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FUZZY CONTROLLER SYNTHESIS FOR BUILDING SHADING CONTROL

Abstract: *In this paper it is proposed Takagi Sugeno fuzzy controller to control the window shade deployment. The controller is implemented in Matlab software and interfaced with the building energy simulation in EnergyPlus. Energyplus can accurately simulate actual building performance and energy consumption but its capabilities are insufficient for advanced control system design. A co-simulation platform MLE+ is used for the control of the shading deployment status and shade angle schedule. Both conventional and advanced building control architectures can be implemented using Matlab.*
Keywords: *Shading control, Takagi Sugeno fuzzy controller, Matlab, Energyplus, MLE+*

1. INTRODUCTION

Building simulation tools for simulation of the system model and tools to design, evaluate and develop modern control techniques and methods play an important role in the design of energy-efficient buildings. Building simulation tools like EnergyPlus [1] is a very useful tool to investigate behavior of buildings and for evaluating their energy efficiency and sustainability. This software allows using schedule input of the parameters that affect on the thermal behavior of buildings, such as lighting, electrical equipment, the presence of people in the house, etc. This software also takes into account external influences to buildings such as solar radiation, shading, infiltration, wind direction, etc. Although EnergyPlus simulation tool can accurately simulate energy consumption of a building, its capabilities for modern control design and optimization are inadequate. A popular tool for building energy co-simulation is the Building Controls Virtual Test Bed [2], but it has a few limitations [3]. MLE+ [4] is an open-source Matlab/Simulink toolbox for building energy simulation and control development and validation. The MLE+ is applied to the optimal supervisory control problem of heating, ventilation, and air conditioning systems, [5]. The co-simulation platform MLE+ is introduced to implement an intelligent resilient control strategy in [6].

Shading control example used in this study already exists within MLE+ [7]. Fuzzy controller is implemented in Matlab and exchanges data with EnergyPlus via MLE+ co-simulation tool. In the recent years computational intelligece controls such as fuzzy control, neural network, neuro fuzzy have proved to be a very powerful tool for solving challenging realworld problems with uncertain and unpredictable environments. Control of complex and non linear systems is an important task and various fuzzy control strategies have been used to deal with nonlinearity of dynamic systems. Fuzzy control is a significant area of real uses of the fuzzy sets. In this paper it is proposed controller to control the window shade deployment such that the transmitted solar radiation through the window never exceeds a certain threshold.

2. BUILDING FUZZY CONTROLLER SYNTHESIS

2.1 Coupling control and building simulation

The analyzed building consists of three zones. The large window equipped with blinds/shades is located at the West zone of the building. The window is exposed to strong solar radiation during the day.

The goal is to control the window shade deployment of the west zone such that the transmitted solar radiation through the window never exceeds a certain threshold. The window blinds is controlled using shading deployment status and shade angle schedule. Design a controller in MLE+ monitors the angle and intensity of the solar radiation incident. The blinds will be deployed and the shade angle will be set to reduce the possibility of glare when the incident solar radiation exceeds a certain threshold (100 [W/m^2]).

deployment status (ShadeStatus) and shade angle schedule (ShadeAngle). Input variables of the proposed fuzzy controller are the angle of the solar radiation incident (IncidentAngle) and intensity of the solar radiation incident (Zone_West_Solar) and the sensible cooling rate (Zone_Sensible_Cool_Rate).

Matlab code of the proposed controller is:

```
   if Zone_West_Solar > 100 % 100 W/m^2
      % DEPLOYED WHEN SOLAR RADIATION EXCEEDS THRESHOLD
      fismat=readfis('fism');
      input=[Zone_Sensible_Cool_Rate; Zone_West_Solar];
      ShadeAngle=evalfis(input,fismat);
      ShadeStatus = userdata.Shade_Status_Exterior_Blind_On;
   else
      % SHADES NOT DEPLOYED
      ShadeStatus = userdata.Shade_Status_Off;
      ShadeAngle = IncidentAngle;
   end

   % FEEDBACK
   eplus_in_curr.ShadeStatus = ShadeStatus;
   eplus_in_curr.ShadeAngle = ShadeAngle;
```

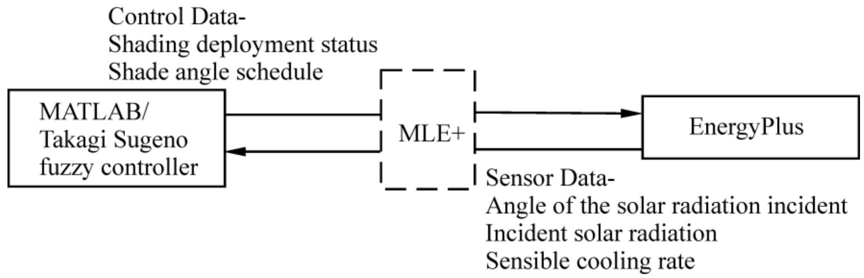

Figure 1. Closed-loop control using Matlab and EnergyPlus.

