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ORIGINAL ARTICLE

Projector phone use: practices and social implications

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Abstract Phones with integrated pico projectors are starting to be marketed as devices for business presentations and media viewing, and researchers are beginning to design projection-specific applications and interaction techniques to explore a broader array of possible uses. To begin to document how people use projector phones outside the laboratory, we present the results of a 4-week exploratory field study of naturalistic use of commodity projector phones. In our analysis, we consider how context, such as group size, relationships, and locale, influences projector phone use. A key observation is that users can readily exploit the new facilities of these devices to author interesting effects by employing representational techniques such as superimposition, scaling, translation, and motion. Thus, even the "basic" projector phone platform affords novel interaction modalities. Finally, we discuss the social implications of projector phone use for privacy and control, extrapolating from our observations to envision a future in which these devices are ubiquitous. With ubiquity, projector phone use may become problematic in public settings, motivating new rules of etiquette and perhaps laws, yet it may also engender new forms of creative expression.

Keywords Projector phones · Field study · Social practices

1 Introduction

Pico projectors are increasingly being embedded in consumer electronic devices, such as mobile phones (e.g., LG Expo and Samsung Galaxy Beam) and digital cameras (e.g., Nikon Coolpix s1000pj). Pico projector sales are predicted to increase from half a million units (worth $117 million) in 2009 to 142 million units (worth $13.9 billion) in 2018, with sales of embedded units expected to be double that of stand-alone units [38]. As sales increase, the prices are expected to drop to as low as $20 by 2011, and projectors are likely to become standard cell phone components [21]. Projector phones may become as common as camera phones.

Commodity projector phones are being marketed primarily to business consumers, for presentations and ad hoc meetings. Although proposed consumer applications are limited to media viewing, researchers are beginning to design new applications and projection-specific interaction techniques to explore a broader array of possible uses. Observations of how people use projector phones outside the laboratory are crucial to informing the design of future devices, interfaces, and applications.

In this paper, we present the results of a 4-week, 10-participant study of how people use commodity

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projector phones ÔÔin the wildÕÕ. To the best of our knowledge, this work is the Þrst long-term, unconstrained, exploratory Þeld study of projector phone use. We present observations from our study, describing usersÕ experiences and highlighting emergent practices. In our analysis, we consider how context, such as group size, relationships, and locale, inßuences projector phone use. A key observation is that users can readily exploit the new facilities of projector phones to author interesting effects by employing representational techniques such as superimposition, scaling, translation, and motion. Thus, even the ÔÔbasicÕÕ projector phone platform affords novel interaction modalities. We discuss the implications of projector phone use for etiquette, privacy, and control, highlighting potential beneÞts, risks, and failure modes. We further extrapolate from our observations, to envision a future in which projector phones are ubiquitous. The results of our exploratory study are intended to document naturalistic practices, inform design, and expose areas for further research.

2 Related work

Camera projector systems have been extensively studied. Seminal work in this area, including WellnerÕs DigitalDesk [35] and UnderkoffÕer et al.Õs Luminous Room [33], used Þxed, overhead cameras and projectors to digitally augment usersÕ interaction with the physical environment. The Everywhere Displays system [23] explored the concept of ubiquitous graphical interfaces, using steerable projectors to create multiple interactive surfaces within an environment.

Researchers later investigated techniques for interacting with handheld projected displays. Raskar et al. [26, 27] studied geometry and location-aware projection. Other researchers have proposed moving cursors and activating selections via the handheld device [3], touching the projection surface with Þngers or overlapping multiple projections [32], or moving the projector to direct the beam of a ÔÔspotlightÕÕ within a virtual information space [25]. Cao et al. [6, 7] expanded on this spotlight metaphor, employing handheld projectors and pens to deÞne and interact with virtual information spaces embedded in the physical environment in single and multi-user scenarios.

Recent work has explored applications and interaction techniques for small, mobile, portable, or wearable projectors. Blasko et al. explored interaction with a simulated wrist-worn projector via forearm movement and a touch-sensitive wrist-worn device [5]. Also, in Willis and PoupyrevÕs MotionBeam metaphor, the motion of the projector expresses the motion of the projected object [36]. Mistry, et al., studied tangible and gestural interaction with WUW, also known as SixthSense, a wearable camera projector system [22]. Harrison et al. [15] analyzed vibrations to detect taps on the skin and demonstrated using their Skinput technique to interact with an interface projected on the body. Researchers have also explored projector-device ensembles to increase interactive space. BonfirePt [17] integrates projectors with a laptop to extend interaction to the table. Similarly, PenLight [30] and MouseLight [31] use projection to increase the interactive space for digital pens, providing visual feedback for interaction with paper.

Recent advances in hardware have enabled researchers to study mobile phones with attached pico projectors. The Map Marauders Light system projects buddiesÕ locations onto paper maps, leveraging the phonesÕ location-sensing capabilities and large projected displays [19]. Greaves and Rukzio comparatively evaluated mobile phone screens and projected displays for photograph browsing tasks [13] and found that users preferred projector-based over phone-based interaction. They also developed a framework for collaborative media viewing and sharing with projector phones [14]. Cowan and LiÕs [9] ShadowPuppets system explored using shadow gestures for collocated collaborative interaction with projected displays of mobile devices.

