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Preliminary study of learning individual thermal complaint behavior using one-class classifier for indoor environment control

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ABSTRACT

This paper proposes a data-driven learning method to describe the personal thermal complaint behavior in a complaint-driven environment control system. The complaint-driven system only uses personal human complaints to control the personal office environment. It avoids the user's direct control on the set-point of the room, which usually results in unreasonable and uncomfortable set-point. A two-stage classifier model is proposed, using personal thermal compliant data with respect to the transient and steady complaint behaviors. The classifier structure is developed based on the properties of human thermal perception with parameters to learn for different users. Quantitative results using experimental data show that the model has lower false negative rate than traditional data-driven classification model and acceptable false detection rate. Practical implementation and subjects' questionnaire evaluation demonstrate the satisfying performance of the model in real environment control. We also discuss the limitations and potential extensions of the model at the end of this paper.

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1. Introduction

Current ordinary office environment control systems are all based on set-point scheme. One typical case is the centralized control by operation managers in buildings. Another typical case is the user-specified set-point control, i.e. occupants set the operational set-points of the indoor environment themselves. These systems suffer from either limited individual comfort satisfaction or unreasonable set-points from the occupants. The survey results in Ref. [1] also reveal that the inconsiderate use of the set points can jeopardize the system control efficiency and thus decrease the energy efficiency. Personalized complaint-driven indoor environment control is a promising solution to these problems, where occupants only complain to the system by a Human Machine Interface (HMI) if they feel uncomfortable. Then, the system will automatically change the indoor environment according to the occupant's historical record to meet the occupant's requirement. The overall structure of the system is illustrated in Fig. 1. Complaint is the most direct and intuitive reaction of human to the environment and thus the system is more user-friendly. Occupant, environment and the control system form a closed-loop. Related work about the system and preliminary experiment has been presented in Ref. [2]. However, without the set-point command, the system will face the problem of how to interpret the individualized human complaint to control the environment, i.e. the bold margined box in Fig. 1. This paper focuses on modeling the individualized human thermal complaint (hot and cold complaints), which is the most important aspect in indoor environment control [3]. The self-learning personalized complaint model can be used in the personal comfort control system [4]. It is also a necessary step before considering multi-person cases.

Thermal complaint is an expression of thermal discomfort. Thermal comfort has been studied intensively for many years and those fruitful results might be helpful to understand the thermal complaint. A well-known work is the Predicted Mean Vote – Predicted Percent Dissatisfied model (PMV-PPD) proposed by Fanger [5,6]. It gives a uniform description of how the thermal sensations are related to the environment parameters and the personal factors. A series of studies following PMV were carried out by many researchers, such as Humphreys and Nicol [7], where they validated the PMV using ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers) database and analyzed the origins of the bias of PMV. Wu [8] incorporated the building architectural parameters into empirical PMV. Langevin et al. [9] used the Bayesian estimation on the data from both laboratory and field settings to estimate the acceptability distribution and revise the

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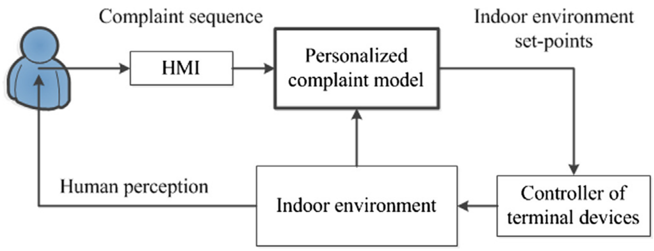

Fig. 1. General framework of complaint-driven control system.

PMV-PPD curve. Another type of model is the physiology based model, such as the two-node model [10] and the multi-segment human body model [11]. Re-evaluations, further discussions and extensions are still ongoing [12,13]. Researchers also utilized field studies to investigate the human comfort such as the transient thermal comfort [14] and the adaptive models of comfort [15,16], the green occupant's altitude towards green buildings [17]. An overview on field studies in the past few decades can be found in Ref. [18]. However, most of the models try to establish a mapping between the environmental parameters and the human comfort vote, typically the ASHARE 7-level scale. Although they have played important roles in indoor environment design and evaluations, they can't be directly converted to individual complaint model quantitatively. Federspiel CC [19] proposed a stochastic process model to describe the complaint frequency for a group of persons. They also did not consider the individual difference and cannot be used on-line [20].

