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ONLINE SYSTEM IDENTIFICATION IN THERMAL RESPONSE OF REAL BUILDINGS

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Abstract: *The paper presents two approaches to identify online the thermal model of a room. The identify model is intended to be use for energy consumption optimization. The model of the room and the identification algorithms were implemented and simulated in Matlab/Simulink. The obtained results are compared in order to determine the best approach for use in this case of systems.*
Key words: *online identification, Matlab/Simulink, thermal process, ARX model*

1. INTRODUCTION

Reducing and optimization of the energy consumption in the residential sector is an important issue in the context of the global warming effect. An essential step in this direction is the implementation of a measuring system and monitoring of the energy consumption. This thing can lead to a better energy usage of the different consumers. In the same time are necessary strategies that take into account the changing of the user behavior. In this context, it's necessary the realization of a simulator that will permit the study of different strategies for reducing the energy consume. As it's known, the main part of the energy consume of a house is represented by heating. From this reason, a first step is realization of the thermal model of a house. In literature are presented many examples of modeling and simulation of energy consumption in a household (Gustafsson et al., 2008; Mendes et al., 2003; Hudson & Underwood, 1999).

Due to the differences between each apartment a model that can define all cases cannot be made. Using an online identification method the model of a room can be obtained, or an existing model can be adapted to the particularities of each establishment. The identification is made using only the inputs and the outputs of the system. The input in this case is the thermal energy used for heating and the output is the temperature inside the room.

The model can be use to take online decisions regarding the evolution of the room temperature or to suggest a plan for the room heating. In the first case the obtained model is used by an adaptive control algorithm and the decisions are made automatically by the system. In the second case the model is used by an adaptive prediction algorithm in this case the decisions are made by the user.

The model use to determine the room dynamics is an ARX (Auto Regressive with eXogenous terms) model. The mathematic form of the model is presented in equation (1).

$$y(t) + a_1 y(t-1) + \cdots + a_{na} y(t-na) = b_1 u(t-nk) + \cdots + b_{nb} u(t-nk-nb+1) \quad (1)$$

The terms *y(t), y(t-1)....y(t-na)* represents the past *na* outputs of the system , *u(t-nk),.....u(t-nk-nb+1)* represents past inputs of the systems. The structure is completely define if the terms *na*, *nb* and *nk* are known. The *nk* parameter represents the system dead time.

2. ONLINE IDENTIFICATION METHODS

In this chapter two recursive identification methods will be presented. Both methods were implemented in Matlab/Simulink. The general form of the recursive algorithm is presented in equation 2.

$$\theta(t) = \theta(t-1) + K(t)(y(t) - \hat{y}(t)) \quad (2)$$

The term $\theta(t)$ represents the model parameters vector that is estimated at time *t*. The term *y(t)* represent the output at time t, and $\hat{y}(t)$ is a prediction of value *y(t)* based on observations up to time *t-1.* The gain *K(t)* determines the way the current prediction error $y(t) - \hat{y}(t)$ will modify the parameters vector. The form of the term *K(t) is:*

$$K(t) = Q(t)\psi(t) \quad (3)$$

where : $\psi(t)$ - is the gradient with respect to θ

$Q(t)$ – is a matrix that affects the adaptation gain and the direction in which the adaptation is made

The matrix $Q(t)$ can be developed in different ways, in this paper two of them will be presented. In the first case the matrix is computed from the Kalman Filter, the identification algorithm became:

$$\hat{y}(t) = \psi^T(t)\theta(t-1) \quad (4)$$

$$Q(t) = \frac{P(t-1)}{R_2 + \psi(t)^T P(t-1)\psi(t)} \quad (5)$$

$$P(t) = P(t-1) + R_1 \frac{P(t-1)\psi(t)\psi(t)^T P(t-1)}{R_2 + \psi(t)^T P(t-1)\psi(t)} \quad (6)$$

The algorithm is completely defined by R_1, R_2, P(0), $\theta(0)$ and a sequence of data y(t), u(t) {t=1,2,….}.

Another approach is to discount old measurements exponentially, so that the recent values have more weight in the model description. The forgetting factor is influence by the λ parameter; typical values for it are in the range of 0.97-0.995. The identification algorithm became:

$$Q(t) = \frac{P(t-1)}{\lambda + \psi(t)^T P(t-1)\psi(t)} \quad (7)$$

$$P(t) = \frac{1}{\lambda}\left(P(t-1) - \frac{P(t-1)\psi(t)\psi(t)^T P(t-1)}{\lambda + \psi(t)^T P(t-1)\psi(t)}\right) \quad (8)$$

The name of the algorithm is Forgetting Factor Approach to Adaptation, with forgetting factor λ.

3. DYNAMIC MODEL

The model of the house used for simulation is based on the model developed in (Gustafsson et al., 2008, Balan et al. 2009). Similar models are used in (Yu & Passen, 2004; Camacho & Bordons, 1999).

