Building and Environment 72 (2014) 332–342

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

# Sensor-aware elevator scheduling for smart building environments

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ARTICLE INFO

*Article history:*
Received 24 May 2013
Received in revised form
9 November 2013
Accepted 13 November 2013

*Keywords:*
Elevator scheduling
Sensor
Smart building
Smart living

ABSTRACT

In a modern smart building, sensors can detect various physical information such as temperature, humidity, motion, and light, which can be used for smart living services. This paper presents an efficient elevator scheduling system by making use of indoor sensor technologies. Specifically, multiple sensor devices consisting of RFID, video, and floor sensors are used together to detect the candidate elevator passengers' behavior before they push the elevator call button. The detected information is then delivered to the elevator scheduling system through building networks. By using this information, our scheduling system generates a reservation call for candidate passengers and controls the moving direction and the moving time of elevator cars efficiently. Extensive simulations with various passengers' traffic conditions show that the proposed system performs significantly better than the conventional elevator scheduling system in terms of the average waiting time, the maximum waiting time, and the energy consumption of elevator systems.



## 1. Introduction

Recent advances in sensor technologies enable a plenty of smart living services in our daily lives. For example, in a smart building environment, various physical information such as temperature, humidity, motion, light, and sound can be collected from sensors, and then transferred immediately to the building control system. This allows the detection and tracking of environmental conditions and human behaviors, which will be exploited for a plenty of services such as energy-saving, comfort, healthcare, and security [1]. HVAC (Heating, Ventilating, and Air Conditioning) is a representative system that utilizes sensor technologies. HVAC controls the air condition and temperature of a building according to the weather and the existence of human beings in the building.

Elevator scheduling is another important service that can be involved in sensor technologies in a smart building. There is a report that HVAC and elevator services are the two major complaints of building tenants [2]. We aim to improve this situation by presenting a novel elevator scheduling system that utilizes indoor sensor technologies. As human behaviors and movements can be estimated precisely with current sensor technologies such as camera, audio, optical, and floor sensors [1,3–5], an elevator control system can recognize the arrival of passengers before actual call buttons are pushed. The system, then, utilizes this information for an efficient scheduling of elevator cars, leading to reduced latency and power consumption. Though lots of researches on elevator scheduling have been performed to achieve the same goal, utilizing sensor technologies to obtain passenger information is in the initial stage of elevator scheduling problems. To the best of our knowledge, our previous research was the first attempt to do so but it was limited to a single sensor technology and is not applicable to group elevator systems [6]. This paper uses multiple sensor technologies to predict passengers' information more precisely. We validate the effectiveness of the prediction system and present a general framework for the group elevator scheduling system that uses these multiple sensor technologies.

There are several performance criteria of elevator scheduling systems such as minimizing the waiting time, the riding time, and the energy consumption. Most existing studies have focused on minimizing the average waiting time since passenger's dissatisfaction grows rapidly as the waiting time increases [7]. Our elevator scheduling system focuses on reducing the energy consumption as well as the average waiting time.

The elevator scheduling problem is difficult because of complicated elevator dynamics, uncertain traffic in various patterns, and multiple goals to be optimized simultaneously. Thus, previous studies use various optimization techniques such as genetic algorithms and fuzzy systems [8–10,11–28]. Also, to collect more

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0360-1323/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.11.013

information on waiting passengers, some facilities such as cameras and additional buttons are adopted [10,18]. Some research predicts passengers' traffic pattern using peak-time distribution to consider human life patterns [9,13,14]. However, prediction and adaptation used in existing research is limited as elevator scheduling systems recognize passengers' information only after they push the elevator call button. Unlike previous studies, our system detects passengers' information by smart sensor technologies before they arrive at the elevator, and uses this detected information in scheduling elevator cars efficiently. Specifically, we generate a reservation call for candidate passengers detected by sensors and control the moving direction and the moving time of elevator cars for the reservation calls.

To evaluate the performance of our elevator scheduling system, we conduct experiments with various workload conditions. The results show that the proposed elevator scheduling system performs better than the conventional elevator scheduling system in terms of the passengers' average waiting time, the maximum waiting time, and the energy consumption of the elevator system significantly. Specifically, the improvement of the average waiting time and the energy consumption is in the range of 15–30% and 28–31%, respectively, by controlling the moving time and the moving direction of elevator cars for reservation calls.

