Exploring the Role of Autonomous System Behavior in Lighting Control

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ABSTRACT
Modern distributed lighting systems require advanced control systems because of the large amount of light sources and manipulable parameters. In this position paper we explore the unknown dimensions that can be used to describe control from full-user to full-system control. We believe a hybrid between the two will be most desirable. Combined with explicit user interaction, autonomous system behavior will create intelligent systems, able to adapt to users and contexts. This provides interesting opportunities for improved user experience as well as functional added value, for instance in energy saving or easy commissioning of light infrastructure. Based on different types of interactions, different levels of interaction-initiative and different interaction layers, a useful mapping of such hybrid control can be made. In our lighting living labs, we have implemented different controls in order to evaluate them on the basis of user experience.

Keywords
Autonomous System Behavior, Lighting Control

1. INTRODUCTION
Imagine a room in which the walls and ceiling are made of luminous materials that consist of countless LEDs. The illumination from the surfaces will create focused bright spotlights at some points and subtle atmospheric glows in the surrounding areas; while in another part of the room, the illumination resembles a mildly colored paint. As people move through the room, and engage in different activities, the light morphs along to support them by providing suitable illumination, and if desired also inspiration, information or support in (social) relations.

Modern lighting systems provide us with opportunities that go well beyond mere illumination of our environment. Highly dynamic light sources will be embedded in the areas in which we live and work, as well as in the objects within these areas. All these light elements will be connected, and digitally controlled.

This development will turn our environments into lighting platforms that will not only allow us to observe our surroundings and perform our tasks, but can also support other functions and activities. Light provides visibility, and enhances productivity; but light also plays an important role in the effects of an environment on people's mood and well-being, and possibly on their social behavior. Furthermore, light can provide us with unobtrusive information about relevant topics.

Inherent to the increase in opportunities is an increase in the interaction complexity that is related to the combination of a large amount of individual light sources and manipulable parameters. Furthermore, most opportunities of light that go beyond illumination are not easily obtained manually (e.g. emotional effects). Because of this complexity 'fully manual', user control is undesirable. On the other hand, 'fully automatic' system control also has drawbacks and seems undesirable. It will inevitably result in false decisions and undesirable effects. Because of false expectations it might cause a decreased perceived feeling of control by the users and low rates of acceptance.

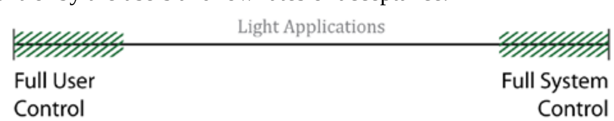


Fig 1. Control over future Light Applications will neither be fully manual nor fully autonomous

Therefore a hybrid between user control and system control seems most desirable (figure 1). This raises questions about what this behavior will look like. Parasurman proposes a model describing levels of interaction between user and 'automation' [4]. We build on this idea, and aim to explore the design space for user system interaction with lighting in terms of control and initiative, related to both user and system. Moreover, the system will demonstrate a certain degree of autonomous behavior, implying that not all outcomes are systematically pre-programmed but that new and possibly unexpected behavior can be the result of interactions. Such autonomous systems could provide appropriate and meaningful behavior, adapted to the user and the context of use.

In our approach, we aim to enable and enrich interaction with future lighting systems and to obtain an understanding of this hybrid control and autonomous system behavior. To gain this understanding, a research through design approach is employed in which we implement and evaluate different instances of control in a living lab context.

Three things are important in the approach towards the control of intelligent lighting systems. First are the opportunities that autonomous system behavior offers in the interaction. Second is the relation between user and system. Third is the approach towards the source of the system's intelligence. These issues will be explored in the subsequent sections. The paper concludes with a description and discussion of various implementations in our lighting living lab.

2. OPPORTUNITIES FOR AUTONOMOUS SYSTEM BEHAVIOR

Autonomous system behavior can support the interaction in various ways and have various functions. This behavior refers to intelligent systems that are able to take decisions based on contextual information. In this section we describe some initial ideas about potentially interesting opportunities for autonomous system behavior in lighting control; both from an experience perspective as well as from a more traditionally functional perspective.

