# A Research Overview of Mobile Projected User Interfaces

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## Introduction

The miniaturization of projectors has gained a certain momentum over the last few years. Devices have reached the market that can fit into the palm of a hand (cf. Fig. 1) and market growth is expected to lead to revenues of up to $10 billion by 2017 [13]. These so-called pico projectors are typically available as stand-alone devices with varying characteristics in terms of the supported resolution, brightness, form factor, and connectivity. Pico projectors are also being integrated into Smartphones, an example being the recent release of the Samsung Galaxy Beam.

This new class of devices opens up interesting opportunities for novel user interfaces that enable interaction *beyond* the desktop. Pico projectors allow us to project digital imagery into physical space virtually anywhere and anytime. They thus serve as one enabling technology for the vision of ubiquitous interaction. One of the key application scenarios are mixed reality interfaces [29] that overlay digital content onto physical objects. These interfaces require algorithms, for example for object recognition and tracking, projection mapping and alignment. They also face hard challenges such as robust real-world registration, nonplanar projection surfaces, hand jitter and keystone distortion, color faithfulness, sensor fusion, networking issues, and device integration. Mobile projected user interface research therefore draws on a plethora of fields of computer science, such as human–computer interaction, computer vision, graphics, computational geometry, interaction design and the like.

In turn, pico projector technology has attracted the attention of various research communities and work is being regularly disseminated at workshops [11], in journal special issues [42], at top-tier international conferences such as the ACM Conference on Human Factors in Computing Systems (CHI) or the ACM Symposium on User Interface Software and Technology (UIST), as well as national conferences such as Mensch & Computer (M&C).

This article surveys the research on mobile projected user interfaces. While other articles [9, 10, 41] touch upon the same domain, surveying for instance social practices, implications or interaction technologies, this article contributes a timely and comprehensive review of the user interface research landscape. The article is structured as follows: a brief overview of pico projector technology is given, outlining the main challenges for developing mobile projected user interfaces. Next, the article provides an overview of research according to three pertinent research directions: (i) nomadic, (ii) handheld and (iii) tangible projection interfaces. The article concludes by outlining future research challenges and indicates trends in neighboring research fields that might foster innovation in the mobile projected user interfaces domain.

## Technological Background

Three imager technologies are used in currently available pico projectors: Digital Light Processing (DLP), Liquid Crystal on Silicon (LCoS), and

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## Abstract

In the last few years, the miniaturization of projectors has gained certain momentum. Today, projectors are available that can easily fit into the palm of a hand. Moreover, these devices are even being integrated into mobile phones. Mobile projectors allow users to project digital imagery into physical space virtually *anywhere* and *anytime*. The unique characteristics of small-scale projectors open up interesting opportunities for mobile user interface research. This article provides a comprehensive overview of research on mobile projected user interfaces according to three pertinent research directions: (i) nomadic, (ii) handheld, and (iii) tangible projection interfaces. Furthermore, the article outlines future research challenges and indicates trends in neighboring research fields that might foster innovation in the mobile projected user interfaces domain.


Laser-Beam-Steering (LBS). DLP allows for small manufacturing sizes (e. g., AAXA P2 jr. [1], Fig. 1a) while suffering from glitches such as the "rainbow effect" (an anomaly due to the utilized color wheel in DLP projectors that manifests itself as red, blue, and green flashes in high-contrast scenes). LCoS provides a better color image without rainbow effects at the cost of slightly inferior contrast ratios and larger product sizes (e. g., AAXA P3 [2], Fig. 1b). LBS provides the best image results with an always in-focus projection at the price of higher manufacturing costs (e. g., AAXA L1 [3], Fig. 1c, and the discontinued MicroVision SHOWWX+ [28], Fig. 1d). Other well-known manufacturers include Acer, General Imaging, Optoma, Aiptek, 3M, and Brookstone.

