Pers Ubiquit Comput
DOI 10.1007/s00779-011-0373-5

ORIGINAL ARTICLE

A pre-history of handheld projector-based interaction

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Received: 22 December 2010 / Accepted: 24 February 2011

Abstract I present a pre-history of contemporary handheld projector-based interaction to inform the design of future interactive systems. I begin by documenting the two main types of pre-cinema handheld projection from Europe and Japan, the handheld magic lantern and the *utsushi-e* performance. I then present a summary of projection techniques used by performers when interacting with these devices. I situate these techniques within contemporary research and illustrate how they are being used and built upon with contemporary technology. Finally, I discuss how knowledge of pre-cinema handheld projection devices, techniques, and performance can inform the design of future handheld projector systems.

Keywords Handheld projector · Magic lantern · *utsushi-e* · Interaction techniques

1 Introduction

The last several years have seen a stream of handheld projectors arrive on the market or embedded into devices such as mobile phones and digital cameras. This trend looks set to continue with market research predicting as many as 39 million devices with embedded projectors on the market by 2014 [3]. Handheld projectors can project content into almost any space; their size allows users to grasp them in a single hand, attach them to their bodies, or move them from space to space. Developing interaction techniques for handheld projectors has been a growing area of interest in the field of Human–Computer Interaction (HCI) and in particular for researchers in Ubiquitous Computing.

HCI research to date has approached interaction with handheld projectors from various directions. Studies have attempted to understand user perspectives on the technology [4, 5]; researchers have proposed potential interaction scenarios [6–8]; summaries of the available technology have been published [9, 10]; numerous prototype systems have been developed utilizing current technology, e.g., [11–13]; and other prototype systems have simulated future technology [14–17].

Research has so far approached the topic based on a contemporary technological understanding of the handheld projector. In this paper, I pursue a different approach that explores the historical precedents of handheld projector-based interaction. I take an inclusive view of handheld projectors, to encompass any portable device that projects animated imagery. This has the advantage of expanding our understanding beyond a single technology platform.

In this paper, I address three research questions related to handheld projector-based interaction:

1. What are the historical origins of handheld projector-based interaction?
2. How does historical handheld projector-based interaction relate to contemporary research?
3. How can historical handheld projector-based interaction inform the design of future systems?

With the growth of interest in handheld projector-based interaction, it is an ideal time to look more deeply at the broader historical context of handheld projection. In the remainder of this paper, I address these questions in the following manner.

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Published online: 21 April 2011

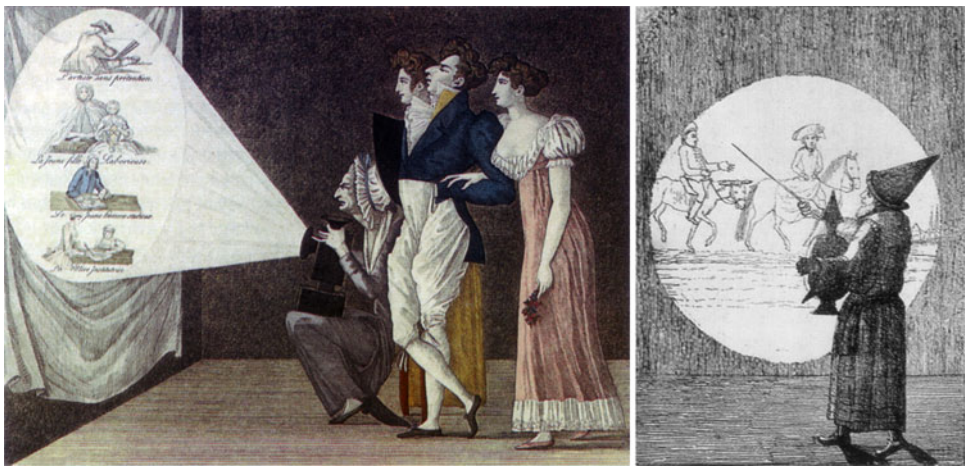

Fig. 1 Illustrations depicting the use of early handheld magic lanterns were often artistic impressions rather than accurate technical representations. Left: *Le Vieux Style*, 1811 (Jack Judson Collection). Right: *Troldmandes selfomme Forestilling*, ca.1780, [1] (Jack Judson Collection)

Firstly, I document a body of historic work involving pre-cinema handheld projection devices. I present a survey that outlines the two main types of pre-cinema projection devices used in Europe and Japan. I consider this work to be a pre-history for contemporary handheld projector-based interaction.

