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A tracking cooling fan using geofence and camera-based indoor localization

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ABSTRACT

Compressor-based cooling systems have a large impact on energy consumption in modern buildings, particularly in the tropics. Elevated air movement by electric fans is a cost-effective cooling method for both energy saving and thermal comfort improvement. In this paper, a tracking cooling fan using geofence and camera-based indoor localization is proposed. Personal cooling service is provided based on the detection of the occupant in the area bounded by virtual geofences. The proposed camera-based indoor tracking system is able to accurately locate the positions of the occupant, determine the direction of air flow, and calculate the occupant-fan distance. The tracking fan is able to provide the needed air speed determined by PMV-SET thermal comfort model using a calibrated mapping algorithm. The effectiveness of the proposed system has been verified through experiments which show that the system is able to operate with low power while improving thermal comfort. The system can be used in an air-conditioned environment with higher temperature setpoint to save energy or in a naturally conditioned environment for thermal comfort enhancement.

1. Introduction

In warm climates, compressor-based cooling is the main contributor to the energy consumption in buildings. In the United States, compressor-based cooling accounts 13% and 14% of primary energy consumption in commercial and residential buildings respectively [7]. In tropics such as Singapore, the electricity consumed by air conditioning comprises up to 50% of total electricity usage by buildings [22]. Timing and quantity of energy use associated with cooling have large impacts on cost, greenhouse gas emission, peak load of electricity use and reliability of electrical grid.

Raising cooling setpoint of air conditioning system can both bring financial benefits [8,11,26,27,30] and reduce negative impact on the environment [21] but it may run the risk of sacrificing the comfort level felt by occupants, directly influencing their health, well-being, and productivity.

The challenge can be overcome through elevated air speed generated by electric fans which is a cost-effective and energy-efficient cooling method. Unlike compressor-based cooling systems which lower the air temperature and humidity, electric fans increase the air movement around people. Air movement has significant cooling effect and increases the acceptable range of indoor temperatures [18,29,37]. It can be used in conjunction with the air conditioning system.

Most of cooling fans are not connected to the building management system (BMS) and the few that are connected operate based on maximum occupancy assumption, fixed air speed and schedules. Buildings lack intelligent reasoning to customize the fan operation to meet the needs of occupants resulting in wasted energy and sub-optimal thermal comfort. This could be due to the following points:

(a) Fans do not know the positions of people. This may cause inconvenience in the cases that the occupant is not willing or does not have the chance to redirect the fan or manually adjust the fan speed, especially when an occupant moves along his workspace or in the building (Fig. 1). Hence both the direction at which the fan blows air and the fan speed setting should be changed accordingly.
(b) There is lack of real-time input of occupancy information to the BMS, such as the number and positions of occupants. It is

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Fig. 1. An example of how occupant position may change in time.

difficult to track the positions of an occupant in a dynamic indoor environment where the layout and the occupancy keep changing.

(c) Traditionally, air speed is not measured due to the high cost of omnidirectional hot-wire anemometers.

For the points mentioned above, (a) and (b) refer to the issue of occupancy detection and tracking for fans operation. Point (c) is about the air speed measurement for thermal comfort. The aim of this paper is to develop a tracking cooling fan system to address the problems stated above.

1.1. Occupancy information for cooling

Occupancy information plays an important role in building cooling and fan operation. For the heating, ventilation and air condition (HVAC) system, Daikin employs "intelligent eye" infrared sensor [5] to detect human movement but it is no more than ascertaining whether or not there are people in the room. Mitsubishi utilizes eight "move-eye" infrared sensors [17] in their air conditioning system for human and environment detection by acquiring thermographic data. However, using the infrared sensor may not be accurate on measuring the skin temperature if the sensor is far from the person. Additionally, it is household-oriented and may not be suitable for personal cooling in the office environment. Previously developed smart fans [35,43] are able to direct the air towards people based on the occupant detection but adjustment of fan speed is not considered. Other smart systems [3,15] determine the fan speed setting by temperature or humidity but the occupant-fan distance is neglected. Since the air speed attenuates during the propagation, the distance has great influence on the thermal sensation on people.

A number of developed human detection and tracking solutions can be found in the literature, including PIR (passive infrared) sensor [6,9,13], RFID (radio-frequency identification) [14,23,42] and CO_2 sensor [32,34]. While each of these methods has advantages, it also has its own limitations. For example, PIR sensors based approaches are compromised by other heat sources with strong radiation (e.g., the direct or reflected sun radiation) and can only provide binary information indicating the presence/absence of a person [14]. Most RFID-based systems rely on proximity detection of mobile readers by tags which could be expensive and the density of reference tags is crucial and hard to determine [24]. The performance of CO_2-related solutions highly depends on the calibration and commissioning of measurement instrumentations [34].

Custom-digitized geofence has emerged as a significant area of interest for location-based service (LBS) over the last decade. A geofence is defined as a virtual perimeter for a real-world geographic area and LBS can be delivered when a target enters or exits a geofence. Ref. [25] presents fundamental concepts of geofencing and its applications in the transport and logistics sector. Ref. [19] discusses geofence-based notification as general-purpose service from commercial promotion to tourism, traffic information, public service and safety. Ref. [20] employs network proximity rules as geo-based boundaries to effectively deploy indoor location based services and provide significant energy saving for mobile devices compared with the traditional methods.

In this paper, a tracking cooling fan using geofence and camera-based indoor localization is proposed for thermal comfort and energy savings. The cooling area of the electric fan is divided into several sub-area bounded by predefined geofences. By detecting the occupant enter which geofenced sub-area, the direction of air flow is determined. Compared to infrared radiation based PIR sensor or proximity detection based RFID, camera-based vision analysis technique [4,10,12] for indoor tracking is able to provide highly accurate position estimates with the resolution being from 0.01 cm to 1 cm [16]. The approach brings convenience for the occupants since there is no need for them to carry extra devices. The proposed indoor tracking system identifies the tracked targets from the images taken by the camera fixed in the tracking area and the captured images are then checked against a pre-calibrated database to give position estimates. The system estimates the