Chapter 11
Interaction with Adaptive and Ubiquitous User Interfaces

Jan Gugenheimer, Christian Winkler, Dennis Wolf, and Enrico Rukzio

Abstract Current user interfaces such as public displays, smartphones and tablets strive to provide a constant flow of information. Although they all can be regarded as a first step towards Mark Weiser's vision of ubiquitous computing they are still not able to fully achieve the ubiquity and omnipresence Weiser envisioned. In order to achieve this goal these devices must be able to blend in with their environment and be constantly available. Since this scenario is technically challenging, researchers simulated this behavior by using projector-camera systems. This technology opens the possibility of investigating the interaction of users with always available and adaptive information interfaces. These are both important properties of a Companion-technology. Such a Companion system will be able to provide users with information how, where and when they are desired. In this chapter we describe in detail the design and development of three projector-camera systems(UbiBeam, SpiderLight and SmarTVision). Based on insights from prior user studies, we implemented these systems as a mobile, nomadic and home deployed projector-camera system which can transform every plain surface into an interactive user interface. Finally we discuss the future possibilities for Companion-systems in combination with a projector-camera system to enable fully adaptive and ubiquitous user interface.

11.1 Introduction to Ubiquitous User Interfaces

Traditionally, user interfaces are part of a physical device such as a laptop, a tablet or a smartphone. To be able to interact with such user interfaces fluidly throughout the day, users have to actually carry those devices with them. In [19], Mark Weiser describes his vision on technology which will blend into the user's environment and offer omnipresent interfaces. Current systems are not yet able to offer these characteristics Mark Weiser envisioned. Researchers started to use projection to simulate these types of interfaces.

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S. Biundo, A. Wendemuth (eds.), *Companion Technology*, Cognitive Technologies,
DOI 10.1007/978-3-319-43665-4_11

As already introduced earlier in Chap. 1, a *Companion*-System complies with several abilities such as individuality, adaptability, flexibility, cooperativeness and trustworthiness. This chapter focuses particularly on two abilities of a *Companion*-System [1]: *availability* and *adaptability*. Both these characteristics are investigated using Projector-Camera Systems.

One essential part of availability is the capability to access large information displays at any given time at any given location. The basic concept of an office environment offering these capabilities was introduced by Raskar et al. [16] using Projector-Camera Systems. Depth cameras were used to enable interaction with the projected interfaces. The cameras are adjusted in the same direction as the projector, thus allowing us to sense interactions such as touch on top of the projected image. Touch interaction was implemented using either infrared-based tracking [11, 22], color-based tracking [14] or marker-less tracking [8, 18, 20]. This basic concept was furthermore enhanced by attaching motors to the Projector-Camera Systems, allowing us to reposition the interactive projection almost everywhere inside the room [15, 21]. Raskar et al. [16] furthermore leveraged the tracking capabilities to adapt the image of the projection on to the projection surface, allowing us to project onto non-planar surfaces. Nowadays, basic Projector-Camera Systems can be built solely using consumer available products [7]. The necessary software to calibrate and implement the interaction on the projection can be developed by using toolkits such as WorldKit [24] or UbiDisplays [7]. Such toolkits offer quick and easy calibration and installation of projectors and depth cameras resulting in a touch sensitive projection interface created using solely consumer products.

Despite this progress in Projector-Camera Systems, researchers mainly focused on technical improvement and big laboratory setups resulting in little knowledge about the use of Projector-Camera Systems inside a real life environment. However, home deployment and real life usage open new questions about the design, interaction and use-cases of Projector-Camera Systems. Furthermore, there is currently a lack of small, portable and easily deployable Projector-Camera Systems which can be used for an in-situ study. In this chapter, we present in-situ user studies exploring the design-space of Projector-Camera Systems. Based on this study we are going to present three prototypes (*UbiBeam*, *smarTVision* and *SpiderLight*) which each focus on one of the use-cases/interaction concepts derived from the study results.

11.2 In-Situ User Study Using Projector-Camera Systems

To the best of our knowledge, no exploratory in-situ study was conducted focusing on the use and interaction with Projector-Camera Systems in a home environment. Huber et al. [10] did a qualitative user study by interviewing several HCI (Human-Computer Interaction) researchers on interaction techniques of pico projectors. The interviews however took place in a public environment and were focused solely on the interaction with small projectors. Hardy [6] deployed a Projector-Camera System at his working desk and used it for over 1 year. He reported valuable experiences and insights in the long term use of a Projector-Camera System inside an office environment. To investigate the use of home deployed Projector-Camera Systems, we conducted an in-situ user study using a mockup prototype in the home of 22 participants. The goal was to gain a deeper understanding of how the participants would use and interact with a Projector-Camera System in their own homes.

11.2.1 Method

To collect data, we conducted semi-structured interviews in 22 households (10 female, 12 male) and participants being between 22 and 58 years of age (M=29). We decided to interview participants in their homes since they were aware of the whole arrangement of the rooms and could therefore provide detailed insights into categories such as placement. Furthermore this helped to create a familiar environment for the participant which led to a pleasant atmosphere. This also allowed us to cover a variety of different use cases and rooms such as: the living room, bedroom, bathroom, working room, kitchen and corridor. The study was conducted using a mockup prototype consisting of an APITEK Pocket Cinema V60 projector inside of a card box mounted on a Joby Gorillapod. The cardboard box provided illustrations of non-functional input and output possibilities such as a touchpad, several buttons, a display and a depth camera. This low-fidelity mockup helped the participants to imagine how a future Projector-Camera System could look and what capabilities it could have.

