LumEnActive and Pervasive Digital Signage Projection

Stefan Rapp and Irene Weber

Conante
Fellenoord 130
5611ZB Eindhoven
The Netherlands

Dr. Stefan Rapp
Uhlandstr. 10
78559 Gosheim
Germany

{rapp,weber}@conante.com

Abstract. We present LumEnActive, a digital signage system based on steerable projection, and commercially available as a product. It is pervasive in several aspects: first, through its steerable light beam, LumEnActive can project digital information over a wide area in a room or shop. In contrast to other digital signage solutions using standard LCD or plasma displays, this opens up many possibilities to let digital content directly interact with goods or shop interior, thus forming a truly ubiquitous display and allow for a projected variant of augmented reality. Second, it can very easily be integrated into pervasive communication infrastructures: it is easily interfaced with various multi-touch tracking systems, so that LumEnActive's projected light spot can follow across (also multiple) multi-touch active surfaces. It can display remotely hosted digital signage content via the virtual network computing (VNC) protocol as well as pages from (embedded) web servers. Video streaming up to full HD is supported. LumEnActive is a most powerful and flexible digital signage solution for a wide variety of applications. In our paper, we sketch how the system works, detail several application scenarios and show how the system can be deployed and interfaced with other components.

1 Introduction

Digital signage (DS) is getting increasing attention in retail and outdoor media. More and more, DS will play an important – and in a few years possibly the most important – role in the advertising media industry. Today, most indoor solutions are based on large LCD monitors or Plasma screens, while larger outdoor applications are often based on LED screens. Where light conditions permit, digital projectors are more and more being used to display static or animated content in shops and public places, thanks to the exceedingly large achievable display sizes at comparably small cost. The type of content that is shown is mostly rather traditional material similar to TV-advertisements, but there are also interactive applications that bring with them the promise for an extended engagement of customers with a product or service. If an information kiosk setting is used, many technologies and design approaches known from Internet or PC-application development can be reused, however, not always an interaction like with an online-shop is preferable in a retail setting. Here for example also the haptic and olfactory senses are transporting product qualities, and thus shop owners will want to utilize these in convincing a shop visitor to also become a buyer.

LumEnActive [4, 9, 7] is a technology that can help digital signage to overcome the limitations of a TV-screen like appearance, and get back again into the realm of haptic product exploration. LumEnActive is using steerable projection, the output of a

digital projector can be deflected in almost any direction, to allow for truly ubiquitous DS. It can project digital information to almost any spot over an extended area where customers consider goods. It can guide customers to special offers, or assist them when they have increased information needs, wherever they are positioned. The LumEnActive software makes sure that the projected content is readable and appears undistorted on almost arbitrarily oriented surfaces, such as walls, tables, shelves, or on the floor.

LumEnActive offers features that are beneficial in a DS setting: It leverages the psychological effect that movement attracts attention, through its ability of a continuous movement of the projection area. It can thus guide the attention of shoppers and focus them on highlighted product offers in sequence. It allows flexible provision of DS without moving and remounting of hardware. It can even be made adaptive to the situation: it allows information-kiosk type applications on almost any surface in a room with intense user interaction, or it can just be used to create a desired atmosphere by a projected ambience or specific luminous staging. So, LumEnActive can seamlessly be scaled over the whole range of possible user engagement levels with DS, from an intense engagement over a subtle enrichment to a complete disappearance of the DS solution where the product itself can be explored completely unaffected. As most DS solutions only address the visual and auditory channels, and a linking to products must be achieved indirectly for example through branding, LumEnActive can weave together virtual content with real products directly, and thus address all senses from audio-visual information to the haptic and olfactory features of the product.

The paper is organized as follows: in the next section, we describe briefly how LumEnActive works and discuss some of the related work. In Section 3, we present some application scenarios where LumEnActive can be utilized, some of which we have already implemented for pilot customers. In Section 4, we show how easy it is to integrate LumEnActive into an existing DS infrastructure, and describe the integration possibilities from a technical viewpoint.

