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Pico Projectors—Firefly or Bright Future?

Raimund Dachselt
University of Magdeburg | dachselt@ovgu.de

Jonna Häkkilä
University of Oulu | Nokia Research Center | jonna.hakkila@nokia.com

Matt Jones
Swansea University | always@acm.org

Markus Löchtefeld
German Research Centre for Artificial Intelligence | markus.loechtefeld@dfki.de

Michael Rohs
University of Munich | michael.rohs@ifi.lmu.de

Enrico Rukzio
University of Duisburg-Essen | enrico@rukzio.de

▸ Figure 1. A pico prototype housing an iPod, a projector, and distance sensors.

There's something magical about light. Perhaps you can remember using a flashlight as a child to trace a space story on the bedroom ceiling, or, more exciting still, to enhance scary stories under the canvas of a camping holiday. Or, on a long, lazy summer afternoon, the school vacation coming soon, reflecting the sun off the glass of your watch, daringly close to the teacher's face.

Today's mobile technology landscape already has its magical devices: the alluring touchscreen phones and tablets. Perhaps, though, in these trapped-light boxes, we are missing something of the wonder of projection. Heads down, we prod the surface of these Narcissus pools, consumed mainly by our own reflections as we engage in the digital world.

There is an emerging mobile technology, however, that might save us from such introverted computing. Through the emergence of various pico-projector technologies, it is now possible to build projector phones, camcorders with built-in projectors, and small accessory projectors that can be connected to other mobile devices.

In terms of both quality and impact, these small video-output devices are near the state of the art seen in camera phones a decade ago. They are niche, geeky devices, and the marketing scenarios presented in ads are disheartening: businessmen watching catch-up TV on a hotel wall, groups of executives enjoying an ad-hoc PowerPoint presentation at the watercooler.

Camera phones, of course, were a key driver for the content sharing—locally and remotely—that became the social-networking ecosystem. For those of us involved in pico-projection research, the question is, what sort of changes might be in store 10 years from now if high-performance projectors become mainstream?

Here we take a closer look at the challenges and design questions that need addressing, touching on technical, interaction, application, and social issues. We look at the commercial state of the art and look forward to the possible future envisioned in research labs.

Technical Issues

Let's turn first to the most obvious apparent limitation: output brightness. Current personal projectors can display between 20 and 50 lumens, which might increase up to 100 lumens in the next few years. They are therefore not nearly as bright as some low-cost fixed projectors, which can have more than 2,500 lumens. This implies that personal projectors can only effectively be used indoors without direct sunlight and outdoors at night.

However, a key element is energy consumption. The brightness output of projectors seems to have been driven by the movie-watching scenarios mentioned here. The projectors must be able to provide 90 minutes to two hours of projection time on a single charge. If manufacturers allowed applications or users to trade brightness for energy consumption, then it would be quite possible to enable a brighter projection for shorter and more frequent usages of a projector phone in truly mobile settings.

The physical size of pico projectors is constrained by the projector hardware and the battery, which together is in the region of 20 cm^3. This is small enough for devices like mobile phones but too large to include them, in the medium term, in small, wearable devices like earphones, watches, or clip-on music players. So for the time being, these are going to be handheld interaction devices.

In the literature, a widely seen interaction style involves holding the projector in one hand and touching the projection with the other hand to point at and manipulate objects. For these visions to work, it is desirable to have a projector with a short throw—that is, the projector must display a large enough area without the user having to stand a long way from the surface. Otherwise the projection will be out of reach and unusable, like standing a meter from your tablet's touchscreen. Some devices already accommodate this interaction requirement, projecting a display with a diagonal size of 20 inches when held just at arm's length from the projection surface.

Whether the picture is automatically in focus or the user has to focus the image manually is a further important technical question that has a significant effect on the interaction with these devices. Pico projectors that use a laser as their light source have the advantage that the image is always in focus. When an LED is used as the light source, the user has to adjust the focus manually every time the distance to the projection surface changes.

