Demo: Fine-tuned Lighting Control Leveraging Smartphone-based Occupancy Detection

Alexander de Moes[†], Jens Joachim K. Pedersen[*], Chayan Sarkar[†], R. Venkatesha Prasad[†]

[†]Delft university of technology
[*]Technical University of Denmark

a.f.a.demoes@student.tudelft.nl, s103023@student.dtu.dk, {c.sarkar, r.r.venkateshaprasad}@tudelft.nl

Abstract

Recently occupancy-based lighting control has shown a great promise towards achieving better energy efficiency. Generally, traditional systems use additional sensors to detect user presence with higher precision to better the control algorithms. In this work, we show how a smartphone-based indoor localization can be utilized for this purpose without deploying additional sensors. Apart from automatic controlling of the lights, our system provides a sophisticated manual control, where each light unit can be controlled by just pointing the phone towards it. Based on our experiments, we show that up to 67% more energy saving is possible using our systems compared to traditional methods.

Keywords

Indoor localization, automated lighting control

1 Introduction

Artificial lighting accounts for a major fraction of electricity consumption in office buildings. People often tend to forget switching off the lights when leaving the room or when the natural light condition is sufficient. A smart system, which controls lights based on occupancy in a building and natural light condition, can save a lot of energy, thus reduce the electricity cost. Existing methods use occupancy detection sensors, which can vary from one sensor per room to a separate sensor for every unit [1]. We demonstrate a smartphone-based indoor localization based system leveraging fine-tuned occupancy detection.

We describe a scalable system architecture where every light unit can be controlled automatically without any extra sensor deployment. Additionally, the application provides proximity and direction detection mechanism, which enables the user to control the lights by just pointing his mobile phone to individual light units (single or a cluster of bulbs).
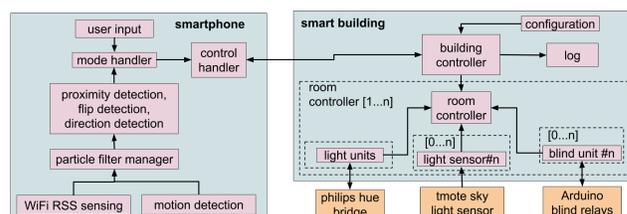

Figure 1. Overview of the system architecture.

2 System overview

The system design follows a layered architecture as described in [3] (see Fig. 1). It has two parts: (i) a smartphone application, which sends the user location and user orientation to a controller; and (ii) the light control is done through a server application, called the building controller. The controller, using the notification of users' location, determines the occupancy in various parts of the building, and instructs individual room controllers. We used Philips Hue bulbs in our system as they can be controlled remotely. To control the brightness level of each Hue bulb, the smartphone App sends a message containing the location of the user inside the building. Additionally, the room level controller gathers data from different light sensors to decide whether to adjust brightness of the light units based on changed natural light conditions. A proportional control is used for each pair of light bulb and light sensor.

3 Smartphone application

The application has localization and manual mode. The layout of the application can be seen in Fig. 2. In the localization mode, the phone can determine location of the user automatically and report this to the building controller. In manual mode, the App provides different methods to control the light units, e.g., proximity detection identifies the user's position, direction detection identifies the direction the user is looking, flip detection identifies when the user simulates flipping. The lights are turned on/off when the user points the phone towards the light bulb and flip it. These methods are described in the following subsections.

3.1 Indoor localization

We use a particle filter based localization method [2]. Steps are detected with the help of the accelerometer and the direction of the smartphone is determined with the magnetometer. The movement of the particles is based on the
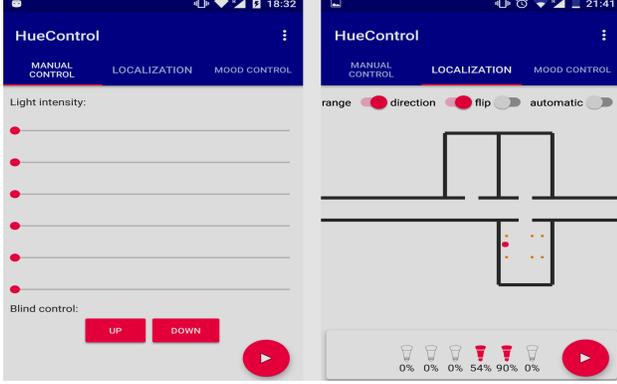
Figure 2. The App can be used in manual mode (left) or automatic mode (right). In the automatic mode, occupancy is detected based on localization algorithm.

amount of steps, step size of the user, and the direction in which the user is moving. We achieved an accuracy of 2-4 meters, which is sufficient.

