# Where Is Mobile Projection Interaction Going? The Past, Present and Future of the Mobile Projected Interface

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**Abstract.** With the rapid development of portable projection technologies and the miniaturization of sensors, the magnitude mobile projector system provides an alternative access to mobile interaction and communication. In this review, we survey and discuss the mobile projected interactions that enable seamless integration of techniques into real world tasks. We first briefly describe the background of emerging projection interaction from past to present. Then we conduct a statistic literature review by collecting data from top tier conferences in the field of Human-Computer Interaction. We next present our two applications corresponding to the new affordances of mobile projectors. We finally conclude with a discussion of the challenges, ranging from hardware issues, social issues, device and sensor fusion in the context, input gesture design and usability, as well as the opportunities provided by mobile projected interfaces.

**Keywords:** Mobile projectors, Ubiquitous computing, Mobility, Affordance, Projection interaction, Context, Literature review, Pico-projector.

## 1 Introduction

As one of the methods for demonstrating information and displaying images, projection techniques have been used by humans for hundreds of years. Previous use of projectors or projector-like prototypes was limited to displaying images and showing stories. In recent years, with the development of sensors, devices, and projection techniques, the projector is not only used to project visual images but is also leveraged to interact. Furthermore, miniaturization of projectors provides more opportunities for researchers to explore interaction modalities and interfaces that are different from traditional ones, and also enables creation of mobile projection ubiquitously. Also, projectors have distinct properties from other displays, namely scalabilities and mobility. These properties can be used to inform novel interaction design, but also raise new challenges and social issues for researchers. Besides, the context concepts and relative technologies introduce implicit inputs and outputs to ubiquitous computing. The context collected by visual markers and other sensors could be made available to computers and used to assist interaction.

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In this paper, we provide an overview and panoramic snapshot of mobile projection interaction. This paper starts by discussing projection interaction from the past few years to the present, and then sets the definition of mobile projection, also distinguishing it from large display projection and table range projection. We then conduct a literature review with top tier conference sources. We collect data in the first step, and discuss the results from collected and classified data in the second step. In the section of new affordances, we discuss the affordances and present our two applications corresponding to each affordance. Finally, we walk through the challenges and social issues to be addressed, and also propose some potential suggestions and solutions.

## 2 Projection Interaction from Past to Present

In this section, we briefly review the history of projection from past to present, and identify nomadic projection interaction and mobile projection. We do not discuss the former use of projection, but only focus on development in recent decades.

The projector is the display device for presenting visual images as well as projecting graphical user interfaces. In recent years, projector miniaturization has led to the emergence of mobile devices with embedded projector or palm-size projectors. Projector components start to be embedded in household digital cameras and mobile phones. Besides its role as an auxiliary accessory, the actual pico-projector as a standalone device has the ability to connect with other devices and to project images of high quality. Also, pico-projectors are small enough to be worn on the body, held in the hand or put into the pocket.

Before the emergence of mobile projectors, the interactions of large-size projectors were explored by researchers. Projection interaction has experienced fixed large display interaction in a room or in public, table range projection interaction, limited to the scope of the desk, and mobile and personal projection interaction either with small-size embedded or standalone projectors.

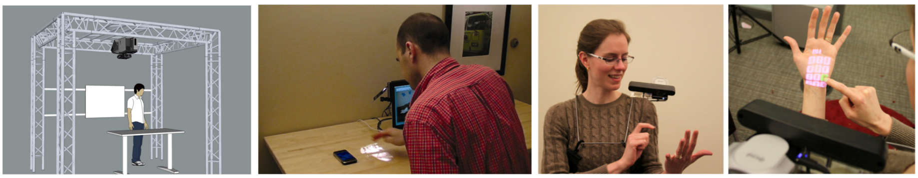

**Fig. 1.** Large display projection [25], table range projection [13], mobile projection [9]

Paper Windows [11] describes a projecting window prototype that can simulate manipulation of digital paper displays. The user can thus perform tasks by interacting with paper documents using his fingers, hands and stylus. The Quickies [20] system is designed to augment sticky notes as an I/O interface. The DisplayObjects [1] proposes a workbench allowing the user to interact with projected information on the physical object. These studies all investigated either large display interaction or table range interaction.

One of the possible solutions for enabling ubiquitous projection interaction is nomadism, where the user is not equipped with any wearable or mobile devices. An alternative solution is mobility, where the user is equipped with wearable or mobile devices. We identify fixed large display interaction and table range interaction as nomadic interaction, and mobile and personal projection interaction as mobile interaction. In this paper, we focus on mobile projection interaction rather than nomadic projection interaction studies such as IllumiRoom [12].