Secondly, I outline and categorize the projection techniques developed for use with early projection devices and contextualize them within contemporary research. I outline how these techniques are currently being advanced using contemporary technology. Early projection techniques established important precedents that have specific relevance to contemporary HCI research.

Thirdly, I discuss how knowledge of historical handheld projector-based interaction can be applied to contemporary research. Understanding how and why these devices were used can inform the design of future systems.

2 Pre-history

Early handheld projector-based interaction is closely linked to the magic lantern, an early type of projection device first described in 1646 [18]. Light emitted from a candle or oil lamp would be collected by a concave mirror and projected on through a painted slide. Light passing through the lantern's lens would project an enlarged version of the slide image onto a screen. Magic lanterns were used extensively with the *Phantasmagoria* ghost show that was popular in Europe during the 1800s [19]. Numerous technical innovations were developed to allow the projection of multiple superimposed images and to animate the size of imagery by mounting the device on wheels [19]. A complete survey of pre-cinema projection devices is beyond the scope of this paper; instead, I focus attention on *handheld* projectors and their relevance to contemporary research.

2.1 Handheld magic lanterns

Handheld variations of the magic lantern exist, but constitute only a very small section of the overall magic lantern landscape. In most cases, magic lanterns were constructed from metal, meaning heat emitted from the light source made holding them with bare hands impractical. This was further confounded by the need for the projectionist to use their hands to change slides and adjust focus at the same time. Illustrations that show the use of handheld magic lanterns tend to be artistic impressions rather than technical explanations of how these devices were used (Fig. 1). These illustrations ignore many of the practical realities such as the heat of the lantern casing, the smoke emitted from the device, and the size requirements of the light source and optics.

2.1.1 Belt-mounted magic lanterns

Belt-mounted magic lanterns were a rare variation that utilized a belt attached to the rear of the device to support 'mobile' usage. As the belt supported the weight of the device, the hands of the projectionist were free to change slides and adjust focus (Fig. 2). To accommodate mobile usage, the lantern pictured in Fig. 2 has a smoke outlet that faces away from the projectionist. However, the heat generated from the light source combined with the close proximity to the projectionist's body would limit the duration of use and mobility.

Figure 4 depicts the use of the belt-mounted magic lantern to entertain a family. The same magic lantern can be found in the collection of Prof. Erkki Huhtamo, along with its accompanying slides (Fig. 3). This series of imagery paints perhaps the clearest picture of the use of the magic lantern for handheld projection. The rear projection screen and hand adjusting the lens focus suggests a similar

Fig. 2 A rare belt-mounted variation of the magic lantern created by Philip Carpenter, 1823 (Erkki Huhtamo Collection)

projection style to the *Phantasmagoria* ghost show, where the projector was wheeled towards and away from the screen to shrink and enlarge the projected image. Little evidence is available to substantiate how the projectionist manipulated the device to perform and 'interact' with the audience.

2.1.2 Magic lanterns with handles

Although magic lanterns with handles were a more common sight than the belt-mounted variety, there is little evidence to suggest they were designed for handheld use. In many instances, handles appear on lanterns with solid bases and legs that suggest use from a mounted position. Illustrations from the time depict their use in both handheld and mounted positions (Fig. 5).

The most likely candidates for handheld use are the smaller toy magic lanterns that were produced in large quantities in Nuremberg, Germany. Figure 6 illustrates two such lanterns that have a rear handle and are of suitable weight to be carried freely in one hand. Figure 7 depicts the use of a magic lantern with handle in a family setting; the projectionist is seated and ready to change slides. We can speculate that he is about to make the character 'walk' using slide changes and movement across the screen.

I have painted a preliminary picture of handheld use of the magic lantern in Europe. By examining artistic illustrations of 'usage' and considering the affordances of the devices themselves, we can imagine how they might have been used. Unfortunately, there is little reason to think that 'handheld projection' was anything more than a handful of isolated cases. The vast majority of magic lanterns created in Europe were used from a fixed position. This is radically different in Japan, where the magic lantern was re-invented as a *handheld device*.

2.2 Utsushi-e

In the early 1800s, the magic lantern was adapted in Japan from a metal case to a wooden form factor known as a *furo*. In the tradition of Japanese, storytelling the *furo* was used to act out stories by rear-projecting images onto a rice paper screen (Fig. 8). The art form came to be known as *utsushi-e* and was popular among the common people between approximately 1803–1903 [20].