***Experience* - Controlling numerous light sources**

Autonomous system behavior will be an inherent part of modern lighting control systems. Controlling each LED of a lighting platform individually will be virtually impossible due to the sheer amount of individual light sources, and the complexity that is a result of the combined possibilities of the new LED light sources. The location, size and shape of a light, it's focus, beam, intensity, color, and dynamics have to be determined for each moment and each circumstance. Mediation of appropriate information (selection and presentation) about possible settings and resulting light outputs could be an important role for the system.

***Experience* - Enable additional opportunities of light**

The functionality that such a lighting systems offers, combined with our increasing knowledge about the effects of light on people, provides us with additional opportunities that may require control beyond the capabilities of the end user. It has been indicated that besides visual effects, light has biological, emotional [1] and social [2] effects on people. The subtleties in lighting (e.g. color temperature and dynamics) which are required to achieve these effects, are beyond what a user could manually or perhaps even consciously set, which means that autonomous system behavior is required to realize these effects. Also in this case, as a mediator, the system may suggest particular applications that are suitable in particular situations.

***Functional* – Energy consumption**

Besides aiding the experience of artificial light, autonomous behavior in lighting systems may also support more traditional challenges. A smart lighting system can conserve large amounts of energy, by appropriately dimming the light or turning it off. It can do this simply based on presence of people in a room, but moreover, it may provide more local and focused lighting as well as lighting that better suited for particular activities. In doing so, the efficiency can be increased while simultaneously improving the user's experience.

***Functional* – Installation and commissioning**

The installation and configuration of lighting systems, especially in large buildings, can be made a lot easier when it is being supported by a smart system. A plug and play approach for lighting installers, that only have to provide a power connection to the luminaires is ideal, but requires a smart and partially autonomous system (e.g. self-configuration or localization mechanisms) to support the process.

Summarizing, in terms of user experience, the opportunities for autonomous behavior are twofold. On the one hand, one can aim to tackle the design challenges posed by the increasing opportunities of light. On the other hand autonomous behavior may benefit the user in terms of comfort and well being. Besides user experience, autonomous behavior can be beneficial for energy conservation and installation efficiency.

3. RELATION BETWEEN USER AND SYSTEM

As stated, we propose a hybrid between user and system control, and aim to explore the related design space. If we try to create a mapping of this design space, what exactly are the dimensions of such a mapping? In other words, how do we describe the relation between user and system?

The design space could be spanned by different *types of interaction*. Secondly, *initiative*, or interaction activity, could be an important factor in control mappings. Thirdly, *interaction layers* could constitute a mapping parameter. We will elaborate on these three parameter sets.

Types of interaction range from giving instructions (i.e. switch, selecting preset etc.), dialogue (i.e. system and user interact to find the best option, system can ask for specific context or preferences or give suggestions), to direct manipulation: a user explores the lighting conditions by manipulating objects (in a virtual or physical space) and stops when satisfied. Also advanced Graphical User Interfaces and Tangible Interaction styles fit in this category.

Initiative relates not only to control itself (i.e. who is taking decisions on the actual light settings), but also to the process of reaching a decision, and the relationship between user and system. Similar to human-human interaction, and their process' of collaborative decision making, also user and system might 'collaborate'. A series of small decisions resulting from a dialogue between user and system will eventually lead to a decision on a suitable lighting condition.

Different types of interactions and different levels of user and or system initiative lead to different control options. Comparable to Parasuraman's levels of human interaction, different categories can be recognized as displayed in table 1.

Interaction layers can also be used as a concept to describe the relation between user and system. Interaction layers refer to the abstraction from setting the technical parameters of light to more high-level concepts. In the current situation, users often control the low level parameters (on-off/dimming) of light, while they could also control the resulting *light behavior* (i.e. dynamic atmospheres that are intended to be relaxing, energizing, providing privacy, concentration etc.). At an even higher level, users may control light through the selection of a context or activity they intend to perform (such as reading, brainstorming, meeting etc.) and let the system select the appropriate light settings.

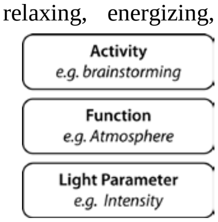


Fig 2. Interaction at different levels

Given these three mapping dimensions, multiple control systems can be implemented and compared. Consequently, multiple decisions need to be taken depending on context and preferences: first the appropriate level of initiative needs to be selected, second the appropriate interaction type needs to be established, and finally a suitable decision (suggestion or action) needs to be taken at a certain interaction layer.

