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Developing a Real-time Luminous Facilities Management System in Residential Care Homes

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Abstract. An integrated Real-time Luminous Facilities Management (Rt-LFM) system website has been developed, including hardware for data collection and software for data storage and download instantly. Two lighting sensors (illuminance, and color temperature) have been combined into a single device for measuring the continuous luminous data in the residential care homes. A wireless sensor network has been established through the combination and connection of lighting sensors to monitor the luminous conditions. The dynamic luminous environment data can then be saved and downloaded in the cloud-based system. By using the Rt-LFM system, the caregivers and managers in the residential care homes can promptly realize the luminous environment based on the instant data, while the construction professionals can then well design the building services for new homes or renovation. It is expected that the long-term health of our elderly will be improved finally. Furthermore, the subsequently improved elderly health conditioning will also relieve the medical burden of the government in central.

1. Introduction

Population aging is very common worldwide with the boost of the number and proportion of the elderly, and the elderly aged 60 and above are estimated to outnumber children aged ten and below in 2030 [1]. It is expected that the elderly aged 65 and above will keep increasing its proportion in the total population (e.g., from 17.7% of the total population in 2019 to 31.1% in 2030 in Hong Kong) [2]. Due to limited mobility, the elderly spend most of their time in the indoor environment. Thus, the creation of an age-friendly indoor environment becomes vital to ensure a comfortable, healthy, and safe environment for the elderly [3]. Luminous environment, referring to the lighting conditions of a physical environment, is an essential part of the indoor environment that may have a vision and non-vision effect on people, such as the sensation of the surroundings, working productivity, sleeping quality, emotions, fall and so on [4-6].

Residential care homes provide accommodation and care services for the elderly, while the elderly residents normally have special needs of lighting conditions on account of their ageing eyes and other age-related physiological changes [7-8]. However, poor luminous environments and insufficient lighting are ubiquitous in residential care homes for the elderly [9-10]. Therefore, it is necessary to develop a device for monitoring the luminous environment. The collected data can be used by the managers and caregivers in residential care homes for checking and monitoring the luminous

environment and further provide feedback for construction professionals to design and renovate the residential care home, including space, windows, doors, building services, etc.

2. Luminous facilities management for the elderly in residential care homes

By the age of 50, most people have experienced some vision changes. The prevalence of visual disabilities in the >70 years age group is 40 times higher than in middle age (40-59 years) [11]. The elderly often experience various visual deficits, such as low visual acuity and visual field, sensitivity to glare, weak contrast sensitivity, and color discrimination [7]. In addition, the elderly need higher levels of light in consideration of their limited mobility, frail body, and reduced balance. Poor lighting conditions have become one of the leading causes of falls for the elderly [12].

Lighting has two major effects on the individual, including a source of information about the environment (i.e., visual effect) and the photobiological effect through the skin or photoreceptor [13]. It has been founded that lighting plays a vital role in the elderly's visual health, working performance, cognitive and behavioral changes, mood, and safety. Blue light can induce circadian and sleep dysfunctions [14]. Indoor lighting (e.g., illuminance, color temperature, etc.) can also convey emotional meanings and then influence persons' performance [15]. Furthermore, more safety issues may arise for the elderly because of the dim light and uncomfortable glare [16]. In a word, lighting is very important for our daily work, life, and our health. It is also claimed that the cognitive state may be improved by using bright light therapy, especially for those in early-stage Alzheimer-type dementia [17]. Hence, monitoring the illuminance and color temperature of lighting is indispensable to investigating the effects of lighting on the elderly.

Luminous facilities management (LFM), referring to luminous space management, building services, and supporting facilities, is the strategic management of the luminous environment, including natural and artificial lighting of the building. It is very crowded in residential care homes in Hong Kong as the minimum area of floor space per resident in residential care homes is only $8m^2$ (medium care level) and $9.5\ m^2$ (high care level) [18], which induces more serious luminous environment issues for the daily life and health of the elderly. Thus, it is more urgent to improve the LFM of residential care homes in Hong Kong than in other cities. With the increase in the number of elderly living in residential care homes, the luminous environment conditions will be more and more critical. Not only the managers and caregivers should very clearly know the luminous environment conditions and take timely and long-term LFM actions, but also the government can supervise the luminous environment conditions in residential care homes. An integrated Real-time Luminous Facilities Management (Rt-LFM) system will definitely improve the LFM in residential care homes, then enhancing the quality of life, quality of care, and long-term health of the elderly.