The interviews were conducted in three parts. First, participants were briefed on the concept of ubiquitous computing/ubiquitous interfaces and introduced to Projector-Camera Systems. The second part was a semi-structured interview on the use and capabilities of Projector-Camera Systems. In the third part, participants had to go through each room in which they stated they wanted to use a Projector-Camera System and create and explain potential set-ups (Fig. 11.1). This resulted in participants actually challenging their own creations and led to a fruitful discussion with the interviewer.

The data gathered was analyzed using a grounded theory approach [17]. Two authors independently coded the data using open, axial and selective coding. The research questions for this exploratory study were: “How would people use a small and easy deployable projector-camera system in their daily lives? When and how would they interact with such a device, and how would they integrate it into their home?”

Fig. 11.1 Users building and explaining their setups (mockup highlighted for better viewability)

11.2.2 *Results and Findings*

We discovered four main categories [3] the participants were focusing on when they handled Projector-Camera Systems in their home environment:

- **Projector-Camera System placement**: *Where was the Projector-Camera System mounted inside the room?*
- **Projection surface**: *What projection surfaces did the participant choose?*
- **Interaction modalities**: *What modalities were mentioned for the input and why?*
- **Projected Content/Use Cases**: *What content did the participant want to project for each specific room?*

11.2.2.1 Content and Use Cases

Specific use cases were highly dependent on which room the participants were referring to. Nevertheless, two higher concepts derived from the set-ups the participants created: *information widgets* and *entertainment widgets*. The focus of *information widgets* was mainly to aggregate data. The majority of the use cases focused around an aid in finishing a certain task characteristic to the room. *Entertainment widgets* were mostly created in the living room, bedroom and bathroom. The focus of these was to enhance the free time spent in one of these rooms and make stays more enjoyable.

11.2.2.2 Placement of the Projector-Camera System

The placement was also classified into two higher concepts: the placement of the device *in reach* and *out of reach*. During the study, participants placed the Projector-Camera System within their reach and at waist height in the bedroom, bathroom and in the kitchen. The reasoning behind it was they could effortlessly remove it and carry it to a different room. In the living room, working room and corridor participants could imagine a permanent mounting and therefore placed the Projector-Camera System *out of reach*. The placement was done in a way so that the device could project on most surfaces and was "not in the way" (P19).

11.2.2.3 Orientation and Type of Surface

Even though it was explained to participants that projection onto non-planar surfaces is possible (due to certain distortion techniques), they always preferred flat and planar surfaces. Only one participant wanted to project onto a couch. The classification made for the projection surfaces was *horizontal* (e.g. table) or *vertical* (e.g. wall) orientation. Both types were used equally often throughout all setups inside the kitchen, bedroom, working room and living room. Only in the corridor and bathroom did the majority create vertical surfaces due to the lack of large horizontal spaces.

11.2.2.4 Interaction Modalities

In terms of modalities all participants focused mostly on speech recognition, touch, and a remote control. Techniques such as gesture interaction, shadow interaction or laser pointers were mentioned occasionally but were highly dependent on a very specific use case. The main influence on the preferred modality was the room and the primary task in there. *Out of reach* placements were mainly controlled using a remote control and *in reach* using touch interaction. One participant explained his choices are mostly driven by convenience: "You see, I am lazy and I don't want to leave my bed to interact with something" (P22).

11.3 The *UbiBeam* System

We designed *UbiBeam* based on the insights from the in-site study [5]. The focus was to create a small and portable Projector-Camera System which can be deployment in the majority of the rooms. In terms of a *Companion*-System, *UbiBeam* should offer *availability* in terms of everywhere available user interfaces and *adaptability* in the form of adapting the location of the interface and the interaction modality, depending on the use case. The system consists of several components such as a projector, a depth camera and two servomotors to be able to transform every ordinary surface into a touch-sensitive information display. In the future such a device could have different form factors such as a light bulb [12] or a simple small box [13] which can be placed inside the user's environment. The design of these devices will therefore focus on aspects such as deployment and portability and not solely on interaction. *UbiBeam* was a first step towards a home deployed Projector-Camera System which can work as a research platform to gather more insights on everyday usage of Projector-Camera Systems.

11.3.1 Implementation

The goal was to create a platform which can be easily rebuilt. The proposed architecture describes a compact and steerable stand-alone Projector-Camera System.

11.3.1.1 Hardware Architecture

We decided to use the ORDROID-XU as the processing unit for *UbiBeam* (Fig. 11.2) which offers a powerful eight-core system basis chip (SBC). As a depth camera *UbiBeam* uses the Carmine 1.08 of PrimeSence. Its advantages over similar Time-of-Flight cameras are its higher resolution and its good support by the OpenNI framework. The projector is the ultra-compact LED projector ML550 by OPTOMA (a 550 lumen DLP projector combined with an LED light source). The projection distance is between 0.55 and 3.23 m. Pan and tilt is enabled using two HS-785HB servo motors by HiTEC (torque of 132 N cm). The auto focus is realized similar to [23] by attaching a SPMSH2040L linear servo to the focusing unit of the projector

