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Adaptive Lighting Environments:

A joint PhD project in Industrial Design, Computer Science & Electrical Engineering

Where innovation starts

Project context ▪ A common interest in intelligent lighting brought six TU/e departments to start a joint research project entitled I-Lighting the World. The intention behind this collaboration is to have the skills and knowledge fields of the six departments enrich each other, allowing for advancements that can only be made with this broad set of backgrounds. The I-Lighting the World project consists of two main research tracks: Natural Lighting Solutions, conducted by BK, IEIS and TN, and Adaptive Lighting Environments by W&I, EE and ID. The Adaptive Lighting Environment track involves three PhD students, one of each participating department.

Relevance ▪ The environments of artificial light that surround us have a profound effect on our everyday life. Public lighting extends outdoor activity into the evening and night. Inside the home, atmospheric light schemes serve as catalysts for the social activities we conduct. In semi-public places like shops, light creates optimal conditions for the commercial activities to take place. Throughout history, each new lighting technology markedly influenced and enriched social life in a new way, demonstrating that light has a strong influence on people's social lives. The influence also works the other way around: social needs continuously serve as a catalyst for technological developments. This mutual influence between technology and the social human being is confirmed in both social psychology and philosophy of technology. A new generation of solid-state lighting technologies (LED and OLED), in combination with intelligent control architectures, is about to emerge. This high-tech lighting has the potential to create new, unseen and enriching influences on people's everyday activities and lives. But how can we focus our efforts on those technological innovations that are embedded in a social context?

Multidisciplinary research ▪ In this project, technological innovation and social relevance inspire each other, which is a unique approach made possible by combining expertise from the three departments of EE, W&I and ID. This combined approach will generate breakthrough knowledge about both the technological issues in lighting and their social implications. Concretely, the research from the different disciplines is centred around the design, prototyping and evaluation of Adaptive Lighting Environments. ALE's are adaptive both in terms of hard- and software, and are situated in specific social contexts. We currently discern three kinds of adaptivity: (1) adaptivity of system topology (possibility to add or remove system nodes), (2) adaptivity in user activity and high-level behaviour inference (learning to draw better conclusions from sensor data), and (3) adaptivity in actuation (learning to respond better in a given situation).

Application areas ▪ The current research involves ALE's in a home care environment and in an educational environment. Both application areas are broadly defined and should be further specified at the outset of the project, with the help of experts in the field. For illustration purposes, we specified a set of specific functionalities to consider. In the home care environment these are the following:

- Adaptive light helping dementia patients conduct specific everyday activities, by highlighting and augmenting relevant objects in their home environment.
- Adaptive light guiding patients to restore their day and night rhythm.
- Adaptive light helping patients recover from depression, or chronic stress.
- Adaptive lighting improving emotional well-being in general.

In an educational setting, the following specific functionalities can be considered for a range of learning environments (e.g., university, primary school, etc.):

- Adaptive light giving students and teachers feedback about attention and interest levels.
- Adaptive light serving as ‘attention grabber’ for teachers.
- Adaptive light stimulating concentration and the activity level of students.
- Adaptive light to guide group learning processes.
- Adaptive light transforming a non-educational context into an educational one, by augmenting specific objects with information.

ALE design criteria ▪ To ensure the projects remain relevant to the knowledge aims of the ALE project, and to increase practical feasibility, the following criteria should be met in the development of these adaptive light applications:

- Each ALE should be modular and scalable. A flexible number of low capacity nodes should be able to communicate with a flexible number of high capacity nodes.
- The ALE should be built on a lightweight system architecture, which means that memory footprint and communication overhead should be small.
- Resource management should be explicitly addressed and optimised.
- The ALE should be able to extract data from its environment, derive knowledge on user activity and high-level behaviour, and adjust its own behaviour accordingly.
- Installation and operation should be feasible and pleasurable for the target users, and should not require engineering.
- Human-system interaction design should fit the targeted context and people. Points of attention are incorporating meaningful feedback about system state and quality of system estimations, while offering meaningful possibilities for a person to give system input.
- The ALE should be prototyped to a level that allows evaluation with the targeted people in the targeted context. This poses high demands on robustness, and level of detail.

Knowledge aim/challenges ▪ Two kinds of research questions will be addressed in this PhD research, i.e., application specific questions to ensure the ALE’s are truly relevant to their context and technical questions that target general knowledge in the fields of electrical engineering, computer science or industrial design.