2 Background and related work

Before we can discuss applications of LumEnActive, it is in order to describe briefly how LumEnActive works. As mentioned above, the distinctive functionality of LumEnActive comes from the interplay between a reflection unit – a computer-controlled, two-axis rotatable mirror in front of a digital projector – and the LumEnActive software that generates the projected image and drives the mirror in a tightly coordinated fashion. We decided on a reflection unit instead of moving the projector as a whole, as it offers greater flexibility in choosing a projector's light intensity and associated operating costs according to specific project requirements. The setup can be used with very small, inexpensive, but rather dim LED-projectors, over standard office-use projectors up to the strongest but extraordinarily expensive high end projectors. The reflection unit is constructed for durability, and maintenance free 24/7 operation, and can reach 270 degrees range with panning and about 110 degrees with tilt. As these measures are for the image center, depending on the characteristics of the projector's optics, almost all portions of the walls as well as the complete floor can be projected to, if LumEnActive is mounted at the ceiling in the center of a room.

When the projected light spot moves across the room according to the actuated mirror, the interesting aspect of LumEnActive is that the projected content is *not* moving with it, but stays stationary with the wall or floor. Whatever content, be that images,

text or video, is placed at a specific spot, where it stays whether illuminated with the projector or not. Figure 1 shows an illustration of a LumEnActive system. In essence, the impression is that the whole room is covered with a virtual pane, and when the projected light spot is being moved, it reveals the portion of the virtual pane that it illuminates, like making visible some objects with a flashlight or highlighting an actor in a dark theater with a spotlight. This style of interaction is hence called the flashlight metaphor [8]. The seemingly simple and thus intuitive behavior is possible because behind the scenes, the LumEnActive Software does all the calculations to make sure that the content appears undistorted, by utilizing the power of current 3D graphics hardware acceleration cards. This decoupling of the movement of the projected light spot and the stationary location of content is the source of the device's easy usage, and foundation for many interesting application possibilities in advertising and retail applications.

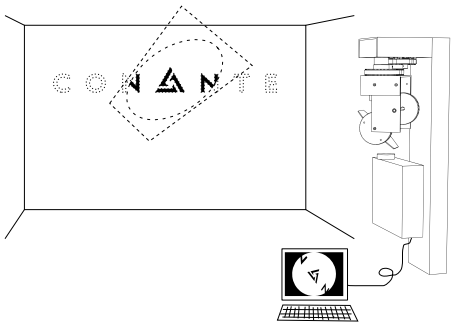

Fig. 1. Schematic illustration of a LumEnActive system. While the light spot can be moved, a portion of a virtual pane is projected. Images are distorted but then appear correct on the wall.

LumEnActive is based on Spotlight Navigation [8], a user interface and interaction paradigm for mobile, handheld projectors, for which a large portion of the algorithms and interaction technologies contained in the LumEnActive software were originally designed. Although independently developed, LumEnActive also shares similarities with Everywhere Displays [6]. The main difference between LumEnActive and Everywhere displays is in the overall conception: whereas in Everywhere displays, a steerable mirror is used to switch between several previously calibrated display areas (and subsequent on which touchscreen-like interaction may occur), LumEnActive is assuming a continuous work space, aligned with the surfaces of a room, from which only a part is projected at a time. While with everywhere displays a rectangular screen is assumed, that is fully inside the potentially arbitrarily shaped trapezoid that projectors produce when projecting at an angle, with LumEnActive, a portion of a conceptually unlimited space is shown, in general a larger space than can be projected at a time. Finally, where with everywhere displays, there is a switch from one display area to another, LumEnActive continuously shows a portion of the virtual world, also during the motion of the projected light spot. This can be done, because LumEnActive utilizes an internal 3D-modelling rather than a number of calibrations for a number of predefined places. On a more general level, Spotlight Navigation and LumEnActive are also related to situ-

ated information spaces by Fitzmaurice [1], who uses location aware LCD displays for interaction.

