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From hybrid model predictive control to logical control for shading system: A support vector machine approach

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ABSTRACT

This paper deals with the control of the blind system for building to prevent the thermal discomfort, which may occur during mid-season and summer. In the first part of this article, the problem is formulated with a Hybrid Model Predictive Control approach. However, the implementation of this solution on an industrial product remains a big challenge due to the limited computing capacity of this latter. As a result, we propose in the second part a logical controller whose rules and parameters are based on a learning from the behavior of the optimal controller using support vector machine (SVMs). In addition, we aim to demonstrate the importance of a proper selection of the measurements for the learning problem. In the last part, various simulations are performed with SIMBAD, a Matlab toolbox dedicated to building simulation, to assess the performance of the learned controller.

1. Introduction

In Europe, the building sector is the biggest consumer of energy among all sectors of the economy (43% of total energy consumption). To reduce consumer energy bills, buildings nowadays have a high thermal insulation and larger glazed openings. On the one hand, this new design makes it possible to take full advantage of solar radiation to heat the building and hence to reduce energy consumption in winter. On the other hand, it can cause overheating in mid-season and in summer. An optimal control of shading systems such as blind, roller shutter should maintain occupant's comfort level (thermal and visual) while controlling the solar heat gain and achieving a minimum of natural daylight without use of the electrical lighting. Hence it contributes to a significant saving on cooling and lighting consumption.

In the literature, many studies have been performed and have shown a potential for energy savings by using an automated control for shading devices [1–3]. Generally, the control algorithm chosen by many researchers is Rule-Based Control algorithm (RBC) – still the standard approach in today's building automation. RBC employs rules of the kind "if *condition* then *action*". Currently, building simulation programs such as TRNSYS or EnergyPlus have integrated a simple RBC based on a variety of parameters such as solar radiation, indoor and outdoor temperature, work plane illuminance, although the blind position is limited to fully open and fully closed.

In addition, recent studies have shown that Model Predictive Control (MPC) is a better choice not only for control of the blind [4] but generally for energy efficient control in building due to its advantages over other control strategies like the on/off or PID. Indeed, its main benefit is the ability to handle constraints in an optimal control environment and to anticipate the future behavior. However, the major challenge of this approach is its implementation in industrial products, which have a calculation capacity limited.

As a result, interests on methodologies to learn from the MPC behaviors and then to deduce a simpler controller like RBC have grown quickly in the last few years. Authors in [5] proposed a generalized linear model to mimic the general characteristics of the optimal results. Recently, several well-known algorithms in the field of Machine Learning such as support vector machine (SVMs) and AdaBoost are considered in [6]. However, these works have only focused on learning binary decisions.

In this paper, we employ the SVMs method to approximate the optimal controller MPC for blind control whose decisions belong to various blind positions. To the best authors' knowledge, this is the first time a multiclass SVMs problem is studied in such a context. The other main contribution of this work is the investment on the importance of ranking the measurements. On the one hand, it helps to reduce the complexity of the resulting controller and its implementing cost, which is especially interesting from the industrial point of view. On the other hand, it is necessary in order to guaranty a better performance of the solution. In addition, we offer a convenient and simple way for the logical controller to adapt the parameters according to occupants' demand for more

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thermal or visual comfort and without performing a new learning problem.

The paper is organized as follows. A brief presentation of the Hybrid Model Predictive Control is proposed in Section 2 where MPC optimization problem is formalized, including the models in use, the criteria on thermal/visual comfort and the constraints on limited number of movements. The SVMs technique and the proposed methodology to deal with the Multiclass problem and then to build a logical controller from the optimal case are represented in Section 3. Section 4 illustrates the importance of Feature Selection technique as well as the performance of the approximate controller in various simulation cases. We conclude in Section 5.

2. Hybrid MPC for blind control

The blind position is generally limited to fully opened or fully closed. In our case studies, the blind position are fixed at 4 positions, i.e. fully opened, fully closed, closed at 50% and closed at 75%, which are discrete variables, $u_b \in \{0, 0.5, 0.75, 1\}$. On the one hand, two intermediate positions give more degree of freedom to ensure the thermal comfort without deteriorating the visual comfort of the occupant. On the other hand, by considering the blind position as a discrete variable, it is easier to limit the position changes and thus ensuring a better blind life cycle by preserving its motor. Hence, this section is focused on the control of Hybrid systems using MPC. Several results in this research field can be found at [7].

