Intelligent lighting, smart living

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The Intelligent Lighting Institute outlines the goals, applications, and enabling capabilities of smart lighting

'Smart lighting' refers to lighting, and lighting systems that behave in an intelligent way. These systems expose behaviour that is an improvement over standard (non-smart) systems in several measures of cost, while their behaviour is typically more complex than simply switching on and off. The measures of cost pertain to energy usage, appropriateness of the light distribution and end users' mental and physical health.

Three recent technology advances enable smart lighting. First, the development of solid state lighting (SSL) brings the digitisation of light, i.e. light as an instantaneously and interactively controllable medium. Second, the advent of embedded sensors and actuators in combination with (wireless) communication brings the Internet of Things. Third, data analysis techniques help systems to understand their context, allowing data-based adaptive behaviour.

Smart lighting has application domains in domestic, educational and professional indoor environments as well as in public outdoor spaces. And while technology progresses and insights increase, new applications are invented. Light can be used as an actuation technology to influence people. Applications can have an artistic appearance, they can solve a particular lighting problem, they can be used in commerce or propose a very new way to interact with light. There is much to be learnt.

The goal of smartness

The primary goal of intelligent lighting is creating optimal light settings for human functioning. Traditionally, this includes providing conditions that maximise visibility and minimise discomfort, but it also pertains to creating a suitable atmosphere for the user's ongoing tasks and activities. More recent insights emphasise the healthy entrainment of users' internal biological clock and meeting transient psychological needs of, for instance, rest or activation. Light, as we currently understand it, has important implication for visual and cognitive performance and physical and mental health. With our growing insight in both image-forming and non-image-forming pathways of light has come the realisation that optimal lighting will differ between users but will also vary with tasks at hand and time of day.

A second goal is to reduce the energy usage of lighting systems. This has long been part of the design of lighting systems, starting with the use of a simple presence sensor. When a system is more aware of the current situation, the lighting control becomes much more accurate and more satisfying. For example, different colours can be chosen, parts of the room or the building that are not used can be dimmed without a user noticing, lighting can be adjusted towards the activity of the people in the room and daylight can be used in innovative ways. Reducing energy usage becomes a focused goal of the system.

The third goal is to reduce obtrusive lighting, specifically in outdoor applications. Smart lighting can bring darkness back into quieter areas. Rather than switching the lighting completely off, smart behaviour in response to activity in the street is shown. This positively impacts energy usage and the feelings of safety of people in the street.

Enabling technology

LED-based lights are manufactured using a similar process to electronic chips. LEDs have evolved into a mature alternative for traditional lighting, with a much higher efficiency and life expectancy. LEDs are easily controlled through small microprocessors and in this way colour and luminous intensity can be controlled over a large range. Using new mathematical insights, lenses and reflectors can be constructed that allow arbitrary patterns to be created. In this way, lighting has become an ICT technology, inheriting properties of flexibility and programmability.

Technology advances have led to a decrease in the size and energy usage of the integrated circuits that implement digital processing and storage capabilities. In combination with advances in MEMS technology, small sensors and actuators can be manufactured for low prices. This enables the development of distributed lighting systems with local storage and processing to behave more intelligently, i.e. to be more knowledgeable and more aware.

A third advance is the development of communication, making it possible and financially feasible to connect these small devices into networks. The Internet Protocol has shown to be pervasive and connects all devices into a global network. Each object or light can thus be connected and controlled through the internet. This is the Internet of Things or, rather, the Internet of Lights. Lighting, in fact, appears to offer a fine-grained infrastructure to Internet of Things implementations through its ubiquitous presence in the spaces people use.

Sensors and other interconnected devices generate data. The more devices are connected to the internet, the more data becomes available. Data comes from varying sources, not only from lighting systems themselves. The ability to process huge amounts of data in real time and to filter relevant from irrelevant data leads to a better understanding of the context systems are working in. This understanding can take the form of learning behaviour in which data about user behaviour is used to improve control, or it can be grounded in input from external data sources (e.g. the weather or a user profile) with a similar objective.

Application domains

In outdoor lighting, the main objectives are to improve feelings of comfort and safety, to reduce obtrusive light and to reduce energy usage. The last two objectives require dimming down the lights as much as possible, while the first requires the right lighting at the right moment. Energy reductions in outdoor lighting are already substantial when traditional lights are replaced by LEDs. Smart dynamic (down) tuning offers further reductions and reduces intrusiveness. Using more advanced sensor technology, an understanding of the situation on the street can be derived. This increased understanding subsequently allows the contemplation of even more innovative applications, for instance around the theme of crowd management: using light as actuation, crowds can be influenced, e.g. to walk in a certain direction or to reduce a conflict.

In professional and educational contexts, it is possible to install integrated lighting and climate control systems shaped to the particular environment. These systems behave according to a chosen strategy, balancing energy usage, user comfort, and user performance. Smartness is key here; for example, frequent changes may optimise the energy savings but become a nuisance to a person in the particular space. Only smart control of the electric lighting system and the daylight system can achieve energy savings, e.g. by taking external conditions and user activities into account. This smart control needs to be able to adapt to personal needs and preferences of different individuals, i.e. it must have the ability of learning users' expectations.

The home situation is particularly challenging. Similar to the office environment, the goal is to comfort users and reduce energy. However, there is little control over the available infrastructure or the shape of spaces. In comparison to offices, data collection is much less structured. For smart lighting to become successful here, machine intelligence will be required even more.

Ongoing work at the Intelligent Lighting Institute (ILI)

ILI, at Eindhoven University of Technology, is a research institute spanning five different disciplines. Three research lines form the basis: Sound lighting (the effect of lighting on humans); Bright environments (intelligent lighting infrastructures); and Light by design (theory and practice of shaping light distribution). In addition, the Open Light programme investigates novel lighting applications, concepts and systems.

Besides local laboratories, ILI is involved in living labs on the TU/e campus and in the city. Installations have been realised for implementing dynamic dimming in a residential area, and for exploring the potential of dynamic light scenarios for improving


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the atmosphere and defusing potentially violent events in a popular bar area in Eindhoven. These research efforts, co-ordinated and performed by ILI, allow the investigation and further development of smart lighting applications in complex and realistic environments.

A prime example of the possibilities smart lighting offers is the new office building 'The Edge' located in Amsterdam-Zuid. Designed by PLP Architecture, London, the building has a total floor area of 51,000m^2. All of the more than 6,000 luminaires are equipped with LEDs, host five sensors each (occupancy, photo element, temperature, humidity and CO_2) and are connected to POE Ethernet hubs. Building occupants can locally control the lighting with their smart phones when settings do not match personal requirements. Such settings can be learnt by the system and reproduced when this user returns or visits any other area. Similar technology is being implemented in the Eindhoven University of Technology's main building, creating a living lab and enabling even more intensive interdisciplinary research on campus.

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