Much documentation on *utsushi-e* has been lost due to events such as the Great Kanto earthquake in 1923 and the Second World War. Genjiro Kobayashi's Japanese language book '*Utsushi-e*' is one of the main sources of information and provides detailed illustrations of how *Utsushi-e* was performed [20].[1] Although a handful of other Japanese language publications document *utsushi-e* [21–23], English language documentation is limited.[2] Based on the above sources, I describe the *furo* projection device and its functionality, summarize the *utsushi-e* performance, and in the subsequent section document, and categorize the projection techniques used by performers.

2.2.1 Furo

A major difference between the European magic lantern and the Japanese *furo* was its construction using a light wood (Fig. 9). European magic lanterns were typically constructed using metal and their casing would become very hot during use. The Japanese cedar or Paulowina used to construct the *furo* made the device incredibly light and insulated the heat from the oil lamp inside. This allowed the performer to grasp the device directly with their hands and move it in both subtle and exaggerated ways.

The size of the *furo* body ranged from 24 to 27 cm wide, 19–24 cm high, 13–15 cm deep, and weighed approximately one kilogram. On its front was a slot for the slide holder to be inserted. Each slide holder had between 3 and 5 slides positioned side by side in sequence. The performer switched between slides by physically moving the slides back and forward. The slide is positioned right next to the condenser lens that focuses the light from the oil lamp. The

[1] An unpublished English translation is available in the library of the Magic Lantern Castle Museum.

[2] Several notable English language sources are Prof. Machiko Kusahara's *utsushi-e* website [24] and NHK World's recent documentary on *utsushi-e* [25].

Fig. 3 Slides used with the belt-mounted magic lantern (Erkki Huhtamo Collection)

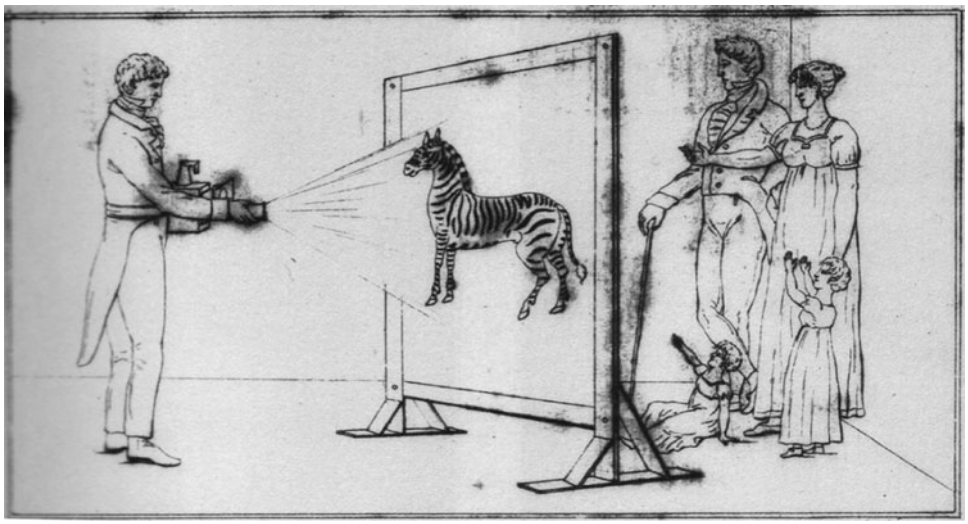

Fig. 4 Illustration showing the use of a belt-mounted magic lantern to entertain a family (Erkki Huhtamo Collection)

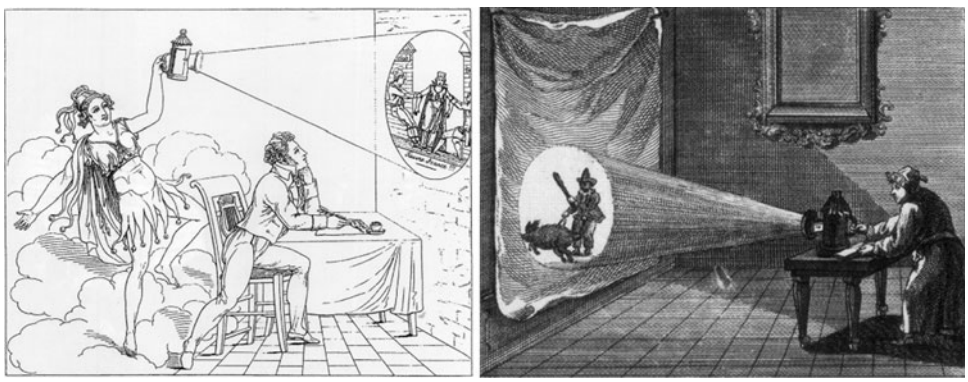

Fig. 5 Magic lanterns with handles were depicted in use from both handheld and mounted positions. Left: *Frontispiece of Les Folies du siècle,* 1817, [2] (Jack Judson Collection) Right: *Troldmandens Laterna Magica*, 1780, [1] (Jack Judson Collection)