Currently state-of-the-art pico projectors are limited in three major aspects:

1. **Limited display resolution:** currently available devices support only resolutions of up to 1024 × 600 pixels. There is thus a huge gap between those and the high-resolution rendering support that larger projectors, as well as current display technologies offer.
2. **Low brightness:** one of the major caveats of current pico projector technology is their display brightness which is usually limited to up to 100 ANSI lumen (DLP, LCoS) or 20 ANSI lumen (LBS). Unfortunately, this is noticeably inferior when compared to the 2500–3000 ANSI lumen that larger projectors offer. As a result, they require settings with low lighting for the projection to be visible and can hardly be used outdoors in bright sunlight.
3. **Limited interaction support:** as of today, pico projectors are mainly envisioned as a screen replacement or extension and thus provide only limited interaction support off-the-shelf. They usually feature button-based input on the device to setup the projection preferences or control multimedia playback such as picture slideshows or videos.

While limitations 1 and 2 are subject to further technological advancements, there is a growing body of research on improving interaction capabilities and designing novel mobile projected user interfaces. The human–computer interaction communities are primarily focusing on leveraging the unique affordances of pico projectors, i. e., their portability and capability of projecting digital artifacts into the real world. The community effort has also brought forth the first toolkits that aim at easing the development of mobile projected user interfaces [15, 50] and helping to overcome common issues such as hand jitter and keystone correction when operating for instance handheld projection interfaces. In the following, an overview of the research landscape of mobile projected user interfaces is given.

**a** **b** **c** **d**

***Fig. 1 Exemplary set of widely used pico projectors. (a) AAXA P2 jr. [1], (b) AAXA P3 [2], (c) AAXA L1 [3], and (d) MicroVision SHOWWX+ [28]***

**Zusammenfassung**
In den letzten Jahren ist die Miniaturisierung mobiler Projektoren stark vorangeschritten. Inzwischen existieren Geräte, die leicht in der Hand zu tragen oder gar direkt in Smartphones integriert sind. Diese Projektoren ermöglichen es Benutzern, digitale Inhalte *überall* und *jederzeit* in den physischen Raum zu projizieren. Die einzigartigen Charakteristiken dieser Projektoren eröffnen interessante neue Möglichkeiten im Forschungsfeld der mobilen Mensch-Computer-Interaktion. Dieser Artikel gibt eine umfassende Übersicht über existierende mobile projizierte Benutzungsschnittstellen. Diese werden in drei wesentlichen Forschungsrichtungen diskutiert: (i) Nomadic, (ii) Handheld und (iii) Tangible Projection. Zudem zeigt dieser Artikel sowohl offene Forschungsfragen, als auch Trends angrenzender Forschungsrichtungen auf, die zu weiterer Innovation im Bereich der mobilen projizierten Benutzungsschnittstellen führen können.

## Research Overview

It is worthwhile noting that there is a greater body of knowledge on projection-based interfaces with larger projectors. Prior work in this field dates back to the early 1980s, when Michael Naimark investigated immersive projection environments in art installations [36]. However, compared to larger projectors, the affordances of pico projectors are fundamentally different: they are portable and can thus be attached to *virtually anything*; also, they have a very small and strictly limited projection ray that empowers users to project digital information into physical space *virtually anywhere*.

As outlined earlier, one major drawback of pico projectors as-is is their rather limited input capabilities. To foster rich interactions, it is common practice to enhance those by adding sensing capabilities such as camera units (ranging from standard RGB webcams to more sophisticated depth cams such as the Microsoft Kinect), accelerometers, gyroscopes, and other types of low-level sensors. This movement has led to a growing body of research on mobile projected user interfaces that leverage on these additional sensory capabilities. Existing work can be classified according to the relation between projector and projection surface, leading to three salient research directions:

a) **Nomadic Projection Interfaces (cf. Fig. 2a):** These are interfaces that rely on the pico projector being fixed in the vicinity, for example on a tripod or attached to a laptop, to project onto a fixed projection surface. These interfaces require little setup time and can be carried around in a nomadic fashion; roaming from location A to location B. Typically, a user can then interact with the projected user interface through surface-based input, such as multitouch or digital pen input.
b) **Handheld Projection Interfaces (cf. Fig. 2b):** These interfaces leverage on the small form factor of pico projectors and require the user to hold the projector in their hand. The projector itself is typically used for input, either via direct input such as buttons on the projector itself or by moving the projector like a flashlight.
c) **Tangible Projection Interfaces (cf. Fig. 2c):** This emerging interface type investigates how pico

