Projector Phones:
A new Class of Interfaces for Augmented Reality

Johannes Schöning[1], Markus Löchtefeld[1], Michael Rohs and Antonio Krüger[1]

[1]DFKI GmbH, Campus D3_2, Stuhlsatzenhausweg 3, D-66123 Saarbrücken, Germany
{schoening, markus.loechtefeld, krueger}@dfki.de
[2]Deutsche Telekom AG Laboratories Ernst-Reuter-Platz 7 D-10587 Berlin, Germany
Michael.Rohs@telekom.de

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ABSTRACT

With the miniaturization of projection technology the integration of tiny projection units, normally referred to as pico projectors, into mobile devices is no longer fiction. Such integrated projectors in mobile devices could make mobile projection ubiquitous within the next few years. These phones soon will have the ability to project large-scale information onto any surfaces in the real world. By doing so, the interaction space of the mobile device can be considerably expanded. In addition, physical objects in the environment can be augmented with additional information. This can support interaction concepts that are not even possible on modern desktop computers today. We claim that mobile camera-projector units can form a promising interface type for mobile Augmented Reality (AR) applications. In this paper we identify different application classes of such interfaces, namely object-adaptive applications, context-adaptive applications, and camera-controlled applications. In addition, we discuss how the different spatial setups of camera and projector units will have an effect on the possible applications and the interaction space with the focus on the augmentation of real word objects in the environment. Furthermore, we present two examples of applications for mobile camera-projector units and present different hardware prototypes that allow augmentation of real world objects.

INTRODUCTION & MOTIVATION

Mobile phones are used for a wide range of applications and services in today's everyday life, but still they have many limitations. Aside from the lack of working memory and the small display size is one of the major bottlenecks. Digital projectors are shrunken to the size of a mobile phone. The next step is to integrate them directly into the mobile device. Up to now several prototypes have been presented, and the first series-production device is already up for pre-order. First prototype phones with integrated projectors already exist and are available on the consumers market but both models are currently not available on the mass market. Such phones could overcome the shortcomings of the small screen and make it possible to present large and complex information like maps or web pages without the need for zooming or panning [Hang et al. 2008]. Considering the anticipated widespread availability of phones with integrated cameras and projectors in just a few months, surprisingly little research has been conducted so far to investigate the potential of such a mobile unit (in the following we use the term mobile camera-projector unit as a synonym for a mobile phone equipped with a camera and a projector). We identify different application types based on the spatial configuration of the camera and the projector. As part of this classification, we derive three different application types using of different spatial layouts of cameras and projectors: congruent setups, partially intersecting setups and disjunct setups. Such a classification is useful to structure the design space of mobile camera-projector systems, because we think other researchers can categorize their applications to focus on specific problems and topics of each type. Our approach needs to be elaborated further and more deeply by others researches, but we think it still gives a good framing of this important problem for the usability of mobile camera-projector units, because mobile projector phones and mobile projection is still a young research field.

The remainder of this paper is structured as follows. Related work in the field of mobile projection and mobile camera projector units as well as the general interaction with mobile devices is presented in Section 2. Section 3 describes the different application classes of these interfaces. In this conceptual section we also discuss how the spatial layout of the camera relative to the mobile projection unit can affect the characteristics of applications for this new sort of hardware. Next, two example applications are presented: *Map Torchlight* and *LittleProjectedPlanet*. Map Torchlight is an application that combines high resolution paper maps with lightweight mobile projection to augment the paper map directly with additional personal and dynamic information. The mobile camera-projector unit is tracked over a paper map and precisely highlights points of interest, streets, and areas to give directions and other guidance for interacting with the map

[Schöning et al. 2009]. With the LittleProjectedPlanet prototype [Löchtefeld et al. 2009] we explore the possibilities of camera projector phones with a mobile adaptation of the Playstation 3™(PS3) game LittleBigPlanet™. The camera projector unit is used to augment the hand drawings of a user with an overlay displaying physical interaction of virtual objects with the real world. Players can sketch a 2D world on a sheet of paper or use an existing physical configuration of objects and let the physics engine simulate physical procedures in this world to achieve game goals. In addition, we discuss the technical setups we used in both prototypes. Finally, we provide some concluding remarks and outline different scenarios where mobile camera projector units can be useful in the future.

