Chapter 36
Energy-Aware Intelligence in Smart Spaces:
A Case Study using Computer Vision and Machine Learning for User-Behavior Analysis

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ABSTRACT

The improvement of energy efficiency in our society has become an urgent issue for sustainability under global warming. The authors present research issues on sensor-based smart environments for energy-aware intelligence, and showcase a study of algorithms for monitoring human activities that provides the context awareness to the smart environments. In order to build energy-aware environments, it is desirable to embed intelligence into the environment itself so that the environment can interpret human behavior in order to adjust itself to human activities occurring in the environment. This is achievable by integrating the environment and the intelligent computing facilities. The computing facility embedded in the environment is equipped with intelligent algorithms that can monitor salient features indicative of the events and learn and recognize changes in the environment. Recent developments in sensor-based intelligent systems can provide suitable algorithms and facilities for building such energy-aware smart environments. The authors present a framework for monitoring human activities in daily living toward the energy-aware intelligence that can detect and learn inhabitants' behavior patterns in the smart environment.

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INTRODUCTION

The improvement of energy efficiency in our society has become an urgent issue for sustainability in the current era of global warming. The energy efficiency is closely related to the design of infrastructure such as buildings, transportation systems, Information Technology (IT) devices, etc. The energy efficiency also depends on how people use such infrastructure. There is a conflict, however, between the need for energy efficiency in human-inhabited environments and the inhabitants' desire for comfort. For example, reducing the cost of air conditioning or heating for a building would result in the increased humidity in summer or the chilly indoor temperature in winter, respectively. Therefore, it is imperative to achieve the balance between the cost and the comfort. For example, in case of room temperature, the typical practice of controlling the room temperatures in a building is to have a building maintenance technician adjust the lowest and highest levels of the thermometer setting at each room for each season. In case of room illumination, human involvement of such kind can be minimized by installing an infrared motion sensor to detect the inhabitants' motion to recognize their existence and controlling the on/off switches of the lighting equipments. In these examples, however, the control of actuators for heating, air conditioning, and lighting, is fulfilled in a brute-force manner. That is, once set, the actuators will work consistently in the same way no matter what situation the environment would be in. For example, the temperature of a classroom with 50 students at class will be the same as the temperature of the classroom without anybody during off-class period on weekend. It is of course possible to manage the classroom temperature differently on weekdays and weekends by incorporating the day's information into the control system. This would require more sophisticated control systems and extra manual interfaces. The systems that require extra human involvement, however, are not scalable. How much manpower would be needed to manage several hundred classrooms on a university campus? What happens to the system if the technician's maintenance is delayed? What if the pattern of human activity changes unexpectedly (such as accidents, multiple users, and guests, etc.)? We need more intelligent systems for energy-aware environments that can automatically adjust themselves according to the activities of the inhabitants in the environment. One of the core research issues in energy-aware environment is the development of the computer vision and machine learning algorithms to understand human activity in the environment.

In this chapter, we present a case study of computer vision and machine learning that recognizes human activity in sensor-augmented smart spaces for energy-aware intelligence. Figure 1 shows the schematic diagram of the proposed system framework.

Smart environment or *smart space* is "a small world where different kinds of smart device are continuously working to make inhabitants' lives more comfortable" (Cook & Das, 2004). The terms *environment* and *space* are interchangeably used in this context. Mark Weiser who coined the term 'ubiquitous computing' says that smart environment is "a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network" (Cook & Das, 2004). With the richness of sensor types and their numbers embedded in the environment, smart environment is closely related to "ubiquitous computing."

From the perspective of energy-aware intelligence, the smart environment is regarded as an intelligent system that detects certain changes in the environment, autonomously learns patterns of inhabitants' activities, and adjusts the environment itself to optimize resource usage such as heating, cooling, and lighting, etc., while providing the inhabitants with best convenience in an autonomous manner. In this sense, the smart environment is

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