Energy-efficient Lighting Control in Smart Buildings based on Occupancy Reasoning

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Abstract
We propose light control algorithms for smart environments. The proposed optimization formulations maintain people's comfort while reducing the energy cost of lights. Camera sensors are deployed to make occupancy reasoning. By taking people’s positions and preference as constraints, the light setting can be optimized for people’s satisfaction in occupied area. Simulations on the occupancy results from experiments are provided to verify the proposed algorithms.

I. SUMMARY
The present generation of smart light control systems aim to provide a comfort environment while reducing energy consumption [1]. To achieve this goal, the system needs to adjust the light setting for the area with people occupied and turn off the unnecessary lights in the unoccupied areas. Such system requires deployed sensors for data collection and optimization algorithms for light control. To build above system, we consider a light control system based on occupancy information that is provided by a camera network.

We assume that there are \( N \) calibrated camera sensors in the room. The camera sensors periodically make observations and send processed data to a base station. The base station then uses the information to make occupancy reasoning. We adopt the occupancy reasoning algorithm proposed in [2]. In our algorithm, each camera makes an observation, and runs the background subtraction to obtain the moving foreground. The bounding box, Regions of Interest (ROI), of each segmented foreground is then extracted. Each camera then projects the ROIs back into space and forms several cones. The intersections of these cones form polyhedrons, and each polyhedron in the 3D space indicates the space being potentially occupied. The space is discretized into several points, and only those points are checked for occupancy. By checking the sampled points, the computation power can be reduced. Given the polyhedrons, we check if a point is in the intersection of the polyhedrons. If a point is in the intersection of the polyhedrons, that point is occupied. Therefore, we can learn if an area is occupied.

We assume that \( L \) lights are installed in the room. The base station can control each light based on people’s positions. We consider two types of lights. For the first type of lights we assume that the light intensity can be adjusted continuously. For the second type of light, we assume that the lights can only be either turned on or off. Our goal is to minimize the energy consumption of the lights while maintaining users’ satisfaction of the light condition. In order to quantify users’ satisfaction, we adopt the concept of the utility functions introduced in [1]. A utility function maps the light intensity to a value. Higher value means higher satisfaction. We can have different utility functions for different positions. For example, the utility functions around the desk can be different from the utility functions around the door area. Given people’s positions and the utility functions, the intensity control problem can be formulated as a convex optimization problem. On the other hands, because the switch control problem is NP-hard, we propose a heuristic algorithm for it.

We show the light control simulation results based on the occupancy reasoning of the experimental data. The simulations were recorded as videos. The snap shots of the videos for intensity control are shown in Fig. 1. The left upper corner shows the layout of the room, where the 10 cameras are shown by the red squares, and the occupied area is shown by the blue solid ellipsoid. The 6 lights are represented by empty circles while bigger circles imply stronger light intensity. The green dots show the sampled points of the space, brighter color means the utility value of that point is higher. The figure below shows the intensity of each light over time, and on the right side we show the raw image from one of the camera sensors. The snap shot for the switch control is shown in Fig. 2. In this simulation, we assume that there are 97 lights represented by small circles.

The figure below shows the total number of lights that are turned on over time.

REFERENCES

1The video clips can be downloaded from http://wsnl.stanford.edu/videos/occupancy/index.html
Fig. 1. A snap shot of the video for intensity light control.

Fig. 2. A snap shots of the video for switch light control.