RELATED WORK

Initial research on mobile projection interfaces was conducted by Raskar et al. with the iLamps [Raskar et al.2005]. While the iLamps mainly focused on creating distortion free projection on various surfaces, or using multiple projectors to create a larger projection, the follow-up of the iLamps, the RFIGLamps [Raskar et al. 2004], were used to create object adaptive projections. Set in a warehouse scenario, the RFIGLamps could be used for example to mark products where the date of expiry is close to the actual date. Blaskò et al. explored the interaction with a wrist-worn projection display by simulating the mobile projector with a steerable projector in a lab. To examine the possibilities of multi-user interaction with a mobile projector, Cao et al. used an instrumented room to create several information spaces, which could be explored with handheld projectors [Cao and Balakrishnan 2006]. Cao et al. also investigated the usage of mobile projector in a multi-user scenario [Cao et al.2007]. Hang et al. [Hang et al. 2008] have outlined the advantages of projected displays in contrast to displays of a mobile phone for exploring large-scale information. With the Wear Ur World (WUW) prototype of the SixthSense project of the MIT, Mistry et al. [Mistry et al. 2009] exemplarily showed that mobile projection could be utilized in every day life. According to Mistry et al. WUW was built of parts that are available today for around $350 (in addition a laptop in a backpack is needed to run the services provided in WUW), this shows again that mobile projection lies in the near future. Tamaki et al. recently presented [Tamaki et al. 2009] Brainy Hand, which is a simple wearable device that adopts laser line, or more specifically, a mini-projector as a visual feedback device. Brainy Hand consists of a color camera, an earphone, and a laser line or mini-projector. This device uses a camera to detect 3D hand gestures. An earphone is used for receiving audio feedback. Song et al. [Song et al. 2009] presented with PenLight, which is a mockup to explore the interaction design space and its accompanying interaction techniques in a digital pen embedded with a spatially-aware miniature projector.

From this development a rich design space for mobile augmented reality applications could emerge. With a built in projector not only the graphical scale of the applications can be increased, also the range of possibilities for developing mobile augmented reality application will widen. In combination with the built-in camera of the mobile device, mobile camera-projector units become a powerful interface for mobile AR applications. To create visual overlays for augmented reality games, in the past often head-mounted displays where used [Sutherland 1968]. This retrenched not only the comfort of the user it also limited mobility. Another common technique for dynamic overlays is to use the screen of the mobile device like a magic lens [Bier et al. 1993] and so be struggle again with the small size and resolution. Moreover such a magic lens display is not really scalable when thinking of multi-user settings. Therefore we think that projecting an additional display or augmenting real world objects with additional information can extend the range of possible applications.

DIFFERENT SPATIAL CONFIGURATIONS OF MOBILE CAMERA-PROJECTOR UNITS

Today's prototypes of mobile (camera) devices with integrated projectors are very limited in the functionality of the projector. Often the projector unit is just used to project media such as pictures or videos onto any surfaces. The projector is therefore mainly used to extend the real estate of the mobile device screen. To fully exploit the potential of mobile projection we discuss the impact of different spatial layouts of the camera relative to the projector unit on the interaction.

Spatial Layout of camera and projectors

Figure 1: Different spatial layouts of integrated projector and camera in a mobile device. The camera and its field of view (FoV) is indicated with a red cone. The projector is and its field of projection (FoP) is indicated with a blue cone.

When discussing the spatial arrangement of the camera to the projector we first want to define the terms camera field of view (FoV) and the term field of projection (FoP). The FoV of the camera is defined, as the area the camera is able to "see". The FoP is the area the projector is able to project on.