3. Wireless sensor network and internet of things for monitoring environment

Internet of Things (IoT) is a widely developed paradigm for equipping objects with sensors, actuators, and processors to facilitate communication, interaction, and cooperation among various objects and users [19-20]. As one of the key technologies in IoT development, wireless sensor network (WSN) enables objects and devices to sense and communicate environmental conditions [21]. The WSN is a network of sensing devices connected together by wireless means for monitoring the environment, wildlife, earthquake, etc. [22-23]. The sensors in a WSN perform three basic tasks: collection, processing, and transmission of data relating to the physical environmental conditions [24].

The WSN has been proven innovative technology that is being widely used in many areas, as it achieves various advantages for the end-users (e.g., feasible locations for installation, easy for recording instant data, large capacity to store the data, and convenience to downloading the data). In recent years, the WSN has been widely used to monitor environmental conditions, such as lighting, temperature, sound and humidity changes in the workplace environment, and indoor air quality in underground coal mines [25-26]. This study aims to develop an integrated Rt-LFM system for the elderly living in residential care homes. Therefore, WSN is proposed to be used in residential care homes for a wide

range of LFM that requires dynamic elderly health conditions and various lighting information in different built environments.

4. An integrated real-time luminous facilities management (Rt-LFM) system

Two key luminous environment components influencing elderly health in residential care homes were identified, including illuminance and color temperature [10, 27]. The holistic Rt-LFM system was shown in Figure 1, including the sensor layer, network layer, and interface layer. The two types of sensors were combined into one integrated sensor device for data collection in residential care homes (see Figure 2). Channels were created on the IoT analytics platform to store the time-series data in the cloud, while a RESTful API was developed connecting to the integrated Rt-LFM device and the IoT analytics platform. The collected time-series data were uploaded to the cloud, and the instant data can be checked and downloaded from the IoT analytics platform.