Fig. 6 Toy magic lanterns with handles attached to the rear (Jack Judson Collection)

Fig. 7 Illustration showing the use of a magic lantern with a rear handle to entertain a family [1] (Jack Judson Collection)

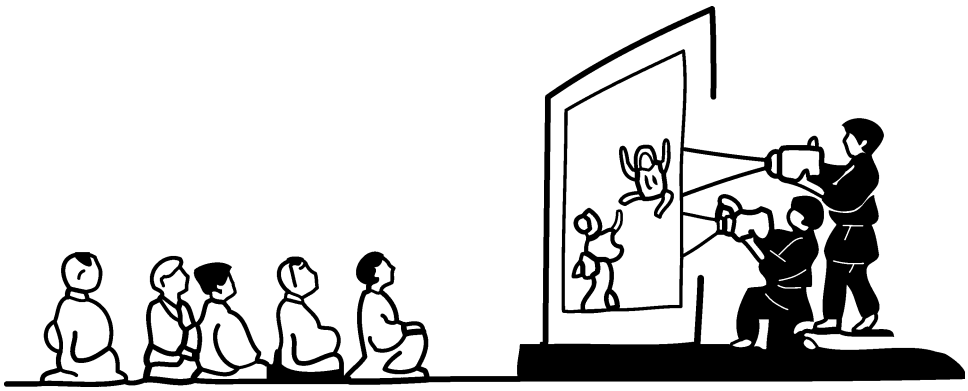

Fig. 8 *Utsushi-e* was a Japanese performance that utilized handheld projectors to act out a story

light passes through the slide and on through the projection lens to enlarge the slide image.

Slides were created by painting directly onto glass and could be as small as 5 cm × 5 cm, making it a time consuming process to manually paint them. Approximately 100 images would be used during each story. Slides were typically painted on a black background for use as foreground images, meaning the performer could freely move the device without drawing attention to the rectangular projection frame. The black background also enabled other imagery to be projected on top of the projection if desired.

The manual manipulation of the *furo* contrasted with the technical sophistication of European magic lanterns that had levers, gears, cranks, and multiple projection lenses. The affordances of these devices had a direct influence on the style of performance that later developed in Europe and Japan. The wheel-mounted magic lantern used in the European *Phantasmagoria* show was restricted to linear movement toward and away from the screen, although more precise multiple image montage and mechanical slide movement could be used. The *furo* allowed *utsushi-e* performers to freely move the projector up, down, left, and right as well as zoom in and out. Rather than use mechanics, effects were performed manually by manipulating the slides or occluding the projection.

2.2.2 Performance

Utsushi-e performance was influenced by earlier Japanese theatrical entertainment such as *kabuki*, *bunraku*, *rakugo,* and *sekkyobushi*. Approximately eight performers would be involved in an *utsushi-e* performance including projectionists, storytellers, and musicians. The audience faced towards a screen that could be as large as 5.4 m wide by 1.8 m high. Behind the screen were as many as five projectionists who each manipulated a *furo* to create one part of the overall image (Fig. 8). The *furo* could be placed on stands to project static imagery or manually moved and angled to create dynamic imagery. The musicians would play the *shamisen*, a three stringed musical instrument, and

Fig. 9 An exact replica of a nineteenth century Japanese *furo*, made by Fumio Yamagata (Jack Judson Collection)

sing or narrate with the storyteller on the outside of the screen.

The stories told during an *utsushi-e* performance ranged from theatrical pieces known in other forms of Japanese story telling to ghost stories, war epics, and short pieces demonstrating specific projection effects. For example, seasonal themes common in Japan such as the budding of cherry blossoms in the spring, the changing color of leaves in the fall, or exploding fireworks during the summer. Projected imagery would include animated people, characters, and animals, as well as static background imagery such as houses, trees, and rivers. Performances would take place at theatres, temples, schools, and homes.

With the arrival of cinema, the popularity of *utsushi-e* declined significantly. Today the art form is preserved through workshops and performances by Fumio Yamagata and the Minwa-za Theatre Company in Tokyo, Japan [26].