Numerous short-term Þeld studies have focused on mobile phone use and related social practices [16, 18, 24]. In the personal-projection space, Greaves et al. [12] conducted a 3-day Þeld study in which the researchers projected maps and media in public places, and Wilson et al. [37] conducted a study in which they periodically prompted users over a 1- or 2-day period to project supplied media content. We previously considered social applications of projector phones through a scenario-based design exploration [8]. To the best of our knowledge, extended Þeld studies have not yet been conducted to document naturalistic use of projector phones.

3 User study: how do people use projector phones in the wild?

In our study, we were seeking to discover what people could and would do in the course of their daily activities. In particular, would people use projector phones for business presentations and media viewing or would they go beyond that? If so, how and what are the possible implications for future use and design? To provide evidence that a particular use is possible and actually happens, observation of real-world use is required. Consequently, we chose to conduct a small-scale 4-week exploratory study in the wild. While such a study design is appropriate for our research questions, in order to draw additional conclusions about typical or average behaviors and unusual phenomena, a more extended study would be required.

Participants: We recruited 10 participants, 4 female and 6 male, ages 22Ð46 (average 31.9). We assigned

each participant a pseudonym, starting with letters A through J. Anna is a computer science graduate studer Ben is an artist/teacher, Charles is a salesperson/holist health instructor, Darryl is a chef/photographer, Faye is a seminary graduate student, Emily is a stay-at-home mom jewelry artisan, Gabriel and Helen are undergraduate stu dents, Irving is an artist/teacher, and James is a comput programmer.

Methods: This study was exploratory in nature, inten- ded to discover uses and sample phenomena. In order ensure that the observed projector phone uses arose na rally, the study imposed minimal constraints on the users The participants received no guidance on how they shoul use the projector. We simply provided a projector phone with unlimited data service, showed the participants how to activate the projector function, and asked them to carry it with them as much as possible for the duration of the study We gave participants the choice of carrying the provided phone instead of or in addition to their own mobile phone, and all opted to carry both.

We ran this study in parallel with a study of UbiSketch, an application that enables the sharing of paper-based sketches on social networks, via mobile phones [10, 34]. With UbiSketch, a user draws or writes with an Anoto [1] digital pen on paper, the pen digitizes the sketch—streaming information by Bluetooth to a mobile phone—and the mobile phone forwards it to services on the Internet, such as Facebook, Twitter, or email.

We conducted pre-study training sessions and intera views to assess participantsÕ previous experience using mobile projectors. We then conducted weekly follow-up interviews regarding their experiences. At the end of the study, we had a Þnal interview with each participant. We analyzed this qualitative data using elements of grounded theory, grouping participantsÕ responses by afÞnity, and we present results that emerged from the data.

Apparatus: The LG Expo (Fig. 1a) is a Windows Mobile smart phone with a touch screen, stylus, and QWERTY keyboard. The phone weighs 147 grams, and its dimensions are 114 × 56 × 15 mm. It has an inte- grated, removable projector, which weighs 50 g and atta ches onto the back of the phone, approximately doubling the phoneÕs depth. The HVGA resolution (480 × 320) DLP pico projectorÕs brightness is rated at 5 lumens, and it is focused manually by manipulating a physical slider. The projector is activated by sliding open a physical panel above the projector and then sliding a GUI widget on the touch screen to conÞrm. Closing the physical panel deac- tivates the display. Projected content is identical to that of the LCD display (Fig. 1b).

The ExpoÕs projection is not visible in bright light. In moderate lighting conditions, an approximately 6 ft pro- jected image is easily visible from a 10 ft throw, and in

(a) (b)

Fig. 1 a LG Expo projector phone, b Projected display mirrors LCD screen

darker conditions, the size and throw distance can be more than doubled. Our tests indicate that the phoneÕs battery power (1,500 mAh) lasts around 2 h when the projector is on, and the phone can be plugged in for sustained projec- tion. The ExpoÕs camera and projector cannot be operated simultaneously and are oriented orthogonally.

Pre-study data: Eight of the participants had never used a pico projector or projector phone before. Two of the participants had used a projector phone previously: Anna had experimented with a friendÕs once, and Ben had more extensive experience, having used one for several months. Of the 8 participants who had not used pico projectors, 3 had used large portable projectors: Darryl and Faye owned one that they used to watch movies and play video games at their home or at friendsÕ homes, to make presentations at school or work, and to create backdrops for artistic pho- tography, and Irving had used one to present slideshows to his students. 6 of the 8 without projector phone experience had seen one in person or in an advertisement or video demonstration, and 2 had never seen one at all. All 8 expressed interest in using a projector phone, citing the following reasons: ÔÔitÕs new and sounds cool,ÕÕ it could project a display much larger than that of a typical mobile phone screen, and it would enable them to use their phones more sociallyÑwith friends, children, or students.

