LightBeam: Nomadic Pico Projector Interaction with Real World Objects

Jochen Huber

Technische Universität
Darmstadt
Hochschulstraße 10
64289 Darmstadt, Germany
jhuber@tk.informatik.tu-
darmstadt.de

Jürgen Steimle

Technische Universität
Darmstadt
Hochschulstraße 10
64289 Darmstadt, Germany
steimle@tk.informatik.tu-
darmstadt.de

Chunyuan Liao

FX Palo Alto Laboratory
3174 Porter Drive
Palo Alto, CA 94304 USA
liao@fxpal.com

Qiong Liu

FX Palo Alto Laboratory
3174 Porter Drive
Palo Alto, CA 94304 USA
liu@fxpal.com

Max Mühlhäuser

Technische Universität
Darmstadt
Hochschulstraße 10
64289 Darmstadt, Germany
max@tk.informatik.tu-
darmstadt.de

Abstract

Pico projectors have lately been investigated as mobile display and interaction devices. We propose to use them as 'light beams': Everyday objects sojourning in a beam are turned into dedicated projection surfaces and tangible interaction devices. While this has been explored for large projectors, the affordances of pico projectors are fundamentally different: they have a very small and strictly *limited projection ray* and can be carried around in a *nomadic* way during the day. Thus it is unclear how this could be actually leveraged for tangible interaction with physical, real world objects. We have investigated this in an exploratory field study and contribute the results. Based upon these, we present exemplary interaction techniques and early user feedback.

Keywords

Pico projectors, handheld projectors, mobile devices, augmented reality, mixed reality, embodied interaction

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous.
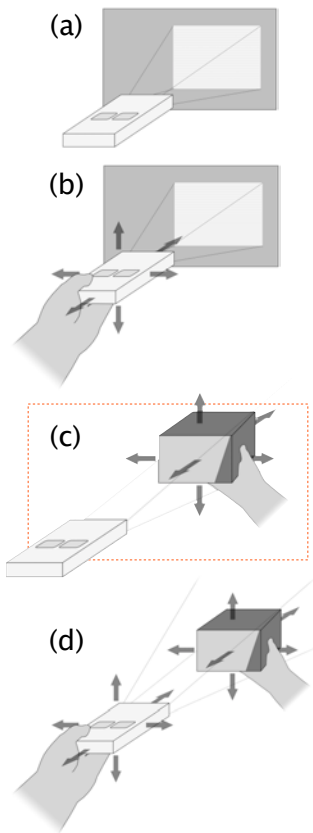
General Terms

Design, Human Factors, Theory.

Figure 1. Conceptual levels for pico projector interaction:
(a) fixed projector, fixed surface
(b) mobile projector, fixed surface
(c) fixed projector, mobile surface
   (LightBeam)
(d) mobile projector, mobile surface.

The LightBeam

The capabilities of pico projectors have significantly increased. In combination with their small form factors, they allow us to dynamically project digital artifacts into the real world. There is a growing body of research on how they could be integrated into everyday workflows and practices [11]. For instance *Bonfire* [6] or *FACT* [7] augment physical surfaces with interactive projections to support e.g. multi-touch input or fine-grained document interaction. Other examples are indirect input techniques using gestures [2] or shadows [4]. All require both surface and projector to be at a *fixed position* during interaction (cf. Fig. 1a).

The mobility of pico projectors has inspired several techniques, where projectors are held in hand and project onto static surfaces (cf. Fig 1b). Cao et al. [1] developed various projector-based techniques (for so-called flashlight interaction), as well as pen-based techniques for direct surface interaction. Other projects such as *SideBySide* [14], *RFIG Lamps* [10] and *MouseLight* [12] focus on augmenting static surfaces with digital information using a handheld projector. A few projects also investigated wearable projection, where the pico projector is worn like an accessory. Prominent examples here are *OmniTouch* [5] and *Sixth Sense* [8]. Although these projects support projection onto essentially mobile objects such as a human arm, these objects are only used as interactive surfaces, not for tangible interaction, where the pico projector is fixed and the object is moved in 3D space (cf. Fig 1c).