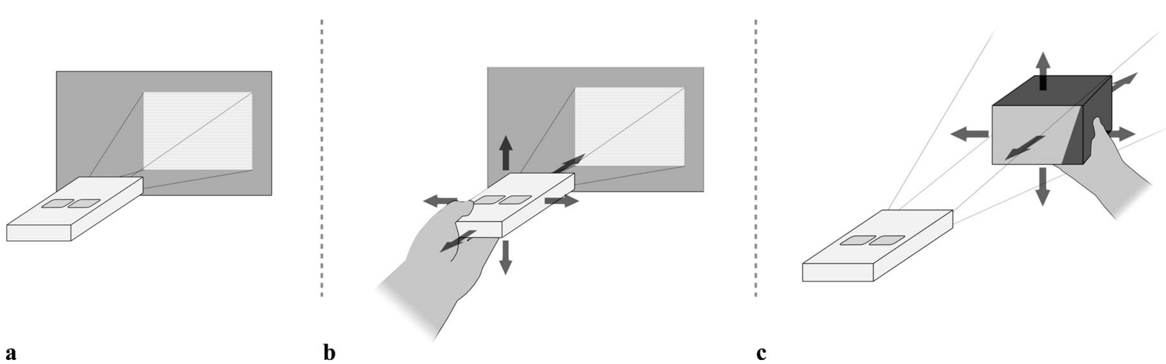

*Fig. 2 Conceptual sketch of mobile projection interfaces. (a) Nomadic Projection, (b) Handheld Projection and (c) Tangible Projection Interfaces*

*Fig. 3 Exemplary nomadic projection interfaces, from left to right: LuminAR [24], FACT [23], GuitAR [26]*

projectors can be integrated into for instance wearable interfaces to foster rich tangible interfaces. The projection is tightly and meaningfully integrated with physical objects, for example a user's body or everyday objects. Interacting with the physical objects through touching or moving them is then mapped to user interface controls.

The boundaries between these research directions are of course neither rigid nor fixed. In particular, they can also be combined as in the case of (b) and (c) for bi-manual interaction concepts with pico projectors [20], where both projector and surface can be considered mobile. This classification serves as only one example, focusing on the relation between projector and surface. Other classifications exist that provide for example a more interaction-centric perspective [41]. In the following, each of the three research directions is illustrated and an overview of relevant research projects is given.

## Nomadic Projection Interfaces

Projectors provide a convenient way of displaying information on-demand without the need for an actual display. However, one of the main caveats of desktop-scale projectors is their form factor. Pico projectors overcome this limitation and can be easily carried around. In particular, they allow for quick mount and dismount virtually anywhere in a nomadic fashion. Along these lines, researchers developed nomadic projection interfaces as a supplement to existing workflows: serving as an additional, static display supplement in the working environment and augmenting mobile artifacts to enrich learning and work.

**Supplementing Static Working Environments with Additional Interactive Displays.** An early example of providing additional display space through pico projectors is a project called Bonfire [22]. Two camera-projector units are attached to a laptop and therefore extend the display area to the left and right hand sides of the laptop. The projection is used as an interactive surface, allowing users to employ multitouch gestures on the projected area. Moreover, the system recognizes everyday objects such as a coffee cup through vision-based methods and can project additional information besides the object. The system, however, does not project onto the objects themselves.

Similar to the idea of Bonfire is the one of LuminAR [24] (cf. Fig. 3). It is a portable projector-camera unit, designed as a desk lamp that projects onto the desk. It rethinks the idea of the classical light bulb to not only emit light, but provide meaningful in- and output capabilities (inspired by Underkoffler et al.'s seminal work on the I/O Bulb [48]). In addition, the desk lamp itself is also a robotic arm, allowing it to re-position the projection on-demand. The projection itself can be controlled via gestures and can be seen as an interactive complement to the traditional desktop workspace, very much like a digital tabletop.

One example of a nomadic projection interface that integrates with traditional workflows is FACT (Fine-grained And Cross-media inTeract) [23] (cf. Fig. 3). It is an interactive paper system in which the interface consists of a small camera-projector unit (mounted on a tripod/attached to a desk lamp), a laptop, and ordinary paper documents. FACT exploits the camera-projector unit for precise content-based document recognition, based on natural features, allowing it to work with arbitrary printed text. It furthermore allows 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 at the word and issue a "Keyword Search" command. As a result, the projector highlights all occurrences of that word on the paper. Both projector and paper document need to be placed at a fixed position for fine-grained document interaction.