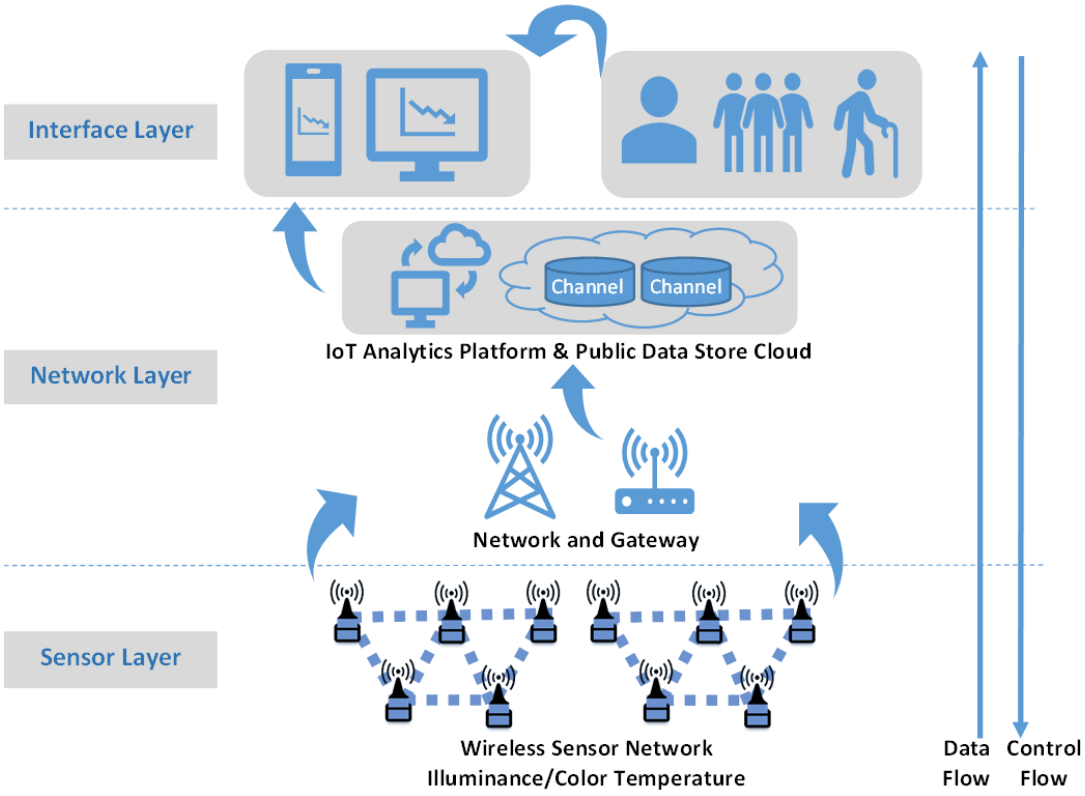

Figure 1. An integrated real-time luminous facilities management (Rt-LFM) system.

Many technical problems need to be solved before setting up the Rt-LFM system in residential care homes. Some of these problems are commonly seen in other sensor technologies, while others are unique to indoor environmental monitoring. Firstly, an emerging issue is the low degree of standardization. No global public body governs the frequencies used for indoor environment sensors. The frequencies used for indoor environment sensors in one country are currently incompatible with those in other countries. The different standards were compared to choose the suitable sensors that can be used for monitoring the luminous environment in Hong Kong. Secondly, the big size of the final integrated sensor device case creates difficulty in installing in the condensed living environment of the existing residential care homes. To minimize any disturbance to the end-users in residential care homes, it is necessary to keep the sensor device as small as possible (see Figure 2). Thirdly, the sensors may be disturbed by each other within a case. Thus, the sensor case is well-designed to reduce the interference between sensors, such as the heat generated by working sensors. Fourthly, it is not easy to

instantly find the unworking sensors and disconnection between the Wi-Fi receivers and Wi-Fi transmitters, which may induce missing data (i.e., discontinuity of data collection). The instant checking for the data can help users find those problems instantly.

Figure 2. Sensor device of Rt-LFM system.

An open data platform for the IoT was used to aggregate and analyze the data collected by the sensor devices. Firstly, a database was designed to store the data, including time series, data fields, etc. Secondly, the licenses were purchased in the IoT platform for generating channels for each sensor. Finally, channels were created on the IoT analytics platform for the storage of the time-series data in the public cloud. When the sensor devices start to work, the end-users (i.e., managers and caregivers in the residential care homes, designers, building service engineers, or elderly residents) can check and download the data through the cloud. The Rt-LFM system then monitored the luminous environment in residential homes.

In order to ensure sensor accuracy and system integrity, sensors were calibrated and periodically checked. It is crucial to install stationary sensors in locations where the calibration can be performed easily. The intervals between calibration can be different from the sensor to sensor. Generally, the sensor manufacturer recommends a time interval between calibration, while it is a good general practice to check the sensor closely during the first 30 days after the installation. Therefore, the problems can be identified in the actual site (e.g., an inappropriate sensor location, interference from other sensors, objects, or the loss of sensitivity), ensuring the sensor functions as well as obtaining a good degree of confidence for the installation.

5. Application for monitoring luminous environment in residential care homes

To get the accurate illuminance level for the working and daily life of the elderly, the sensor measuring the illuminance should be installed at 76 cm above the floor without any shading around to get the ambient light levels, at the visual task height to get the task light levels, at a vertical position of face to get the make-up or shaving light levels [28]. The lighting conditions in the instant situations may be varied a lot in different locations of a single room. Therefore three or more locations (e.g., near the window/door and centre of the room) were chosen to install the developed sensor devices to get the average ambient light levels.

The integrated sensor devices have to work with continuous power. The installation of the devices should consider the locations and amount of power sources. Moreover, the physical environment, such as walls, doors, distance, and so on, may influence the signal strength of the Wi-Fi transmitters. The strength of each Wi-Fi transmitter has to be adjusted depending on the particular room size and the density of wall materials. To identify the connection distance between Wi-Fi receivers (within sensor device) and Wi-Fi transmitter (external) clearly and well manage all sensor devices systematically, a number of Wi-Fi transmitters should be set up based on the size of the residential care homes (e.g., one transmitter for room size of 10 x 10m). All the detailed arrangement has to be adjusted and tested based

on the settings (e.g., tables, cabinets, windows, doors, etc.) and plan of the residential care home and confirmed by the staff in the residential care homes during the installation.