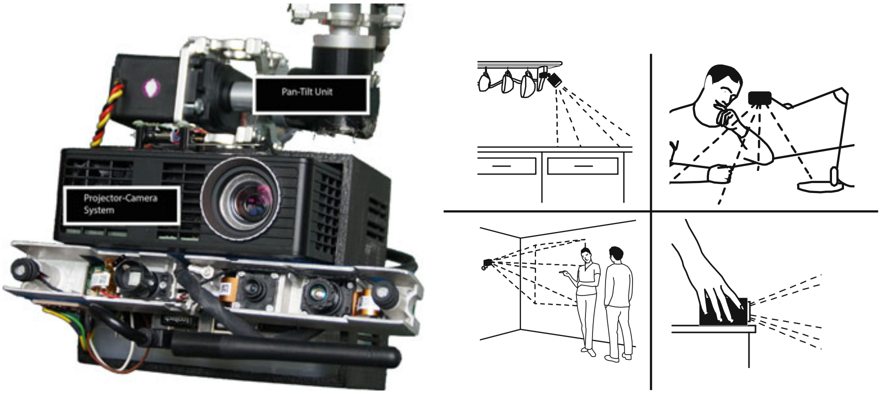

Fig. 11.2 The UbiBeam system in combination with the envisioned use cases for a home deployable Projector-Camera System

and refocusing based on the depth information. The control of the actuators is done by an Arduino Pro Mini. All the hardware components can be bought and assembled for less than 1000 USD.

11.3.1.2 Software Implementation

Since the goal was to create a stand-alone Projector-Camera System we tried to use lightweight and resource saving software. As an operating system we decided to use Ubuntu 12.04. The depth and RGB images were read and processed using OpenNI and OpenCV. UI widgets were implemented in QT, a library for UI development using C++ and QML. This allowed us to use an easy markup language (QML) to allow developers to create their own widgets.

UbiBeam was designed with the concept of an easy deployable system. Therefore, after the deployment at one particular location, the system automatically calibrates itself and enables touch interaction on the projection. The user can then create simple widgets using touch (e.g. calendar, clock, image frame) over the whole projection space. The orientation of the projection can either be controlled using the smart phone as a remote or dynamically by certain widgets (*adaptability*). After moving the device to a new space the auto focus and touch detection recalibrates automatically and creates a new interaction space.

11.3.2 Evaluation

To validate the quality of the proposed UbiBeam a technical evaluation was conducted. In particular, the precision and speed of the pan-tilt unit were examined as well as the touch accuracy.

11.3.2.1 Pan-Tilt Unit Performance

The task of the pan-tilt unit is to move the UbiBeam fast and accurately to a desired location. The two properties accuracy and pace were assessed in a laboratory study.

Alignment Accuracy The accuracy approaching a previously stored position was determined by placing the UbiBeam at a distance of 1 m to a wall. The projector was displaying a red cross to indicate the centre of the projection. Then the pan-tilt unit was commanded to approach the stored position from eight defined starting points. The position where the red cross came to a standstill was marked on the wall. Starting points were up, up-right, right, right-down, down, down-left, left, and left-up. Where up and down indicates a vertical shift by 45° from the stored position. Accordingly left and right indicates a horizontal shift by 90°. The measured distances in horizontal and vertical direction between the marked and

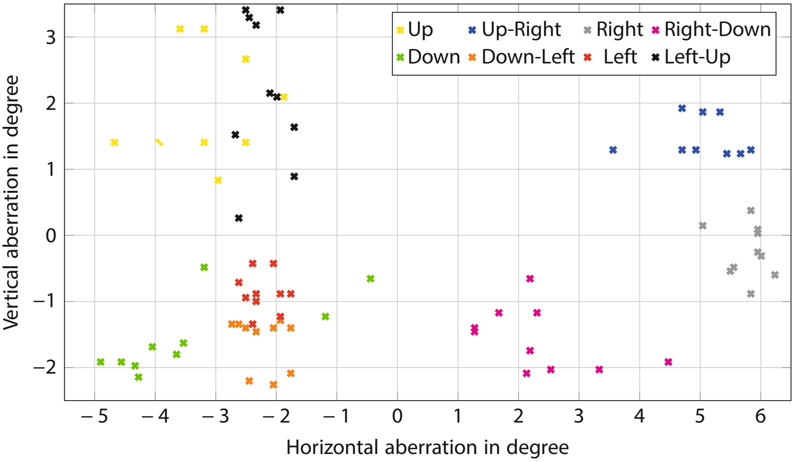

Fig. 11.3 Results of the positioning task for the pan-tilt motors

stored position lead to an angle of aberration. The stored position was approached ten times from each starting point. Thus 80 data points were obtained. A plot of the data is shown in Fig. 11.3. The average horizontal misalignment is 3.29°. For vertical alignment, the average error is 1.48°. Hence, the misalignment in an arbitrary direction is 3.74°. This accords to a shift of less than 10 cm if the surface is 150 cm away from the projector. A likely reason for the smaller misalignment in the vertical direction is caused by an accelerometer additionally used to control the servo for horizontal alignment. Since for horizontal alignment, no secondary sensor is used, the alignment is not as good. Overall the alignment is good enough to re-project a widget at almost the same location in the physical world, but is not sufficient enough to augment small tangible objects, for example a light switch. A more accurate alignment could be achieved by more powerful servos with a high-fidelity potentiometer.

