MOSAIC-CHART BASED VISUALIZATION IN BUILDING AUTOMATION SYSTEMS[1]

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Abstract

Today's building automation systems must be capable of dealing with a large number of simultaneously occurring events. Human operators monitor these events in order to maintain situational awareness, to detect physical intrusion or hardware problems, and other irregularities. We transferred the so-called temporal mosaic charts to building environments and compared their use with entropy-enriched Gantt charts and classical logfile analysis.

Keywords: building automation, smart homes, visualization

1 INTRODUCTION

Building automation systems (BAS) are complex distributed systems used for monitoring, controlling, and managing buildings. BAS consist of a large number of devices connected to a network. These devices include sensors, actuators, and controllers; with each device reporting its values to others over the network. For instance a given sensor reporting the temperature, state of a window (e.g. open/closed) or the recent access to a protected room. We call actuator state changes and sensor value changes *events*. For large installations with thousands of BAS devices, the monitoring of events can become very complex and demanding for human operators. Therefore, advanced visualization systems are required to support operators, e.g. for BAS anomaly detection and physical security monitoring such as perimeter security for airports and public places. These visualization systems need to allow easier monitoring of the large number of simultaneously occurring events within a BAS.

We have adapted the temporal mosaic chart visualization by Luz *et al.* [3] to the area of BAS. In comparison to conventional Gantt charts used for visualization of time-based data, temporal mosaic charts enable visualization of parallel events while providing a more efficient screen real-estate usage. Our modified events visualization is based on seven priority levels, with each color-coded to indicate its event type, and arranged on temporal mosaic chart based on its entropy to enable a weighted representation. For

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instance, in our visualization, a normally occurring, small temperature change within a room is shown in a different color and less emphasized than the representation of an event associated with a window opened at night which is usually closed during the day.

We describe a prototype implementation of this visualization, using BAS event logs recorded at the University of Applied Sciences Augsburg. We also present an evaluation of the effectiveness of our approach based on two user studies with five professional building operators.

The remainder is structured as follows. We introduce fundamentals in Sect. 2, while Sect. 3 describes our evaluation and its results. Section 4 summarizes our findings.

2 FUNDAMENTALS AND PROOF OF CONCEPT IMPLEMENTATION

Providing an overview of events within and around buildings is covered by many commercial products such as *Siemens Building Technology*'s *airport surveillance*[2] system as well as by academic research projects such as *IT4SE*[3].

One approach to visualization of simultaneously occurring events is presented in [4] and implemented in a tool named *Chronos* [3]. Chronos provides temporal mosaic charts for events which aim to overcome some of the limitations of Gantt charts, including their poor representation of detail and inefficient use of screen real-estate [3]. Unlike Gantt charts, temporal mosaic charts combine parallel occurring events, which are visualized by separate streams in Gantt charts, into a single stream so as to use the provided screen space more efficiently. In previous research, it was shown that temporal mosaic charts outperform Gantt charts [3] for scheduling tasks. As task scheduling is very similar to BAS event visualization, our work does not aim to compare Gantt and temporal mosaic charts again, but instead it extends both visualizations to the context of larger BAS environments and therefore modifies Chronos as follows:

- Two modifications were made to the temporal mosaic visualization. Firstly, the size of an event type (e.g. temperature change) within the stream is linked to the event's entropy in order to prioritize important events. Secondly, we used color codes to make it easier to spot different types of events.
- The Gantt chart visualization was also modified to highlight different streams in a way that events linked to higher entropy are easier to spot. As with the temporal mosaic charts, we introduced the same color codes for Gantt charts.
- We implemented support into Chronos to perform visualization based on events provided by *BACnet* (*bacnet.org*) and *HomeMatic* (*www.homematic.com*) BAS.

3 USABILITY EVALUATION OF CHRONOS

We conducted a user study to evaluate the effectiveness of the modified visualization for monitoring BAS events. According to Nielsen 85.00% of known usability issues can be found with the help of five participants [5]. In order to reflect the full spectrum of potential end-users, our usability experiment was conducted with five full-time building operators from the University of Applied Sciences Augsburg. To verify the competence of the test persons, all operators had to fill out a questionnaire in advance in which they were asked what type of BAS they use in their regular work and for how long they have been working with BAS. All five operators were experienced in working with large BACnet environments with an average experience of 4.8 years. They were therefore considered experienced end-users and suitable to take part in this study.

[2]http://www.buildingtechnologies.siemens.com/bt/global/en/market-specific-solutions/airports/airport-security/pages/airport-security.aspx

[3]"**IT** **f**or **S**mart renewable **E**nergy generation and use", http://www.it4se.net

A usability testing requires objective data on the actual actions of the participants [5]. What happened before or between the individual actions can only be obtained indirectly from facial expressions, gestures and statements of the participant using the *Think Aloud Method* [5]. With the help of eye tracking, it is possible to evaluate the eye movements and the fixations on specific regions on the screen, which are collected and stored [5]. Eye tracking enables to find out which elements have been carried out in which order and which have not.

For the evaluation of the temporal mosaic and Gantt charts, examples from the daily practice with a building automation tool have been used:

a) Temporal mosaic chart

The operators were asked to find out – with the help of Chronos – why the lightning in an office room was not automatically turned off in the evening, although no persons were present in that room. Three of five operators were able to correctly identify the "motion sensor" as the source of the problem, needing an average of 83 seconds to conclude the correct result.