**Augmenting Mobile Artifacts to Enrich Learning and Work Practices.** The portable nature of pico projectors can of course also be used to augment mobile artifacts such as instruments or books. For instance, within the scope of GuitAR [26], Löchtefeld et al. investigated the augmentation of a guitar with a pico projector to directly project instructions onto the fret board of the guitar (cf. Fig 3) to scaffold guitar novices in mastering the instrument. The projector is mounted on the headstock of the guitar using a tripod. The system itself does not feature any sensing capabilities and as such is restricted to displaying additional information such as where to place fingers when playing a chord.

Dachselt and Sarmad [12] propose the concept of Projective Augmented Books. They envision a device that works like a reading lamp that can be attached to a book, therefore augmenting it through projections. The prototypical implementation supports pen-based gestures for virtually annotating printed text and carrying out digital functionality such as copy&paste and text translation. They also implemented a tangible tool palette that allows users to quickly change stroke, color, and functionality of the digital annotations.

In Penbook [59], Winkler et al. augment a tablet computer on a stand with a pico projector. The projector then projects onto an attached projection screen in front of the tablet. With a wireless pen, users can write digital information onto the projection surface. Users can interact simultaneously with both projected information and content that is displayed on the tablet computer, turning Penbook into a dual-display device. The authors specifically explore applications in a hospital context to scaffold work practices.

## Handheld Projection Interfaces

The unique form factors of pico projectors make a compelling case for investigating handheld projection interfaces [56]. Handheld projection dates back to artistic performances in the early 17th century: for instance, handheld units that bundled light from a candle using a concave mirror and projecting it through colored slides were used to create projected imagery. These so-called magic lanterns found their application in storytelling performances (see [51] for a comprehensive overview). Drawing on this wealthy source of inspiration, researchers have investigated various forms of handheld projection interfaces: they comprise techniques to explore and augment large information spaces such as paper maps, environment-aware projection interfaces, multiuser projection interfaces for co-located and remote collaboration, as well as mid-air interfaces for handheld projector interaction.

**Exploring and Augmenting Large Information Spaces.** A large set of interfaces leverages the narrow and pointed projection ray of pico projectors to precisely augment large-scale physical documents or explore virtual information spaces through handheld interaction. Pioneering work has been carried out by Rapp et al. [37] who used mobile projectors for so-called spotlight navigation (often also referred to as a flashlight metaphor). Here, the projector is held in the hand like a flashlight and illuminates a certain area of the physical space. In this very area, it projects virtual information. The actual information space, however, is much larger but cannot be displayed in its entirety due to the projector's narrow projection ray. By moving the projector further parts of the information space can be revealed. This kind of interface is very much comparable to today's common interfaces such as Google Maps, where only a small part of the map is visualized in a window; panning the window reveals further parts of the map.

Prominent work was also conducted by Cao et al. [5]. They developed various handheld interaction techniques, mainly based on the flashlight metaphor, as well as pen-based techniques for direct input on large projection surfaces such as walls. The idea of exploring and augmenting paper maps was investigated in projects such as MapTorchlight [43]. Moving the projection ray of handheld pico projectors across a physical paper map reveals the information related to the illuminated area. A similar application scenario of using mobile projectors on physical maps was studied in [14]. Other examples are Marauder's Light [27], MouseLight [46], and PenLight [45]. The latter two also allow for direct pen

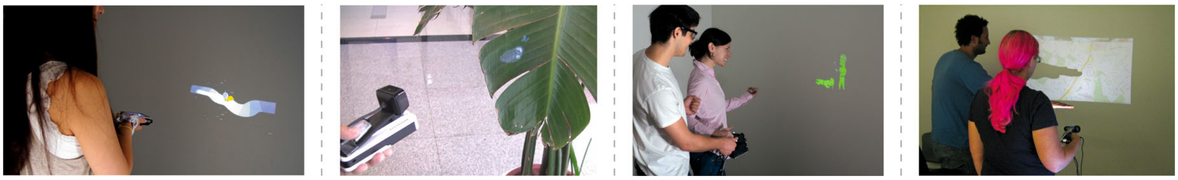

***Fig. 4** Exemplary handheld projection interfaces, from left to right: MotionBeam [53], PicoPet [62], SideBySide [52], ShadowPuppets [8]*

input on the physical document, being beneficial for example for urban planning tasks.