Autonomous System Behavior	
Active system, Passive user *System takes actions based on user and context information; user relies on system*	
User waits for system action and vetos	System takes action
User waits for system action and approves	System offers one suggestion
Active system, Active user *Dialogue*	
User asks options for settings	System offers multiple suggestions
Active user, passive system	
Direct Manipulation User explores by manipulating objects; stops when satisfied	System obeys
Instructions User determines settings	System obeys
Passive system, passive user *Nothing happens*	
Full User Control	

User Initiative | System Initiative

Table 1: Overview of Types of Interaction and Levels of Initiative

Decisions on these issues will also influence the (user) acceptance of system autonomy. A passive 'slave-like' system is on the safe side: If no system initiative is taken, no unexpected things happen, and as long as the system obeys commands immediately no-one will complain. However, more challenging relations are those between 'partners': user and system understand the intentions and the needs of one another and act and respond as collaborating individuals. We aim to explore such relations in our studies.

4. APPROACHES TOWARDS INTELLIGENT SYSTEM BEHAVIOUR

Assuming a system that makes intelligent decisions, where does the intelligence come from? And how does this behavior emerge from the available context and user interaction? Within the field of Artificial Intelligence (AI) numerous approaches are available to create intelligent behavior in (lighting) control systems. Potentially valuable approaches include multi-agent systems (MAS), decentralized implementations, emergent behavior, neural networks, and machine learning. These approaches will be among our initial implementations; we will briefly discuss them.

Multi-Agent Systems (MASs) are systems composed of multiple interacting, intelligent agents and their environment. In our context, agents are light sources, sensors, and people. When there is no central controlling agent, the system is often referred to as a **decentralized system**. Such a system consists of a number of agents that have interactions (i.e. communicate, coordinate, negotiate) with each other and with their common environment, according to basic (local) interaction rules and local information. The agents together demonstrate a global behavior that emerges from interaction dynamics and cannot be described by the design of the individual agents. As agents have no knowledge of the desired system behavior, the challenge is to define their (local) interaction/communication rules, such that a desired global behavior emerges. Various **Machine Learning** algorithms may also benefit the autonomous system behavior as they allow the system to learn from interactions with the user. Classification algorithms for instance allow a system to distinguish between situations and set the lighting based on previous user preferences. **Neural networks** can create an understanding of the relations between the various system inputs and allow the system to recognize and learn about implicit patterns.

Besides the AI principles, smartness of a system may also stem from the **People** using it. Lighting designers or expert users may contribute to the system's intelligence through communities. The system can also learn by collecting users' preferences and applying these in other situations.

5. INITIAL IMPLEMENTATIONS

To allow exploration and evaluation of different *opportunities*, *relations* and *approaches* regarding autonomous system behavior, an initial implementation of a smart lighting platform has been developed; *Breakout 404* [3]. This 'breakout area' is situated in our university department and is used regularly by employees and students for informal meetings or for personal retreat. For this specific context we developed a lighting platform consisting of various lighting fixtures and numerous embedded sensors, see figure 3. Furthermore, different user interfaces, both screen based and tangible were developed for user interaction. All elements of the platform are interconnected and communicate, and can therefore be used to create different forms of autonomous system behavior. We describe some of the initial implementations below; and discuss them regarding opportunities, relations (type, initiative, layer) and approach. Also we briefly describe some preliminary conclusions from informal evaluations regarding user experience and the level of perceived control.

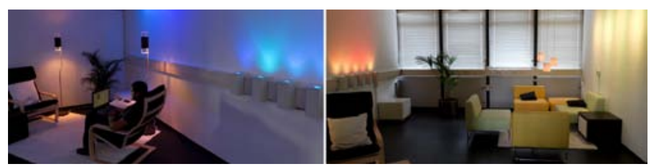


Fig 3. Two still images from the living lab; Breakout 404

Lighting Presets

In an initial setup, using the knowledge of a lighting designer, we have created six lighting atmosphere presets. Through a smartphone application, users are able to select one of the presets to match their preference. Icons were used to resemble the corresponding atmosphere, see figure 4a. This mapping of a graphical 'atmosphere description' to a more complex ensemble of various light sources is a basic form of system behavior and reduces the complexity for the user when controlling numerous light sources. In terms of the relation; the *user takes all initiative* and *instructs* the system at a *function layer*.