To provide initial focus in the research effort, a pre-selection is made of promising technological domains and powerful theoretical frameworks about human-technology interaction. This selection also takes into account the strengths of the participating departments, and provides the primary focus for knowledge generation in the research. Given the broad range of questions, the PhD candidate will need to find focus in the proposed range of research questions. Knowledge generation is targeted in the following domains:

- Reconfigurable, adaptive and modular system architecture. A dynamic context like a home or educational setting benefits from a lighting environment that is self-adapting and that can be adapted by the end-user, based on interactions and awareness of the environment. This requires an advanced distributed system and software architecture, functioning in a dynamic system of lighting modules. Software research on how to develop such an open interactive system is accompanied by design research about how to design human-system interfaces to these modular lighting systems. In addition requirements for distributed processing of sensor data and actuation will influence architectural design choices. More specifically formulated:

- How can we design system behaviour, when the specific set of nodes is flexible or partly unknown in advance?
- What confidence levels should a system reach before it acts on its interpretations of sensor data?
- How can an adaptive system keep track of its topology when 'nodes' are added or extracted?
- How can we ensure operational stability of an adaptive system?

- Novel sensing and communication technologies. In complex, modular lighting environments, information about system configuration and performance as well as about user behaviour needs to be acquired and must be communicated both between lighting modules and with gateways that serve to commission and control the system. Innovative distributed sensing and communication schemes need to be developed that underpin the modular system architecture, that support a sufficiently high information payload to permit sophisticated dynamic lighting effects, and that are sufficiently robust, cheap, and perceptually invisible for actual use. Specific questions are the following:
    - How can a system measure and interpret individual behaviour and group dynamics?
    - What message types and formats should a modular system of heterogeneous nodes use to be able to function?
    - How can a system discover new services, nodes and resources efficiently?
    - Can we discover a relation between different types of sensor configurations and the way people interact with a system?

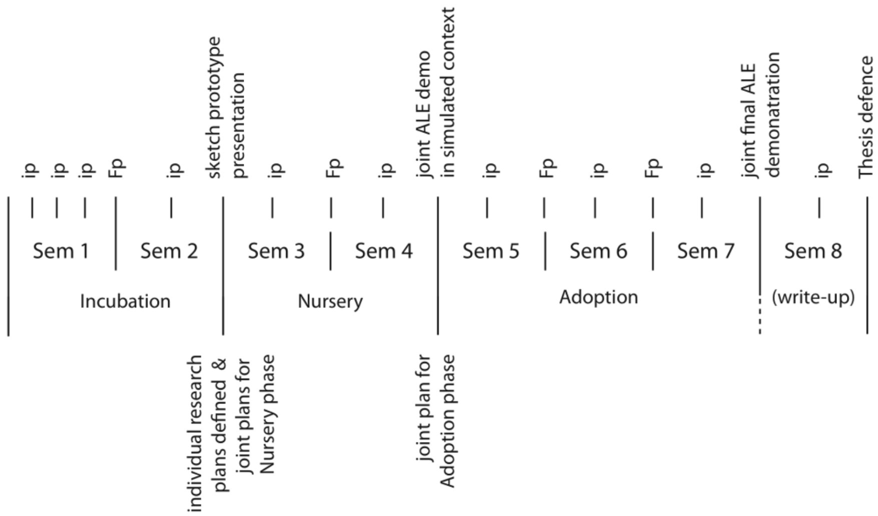
- New human-system interaction styles. Incorporation of complex and novel lighting technologies in lighting systems, functioning in a real life social context, requires development of new human-system interaction styles. Frameworks about technological mediation, ethics and aesthetics and rich interaction inform research into new human-system interaction styles.
    - How can we inform a user how to add and extract nodes in an adaptive system?
    - When should a system offer implicit control and when should it offer explicit control over system parameters?
    - What are the success measures of an adaptive system embedded in a social context?
    - How can a system provide meaningful response based on the quality of its estimations?

Research approach ▪ The proposed research project follows a research-through-design methodology. The joint design, engineering, prototyping and empirical testing of Adaptive Lighting Environments plays a central role in structuring and strengthening the research with the aforementioned knowledge aims. These ALE's can be considered platforms for research. Three

PhD students, one from W&I, EE and ID, conduct research in their field to generate knowledge in their own domains, while contributing to and getting data from the joint ALE experiments. The coordinated combination of the three expertises will benefit each individual project, since together they can create sophisticated research platforms that no researcher, with his individual expertise, could create.
A special approach for this multidisciplinary research-through-design is suggested, named the 'Growth Plan'. This Growth plan is a three-phase development and evaluation plan for ALE's, each phase including incrementally advanced technological aspects, and incrementally realistic social contexts for experimental evaluation:

- The first phase, called Incubation, involves highly innovative and explorative lighting concepts and the supporting interaction, interoperation and communication technology. Trials are created and tested in short, iterative research-through-design cycles.
- In the second phase, the Nursery, the resulting ALE concepts are developed to a high level of detail and tested in a controlled lab environment.
- The final phase is the Adoption, in which Adaptive Lighting Systems are placed and evaluated in real life contexts, to generate knowledge related to the real life technical and social workings of the systems. By exercising different scenario's of change and interoperability including embedding lighting systems within the context of Consumer Electronics devices we will increase our understanding of ambient technology, and find new and advanced examples of interoperating lighting with functions in the environment.