4 Observations

Of the ten participants, Þve used the LG ExpoÕs integrated projector throughout the study for a variety of reasons. Anna explained that she used it ÔÔbecause it was attached to

my phone and it was cool.ÕÕ Charles concurred, using the projector ÔÔbecause it was there,ÕÕ and adding: ÔÔIf I had one on my standard phone, I would use it all the time.ÕÕ Ben enjoyed showing off the novelty of the device, explaining, ÔÔthe wow factor is high.ÕÕ Several participants cited the large size of the display: ÔÔthe freedom to make that image biggerÕÕ (Ben), ÔÔit gets bigger than my laptop screenÕÕ (Charles), and ÔÔthe screen on the phone is so littleÕÕ (Darryl). Four of the Þve participants who used the projector carried it with them at all times and kept it attached to the phone. Anna explained why she carried the projector: ÔÔYou never know when you might need a projector, and I didnÕt want to be caught without one.ÕÕ

The remaining Þve participants did not use the projector beyond some initial experimentation, despite expressing interest in using it. Some participants explained that they did not use the projector because they forgot about it or did not have a reason to use it, suggesting the lack of an enticing application. Others explained that they did not have the projector with them at the time they wanted to use it. We believe that more participants might have used the projector if it was integrated into their primary mobile phone, since availability of the device is key to supporting spontaneous interaction. Four of the Þve participants who did not use the projector did not always carry it with them, and none of them kept the projector attached to the phone. These participants explained that they did not keep the projector attached because it was too bulky to Þt in a purse or pocket, it was too heavy, they were concerned about breaking it, or they thought leaving it attached would drain the phoneÕs battery faster.

Projector usage varied in duration and frequency Table 1 illustrates this usage by the Þve participants that used the projectors throughout the study. Ben and Charles who used the projectors regularly, grew quite partial to them. Ben expressed: ÔÔI love the projector phone. I don't even want a phone that doesnÕt have a projector in it now.ÕÕ Charles concurred, saying, ÔÔIÕm in love with that projector. I think itÕs the coolest thing since sliced bread.ÕÕ

Participants projected the display onto a variety of surfaces, including people, peopleÕs clothing, and architectural elements (e.g., walls, ßoors, ceilings, windows, and building facades), and generally whatever was at hand in the environment (e.g., dishes and tablecloths in a restaurant). They also projected while on the go, from within moving cars and while walking. As Ben explained, ÔÔItÕs so natural to project on any surface Õcause [the projector] is right in your hand and wherever you move it, youÕre projecting.ÕÕ

Participants had differing opinions about the types of projection surfaces they preferred. Ben preferred ÔÔa lighter, smoother surfaceÕÕ because the projection was easier to see, and Anna concurred. In contrast, Darryl preferred a surface with more texture. He explained that when he projected while using UbiSketch, the projected sketch acted as a conceptual bridge between the physical and digital worlds: ÔÔpaper has texture, the Internet has no texture, so to have a digital projection on a wall that inevitably does have some kind of feel to it… it was kind of a nice segue for me to go from perceiving it on paper to perceiving it digital, having it projected digitally in the tangible planeÕÕ (Darryl).

The projected content primarily consisted of photographs and videos, including self-authored media. Four of the participants projected UbiSketch sketches, during or after sketching (Fig 2). Darryl explained that the projector did not affect the way he interacted with applications because the phone did not support projection-speciÞc interaction: ÔÔIt didnÕt do a lot for the actual function of the phone because itÕs all touch screen [interaction], so you

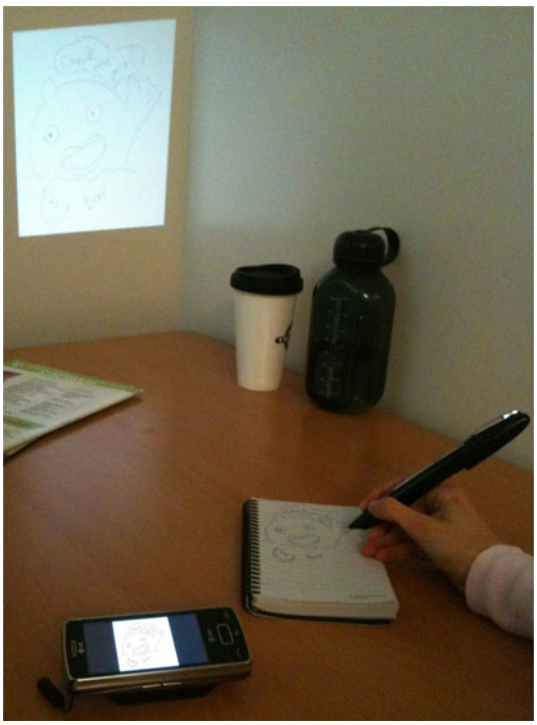

Fig. 2 Projecting while using UbiSketch. Phone screen and projected display show digitized version of paper sketch

Table 1 Projector usage: frequency and duration

Participant	Frequency of use per week (times)	Duration of use per instance (min)
Anna	3Ð4	1Ð5
Ben	5Ð6	5Ð10
Charles	9Ð13	10Ð30
Darryl	1Ð2	10Ð30
Emily	3Ð4	5Ð10

need to be looking at the screen anyway to be able to play with a lot of things.ÕÕ

Participants expressed some dissatisfaction with the device. For example, Darryl complained that the limited brightness of the projector precluded daytime, outdoor use, saying, ÔÔon anything but a really dingy day, itÕs a little bit under power to compete with the sun.ÕÕ Ben concurred, adding, ÔÔIn the daytime, you just canÕt show it to anybody. ItÕs like, ÔWell, if you turn all the lights off.ÕÕÕ Many participants also complained about the projectorÕs power consumption, which rapidly drained the phoneÕs battery, and how hot the projector became during prolonged use.