In MotionBeam [53], users steer a projected virtual character through virtual worlds (see Fig. 4). The character is bound to the projection. Moving the projector also moves the character and in turn reveals only a part of the game world. The game itself is played on a fixed projection surface such as a wall.

**Environment-aware Handheld Projection Interfaces.** Various interfaces focus on making handheld projections environment-aware: the projector reveals information depending on where the projector is situated in physical space and what parts of the environment, for example physical objects, are actually targeted by the projection ray.

Early examples are projects by Raskar et al., iLamps [38] and RFIG Lamps [39]. The overarching goal for both projects was to develop technology for projecting onto nonplanar surfaces and therefore augmenting arbitrary objects with additional information. The idea of environment-aware projection interfaces has been developed further by Molyneaux et al. [32–34] in so-called smart objects. They investigated how physical objects can be turned into interactive projected displays. The main focus of the work was on orchestrating a technical infrastructure, allowing for reliable and robust object detection through model-based approaches.

More recently, Molyneaux et al. [35] have presented two camera-projector systems, which support direct touch and mid-air interaction. The systems leverage on an ad-hoc generated model of the physical space. The model is obtained by scanning the environment using depth-sensing cameras. The projected interfaces can then be precisely situated in physical space. In particular, the 3D shape can impact the behavior of projected imagery, for example a rolling ball projected onto a table would bounce off its edge. However, once the model has been obtained, objects must remain at a fixed location.

A slightly different notion of environment-awareness is explored in PicoPet [62] (see Fig. 4). The basic idea is that the user projects a virtual pet into the physical space using a handheld projector. Behavior and evolvement of the pet depend on where it is projected. Hence, colors, textures, objects, and the presence of other virtual pets in the physical environment impact one's own pet. These features are recognized using a camera that is mounted on top of the projector.

**Handheld Multiuser Interfaces for Collaboration.** A large body of research explored the potential of handheld projector interfaces for both co-located and remote collaboration. Most works assume that each user utilizes one handheld projector.

Pioneering work by Cao et al. [6] introduced first principles for co-located collaboration using handheld projectors. They primarily investigated fundamental issues such as: (i) combination of multiple handheld projections for composite display, (ii) access control to shared objects contained in multiple projections, and (iii) transfer of well-known information visualization paradigms such as overview+detail or focus+context to multiple projects (e. g., one user projects an overview, another co-located user projects the detail view). Weigel et al. [49] extended the focus+context concepts by integrating pico projectors with stationary displays. When near to a display, projecting onto it reveals a focus area; projecting from afar shows the context while the focus is shown on the stationary display.

Willis et al. also investigated co-located collaboration with one handheld projector per user in SideBySide [52] (see Fig. 4). Besides their technical contribution of facilitating ad-hoc collaboration with minimal setup, they investigated various multiuser interface designs for (i) mobile content exchange, (ii) education, and (iii) gaming. Co-located collaboration was also explored by Cauchard et al. [7] in terms of novel gesture-based, shared input techniques for handheld projected interfaces, as well as by Robinson et al. in PicoTales [40] for collaborative ad-hoc creation of story videos.

Inspired by the advent of projector phones, Winkler et al. explored remote collaboration using handheld projections [58]: when the projector phone is held to one's ear to answer a call, the built-in projector is used to project an interactive surface in the vicinity, for example onto a table. The user interface provides distinct private and shared areas to both caller and callee, enabling for instance file exchange and information access between both parties during a phone call.

**Mid-Air Interfaces for Handheld Projectors.** While the aforementioned handheld interfaces primarily leveraged direct input on the projection surface or embodied interaction techniques using the projector itself, several projects investigated mid-air techniques that do not require interacting on the projection surface. One example is ShadowPuppets, a prototype that allows users to cast hand shadows as input to mobile projector phones [8] (cf. Fig. 4). Cowan and Li explored different user interfaces such as a map and a photo browser. Their setup implicitly also supports co-located interaction of multiple users: one user holds the projector and therefore projects the interface, while another user, standing in-between the projector and the projection, can cast shadows to interact.

