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Model Predictive Control for Individual Room Control

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Abstract: This paper deals with model predictive control (MPC) for individual room control (IRC). Two models of a selected room were assembled, each with different complexity. The first of them is used as an exact replacement of the real room for a controller verification, the second one is used for a state observer and MPC controller design. Both the models were created using only a building documentation, what can be suitable especially for large buildings with hundreds of rooms. It was shown that MPC controller can be advantageously used for room temperature control. In the next work weather forecast and occupancy estimation could be incorporated into MPC controller design, what can bring energy savings.

Keywords: model predictive control, individual room control, temperature control, state observer.

1. INTRODUCTION

Model predictive control (MPC) has been successfully used in various control applications, starting from oil plants (García et al. (1989)), chemical industry (Gustafson (1987)), power plants (Gibbs et al. (1991)) and others.

In last years MPC was many times proposed for use in heating, ventilation and air conditioning (HVAC). Prívara et al. (2011) deployed MPC for university building heating control and reached significant energy savings, Rogers et al. (2014) proposed MPC controller for family house and achieved improved comfort and Huang et al. (2014) dealt with HVAC control for airport terminal building. Comprehensive review of MPC usage in HVAC has been created by Afram and Janabi-Sharifi (2014). Most authors focuses only on control of the building as a whole, where heating and cooling is centralized. It is the common case of older buildings, but the situation is different for recently constructed buildings.

Usually almost every room in such a building is equipped with individual room control (IRC), which addresses temperature control in individual rooms of the building. It usually consists of (sometimes programmable) controller with inputs and outputs, a control panel with a temperature sensor, a heating radiator with an electrically driven valve and a cooling fan coil with a variable speed blower and an electrically driven valve. Certainly there are many possible configurations, we chose the one described above as the most common one. Commonly the valves are controlled by PI controllers, which needs to be properly designed to achieve sufficient comfort for people in the room and energy efficiency for the building owner.

However even if the classic control system is properly adjusted, it can not take into account the weather forecast or occupancy estimation. So for example when the ambient temperature should rise (or the sun will be shining) according to forecast, the MPC controller can turn off the heating radiator and anyway the temperature will reach the setpoint and moreover with some energy conservation due to no (or minimal) temperature overshoot. Considering one room it might not be substantial amount of energy saved, but when it would be extended to whole building or even a campus, the savings may be significant.

In this paper we focus only on basic MPC usage for IRC (without forecasts and estimations), because MPC controller suitability must be verified before implementing complex control rules.

As a process model is strictly needed for MPC, we had to choose the way how to obtain it. Since the building documentation we have is very exact, we tried to build the model only using it. So we found out the heating and cooling power, construction materials and room dimensions and these information was used to build a room thermal model. This approach is beneficial especially for its easy repeatability for another room.

2. THERMAL MODELS OF A ROOM

Two dynamic thermal models of the room were assembled. The first one is based on Simulink Simscape library and is very complex and accurate. The second model was constructed using replacement scheme, which was afterwards used to build the state-space model.

Simscape model is created using thermal masses, conductive heat transfer and heat sources. The base of the model is the air in the room, which is connected to the building elements (like wall, ceiling, window etc.) and these are coupled to the other rooms and to the ambient air. Each building element is composed of multiple layers, which corresponds to a real element structure. For example the wall between the room air and the ambient air is composed of seven layers (drywall, air, bricks, steel plate, mineral

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$$\frac{d}{dt}\begin{pmatrix}\vartheta_1(t)\\ \vartheta_2(t)\\ \vartheta_3(t)\\ \vartheta_4(t)\\ \vartheta(t)\\ \vartheta_o(t)\\ x_{FC}(t)\\ x_{rad1}(t)\\ x_{rad2}(t)\end{pmatrix} = \begin{pmatrix} -\frac{1}{C_1R_1} & 0 & 0 & 0 & \frac{1}{C_1R_{1i}} & \frac{1}{C_1R_{1o}} & 0 & 0 & 0\\ 0 & -\frac{1}{C_2R_2} & 0 & 0 & \frac{1}{C_2R_{2i}} & \frac{1}{C_2R_{2o}} & 0 & 0 & 0\\ 0 & 0 & -\frac{1}{C_3R_3} & 0 & \frac{1}{C_3R_{3i}} & \frac{1}{C_3R_{3o}} & 0 & 0 & 0\\ 0 & 0 & 0 & -\frac{1}{C_4R_4} & \frac{1}{C_4R_{4i}} & \frac{1}{C_4R_{4o}} & 0 & 0 & 0\\ \frac{1}{C_rR_{1i}} & \frac{1}{C_rR_{2i}} & \frac{1}{C_rR_{3i}} & \frac{1}{C_rR_{4i}} & -\frac{1}{C_rR_i}-\frac{C_{AHU}}{C_r} & \frac{C_{AHU}}{C_r} & -\frac{4P_{FC}}{75C_r} & 0 & \frac{32P_{rad}}{625C_r}\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{300} & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{160} & -\frac{2}{625}\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{512} & 0 \end{pmatrix}\begin{pmatrix}\vartheta_1(t)\\ \vartheta_2(t)\\ \vartheta_3(t)\\ \vartheta_4(t)\\ \vartheta(t)\\ \vartheta_o(t)\\ x_{FC}(t)\\ x_{rad1}(t)\\ x_{rad2}(t)\end{pmatrix} + \begin{pmatrix} 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ \frac{1}{16} & 0\\ 0 & \frac{1}{16}\\ 0 & 0\end{pmatrix}\begin{pmatrix}u_c(t)\\ u_h(t)\end{pmatrix}, \quad (1)$$