While the tangible character of physical objects in combination with projections has been explored for large projectors [9], the affordances of pico projectors are fundamentally different: they are *mobile* and have a very small and *strictly limited projection ray*. Thus we tend to think of pico projectors more like personal devices, which are carried around in a *nomadic* way during the day and used in a plethora of situations and places, such as workplaces or cafés. Due to their unique affordances, it is unclear (1) how the mobility of both pico projectors and physical objects could be actually leveraged for tangible interaction in 3D space and (2) what kind of projected information actually matches the affordances of physical objects. Intuitive handling of such objects has the potential to foster rich, non-obtrusive UIs. In this paper, we contribute *LightBeam*, which aims at filling this void.

In LightBeam, the pico projector is fixed in the vicinity of the user and not constantly held in hand (cf. Figure 1c). The projection is regarded as a constant ray of light into the physical space; "always-on". The projector itself is augmented with a camera-unit and can track objects within its ray in 3D space. Figure 1 separates the composition of projector and object mobility. In practice, the boundaries are not rigid and the individual approaches can be combined, leading also to mobile projector interaction with mobile objects (cf. Fig. 1d).

The contribution of this work in progress is two-fold: (1) As our main contribution, we have explored the LightBeam concept in a qualitative field study with interaction design researchers. Our results provide initial insights into the design space of *nomadic,* pico-projector-based tangible interaction with *mobile* real world objects. (2) Based upon our qualitative results, we conceived and implemented interaction techniques for 3D object interaction with pico projectors in nomadic usage scenarios. These have in turn been evaluated in early user feedback sessions.
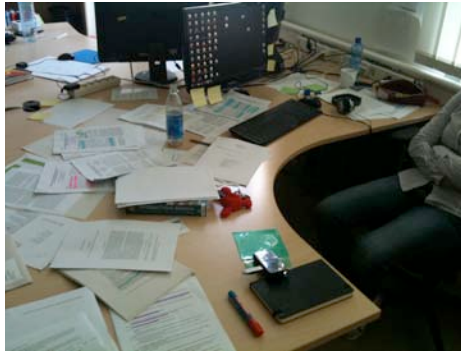
Figure 2. Example photographs from the two settings in the exploratory field study; personal desk (top) and café (bottom).

Exploratory Field Study

We conducted an exploratory field study to gain a deeper understanding of how pico projectors can be used with physical objects in the context of LightBeam.

Study Design. We recruited 8 interaction design researchers (7m, 1f) between 25 and 33 years of age (mean 28y). Their working experience ranged from 1 to 6 years (mean 4y). We used an Aaxa L1 laser pico projector, as a low-fidelity prototype. The projector was restricted to displaying multimedia content (e.g. videos). The projection was not adapted to any projection targets because we did not want to influence the participants by any design. It was therefore always shown in full size. We conducted the study in two different places (order counter-balanced) with each subject: the subject's workplace and a café close by (cf. Fig. 2). We selected these two places mainly for three aspects: spatial framing, social framing and the manifold nature of objects contained within these places. The participants were seated in both settings. Each session lasted about 2 hours in average.

Data Gathering and Analysis. We chose a qualitative data gathering and analysis methodology, which we performed iteratively per session. We used semi-structured interviews, observation and photo documentation. The main objective was to observe the participants while using the projector for certain interactions in the field. The interactions themselves were embedded in semi-structured interviews, lead by one of the authors. The participants were either asked how they would project and interact with certain content or deliberately confronted with a projection as shown in Figure 3 (details omitted due to space limitations). The semi-structured interviews were highly interactive and had the character of brainstorming sessions. After each session, the interviews and observations were transcribed and analyzed using an open, axial and selective coding approach [13]. The scope of the next session was adapted according to the theoretical saturation of the emerging categories. The coding process yielded various categories, depending on which objects were selected as projection targets and how objects actually foster input capabilities.

Results I: Objects as Output

In the interviews, the participants noted that the affordances of objects determine whether and how an object can be used for output of digital artifacts.