Participants did not commonly interact via the phoneÕs touch screen, e.g., to browse for content, while projecting. A typical scenario would involve searching for content via the touch screen, then activating the projector to display the content, and temporarily suspending projection during any further touch screen interactions. Users often did not turn the projector off and on during these transient interactions, since this would require too much effort. Instead, they would tangibly and directly occlude or avert the projectorÕs beam, e.g., by covering it with a hand, or re-orienting it to reduce its visibility.

4.1 Usage scenarios

We now describe private, semi-private, and public scenarios of use, drawn from our Þeld study. Analysis and discussion follow in the next section.

4.1.1 Private

As one might expect, all the participants reported using the projector simply because it afforded a large display, relative to the size of their mobile phone, laptop, or television screens, and because it was portable. For example, when BenÕs girlfriend watched television in the living room, he would sometimes watch projected videos in the bedroom to avoid conßict. He used the phone rather than his laptop, since the projected display was larger and the laptop was comparatively cumbersome to move around the house. He explained that he would typically take his phone into the bedroom for transient viewing, to watch ÔÔthings that are under ten minutes mostly, like quick, little things.ÕÕ Charles also watched videos, enjoying the ability to project a display anywhere. For example, he liked to lie in bed and watch videos on the ceiling. He would typically plug the phone into a charger for sustained, non-mobile use.

Darryl sometimes projected in conjunction with UbiSketch; while sketching on paper, he would project the digital version of his sketch onto a nearby wall. He explained that he did this to enlarge the sketch to ÔÔsee a bigger representation than what was on paper of what I was drawing.ÕÕ He also found it easier to refer to the large projected sketch to conÞrm that the digitized version matched the original to ÔÔmake sure things showed up where they shouldÕÕ rather than ÔÔtrying to pick out details on the phone.ÕÕ

Charles used UbiSketch to create and digitize paper-based sketches and then used the projector to scale them up and transfer them onto canvas. He explained, ÔÔYou do a sketch. You project it onto a canvas and draw the sketch onto a big, real canvas.ÕÕ He preferred to sketch on a small scale because it felt natural and comfortable, and the projector made it easy to scale sketches up. He remarked, ÔÔI may as well just project what I want to do and do the drawings small, because my hand works really well on a small scale.ÕÕ He suggested that grafÞti artists could use a similar approach to project artwork onto public surfaces.

Anna used the projector to show her husband something sheÕd drawn for him with UbiSketch. She sketched a cartoon Þsh that was in a commercial that they enjoyed and later projected it onto the ceiling over their bed. She animated the projected Þsh while she and her husband sang the song from the commercial, explaining, ÔÔI made the Þsh dance on the ceiling.ÕÕ By reenacting the commercial, they shared an inside joke.

Charles showed his friend a video of sharks a local surfer had Þlmed. He rested the projector on a piece of furniture on one side of his bedroom and pointed it toward the opposite wall behind the bed, where he was sitting. He explained that the experience felt immersive: ÔÔWhen itÕs projected on a screen right by my bed, it has that whole sense of lÕm really in… it it was like swimming in the water… Swimming with sharks. I donÕt want to do it in real life, but that was fun.ÕÕ Because the video was projected onto himself and the wall behind him, Charles felt that he was virtually swimming with the sharks in the video.

4.1.2 Semi-private

In one of AnnaÕs initial experiments with personal projection, she had a friend project a self-portrait onto her face. They played with aligning the projected photograph with her face, adjusting distances, angles, and lighting, and then another friend took a photograph, which they posted on Facebook (Fig. 3). Anna and her friends found the image of her actual face merged with her projected face to be quite creepy, looking in some ways real yet in other ways unnatural; it was hard to distinguish between the real and virtual elements of the scene. They laughed a lot during the playful process of creating the photograph.

Emily and her family sometimes projected while sketching with UbiSketch at family gatherings. She described one scenario: ÔÔMy sister-in-law was drawing, and so she put [the projection] up so we could all look at

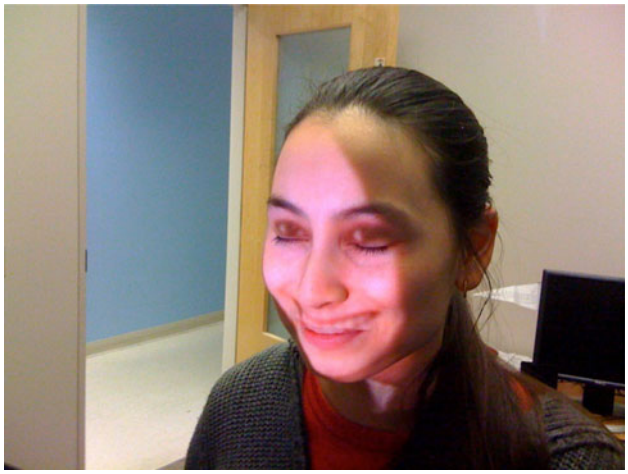

Fig. 3 Projected face (eyes open, smiling) on real face (eyes and mouth closed)

what she was drawing.ÕÕ The large display enabled everyone in the room to watch, discuss, and share in the experience. Emily explained, ÔÔIt was really neat to do it while she was drawing, because then everyone could see it people were commenting on what was being drawn.ÕÕ Without projection, only a few nearby people would have been able to see what her sister was drawing on a small piece of paper.