While current pico projectors are designed for relatively simple use cases, lab prototypes are often hacked to allow experimenting with greater functionality (see Figure 1).

Novel Interactions and Applications

While the technical platform is already at a stage to afford interesting interactions and applications, the commercial reality at present is somewhat pedestrian. In fact, the level of interactivity is similar to that of a laptop being connected to an ordinary projector. The image to be projected is typically the same as what's on the mobile display, and interaction is limited to the device itself. The interaction and display space remain separate; the user does not directly interact with the projection itself. Interaction on the device (e.g., via multi-touch) or with the device (e.g., using tilt gestures) has influence on one single display. If the image is projected, the main benefit is that it can easily be shared among a small group of users. Interaction with the projection itself is limited to changing the position and scale, as the usage situation requires.

There is so much more that can be done [1]. A simple step, of course, is to decouple the device's display—the phone's or tablet's touchscreen, for instance—from the projection (see NTT DoCoMo [2]). This would allow interaction with different views of the same data at once.

However, there are more exciting ways of using mobile projections. Imagine a space in front of you right now—perhaps the wall of the cafe where you are sipping cappuccino while reading this article—as draped in an invisible canvas. While pointing on this surface with your tiny handheld projection device, you can reveal parts of the information space as if they were located under a spotlight. Tracking the device's absolute position with regard to the wall allows the appropriate parts of the overall information space to be shown at their exact position. Additional interactions on the device and with the device are possible—for instance, moving closer to the wall or performing a gesture for zooming or selecting data. (See Lisa Cowan's sidebar here for examples of how people use projectors in the wild.)

This flashlight or spotlight [3] form of projection has similarities with the well-known augmented reality (AR) applications, in which real objects are overlaid with additional information. Traditional AR always requires a head-mounted display or a handheld device serving as a "magic lens." These AR setups limit the view to a single user equipped with either of these devices. In contrast, mobile projections are visible to everybody at the same time and have the potential to truly augment objects in our environment without hampering collaboration.

We can go beyond using a wall as a backdrop for illuminating an otherwise static information space. Just imagine the content being displayed on the wall to be moving or animated. Characters of a game would, for example, try to escape your projected display frame. To follow them you would need to move your handheld projector in their direction. To tie together movement-sensor input and projector output within a single handheld device is the intriguing idea of the *motion beam* metaphor. (See Karl D.D. Willis's sidebar on collaborative interactions.)

Given the dynamic and mobile nature of projections, we can envision ways of collaborative interaction, too. The work of Cao, Forlines, and Balakrishnan [4] and follow-up research has investigated multiple users interacting with each other using "display torches." Again, tracking is required to display the appropriate parts of the information space with regard to the current position and orientation of the users' projections. Combining a rich vocabulary of on-the-device, with-the-device, and across-devices interaction, fascinating possibilities for playful user experiences emerge. Multiple game players could, for example, project dynamically changing content, such as building bricks, onto a wall. Players would need to combine their bricks by constantly moving their projector phones while adjusting the bricks' sizes to match the other bricks, using multi-touch gestures on their phones.

PRESENT AND FUTURE USES

Lisa Cowan

We have begun to document how people use projectors in the wild. Our initial observations have revealed that in addition to the expected passive uses, many active practices emerged. For example, one participant in our study projected fire onto a colleague's back at work to mischievously imply that she was burning, and "swam" with projected sharks in his bedroom to convey an impression of immersion while telling a story to a friend. Thus, even the basic projector phone platform supports novel interaction experiences.

Turning from basic platforms to future forms, we are designing new projection-specific interaction techniques to explore a broader array of possible uses. We created ShadowPuppets, a technique that allows users to cast hand shadows as input to mobile projector phones, precluding the need for visual attention to the handset and additionally supporting collocated input [1]. For example, if users are looking at photos or maps together, they can zoom in or out by casting shadows of their hands opening or closing; they can pan by moving their hand shadows in the desired direction; and they can select particular elements by pointing at them with their shadows (as shown in the photo here). The results of our user studies suggest that shadows can provide a natural, intuitive way of interacting with projected interfaces and can support collocated interaction.