Interaction around a handheld projector has also been studied by Winkler et al. [57]. They investigated various pointing techniques around a projector phone in mid-air to manipulate the user interface. Pointing behind the projector steers a cursor in the interface; moving the finger then translates to moving the cursor.

## Tangible Projection Interfaces

The previous two research directions mainly focus on the portability of the pico projector. A third emerging research direction places an emphasis on the tangible nature of the projection surfaces themselves, be it one's own body or physical objects that are projected onto and then moved in physical space to control the user interface. This thematic scope has been extensively researched for large projection spaces, for example in PaperWindows [19] which uses paper as projection surfaces, Armura [17] which leverages on-body projection and interaction, or LightSpace [55], where basically any fixed surface in a small room installation is being recognized for interaction on, above, and between the surfaces.

The unique affordances of pico projectors however allow us to go beyond large installations towards truly mobile scenarios in terms of (i) wearable projection interfaces that particularly leverage the human body for interaction; and (ii) mobile projection interfaces that project onto physical objects for tangible interaction.

**Wearable Interfaces.** A prominent wearable projection interface is Sixth Sense [30], although not targeted for tangible interaction per se. A camera-projector unit is worn as a necklace. Physical surfaces such as walls, but also parts of the body can then be used as a projection surface. Users are able to interact with the projection using in-the-air gestures in front of the camera. Lifting for instance one's wrist in front of the unit displays a watch.

Skinput [18] also leverages body parts as projection surfaces and allows for touch input directly on the body (cf. Fig. 5). The tangible nature of touching one's own body provides instantaneous tactile feedback. This effort has been further refined in OmniTouch [16], which broadens the scope and enables touch input on arbitrary surfaces using a depth-camera and a pico projector (cf. Fig. 5).

A slightly different approach is pursued in Cobra [61]. It uses a flexible cardboard interface in combination with a shoulder-mounted projector. The cardboard can be bent as tangible input

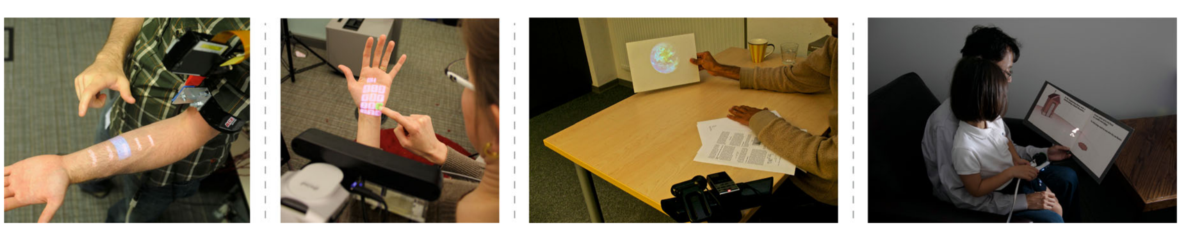

*Fig. 5 Exemplary tangible projection interfaces, from left to right: Skinput [18], OmniTouch [16], LightBeam [21], and HideOut [54]*

for mobile gaming but needs to be held at a fixed position.

**Tangible Interfaces.** The tangible affordances of everyday objects for mobile projection interfaces were explored in LightBeam [21]. A camera-projector unit is placed in a user's vicinity and provides a dedicated interaction space through its highly limited projection ray (cf. Fig 5). The unit employs a depth-sensing camera to work with arbitrary objects without the need for instrumenting the environment with artificial markers. Moving objects into the beam charters them with both output and input functionality. Physical affordances of objects, such as the rotation of a coffee cup or the gradual movement of a physical paper into the beam, can then be leveraged for tangible interaction with the projected interface. Huber et al. proposed two salient application scenarios: (i) leveraging everyday objects in the vicinity as peripheral awareness devices and (ii) mobile augmentation of and interaction with physical documents.

In HideOut [54], Willis et al. developed a mobile projector-based system that explores interaction techniques with tangible objects and surfaces (see Fig. 5). The system detects hidden markers that are applied using infrared-absorbing ink. The markers then provide hints to the system as to where to project. One pertinent example is interactive storytelling, where the system projects onto a physical book. Flipping pages or moving the projector can be used to animate characters to convey a compelling story. Other application scenarios comprise media navigation tools and mobile games.