Milestones ▪ A general timeline with joint milestones of all three PhD projects is suggested to facilitate the joint process. See the graphic below. Regular joint informal presentations are scheduled (indicated with 'ip') for discussion of progress, and to learn from each other's approaches. Formal presentations to a larger audience (promotors, other researchers) are scheduled each semester.



Computer Science specific appendix

Generally, smart space components are programmed prior to deployment phase in order to compose a rich service by exposing their functionality to the system. Therefore, there lies very little flexibility in adapting smart space services to unforeseen context changes. However, smart lighting environments are envisioned to be very dynamic and to provide intelligent services through devices (network nodes) that are extremely limited in resources, i.e. luminaries and sensors. Thus, resources such as computational power, energy and memory existing in such nodes are typically not sufficient for supporting complicated architectural frameworks such as Open Services Gateway initiative (OSGi) and Network on Terminal Architecture (NoTA) . In order to overcome this issue, a gateway approach can be adopted, where a high capability gateway acts as a bridge between a smart space of low capability lights and sensors, and another of high capability components. It is then the responsibility of the gateway to translate message formats and ontologies defined in these smart environments to each other. Behind the gateway, the light and sensor nodes can interoperate (within themselves directly and with other nodes via gateway) through a lighter service-based architectural framework, such as an advanced version of the OSAS (Open Service Architecture for Sensors) framework (Bosman et. al. 2009). In order to achieve flexibility, system components must be programmed such that future, as yet unforeseen, cooperation and adaptations are simply realizable, and actually work.

W&I PhD candidate should have experience in:
* distributed systems
* software/hardware architectures
* C and Python (optional) programming
* multidisciplinary projects and teamwork
* writing and presentation

References

http://osgi.org
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Electrical Engineering specific appendix

Activity and context inference in ambient intelligent environments

Both artificial and natural light surrounds us every day. It cues day-night rhythms, moods, attention, and could communicate information such as for home care patients. These properties are particularly enhanced through novel solid-state lighting technologies (LED and OLED) in combination with adaptive control functions. Thus, new enriching environments could be enabled by actuating these lighting functions in smart ways. Activity and context information from the environment and its occupants, gathered by a distributed modular architecture of sensing and processing elements can enable this functionality. In this project applications of adaptive lighting will be investigated in personal assistance to coach dietary activities and in an educational setting, regarding attention and interaction. Mental and emotional context information will be important in both applications.

The goal of this PhD project is to create conceptual frameworks and practical demonstrations of activity and mental context-awareness in dietary activity and education. In particular, the candidate's work will focus on developing novel modular and adaptive activity and context recognition techniques that can be used to control lighting functions based on information obtained from ambient and on-body multi-modal sensors. An important aspect will be the dynamic self-adaptive operation. The candidate's work will span electronic systems, pilot studies, signal processing, and pattern recognition fields, with a focus on the latter.

This PhD project is embedded in a joint endeavour involving in total 3 PhD students from the departments industrial design, computer science, and electrical engineering at TU Eindhoven. Thus this project will provide unique opportunities to become acquainted and inspired by related fields in distributed system architectures, wireless sensor networks, human-computer interaction, and design. Besides demonstrated talents and experience, teamwork in this multidisciplinary group is a primary concern for the candidate selection process.

For further information please contact Oliver Amft, amft@tue.nl. Applications including a full CV and a letter of interests should be submitted to the same address. The position will be filled as soon as possible.

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Industrial Design specific appendix

Societal trends and technological trends present Industrial Design with the challenge to move towards a more systems oriented way of designing. Dealing with the complexity of systems in design requires new techniques and theoretical frameworks. The Industrial Design PhD researcher asks the 'how to design for…' question, aiming to create theoretical frameworks and techniques that help in the aforementioned challenge. The ALE project focuses on a specific set of challenges that relate to system adaptivity in the three ways that are mentioned in the previous. The ID PhD candidate should find focus within this set of challenges. Essential for the ID PhD is to relate system characteristics to human implications in design. The theory of Technological Mediation (Verbeek, 2005), and Ethics and Aesthetics in Interaction (Ross, 2008) serve as a basis for incorporating human implications in the design of systems. The ID PhD will also ensure that the ALE's that are developed in the ALE project are relevant for the intended contexts.

In selecting the ID PhD candidate, the following characteristics are highlighted:
* affinity with and skills in design research
* the level of design skills in interactive product and/or system design
* experience in and affinity with multidisciplinary projects and teamwork
* writing and presentation skills
* affinity with and skills in integrating technology
* affinity and skills in user involvement in design
* experience with and vision in intelligent lighting design

References

Verbeek, P. P. (2005). What things do - Philosophical reflections on technology, agency, and design. Penn State: Penn State University Press.
Ross, P.R. (2008) Ethics and aesthetics in intelligent product and system design. PhD thesis. Eindhoven: Eindhoven University of Technology.

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