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Controlling the fluid factors of an environment by sensor and actuator networks

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ABSTRACT

Recently, wireless sensor and actuator networks (WSANs) have been widely discussed. An important application of WSANs is the control of environmental fluid factors, such as temperatures, in an environment. In this paper, we study the control of temperatures in an indoor environment with energy saving in mind. Temperature sensors are deployed in a regular grid or a random manner. Actuators are controllable air conditioners with multiple outlets. Users may be located in any places in the environment. We consider two user satisfaction models: *binary* and *continuous*. Based on these assumptions, we present models and control mechanisms to adjust air conditioners to meet users' requirements. Simulation results show that our mechanisms can indeed achieve our goals in an efficient way.

1. Introduction

The rapid development of wireless communications technology and embedded microelectromechanical systems has made *wireless sensor and actuator networks* (WSANs) possible. A WSAN [1–3] is a distributed system consisting of sensor and actuator nodes interconnected by wireless links. Utilizing sensed data from deployed sensors, actuators can perform actions accordingly. The possible applications of WSANs include environment control [4,5], environment monitoring [6,7], localization [8,9], etc.

Environment control is one of the most important WSAN applications. Through the data reported by sensor nodes deployed in the environment, we may automatically trigger actuators, such as lamps, air conditioners, and humidifiers. Many appliances have been developed with such features [10]. However, most of these products are on-and-off or discrete kinds of control. They do not address the users' preferences and activities and the control of fluid factors, such as air temperatures, in the environment. Note that controlling fluid factors is more challenging than controlling things that spread in a regular shape, such as light. The above observation motivates us to study the control of air temperatures, a form of fluid factors, by WSAN.

In a building, more than one third of electricity is spent on HVAC (Heating, Ventilating, and Air Conditioning) according to [11]. How to automatically adjust HVAC systems to meet users' requirements while reducing energy consumption is an important issue. Traditionally, PID (Proportional–Integral–Derivative) controller [12] is a common control mechanism. PID controller, which attempts to correct the error between the measured and desired value by a feedback mechanism, is the generic control loop feedback mechanism. PID controller can quickly converge while setting parameters suitably. However, the PID controller is not suitable for air conditioner control because temperature needs longer time to achieve the steady state. For example, when we turn on an air conditioner, the indoor temperature needs a long period of time to

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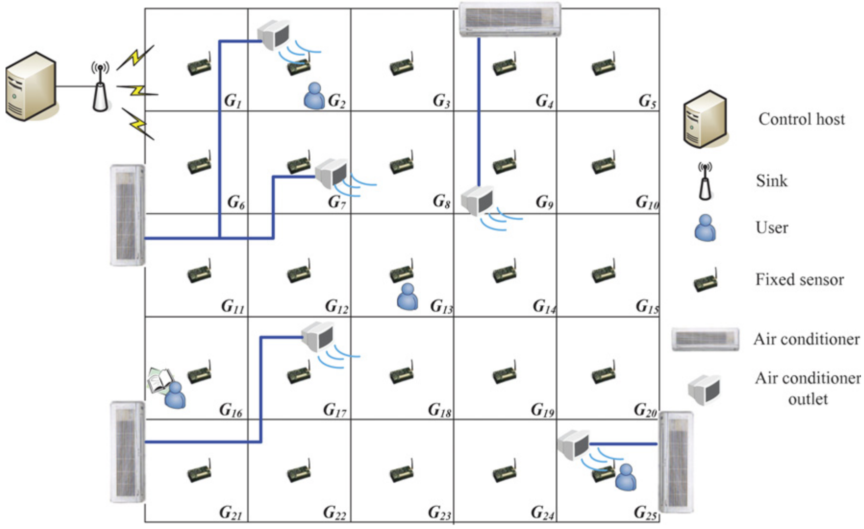

Fig. 1. The network architecture of our system.

achieve a steady state. Recently, several control strategies [13–19] for HVAC have been proposed. A neural network-based strategy for thermal control is presented in [13]. The system can maintain a comfort level within the desired temperature range. A fuzzy logic controller that addresses both energy consumption and comfort requirements is proposed in [14]. A multi-sensor, single-actuator HVAC control system that tries to minimize discomfort and energy consumption is presented in [15]. Some HVAC control mechanisms [16–20] save the energy consumption by predicting or detecting the occupancy. A commercial product of smart thermostat [21] for home learns the personal schedule for energy-efficient control of the indoor temperature. These solutions either fail to consider users' requirements or fail to allow users to have different requirements. Although our prior works [4,5] for the intelligent light control consider users with different requirements, the mechanism cannot be applied to the control of fluid factor directly since the fluid factor may spread irregularly.

This paper considers both users' requirements and energy consumption when controlling the fluid factor in an indoor environment. Fig. 1 shows our network architecture. The field is divided into regular grids, each of which is deployed with a temperature sensor. The control server is responsible for collecting temperature values from all sensor nodes. Multiple controllable air conditioners are deployed in the environment, each of which may have more than one air conditioner outlet. We assume that the indoor environment such as an office space is large enough to have obvious temperature changes from each outlet to the whole environment. Users may locate arbitrarily in the field and each user has his/her own preferred temperature profile. Our goal is to control the temperature of the environment by adjusting the power levels of air conditioners to satisfy more users while saving energy.

The contributions of this work are as follows. First, we consider temperature requirements for individual users in our control policy since the temperature adaptability of users may differ. Second, we exploit a regression-based training mechanism to learn temperature changes after controlling the air conditioners for avoiding the need of feedback control. Third, we consider two different satisfaction models for modeling the user's need. Finally, we may eliminate the assumption of the grid deployment of sensors by slight modifications to our approach.

The remainder of this paper is organized as follows. Section 2 formally defines our network scenario and problem. Section 3 presents our controlling schemes for different models. Performance evaluations are presented in Section 4. Conclusions are drawn in Section 5.

2. Problem definition

In our system, the field is divided into n regular grids labeled as $G_1, G_2, \ldots, G_n$. There are n fixed sensors, m air conditioners, and q users in the field. In each grid G_i, $i = 1 \ldots n$, there is a fixed sensor s_i, which can report G_i's current temperature v_i. Each air conditioner a_j, $j = 1 \ldots m$, is controllable and provides multiple levels for operation. The current level of a_j is denoted by d_j. A larger level value means that higher power consumption will be needed for operating in that level. For example, the level of an air conditioner which is set to 28 °C is smaller than the one which is set to 23 °C. Different mapping functions for levels and power consumption should be defined for different kinds of appliances. Moreover, considering physical limitations, we assume that $d_j^{min} \le d_j \le d_j^{max}$. Each user u_l, $l = 1 \ldots q$, has a temperature requirement and we assume that the system is able to detect u_l's current location, represented in terms of grids (how to conduct indoor localization is beyond the scope of this paper; the audiences are referred to [8,22] for more details). In this environment, we also assume that there are heat sources at the boundary of this environment, e.g., sunlight through French windows,

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