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A DECENTRALIZED APPROACH ON THE ENERGY MANAGEMENT IN BUILDINGS

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Abstract: Buildings are accounted to consume around 40% of the total energy in Europe and USA, even more – up to 60% - in Canada and Scandinavian countries, and the rate of growth of the number of buildings follows the growth of the population. In this context, there is a vast literature dedicated to finding solutions for saving energy through innovative control systems of the heating, ventilation and lighting in residential and commercial buildings. This paper proposes a solution for controlling the HVAC system in small and medium size buildings by means of a distributed neural network, implemented using low cost microcontrollers, connected with passive infrared (PIR) motion detectors. This network is capable to detect and learn user occupancy and activity patterns, relevant for the energy management of the building. Unlike other similar systems, in our approach the energy management is entirely decentralized, relying exclusively on the above mentioned distributed ANN.

Keywords: Building management systems, Energy saving, Activity recognition, Distributed neural networks.

1. INTRODUCTION

In most developped countries, buildings are accounted to consume more energy than the industry or the transportation system (see EIA, 2016a; EIA, 2016b; EIA, 2016; European Parliament, 2010; Nguyen & Aiello, 2013). Figure 1 shows the structure of energy consumption in Europe. In North America, the proportion of the energy demand of the buildings in the total energy consumption is even higher. However, as noted by Nguyen & Aiello (2013), and Frost & Sullivan (2007), up to one third of all the energy used in buildings can be saved by using relatively simple measures.

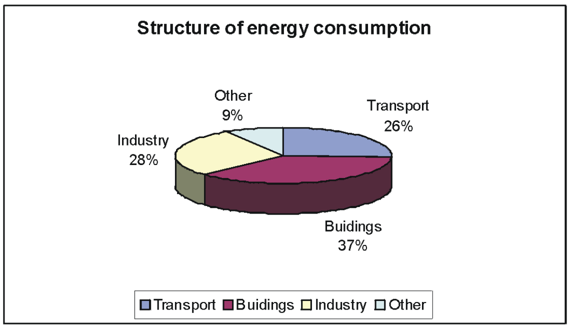

Fig.1. Structure of the energy consumption in Europe

Among the most promising approaches for energy saving, Corucci et al. (2011) and De Paola et al. (2014) cite:

- Developping a so-called "energy consumption awareness" at the user's level. Note that some authors (e.g. Tokuda et al, 2013) suggest the implementation of "energy aware appliances", while others (see Agarwal & Weng, 2012) extend this concept to "energy aware buildings".

- Reducing standby consumption. The simple measure of switching off some appliances rather than letting them in stanby can be very efficient, knowing that some appliances, which are left in standby for extended periods of time, consume more energy in stanby that in normal operation.

- Automatically scheduling the operation of certain devices or machines (e.g. dishwashers, washing machines), may reduce the peak energy demand and optimize the overall energy costs.

- Finally, the adaptive control of the heating, ventilation, air conditionning (HVAC) systems, and lighting in accordance with certain activity patterns of the occupants of the buildings, may significantly reduce the energy consumption without affecting the overall comfort of the users.

This last energy saving strategy is used in the solution proposed in this paper. Following this approach, we describe a system wherein the reference temperature for the HVAC is generated by a distributed artificial neural network (dANN), implemented by means of a network of low cost microcontrollers that monitor the passive infrared (PIR) motion detectors normally present in any building as part of the security system.

The solution described here makes the object of the patent application RO128439-A2 (Susnea & Vasiliu, 2013).

Apart from this introduction, the structure of this paper is as follows:

- Section 2 contains a brief description of the related work.

- Section 3 contains the actual presentation of the proposed solution.

- Finally Section 4 is reserved for discussion and conclusions.

2. RELATED WORK

The solutions aimed to create systems capable to optimize the energy consumption of buildings by observing the behavior of the occupants range from designing improved thermostats (Gao et al. 2009; Lu et al., 2010) to rethinking the concept of "smart home" (see Alam et al., 2012).

A review of the recent research regarding these topics is available in (De Paola et al., 2014) and (Zehnder et al., 2015).

Among the technologies used for occupancy detection and user activity recognition, De Paola et al. (2014) cite:

- Video Cameras
- Motion detectors (PIR)
- Door sensors/switches
- Floor sensors
- RFID tags for object identification and localization
- Sound sensors
- Power sensors

Each of the above mentioned sensors have their own advantages and drawbacks, but from the perspective of the final cost of the system, using the PIR motion detectors appears to be one of the most convenient solutions.

In what concerns the actual artificial intelligence (AI) techniques used for activity recognition, De Paola et al. (2014) enumerate:

- Data mining,
- Bayesian networks,
- Hidden Markov Models
- Fuzzy logic
- Neural networks,
- Reinforcement learning

For a more in depth review of the research literature in the field of activity recognition see (Turaga et al., 2008).

The simplest to create a link between certain activity patterns and the operation of the HVAC system is to instruct the HVAC to adjust the reference temperatures of the thermostat according to a schedule based on an estimate of the building occupancy during certain time intervals.