In an initial evaluation, people generally appreciated the large effect of the presets (little effort, large effect), however sometimes felt the presets did not necessarily match their preferences, nor were they able to 'slightly adjust settings' (e.g. dim a little bit).

Localized Lighting Presets

In a slightly more advanced variation, the same presets were available, however this time a tangible object, a cube, could be used to select an atmosphere by changing the upward-facing side (see figure 4b). The location within the space determined which of the lights would respond.

In general, people found that the physical representation (in comparison to the touch screen of the phone) was more convenient as no app-startup was required and the control was immediately visible and available. The object also clarifies social issues such as who's in control.

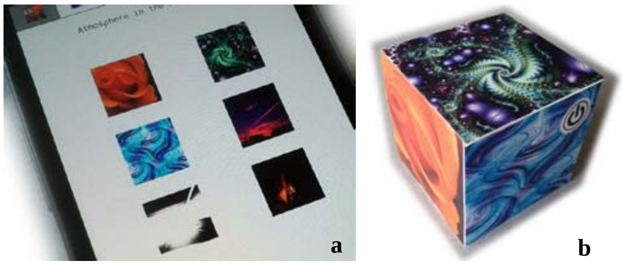
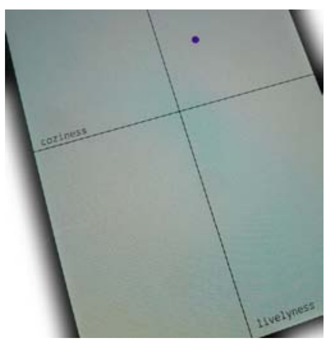


Fig 4. (a) The atmosphere selection application and (b) the cube used to select localized presets

Parametric Atmosphere Setting

In another smartphone application, the user could not select presets, but could select the *coziness* and *liveliness* of the atmosphere independently in an onscreen 2-axis field (see figure 5). The system would then translate this into a corresponding light setting. The axis were chosen based on a study in which the two dimensions were found to be a suitable atmosphere descriptor [5]. The translation into a lighting design was done in collaboration with a lighting designer.

Again, the opportunity is reducing complexity. Also here is high degree of *user initiative*, although the system offers more freedom. Instead of giving instructions, the user can *directly manipulate* the lighting conditions (at a *function layer*) and learn what the different settings could mean for his/her purposes.



Although not formally evaluated, people indicated that they enjoyed the freedom, although most were not sure whether they would desire such freedom in a real life setting.

Fig 5. Parametric atmosphere selection smartphone application

Automatic Light Switch

One of the initial implementations concerned an automated system that set the lighting to a particular atmosphere when a user enters the area, and turns back to an idle mode when leaving. The *system takes all initiative* and immediately *acts*, such that the user has to rely on the system.

This behavior was mostly taken for granted and appreciated, as long as it did not accidentally turn idle when people are still in the area and not detected by the sensors. If this happened, people were unsatisfied. They were rather quickly able to turn on the lights back on, by waving their hands as most people seemed familiar with this scenario from different occasions.

Preference Prediction

A preference prediction algorithm based on discrete rule based classification selects a lighting condition that should match the preference of users in a particular situation. Contextual parameters such as the type of activity people are going to do, the amount of natural daylight, time of day, and the number of people in the area are taken into account. When a user enters, the system predicts the most suitable lighting and sets it. If the user is not satisfied or prefers a change, he/she can indicate this through a smartphone, and the system will both change the lighting, and adapt its behavior over time. This system is relatively intelligent, because it combines user preferences with environmental conditions.

The interaction relies on a *dialogue* between user and system, where the system takes the initial initiative, which can optionally be followed up by the user. The study with this system is currently ongoing and we will soon be able to provide initial conclusions.

6. CONCLUSIONS and OUTLOOK

In this position paper we have explored several aspects of autonomous system behavior in the interaction with modern lighting. We make a plea for hybrid control and introduce three scales on which user and system control can be mapped. The mapping can be used for comparison and evaluation. We have explored *opportunities* for autonomous behavior, the possible *interaction -types, -initiatives and -layers*, and touched the topic of *approaches* towards intelligence. Finally we provided some examples of our own work related to autonomous system behavior.

In ongoing future work, we continue to exploration of the various aspects and try to obtain a more coherent overview of all elements at play. We continue to develop more implementations of autonomous control systems, including the potential neural networks offers and applying light sources as decentralized multi-agents.

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