Toward Bimanual Interactions with Mobile Projectors on Arbitrary Surfaces

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ABSTRACT
The field of personal mobile projection is advancing quickly and a variety of work focuses on enhancing physical objects in the real world with dynamically projected digital artifacts. Due to technological restrictions, none of them has yet investigated, what we feel is one of the most promising research directions: the (bimanual) interaction with mobile projections on arbitrary surfaces. To elicit the challenges of this field of research, we contribute (1) a technology-centered design space for mobile projector-based interfaces and discuss related work in light thereof, (2) a discussion of lessons learned from two of our research projects that support the mobile interaction with planar surfaces, and (3) an outline of open research challenges within this field.

Author Keywords
Mobile projectors, handheld projectors, mobile devices, augmented reality, embodied interaction, design space.

ACM Classification Keywords
H5.m. Information interfaces and presentation: Miscellaneous.

General Terms
Design, Human Factors, Theory

MOTIVATION
Mobile projectors allow us to significantly increase the limited screen real estate of mobile devices. The projection can be situated in the real world. This allows for the augmentation of physical objects with digital artifacts in an immersive way. In this way, users are able to focus their attention on the real world and directly interact with these objects. The enabled interaction styles essentially depend upon three orthogonal dimensions: (1) the shape of the *projection surface* (planar vs. non-planar), (2) the utilized *tracking technique* (natural vs. artificial features), and (3) the *projector placement* (static vs. dynamic).

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These dimensions set the base for the three contributions of our paper: we first set up a technology-centered design space for mobile projector-based interfaces and discuss related work within this space. Second, we report on lessons learned from two research projects to better understand the challenges in this field. Last, we point out potential future research directions toward bimanual interaction with mobile projectors on arbitrary surfaces. We feel that this is one of the most promising but also challenging approaches to interact with mobile projectors and physical objects.

DESIGN SPACE
Most of the previous work has focused on the projection onto flat, planar surfaces [2,5,8,10,11] with a dynamic projector placement (e.g. handheld) and using artificial features (cf. Table 1). The artificial features are required to overlay the physical visual appearance with situated digital contents in mobile situations (e.g. on paper using an Anoto pattern [11]). Projects like FACT [7] or Bonfire [5] show that conceptually similar results can be achieved when using natural features. However, for this purpose, they require a static placement of the projector.

The aforementioned projects utilize a planar projection surface. To our knowledge, iLamps is the only system that uses non-planar surfaces for *dynamic* projection [9]. But also this approach requires artificial features (using piecodes as fiducials). Only few approaches allow users to manipulate the projection surfaces in 3D [1,3,6]. However, they use a larger, static projector, not a dynamic projector, and additionally rely on artificial feature tracking.

In summary, previous work has only allowed for a projector at a *dynamic* position with immobile, planar projection sur-

Table 1. Design space

Feat.	Projector Position	Planar Surfaces	Non-planar Surfaces
Artificial	*Stat.*	MouseLight [11] MapTorchlight [10] 6^{th} Sense [8] and [2]	Shader Lamps [1] PaperWindows [3] Xpaaand [6]
	Dyn.		iLamps [9]
Natural	*Stat.*	Bonfire [5] FACT [7]	
	Dyn.		

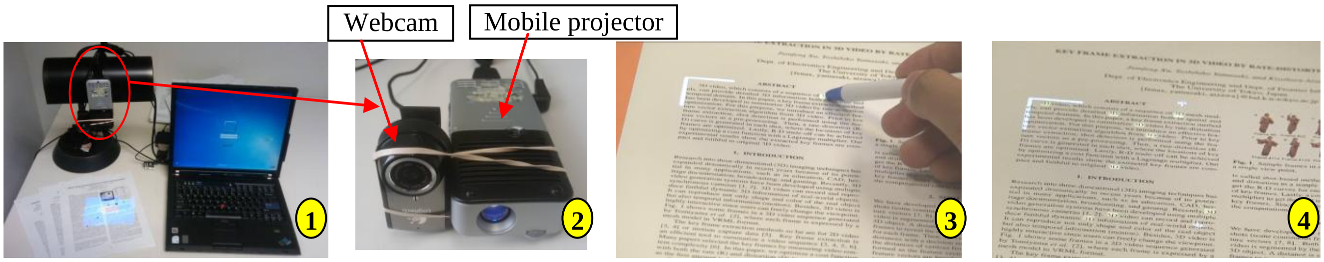

Figure 1. (1) FACT interface prototype, (2) Close-up of the camera-projector unit, (3) A word (highlighted by the projector) selected by a pen tip for full-text search, (4) The resulting occurrences of the word highlighted by the projector.

faces, or allowed for manipulating the projection surface using a projector at a *static* position. We are convinced that it is important to advance the field in the yet unexplored direction of bimanual interaction with dynamic projectors *and* mobile arbitrary projection surfaces (i.e. no artificial features or constraints on shapes). It will pave the way for novel interaction techniques that enable more natural and realistic deployment of the mobile projector-based interfaces in everyday tasks.

Toward this goal, we have already implemented two projector-based interfaces: FACT (described in detail in [7]) tracks ordinary paper documents with their natural features and enables word-level augmented reality interaction with the documents. SteadImage addresses automatic hand jitter and keystone correction in using a dynamic projector. In the following sections, we briefly describe FACT and SteadImage, and report on the lessons learned from these two projects. Based upon the reflection of our work, we conclude with challenges and open research questions in this field.

