Peripheral Devices for the Right Light

The EnLight project looked for greatly improved energy efficiency and user comfort in lighting applications. Werner Weber from Infineon Technologies, Lex James from Philips Research, Arjan van Velzen from Plugwise, Bruno Vulcano from Legrand, Micha Stalpers from AME, Arend van de Stadt from Eagle Vision Systems, Jens Döge from Fraunhofer IIS/EAS, and Wilfried Rabaud from CEA Leti explain how a closer relation between the user and provided light made it happen.

The closer the relation between the user and his requirements in terms of light provided in space and time, the better the comfort. These demands were fulfilled by advanced sensors and EnLight's distributed rules-based intelligence concept. Various physical parameters are important and need to be measured to allow proper decision-making such as occupancy, position of people in a room, level of outside lighting and temperature. The sensors developed and implemented into the lighting control network as well as the user controls are summarized in figure 1. Those peripheral devices are connected to the Lighting Control Network schematically shown in the illustration.

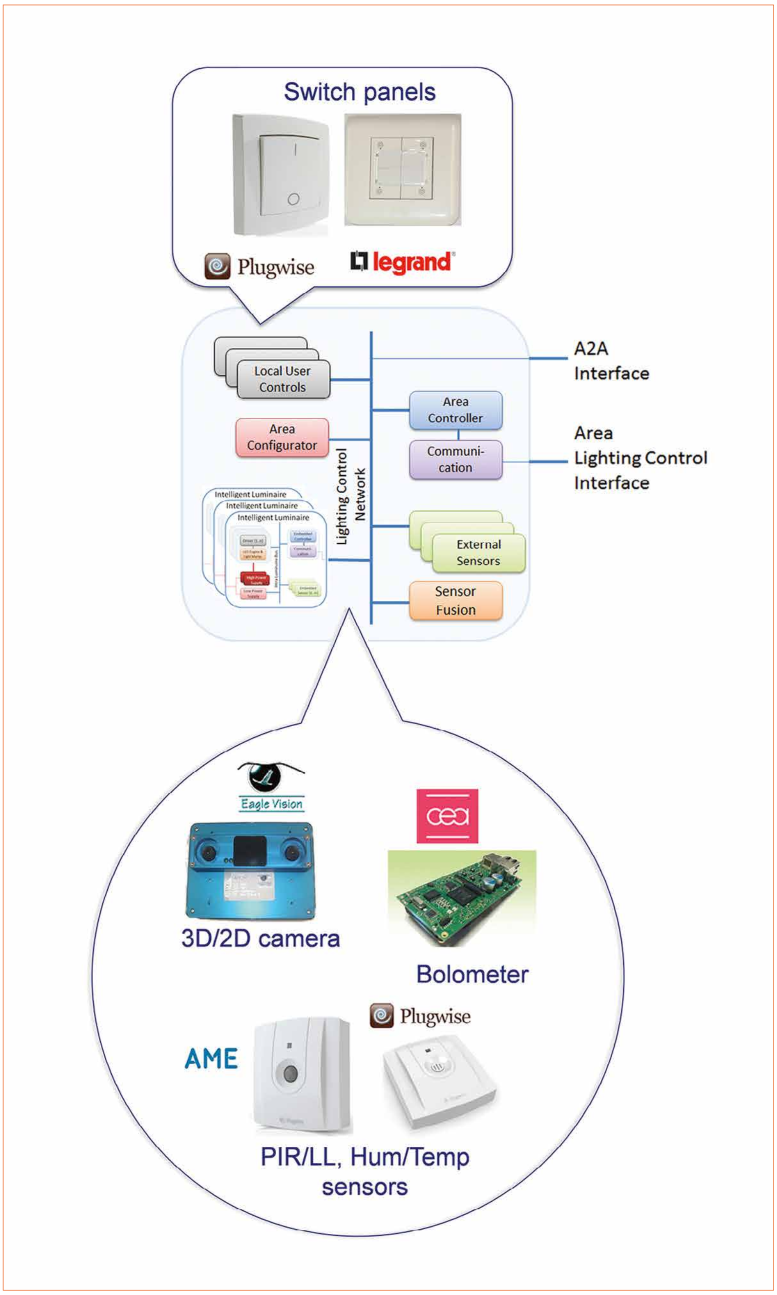

Figure 1: Building blocks developed for sensors and local user controls during the project

Sensors and User Interfaces

Before the different sensors are discussed one-by-one, the role of sensors and controls in this project is highlighted. The context was presented in general terms in the EnLight architecture paper in this article series [1]. Here, a few examples shall clarify the concept.