Alignment Speed The pace of the pan-tilt unit was evaluated in a separate study. Therefore, the time needed for 164° horizontal pan and a 110° tilt was measured. Each movement was repeated ten times from both directions. Since panning and tilting is performed simultaneously, no combinations of tilt and pan were executed. On average the pan-tilt unit needed 3.5 s for the horizontal pan task. For the tilt task, the unit needed 4.8 s. A reason for the slower tilt movement could be the higher force needed for tilting compared to the rotation force. Overall the Projector-Camera System can reach every position in less than 6 s (worst-case: move 135° vertically). This seems to be a sufficient amount of time. Of course, there are faster servos available, but higher acceleration forces could damage the printed case holding the Projector-Camera System.

11.3.2.2 Touch Performance

Touch performance was evaluated in a similar laboratory study. The system was mounted over a desk at a distance of 75 cm. It was tilted down 70° from horizontal, pointing at the desk illuminating an interaction space of 40 cm×30 cm. The set-up is shown in Fig. 11.4. Four red crosses surrounded by a white circle posed as a target. They were distributed on three different surfaces. Two targets at the desk, one at the cardboard box on the left side and one on a ramp composed of a red notebook. In all cases, the diameter of the red cross was 18 mm.

During the study participants had the task to touch the targets as accurately as possible. Participants were instructed to take as much time as needed. Overall, 40 targets were presented in a counterbalanced order, one at a time. A detected touch was indicated by a green border. After touching the target, it disappeared and a new target appeared at one of the three other positions. Time as well as touch position in the projector and world coordinate system were recorded. From that data, the error in mm in the world coordinate system can be derived. Ten participants (all right handed) between 24 and 27 years took part in this study. Hence, 400 touch events were monitored. On average participants needed around 2 min to touch all 40 targets. In less than 1% the touch was not detected on the first approach. This was counted manually. The targets are labeled as follows: cardboard box (T1), ramp (T2), left desk (T3) and right desk (T4).

The mean touch error, variance and standard deviation for the different targets is specified in Table 11.1. Each target had a mean error of less than 20 mm. This requires large buttons for pleasant interaction. However, the small standard deviation for all targets indicates that the offset could be fixed by shifting the input by a few pixels. However, more studies must be conducted to verify this assumption.

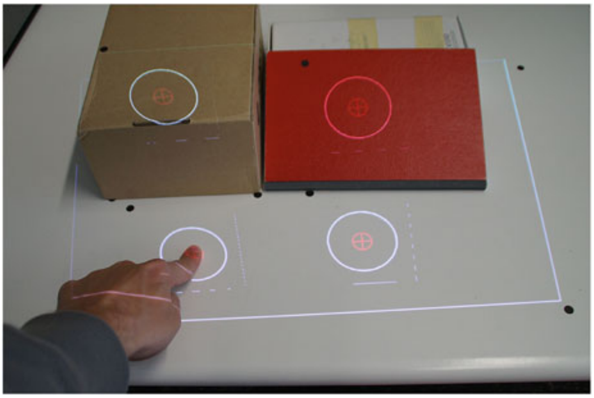

Fig. 11.4 Evaluation setup for the touch interaction

Table 11.1 Statistical data for the touch accuracy in mm

Target	T1	T2	T3	T4
Mean	14.11	19.32	16.58	17.82
Variance	8.48	12.50	8.50	7.57
SD	2.91	3.54	2.92	2.75

11.3.3 Discussion

The technical evaluation of *UbiBeam* has shown that the current setup is fast and accurate enough to support the use cases mentioned by participants in the earlier described user studies. Especially since users exclusively wanted to project on planar surfaces instead of augmenting specific items of their household, the current accuracy of below 2 cm seems sufficient in this regard. Further on, our evaluation of the touch accuracy showed that touches are robustly (99%) recognized and with a deviation below 2 cm. While the latter would clearly be too much for touch recognition on handheld devices one has to consider that the projected widgets of *UbiBeam* are much larger, typically having at least a size of 30×30 cm when projecting from only one meter away. Touch-Guidelines for smartphones typically agree on a minimal 1 cm bounding box required for touchable targets. Considering the at least four times larger displays generated by *UbiBeam*, a 2 cm deviation seems acceptable, although this accuracy should be further improved in the future.

11.4 The *SpiderLight* System

The focus of *SpiderLight* was to explore a body-worn Projector-Camera System and thereby investigate the interaction of a *Companion*-System which is always at hand (*availability*) and generate short cuts to context relevant information (*adaptability*). By observing smartphone users, we see that oftentimes getting hold of the device consumes more time than the actual interaction. Most of the time, the phone is used for micro-interactions such as looking up the time, the bus schedule, or to control a service like the flashlight or the music player [2]. With the recent emergence of wearable devices, such as smartwatches, users can access these kinds of information at all times without having to reach into their pockets. However, most of these wearable devices are merely equipped with a small screen so that only a little amount of content can be displayed and the user's finger is occluding most of the display during interaction (fat-finger problem). At the same time, the development of pico-projectors is progressing, allowing them to be incorporated in mobile phones (Samsung Beam), Tablets (Lenovo Yoga Pro 2) and even wearable devices such as a watch (Ritot). This way, the user overcomes the limitation of a small screen as pico-projectors allow the creation of comparably large displays from very small form factors. The larger display further enables sharing the displayed content with a group of people. Combining this projector with a camera would allow for interactions using the shadow of the fingers (Fig. 11.5). This would lead to having a large information display always available at the push of a finger.