A LumEnActive presentation is usually set up with a mouse or other pointing device. The light spot follows the movements of the pointing device, by rotating the reflection unit accordingly. In a first step, a simple model of the room is defined interactively, by showing the system where the corners of the room are with the pointing device. Also further suitable projection surfaces such as shelves are made known to the system in this way. Then digital content (stored on disk, flash drive or on the network) is placed from a menu, scaled and placed using the pointing device on the available projection surfaces, ceiling or floor. In a final step, the movement of the light spot is recorded by showing the path it should follow. Setting up LumEnActive or modifying a presentation is usually done in few minutes if the content is properly prepared beforehand. Thus it is possible to easily adapt to different physical arrangements in different shops. Different LumEnActive presentations can easily be exchanged using flash drives or the network.

3 Application scenarios

Basic scenarios. In its simplest form, LumEnActive can project DS content stationary on an available projection surface like any other digital projector. Through the ability to correct distortions, the surface that is projected to can be defined more flexibly, as the relation between surface and projection direction does not need to be orthogonal. Having the projected light spot smaller than the surface and let it move around is a good means to attract and guide attention. It is also beneficial as the light intensity can then be much higher yielding more contrast in the pictures or videos as compared to projecting over the complete surface at once.

Augmented reality. The location-aware placement of content allows for a range of *augmented reality* applications, where virtual content directly relates to real objects. For example, a slogan can be projected adjacent to an item on sale, as in Figure 2, or features of the product can be listed right next to it. LumEnActive can project a scenery around a product, communicating, e.g., that a specific mobile phone is looking very nice in the opera as well as in a business meeting and even during leisure times out in the woods, simply by surrounding it with corresponding image material or video shots. Likewise, a beautiful face can be projected over a pair of glasses or above a necklace, or even the captured image of the customer looking at these items. The products remain there in

Fig. 2. The moving light spot attracts attention and makes visitors of a trade fair booth read slogans. Projected oversized and real product bins are mixed. (viscom fair Milano, 2009)

full fidelity for the customer to visually and haptically consider them for purchase. If the product is large enough, also the product itself can serve as projection screen. To illustrate with an example, consider a car dealer. In a showroom for cars, you frequently see slogans, special price offers or a property of a car model written on the hood or side of a car. With LumEnActive, the car dealer can project such information dynamically, thereby adjusting the projected content to the situation at hand or periodically just highlighting an elegant car model without written information. While a traditional projector and some software can realize this scenario for a single car, LumEnActive can serve the display capabilities to many, maybe ten or twenty cars. Even for a single car, the interactive capabilities of LumEnActive significantly simplify the setup of the presentation. Furthermore, the motion of the light spot can specifically draw the attention of customers to a certain model, a special advertised property or a particular value proposition.

Scenario switching. LumEnActive shares with other DS solutions the possibility to change content according to the situation at hand. In contrast to fixed displays, however, LumEnActive can also adapt to the situation the place where information is shown. To illustrate with an example, following up on the car dealer scenario from above: A customer enters a showroom for cars. The sales person (or in the future even an intelligent trained classifier software) classifies the customer as belonging to a certain target group and decides which cars to promote specifically to that customer. Different sequences of movements could be predefined for different customer groups, including or skipping individual cars. Along with different motion sequences, different programs (i.e. content) could be displayed for different customer groups, e.g., leasing rates versus purchase prices, fuel efficiency versus motor power, or prices for different motorization variants of or add-ons for a car model. To give another example: We implemented a prototype of a DS solution for a subway station that shows commercial content in normal mode, but when switched in emergency or evacuation mode, LumEnActive signals the best way to the next emergency exit in an unambiguous and prominent fashion, see Figure 3.