3 Projection techniques

In this section, I document techniques used by performers to animate imagery with handheld projectors. The role of the performer to control and 'interact' with the projector establishes numerous historical precedents for both HCI research and the moving image in general.

Due to the prevalence of handheld interaction in *utsushi-e* performance, the majority of projection techniques are drawn from *utsushi-e*. The techniques fall into four categories used in combination during the performance. After introducing each projection technique, I discuss related contemporary research and technology that can be used to extend these techniques.

3.1 Device movement

The defining feature of the handheld projector is its mobility. Unlike cinema, in which the image frame has a fixed size, location, and shape during presentation, handheld projectors cause the image to move, shake, and distort with every movement of the device. In the case of *utsushi-e*, and perhaps with handheld magic lanterns in Europe, movement of the projector was used to animate projected imagery. The size, weight, and heat-insulating qualities of the *furo* allowed the performer to control the size and location of the image on the screen.

3.1.1 Techniques

a. Translating the image by moving the device up, down, left, and right.
b. Rotating the device to project on more distant surfaces.

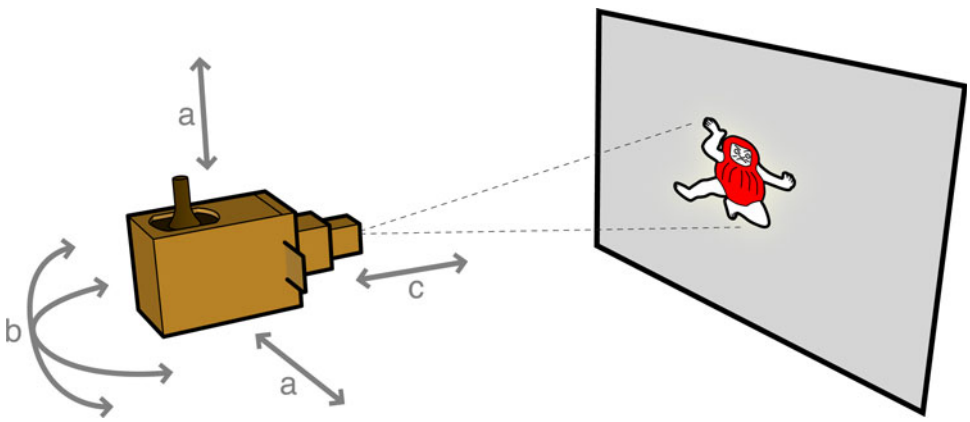

Fig. 10 Physical movement and rotation of the device was used to position projected imagery

c. Scaling the image by moving the device toward and away from the screen (Fig. 10).

3.1.2 Contemporary research

Unlike projectors of the past, accelerometer enhanced or optically tracked projectors can sense projector movement and respond dynamically. Contemporary systems leverage the movement of the device for gestural input. Current research has taken two main approaches. The first is strongly linked to *utsushi-e*, where the image is projected into the environment based on the angle and position of the projection device [27–30]. The second approach instead ties the image to the physical environment, when moving the projector the image stays attached to its existing physical position. This approach is known as the spotlight (or flashlight) metaphor, as the user highlights a point of interest in a larger virtual environment [11, 12, 15].

Device Movement is a fundamental affordance created by the miniaturization of handheld projectors. Contemporary devices have reached such a size that several projectors can be attached to the body without impeding movement [31]. They can also be embedded into smaller objects such as a desk lamp, where interaction takes place by moving the object itself or through gesture [32].

3.2 Projection occlusion

Projection Occlusion occurs when the performer blocks the projection of light to the screen. This was a common technique during *utsushi-e* performance to fade images in and out and to flicker imagery such as fire or fireworks by quickly waving a hand in front of the lens.

3.2.1 Techniques

a. Wiping to make an image disappear using a wooden board.
b. Fading the image in and out by lowering fabric over the lens.
c. Flickering the image by waving a hand in front of the lens (Fig. 11).

3.2.2 Contemporary research

Projectors enhanced with cameras and using computer vision techniques now have the ability to perceive the object occluding the projection or the shadow created. Contemporary systems have used these techniques to augment the user's shadow for dramatic effect in artworks [33, 34], as well as interpret the body's silhouette to form a gestural interface [35, 36]. Occlusion of projected light has also been used as a pointing interface; the shadow cast by a user's hand can be scaled based on the distance from the light source [37]. I am unaware of any specific systems that use projection occlusion with handheld projectors; however, there are related examples of gestural interaction [17] and pointing [14] that could be applied with projection occlusion.