▸ Casting shadows to interact with a map.

ENDNOTE:

1. Cowan, L.G. and Li, K.A. ShadowPuppets: Supporting collocated interaction with mobile projector phones using hand shadows. *Proc. of the 2011 Annual Conference on Human Factors in Computing Systems (CHI '11).* ACM, New York, 2011, 2707-2716.

Lisa Cowan recently completed her Ph.D. in computer science at the University of California, San Diego (UCSD).

COLLABORATIVE INTERACTIONS

Karl D.D. Willis

My work with Ivan Poupyrev at Disney Research explores novel ways to interact with projected content for gaming and collaborative interaction. We draw from the tradition of pre-cinema handheld "magic lanterns" that animate projected imagery using physical movement of the projection device. Rather than attempt to mitigate the effects of projector movement, we encourage it by using the projector as a gestural input device. Our latest *motion beam* prototype, SideBy-Side, for instance, supports multi-user interaction with device-mounted cameras and hybrid visible/infrared light projectors to track multiple projected images in relation to one another [1]. This is accomplished by projecting invisible fiducial markers in the near-infrared spectrum. Users interact together to share digital content, play projected games, or explore educational media. The system does not require instrumentation of the environment and allows multi-user interaction almost anywhere (as illustrated in the photo).

▸ SidebySide gaming.

ENDNOTE:

1. Willis, K.D.D., Poupyrev, I., Hudson, S.E., and Mahler, M. SideBySide: Ad-hoc multi-user interaction with handheld projectors. *Proc. UIST '11.* ACM, New York, 2011.

Karl D.D. Willis is a Ph.D. candidate in computational design at Carnegie Mellon University and a lab associate at Disney Research.

Content sharing using projectors as an *input* device has also been explored. Consider, then, the sometimes time-consuming and frustrating mobile-pairing and file-transfer procedures we have to endure. Instead, the "burn-to-share" system combines mobile projection and optical image capture to carry out these tasks [5].

Besides working from a person's hand, projectors can be attached to static places (e.g., tables or walls) or fixed onto other moving objects, such as cars or bicycles. All kinds of attachments to people fall into this second category, with projectors mounted on heads, wrists, belts, or pendants. This allows interaction with the projected content using your free hands, as has been demonstrated in the widely known Sixth-Sense project developed at the MIT Media Lab [6]. This wearable gestural interface augments the physical world around us with projected information. By means of an additional camera, hand gestures can be recognized on the augmented objects directly using computer-vision techniques.

This type of mobile, wearable projector-camera system has great potential for bringing us closer to the dream of everywhere interaction with arbitrary objects. By simply pointing onto a book or product shelf, projection can reveal additional information. This could be, for example, nutrition information for food or user ratings of an electronic gadget. On an even more sophisticated level, one could change features of real objects by directly interacting with a projected augmentation showing an apparently altered object.

Mobile projection can be brought to the urban environment, too. Researchers have already investigated pedestrian-worn navigational aids that project onto floors of shopping malls. In this sort of situation, both the movement of the projection and the projected content are highly dynamic with regard to the environmental context.

Most of the examples in the research literature imagine a future for developed countries in which pico projectors are one of the many gadgets available to affluent citizens. But mobile projectors also have a chance to become a powerful tool in developing countries, where computers and displays are scarce. One of the biggest-selling mobile phones in Africa was one with a simple built-in flashlight. The challenge is to find applications for the new projectors that will be just as attractive to the hundreds of millions of people currently underserved by computing technology as they are to those accustomed to ubiquitous personal technology.

Social Impacts

It is easy to become breathlessly excited about the possibilities that a new technology brings. Positive scripts for the dramatic worlds we envisage should always be balanced with an appreciation of the less comfortable potential negatives.