Fig. 3. As with other DS solutions, the content can be adapted to the situation, but LumEnActive also allows for a change in location or movement pattern. (Simulation, prototype integrated into research demonstrator)

Information kiosks. There are a range of options for bringing more interactivity to LumEnActive. By coupling input technologies to LumEnActive, as is described in more details in the next chapter, or sensing product identity through barcodes or RFID tags, it is possible to have information kiosk like operation at various places in a shop or

showroom. Here, the light spot projects to the place wherever interaction is requested by a user, comparable to setting up information kiosks using an LCD screen at many locations. Requesting can be done with a range of technologies, for instance most simply by buttons, sensors or touch panels installed at various places in the room, or, by using camera detection technologies. As cameras are much cheaper than displays today, it is also feasible to install a whole array of cameras that 'look in every corner of the room', to sense where a customer requests assistance. For this, several technologies developed for single cameras can be adapted to a multiple camera detection, such as sensing modulated IR light, e.g. [12], uncovering optical markers (fiducials), e.g. [3], or tracking of a specially colored object, e.g. [5]. Through the possibility to move the projected light spot, new forms of information provision can be utilized, that is taking a larger interaction area into account, and also possibly integrating products in the interaction.

Digital auras. Games. Taking this concept further, it is possible to project a digital aura around tracked customers who requested for it, giving them options projected around them that may be selected by foot-tapping on them, see Fig. 4. Obviously, LumEnActive could also be used to simply guide a customer to a shelf that holds a searched for product, e.g. by projecting a trace on the floor that only needs to be followed, or, guide them to special offers or promotions. Of course, LumEnActive is also open to any playful interaction, involving several people, that can kick projected balls across the lobby of a supermarket, try to find their way through a maze that is only visible locally around the user, play Tetris on a wall opposing a gallery et cetera. There are several systems available today that wrap brand image in small games or simple decorative animations, attracting also the eye of users that are not reached (any more) by static print. Many if not all of them can be brought to a new level by utilizing the extended range of LumEnActive as an output technology, and the attraction of a light spot in motion.

Switching from decoration to interaction. Varying spot size. Size and resolution of a projected light spot are depending on the characteristics of the chosen projector, and the distance between the projector and the projection surface. A consequence of the generation of images by the LumEnActive 3D-hardware assisted software rendering is already that the resolution of content is decoupled with the projector's hardware resolution. Images or videos are scaled in arbitrary size, whether the whole or just a part is visible in the projected portion. Recently, projectors enter the market that feature motorized zoom optics of an extended range. With such a zoom range under the control

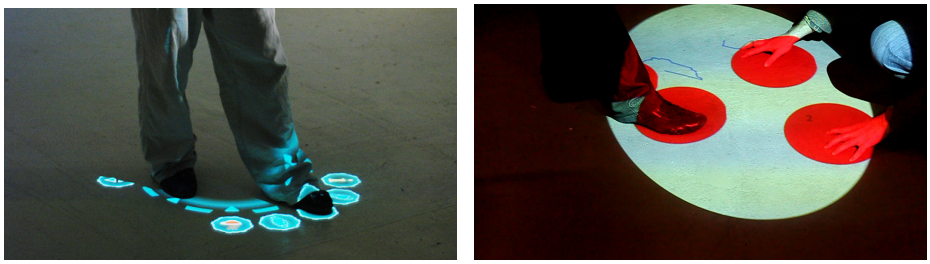

Fig. 4. LumEnActive can follow users over a large floor area by attaching a tracking system and project a digital aura around them, or engage several users in interactive game play over a very large area. (Proof-of-concept demonstrator, Dec. 2009. Left image courtesy this.play, Vienna.)

of LumEnActive, the projected area can be adjusted to the display needs at hand. Using a very wide lens setting, LumEnActive can project decorative illumination like scenery that is putting a showroom in a specific ambience or mood, and when there is the need to give detailed information at a specific spot, it can concentrate the projector's resolution to a small interaction area with a tele setting of the optics. If a projector does not support considerable zooming, it is possible to restrict the outgoing image by software, by black pixels in outer regions of the projected image. While such a masking functionality is included in LumEnActive for decorative reasons (the light spot can be circular, or ornamented for instance), reducing the projected area by masking from software obviously wastes available resolution, making an image less detailed as desired. Of course also two or more LumEnActive systems could be deployed that work in coordination.