Charles used the projector in a mischievous way at work, explaining that he did so to be funny and to show off. He related, ÔÔIÕll be sitting at my desk and IÕll shine something on someone, like on their back and stuff do that kind of stuff to make other people laugh and make them really, really jealous that I have [a projector].ÕÕ He described one incident in which he projected a video of Pre- onto his managerÕs back: ÔÔEverybody was laughing. And then I hid [the projection] and said, ÔSo were your ears burning?Õ. everybody was snickering in the background. It was quite comical.ÕÕ

4.1.3 Public

Some of the participants in the study enjoyed using their projector phones to playfully interact with strangers in public settings. Ben used the projector to pass time when he was waiting in line for rides at Disneyland. For example, he projected a picture of Yoda, the Star Wars character, onto the walls of the enclosed waiting area of Space Mountain, a space-themed roller coaster. He explained, ÔÔitÕs all dark, so you can project really readily in there.ÕÕ He described the reactions of the other people in line, saying, ÔÔOh, they freak out. They absolutely freak out. They just want to know what you have and where to get one. And they want to play with it.ÕÕ He enjoyed attracting the attention of people around the room and started conversations with those waiting nearby.

Ben also used the projector while walking around outside at Disneyland in the evening (Fig. 4a), or while riding dark indoor rides, such as Peter PanÕs Flight (Fig. 4b). He enjoyed playfully adding his own content to the carefully controlled environment of the theme park, yet he was aware of how it could affect other visitors: ÔÔThat changes everyone on that rideÕs experience of that ride. What if we all had those phones? WeÕd all be inßuencing [each otherÕs experiences.] I guess it makes for an interesting, always changing outcome. But, also, itÕs kind of intrusive.ÕÕ One of his friends felt uncomfortable when Ben projected on rides, because she was concerned about the effect on other visitors, yet his brother Charles enjoyed it, relating how he felt

(a) (b)

Fig. 4 Projecting at Disneyland while a walking on Main Street USA, and b riding on Peter PanÕs Flight

during one experience: ÔÔI was laughing so hard, because that was so cool.ÕÕ

Once, while Ben was showing something to a friend by projecting it onto their table at a restaurant, he accidentally shined the projector all over the room, explaining, ÔÔyou move the camera this much, and this much movement here relates to, like, half the room.ÕÕ He noted the projectorÕs potential for intrusiveness, calling it ÔÔa nuisanceÕÕ and ÔÔdisruptive.ÕÕ He added, ÔÔThat phone can take over the room. You can have everyoneÕs attention in, like, 5 seconds. Other people were completely distracted from their dinner due to me playing with my little phone.ÕÕ While relating this experience, Ben expressed concern about the future ubiquity of personal projection, saying, ÔÔI was just thinking how itÕs gonna be in the future when everyone has one of those.. ThereÕs gonna be no Þlter on what images people are seeing all around them. laws are gonna have to be made.ÕÕ Although he enjoyed wreaking a bit of havoc, he saw the potentially serious impact of personal projection, noting, ÔÔItÕs really fun, but it seems to have the levity for something very serious and almost a weapon.ÕÕ

On occasion, Ben also mischievously projected content onto the sides of neighborsÕ houses at night, when the phoneÕs beam was visible at large size. Charles expressed a similar desire to project from the window of his apartment onto a nearby buildingÕs facade, which he was unable to do because the area was well lit. He explained why he would enjoy interacting with strangersÕ in this way, saying, ÔÔIt's because itÕs just so fun to make a big thing that people would drive by and go, ÔWhat the?ÕÕ Why is there a big thing projecting out the window? Why is this happening?ÕÕ A similar motivation to playfully interact with strangers led Ben to project out the windows of moving cars, onto the road and onto the sides of nearby trucks.

Ben also enjoyed playfully projecting at an outdoor, evening concert, sometimes onto the backs of strangersÕ shirts. His girlfriend felt uncomfortable when he did that and was concerned about how people would react. At the same event, Ben also considered projecting a picture of a donut onto or near a group of policemen, but decided against it after discussing it with his girlfriend, for fear of repercussions.

5 Analysis

From the above observations, we can immediately see that the participants went far beyond the anticipated passive uses of projector phones, employing an array of display techniques for a range of applications. AfÞnity analysis revealed several categories of projector phone usage. We Þrst analyze how context inßuenced projector phone interaction. Then, we analyze how users authored interactions, describing novel dimensions of projector phone authorship and the representational techniques employed.