3.2 Proximity detection

To determine the proximity, the location of the user must be determined first. This is done by checking if the particles have converged enough to be able to determine the location. If more than 80% of all particles are within a range of 1.5 meter, the average x and y value of these 80% is taken and set as the user's current location. A line is then drawn from this location to each hue bulb. If this line does not intersect any wall and the length of this line is smaller than the maximum proximity, here 5 m, the bulb is turned on.

3.3 Direction detection

This is similar to proximity detection to determine if the bulb does not intersect a wall or it is too far away. Above that, the direction detection also looks at the angle between the x-axis and the smartphone's direction and the angle between the x-axis and every hue bulb. If the difference between these angles is smaller than a threshold (here 30°), the bulb is turned on. The intensity of the light depends on how much the smartphone angle differs from the hue bulb angle. The magnetic angle is first converted to the conventions of the map, so that 0° is in the direction of the x-axis. To do this, the offset is added to the angle value and the magnetic offset of the building is also added to the user angle, θ_{user} (Eq. 1).

$$\theta_{user} = \theta_{magneto} + \theta_{mapOffset} + \theta_{BuildingInterference} \quad (1)$$

$$\theta_{hue} = atan2(Y_{hue} - Y_{user}, X_{hue} - X_{user}) \quad (2)$$

$$\theta_{offset} \geq |\theta_{user} - \theta_{hue}| = \theta_{diff} \quad (3)$$

$$hue_i = \begin{cases} \frac{\theta_{offset} - \theta_{diff}}{\theta_{offset}} * 100, & \text{if } \theta_{offset} \geq \theta_{diff}; \\ 0 & \text{otherwise,} \end{cases} \quad (4)$$

This angle is then transformed to values between $-\pi$ and π. To determine the angle between the hue bulb and user's current position, $atan2$ function is used. The angle of every hue bulb is calculated using (2). The light intensity of each hue

Table 1. Energy consumption for the three test cases.

test case	Test setup	Watt-hours
1	Bulb with manual switch	46.5
2	Smartphone control	17.9
3	Smartphone with lightsensor	15.4

bulb (hue_i) is based on the maximum offset and the actual offset, see (3, 4).

3.4 Flip detection

When the angular motion on the x-axis is higher than the threshold value and the angular motions on the y- and z-axis are $0\,\text{m/s}^2$, a flip is detected and the bulb in the direction of the phone is turned on. This state is stored, so that when the phone is moved and the magnetic angle changes, the enabled light stays on. The threshold value is empirically found to be $5\,\text{m/s}^2$.

4 Results

To test the energy saving of the system, we considered a user on three different days with a predefined occupancy schedule between 8am to 8pm. We define three different test cases for each of these days. In the first test case, a manual switch is used and the user turns on the bulbs when he arrives and turns them off when he leaves the office building. In the other two test cases, the light is turned on and off automatically based on occupancy. In the third test case, the brightness is also controlled based on the natural light intensity. For this last case, we considered a cloudy day when natural light condition is not sufficient. The results are given in Table 1. Case 3 only consumes one third of energy compared to Case 1, saving 67% of energy.

5 Conclusions

We present a system where light bulbs are automatically controlled based on occupancy and natural light conditions. We used smartphone based indoor localization, which provides a very high room level accuracy (2-4 m). This helps in fine-tuned lighting control for individual light units in a shared space. Based on our experiments, we see an energy saving of up to 67% compared to manual lighting control, where the user turns the light off only when he leaves the office in the evening. We want to extend this work by dynamically learning user preferences from the manual control. We also want to control the window blinds automatically such that usage of artificial light can be minimized as well as the user comfort can be retained.

6 Acknowledgment

7 References

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