## 3 Literature Review

A literature review was conducted to review mobile projection interactions. We focused on papers published from 2009 to 2013 since mobile smart phones and pico-projectors are prevalent during this period. We reviewed the most relevant conference sources that included topics covering mobile projection applications, related innovative interaction modalities, and evaluations. The literature review was conducted in two steps: literature search and literature content analysis. The aim of the first step was to collect articles related to mobile projection research including titles, keywords, abstracts, introductions and contributions. The aim of the second step was to characterize the previous studies and explain how these innovative interaction modalities support mobile projection interaction.

### 3.1 Reviewing Process

The first step in the literature review was to collect the topic-related publications from the identified sources. We first considered the premier forums and conferences as our target sources and identified the following conferences as the most relevant sources: the ACM Conference on Human Factors in Computing Systems (CHI), the ACM User Interface Software and Technology Symposium (UIST), the ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW) and the ACM Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI). The literature review was limited to publications between 2009 and 2013 due to the emergence of pico-projectors and the prevalence of mobile smart phones. To achieve the aims of the literature review, two research processes were conducted: literature search and literature content analysis.

The sources included different types of publications such as full papers, short papers, doctoral consortium, and demos. We focused our study not only on full papers but also on other forms of work in these conferences. Table 1 shows the numbers of publications that were collected from each source between 2009 and 2013. (N/A means it is not applicable for the year of publication.)

We examined 5 main factors including the title, the abstract, the keywords, the introduction, and the contribution. If the keywords contained the words "pico projector", "mobile projector", "mobile projection", "handheld projector" or "handheld projection", the publications were directly kept. If the keywords did not contain such words, the abstracts were examined in a further step. The abstract of each remaining

**Table 1.** The number of publications collected from each source

| *sources* | *2013* | *2012* | *2011* | *2010* | *2009* | *Total* |
|---|---|---|---|---|---|---|
| *CHI Proceedings* | 2 | 1 | 3 | 2 | 1 | 9 |
| *CHI EA* | 0 | 2 | 3 | 3 | 2 | 10 |
| *UIST Proceedings* | 1 | 2 | 2 | 1 | 0 | 6 |
| *UIST Adjunct* | 0 | 0 | 2 | 0 | N/A | 2 |
| *CSCW Proceedings* | 0 | 1 | 0 | 0 | N/A | 1 |
| *CSCW Companion* | 0 | 0 | N/A | N/A | N/A | 0 |
| *MobileHCI Proceedings* | 1 | 1 | 3 | 1 | 0 | 6 |
| *MobileHCI Companion* | N/A | 3 | N/A | N/A | N/A | 3 |
| *Total* | 4 | 10 | 13 | 7 | 3 | 37 |

paper was tested to see whether the paper revolved around the topics of mobile projection interaction: for example, the paper proposed a mobile projection application or conducted an evaluation of mobile projection devices. However, publications that focused on large display projections or table fixed projection interactions were removed. We collected 37 papers from sources, and extracted research topics and subjects from these papers, then classified the papers by topics. The titles, keywords, abstracts, introductions, and contributions were all kept and used in the second step of Analysis and Results.

### 3.2 Analysis and Results

We revolved around the question of what topics and subjects have been explored in this step. We extracted 11 topics from the introductions and contributions of these publications. Then we calculated the numbers of publications of related topics. Most publications dealt with multiple topics. Table 2 shows the topics and the numbers of relative publications.