5.1 Context

As one might expect, contextual factorsÐincluding the privacy of the setting, the group size, and participantsÕ relationshipsÐinßuenced projector phone interaction. In our study, we observed individual and pair interactions in private settings, pair and small-group interactions in semi-private settings, and pair and small-group interactions in public settings.

Projection in private settings, such as bedrooms, involved individuals or pairs. Individual uses were instrumental, for control, or for convenience. For example, Darryl and Charles used the projector as an instrument for enlarging digitized sketches. Ben took the projector into the bedroom for control and convenience while his girlfriend watched television in the living room. In the absence of an audience, individuals did not need to be concerned about projecting appropriate content, conveying a speciÞc message, or presenting themselves to an audience.

Pair interaction in private settings involved sharing content of mutual interest or related to the pairÕs relationship. For example, Charles showed his friend a video about sharks since both were interested in surÞng. Anna and her husband playfully shared an inside joke, reenacting a commercial they both enjoyed. In dyadic use, the presence of a companion inßuenced usersÕ choice and delivery of content, and users could leverage the pairÕs shared interests, knowledge, and experiences in the interaction.

Projector phone interaction in semi-private settings, such as workplace ofÞces or home living rooms, involved small groups of people ranging in familiarity. Use included sharing experiences, play, and exploration. For example, Emily projected to enable a group of her family members to share in the creation of a sketch. Anna and a small group of friends and colleagues playfully projected a self-portrait onto her face to explore blending physical and digital information, while Charles projected content onto his colleaguesÕ backs to tease them. In semi-private use in the presence of participants of varying intimacy levels and possibly incidental viewers, the interaction became a more public performance and the content was less personal.

Projection in public settings involved both pairs and small groups, along with bystanders included in the interaction. Public uses were expressive, entertaining, intended to spark conversation, or mischievous. For example, Ben projected onto the sidewalk while waiting at Disneyland to entertain himself and his friends and attract othersÕ attention. He also projected onto strangers at a concert as a provocative form of joking. In public settings, in the

presence of friends and strangersÞwilling and unwilling participantsÞusers oriented interactions toward both audiences.

5.2 Authorship and representation

The participants of our study went beyond simply choosing what digital media content to project and then passively presenting and/or viewing it. These participants actively and dynamically authored how to project content, in order to convey particular meanings or shape social interactions. A projector phoneÕs mobility and its ability to throw an image over a distance enable novel dimensions of authorship, supporting a unique concentration of representational facilities in a single artifact. We highlight some of these dimensions, the representational techniques they afford, and how these techniques are used in combination.

In particular, we describe how a projector phoneÕs small size and the ease of orienting its projected display support what Luff and Heath term ÔÔmicro-mobilityÕÕ [20]. Users cannot only carry projector phones from place to place, they can readily position and orient projected information during interactions. With a handheld projector, users can adjust the orientation of the display by simply moving their hand. In contrast, a larger projector typically remains in a Þxed position while in use.

5.2.1 Surface

The projection surface(s), including all elements within the projectorÕs beam, adds a physical dimension to the projected content. The surface has material properties, such as texture, color, and geometry, which determine how it reßects light and add tangibility to digital content. For example, Darryl projected sketches onto a wall that had ÔÔsome kind of feel to itÕÕ to add texture to the digitized sketches and perceptually bridge the physical and digital worlds. The surface may also have other affordances or provide metaphorical signiÞcance. A user can quickly and easily re-orient the projector toward a different surface to adjust this dimension, whereas with a static projector the surface (typically a screen) does not change during use.

Because a projector throws an image over a distance, decoupling the device from the display, projected information can be superimposed onto (Fig. 5a), or juxtaposed next to (Fig. 5b), things in the physical environment. For example, when Charles superimposed an underwater scene onto himself, the effect was immersive. The surface and the content can contribute to a blended meaning, as when Charles projected Þre onto a colleagueÕs back to imply that she was burning. In addition, superimposition and juxtaposition can support comparison, making it easier to identify similarities and differences. Darryl used this strategy to identify errors in digitized sketches.

5.2.2 Throw distance and display size

The distance from the projector to the surface determines the size of the projected display, which can scale far beyond the size of the phoneÕs LCD screen. With increasing throw distance, the size of the projection increases and the brightness decreases. The size of a projected image can represent its actual or metaphorical importance, quantity, or size.

The display size can be adjusted directly and tangibly by moving the projector toward or away from the surface, e.g., by moving oneÕs hand, walking, or pointing the projector toward a nearer or farther surface. On an ordinary display,

