LESO-PB has developed a smart and self-adaptive controller for the shading device, included in a global optimised integrated controller (heating/cooling, ventilation and lighting). Although some fuzzy-expert blind controllers have been developed in the past (e.g. the non-adaptive blind controller DELTA [1]), an **adaptive** blind controller remained to be elaborated. In particular, the capability of adaptation to the user's behaviour is the necessary condition to lead to an acceptance of the automatic control system by the user. Furthermore, an adaptation to changing conditions is quite important, too.

2. THE EDIFICIO PROJECT

Project aims

The EDIFICIO (Efficient Design Incorporating Fundamental Improvements for Control and Integrated Optimisation) research project, funded in part by the EU Commission in the frame of the JOULE III Programme, has the goal to develop and test innovative, adaptive, integrated control systems for the optimal energy management and indoor comfort in buildings. This is achieved by using Soft Computing Techniques, especially Fuzzy Logic, Artificial Neural Networks and Genetic Algorithms.

The main objectives of the EDIFICIO project are:

- Development of smart control algorithms for heating/cooling, indoor air quality and ventilation, artificial/natural lighting and integration into a multifunctional smart control system, to improve the BEMS efficiency (maximum comfort for occupant with the minimum energy and maintenance cost)
- Experimental validation of the integrated controller, using both simulations with MATLAB® and tests on real inhabited office buildings

Integrated controller

Four different device categories are considered for the control: the heating/cooling system, the ventilation, the blinds (shading device) and the artificial lighting. The integrated system is built on the principle of three nested levels control loops (see figure 1).

- The level 1 makes the translation from physical values (heating power, blind position, etc...) to the appropriate commands of the corresponding device (changing the heating system valve position, raising or lowering the blinds, etc...).
- The level 2 control loop includes the domain knowledge. It is based on expert fuzzy rule bases and uses adaptive models for thermal, lighting and air quality in order to produce a smart global control strategy. The outputs of this level are the physical values that are the inputs of the level 1 control loop.
- Finally, the level 3 ensures the long-term adaptation of the level 2 algorithms. The adaptation is done in a continuous way to fit to the user wishes and to take into account all the long-term changes in, for instance, the building and device characteristics. This adaptation task is done using Genetic Algorithms. They allow minimising a global "cost function" in adjusting the algorithm's parameters of the level 2 smart controller.

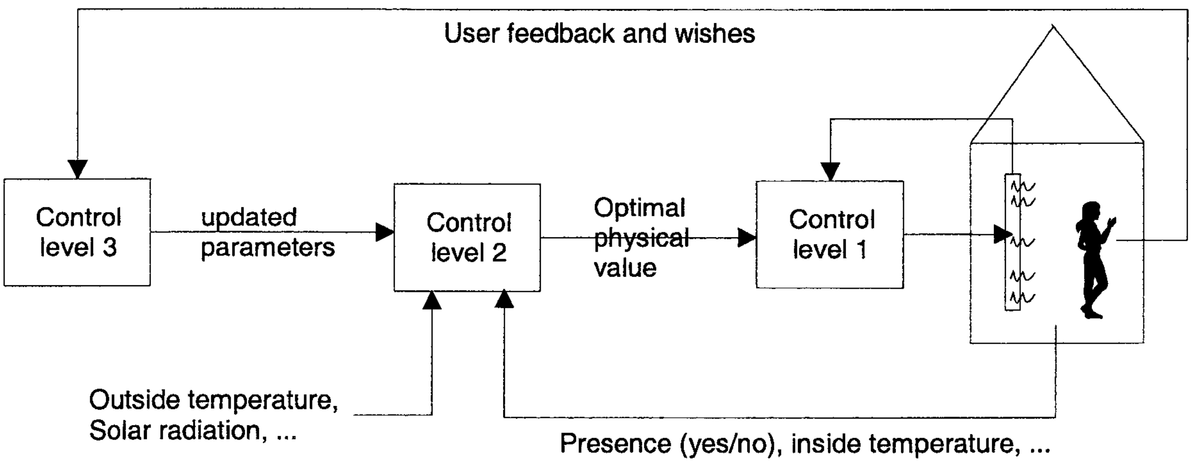

Figure 1: Principle block diagram of the three nested control level loops

The level 1 is specific to each building but both levels 2 and 3 are very easily adjustable to any kind of controller device. The self-adaptation of the system will lead to a simplified commissioning, and a good performance of the system is ensured without complicated parameter adjustment.

3. Expert blind controller

The shading device controller described here corresponds to the controller implemented in the level 2 in the integrated system of the EDIFICIO project. It deals only with textile blinds. However, a similar controller has been developed and simulated for venetian blinds (with both vertical position and slats angle regulated) and its description can be found in [3]. The textile blind controller is splitted into two cases, depending whether the user is present or not in the room. In the case the user is present, the blind controller gives priority in providing optimal visual conditions in the room; otherwise only thermal considerations are taken into account in order to minimise the energy consumption.

