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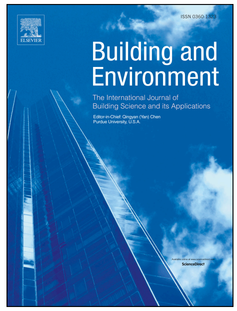

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Vision-based Thermal Comfort Quantification for HVAC Control

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Abstract

This study presents a vision-based approach that employs RGB video images as the sole source for inferring thermoregulation states in the human body in response to thermal condition/sensation variations in indoor environments. The primary objective is to contribute to our envisioned thermoregulation-based HVAC control that leverages actual thermal demands from end-users' thermoregulation states for increased energy efficiency. Our approach has been proposed in the context of four constraints of feasibility and scalability: non-intrusiveness, applicability, sensitivity, and ubiquity. To this end, the approach leverages ubiquitously obtainable RGB-video images (through webcams or smartphones) and photoplethysmography (PPG), a well-known optical technique for measuring blood volume changes in the microvascular bed of skin. Specifically, the approach leverages the mechanism of controlling the blood flow to skin surface (blood vessels' dilation and constriction) to adjust heat dissipation. Given the subtle nature of PPG signals and their susceptibility to noise, we proposed a framework that uses a combination of independent component analysis and adaptive filtering to reduce unwanted and in-band artifacts while preserving the amplitude information of PPG signals. The framework was experimentally evaluated using transient thermal conditions to account for applicability and sensitivity attributes. Therefore, without considering an acclimation time for stability of thermoregulation states, human subjects were exposed to varying temperatures (~ 20 – 30°C) while reporting their thermal sensations. In total, for 10 human subjects out of 15, a positive correlation between vision-based indicators, skin temperature, and thermal sensations were observed demonstrating promising potential in inferring thermal sensations of occupants with sufficient sensitivity.

Keywords: User-centered HVAC system; Personalized thermal comfort; photoplethysmography (PPG); Thermoregulation; Adaptive filtering; Skin temperature.

1. Introduction

The major objective of heating, ventilation, and air conditioning (HVAC) systems is to provide satisfactory thermal conditions for occupants by leveraging thermal feedbacks from the environment. The feedback is commonly represented as temperature variations in an environment with implied user thermal satisfaction. Current HVAC systems are designed to use the predicted mean vote (PMV) model, promoted by standards, such as American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standard 55 [1], as an approach for reflecting occupants' perspective. However, it has been indicated that the use of generalized metrics of the human-related parameters does reflect the characteristics of actual occupants. Consequently, a considerable portion of occupants endure thermal dissatisfaction [2] due to inaccurate thermal sensation estimation (stemmed either from PMV limitations [3-6] or inaccurate information from individuals) or over-cooling/heating [7]. Such operational limitations often bring about considerable reduction in energy efficiency of HVAC systems despite their leading contribution in driving building energy demands [8].

In addressing the aforementioned limitations, integration of post-occupancy feedback from diverse actual occupants [9] into the control loop of HVAC systems is a key step to satisfy individual thermal demands. The fast-pace growth in ubiquitous communication technologies have provided the ground for this change. This class of techniques, which is commonly called personalized (alternatively user-centered or user-led)