4 Integration into pervasive infrastructures

While in the previous chapter we were concerned mainly with the outside looks and some exemplar application scenarios for LumEnActive, in this chapter we will elaborate more on the technical aspects of integrating LumEnActive into existing pervasive infrastructures, and to show possible directions for future work. As a certified product that is operating already in a number of installations, in museum edutainment [9], meeting room installation, trade fair booth decoration, retail shop event, and general user interaction research, LumEnActive brings with it several interfaces that are sufficiently generic to try out new uses of the technology, with easy accessible text-based configuration files and openly available APIs. As a research oriented small company, we are also interested to integrate new functionality into the product that is of general interest, to allow more widespread adoption of the LumEnActive technology in more and more fields.

Control of direction and motion. The fundamental aspect of LumEnActive – projecting in any direction under the control of software – is accounted for by opening up the interface under which the mirror is controlled. In order to let LumEnActive project in a specific direction, a packet comprising a quaternion that defines the direction can be sent to a UDP port (also conversion code from pitch/yaw/roll (Euler-) or pan/tilt-angles and world coordinate system is provided). Such a packet is called a VIDState (for virtual input device state). Virtually all programming languages can send off UDP-packets, so it is possible to easily interface the motion of LumEnActive's light spot with arbitrary, pre-existing software. Next, adapter code is provided to translate TUIO-messages [2] into VIDstate packages. The TUIO protocol is a simple protocol that is widespread in the multi-touch, tangible interaction and tabletop surface computing community. Several multi-touch and fiducial tracking libraries such as touchlib and reactivision can directly output TUIO messages. For instance, we successfully coupled multi-touch floor recognition with a steering of the projected light spot, see Fig.4. By utilizing several multi-touch surfaces, e.g. monitoring several tables or walls in a shop, a single LumEnActive can serve interaction to various spots. For simple applications, such as showing digital content and messages all around a place, and following an always fixed trace, no dedicated software for controlling the direction needs to be written. Instead, the built-in functionality to record so-called tracks can be used. Using the mouse or similar pointing device, the movement that should occur is interactively shown by a user and thereby recorded, for instance a move from highlighting one exhibit to highlighting the next. Up to 99 tracks of arbitrary length can be recorded that way – they are stored on disk in

text format. These tracks are played back in a loop when starting the play back mode of LumEnActive.

Content types. Regarding the content that can be shown by LumEnActive, for end users, the possibility to place videos and images of (almost) arbitrary format and resolution anywhere in the room is the most valuable. For system integrators and researchers, VNC clients are the most interesting type. All media types, images, video or VNC,[1] are placed by opening a menu using the right mouse button. Then, the corresponding file is selected with an integrated file system browser, either content stored on LumEnActive's integrated hard disk or from a USB flash memory card. The system opens a connection to a VNC server also via a stored small text file that describes the server connection details such as network address and port.

Video and images. For video, the decoded image data must be sent to graphics memory 24 to 60 times per second, and thus in practice current PC/graphics card performance limits the playback of video to full HD resolution (but on the other hand it is also difficult to produce material that has a higher resolution than that). For image content, the transfer to the graphics card is needed just once, and hence the resolution is only limited by the graphics card's video memory. We successfully utilized image material with a size in the ten thousand by ten thousand range. Depending on the chosen format, it is also possible to utilize an alpha channel allowing images to have transparent sections, thereby easing the direct composition of elements using LumEnActive. As an unusual feature, LumEnActive supports transparency even for video, allowing for surprising effects.