The EnergyPlus model of the building becomes Matlab S-function using MLE+. A co-simulation platform shown in Figure 1 connecting Matlab and EnergyPlus is used for the control of the shading

2.2 Simulation results

Chicago design day weather conditions were used. Those conditions are as follows:

Location: CHICAGO-OHARE
Latitude: 41.98 deg
Longitude: -87.9 deg
Time Zone: -6.0
Elevation: 201.0 m

Annual Heating 99% Design Conditions DB
-17.3 Maximum Dry-Bulb Temperature {C}
0.0 Daily Temperature Range {deltaC}
99063. Barometric Pressure {Pa}
4.9 Wind Speed {m/s}
270 Wind Direction {deg}
0.0 Sky Clearness
21 Day Of Month
1 Month
Annual Cooling 1% Design Conditions DB/MCWB
31.5 Maximum Dry-Bulb Temperature {C}
10.7 Daily Temperature Range {deltaC}
23.0 Humidity Indicating Conditions (wet-bulb) at Max Dry-Bulb
99063. Barometric Pressure {Pa}
5.3 Wind Speed {m/s}
230 Wind Direction {deg}
1.0 Sky Clearness
21 Day Of Month
7 Month

The Takagi Sugeno controller to control the window shade deployment was implemented in Matlab and interfaced with the building energy simulation in EnergyPlus. In this paper the MATLAB Fuzzy Toolbox is used for the implementation of the fuzzy controller.

The fuzzy rule in Takagi-Sugeno fuzzy system [8] has the format:

If *x* is *A* and *y* is *B* then *z=f(x,y)*

where: *A* and *B* are fuzzy sets in the antecedent; *z=f(x,y)* is a polynomial in the input variables *x* and *y*.

Supposing that the first-order Takagi-Sugeno fuzzy inference system has 2 inputs (x_1, x_2) and one output *y*. Fuzzy partitioning of the input variables of the Takagi Sugeno fuzzy controller is realized by selection of the three primary fuzzy sets. Linguistic labels x_j are A_{1j}, A_{2j}, A_{3j}. In this paper the input variables are Zone_Sensible_Cool_Rate and Zone_West_Solar. Linguistic labels of the input variables are small (A_{1j}), medium (A_{2j}) and big (A_{3j}). The output variable is ShadeAngle. *ZSCR* and *ZWS* denote Zone_Sensible_Cool_Rate and Zone_West_Solar, respectively.

The rule base of the Takagi Sugeno fuzzy controller is:

R_1: If *ZSCR* is small and *ZWS* is small then
$f_1 = -0.07254ZSCR + 16.83ZWS + 1333$

R_2: If *ZSCR* is small and *ZWS* is medium then
$f_2 = -0.07659ZSCR - 0.07507ZWS + 234$

R_3: If *ZSCR* is small and *ZWS* is large then
$f_3 = -0.07659ZSCR - 0.07507ZWS + 234$

R_4: If *ZSCR* is medium and *ZWS* is small then
$f_4 = -0.02668ZSCR + 10.84ZWS + 925.9$

R_5: If *ZSCR* is medium and *ZWS* is medium then
$f_5 = -0.07396ZSCR - 0.1215ZWS + 165.7$

R_6: If *ZSCR* is medium and *ZWS* is large then
$f_6 = 0.05607ZSCR + 10.55ZWS - 3476$

R_7: If *ZSCR* is large and *ZWS* is small then
$f_7 = -0.04983ZSCR + 13.12ZWS + 1114$

R_8: If *ZSCR* is large and *ZWS* is medium then
$f_8 = 0.01602ZSCR - 0.1324ZWS + 44.9$

R_9: If *ZSCR* is large and *ZWS* is large then
$f_9 = 0.03457ZSCR + 11.24ZWS - 3801$

The output of the Takagi-Sugeno

fuzzy controller can be presented as:

$$y = \frac{1}{\sum_{k=1}^{9} u_k} \sum_{k=1}^{9} u_k \left(\sum_{j=1}^{2} p_{kj} x_j + c_k \right) \qquad (1)$$

where:

$u_1 = \mu_{A_{11}}(x_1) * \mu_{A_{12}}(x_2)$

$u_2 = \mu_{A_{11}}(x_1) * \mu_{A_{22}}(x_2)$

$u_3 = \mu_{A_{11}}(x_1) * \mu_{A_{32}}(x_2)$

$u_4 = \mu_{A_{21}}(x_1) * \mu_{A_{12}}(x_2)$

$u_5 = \mu_{A_{21}}(x_1) * \mu_{A_{22}}(x_2)$

$u_6 = \mu_{A_{21}}(x_1) * \mu_{A_{32}}(x_2)$

$u_7 = \mu_{A_{31}}(x_1) * \mu_{A_{12}}(x_2)$

$u_8 = \mu_{A_{31}}(x_1) * \mu_{A_{22}}(x_2)$

$u_9 = \mu_{A_{31}}(x_1) * \mu_{A_{32}}(x_2)$

$*$ denotes *T*-norm.