The purpose of the *SpiderLight* is to facilitate micro-interactions that are too short to warrant getting hold of and possibly unlocking smartphone. Consequently, the *SpiderLight* is not meant to replace the user's smartphone. Instead, we understand

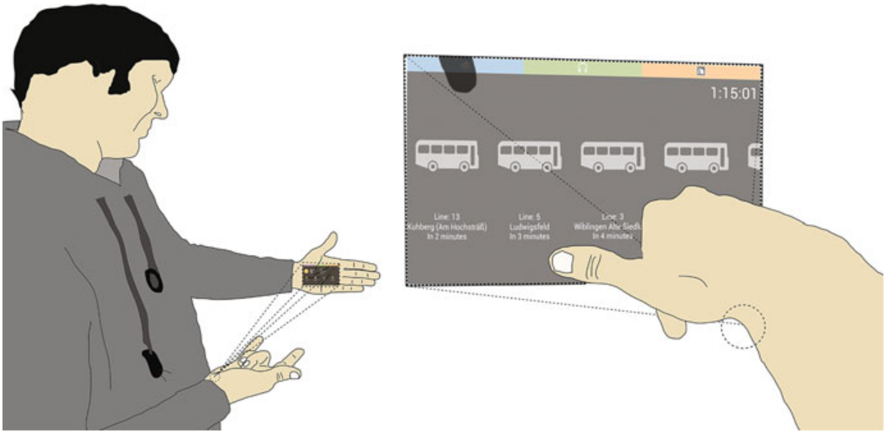

Fig. 11.5 The interaction space of the *SpiderLight*, which delivers quick access to context-aware information using a wrist-worn projector

SpiderLight as an accessory to the user’s mobile phone that has more limited in and output capabilities in favor of a much shorter access time.

11.4.1 Implementation

The implemented system must be able to sense finger movements in line of sight of the projection, sense inertial movements, and project preferably with a wide angle to not excessively constrain the minimum distance between projecting hand and palm or wall. In addition, these components were supposed to be part of a single standalone system, with processing power and power supply on-board. The easiest hardware decision was for the projector to be a Microvision SHOWWX+ HDMI, as it was the smallest laser-beam-steering projector available on the market, providing the widest projection angle, too. The decision for a laser projector seemed inevitably to support quickly changing the projection surface and the projection distance, which would require constant adjustment of the focus using a DLP-based solution and even then could not provide the dynamic focus range required to project on the uneven human palm.

For the central processing unit we considered different commercially available systemboards like Raspberry Pi, Beaglebone, or Cupieboard and small smartphones that provide video output. However, they all seemed too bulky by themselves, considering that projector, camera, battery, and potentially additional sensors would all add to the overall size of the system. Our decision thus fell on an Android TV stick that would provide the same functionality at a much smaller size. In particular, we chose a system based on the Rockchip GT-S21D, that in addition to HDMI out and USB host, as all TV sticks offer, also provides a camera that is originally meant to be used with teleconferencing. Finding suitable cameras of the desired size that work well together with Android is often a very difficult challenge and by choosing a system that already integrated the camera we achieved the smallest possible footprint of the camera. However, the decision also implied two consequences: We decided against a depth camera, which at the time of engineering was not available at the required size and with the required support for mobile platforms like Android. Furthermore, the default placement of the camera required adding a surface mirror to the system to make the camera point in the direction of the projector. As the stick did not provide inertial sensors and inertial sensors of mobile platforms often are not very accurate we added the X-IMU to the overall setup that would allow us to accurately measure the device's orientation and translation for pre-warping the projected image against distortion and recognizing rotational device gestures. Finally, a battery supporting two USB ports with at least 1 A current output on each port was integrated to power the projector and the TV stick, which in turn powers the X-IMU (Fig. 11.6).

The SpiderLight system runs on Android with its UIs created in Java and rendered through OpenGLES. The computer vision and sensor fusion algorithms are written in C++ and integrated using JNI and Android's NDK interface. Apart from the decisions that were already taken regarding the interaction metaphors, we finally had to decide which type of menu interaction we wanted to support. Since more users of a pre-study preferred the approach using finger shadows for menu selection, we used the top menu that was designed with finger shadows in mind and supports absolute pointing (Fig. 11.7a). Conversely, for scroll selection, we selected rotational device gestures that were answered the most in the pre-study. For item selection, again finger shadow selection is used, whereby the first of four top segments returns to the menu selection and the other 2–3 menu items provide selection commands (Fig. 11.7b).

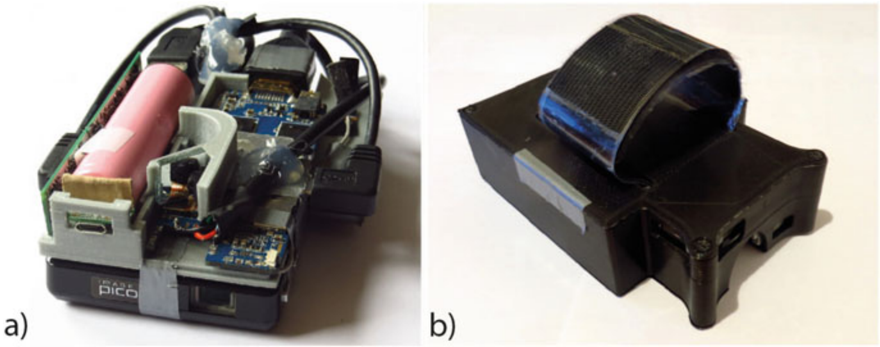

Fig. 11.6 The closure of *SpiderLight* (**b**) and the interior design (**a**) showing the projector at the bottom, the Android TV stick with the camera mirror on the right, and the battery on the left side. Not visible is the X-IMU which sits behind the projector on the lower side