VNC Client. Although DS solutions often do not offer more than playing out images or videos, LumEnActive is also open to display arbitrary application data, over the VNC protocol. VNC has been developed as an operating system (OS) agnostic way of transferring screen content over the network [10]. A server is determining which parts of the screen have changed, and sends the affected pixels over the network. A client on the other side includes the transferred pixels again in the right place, thus reconstructing the same screen appearance as on the server side. Generally, VNC is used to operate a remote PC desktop over the network, and there are proprietary solutions of comparable functionality now since a few years also available from Microsoft. LumEnActive implements a VNC client, so that it can connect to any VNC server implementing the original protocol. We have used LumEnActive to display the VNC servers on various Windows variants, Mac OS X, and various Linux variants. On Linux and other versions of Unix, there are VNC server variants that do not require a real display or monitor. They build up a screen accessible only via VNC in main memory, using a specially modified X-server. The interesting aspect here is that the display size therefore can be much larger as what any current monitor can handle, for instance we routinely use a VNC server with a screen size of 4096 by 3072 pixels. An application written for such a large desktop can then span a whole floor of a large room, and wherever the light spot of LumEnActive projects, the corresponding portion will still have a reasonable, detailed resolution. In combination with the possibilities of directing the light spot with one of the above mentioned methods, it is extremely simple to make real room-spanning or wall spanning (or both) applications with interesting content in a retail or advertisement setting. As a

[1] For the sake of completeness, as a forth media type, it is possible to place ASCII text, but we found that typical uses in advertising require full access to typesetting features, so the preferred way is to typeset text with other applications and place it into LumEnActive as a graphics with alpha channel.

simple proxy, we used the demo application for the TUIO protocol running on a 3072 by 4096 desktop. A VNC connection to this desktop was opened and positioned on the floor to match a floor-wide sensing system producing TUIO events (actually the extent of the sensing was calibrated based on LumEnActive's output). Now, the TUIO events are used to both send LumEnActive's light spot into the direction where the interaction is sensed, and at the same time it is fed into the application running on the VNC server, to generate the visualization for it. The changes are then transferred over the VNC-protocol to the VNC client of the LumEnActive software that renders the area surrounding the sensed interaction undistorted back on the floor. As there can be almost any application hosted on a VNC server (even on any OS, see above), the whole range of information kiosk applications, web applications, Web browsers, flash animations etc. can be effortless integrated into a LumEnActive DS installation. The only shortcoming (that usually can be avoided by an appropriate screen design) is, that changes should be local, especially if very large screen sizes are used. It takes some time to transfer the complete screen of a 4096 by 3072 desktop via VNC over the network, so it is advisable to not unnecessarily update too large portions of the screen at once. In standard applications, as updates are usually quite constraint in space, there is no real difference as compared to working with the application on a local machine.

Semantic interoperability. In the subway station emergency exit scenario, we are connecting LumEnActive to a Semantic Information Broker (SIB), a data store to hold pervasive information conforming to an ontology in RDF-format. The SIB is part of the InterOperabilty Platform (IOP) that is developed by Nokia and further players within the SOFIA project as an open source effort [11]. By the time of the workshop, we expect to have finished the integration of the Knowledge Processor (KP) into the LumEnActive code base, so that a flexible mapping between semantic descriptions of situations, information conditions and events in the SIB on the one side, and actions, configurations, motion patterns and content within the presentation of LumEnActive can be established. Currently our prototype can only switch between two pre-programmed modes of operation, triggered by an evacuation order of the station management. The openness of the platform is interesting also for further uses of a DS system in a public space, when commercial digital signage is not the only use. In addition, the semantic description is beneficial to interface different system components, as the semantic description abstracts from the underlying proprietary protocols. For instance, pervasive environments can deliver information on how crowded a room is into the SIB and the presentation could be adapted to this information. When the ontology clearly defines such concepts, it does not matter what sensor is providing the information, and they are easily interchangeable.