The sensors discussed in this paper provide information but they do not make decisions. Decisions are only made in the luminaire. In this architecture on the one hand, the sensor is acting independently of the way its output is used and on the other hand the control in the luminaire is rather flexible in the use of different sensor data depending on the application. Flexibility is largely enhanced by this architecture which uses a standardized process in the publication of data (e.g. by the sensor) and subscription to the receipt of data (e.g. by the luminaire).

In order to exemplify the context the user can press a button on a panel with two buttons. The button has no knowledge of what it means when it is pressed. The user knows what the pressing of a button means and the luminaire acts on rules to interpret the information.

The pressing of button ONE can mean

- Luminaire 1 to dim-up
- Luminaire 2 to increase the color temperature
- HVAC to increase the temperature

and the pressing of button TWO can mean

- Luminaire 1 to dim-down
- Luminaire 2 to decrease the color temperature, and
- HVAC to decrease temperature

In any case, the button itself only provides the information that a certain button is pressed. The luminaire can interpret this information by a rule-based action.

This example illustrates the decoupling of domains (sensors and luminaires in this case). The decoupling allows the system to react on a sensor signal from a domain that is not lighting related, e.g. smoke alarm provided by a CO_2 sensor:

In this context so-called “virtual sensors” are possible. For example, a luminaire with a decision engine can generate an event stating the presence of persons, rule-based on the information from various presence sensors in a certain area.

Another example of a virtual event is a peak load-limiting signal coming from the smart grid to request temporary power reduction. Luminaires can be provided with rules that react to such an event so the lighting system can respond to the request.

In the following chapters a user interface tool for commissioning application in EnLight systems, a specific local user control, and different presence sensors/ cameras are discussed based on different technical concepts and considering the privacy aspects.

User Interface Tool

Plugwise developed the commissioning tool, which mainly moves toward improved usability of the luminaires (Figure 1, top) [2]. The application provides a large variety of use cases; for example, it can easily change the colors of the luminaires with only one click on the color palette on an iPad or other iOS- or Android-driven devices. Furthermore, the app makes it easy to set up a schedule for the luminaires so they provide varied light colors and intensities in each specified time frame (e.g. 30 seconds purple, 30 seconds orange). The data can be put in manually, but a Bluetooth QR-scanner may also be used to scan the data of the luminaires. The QR codes may be printed or just shown on a computer screen.

The app is not only able to give commands to one single luminaire; there is also an option to group multiple luminaires and create a hierarchical group structure. The size of the group can vary from just a few luminaires in a toilet to a large number of devices within the whole building. In each group, modules can be added and removed and specifics like vendor name and hardware version can be set. If a group is selected in the app a list of all its modules and a list of subgroups pops up and if a module is selected, the tool shows in which groups the module is present and the groups that a module belongs to can be added, removed and saved.

As background information it is important to understand that the commands are executed by a set of rules (based on an Excel file), which are triggered by events; an event might be initiated for example by someone walking in the office. The rules contain different levels of priority and the execution of a rule may result in new “luminaire settings” and “level (de-)activation”. Only the settings of the highest active priority level are displayed, when no level is active the luminaire is switched off.

Each device has its own set of rules and thus every QR code contains its own set of rules. A standard set of rules is applied to each added module, which means that when presence is detected all the electricity turns on in the specific group and if absence is detected, all electricity switches off. In this way energy consumption is reduced, which was one of the great challenges of the project.

Local User Control

Legrand developed a local user control in order to give capabilities to locally provide input to the luminaries (Figure 1, top).