If the Gaussian membership function is taken $\mu_{A_{ij}}\left(x_j\right)$ is given by:

$$\mu_{A_{ij}}\left(x_j\right) = e^{\frac{-\left(x_j - c_{ij}\right)^2}{2\sigma_{ij}^2}}, \; i = 1,2,3 \;\; j = 1,2 \qquad (2)$$

where: c_{ij} and σ_{ij} are the parameters of the membership function or premise parameters.

In Figure 2 and Figure 3 are shown the membership functions of the variable Zone_Sensible_Cool_Rate and Zone_West _Solar.

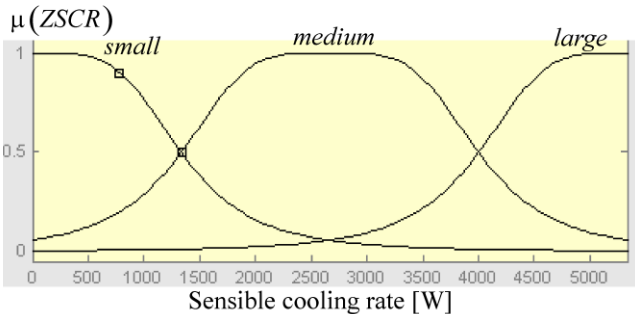

Figure 2. Fuzzy partitioning of the sensible cooling rate.

The output variables of the controller are shown in Figure 4 and Figure 5. The shades are deployed whenever the incident solar radiation exceeds a certain threshold 100 [W/m^2]).

3. CONCLUSION

Co-simulation platform with MATLAB and EnergyPlus is used to implement the proposed fuzzy control strategy. The MLE+ takes advantage of the MATLAB to design and simulate conventional and advanced control architectures. In this paper it is proposed simple controller to control the window shade deployment such that the transmitted solar radiation through the window never exceeds a certain threshold. The building consists of many dynamic subsystems which have mostly non-linear behaviors. Fuzzy logic controller is very suitable for controlling systems with nonlinearity and can efficiently deal with a complex object.

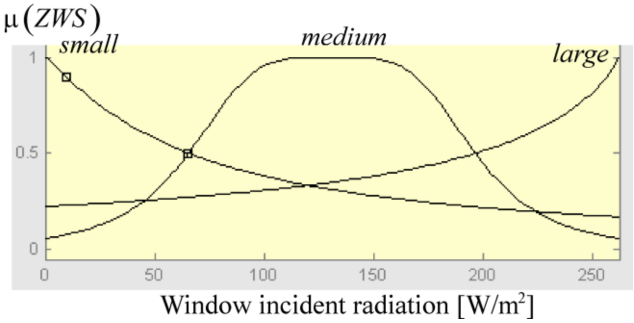

Figure 3. Fuzzy partitioning of the incident solar radiation.

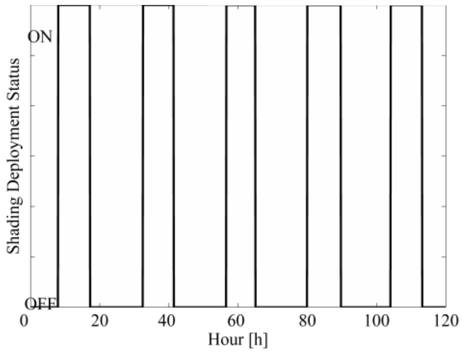

Figure 4. Shading deployment status.

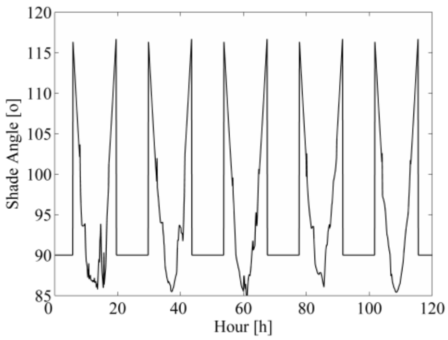

Figure 5. Shade angle.

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