We distinguish between three different spatial layouts: First setups where the FoV and the FoP do not overlap are categorized as "disjunct" because the projection goes to a completely other direction than the visual field of the camera. Setups were the the FoV of the camera and the FoP overlap are categorized in two different classes, which have the direction of the projector as well as the direction of the visual field of the camera in common: "partially intersecting" and "congruent". They differ from the configuration of the lens of camera and projector and their distance to each other. If the visual field of the camera overlaps partially with the projected field, then it is categorized as an intersecting projection. In the third category named "congruent" the entire projected field is situated within the image produced by the camera. Due to different hardware specifications of cameras and projectors (different throwing angles, aperture, and others properties) the actual spatial setups could be very different. Today, due to the technical limitations, just disjunct setups exists. We think the partially intersecting" and "congruent" provide a lot of more potential for new interactions as we illustrate in the following paragraphs.

Disjunct

In the case of disjunct projection, camera and projector are often attached to two different sides of the mobile device (see figure 2 or see the

Figure 2: Disjunct Setup: The field of view of the camera (FoV) is not overlapping the field of projection (FoP).

Epoq EGP-PP0 prototype). As a result, the visual field of the camera and the projected image are not overlapping.

The alignment described is rather unsuitable for the augmentation of physical objects. The tracking systems would identify the objects located in the visual field of the camera, but the projection is directed towards a different angle so directly projecting onto these objects is not possible. Despite that, there are two ways of overcoming this problem. One possibility is determining one's own position in relation to that of an object by means of a spatial model of the environment and subsequently augment the object. Again this approach, however, requires the availability of a spatial model of the environment at all times. Furthermore, this procedure causes a considerable restriction of mobility.

Another possibility is adapting objects or taking advantage of the structure of an object in order to augment it. For example, an optical marker, which can be identified and interpreted by the camera, could be attached to the first page of a book, resulting in the projection of additional information onto the open cover of the book. This would enable users to quickly and easily access reviews, summaries, and other services.

A benefit of systems that use “disjunct projection” is that they allow for optical flow tracking, which is not (just with major hardware modification as described below) possible in the other types of projection, as projection within the image produced by the camera would then impair the tracking process. An infrared filter in front of the camera in combination can overcome this problem in combination a projector emitting no infrared light, but we think mobile cameras with build in infrared filters are still far from the current market. Optical flow tracking could be used to navigate websites, as Blaskò et al. have described in their work. The movements of the camera/projector unit could be translated to instructions for the browser by the tracking system and navigation through a website which is projected onto a wall would be possible. Such navigation is very similar to the experience of a torchlight: it illuminates a part of an object at a time and the object stays static. This interaction metaphor is also used in Map Torchlight application (a partially intersecting setup) described below.

Figure 3: Partially intersecting Setup: The field of view of the camera (FoV) is partially overlapping the field of projection (FoP).

Partially intersecting

In the case of partially intersecting projection the visual field of the camera and the projected field are situated on the same level partially overlapping each other as shown on figure 3. By knowing the angle of aperture of the camera and projector’s lens, the size of the visual field of the camera and the projected field as well as its misalignment can be calculated. This kind of projection is the most suitable for the augmentation of visual objects. The fact that the projected field does not affect or minimally affects the image produced by the camera makes the stable use of visual trackers possible. However, this works only for the augmentation of bigger-sized objects. The field of smaller-sized objects is just too small for the augmentation and the tracking and projection as well as visual tracking would influence each other.

The Map Torchlight application uses a partial spatial synchronous projection for the projection of additional POIs on a large paper map. An additional application, which assists someone in fixing e.g. the engine of a car, could be realized in a very similar way. By attaching visual markers to the engine compartment the possibility is given to determine the position of the mobile camera-projector unit relative to the engine, so that it can mark for example the screws which shall be removed in a particular step of a procedure which allows to perform a task. The advantages (or differences) of a partial overlapping projection compared to a congruent projection is that in the field of view of the camera as well as the field of projection of course are areas that are not effected by the camera respectively the projector. For example the non-overlapped area in the camera field of view can be used to allow gesture based interaction (as proposed by Baldauf et al. [Baldauf et al. 2009]) without interfering with the projection.