$$y(t) = \begin{pmatrix}0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0\end{pmatrix}\begin{pmatrix}\vartheta_1(t)\\ \vartheta_2(t)\\ \vartheta_3(t)\\ \vartheta_4(t)\\ \vartheta(t)\\ \vartheta_o(t)\\ x_{FC}(t)\\ x_{rad1}(t)\\ x_{rad2}(t)\end{pmatrix} + \begin{pmatrix}0 & 0\end{pmatrix}\begin{pmatrix}u_c(t)\\ u_h(t)\end{pmatrix}, \quad (2)$$

wool, aluminium plate and terracotta panels). Each layer has defined thermal capacity and conductive heat transfer to both the adjacent layers. An example of one layer can be found in Fig. 1 (it can represent for example the bricks layer). Subsequently we added other important parts of the room model. The heating radiator and the fan coil are modelled as an ideal heat source with appropriate dynamics and adequate thermal power. Additionally influence of central air handling unit (AHU) was added to make the model as accurate as possible. The parameters of all model components were taken from building documentation, so the model can be constructed for any other room. The model was several times compared to the measured data and it was found that the model is satisfactory, see Fig. 2 and 3. Minor differences between the model and the real room behaviour can be caused by various disturbances (heat generated by human bodies, computers etc.), the measurements were carried out during normal room operation.

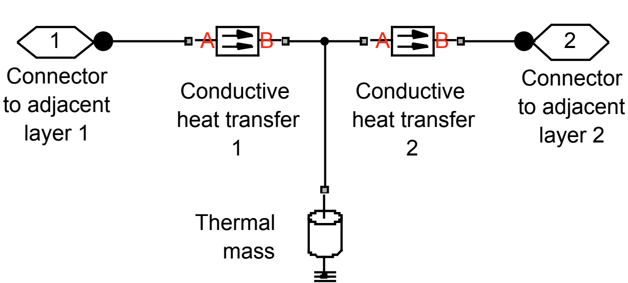

Fig. 1. One layer of construction element in Simscape room model

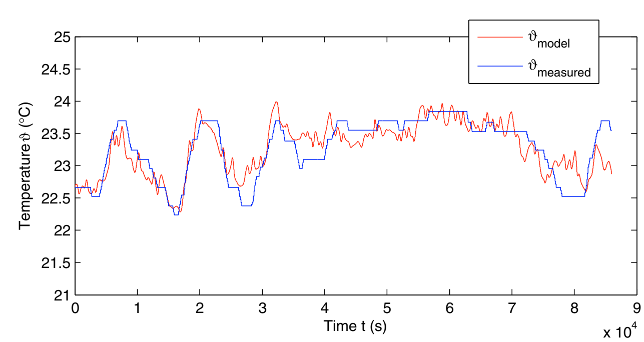

Fig. 2. Comparison of Simscape model and measured temperature during heating

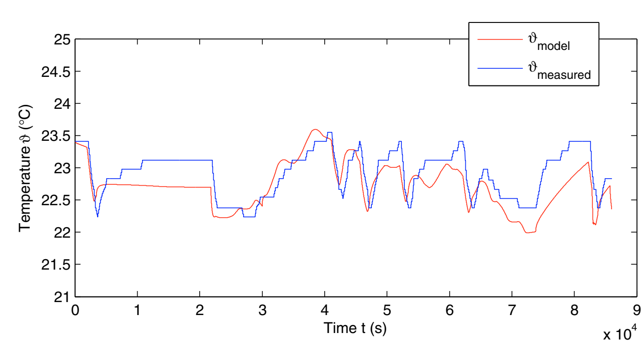

Fig. 3. Comparison of Simscape model and measured temperature during cooling