Consider, then, sharing. As noted earlier, the always-available large-scale display facilitates collaboration, but it could also be easy to accidently share private information with passers-by. Especially with projector phones, it would be easy to publicly reveal private information, such as messages or calendar entries. In currently available commercial mobile phones with pico projectors, there are no privacy mechanisms to prevent this. As today's projector phones are just projecting a mirrored image of the device's display, there is no way of hiding incoming messages or caller IDs from others when using the projection.

The ability to project from a distance also could lead to annoyance or danger for others, either accidently or intentionally. Passers-by can be temporarily blinded when the projection moves and interferes with their field of view. This would be especially dangerous for drivers, dazzled, say, by people in the street playing projector games. Furthermore, it is possible to project symbols or words onto objects and people without their knowledge or agreement. Julius von Bismarck does this with his "Image Fulgurator" as a form of art [7]; what if such practices became widespread? It is uncertain what social norms or even laws to limit public projection will develop. After the introduction of integrated speakers, many people listened publicly to loud music. However, today norms exist that constrain most people from doing so. With projectors, though, making the display private is clearly not an option. There could then be a risk that future mobile devices would be capable of not only spamming our auditory sense but also visually polluting the environment.

Road Map

It is, of course, always dangerous to make predictions about technology. Even so, let's end this article by plotting the trajectory for picos. Within the next five years, we might expect a large proportion of smartphones to have a built-in projector. Initially, these will be used for the sorts of work and play we already see on touch devices: showing and chatting about pictures, laughing at funny videos, plotting a route on a map, and gaming. It's likely that by then the devices' sensors—cameras and motion sensors—will enhance the interaction richness. They will then provide portable surface computing.

The second wave—within 10 years—will see them become an important platform for a range of digital-physical augmentations. By then, projectors will not be simply handheld but attachable, wearable, and embedded. And perhaps by then we will be able to lift our eyes from our handheld mobiles and enjoy a fused physical-digital experience. Now, *that* would be magical.

ENDNOTES:

1. Rukzio, E., Holleis, P., and Gellersen, H. Personal projectors for pervasive computing. *IEEE Pervasive Computing.* Feb. 2011.

2. See http://www.nttdocomo.com/features/mobility27/feature.html

3. Rapp, S., Michelitsch, G., Osen, M., Williams, J., Barbish, M., Bohan, R., Valsan, Z., and Emel, M. Spotlight navigation: Interaction with a handheld projection device. *Advances in Pervasive Computing: A Collection of Contributions Presented at PERVASIVE 2004.* Oesterreichische Computer Gesellschaft, 2004, 397-400.

4. Cao, X., Forlines, C., and Balakrishnan, R. Multiuser interaction using handheld projectors. *Proc. UIST'07.* ACM Press, 2007, 43-52.

5. Virolainen, A., Åkerman, P., and Häkkilä, J. Burn-to-share—Content sharing with mobile projectors. *Proc. Mobile and Ubiquitous Multimedia (MUM).* 2010.

6. Mistry, P. and Maes, P. SixthSense—A wearable gestural interface. In *Proc. of SIGGRAPH Asia 2009, Emerging Technologies* (Yokohama, Japan). 2009.

7. See http://www.juliusvonbismarck.com/fulgurator/

ABOUT THE AUTHORS

Raimund Dachselt is a professor for user interface and software engineering at the University of Magdeburg, Germany.

Jonna Häkkilä is a docent at the University of Oulu, Finland, and works as a research leader at Nokia Research Center, Finland, where she led user-experience and concepting teams from 2007 to 2011.

Matt Jones is a professor of computer science at Swansea University, U.K.

Markus Löchtefeld is a researcher at the German Research Centre for Artificial Intelligence (DFKI) in Saarbrücken, where he is working in the Innovative Retail Laboratory.

Michael Rohs is an assistant professor at the Institute for Media Informatics of the University of Munich (Ludwig-Maximilians-Universität München), heading the Mobile and Physical Human-Computer Interaction group.

Enrico Rukzio is an assistant professor at the University of Duisburg-Essen and a lecturer at Lancaster University.

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