3.3 Multiple projections

Multiple Projection systems montage projected images together on a single screen. During the *utsushi-e* performance, imagery projected from each *furo* would make up one part of the overall image. Techniques to montage multiple images together involved aligning images side by side or on top of one another. Multiple performers, each holding a *furo*, worked in unison to animate their images so they were perceived by the audience as a single overall image, for example, using two separate projectors to depict the launching of fireworks from a boat. From the audience perspective, the experience can be likened to cinema with a single screen, but from the performer's perspective, multiple separate screens were manipulated simultaneously.

Techniques with multiple projections were also used with dual and triple lens magic lanterns from Europe. Although these devices were not handheld, effects such as cross fading and superimposing images were used in a similar way to Japanese *utsushi-e*.

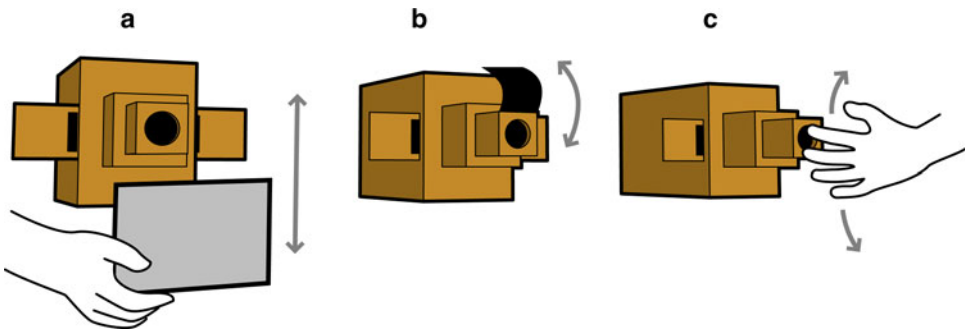

Fig. 11 Projected imagery is occluded to create various effects

3.3.1 Techniques

a. Cross fading between two images by projecting on the same area then fading one image out and the other image in.
b. Superimposing separate images together by projecting from slides with a black background.
c. Combining image segments together to create a single image. Multiple projectors are aligned side by side or on top of each other.
d. Animating superimposed images by aligning them together then moving them apart (Fig. 12).

3.3.2 Contemporary research

Contemporary devices can wirelessly communicate to exchange information between devices in real-time. Computer vision techniques also allow the device to sense the actions of other users in the immediate environment. Rather than relying on the performer to execute actions at set times, devices can receive signals or sense activity and respond accordingly.

Several contemporary systems have implemented multi-projector interaction scenarios involving tasks such as passing ownership of a projected object between users [38], tiled viewing of projected imagery to create a larger image [38], game interactions to collaboratively assemble a jigsaw [39], and lining up projected tiles to create a path for a robot to travel along [40].

3.4 Image design

Image Design consists of the spatial layout or temporal sequencing of slide imagery. Manipulation of slides to animate imagery was prevalent with both the European magic lantern and the Japanese *furo*. Numerous techniques were developed, which proved to be one of the primary methods to animate imagery before cinema. Listed below are some of the most prominent techniques.

3.4.1 Techniques

a. Switching between slides by shifting the slide piece from one slide to the next.
b. Rotating the image. For *utsushi-e,* this was achieved by pulling a string to rotate a circular slide, and for European magic lanterns, a crank attached to a worm drive produced the same effect.
c. Occluding parts of the image with black slide patterns to animate movement. This was achieved by pushing/pulling the entire black patterned slide or one segment of it.
d. Segmenting slides into multiple parts to animate individual movement by directly manipulating the slide.