The remainder of this paper is organized as follows. In Section 2, we provide previous studies that have been proposed for elevator scheduling systems and sensor technologies for smart building environments. In Section 3, we describe our proposed elevator scheduling system in detail. Section 4 shows the performance evaluation results of the proposed system. Finally, we conclude the paper in Section 5.

## 2. Related works

### 2.1. Elevator scheduling systems

There have been a variety of studies on the scheduling of elevator systems to reduce passengers' waiting time. Most of them focus on the group elevator systems, in which a single control unit schedules multiple elevators simultaneously. In group elevator systems, the scheduling problem becomes even more complicated, and thus various optimization techniques such as fuzzy systems [12,22–24,26,29], genetic algorithms [10,15,21], genetic network programming [11], artificial neural networks [13,27,28], and DNA computing methods [42] have been adopted.

Igarashi et al. present a fuzzy system based group elevator scheduling systems [12]. When a passenger pushes the elevator call button, the system evaluates each elevator car using a fuzzy function and assigns the car with the largest evaluation value that can minimize the waiting time of the request. Similar studies have also been performed by Kaneko et al. [22]. Unlike Igarashi et al., Kaneko et al. consider the riding time of the elevator as well.

Kim et al. use genetic algorithms to optimize the scheduling of group elevator systems [10]. They employ cameras to detect the number of waiting passengers at each floor and assign multiple

**Table 1**
A summary of elevator scheduling systems.

| System proposers | Heuristics used | Optimization goals | System overhead | Main research issue | Physical characteristics |
|---|---|---|---|---|---|
| Gudwin et al. [23] | Fuzzy systems with linear context adaptation | Reducing waiting time | Relatively high | Dynamic scheduling with fuzzy systems | – |
| Igarashi et al. [12] | Fuzzy systems | Reducing waiting time | Relatively high | Scheduling with fuzzy systems | – |
| Kurosawa and Hirasawa [24] | Hill climbing and fuzzy systems | Reducing waiting time | Relatively high | Scheduling with combined optimization | – |
| Kaneko et al. [22] | Fuzzy systems | Reducing waiting time | Relatively high | Scheduling with fuzzy systems | – |
| Ishikawa et al. [26] | Fuzzy systems | Reducing waiting time and riding time | Relatively high | Scheduling with fuzzy systems | – |
| So et al. [27] | Neural networks | Reducing waiting time | Relatively high | Traffic pattern recognition with neural networks | – |
| Dewen et al. [13] | Neural networks | Reducing waiting time | Relatively high | Scheduling with neural networks | – |
| Markon et al. [28] | Adaptive control with neural networks | Reducing waiting time | Relatively high | Scheduling adaptively with neural networks | – |
| Fujino et al. [15,21] | Floor attribute control with genetic algorithm | Reducing waiting time, riding time, and car crowding | Relatively high | Scheduling with GA considering floor attributes | – |
| Eguchi et al. [11] | Genetic network programming | Reducing waiting time and riding time | Relatively high | Scheduling with genetic network programming | – |
| Chan et al. [20] | Servicing different floors | Reducing waiting time | Low | Scheduling specific floors with predetermined cars | – |
| Kim et al. [29] | Fuzzy systems | Reducing waiting time and energy consumption | Relatively high | Traffic classified and fuzzy-based scheduling | – |
| Kim et al. [10] | Genetic algorithms, multiple car assignment with cameras | Reducing waiting time, load balancing | Relatively high | GA-based scheduling with camera | Camera at each floor |
| Lee et al. [8] | Linear algorithm | Reducing waiting time and energy consumption | Low | Scheduling based on waiting time and energy | – |
| Amano et al. [18] | Replacing up-down buttons by numeric buttons at each floor | Reducing waiting time | Low | Scheduling with a new user interface | Numeric buttons at each floor |
| Brand et al. [9] | Dynamic programming under Marcov decision process | Reducing waiting time | Low | Up-peak/down-peak analysis and parking strategy | – |
| Pepyne and Cassandras [14,16] | Dynamic threshold based policy under Marcov model | Reducing waiting time | Low | Up-peak traffic analysis and scheduling | – |
| Strang and Bauer [40] | Context-aware algorithm | Reducing waiting time and riding time | Low | Context-awareness techniques | RFID tags |
| Zhao and Liu [42] | DNA computing | Reducing waiting time | Relatively high | Reducing candidate schedules through DNA computing | – |
| Zhang and Zong [43] | Robust optimization model | Reducing waiting time and energy consumption | Relatively high | Up-peak traffic analysis and reducing energy | – |