In practice, however, the predictions on the occupancy levels are seldom accurate, and such a system will either force energy savings by affecting the comfort of the users, or fail to save energy.

One interesting solution to avoid this drawback is proposed in Lifson & Taras (2007), who describe a system wherein the reference temperatures for the HVAC are derived from the weather forecast reports preiodically downloaded from a specialized Internet site.

Osman and Lemke (2005) propose a system wherein an artificial neural network attempts to predict the energy load of the building for several hours ahead.

In Cohen (2009), a simpler and more efficient solution is based on the idea that the occupancy levels of the buildings are accurately reflected by the states of the security system control panel, and suggests a method to control the HVAC in accordance with the state of the security panel.

All the above cited solutions rely on a centralized control system. Using a different approach, in Susnea & Vasiliu (2013), we proposed a decentralized control system capable to adjust the temperature references of the HVAC based on activity patterns detected by a distributed neural network. The following section contains a description of this solution.

3. DESCRIPTION OF THE PROPOSED SOLUTION

In (Susnea, 2012) it is argued that, for any three-layer perceptron it is possible to build an equivalent distributed neural network, consisting in a number of "detachable neurons", which communicate with each other using a specific protocol.

In this approach, the processing and communication tasks for these "detachable neurons" can be easily assigned to low cost microcontrollers, connected in a wired or wireless communication network.

Starting from this idea, we proposed a system with the structure depicted in figure 2.

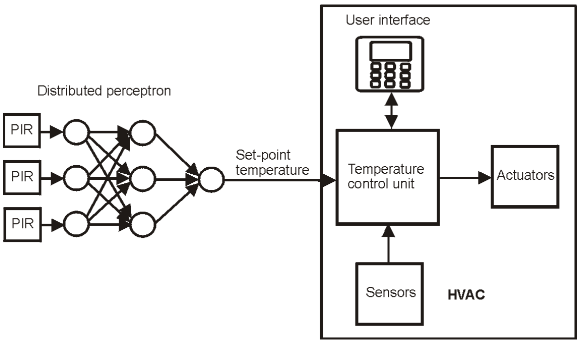

Fig.2. The structure of the proposed system

The input of the distributed ANN is represented by the ON/OFF signals generated by a number of PIR motion detectors, and the output is an analog voltage used to define the reference temperature for the HVAC system.

Obviously, the key of the solution is to find a means to integrate the temporal series of "events" detected by the PIR sensors, into user activity patterns.

We solved this problem by considering a model of the integration of the PIR data as shown in figure 3.

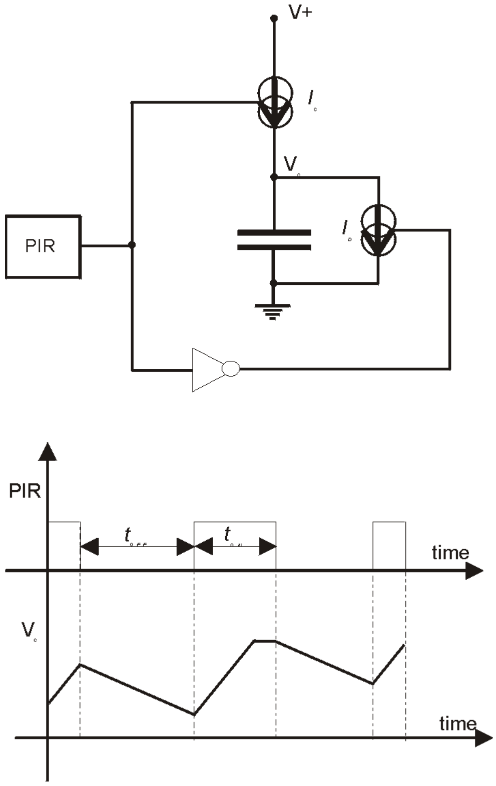

Fig.3. The model of the integration of the PIR provided data

According to this model:

(1) $$V_C = I_C \sum_{\tau} t_{ON} - I_D \sum_{\tau} t_{OFF}$$

where Ic – the charge current, I_D – the discharge current. In practice $I_C >> I_D$.

Obviously, the entire model can be easily implemented by software, running on the microcontroller conected with each PIR motion detector, so there is no need to use any hardware for the integrator.

The resulting ANN operates for a certain time in learning mode (using the classic backpropagation algorithm – see Rojas, 2013) and becomes capable to approximate the reference temperatures of the HVAC previoulsly provided by the human operators.

Once the ANN has learned to generate set-point values for the HVAC starting from user activity patterns, the system can operate independently.

4. DISCUSSION AND CONCLUSION

The solution described here can be a valuable alternative to the "classic" building management systems (BMS), suitable for small and medium size residential and office buildings.

Obviously, the entire concept can be adapted to control the lighting system.

Considering that most modern buildings are currently equipped with security systems that already deployed PIR motion detectors throughout the premises, the cost of the implementation of the proposed system could be significantly reduced by using the existing PIR sensor.

Besides the low cost, the proposed system has all the advantages of a distributed control system: good scalability, robustness to hardware faults, and easy maintenance.

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