Visual optimisation

When the user enters the room, the controller switches in the visual optimisation mode. Several algorithms for blind control have been studied; here only the chosen algorithm, which seems to be the more promising one, is presented. The algorithm is divided into two parts. The first one determines a maximum blind aperture in order to avoid glare (using a fuzzy rule base) and the second one tries to find the blind position (below the maximum value) that leads to the inside illuminance corresponding to the illuminance setpoint chosen by the user.

Maximum blind aperture

There are 25 rules in the fuzzy inference system, four inputs (direct horizontal illuminance, season, height and azimuth of the sun) and one output (maximum blind position). The main principles used in the rules are:

- Priority is avoiding glare, but the system tries however to save some energy by differentiating the rules depending on the season. In winter, during the day the maximum of solar gains is accepted and during the night the blinds are closed in order to increase the insulation and lower the heat losses through the window. In summer, the behaviour is the opposite.
- A position of the sun near the horizon leads to close the blind if the direct radiation is high enough to disturb the user.
- If there is only diffuse radiation incident on the facade, there is no restriction on the maximum aperture of the blind.

The innovative idea of the algorithm is to take into account not only the incidence angle of the solar radiation on the facade (which was one limitation in the DELTA project [1]) but the exact position of the sun relatively to the facade, that means both the azimuth and the height of the sun are used. This allows having different behaviours for different kind of penetration of sun. If the sun illuminates the wall in front of the user or illuminates the user directly, the algorithm may give different blind maximum aperture although the incidence angle is the same in both cases. In particular, it gives the opportunity to adapt the system (through the user wishes) depending on the user position in the room!

Blind position according to the inside illuminance measurement

The final position of the blind is determined by using an "illuminance" ratio RI.

This ratio links the inside illuminance (E_{inside}) with the outside illuminance ($E_{outside}$). It depends on the blind position (*bp*).

$$\mathbf{E_{inside}} = \mathbf{RI}\,(bp) \bullet \mathbf{E_{outside}}$$

Setting the E_{inside} equal to the illuminance setpoint and solving this equation for *bp*, a final position of the blind can be calculated. The only constraint is that the blind position must be lower than the maximum blind aperture previously determined. If the inside illuminance level is still too low, artificial lighting is used to complete the inside illuminance until reaching the setpoint defined by the user.

The measurement of the inside illuminance is not used directly (it is used however for adapting continuously the RI expression in function of *bp*), the benefits are:

- Avoid the oscillations (which could come from a closed-loop control)
- Keep a smart control even if the sensor gives a temporary wrong value (in case of paper on the sensor, etc...)
- Blind position may be predicted (necessary for the heating controller)

Energy optimisation

When the user has not been present for a certain amount of time (typically for 15 minutes at least) the controller switches from the visual optimisation to the energy optimisation algorithm.

The basic idea is taken from [1]. There are two main heat exchanges through a window: one is due to the transmitted solar radiation (direct gain), the other to the thermal conduction caused by the difference between the inside and outside temperatures (gain or loss). Taking into account both contributions, which depend of the blind position, one may calculate a window heat balance. The idea is that the fuzzy controller provides not directly a blind position but a "desired window heat balance" (DWHB). A positive (respectively negative) value of the DWHB [watts] corresponds to the desired heat gains (resp. losses) for the room. The position of blind which gives an actual window heat balance as near as possible to this DWHB is calculated knowing physical parameters of the window and the blind (solar transmission coefficients, heat-loss coefficients).

Nine different blind controllers have been developed and tested. They can be classified according to the inputs of the fuzzy inference system. Two controllers have only the variable *heating power* as input (controllers called "only heating"). Three have only the variable *season* as input (controllers "only season"). The four lasts have both the *heating power* and the *season* as inputs (controllers "both").

The main ideas used to build the tables of rules were:

- The blind controller must always help the heating/cooling system.
- In winter, solar gains should be accepted as often as possible.
- In summer, solar gains should be rejected as often as possible.
- In mid-season, situation is unclear, so several possibilities are studied.

Season	**Winter**	**Mid-season**	**Summer**
DWHB	Pos	Pos_low	Neg

Table 1: Example of fuzzy rule base (controller "only season", version 3), DWHB is the desired window heat balance

The fuzzy variable *season* is not determined from the period of the year but from the average outside temperature during the last 24 hours. Its membership functions are given in figure 3.

The versions differ by the membership function definitions.

The simulation tests have been done with Simulink (from MATLAB®), on a period of one week during three different periods of the year (winter (days 52-59), mid-season (days 100-107), summer (days 192-199) with climate data of Lausanne. For each period, the controllers are tested in two cases: with a heating/cooling system and with a heating only system. Both systems are predictive (inspired from the NEUROBAT project [2]).

The main conclusions of the simulations are:

- The variable *season* is essential in order to have a good blind controller.
- The differences between controllers are particularly visible during the mid-season period.
- It is best to have a positive *DWHB* in *mid-season* when there is no heating.
- The best value to take for the *DWHB* in this case has not been defined. It depends strongly of the kind of heating/cooling system and of the window and room characteristics.
- Three controllers are clearly better than the others: "both v2", "both v3" and "only season v3". They lead to quite comfortable inside temperature and their energy consumptions are the lower ones (see figure 2).