Congruent

Figure 4: Congruent Setup: The field of view of the camera (FoV) is completely overlapping the field of projection (FoP).

A congruent setup is given when camera and projector are attached on the same side (or with appropriate hardware) of the mobile phone as it is the case with the partially intersecting projection with the exception that the entire projected image is shown in the camera field of view. (see figure 4) A disadvantage of these spatial configurations is that the projection could influence the processing of the camera image. However, the congruent projection enables the user to interact directly with the projection without any limitation. The application LittleProjectedPlanet, as described below, introduces in this spatial configuration, which works on the approach of the direct manipulation and which enables the user to operate the projection through the modification of physical objects. Another domain for a synchronous projection setup could be an OCR, which recognizes and marks spelling mistakes. School children would be able to control their homework by holding their mobile phones with the integrated projector upon their exercise books on which the projector could mark the mistakes and give e.g. additional information about them. However, the realization of such a system as an end product for costumers will take considerable research. The main problem is the robustness of the handwriting recognition process.

Other classifications of mobile camera-projector applications and other design issues

Beside the classification based on the spatial configuration of mobile camera-projector systems we could also classify the applications by their type. These are, for example, applications whose projection adapts to objects like it is the case with Map Torchlight (object adaptive applications) or applications on which the content of the projection is navigated by the recognition of an object or a marker and the projected area is independent (context-adaptive applications). The third category contains applications whose projection is mainly navigated by the camera but is independent from context and location (camera navigated applications), an example is WUW [Mistry et al. 2009].

Besides this classification other issues should be taken into account when designing applications for mobile camera projector systems. The related work section provides an overview on the latest research done in this field, e.g. concerning multi-user settings, but some open issues are discussed in the next section.

Not only the spatial configuration of the mobile device camera and the projector play a role when discussing the potential and limitations of mobile camera-projector units. Today, hardware issues still hinder the exploitation of the full impact of mobile camera-projector units. The effects of environmental light, energy problems (current projectors need a considerable amount of energy), and depth of focus, are problems that have to be solved by the hardware manufactures as well as further research. Other limitations, such as the limitations by nature of objects, project against object properties are still not discussed or investigated. “Am I allowed to project on a stranger passing by?”. Many technical challenges still remain and have to be solved by the hardware engineers. They also have to create and enable different spatial layouts of mobile camera-projector units. Effects of hand shaking and tremor can be overcome utilizing accelerometers. Moreover, camera-tracking methods have to be improved. All these factors currently have a big impact on the user experience and have to be taken into account when designing applications for mobile-camera projector units.

EXAMPLES FOR CONCEPT AND APPLICATION CLASSES

In the following section we present two fully implemented prototypes to illustrate the concept presented earlier.

Map Torchlight

Figure 5: The Map Torchlight prototype in use.

The advantages of paper-based maps have been utilized in the field of mobile augmented reality (AR) in the last few years. Traditional paper-based maps provide high-resolution, large-scale information with zero power consumption. There are numerous implementations of magic lens interfaces that combine high-resolution paper maps with dynamic handheld displays [Rohs et al. 2007b]. From an HCI perspective, the main challenge of magic lens interfaces is that users have to switch their attention between the magic lens and the information in the background. With the Map Torchlight application we attempt to overcome this problem by augmenting the paper map directly with additional information. The "Map Torchlight" is an example for a partially synchronous projection and is tracked over a paper map and can precisely highlight points of interest, streets, and areas to give directions or other guidance for interacting with the map.