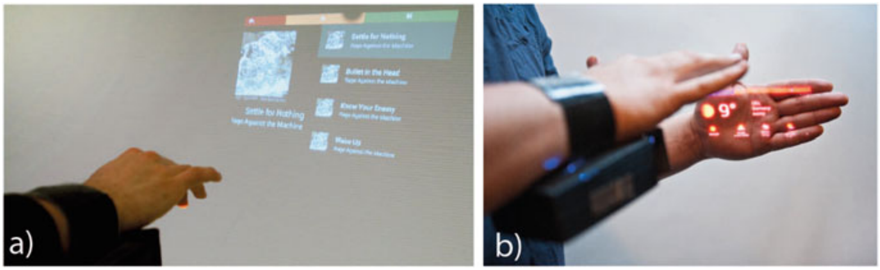

Fig. 11.7 Apart from the always available palm (**b**), any nearby surface (**a**) can be used for better clarity and single-hand interaction. Finger shadows facilitate button selections

11.4.2 Evaluation

To evaluate the performance and usability of *SpiderLight* we conducted a user study using the actual prototype.

11.4.2.1 Method

We recruited 12 participants (6 female) who were all right handed (since the prototype was optimized for the right hand) with an average age of 26 (range: 21–30). Except for two participants all had at least 2 years experience in using a smartphone. The goal of the study was to compare *SpiderLight* with a current smartphone in terms of access time, and usability in three applications that depict typical daily activities. Furthermore, we wanted to collect first impressions of participants using *SpiderLight*. The first task was to look up either the current weather or what time a certain bus is going to the train station. The second task was to scan an AR code and gather certain information (e.g. nutrition facts). The third task was to select a certain song in a music player. Each task was executed twice with a slight modification but stayed the same in term of complexity (e.g. only the piece of information to look up changed).

The study started with the participants being introduced to *SpiderLight*. Afterwards, they had time to practice and explore the system until they felt comfortable. Participants were encouraged to think aloud and give immediate feedback, which was written down. Participants were instructed to stand in front of a white wall and project onto it but without extending the arm to avoid exhaustion. After the introduction participants were using the smartphone and *SpiderLight* to finish the three tasks (tasks and systems were both counterbalanced). Every task started with taking the phone out of the pocket and unlocking it, respectively enabling the projection of the *SpiderLight* system. Once all tasks were finished, the users were asked to complete several questionnaires about their experiences using *SpiderLight*. During the study an error using the music application resulted in participants not being able to select a song. Therefore the third task was not used for the evaluation of the results.

11.4.2.2 Results

Task Completion Time On average it took participants 12.47 s (sd=3.7) for task one and 19.94 s (sd=9.72) for task two, using *SpiderLight*, in comparison to 12.00 s (sd=2.46) for task one and 14.80 s (sd=3.25) for task two, using the smartphone. We assume that the surprisingly high task completion time for *SpiderLight* resulted from the misdetections of input. Despite our efforts, the implementation of *SpiderLight* had sometimes problems in detecting a finger correctly. Therefore some participants resulted in taking longer using *SpiderLight* due to misdetection of input (which was manually recorded during the study). Nevertheless, looking at participants using *SpiderLight* without misdetection of input, the times show that most were able to finish the tasks with times below each smartphone time. We therefore argue that with a better implementation, *SpiderLight* would perform faster compared to smartphones.

Qualitative Feedback In the questionnaires about the usage of *SpiderLight*, participants reported that rotation interaction was simpler to conduct, less physically demanding and had a higher accuracy compared to finger input. This could partly be influenced by the misdetection of fingers, but also from the fact that using the shadow of a finger to interact with a device was more novel and challenging to participants compared to rolling their arm. In a last question participants were asked in what scenarios they would prefer to use *SpiderLight* instead of a smartphone. *SpiderLight* was highly preferred for sharing content and using the camera to scan AR codes, whereby it was less preferred to control the media player. We can explain this through the interaction concept of *SpiderLight*, which is designed for small interactions and quick lookups. Controlling a media player however is a task which can be considered longer and requires several selections such as browsing for a song.

11.4.3 Discussion

The unique advantage of projectors being able to create large displays from very small device form factors makes these devices very suitable for future wearable technology and for supporting micro-interactions. With *SpiderLight* we presented an approach to user interfaces for micro-interactions with wrist-worn projectors. We created a prototype that afforded most of the requirements in a standalone device, addressing several hardware and

(continued)

software challenges. Compared to other "smart devices" *SpiderLight* inhibits distinct advantages: it provides a much larger display than smart watches and can easily be shared in contrast to the display of smart glasses. Although our final evaluation could not entirely prove the superiority of *SpiderLight* over smartphone usage, we have to take the familiarity of users with smartphones and the described tracking issues we faced in the evaluation into account.

11.5 The *smarTVision* System

To evaluate the interaction with a Projector-Camera System in a stationary (home deployed) scenario, we decided to create a prototype for the use case of watching television. This television use case was often mentioned during the in-situ study (Sect. 11.2) and creates new challenges in terms of *availability* and *adaptability*. The interaction should now be possible using a remote control (*out of reach*) and touch (*in reach*). Initially, we analyze the current television setups in users' homes. The traditional setup of one television as the center of the living room is still widespread. However, a current trend shows that users tend to use second screens such as smartphones additionally to the content displayed on the main TV screen. Yet, the current setup does not allow for sharing additional content with others without interrupting the current content. With *smarTVision* [4], we present a concept which allows us to place any number of additionally projected screens inside the living room. We explored the space of input and output options and implemented several applications to investigate different interaction concepts.