We found that 13 papers referred to the topic of personal and mobile projection in augmented reality. We selected these papers by searching for the words “augmented”, “augmentation” and “augment”. We also examined the contents of papers to verify whether the paper related to this topic. For example, iLight can recognize objects and augment information directly on them [15], while PenLight is a system that visually augments paper documents, giving the user immediate access to additional information and computational tools [23]. Two studies considered social effects and social issues [26] [7]. The research [26] explores how people will want to use projector technology, how they will feel when using it, and what social effects the researcher can expect to see. Results from this investigation showed that users are willing to project content, even when in social spaces and with other people around. One contribution indicated that projector phones should support careful control over projected content so that users have no problems maintaining privacy. Also, mobile projection has gradually evolved into the topic of social interaction. The study [17] concluded that integration of projection technology into wearable devices such as smart phones might thus become a promising future opportunity for better suited projection surfaces, with real potential application areas including people with specific diseases who have problems remembering social information, speed dating, business meetings or conference networking. Four papers [9] [19] [10] [17] focused on worn projector interactions, including discussing the position for fixing the wearable devices. Fixing points on the body varied from the shoulder, the head, and the arm, even including a shoulder bag attached to the body. With the emergence of commercial projector phones, six papers such as [14] [6] [18] [21] [4] explored the related research. Besides wearable pico-projectors, mobile phones integrated into the projector have also been used to display, overlay or augment the image to assist interactions. Utilization of hands and fingers as input techniques has already been studied for a long time now. In the mobile environment, pens, hand gestures, and even the projector itself have been leveraged to input. Seven studies such as [24] [6] [22] [27] [5] explored novel input devices, methods and navigations, combined with mobile projection. Nine studies on multi-user interactions and eleven studies on multi-device interactions were investigated. These studies covered issues such as how multi devices co-work spontaneously, what are the roles of multi users, and how to transfer media items among devices. Studies concerning exploration of innovative interfaces (5 papers) and applications (5 papers) based on mobile projection interaction were also important topics in the papers reviewed. The user interface with ubiquitous computing considers a broader range of inputs than the desktop interface. In the mobile situation, it leverages not only explicit inputs including human gestures, voices, gaze, etc., but also covers implicit input of context data from various sensors [3]. Although only one paper focused on mobile projection with implicit context input [2], this is a potential topic and will be considered further in the near future.

**Table 2.** The topics and numbers of relative publications

| *Topics* | *Numbers of Publications* |
|---|---|
| personal and mobile projection in augmented reality | 13 |
| social effects with mobile projection interaction | 2 |
| social interaction using mobile projectors | 3 |
| worn projector interaction | 4 |
| mobile projector-phone interaction | 6 |
| input of mobile projection interaction | 7 |
| multi user interaction and collaboration | 9 |
| interfaces of mobile projection | 5 |
| new application areas of mobile projection | 5 |
| mobile projection with implicit context | 1 |
| multi display interaction | 11 |

## 4 New Affordances

Compared with transitional desktop interaction and large display projection as well as table projection interaction, we found that the mobile projector possesses the new affordances of mobility and scalability. We discuss these two new affordances in this section, explaining our two research actions into these two new affordances, including interaction design, a brief introduction on development, and the evaluation results.

### 4.1 Mobility

Existing mobile projection interaction research focuses more on investigation into stationary settings, which cannot satisfy the requirements of interaction in sophisticated daily life especially when people are walking or moving. To investigate effective hand gesture input and projection output in mobile settings, we propose a wearable camera-projector system with pinch gesture and hover gesture [30]. We stabilize the camera-projector device unit on the ear: its projection image can move with head motion and closely follow eyesight. We employ the pinch gesture for pointing, drag-drop action and painting. To investigate how the user might interact with this system in both stationary and mobile settings, we compare the interactions of hover gesture and pinch gesture, and also evaluate projection output in three situations such as standing, sitting and walking. We discuss interaction time, the average selection time, and interaction errors, as well as users' preferences. These findings imply the importance of interaction based on hand gestures input and projected output in a mobile situation rather than only in a stationary state. Results from our experiments have shown that the pinch gesture undergoes less influence than the hover gesture in mobile settings. Mobility impacted both gestures. Also, the drag-drop action is more stable to interact than the pointing action when the user is walking. The ear side position is a good position to display, but we need to improve stability and lower weight. The manual focus would influence interaction with the scalable interface. Also, mobility highlights four limitations: lack of coordination, jitter hand effect, tired forelimbs, and the extra attention paid, which need to be considered to inform mobile projection interaction design.

### 4.2 Scalability

While studying mobile projection interaction, we found that the projector possesses the property of scalability, with which it can display different sizes of the interfaces according to surface size and the distance between the projection surface and projector. Unlike the screen with non-scalability, if we provide the same content and layout to the different size interfaces, usability will decrease. This problem occurs commonly with the adaptive interface: usability will be lower if we transfer directly the same elements and layout from the web browser on a traditional desktop screen to the small screen of mobile devices. The difference between scalability and adaptability is that the former exists in one device, while the latter exists in several devices. With the aim of solving the aforementioned problem of scalability, we propose an approach to provide the appropriate interfaces by detecting the distance between the surface and the pico-projector [31]. We also performed a scalability evaluation. We found that the nearer interface can provide a phone-like experience, higher efficiency for selection, a comfortable visual reading field and fewer disturbances for privacy, while the farther interface can offer a larger display experience and the possibility of sharing. To maximize the performance of scalability to improve design, more factors should be considered such as colors, textures and sizes of surfaces. Thus, besides planar surfaces, non-planar projective surfaces and daily colored surfaces, such as the surface of the cup, which is curved in the horizontal direction and has different colors than white only, should be considered. In addition, the projected augmented information requires perception of the surface and form of the object in the context.

