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Evaluation of visualization techniques for use by facility operators during monitoring tasks

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ABSTRACT

Facility operators interact with building automation systems (BASs) on a regular basis for various purposes such as facility maintenance, occupant comfort, equipment monitoring, safety and security. Evaluation of various BAS interfaces showed that there are challenges faced by facility operators that impede their efficiency and accuracy of their responses to reported situations. These challenges revolve mainly around the lack of spatial context for the monitored sensor readings and equipment statuses, and operators' information overloading. Various visualization techniques have been used in commercially available BASs, however, their impact on the situation awareness of facility operators is not clearly known. This study focuses on this need and evaluates various visualization techniques that best suit to the needs of facility operators. This study identifies visualization techniques that are applicable to encode sematic information in spatial context, and details the design and implementation of user studies that were performed with seventeen expert and six novice facility operators to understand the impact of visualization techniques on operators' accuracy and timeliness to reported situations in relation to building system monitoring. The findings suggested that visualization-based interfaces generally improve the accuracy and efficiency of facility operators' decisions in monitoring tasks as compared to interfaces designed mainly with tabular displays. The results can be used by practitioners in the industry, not only for greenhouse facility monitoring, but also for facility monitoring in general, and by vendors to consider for their BAS interfaces.

1. Introduction

Modern building automation systems (BASs) using direct digital control (DDC) not only provide automatic control of indoor environments, but also allow remote monitoring and control for facility operators. Real-time monitoring of BASs' operational conditions is fundamental to ensure prompt response to abnormal situations in a facility [1]. However, modern sophisticated BASs sometimes surpass the facility operators' capability to manage them [1]. It is found that human factors, including operator errors, unawareness, interferences, and indifferences, are one of the most important factors that lead to system control problems, and that accounts for 29% of all problems in BASs control [2]. Therefore, it is important that the interfaces used by facility operators' are designed in such a way that they enhance facility operators' situation awareness on operational conditions and minimize operator errors when interacting with BASs.

This research study was motivated by a case study that was conducted in a greenhouse facility. We have conducted interviews, shadowing and contextual inquiries, during which we explored the way facility operators use BASs in their daily routines. Interfaces of BASs in greenhouse facilities are even more important than those designed for regular commercial buildings because they require more frequent monitoring to ensure that the plants are in healthy conditions at all times. In the case study, the authors also evaluated the interface of the BAS that is currently in use at the greenhouse facility, together with a sample set of BASs used in other greenhouse facilities or regular buildings. These BASs were selected from the industry as well as the ones that were described in details in previous research studies. It was identified from the evaluations that there are two main issues with the way information is provided to facility operators: (1) lack of spatial context for sensor readings and equipment statuses and (2) information overloading, which reduced the efficiency and accuracy of facility operators' decisions to perform their daily monitoring tasks. Both of these challenges indicate a need for environments which can provide spatial context of sensor readings and equipment statuses while minimizing information overloading for facility monitoring tasks.

Visualization is known to improve human's perception and efficiency of dealing with complex and/or large volumes of data [3]. Various visualization techniques have successfully been used by previous research studies to support different monitoring tasks, such as monitoring of construction fields [4], data centers [5], energy use in cities [6], and sensor networks [7–9]. The study presented in this paper builds on this premise that human's perception and efficiency change with the way