Interaction Concepts

The general advances of a mobile projection system also show up in our Map Torchlight system: The projection area is larger and the mobile projection can overcome the switching cost of magic lens interfaces. The basic interaction pattern is similar to magic lens interfaces. Sweeping the camera projector unit over the map, the projector will, for instance, highlight different POIs on the map. Because the projection is significantly larger than the device display (around 4 times in our setup) more dynamic information can be directly presented on the map (as can be seen in figure 5). It also provides a higher resolution compared to a standard mobile device display, if the projector is controlled independently from the device display. As shown in figure 5, larger objects can be highlighted compared to a traditional magic lens interfaces. The projector can also be used to collaboratively interact with a map by using the map as a shared screen. For instance, one user can tell another a route through the city by moving a projected crosshair over the map. The waypoints could then be stored in a Keyhole Markup Language (KML is a is an XML-based language schema for expressing geographic annotation and visualization) file and transferred via Bluetooth to the second user's mobile device. Again, in all of these examples, there are no switching costs for the users. A downside of projection is that the real-world view cannot completely be blocked out, as is possible with (video see-through) magic lens interfaces.

Implementation

The Map Torchlight is fully implemented for Nokia mobile camera phones (S60 3rd edition). We use the tracking toolkit by Rohs et al. [Rohs et al. 2007a] to track the mobile device with the attached projector in real time relative to the map (6 DoF). The actual prototype is a Nokia N95 mobile phone with an AIPTEK V10 Mobile Projector (640x480 pixel) attached to the phone using a standard AV cable. The whole setup weighs about 360 grams. Due to technical limitations the mobile phone screen can only be mirrored and not be extended on the projector. Due to this issue, the projector always shows the mobile screen content, even if detailed information is presented on the mobile device screen. The focus and projection size needs to be calibrated manually, because the focus of the projector can only be adjusted manually. The tracking algorithm processes about 12 frames per second.

Figure 6: The LittleProjectedPlanet prototype in use. A user is projectiong virtual marbles on a track she sketched on a whiteboard (1). The virtual marble balls adapt to the environment and roll down the track (2-4).

LittleProjectedPlanet

With the LittleProjectedPlanet prototype we explore the possibilities of camera projector phones with a mobile adaption of the Playstation 3™(PS3) game LittleBigPlanet™. The camera projector unit is used to augment the hand drawings of a user with an overlay displaying physical interaction of virtual objects with the real world. Therefore a spatial synchronous projection setup is needed. Players can sketch a 2D world on a sheet of paper or use an existing physical configuration of objects and let the physics engine simulate physical procedures in this world to achieve game goals. We propose a mobile game combining hand drawn sketches of a user in combination with objects following a physics engine to achieve game goals. Enriching sketching in combination with physical simulation was presented by Davis et al. [Alvarado and Davis 2004, Davis 2002]. The ASSIST system, was a sketch understanding system that allows e.g. an engineer to sketch a mechanical system as she would on paper, and then allows her to interact with the design as a mechanical system, for example by seeing a simulation of her drawing. Interestingly the *ASSIST* system was bought by the creators of the game LittleBigPlanet™ and parts of *ASSIST* were integrated into the game play.

In contrast to the *ASSIST* system we present a game that is designed for mobile projector phones combing real world objects and projected ones utilizing a physics engine. We think that this kind of mobile projection camera unit can been utilized to improve the learning and collaboration in small groups of pupils (cause of the mobile setup of our prototype) in contrast to more teacher-centred teaching e.g. one interactive white board (as shown by Davis et al. [Alvarado and Davis 2004, Davis 2002].).

Game Concept

The slogan of the popular game LittleBigPlanet™ is “play with everything” and that can be taken literally. The player controls a little character that can run, jump and manipulate objects in several ways. A large diversity of pre-build objects is in the game to interact with, and each modification on such an item let them act in a manner physically similar to those they represent. The goal of each level is to bring the character from a starting point to the finish. Therefore it has to overcome several barriers by triggering physical actions. But the main fascination and potential of the game is the feasibility to customize and create levels. Creating new objects is done by starting with a number of basic shapes, such as circles, stars and squares, modify them and then place them in the level. Having done so, the user can decide on how these objects should be connected mechanically.