The signal strength of the internet connection may be interfered by human motion, and the shade of surrounding objects easily influences the lighting conditions. Therefore, it is necessary to avoid people frequently walking between the integrated devices and the Wi-Fi transmitters. Furthermore, the installed integrated Rt-LFM device should not influence the daily life of the residents as well as the daily caring of the caregivers. Thus, with the requirements mentioned above, the tables or other furniture that is seldom used should be firstly considered as the installation locations (see Figure 3).

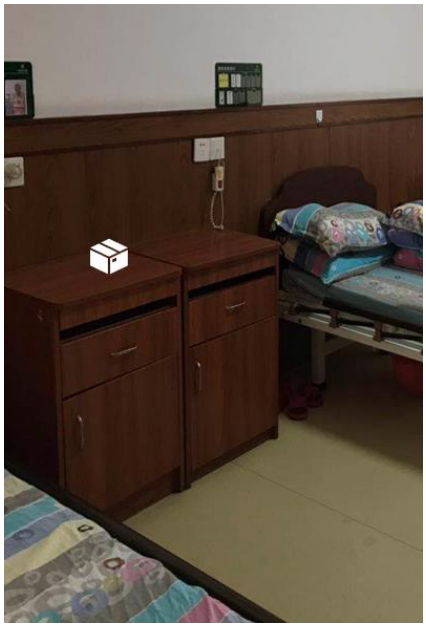

Figure 3. Installation positions of sensor devices in residential care homes.

6. Summary

Lighting influences many aspects of the elderly in their daily life, such as visual health, circadian rhythms, cognition, behavior, and mood. The elderly with visual deficits, limited mobility, reduced balance, etc. demand special lighting conditions in residential care homes. However, poor lighting conditions are not uncommon in residential care homes. To better manage, renovate and design the LFM in residential homes, it is necessary to monitor the luminous environment for maintaining a comfortable, healthy, and safe indoor environment for elderly residents.

An Rt-LFM system was designed and developed in this study to monitor the illuminance and color temperature of the indoor lighting by using the WSN and IoT technologies. Three layers, sensor, network, and interface layer, were included in the Rt-LFM system. The sensors were integrated into a small case to minimize the disturbance to the end-users in residential care homes. An open data platform for the IoT was used to aggregate and analyze the data collected by sensor devices. The collected data can be checked and downloaded in the cloud easily. The installation of the Rt-LFM system should be based on the actual settings and plan in a residential care home and the requirements of the end-users. The Rt-LFM system has been tested in the residential homes. It was practical to collect the lighting data continuously. The levels of illuminance and color temperature in different locations and rooms could be checked instantly, and the data was downloaded from the public store cloud for further analysis. It has been proved that the Rt-LFM system can be used for research purposes. In the next stage, the

experiences and feedback from other users (e.g., the elderly, caregivers, and facility managers) will be gathered, and the Rt-LFM system will be optimized based on their suggestions.

It is definitely sure that the Rt-LFM system can enhance the long-term health of the elderly by minimizing lighting-related discomfort, hazards, and diseases and maximizing the visual and living comfort in the homes. The integrated Rt-LFM system will not only benefit the health of the elderly in residential care homes but also reduce the caring risks of caregivers and home managers. By using this Rt-LFM system with flexibly placed sensors, managers in residential care homes can instantly know the lighting conditions anywhere and take action to manage the LFM promptly. The diagrams formed by long-term data are also beneficial to reveal the overall quality of the luminous environment, and they can be used to guide and improve facility management strategies. Accordingly, the medical burden of the government is also expected to be decreased.

In addition, the data generated from different types of buildings can be analyzed in the future. Older residents' visual comfort and satisfaction with LE can be collected simultaneously. It is possible to get the optimal LM design in different types of buildings for satisfying their various needs combined with the objective environment data and subjective evaluations of the elderly. Accordingly, the lighting standards for the elderly can be specified and adjusted in the future. Building service engineers, designers, and other construction professionals can use the findings and standards to design and renovate residential care homes.

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