Two kinds of ZigBee end device systems were introduced:

- A wall switch able to be installed and fixed wherever the end user wants
- A table remote control

Both run on batteries. In addition to the ZigBee EnLight Profile embedded in these devices and compared to other solutions on the market, Legrand improved ZigBee commissioning management reliability within the proposed architecture.

Modifications done on the commissioning sessions were as follows:

- Return to factory configuration functionality: allows deleting all bindings which are initiated between the ZED (ZigBee End Device) and its ZigBee Router (ZR)
- Auto Remove functionality: after a commissioning session, products are working in a normal use mode. In case a ZR is not able to join, after several attempts, the ZED removes the ZR address from its binding table. As soon as this ZR has been removed from the binding table, the ZED sends a Subscribe Announcement signal to allow new ZR's to join or to allow the ZR which has been excluded from the binding table to re-join. This algorithm allows for an automatic clean-up of the binding table in case a ZR is broken or has been removed. It also allows a solution for RF communications issues which may occur
- Child - Parent Management: In terms of the ZigBee vocabulary, a ZED is the child and a ZR is the parent. Each ZED communicates with the ZigBee network through its parent. It is not mandatory that a child is bound to its parent. In case a parent is not seen by a child, the child has to manage a way to find another parent to talk with the ZigBee network. Moreover, the child also has to manage situations in which its previous parent is returning into the network. These situations are encountered when a power outage occurs during an installation

As a consequence of these measures communication reliability was increased.

People Tracker

Eaglevision developed a people tracker system [3] (Figure 1, bottom). This EagleGrid system is a marker-less 3D People Tracking System. It is a scalable network of small, people detection sensors, called EagleEyes, which are connected. These sensors cover large areas including complete floors in buildings. No tags like RFID, Bluetooth or other badges are needed. The system is based on stereo vision and advanced 3D imaging. The open network interface to external systems makes it possible to process the tracks and other detected events.

The camera images are processed on the local processor and do not need a central server. This architecture avoids heavy network load and supports the "privacy by design" principle because server image storage is not required. In collaboration with our application partners complete applications and solutions are implemented.

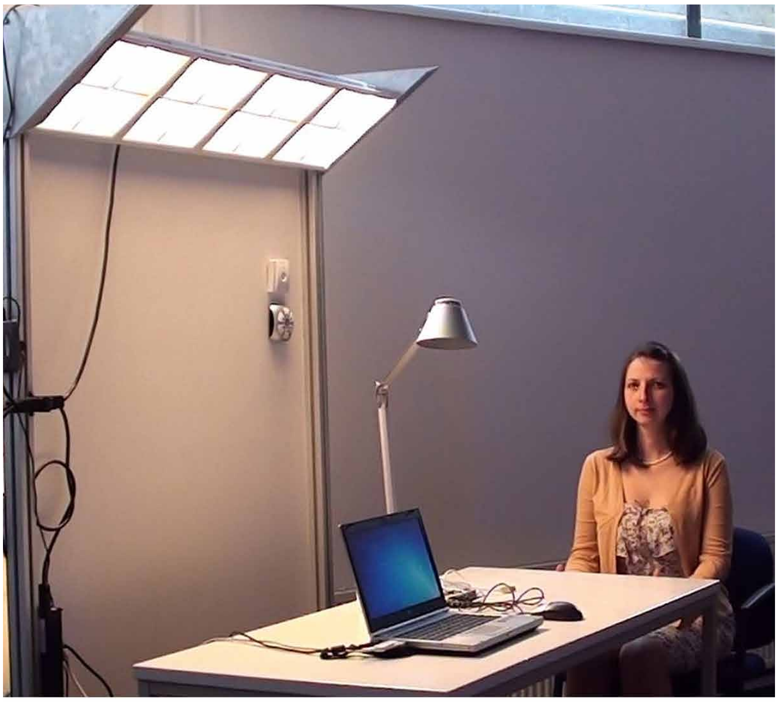

Figure 2: Standing/sitting detection demonstrator. The lighting situation adapts automatically when a person is sitting down or standing up

The tracking system can be used in all indoor places where people need to be tracked and safety events are automatically detected. The system respects people's privacy by design because the images are processed locally.