We took this designing approach as an entry point for a mobile augmented reality game using a mobile camera projector unit. It allows the user to design a 2D world in reality, which is then detected by a camera. Out of this detection a physical model is being calculated. Into this model the user can place several virtual objects representing items like tennis balls or bowling balls. These virtual objects then get projected into the real world by the mobile projector. When starting the physic engine, the application simulates the interaction of the virtual and the real world objects and projects the results of the virtual objects onto the real world surface.

Just like in LittleBigPlanet™ our application offers the user different ways of playing: One is like the level designer in LittleBigPlanet™; the user can freely manipulate the 2D World within the projected area and place virtual objects in it. Similar to children building tracks for marbles in a sandpit, the player can specify a route and then let the virtual marbles run along it. A different gaming mode is a level based modus, but instead of steering a character as in LittleBigPlanet™, the user designs the world. As a goal the user has to steer a virtual object e.g. a tennis ball from its starting point to a given finish. The game concept uses a direct manipulation approach. Enabling the player to modify the world at runtime let the real world objects become the users tangible interface. But not only the objects are used for the interface, by changing the orientation and position of the projector the user can also modify the physical procedures (e.g. gravity by turning the mobile camera projector unit).

Interaction Concepts

For designing a 2D world the players can use several methods. Basically they have to generate enough contrast that can be detected by using a standard edge recognition algorithm (utilizing the Sobel operator). Sketching on a piece of paper or a white board for example can do this, but simply every corner or edge of a real world object could generate a useful representation in the physics engine. So there is no need for an extra sketching device or other for example IR based input methods. Just requiring the camera projector unit itself the game is playable nearly anywhere with nearly everything and it is easy to set up. Figure 6 shows how a user is projecting virtual marbles on a track she sketched on a whiteboard. An important problem to allow a smooth and seamless interaction for the user is that the “gravity in the projection” is aligned with the real worlds gravity. For that a Nintendo Wii is attached under the camera-projection unit. Also gravity can be utilized in the game to control some action. A user can take control of the gravity by changing the orientation of the projector. Doing this the user can let virtual objects “fly” through the levels.

Implementation

Due to the unavailability of sophisticated projector phones (with an optimal alignment of camera and built-in projector and e.g. a GPU that is able to process the physics simulation) we used, in contrast to the Map Torchlight application, a Dell M109S, a mobile projector with a maximum resolution of 800 by 600 pixels and a weight of 360g, in combination with a Logitech QuickCam 9000 Pro. All together our prototype weighs around 500g and is therefore okay to handle (e.g. compared to the prototype used in Map Torchlight (see above) our prototype is "just 240g" heavier, but the projector has 50 lumen instead of just 10 and also has a higher resolution). We think this prototype provides a good trade-off between mobility and sophisticated projection quality. In contrast to the few mobile devices with built in projectors, our projector and camera are mounted in such a way that the camera field of view fits the projected area (spatial synchronous projection). But because of the different focal lengths of camera and projector in this setup the camera image is always wider than the projected image. Therefore the camera is installed in front of the projetor as can be seen in figure 6. For controlling the application and to determine the orientation (to set the gravity) a Nintendo Wii remote is attached to the camera projector unit. Most actual Smart Phones are already equipped with an accelerometer or an electronic compass, so the functionality of the Wii remote can easily be covered using a mobile phone. The application is fully implemented in Java using the QuickTime API to obtain a camera image. As a physics engine Phys2D, an open source, Java based engine is used. The communication with the Wii remote is handled by WiiRemoteJ. Connected to a standard laptop or PC the camera projector unit has a refresh rate of approximately 15fps when running the application.

The area of the camera image containing the projected image is processed via an edge recognition algorithm. Every pixel of a detected edge gets a representation as a fixed block in the physics engine. That gives the user total freedom in designing the world. Such a physic world update is done every 300ms but it can be stopped by the users, for example for editing the sketch. Adapting the gravity of the physical model to the actual orientation of the camera projector unit is done through calculating the roll (this denotes the angular deviation along the longest axis of the Wii remote) of the Wii remote.