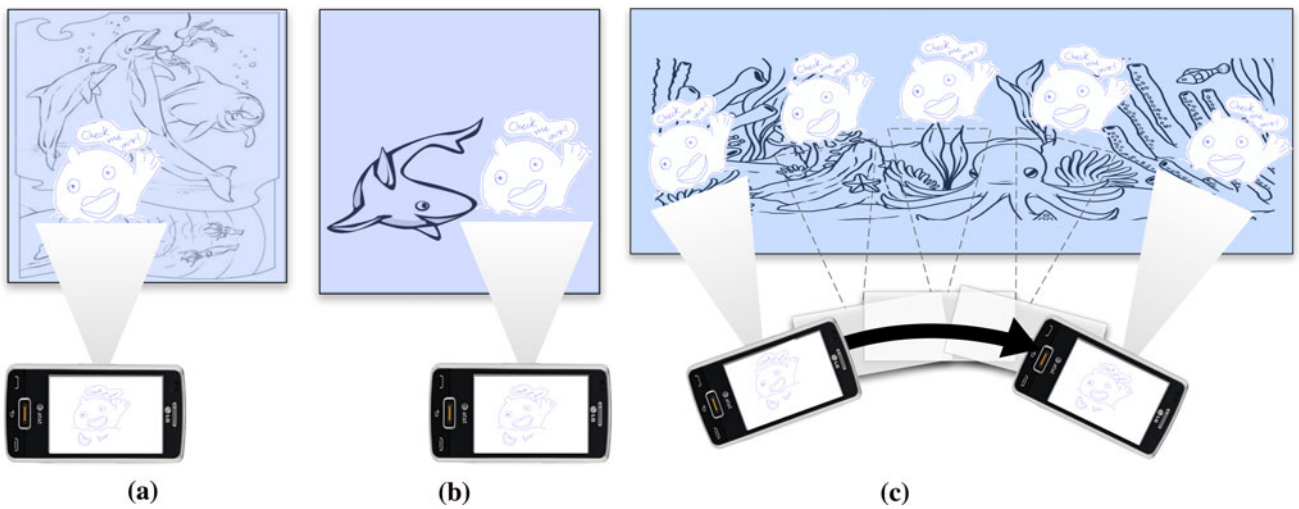

Fig. 5 Representational techniques: a superimposition, b juxtaposition, c animation

such as a phoneÕs screen, as you enlarge an image beyond the size of the display it is clipped. In contrast, when you enlarge a projected image by increasing the throw distance, the entire image gets bigger. A change in size can represent literal or Þgurative growth or reduction or indicate a change in emphasis.

Scaling can enable visualization at human scale, supporting comprehension and interaction. For example, DarrylÕs projected sketches were larger and easier to see at a glance than those on the phoneÕs screen. Here, Darryl combined representational techniques, juxtaposing an original analog image and a magniÞed digital image. In addition, Charles used UbiSketch and the projector phone to digitally mediate the physical enlargement of a sketch, transferring it from paper, to phone, to canvas.

5.2.3 Lateral motion

A user can position projected content by moving and orienting the projector in three-dimensional space to translate, scale, rotate, and/or warp the projected image. The throw distance can amplify the effects of these actions, enabling a small change in the projectorÕs orientation to cause a large change in the appearance of the projected display. In contrast, in a traditional setup, the projector remains Þxed during use, and with an ordinary display, the motion is not ampliÞed.

These novel affordances of projector phones can support animation. For example, Ben projected a Snoopy cartoon around the walls inside his home to make the character ßy, simply rotating the projector in his hand to make the projected display move quickly around the room. Here, as well as when Anna made a projected cartoon Þsh ÔÔdance on the ceilingÕÕ, we see how the relative motion of the projector can represent animation of the projected information (Fig. 5). When Ben projected from a moving car onto the side of a moving truck, tracking its position with the projected beam, the projected information did not appear to be moving because its position relative to the truck did not change.

5.2.4 Visibility

Users can dynamically adjust the visibility of the projected display and its source. While projecting, users can hide speciÞc information or interactions, such as browsing for content, by occluding the projectorÞturning it off, covering it with a hand, or averting it with a simple hand motion. The ease and directness of showing or hiding the projected display is a novel feature of personal projection.

Projected information may also be oriented such that it is visible to, or occluded from, particular viewers. For example, Emily projected while sketching so that her family could share in the activity. In contrast, Charles projected onto peopleÕs backs to tease them; those who were in on the joke could see what he projected, while those on whom the joke was being played could not. CharlesÕ example highlights how users exploit micro-mobility in projector phone interactions to share, hide, and orient information. Users can also adjust the projected displayÕs size to control its visibility.

A user can choose whether or not to reveal his or her identity. Anonymity may sometimes be desirable, for example, to reduce oneÕs accountability in political, artistic, or playful interactions. In this vein, Charles suggested projecting out a window from inside his apartment, and Ben projected onto distant surfaces and from within crowds of people at Disneyland.

6 The future

Analysts predict that projectors will soon be standard features embedded in mobile phones, much like cameras today. Further, we expect that specialized interaction techniques, in which the projected display is a space for input and output, will be widely adopted. We envision a future in which projector phones are ubiquitous and projected displays support interaction, rather than just passive viewing.

Participants in our study enjoyed showing off their projector phones and using them to attract attention from friends as well as strangers. However, as these devices become ubiquitous, their novelty will fade, as will the division between those who have projector phones and those who do not. Further, when personal projection becomes commonplace, the act of projecting will no longer attract attention from people who are simply curious about a technology they have never seen before.

Even as novelty fades, the increased density of projector phone use could result in greater intrusiveness [23]. Projection can be disruptive to incidental viewers, potentially cluttering the visual space or even offending. People may see oneÕs projected display without wanting to, which is analogous to forced eavesdropping on mobile phone conversations today. The projected information could be inappropriate, or people might simply not wish to see it. Crowding could lead to contention over shared space. Also, multi-user and/or multi-projector usage scenarios will likely become more common, potentially increasing the risk of intrusiveness.