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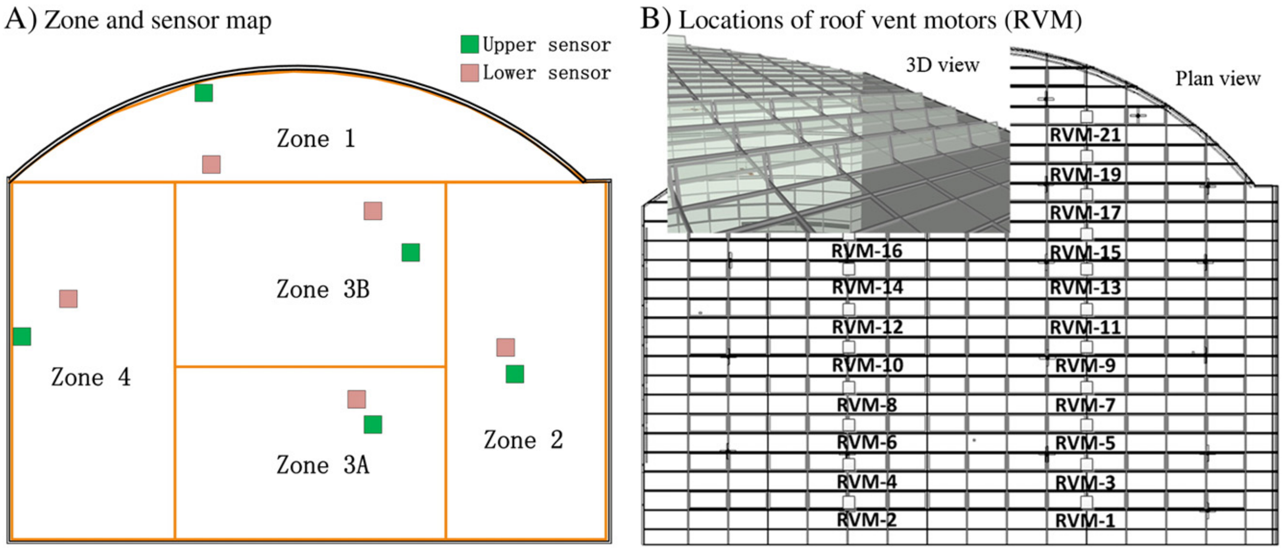
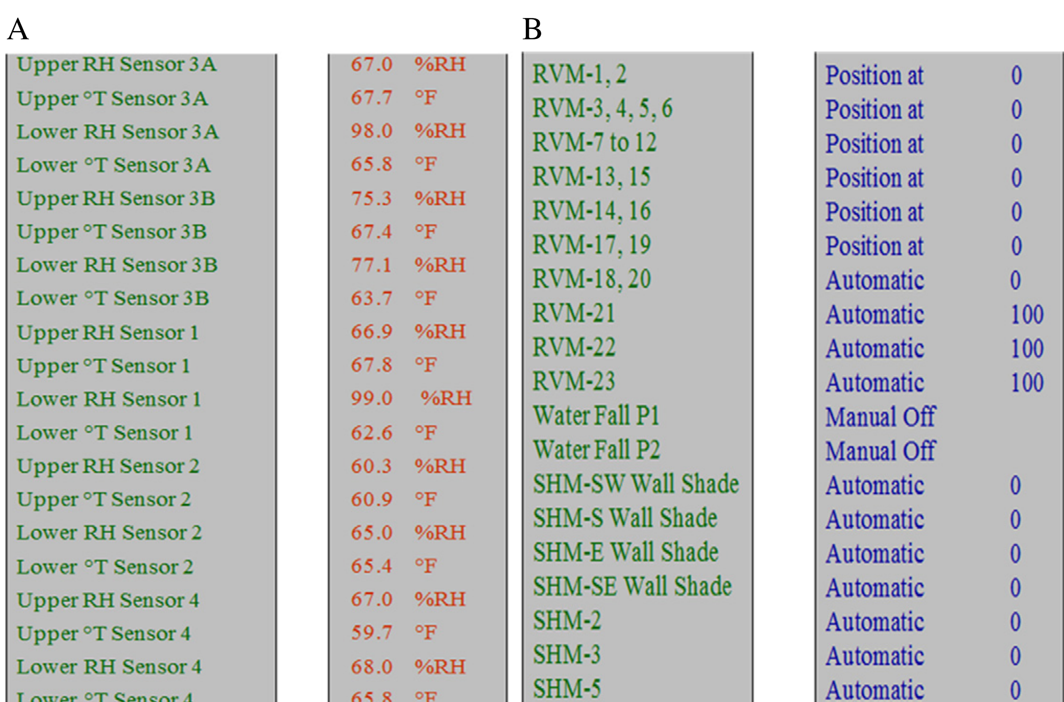


Fig. 1. The greenhouse facility zones, sensors and controlled roof vent motors. A. Zone and sensor map. B. Locations of roof vent motors (RVM).

information is presented to them and hypothesizes that visualization techniques that are used to display necessary information in facilities could enhance facility operators' accuracy and efficiency during their daily monitoring tasks.

In order to test this hypothesis, the authors conducted an extensive review of visualization techniques that have been used in previous research studies, with an emphasis on the ones that merge semantic information with spatial information, due to the need of relating sensor and equipment status information to the space information. Information needed by facility operators during typical monitoring tasks in their daily routines was identified and used as a baseline to evaluate the impact of different visualization techniques in facility operators' perception, responses and accuracy of their decisions. The authors used low-fidelity prototyping method [10] to implement the visualization-based interfaces. Low-fidelity prototyping method has been adopted in this research study because of its effectiveness of getting end user's feedbacks with low development cost, quick turnaround time and iterations of multiple design options [10,62]. A detailed explanation of how these low-fidelity prototypes have been used in the study is provided in Section 4. Two quantitative metrics – accuracy rate and time of completing the tasks using different interfaces, and one qualitative metric – users' preferences, were used for the evaluation. This



*Note: *0*: Vents are closed; *100*: Vents are open; *Position at*: equipment under manual control; *Automatic*: equipment under BAS control.

Fig. 2. Snapshots from the BAS interface of the greenhouse facility. A. Snapshots from the BAS interface showing the sensor data. B. *Snapshots from the BAS interface showing the controlled equipment statuses.