CONCLUSION

We have presented different application classes of interfaces utilizing a mobile camera-projector unit. The interfaces all focus on the augmentation of real word objects in the environment. We showed how the different spatial setups of camera and projector units effect the possible applications and the physical interaction space. This classification can help to structure the design space of mobile projection applications. Of course many open issues still remain. As discussed earlier not only the spatial configuration of the mobile device camera and the projector play a role when discussing the potential and limitations of mobile camera-projector units. Today, hardware issues still hinder the exploitation of the full impact of mobile camera-projector units. The effects of environmental light, energy problems (current projectors need a considerable amount of energy), and depth of focus, are problems that have to be solved by the hardware manufactures as well as further research. Our research tries to make a contribution into the direction that by assuming we will have better hardware of mobile-camera projector units, we will have more powerful applications such as Map Torchlight and LittleProjectedPlanet. Both implementations show how researchers can overcome the current hardware problems and investigate the area of mobile camera-projector systems more deeply. With our categorization using different classes based on the spatial configuration we want to establish a first initial framework for mobile camera-projection systems. With our example applications we highlighted the potential of mobile camera-projector units. We think that they have a big potential to enrich the usability of mobile devices. They enable larger presentation sizes and are well suited for multi-user settings. In future work we intend to evaluate how mobile projection interfaces are superior to classical AR interfaces such as HMDs and magic lens interfaces.

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Authors Bio

Johannes Schöning is a senior researcher at the German Research Centre for Artificial Intelligence DFKI in Saarbrücken. He received a Diplom (MSc) in Geoinformatics at the University of Münster at the Institute for Geoinformatics in 2007. His research interests are new methods and interfaces to intuitive navigate through spatial information, mobile augmented reality applications, Wikipedia as a knowledge database and home grown multi-touch surfaces. He organized the first Multi-Touch Workshop, held in Münster in 2007 and the follow up bootcamp "Build-your-own" Multi-touch Surface in conjunction with IEEE Tabletops 2008 in Amsterdam. In 2010 he will be the general chair of Interactive Tabletops and Surfaces (ITS 2010, former Tabletops).

Markus Löchtefeld is a junior researcher at the German Research Centre for Artificial Intelligence (DFKI) in Saarbrücken where he is working in the Innovative Retail Laboratory. He received a Diplom (MSc) in Geoinformatics at the University of Münster at the Institute for Geoinformatics in 2009. Currently his research focuses on new interaction techniques for mobile phones with integrated projector. Besides that he is interested in mobile augmented reality applications as well as mobile context-aware applications.

Dr. Michael Rohs is a senior research scientist with Deutsche Telekom Laboratories at TU Berlin. His primary research interests are in mobile human-computer interaction and pervasive computing. This includes the integration of physical and virtual aspects of the user's surroundings, sensor-based mobile interaction, and interaction techniques for handheld devices. An example is using camera phones as magic lenses for large-scale paper maps in order to overlay personalized, up-to-date information. Another example is pressure-based multitouch-input for handheld devices for controlling 3D objects. He obtained a Ph.D. in Computer Science from ETH Zurich, Switzerland, a Diplom in computer science from Darmstadt University of Technology, Germany, and a Master's degree in Computer Science from the University of Colorado at Boulder, USA.

Prof. Dr. Antonio Krüger is a professor for computer science at Saarland University and the scientific director of the Innovative Retail Laboratory (IRL) at the German Research Center for AI (DFKI) since April 2009. Until then he has been a professor and the managing director at the Institute for Geoinformatics (ifgi) at the University of Münster. His main research interests are mobile and Ubiquitous Spatial Assistance Systems, combining the research fields of Intelligent User Interfaces, User Modelling, Cognitive Sciences, and Ubiquitous Computing.