FACT

FACT (Fine-grained And Cross-media inTeract) is an interactive paper system of which the interface consists of a small camera-projector unit, a laptop, and ordinary paper documents without any barcodes or markers (Figure 1-1 and 1-2). FACT exploits the camera-projector unit for precise content-based image recognition and coordinate transform, allowing users to draw pen gestures to specify *fine-grained* paper document content (e.g. individual Latin words, symbols, icons, figures, and arbitrary user-chosen regions) for digital operations. For example, to find the occurrences of a word in a paper document, a user can point a pen tip to the word (Figure 1-3) and issue a "Keyword Search" command. As the result, all occurrences of that word on paper are highlighted by the projector (Figure 1-4).

STEADIMAGE

Different from FACT, SteadImage addresses two issues that arise when the user holds the projector in a hand in mobile situations: (1) hand jitter and (2) keystone effects. Both problems are for instance highly relevant when playing back videos using mobile projectors. In this case, mobile projectors are rendered unusable when the projection is either constantly shaking due to hand jitter or distorted due to keystone effects. Instead of high-end tracking hardware such as Vicon (as used in [2]), SteadImage is based on low-cost infrared-based tracking with a Nintendo WiiMote with Motion Plus mounted on an AAXA L1 laser pico-projector. The WiiMote's infrared camera captures an infrared beacon mounted onto the projection surface (see Figure 2) to determine the projector's pose and orientation with respect to the beacon. This is combined with both gyroscope and accelerometer data to correct keystone and jitter effects and thus locally stabilizes the projection.

Physical Interaction Techniques

With SteadImage the projected image remains at a fixed location, regardless of both effects, unless the projector movement exceeds a certain threshold. This fosters both fine- and coarse-grained physical interactions:

Tilt-based interactions: Since the projection is invariant to tilting gestures, tilting the device to the right (or to the left) enables users to fast-forward (or rewind) the video without losing the original focus on the projection. More tilting-based interactions can be applied analogously to those presented in [4].

Gesture-based interactions: Shaking the projector along e.g. the horizontal axis can be used for non-linear video navigation. Shaking the projector to the right (or left) allows users to switch between video key frames. Since the video remains locally stable, further visual feedback can be projected while performing the gesture.

DISCUSSION

Our experiences from both FACT and SteadImage shed light onto the design of future projector interfaces. First of all, FACT proves the feasibility and high precision of natural feature-based recognition of planar projection surfaces. For this purpose, FACT requires the projector to be placed

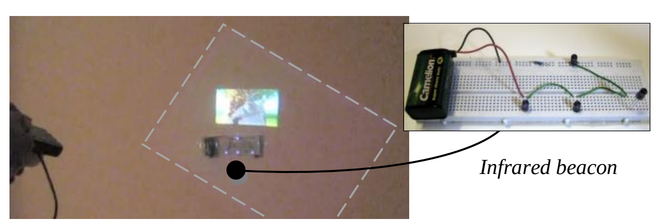

Figure 2. Corrected video projection. The dashed line marks the physical projection area.

statically. SteadImage overcomes this limitation and shows that even with low-cost hardware such as a WiiMote, a mobile projector can be situated in 3D space at the cost of utilizing artificial feature tracking. This encourages us to combine both efforts and extend them to planar and further to non-planar surfaces in 3D space. The overall aim here should be to overcome the limitations imposed by both approaches by for instance exploiting novel 3D tracking devices such as depth cameras (e.g. Microsoft's Kinect).

Secondly, a projector interface should take into account the context for optimized projection results. For instance, the content on the projection surface may interfere with the projected information, and therefore the in-situ projection may not be the best (e.g. a projected menu can be occluded by underlying text). In this case, we can delegate the augmenting information to an off-situ projection or to a separate screen. Moreover, considering the high power consumption of a mobile projector, it could dynamically adjust its brightness, depending on the brightness of the projection surfaces. In this way, it could achieve good display contrast without running out of battery too fast.

Finally, neither FACT nor SteadImage support bi-manual interaction that comprises both the projector and the projection surface. However, there are interesting applications such as asymmetric bimanual interaction: users can for instance use the non-dominant hand to position the projection surface in 3D space, therefore for example reviewing different parts of a virtual but physically situated information space (comparable to a tangible view [12]). The dominant hand then moves the projector to adjust the surface-projector distance, enabling a tangible semantic zoom that displays information at different detail levels.

CONCLUSION AND FUTURE WORK

In this paper, we have sketched a technology-centered design space for mobile projector-based interfaces and discussed related work in light thereof. Moreover, we reported on lessons learned from two of our research projects, which both support the projector interfaces with planar surfaces.

While FACT supports fine-grained interactions with the projection surface, SteadImage supports one-handed interactions with the projector itself. Combining both approaches results in more degrees of freedom and allows particularly for bimanual interaction (e.g. projector in one hand, projection surface in the other). This leads to challenging research questions: (1) For what kind of interactions is bimanual manipulation helpful? (2) What commands should be delegated to each hand? (e.g. macrometric tasks such as roughly positioning the paper with the non-dominant hand, and fine-grained manipulation using the projector in the dominant hand) (3) How precise can the interaction with the projector be?

Along the proposed direction are broader research questions, including (4) how can we robustly recognize and track markerless objects, such as printouts, in 3D space with unrestrained pose while visually enhancing them with dynamic projections? (5) What kind of gestures should be adopted for such an interaction? And if so, (6) are there any design guidelines for these gestures?

We believe that by investigating these questions, we can advance research toward supporting (bimanual) interaction with arbitrary surfaces in three-dimensional space.

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