As projector phones become ubiquitous, etiquette will necessarily develop to socially manage when, where, and how it is appropriate to use them. Different notions of acceptable behavior will be deÞned by the context. For example, shining a projected display onto someoneÕs body might require a sufÞcient level of intimacy, or at least that

personÕs consent, or it could be considered impolite. Also, it might be appropriate to project content around the room at a party or onto oneÕs table at a restaurant, but not around the room at a restaurant. Yet as Ben remarked about his restaurant experience, it can be hard to manage disruption of incidental viewers. Due to the broadcast nature of projection, those doing the broadcasting are accountable for what and how they choose to project and the possible effects on viewers. Additional social controls, such as private or governmental regulations, may also be enacted where etiquette is not sufÞcient.

Projector phones also have privacy implications. A standard phoneÕs display can only be seen at close range due to the small screen size and narrow viewing angle, which imparts a degree of privacy. In contrast, a projected display can be larger and visible from a greater distance, potentially risking the privacy of projected content. In our study, participants seemed to understand what they should or should not project in a given context, and they did not express any privacy concerns. Yet their experiences highlight potential failure modes.

A projector phone user can quickly and easily orient and scale the projected display, which can be beneÞcial but can also risk unintended disclosure. For example, when Ben unwittingly shined the projector around the restaurant rather than toward the table he shared with his friend, the interaction changed from semi-private to public, and the projected information was revealed to unintended viewers. Unless a user is in a private setting in which only intended viewers are present, this sort of privacy breach is a possible concern.

Further, as technology matures, projection space will become interactive. Techniques for interacting with projector phones at a distance could increase the risk of unauthorized access and require additional security measures. An unauthorized user could potentially gain control of the device by interacting with the projected display, and active control presents a greater threat to security than passive viewing.

Researchers have already been exploring techniques that enable users to interact with projected displays by moving the projection device, touching the projection surface, or gesturing in the air between the device and the surface [5, 7, 9]. Multi-user and multi-projector interaction techniques, which leverage the projectorsÕ beams for shared input and output, have also been studied. Many of these techniques support collaborative interaction, and we anticipate that mobile phones will increasingly become tools for collocated collaboration. Social protocols will likely develop for managing shared control.

As specialized interactive techniques become more widely adopted, the nature of usersÕ interactions while projecting will change. Consider how participants in our study avoided interacting with the phoneÕs touch screen or buttons while projecting, averting, or occluding the projector during those interactions. It can be difÞcult to hold the projectorÕs beam steady while performing GUI interactions, and the user might need to re-orient the device to comfortably see the screen and manipulate the controls. We expect that specialized interaction techniques will support more sustained, complex usage scenarios. These interaction techniques can further enable users to create, and not merely consume, content via projected displays.

Projection can be a powerful medium for creative expression, and in recent years, artists and political activists have been employing portable projectors. For example, GrafÞti Research LabÕs Laser Tag system [11] enables artists to project grafÞti onto large, distant buildings with powerful projectors, and Greenpeace activists have projected political images onto a nuclear power plant. Also, artist Julius von Bismarck created the Image Fulgurator [4], an apparatus that brießy projects an image while a ßash photograph is being taken, so that the projected image appears in the photograph without the photographerÕs immediate knowledge. And, the MobiSpray system turns a mobile phone into a virtual ÔÔspray canÕÕ that can control a grafÞti application, enabling users to paint the physical world with projected imagery [29].

As small, mobile, personal projectors become ubiquitous, these forms of art and activism will become more accessible, since large, costly projectors will no longer be required. In our exploratory study, we have already begun to see playful, mischievous, and expressive uses of projection in public spaces. For example, Ben projected onto the sides of his neighborÕs houses and contributed to the ambient entertainment at an amusement park. In the future, we anticipate that individuals and groups will employ personal projection for artistic and political expression.

7 Conclusion

Personal projection enables rich forms of discovery and expression that leverage the affordances of the physical and digital worlds. Participants in our study projected to share information and activities with co-present people and to transfer information between the digital and physical realms. They also played with bringing these realms into and out of alignment to aid cognition, blend concepts, and augment reality.

The uses observed in our study went far beyond the anticipated passive uses of projector phones. Users authored effects actively and dynamically by manipulating projector phones in tangible and direct ways, exploiting their support for micro-mobility and their ability to throw images out over a distance. These personal projection devices afforded a variety of representational techniques, such as

superimposition, juxtaposition, scaling, and animation. The somewhat unexpected usage scenarios revealed in our study can inform the design of novel applications and interaction techniques for projector phones.

With ubiquity, everyone will have access to one or more personal, mobile, large displays. Yet projector phone use may become problematic in public settings, motivating new rules of etiquette and perhaps laws. Also, specialized applications and interaction techniques will turn projector phones into tools for tangible interaction, collocated collaboration, and creative expression. In a future with ubiquitous personal projection, managing the privacy of projected information and controlling access to projected interfaces will become increasingly important.

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