The basic concepts allows the user to create several projected interfaces on the floor, the wall and the ceiling (Fig. 11.8b). Each location can be suited for a different use case (e.g. scoring information to a basketball game at the ceiling) and can either be controlled by the user or by the system (*adaptability*). The interaction with *smarTVision* is done either using the smartphone application (e.g. share player information to a basketball game on the floor) or via touch (e.g. scroll through different basketball players at the table). These should explore the two categories of *in reach* and *out of reach* projected user interfaces.

11.5.1 Implementation

To study the *smarTVision* concept we designed and implemented a prototype system. The hardware was attached to a stage lighting rig mounted on two tripods (Fig. 11.8a). The rig itself was positioned above a touch and a couch table. Three BenQ W1080ST projectors were mounted on the rig to be able to project onto the space from the couch up to the wall. A fourth projector placed below

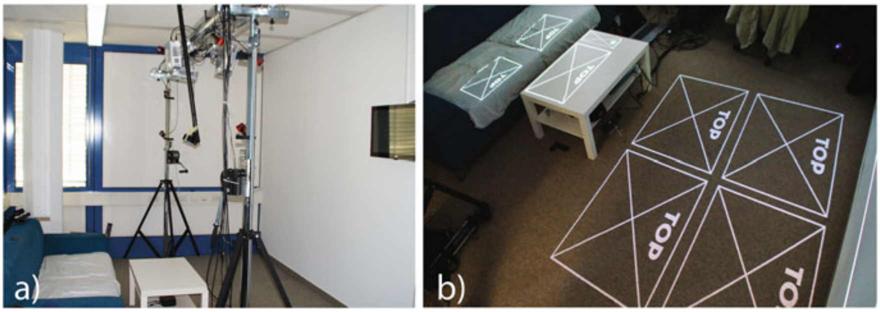

Fig. 11.8 The prototype hardware setup: a traverse mounted on two tripods spans across the room, holding a depth camera and projectors (**a**). The projected display space of the prototype allows us to create several surfaces (**b**)

the couch table created the projection onto the ceiling. This setup allowed for rendering any visual content on this continuous display space. The interaction was implemented using a Microsoft Kinect attached above the table and the couch. Using the UbiDisplays toolkit of Hardy et al. [7] allowed us to create a touch sensitive projection on the couch and on the couch table. In addition to the touch interaction, a LeapMotion placed on the couch allowed for controlling *out of reach* projections using gestural interaction (e.g. swipe through content). To manage complex applications *smarTVision* used a central Node.js server for the coordination between the internal application logic.

To illustrate and research the benefits of *smarTVision* we implemented several demo applications. In this section we will focus on four of these applications, namely *second screen manager*, *sharing mobile phone content*, *sports play application* and *quiz application*.

Second Screen Manager The second screen manager allows the users to extend and augment the traditional setup by placing additional content in the projection space. Initially, a subset of available television channels is presented to the user on the couch table. By selecting one channel via touch input, the user can assign the position of this channel to any new location. In addition to different camera perspectives, the user can also place related content such as social media feeds. The second screen manager provides a straightforward interface for placing and managing second screens inside the projection space.

Sharing Mobile Phone Content As already mentioned by participants of the in-situ study in the first section, interaction with Projector-Camera Systems should not only create new modalities but also blend with currently used technologies such as smartphones. Therefore, we implemented the functionality to share content such as images, videos and URLs from a personal device (e.g. smartphone, tablet, laptop). The *smarTVision* mobile application allows the user to connect to the backend and share his content on any surface inside the projection space. The interaction with the content is then controlled using the personal device. This reflects the feedback of users on interaction with *out of reach* interfaces using remote controls.

Sports Play Application To evaluate the concept of *adaptability*, we implemented a content specific application which supports watching a basketball game broadcast. The main screen will show the main camera of the game, whereby the system blends in additional information such as player highlights, scores and detailed statistics. The user is still able to control the content using touch interaction on the couch table. The adaption is currently only based on the action inside the broadcast and not based on the user's emotional state. However, this could easily be added when the user's emotional state is sensed in a good manner.

Quiz Application To explore multi-user interaction we additionally implemented an application which allows the user to play along with a quiz show broadcast (Fig. 11.9). Users are provided with a projected second screen next to them on the couch. Using touch, they can select their answer to the question currently discussed in the quiz show. Corresponding to the revealing of the correct answer a user is either illuminated in green (correct) or red (wrong). This application highlights the concept of *availability* of a *Companion*-System. The system is able to project a user interface next to and even on to the user to enable input in a comfortable position.

