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VIOLAS: A vision-based sensing system for sentient building models

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Abstract

We describe the design, implementation, and test of VIOLAS, a vision-based system for object location and occupancy sensing in sentient buildings. Sentient building operations require the existence of a dynamic and self-updating model of building context, components, spaces, systems, processes, and occupancy. Such a model can support applications in building and facility management as well as indoor–environmental controls. Specifically, comprehensive self-updating models can facilitate the implementation of simulation-based building systems control strategies (e.g. for heating, cooling, ventilation, lighting, etc.). Since the underlying model for such operations must possess the capability to autonomously update itself, a versatile sensing mechanism is required that provides context awareness, i.e., real-time facility state information. The research described in this paper aims to examine and demonstrate the potential of vision-based sensing solutions to meet this requirement. For the generation of a comprehensive, self-updating space model, the prototype system particularly requires object identification and location sensing as well as occupancy detection. Toward this end, VIOLAS offers a flexible and scalable arrangement of hardware and software components (tied together via Internet), which is generally well suited to the requirements of sentient buildings.

Keywords: Sentient buildings; Self-updating space models; Computer vision; Object identification; Location sensing; Occupancy detection

1. Introduction

Building automation is expected to improve building performance by reducing the operation and maintenance costs of buildings (e.g. for heating, cooling, and lighting, etc.), improving environmental performance, augmenting human comfort, and providing higher safety levels. However, data collection and monitoring activities in current building automation systems are rather limited: the focus is mostly on service systems such as elevators and office equipment. There is a lack of systematic and scalable approaches to comprehensive facility state monitoring throughout buildings' life cycle. One possible approach toward achieving a higher level of building automation technology is provided by the concept of sentient buildings [1]. Sentient buildings possess a dynamic, comprehensive representation of their context, components, systems, spaces, processes, and occupancy. They can autonomously and in real-time update this representation based on sensory information from a comprehensive sensory infrastructure. Thus, a sentient building possesses at all times up-to-date and high-resolution information regarding the state of room enclosure surfaces, objects and furniture, building components such as doors and windows, environmental systems (for heating, cooling, lighting, etc.), occupants' presence and movements, and other static or dynamically changing building entities.

Most importantly, sentient buildings use this dynamic representation to support operations in building and facility management, user services, and indoor–environmental systems control. For example, simulation-based control algorithms can be implemented efficiently given the availability of such representations [2]. These algorithms control specific building operations (for heating, cooling, lighting, etc.) through the analysis of the building model with an embedded simulator component. In a simulation-based control strategy, the permutation space of control options (alternative states of control devices) are mapped to the immediate future using the simulation model. This simulation model is fed with data from the self-updating building and context representation. The implications of alternative control options are then obtained via simulation and compared based on the preference settings of

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building users. From this comparison, the preferable course of control action can be deduced.

Fig. 1 briefly demonstrates the architecture of such a control system using the example of lighting controls. First, a data collection unit collects the *environmental data*. A weather station augmented with a sky-scanner [3] located on the building dynamically reports on the outdoor conditions (temperature, humidity, wind velocity, global irradiance, sky luminance distribution). The actual state of *control devices* (i.e., position of the remotely controllable blinds, the dimming setting of the luminaries) are monitored and submitted to the model in real-time.

The room model, augmented with outdoor data and systems state data are provided to the lighting simulator to predict the performance implications of alternative control device settings for the next time interval. Based on the returning results and consideration of user preferences, the preferable control option can be identified and brought about (either directly by the system or via information to the occupants). This cycle is regularly repeated in order to maintain optimal lighting conditions (in view of cost and comfort) despite changing conditions in the outdoor and indoor environment.

To achieve this functionality, the presence of a continuously updated room and occupancy model is sine qua non. VIOLAS is conceived, implemented, and tested as a prototype vision-based object location sensing and occupancy detection system. It is designated to provide a sentient buildings model with a steady flow of up-to-date data on the state of rooms (surfaces, objects and occupancy). Such information together with data on outdoor conditions and system states constitute the information core of sentient building's self-updating representation.

2. Requirements

The specifications of the objects in the test space are stored in an object inventory as depicted in Fig. 1. The initial generation of a space model can make use of this information. However, a self-updating capability requires the continuous collection of additional information. The objects in the space must be identified and their location must be determined in real-time. The location information must entail both *position* and *orientation* data. Furthermore, operational applications (such as lighting controls) need occupancy information. Thus, in addition to the environmental data (weather and sky conditions), the model generation requires up-to-date object information toward constructing a comprehensive space model (Fig. 1).

Thereby, the technical solution for object identification and location sensing must consider specific requirements pertaining

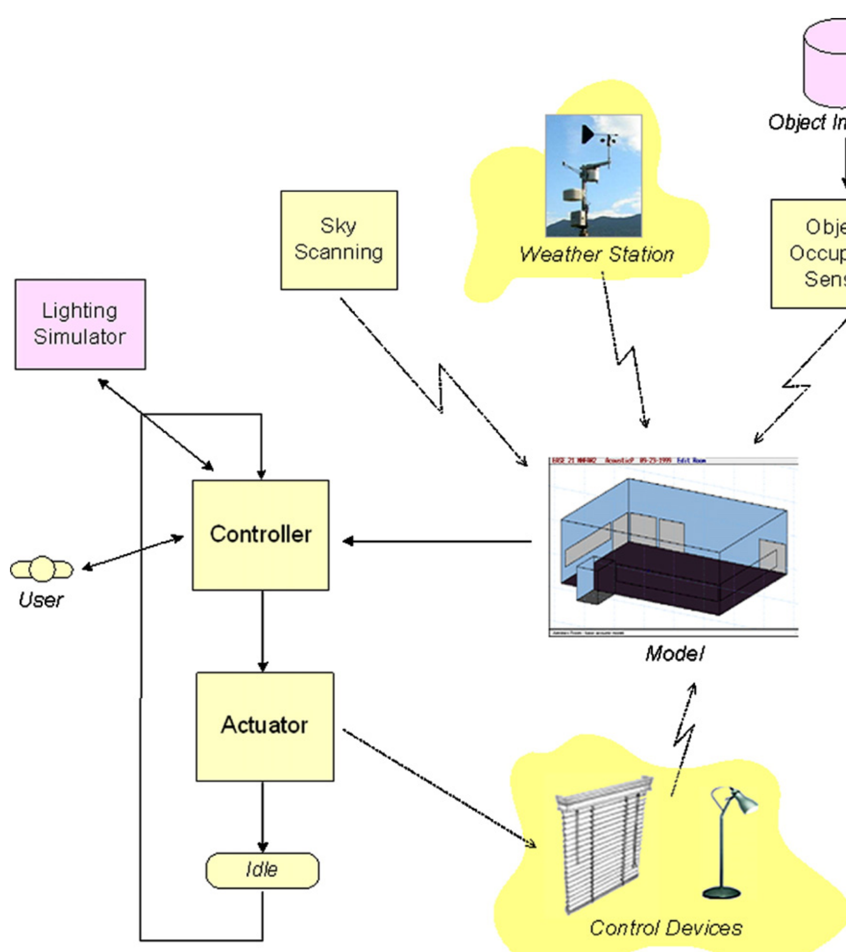

Fig. 1. Flow diagram of the lighting control system.