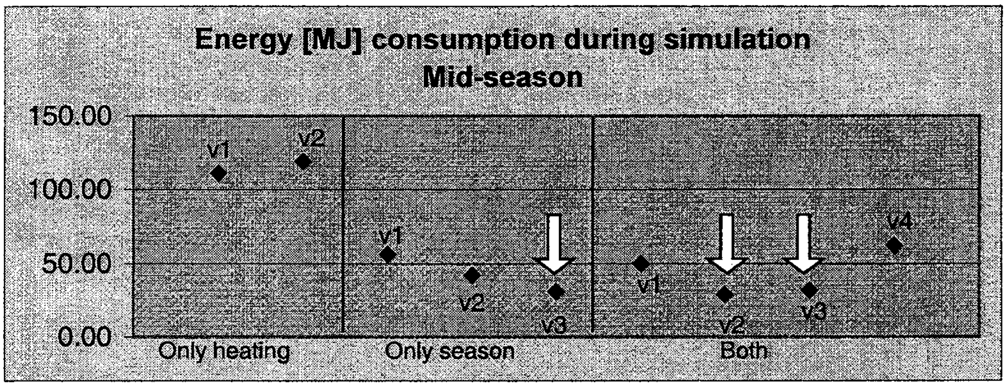

Figure 2: Energy consumption of the nine controllers during the mid-season simulation

For the EDIFICIO project, the "only season v3" controller has been chosen. Although this controller is not the best considering the energy consumption, it does not use the *heating power* variable and therefore avoids a cross coupling heating-lighting. This would otherwise occur: the heating controller **needs** the blind position produced by the blind controller (in order to predict the future inside temperature), and the lighting controller would **need** the *heating power* variable produced by the heating controller. This cross coupling could have lead to possible instabilities.

4. SELF-ADAPTATION

Each night, a process of adaptation is undertaken. Using Genetic Algorithms, the system adapts itself to the user's behaviour and to the parameters of the building and the environment.

The genetic algorithm used for this task works as follow:

Each potential solution is coded in the genome as the parameters of the fuzzy inference system. More precisely, small variations of the membership functions parameters from the original lighting controller are coded (see figure 3). Each individual corresponds to a slightly different lighting controller. After generating randomly a population of individuals, the genetic operators (selection, crossover and mutation) are applied in order to obtain a new population. This is repeated until a sufficiently good solution is found. The individuals (controllers) are evaluated with a kind of cost function, which take into account several things together: energy consumption, visual comfort provided, estimated user acceptance (coming from wishes expressed by the user).

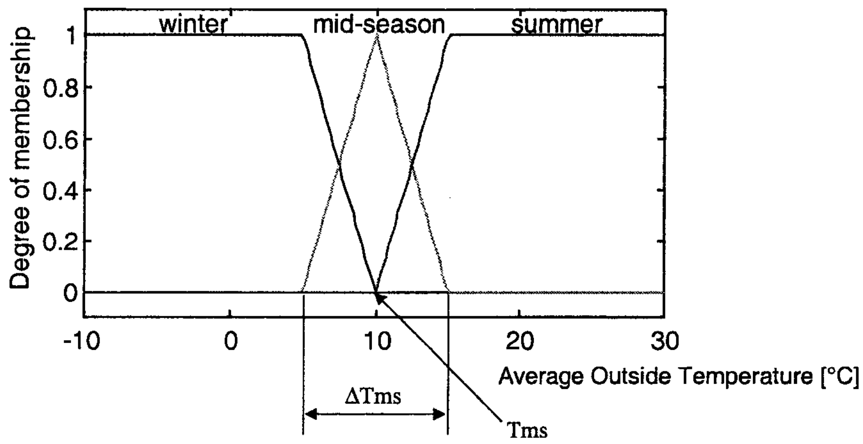

Figure 3: Fuzzy parameters that will be adapted using the Genetic Algorithms (here the parameters Tms and ΔTms are considered)

Furthermore, there is also a continuous adaptation of the different models used in the controller (e.g. the illuminance ratio model) by updating the model's parameters.

5. Conclusion

The shading device controller presented here has several advantages over the other known blind controllers. It is integrated in an optimised global controller. In particular, it takes into account thermal aspects and is able to help strongly the heating/cooling system. Furthermore, it is self-adaptive, which means that the controller learns the user's behaviour and adapts itself to the building and its environment. The benefits are a better user acceptance of the automatic system, an easier commissioning and robustness towards the changes of the building characteristics and towards some possible dysfunction. Nevertheless, the quality of the control system is strongly dependent on the user's behaviour: if the user does not express his wishes, the good capability of user adaptation will not be used.

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References

1. M. Bauer, J. Geiginger, W. Hegetschweiler, G. Sejkora, N. Morel, P. Wurmsdobler: DELTA, a blind controller using fuzzy logic. Final OFEN Report, LESO, EPFL, 1996

2. J. Krauss, M. Bauer, N. Morel, M. El-Khoury: NEUROBAT, a neuro-fuzzy expert system in building control. Final OFEN Report, CSEM/LESO-PB, 1998

3. A. Guillemin, N. Morel: Lighting controllers, venetian blinds. Technical report, LESO, EPFL, may 1999