Which Objects are Used for Projection?
We observed a direct correspondence between the degree of attentiveness the participants were required to pay to the projection and both size and shape of an object that was chosen as the projection target. Content such as presentation slides, where it is crucial to grasp the whole level of detail and a high degree of attentiveness is required, was projected onto larger, less mobile and rigid surfaces such as larger boxes, tables or the floor; but not onto walls, due to being "impolite and a disturbance to others" (P5) or a privacy issue (mentioned by all participants). Cognitively less demanding content, such as short YouTube clips or photos, was projected onto rather small and even non-planar objects, e.g. P7 commented in the situation of Figure 3: "Even though it is distorted towards the edges of the cup, I do not mind, since it is not a high quality movie". With respect to the LightBeam concept, participants reported that deformable objects are perfectly suitable for "taking a peek into the beam" (P5). P5 imagined that the projector was constantly

Figure 3. Scene from the session with P7: the interviewer deliberately projected a movie clip onto a cup on P7's personal desk. The interviewer first observed how the participant would react to this and then continued the interview process.

projecting into space without a target object and was able to display notifications, like on his Android smart phone. "By lifting a paper and moving it into the beam", he explained, "I can just take a look at my notifications, you know, to look if something is *there*".

Objects are Frames
The natural constraints provided through the boundaries of physical objects were also considered important. P7 noted: "I want to put things into frames. Objects on my desk provide this frame, whereas my table itself is too large–there is no framing". It was considered crucial that the projection is clearly mapped to the object. P8 elaborates on this by saying: "Objects are like frames for me, they provide space and receive the projection". This is fundamentally different to a projected *virtual* frame as used in [1], since the *physical* objects are decoupled from the projector's movement.

Results II: Objects as Input
While larger surfaces provide extensive display area for detailed output, they are hard to move and therefore are rather fixed in physical space. Smaller physical objects however afford manipulation in 3D space.

Physical Embodiment of Digital Artifacts
We observed that all of the participants used the mobility of physical objects to control who is actually able to see the projected content. This leads to a rather object-centric perspective on interaction, as P3

outlines: "It is not the device I care about, it is the object with the projection." Moreover, P4 argues that "the data is on the object, it is contained within it. The digital artifact is embodied through the physical object."

Using Objects as Tangible Controls
The participants also argued that since the data is bound to a physical object, the object itself could be used as a tangible control. P7 states that for this purpose he makes "an abstraction from the actual object towards its geometry". He therefore concludes: "For instance, when I look at my coffee mug, I see an object which can be rotated by grabbing its handle; I would want to use this for quickly controlling something like a selection".

Overloading Mappings of Physical Objects
Projecting onto an everyday object and mapping digital functionality to it is more than just a visual overlay in physical space. It also redefines the object's purpose. Moreover, a projection locks objects in physical space, as P7 elaborates: "If I used this coffee mug as a tangible control for an interaction I heavily rely on, I would certainly have to forget its use as a mug. It would have to remain at that very place." The consensus across the participants was that overloading the mapping of physical objects is good, for short terms, as P5 described: "I would want to just put the object within the projector beam, carry out an interaction and remove the object from the beam".
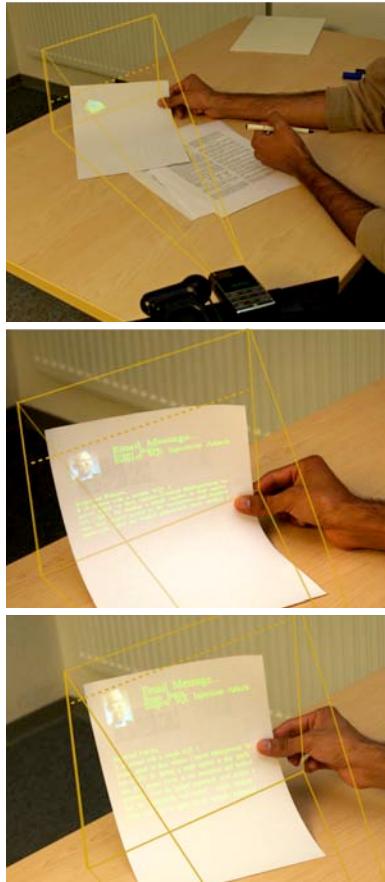
Figure 4. From top to bottom, levels of detail: (1) a small envelope is displayed due to the limited projection space. (2) By gradually lifting the paper, the level of detail is adjusted, (3) more text is displayed and automatically wrapped within the boundaries.