With the EagleEye stereo cameras 3D images are acquired and processed. By advanced algorithms individual persons are tracked in 3D and their route and poses over larger areas (including multiple cameras" field of view) are measured. Based on this method of tracking data, many applications are available such as direction sensitive counting of people in broad passages, detection of a fallen person, counting the exact number of persons in a room (for example for access control), measurement of queues and service times, and monitoring of human behavior (detection of elderly persons wandering in unsafe situations).

Within the project an office demonstrator was developed. The demonstrator reacts to human behavior as follows: in an office setting the lighting is modified automatically (in color and intensity) based on the pose of the person(s) in the illuminated neighborhood. In the demonstrator the lighting color moves from "reddish weak" to "blueish intense" when the person is standing up, for example to give a presentation (Figure 2). With this lighting configuration, the attention of the other attendees will be optimal and focused on the presenter. As soon as the person sits down again, the lighting returns to the original situation for a more soft evaluation discussion.

This demonstrator stands for a large variety of possible use cases of the EagleEye as smart sensor integrated in an intelligent lighting system, creating a very smart building. Application areas are office, hospitality, retail, security and (home) care.

Motion Detector and Temperature/Humidity Sensor

Existing motion and temperature/humidity sensors from Plugwise/AME were adapted to support the EnLight functionality and ZigBee communication protocol [4] (Figure 1, bottom). The sensors were battery powered devices and therefore act as sleepy end devices according to the ZigBee specification. They rely on the luminaire in the neighborhood to act as their ZigBee "parents". The sensors are in deep sleep (no radio) as long as there is no detection of an EnLight event. As soon as a relevant event occurs, i.e. detection of movement or a timer for reporting, the sensor wakes-up, gathers the event data (typically light, motion temperature or humidity measurements), switches on the ZigBee radio and sends the event via its parent luminaire over the air to the subscribers. Please note that this fits seamlessly in the EnLight model as described before.

Both the motion detector and the temperature/humidity sensors offer the following common functionalities:

- Leave the old network and join new network upon network button press (> 7 seconds)
- Announce to other devices in the network upon a button press to allow configuration and subscription
- Configure operational parameters such as "reporting period", "humidity delta reporting threshold" or "absence timeout"
- Report measured data on a periodical basis in the form of EnLight events

The motion sensor offers:

- Subscription on presence events, absence events
- Subscription on periodic reporting of light measurements and presence
- Notification of presence and absence (no presence for a configurable amount of time) to subscribers

The temperature/humidity sensor offers:

- Subscription on periodical reporting of temperature and humidity measurements in the form of EnLight events
- Reporting conditionally based on a change in measured values for temperature and humidity. For example, the temperature is only reported in case the measured temperature deviates more than 5°C from the previously reported value

CMOS Camera

Within the scope of the project, Fraunhofer IIS/EAS developed a low-power presence detector, based on an image-sensor system-on-chip (SoC) [5]. In contrast to traditional solutions, such as passive infrared (PIR) sensors, this system processes the image in the visible and near infrared spectrum, and derives texture features from visual information. A self-learning multi-modal algorithm analyzes the scene at a frame rate of up to ten frames per second. People can be localized within the field of view and distinguished from technical objects according to the active area and typical motion. In contrast to gray-scale algorithms the chosen approach is highly tolerant to brightness variations occurring due to incoming sunlight or switched luminaires.

We performed tests using a hardware / software prototype based on a commercial image sensor as well as an FPGA-implementation of the processing-pipeline (Figure 3, left), and simulations. They show the reliability of the method. Moreover, the experiments demonstrate that a high-dynamic-range image acquisition increases the effectiveness even further, especially for mixed lighting with the inclusion of sunlight or shadows.