5 Conclusion

We presented LumEnActive, a very capable and generically useful digital signage system based on steerable projection, that can be utilized in a wide variety of applications. LumEnActive is available as a product and is used in other fields already. Stemming from a research environment, the system shows an open spirit towards extensions and connecting it with other technologies. We proposed some scenarios in which LumEnActive could be used. Most of these scenarios can directly be rolled out to practical use from a technical point of view. As a generic solution to showing information at ubiquitous locations, we expect to learn also creative new uses from our customers, and researchers wanting to accelerate their research with the technology.

The possibility to let LumEnActive play over a larger portion of a space is interesting for pervasive advertising and shopping in various aspects. Firstly, the motion of the projected light spot attracts attention. Then, often people are curious about how the system works, or simply watch what the moving light spot will reveal next. LumEnActive is useful also for directing the attention to specific places, for instance it can be used to guide persons to a requested product, or present alternatives to a customer, as in the car dealer example. Because of the projection, variants of augmented reality can be deployed in a shop scenario, where digital content is interacting with real products, that are there for customers to visually and haptically explore in full fidelity, while still being able to access a wealth of information if required by the customer, or consult recommendation systems on a planned purchase, or the data accumulated from the manufacturing and logistics chain. Besides purely decorative uses of LumEnActive, a very interesting field is interaction and game play, through which brand image or products can be communicated to a target group, like is current practice today already with marketers' online games. Compared to online games, an interactive installation of LumEnActive in a shop should for many businesses be more interesting, as the purchasing decision can be done in a much closer spatial and temporal coherence.

The work presented here has partially been funded by Artemis-JU and SenterNovem within the SOFIA project (Artemis JU 2008 call, project number 100017).

References

1. G. W. Fitzmaurice. Situated information spaces and spatially aware palmtop computers. *Commun. ACM*, 36(7):39–49, 1993.
2. M. Kaltenbrunner, T. Bovermann, R. Bencina, and E. Costanza. Tuio - a protocol for table based tangible user interfaces. In *Proceedings of the 6th International Workshop on Gesture in Human-Computer Interaction and Simulation (GW 2005)*, Vannes, France, 2005.
3. H. Kato and M. Billinghurst. Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *IWAR '99: Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality*, pages 85–94. IEEE CS, 1999.
4. LumEnActive web site, http://www.lumenactive.de.
5. K. Miyaoku, S. Higashino, and Y. Tonomura. C-blink: a hue-difference-based light signal marker for large screen interaction via any mobile terminal. In *UIST '04: Proc. 17th annual ACM symposium on User interface software and technology*, pages 147–156. ACM, 2004.
6. C. Pinhanez. The everywhere displays projector: A device to create ubiquitous graphical interfaces. In *Proc. of Ubiquitous Computing 2001 (Ubicomp"01)*, Atlanta, September 2001.
7. S. Rapp. Spotlight Navigation and LumEnActive: Ubiquitous projection user interfaces. In *Pervasive 2010 Adjunct Proceedings (demo sessions)*, Helsinki, May 2010.
8. S. Rapp, G. Michelitsch, M. Osen, J. Williams, M. Barbisch, R. Bohan, Z. Valsan, and M. Emele. Spotlight navigation: Interaction with a handheld projection device. In *Advances in Pervasive Computing: A collection of Contributions Presented at PERVASIVE 2004*, pages 397–400. Oesterreichische Computer Gesellschaft, April 2004.
9. S. Rapp and I. Weber. LumEnActive: a novel presentation tool for interactive installations. In *Proceedings 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST*, Pisa, Italy, November 2005.
10. T. Richardson, Q. Stafford-Fraser, K. R. Wood, and A. Hopper. Virtual network computing. *IEEE Internet Computing*, 2(1):33–38, January/February 1998.
11. Smart M3, http://sourceforge.net/projects/smart-m3.
12. R. Want, A. Hopper, V. Falcão, and J. Gibbons. The active badge location system. *ACM Trans. Inf. Syst.*, 10(1):91–102, 1992.