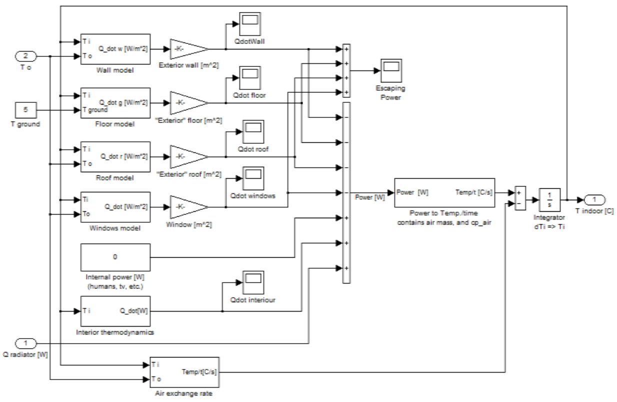

Fig. 1. Simulink model of a room

In fig. 1 the Simulink model of the room is presented. The model includes the thermal dynamics of the room walls, the windows, the doors, heat sources and the dynamics of the interior air currents. The model also includes internal sources like humans, computers, televisions etc.

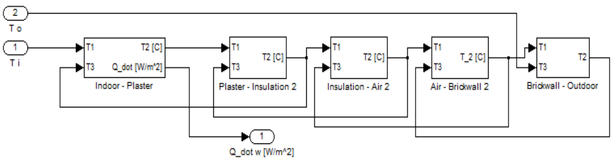

Fig. 2. Simulink model of a wall

The Simulink model of an external wall is presented in figure 2. As one can see the model includes all the layers of a wall, each one communicating with the other blocks through temperature ports.

The model parameters and the temperatures are displayed in the graphic interface presented in figure 3. The user can modify different parameters of the model, exterior temperature, inside desired temperature, etc.

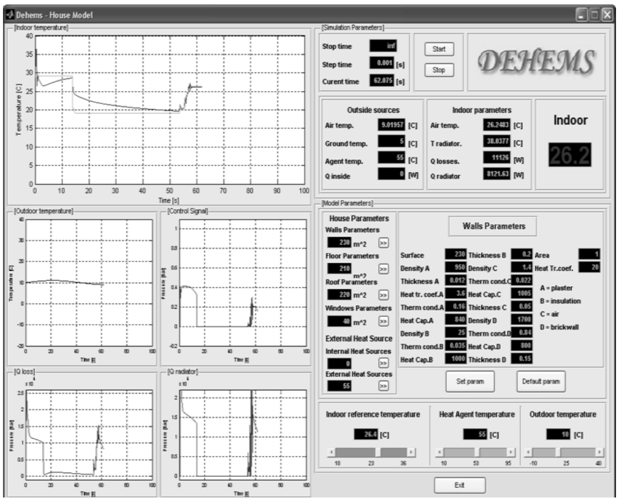

Fig. 3. Model interface

4. EXPERIMENTAL RESULTS

The identification algorithms were implemented in Simulink. The identified process was the model of a room; the model was presented in the previous chapter.

In order to visualize the experimental results, a graphic user interface was developed; the interface is presented in fig. 4. The interface presents the evolution of the system output and the evolution of the model parameters. Based on the identified parameters, the interface determines the position of the model poles and zeroes.

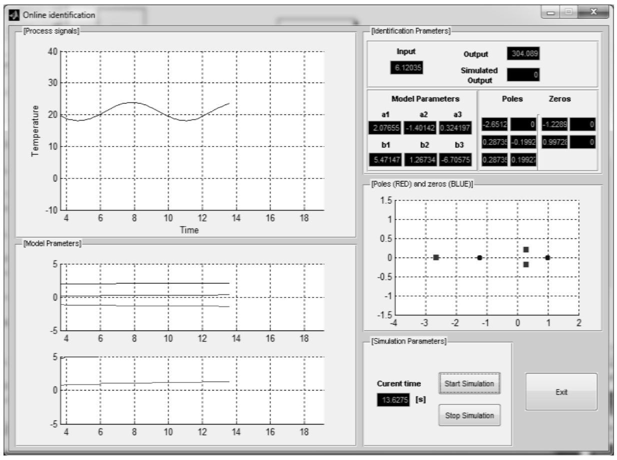

Fig. 4. User interface

The parameters of the identify model were: na=3, nb=3 and nk=5. The sample time use was 1 minute. Using the first method the obtained parameters were *a=[2.07, -1.4, 0.32], b=[5.47, 1.26, -6.705]*, and with the second method *a=[3.1, 2.1,- 4.11], b=[0.12, -1.3, 0.88]*. The obtained models were simulated in parallel with the room model and the best results were obtained using the Kalman filter approach.

5. CONCLUSION

The paper presented two approaches for online identification of a thermal model of a room. First method based on the Kalman filter gave the best results for the tested plant. The algorithm use as input the thermal energy and as output the room temperature, all other parameters that influence the thermal behavior of the room are consider disturbances. The implemented user interface gave the opportunity to easily visualize the evolution of the model parameters and the simulated response of the model.

The tested algorithms are intended to be further use for model based adaptive control algorithms and for prediction algorithms.

6. ACKNOWLEDGEMENTS

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