For the visualization of the heatmap diagram, we used the *Absolute Gaze Duration Heatmap (AGDH)*. An AGDH shows the accumulated time participants spent looking at the different areas of the stimulus. Each fixation made by each user adds a value to the heatmap and is proportional to its duration [1]. The AGDH of the mosaic chart is shown in Fig. 1 (left side) and indicates that three areas of the screen were within participant's primary focus, namely the date of the event, the room number J305, and the sensors for the room.

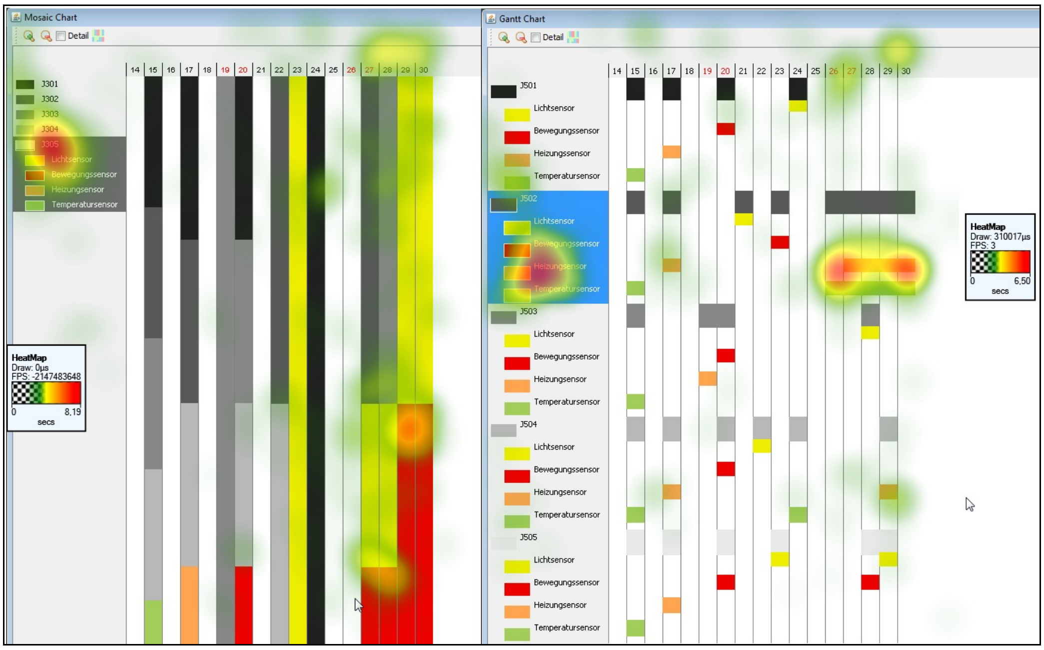

Figure 1: AGDH heatmaps of the temporal mosaic chart (left) and the Gantt chart (right)

Additionally, a post-test was performed using an additional questionnaire, in which four of the five operators came to correct conclusions.

b) Entropy-enriched Gantt chart

For comparison of the temporal mosaic chart with the entropy-enriched Gantt chart, a second and similar challenge was posed to the operators. They were asked to determine the cause for a heating problem in a given room.

Five of five operators were able to identify the right sensor as a source of the problem. These five participants needed on average 41 seconds to find the correct result. Fig. 1 (right side) shows the AGDH for the Gantt chart. Similarly to the temporal mosaic chart, the operators primarily focused on the same three spots.

Area of interest comparison

The so-called *area of interest* (AOI) is a part of the stimulus, i.e. the background area of the visualization that is relevant for a research question [2]. In our case, these are the relevant *beams (streams in the diagram)* of the sensors for each room in both charts.

We compared the *time to first fixation* (time from the start of the stimulus display until the test participant fixates on an AOI in the diagram for the first time), the *total fixation duration* (duration of all fixations within an AOI), the *total visit duration* (duration of all visits within an AOI), and the *visit count* (number of visits of an AOI).

time to first fixation:	Gantt average: 6,01 sec,	Mosaic average: 12,06 sec
first fixation duration:	Gantt average: 0,19 sec,	Mosaic average: 0,13 sec
total fixation duration:	Gantt average: 3,61 sec,	Mosaic average: 10,16 sec
total visit duration:	Gantt average: 3,85 sec,	Mosaic average: 17,21 sec

When we compare the different ratios of the eye tracking data from the relevant AOIs, we can observe that the first contact with the relevant AOI in the Gantt chart was on average 6.05 sec faster than in case of the mosaic chart. The first fixation duration on the Gantt chart was slightly longer than in case of the mosaic chart. In relation to the average task processing, the time of the first contact with the Gantt chart AOI was held by 14.5% of the task processing time and 14.7% of the mosaic chart processing time.

Moreover, a comparison between the temporal mosaic chart and a classic logfile analysis was conducted. The participants were therefore asked to additionally find the cause for a heating problem in a given room with the help of a BACnet event logfile (comprising a full daily record with thousands of records). The five participants did not find the error with the help of the logfile and the searching time was on average 85 sec.

4 CONCLUSION

Although temporal mosaic charts are suitable for various scenarios in which parallel tasks need to be visualized (e.g. in the area of task scheduling they outperform classical Gantt charts), we could show that while being linked to a good performance an entropy-enriched Gantt chart is the most suitable choice for visualizing BAS events in comparison to temporal mosaic charts. Classical logfile analysis led to the worst results in our study.

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