Fig. 1 represents the MPC scheme. The control input is the blind position, the disturbances are the solar flux and the outdoor temperature and we seek to control the indoor temperature and the indoor luminance.

2.1. Model

The main benefit of MPC is its ability to anticipate the future building behavior during a finite horizon N. Therefore, models take a key place in the problem. The model used to predict the evolution for each output is described in the following section.

The solar flux and the outdoor temperature are the main factors that influence the building temperature behavior while the indoor luminance is impacted by the solar flux and the current blind position. As a result, we obtained the following equations:

$$x(k+1) = Ax(k) + B_\phi Flux(k)(1-u_b(k)) + B_T T_{out}(k)$$

$$T_{ind}(k) = Cx(k)$$

$$Lum(k) = G\,Flux(k)(1-u_b(k))$$

where $x(k)$ is the state of the system at time k, T_{ind} is one output of system, i.e. the indoor temperature, T_{out} is the outdoor temperature, $Flux(k)(1-u_b(k))$ is the solar energy received in the room which depends obviously on the solar flux and the blind position u_b, Lum is the brightness level, G is a conversion gain between the solar flux [W/m^2] and the luminance [lux].

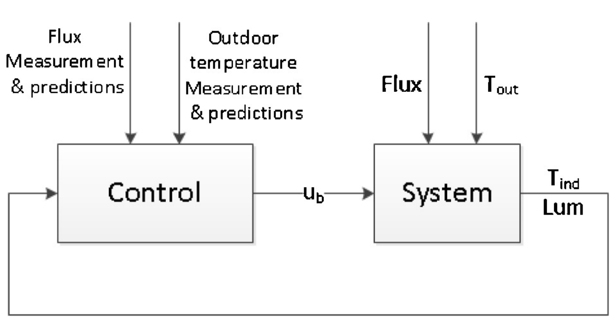

Fig. 1. MPC scheme for blind control.

It must be emphasized that the blind effect on insulation is neglected here. We use a 4 order model for our case studies.

2.2. Problem formulation

In this section, we describe the main parts of the hybrid model predictive control formulation for the blind control.

2.2.1. Optimization problem

The control objective is to ensure the occupant's comfort by preventing over heating. Occupants tend to use two thermal upper bounds: the first one in winter for which the temperature bound is fixed at 24 °C while 26 °C is usually set in summer. It should be noted that the difference between two set-points is mainly due to the different values of outdoor temperature between the two seasons. Indeed, householders prefer a lower bound in winter because the outdoor temperature is low.

In addition, we try to maintain a minimum of daylight, e.g. 300 lux in the room for the visual comfort whenever it is possible. A limited move is also considered to prevent the noise discomfort when changing the blind position and to preserve the motor life cycle.

The given constraints on the indoor temperature and the luminance can be defined by:

$$T_{ind} < T_{sp}$$

$$Lum > L_{sp}$$

where T_{sp} and L_{sp} are respectively the desired bound for thermal and luminance comfort.

The control variable is set:

$$u_b \in \{0, 0.5, 0.75, 1\}$$

where 0 is fully opened; 1 is fully closed; 0.5 and 0.75 are two intermediate positions.

We define J_{temp} the indoor temperature criterion as follows:

$$J_{temp}(T_{ind}) = \begin{cases} 0 & \text{if } T_{ind} \le T_{sp} \\ T_{ind} - T_{sp} & \text{if } T_{ind} > T_{sp} \end{cases}$$

The cost on the luminance bound is penalized when the luminance becomes lower than the visual set-point and can be defined as:

$$J_{lum}(Lum) = \begin{cases} 0 & \text{if } Lum \ge L_{sp} \\ L_{sp} - Lum & \text{if } Lum < L_{sp} \end{cases}$$

The penalization on a blind move is defined as:

$$J_{mov}(\Delta u_b(k)) = u_b(k) - u_b(k-1)$$

2.2.2. HMPC problem

At each time instant k, given the predicted outdoor temperature $T_{out}(k:k+N_h-1)$, the predicted solar flux $Flux(k:k+N_h-1)$, the previous blind position $U_b(k-1)$ and the current state $x(k)$, the optimization problem can be formulated as:

$$\min_{U_b(k:k+N_h-1)} \sum_{j=1}^{N_h} [\gamma J_{mov}(\Delta u_b(k+j-1)) + \delta J_{lum}(Lum(k+j-1)) + \theta J_{temp}(T_{ind}(k+j))] \quad (1)$$