These findings, as well as the algorithmic approach, contributed to the development of the new


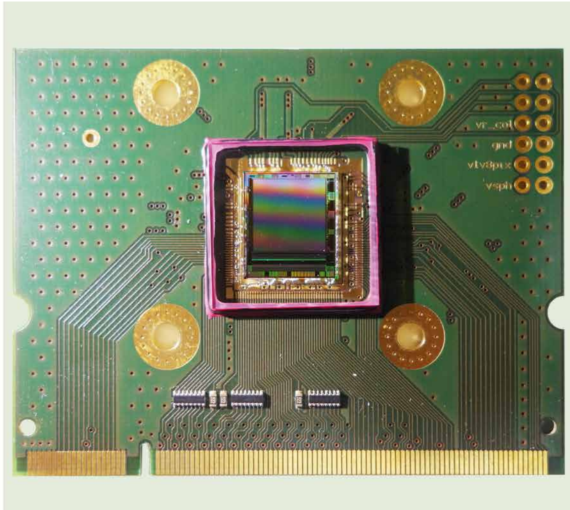

Figure 3: Demonstrator of the presence sensor (left) and image sensor SoC with integrated low power data processing (right)

presence sensor with a novel smart high-dynamic-range image sensor SoC (Figure 3, right). It features a linear-logarithmic characteristic with more than 120 dB dynamic range, and was developed using Fraunhofer's proprietary charge-based mixed-signal sensor-processor platform [6]. The integrated application-specific instruction set processors (ASIP), and the column-parallel processing units have therefore been enhanced for the extraction of texture features.

The internal image-processing has a number of advantages for the presence sensor. The on-chip feature extraction leads to a significant reduction of data to be transferred and reduces the computational effort for the external general-purpose processing unit. A reconstruction of original images outside the image sensor is rendered impossible.

Three key benefits:

- "Privacy by design"
- External processing effort is very low so that a small micro-controller can be used
- Thus the total power consumption is very low

For the sensor with optimized software components on both the image sensor SoC and the micro-controller, a total power consumption of 100 mW is realistic without restricting functionality and comfort.

After installation of the sensor, various regions in the room are configured in the software so that, depending on the location and characteristics of recognized movements, events are issued. By their logical combination it is possible to detect whether a door was opened, whether somebody entered or left the room, where movement is located and how intense it is. The different scenarios are used to control the illumination and window shading according to user requirements. At a desk close to a window, glare can be avoided, and the lighting adjusted depending on what the user is doing; for example reading or working with the computer. In a domestic environment, the color temperature can be adjusted according to the movement and the time of day. In addition, adjustment is possible of the intensity and distribution of light depending on whether the residents are eating, sleeping or watching TV.

Infrared Presence Sensor

In the frame of the project a new kind of presence sensor was developed by CEA Leti (Figure 1, bottom). It is based on a thermal IR (Infrared) sensor that is able to detect presence under arbitrary lighting conditions (daylight, night, etc.) [7]. Detection considers both still and moving people. This development fills the gap between the low-price - low pixel size detectors (PIR, thermopiles, etc.) and the high-price - high pixel size IR imagers (μ-bolometers).

The new IR μbolometer based presence sensor was developed on two parallel tracks: the first one is the development of low complexity detection algorithms (low-level and high-level), and their implementation on the demonstrator that was specifically developed for the project. In this prototype the detection algorithm provides semantic descriptors to the output, preserving intrinsic privacy. The low-level algorithms were designed to avoid thermo-electrical coolers. They enable shutter-less operation of the sensor with fixed pattern noise removal. They are robust to environmental temperature variation, and self-commissioning. The high-level algorithms allow very low complexity target detection: the result of the detection process is provided at the output by semantical descriptors. The result of such detection is illustrated in figure 4, where each square stands for the detection of a person through a dedicated android application developed for the project.

The second track was on the development of a specific integrated circuit. The application specific integrated circuit for autonomous low-cost, low-power steady presence sensing and counting was successfully fabricated on a general-purpose 130 nm technology from Altis semiconductors. The wafers were post-processed in the MINATEC clean-room facility for the implementation of IR bolometers MEMS. The integrated circuit with the IR bolometers built on top forms the sensor focal plane array. The latter is a 128x128 pixel matrix with 128 SIMD RISC processors and 128 application-specific ADCs (patented). A general purpose instruction set is implemented inside the processors which allows a broad range of applications and reduces system cost. Moreover, on-chip processing avoids image transfer and saves power.