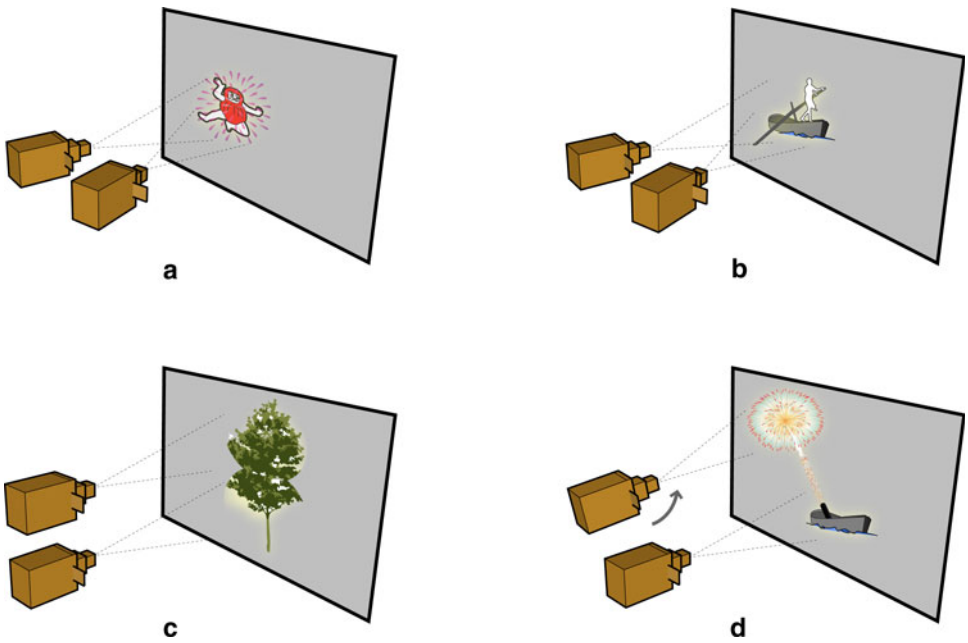

Fig. 12 Multiple projectors were used to combine and animate imagery

e. Coloring an image by moving a colored slide over an outline slide (Fig. 13)

3.4.2 *Contemporary context*

Image Design can be broadly considered as the treatment and effects applied to projected imagery. The technology for contemporary handheld projectors in this area has changed dramatically from the use of glass slides in pre-cinema projection devices. Contemporary devices can dynamically create animated imagery with either 2D or 3D graphics. *Image Design* represents a fundamental consideration for interactive handheld projector systems and encompasses the style of graphics and how they change in response to user input. Imagery can be mapped to user movement based on real-time input from sensors such as accelerometers and gyroscopes. A more detailed exploration of mappings can be found in [29], including discussion of how staging, movement, animation, physics, and perspective treatments can be applied to projected imagery for convincing real-time interaction.

4 Discussion

Although technologically primitive by today's standards, the illusions and performances created by these early devices were extremely popular in the pre-cinema era. I now discuss how knowledge of pre-cinema handheld projection devices, techniques, and performance can be used to inform the design of new handheld projector systems.

4.1 Performance

Early handheld projectors were used predominantly in a performance context. The projectionist would perform by manipulating the projection device in front of an audience. This changes the dynamics of 'interaction' when compared with a contemporary HCI scenario where a user interacts with a system. If we frame HCI as theatre [41], we can consider the user as the actor or performer. They interact with both the system (the projection device), other actors that share the stage, and perform for members of the viewing audience.

As handheld projectors project outward into public space, they provide a spectacle for the viewing audience. Unlike handheld devices with inward facing screens, there is little assumption of privacy and limited opportunities to conceal information [10]. Designing the experience of the viewing audience is a key consideration in a performance context. For theatre, this involves the careful crafting of events onstage and the clever concealment of objects offstage. This raises several questions for the design of new handheld projector systems: Does the interaction invite audience involvement or discourage it? How does the audience interpret and react to projected content? Can new users learn the interface by observing from the audience?

4.2 Large-scale interaction

Utsushi-e performances are notable for their use of multiple projection devices combined on a large screen. Contemporary systems catering to as many as three users have been developed [39], but I am unaware of any work exploring multi-user interaction on the same physical scale as *utsushi-e*. To cover the entire screen, performers would combine angling of the projection device with body movement from one side of the screen to the other. This differs significantly from conventional computer-based interaction performed from a fixed location.

Covering a large surface area with multiple projectors requires either very bright projectors controlled at a distance with arm movement, or dimmer projectors controlled up close with body movement. Much like the projection devices used with *utsushi-e,* the current generation of handheld projectors has limited brightness. To cover a