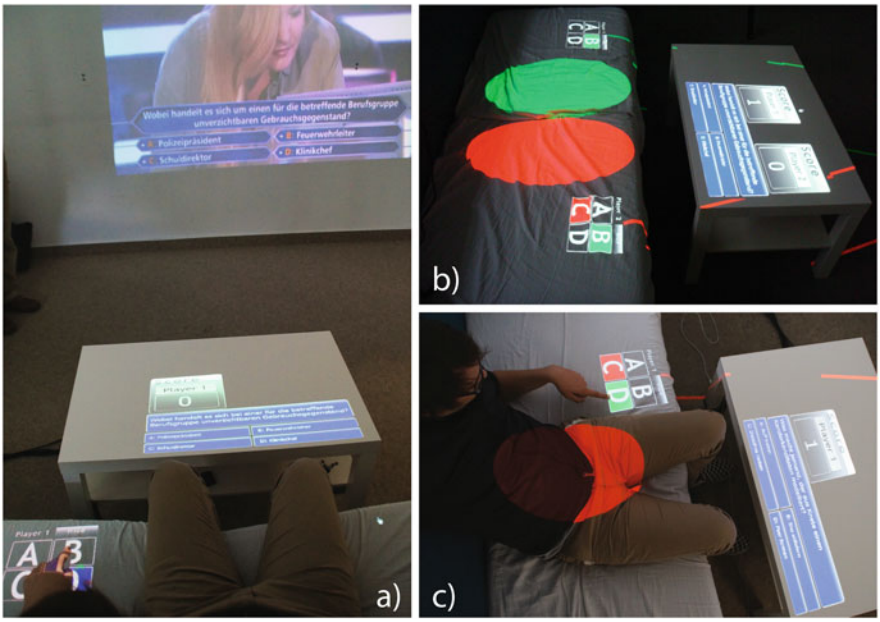

Fig. 11.9 The quiz application. Answer options can be selected via a small interface next to the user (**a**). Depending on the selection, the user is illuminated in a *red* (wrong) or *green* (correct) light (**b,c**)

11.5.2 Evaluation

We gathered qualitative feedback of users regarding the interaction and concepts of *smarTVision*. Therefore, we recruited 12 participants (7 male, 5 female). Participants were always seated in the same spot on the couch and first introduced to the general interaction concept of *smarTVision* and projected user interfaces in general. After the initial introduction, users were given specific training tasks to get familiar with the interaction of *smarTVision* and to explore the applications. After the practice participants had to fill out two questionnaires, one on specific questions regarding subjective feedback and one AttrakDiff questionnaire [9]. The study was video recorded and interactions and reactions were analyzed based on the video recordings. All participants rated *smarTVision* mildly positive in regards to the interface clarity and overview. Participants also agreed on the "good overview over the distributed second screens", showing that the interaction space itself (couch, floor, wall and ceiling) were chosen appropriately for the scenario of watching television. Regarding the readability of content, participants rated *smarTVision* more heterogeneous. Reading text on the wall and ceiling was considered a rather strenuous task. This should be considered for designing home deployed Projector-Camera Systems, so that user interfaces with a higher text density should be presented in the user's vicinity (*in reach*). Regarding the interaction with *smarTVision*, participants mentioned positively the effortless placing of second screen displays and were satisfied with their created results. The AttrakDiff questionnaire resulted in the prototype being a "rather desired" product.

11.5.3 Discussion

The majority of participants rated *smarTVision* as straightforward and easy to use. We focused on the effortless interaction so the system can blend into the user's environment and support him when necessary. This is particularly important if such a device will be deployed inside the homes of participants, so the frequency of use does not decrease over time. These design decisions were further confirmed with the positive result of the AttrakDiff questionnaire. Participants also praised the benefit of *smarTVision*, in being able to work solely without a physical remote control. This emphasizes the degree of *availability* a Projector-Camera System can offer and also the level of *adaptability*, since in certain use-cases (e.g. sharing pictures) participants preferred using a personal device such as a smartphone to interact with the interfaces.

(continued)

In this section we presented *smarTVision*, a continuous projected display space system that enables users to create any number of second screens and place them in their environment. We presented several applications which were implemented to utilize this novel interaction space. Finally, we showed the results of a preliminary user study collecting a first impression of users interacting with a Projector-Camera System combined with a television scenario.

11.6 Conclusion for *Companion*-Systems

In this chapter we presented first an in-situ user study on home deployable Projector-Camera Systems and explored the requirements such a system needs to fulfill to be accepted and used inside a user's home. Based on these insights we presented three implemented prototypes *UbiBeam*, *SpiderLight* and *smarTVision*. Each individual prototype focused on a certain interaction space and explored the particular scenario in the context of *availability* and *adaptability* of a *Companion*-System. *UbiBeam* showed how a small and portable Projector-Camera System must be implemented to conduct user studies at the participant's home. In the future we are planning to deploy the *UbiBeam* system for a longer period of time inside participants' homes and collect data on the frequency of use and on the type of use. The *SpiderLight* system explored how a highly available *Companion*-System can look and how the interaction with a portable Projector-Camera System must be designed to meet user requirements. Finally, with *smarTVision* we explored the interaction of a fixed Projector-Camera System inside a user's living room. The initial focus of the work was on building the prototype and collecting first user impressions. In the future we will focus on conducting a bigger user study and exploring the level and type of *adaptability* such a system can offer to the user. Currently all the prototypes use a simple form of *adaptability*, based on certain events. In collaboration with researchers in the fields of *adaptive planning and decision-making* and *knowledge modeling* a more sophisticated level of *adaptability* can be created. Furthermore, integrating knowledge from projects in the field of "Situation and Emotion" would result in being able to adapt the prototype not only on states of the system but also on the emotional state of the user.

Acknowledgements This work was done within the Transregional Collaborative Research Centre SFB/TRR 62 "*Companion*-Technology for Cognitive Technical Systems" funded by the German Research Foundation (DFG).

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