## Research Challenges and Conclusion

Pico projector technology has opened up an exciting landscape of mobile projected user interface research. The research directions illustrated in this article leverage on three pertinent affordances of pico projectors: their *portability* for nomadic projection interfaces, their *unique form factors* that enable handheld projection interfaces, and the *ability to project onto physical artifacts* such as our own body or everyday objects for tangible projection interfaces in truly mobile settings.

All of these prototypes demonstrate the potential of mobile projected user interfaces for applications such as collaborative work, technology-enhanced learning, interactive art, or mobile gaming. At the same time, they open up a plethora of novel challenges:

– **Technological Challenges:** Limited display resolutions and low display brightness are still an issue with currently available pico projectors. However, even more apparent is the lack of sensory intelligence. Almost all of the projects presented in this article leverage on some sort of sensor to register the virtual projection with the physical world, as well as to track physical objects and sense sophisticated interactions. Integration of sensory equipment into pico projectors is a tough challenge. In particular, sensors such as the Kinect camera rely on infrared light that prevents its application outside in sunlight. With the advent of highly capable mobile processors such as Snapdragon quad-core processors in handheld devices, tracking approaches like LumiTrack [60] might become feasible for mobile projected user interfaces. In the same vein, the integration of pico projectors into for example smartphones is just beginning and requires additional research to compensate for additional power consumption and proper projection output, amongst other challenges. Further research is also required to develop efficient, smart sensing approaches that can be easily integrated with the small form factors of pico projectors.
– **Privacy-aware Mobile Projections:** The visibility of projected user interfaces to for example bystanders is a sincere issue when it comes to displaying privacy sensitive data [9, 10]. First interaction techniques are for instance presented in OmniTouch [16], where projections onto the palm can be shielded by folding one's hand. However, the community has not yet converged in terms of well-established practices and interface guidelines for privacy-aware projection interfaces. One source of inspiration for future research could be Ballendat et al.'s work on proxemic interactions [4] for public displays. Another promising field of research targets so-called multiview displays. The basic idea is that each user looking at the same display is presented with his/her private view of the display. First prototypes are realized in ThirdEye [31] and Permulin [25]. Additional research is required to investigate how these techniques, currently relying on display technology, can be transferred to the mobile projection domain.

– **Nonplanar Interfaces:** Projection surfaces are usually assumed to be flat and planar. However, everyday objects are typically of arbitrary shapes, nonplanar in particular. One of the immediate effects is the visual distortion of the projection. Also, flexible media such as paper provide a rich interaction space that comprises for instance folding, bending, or tearing. This input space has been investigated in desktop-scale projection spaces, for example in FlexPad [47]. Projects such as LightBeam [21] and HideOut [54] presented first insights into the design space of tangible projection interfaces. Yet, sophisticated nonplanar tracking algorithms (cf. technological challenges) are required that overcome for example visual distortion even in mobile situations. Further research is needed to understand how flexible media can be used as rich input means for mobile projected interfaces.
– **Alternative Feedback Modalities:** Projected interfaces are of inherently visual nature. They can be precisely situated in physical space and, in particular, blend in well with physical objects. Touching them however provides only the feedback exposed by the projection surface. A user cannot really make sense of the projection by solely touching it, for example to feel projected widgets such as sliders or knobs. Providing alternative feedback modalities to the user is an ongoing research topic discussed in other communities as well. An exemplary project is AIREAL, which provides mid-air haptic feedback to the user by emitting rings of air that impart physical forces a user can feel [44]. The technology itself cannot be transferred as-is to the mobile projected user interface domain, since it is rather bulky and requires a static setup. Thus, one of the core research topics in the community should be to develop means of incorporating alternative feedback modalities such as haptic feedback into mobile projections.

Mobile projected user interface research is a vibrant field that has gained a lot of momentum since the advent of pico projectors. These small projectors expose a unique and compelling advantage over other emerging mixed reality technologies such as Google Glass: pico projections blend in well with the physical world and thus have the power to mix both the physical and the virtual in situ.

The market expectations for pico projectors seem promising. Yet, there is still a gulf between research prototypes and consumer products. This may be mainly due to current pico projectors being miniaturized versions of their desktop-scale siblings. Incorporating additional sensory intelligence that leverages the unique form factors could bridge this gulf. Providing this interactive leverage to designers, developers, researchers, and consumers alike is key to creating immersive user experiences with projected imagery.

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