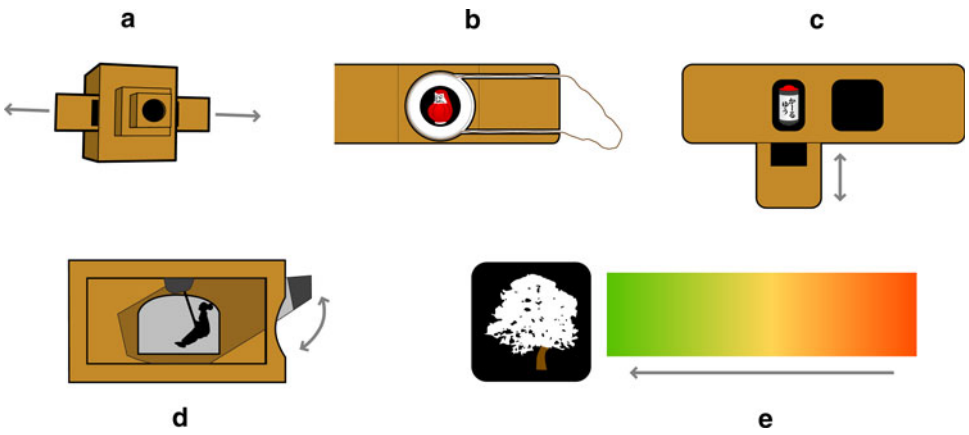

Fig. 13 Slide images are manipulated to create animated content

large surface area, interaction must take place relatively close to the projection surface and encompass active body movement. This poses several questions for the design of large-scale handheld projector systems: Is it necessary for each user to see and understand the entire scene? How does the audience perceive the scene—as isolated fragments or as a unified scene? How can body movement across a large area be used for gestural interaction?

4.3 Gestural interaction

The physicality of interaction with pre-cinema projection devices offers a source of inspiration for developing gestural interaction techniques. These techniques draw upon our understanding of the physical world [42] and our 'body awareness & skills' [43] to produce more expressive interaction than the common 'window, icon, menu, pointing device' (WIMP) style interface. Projection techniques used by *utsushi-e* performers are heavily gestural, with the coordination of hand and body movement a key component in animating imagery. Examples include animating the movement of a character with a rhythmic motion, pulling on a string to spin an image back and forward, or creating a flickering effect by waving a hand in front of the projector. While mechanically simple, these gestures allow enormous expressive range for the performer to work with.

By embedding motion sensors or cameras on the device, we now have the ability to sense gestures and map them to specific functionality. This allows considerable more flexibility than the direct mechanical mappings used with pre-cinema devices. Designers of future handheld projector systems should consider how to best utilize gestural interaction in their system. This can range from the expressive mapping of user movement to projected imagery, to triggering functionality based on pre-defined gestures. For example, blocking the projection with a hand to pause the system, swiping a hand in one direction to skip forward, and in the opposite direction skip back. Many of the pre-cinema projection techniques discussed in this paper provide a useful starting point for the exploration of gestural interaction with contemporary technology.

4.4 Naïve optics

Movement of the projection device was a major part of the *Utsushi-e* performance. To understand how movement of the device corresponds to movement of the projected image, we must draw from our understanding of 'naïve physics' [43]. This includes our naïve understanding of optics, and how light, shadow, and reflection function in our day-to-day life. By pointing with a projection device, our intuition tells us where the light will be cast without a formal understanding of the geometric relationship between a light source and a projection surface.

User movement of the projection device naturally leads to a shaky and sometimes distorted image. Contemporary research has addressed these issues by dynamically correcting the image as the projector moves. Minor shaking of the image is compensated so as to appear static, and distortion is corrected so to remove the keystone effect [44]. Despite what may have been a shaky and distorted image, *utsushi-e* performance was a popular form of entertainment for over 100 years in Japan. The willing suspension of disbelief may have contributed to the audience ignoring imperfections in the presentation to follow the performance. Although many contemporary systems utilize image stabilization and distortion correction, an uncorrected image may well conform better to our naïve understanding of optics. Distortion in particular is a form of visual feedback that lets the user understand the angle at which they are projecting. A future study may seek to determine the benefits achieved when these techniques are implemented or not.

5 Conclusion

There is a rich history of handheld projector-based interaction. I have examined the two main types of pre-cinema handheld projection devices used in Europe and Japan. I documented the projection techniques used with these devices and contextualized them in relation to contemporary research. Finally, I provided discussion and commentary on how knowledge of this pre-history can inform the development of future handheld projector-based systems.

Early handheld projection devices and techniques established important precedents that are relevant to contemporary research. Understanding how and why these devices were used deepens and matures our knowledge of this emerging area of research. With the growing interest from the HCI community in handheld projector-based interaction, now is an ideal time to reflect upon the past so we can understand and create the future.

Acknowledgments I firstly thank Jack Judson for providing me with access to his collection at the Magic Lantern Castle Museum and valuable historical information on handheld magic lanterns. I thank Mark D Gross for assisting with early drafts of this paper. I also thank Erkki Huhtamo for providing imagery and for his valuable lectures at Carnegie Mellon University and Waseda University. This project was partially funded by a GuSH grant from Carnegie Mellon University.

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