With the wide application of information technology in building systems, we bring the data-driven method to describe individual thermal complaint behavior. Rather than designing comprehensive experiments in chamber with control–case groups, we use machine learning techniques to learn the complaint model on-line. The main contribution of the paper is the proposal of a systematic learning method to describe the individual thermal complaint, which is a revisit to the human thermal comfort from a new prospective. It includes the transient and steady stage behaviors and especially applicable for the on-line personal environment control with user-friendly interaction. We first introduce the preliminary experiment and the preliminary observations of the individual thermal complaint behavior. Based on those observations and properties, the data-driven complaint model using multi-linear one-class classifier is presented. Detailed performance analysis using the preliminary data is presented. We also carry out an on-line test to validate the proposed learning method in real implementation. Both the quantitative metrics and questionnaire survey results about the control effects based on the model are presented.

2. Experiment and observations

2.1. Experiment settings and procedures

Due to the limited experimental researches about the individual complaint behavior in literature, we first carried out a preliminary observation experiment to collect complaint data. A test-bed, which is located in Tsinghua University campus, was built, whose size is 6*6 m^2 and the layout is similar to an office room. The test-bed has a dedicated Heating, Ventilating and Air Conditioner (HVAC) system (radiant cooling with independent fresh air unit) and a Human Machine Interface (HMI) for subjects to register their complaints (Fig. 2). The HMI has all kinds of complaint buttons and the complaints will be recorded if user presses them. Sensors to measure the air temperature, relative humidity and air velocity are installed. All the data, i.e. the human complaint data, the environment measurements and the HVAC running parameters are recorded in a real-time database.

The experiments were carried out from late June to late August, 2011, which is summer in Beijing with the monthly average temperature about 29 °C. Six subjects, who had enough time and were interested in the experiment, were engaged (Table 1). Each time, one subject entered the test-bed at the scheduled time and started to do some office work. They were required to dress relative consistent clothes during all the experiments and were instructed to feel free to express thermal complaints through HMI. When complaints happened, the system would respond to the complaint according to some preliminary specified rules to control the temperature and humidity (such as decreasing the temperature by 0.5 °C when hot complaint occurred, vice versa). For each subject, 24 units (each unit is 3–4 h) of experiments were carried out to ensure the data's statistical significance.

2.2. Preliminary observations

There are total 321 hot and cold complaints collected during the 93 units of experiment (hot: 215, cold: 106). The indoor air temperature is overall ranging from 20 to 30 °C, but different for each subject because of the different complaint behaviors. In this study, we focus on describing the individualized complaint behavior using air temperature and relative humidity. The measured mean radiant temperature has a highly positive linear correlation with the air temperature and the difference is consistently less than 0.8 °C. Thus we only use the air temperature in the analysis. Though other factors such as the metabolic rate, clothing index, etc., of course influence thermal comfort, the air temperature and relative humidity are the only two that can be controlled by the HVAC system and are therefore included in the algorithm.

Fig. 3 shows two typical subjects' hot and cold complaints data in the temperature and relative humidity space during their experiments. Each dot in the figure represents a complaint sample, i.e. the environment measurements when the complaint occurred. As we expect, the hot complaints generally happen in relative higher temperature region while the cold complaints in lower temperature region. Although there are only scattered dots in the figure, it is believed that there is a region in which the subject will tend to complain. The individual difference can be reflected through the different locations and shapes of the regions. For instance, the subject in Fig. 3(b) seems to complain hot in a lower temperature region than that of Fig. 3(a).

However, it is not difficult to see that there seems to be no comfort region in Fig. 3. The hot and cold complaint regions are even overlapped. This phenomenon exists for almost all the subjects. Further analysis reveals that subjects' complaint behavior has variations from the arrival period to the steady period in each experiment unit. Fig. 4 gives a further illustration of the data using the time after arrival as x-axis and air temperature as y-axis. We can see that the cold complaints for these two subjects tend to occur more than 1 h after arrival. The hot complaints which occur in lower temperature tend to occur in less than one hour after arrival. The same environment at different time might incur different complaints. This indicates that we need to distinguish the transient and steady complaints. Thermal perception under transient stage has been studied by many researchers, such as Gagge [10], Kaynakli and Kilic [21], and Zhang and Zhao [22]. In transient stage, occupants just arrive in the office; their metabolic rate and thermal regulation of body are in unsteady state because of the various activities outside. Thus, their thermal perception and complaint behavior are different from the steady state. If we separate the

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