The circuit proved its ability to perform privacy-compliant fully-digital thermal image acquisition and on-the-fly processing. Benchmarking with latest commercial products and articles in literature show a power consumption reduction of more than ten times using this new, dedicated integrated circuit (around 0.5 μW/pixel).

Conclusion/Summary

All sensors for the Enlight system that were discussed in this paper concentrate on the important question of presence of people to provide the correct amount of light at low cost and by avoiding impact on privacy of the persons in the room. The technical concepts are different and range from motion sensors, via Infrared presence detection up to cameras in the visible light. In the demonstrators, the interface to the system was based on wireless ZigBee technology. In principle, wired implementations are also possible, and may be used in future applications. Information from the sensors is provided to the network by 'events' generated by the sensors, but no decisions are made at this level. This information may be used and decisions indeed made on the amount and color of light provided by any luminaire or other device in the network.

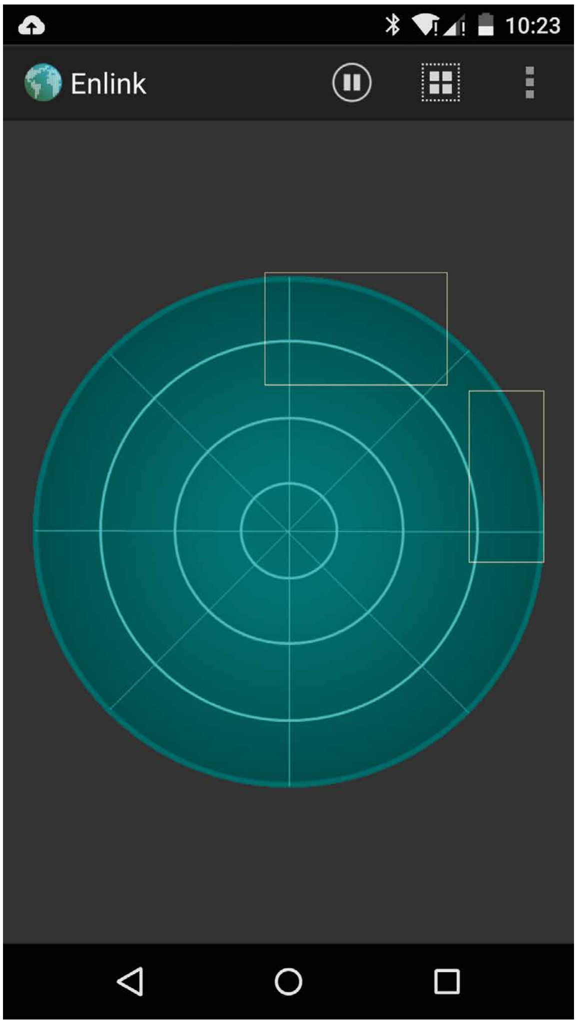

Figure 4:
Results of the detection process; each square stands for a detected person

The Enlight architecture is, of course, not limited to presence detection. Indeed, it provides a very powerful means for control of home environments in general, in times when energy saving is an important topic and electronics for control purposes becomes extremely inexpensive.

References:

[1] "System Architecture for Distributed Intelligence", Alex James, Martin Creusen and Micha Stalpers; LED Professional Review, Issue 48, 2015. Page 72

[2] Plugwise: https://www.plugwise.com

[3] Eagle Vision Systems bv (www.eaglevision.nl): the EagleEye people tracker

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[5] Fraunhofer IIS/EAS, http://www.eas.iis.fraunhofer.de/

[6] Jens Döge, „Ladungsbasierte analog-digitale Signalverarbeitung für schnelle CMOS-Bildsensoren", Dissertationsschrift, TU Dresden, Dresdner Beiträge zur Sensorik, 32, Dresden, 2008.

[7] CEA Leti: http://www-leti.cea.fr/