Examined Interaction Techniques

Based on the findings from our field study, we have designed a set of techniques for *nomadic* pico projector interactions, leveraging both mobility and limited projection ray. We envision future pico projectors to embrace functionality of today's mobile phones. Here, awareness and effective notifications are key to managing the information overload. Pico projectors can be used to bring these into the physical space, turning everyday objects into peripheral awareness devices. Thereby, the pico projector is not in the center of attention, as it was in previous research–*objects are*.

Use Movable Objects to Display Information In-Situ
Awareness information and notifications are typically visualized as low-level information, e.g. an envelope meaning that a new e-mail has arrived. We imagine that physical objects can be leveraged to support easy access to awareness information while being on the move, on demand. Simply introducing an object into the beam reveals pending notifications. Figure 4.1 shows our exemplary interface: the projector is placed on a personal desk while the user is working with a physical document. The sketched projection ray in figure 4 idealizes the highly limited projection area. The dotted line designates the *effective projection* (EP) area. The user lifts the document only a bit and therefore he can take a peek into the beam (small EP) and see if there are any new notifications (*pull-mode*). As a matter of course, objects can also be permanently placed within the beam to immediately receive notifications (*push-mode*).

Support Transition between Different Levels of Detail
The larger the object, the more display space available, the more level of detail can be displayed. We support the dynamic mapping of object size to different levels of details. We particularly leverage the deformability of non-rigid objects: these allow for gradual transitions between different levels of details using one single object. This is also relevant for supporting multiple simultaneous projection targets or for substituting projection targets of different size or shape, when the original projection target has been moved away. Figure 4.2 and 4.3 shows our prototypical implementation. A piece of paper can be gradually lifted within the beam to dynamically adjust the level of detail: the more the paper is lifted, the more lines of an email are displayed (large EP). Thus, the detail level is proportional to the area of the effective projection. As a slight variation of this technique, folding and unfolding a piece of paper within the projection beam affords a discrete transition between different levels of detail.

Use Everyday Objects as Tangible Controls
Inspired by the findings from our study, we use affordances of everyday objects as tangible controls. Prior work [3] mapped one particular object to one digital functionality. In contrast, we do not map one particular object to a certain digital functionality. We advocate mapping the *unique affordances* of everyday objects such as rotating to unique digital functions. We therefore provide a loose coupling of interaction and object, since for instance any object that affords rotation can be used to carry out that very function. Our implementation is shown in Figure 5. We use the rotation of objects, here a mug, to navigate through the displayed pictures. The mug can be withdrawn from the scene at any time. Any other object supporting rotation can be used to carry out this task. Thus the functional mapping is not bound to that specific object.

Figure 5. A photostream from Flickr is projected onto a box and can be navigated by rotating the coffee mug.

Figure 6. Hardware prototype using a Microsoft Kinect, mounted on a suction cup. The pico projector is placed on top of the Kinect. We have added a hi-res webcam on the right hand side.

Technical Overview

Our hardware prototype is shown in Figure 6. As projection surfaces, we currently consider flat surfaces of 3D objects. We model them as 2D planes in 3D space. To support a robust tracking of arbitrary objects, we solely use the Kinect's depth image in our tracking algorithm (description omitted due to space limitations). The projection is mapped using a homography, correcting any perspective errors. We also analyze the optical flow of detected objects in the RGB image, to detect if an object has been rotated.

Early User Feedback and Conclusion

We have evaluated the interaction techniques in interviews with 4 interaction design researchers in our living lab. Our main objective was to get a first impression of how users would utilize LightBeam to interact with physical objects. The session lasted about 3 hours. The participants liked the idea of taking a peek into the virtual world by placing an object within the beam, to then seamlessly switch between different levels of detail. Being able to use virtually any object to control the projection diminished their concerns that objects might lose their original function when being used as tangible controls. One participant commented: "I like this kind of *casual functional overlay*. Now I am not afraid that I will end up with two coffee mugs on my table, since one might be dedicated to one specific function". However, they noted that they might want to bind certain information to objects on purpose, which we aim at exploring as future work.

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