## 5 Challenges

The challenges of mobile projection interaction such as finding the appropriate projection place, social issues, hardware limitations, accessing problems, and input issues will be discussed in this section.

The first challenge is that it is hard for users to find an appropriate place to project the interface, due to the arbitrary surface and the mobile situation of users. Daily surfaces in the real environment are sophisticated and have different colors and textures, resulting in problems for augmentation on the projected interface. Unlike a high quality mobile phone screen, a daily surface usually cannot provide a uniform size, easy-to-project texture, or suitable color. In addition, when people are moving about or in the bus, it is difficult to find a planar surface such as a wall or table to project. Thus, a palm or a book could be an alternative solution. Moreover, protection of privacy is a very important issue.

Secondly, users are willing to share their projection interaction experience with other people, thus giving rise to social issues such as projecting in public. Ju-Chun Ko et al. [16] explore the rights for people to project and be projected in public spaces, and provides some possible solutions. The issues of applying these projected user interface techniques in real life have been discussed. A formative field study in [8] has been explored to investigate users' reactions to public projection. The results indicated that personal projection attracts a large amount of attention, is dependent on the social context, and has been accepted socially. With further exploration of this emerging field, more social issues will be considered and studied.

Thirdly, the insufficient abilities of projector hardware such as low brightness, insufficiently small size, and manual focus adjustment, decrease users' experience of interaction. Current pico-projector products have a low lumens; brightness varies from 15 lumens to 200 lumens, far removed from the requirement to support interaction under normal illumination. Thus, most research work with the pico-projector is performed in a darker environment. While this limitation is likely to be alleviated in a few years, with the emergence of more mature technology, mobile projection interaction today cannot be performed in a true ubiquitous environment. Another problem revolves around where and how researchers can embed and fix the projector. If the projector is as small and light as a button, it is also easy to fix on the body. However, the current pico-projector still has the size of a mobile phone. When people are moving, it will cause problems of jittered hands and tired arms due to the size and weight of the projector. Therefore, projector miniaturization techniques should be considered as an essential issue.

Fourthly, regarding wearable projector systems, accessing time and methods continue to be a big issue. How the user could start and restart the wearable interface quickly and simply just like starting a smart phone is a problem not yet solved. Also, the solution for hibernating and quickly closing the system has not yet been found.

Fifthly, performing efficient recognition of hand gestures as input and looking for the appropriate usability evaluation metrics of inputs are issues still to be dealt with. Even if we endeavor to support interaction in a realistic mobile environment, the restriction still exists. On the one hand, the real background in our daily life is multicolored, which will lead to incorrect recognition of the colored markers located on the fingers. Similarly, in a sophisticated background or a darker environment, efficiency of bare hand recognition will decease to a greater or lesser extent. On the other hand, there are no standard and unified usability evaluation metrics on how to evaluate mobile inputs such as pens, gestures, and other sensors. The current evaluation mainly focused on a specific mobile projection application, but was not aimed at the generic attributes of applications.

Sixthly, the literature review statistics show that the context has not been really considered with mobile projection design. However, it is important to provide the user with information and context collected from the environment. In other words, the projected interface should also be able to obtain in-environment information. For example, the environment can be contextualized beforehand by markers, and the markers can be pasted on the appliance, wall, book, or door, etc. In this way, public and professional guiding information can be used for contextualization. Taking ARToolKit tags as an example, the webcam recognizes the unique pattern of the marker and then provides the related information. In this way, the implicit input of context data from various sensors can be leveraged to assist interaction in the context.

## 6 Conclusion

This paper has discussed previous and ongoing research on mobile projection interaction. It began with an introduction to projectors and related interactions. Then, a brief description ranging from large projectors to personal projector interaction was viewed, and nomadic and mobile projection interaction was discussed and described. Later, a systematic review of previous studies on mobile projection interaction was presented. Also, the methodology for reviewing the literature was covered, including the literature review process, and the results of research questions concerning this emerging field. Moreover, new opportunities and challenges were discussed based on issues of affordances for mobile projectors, social issues and the use of context data. Our aim is to present a clear and global view of the past, present and future of mobile projection interaction, and foster improvement and innovation of design and development with mobile projectors.

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