MotionBeam: Designing for Movement with Handheld Projectors

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CHI 2010, April 10–15, 2010, Atlanta, Georgia, USA.
ACM 978-1-60558-930-5/10/04.

Abstract
In this paper we present a novel interaction metaphor for handheld projectors we label *MotionBeam*. We detail a number of interaction techniques that utilize the physical movement of a handheld projector to better express the motion and physicality of projected objects. Finally we present the first iteration of a projected character design that uses the *MotionBeam* metaphor for user interaction.

Keywords
Interaction techniques, handheld projector, pico projector, character, gesture, movement, motion.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): User Interfaces: Input devices and strategies, Theory and methods.

General Terms
Design, Experimentation, Human Factors, Theory

Introduction
This paper presents the early results of our ongoing exploration into how handheld projectors can be combined with sensing technology to interact with imagery in new ways and create new interactive

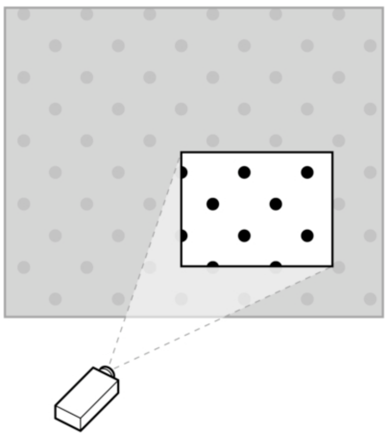

Figure 1. Using the *spotlight* metaphor a handheld projector reveals a section of a larger image or environment.

experiences. The last several years has seen a constant stream of handheld projectors arrive on the market or embedded into devices such as mobile phones and digital cameras. Handheld projectors differ in a fundamental way from the screen-based handheld devices we are used to dealing with day to day. Rather than an *inward* facing screen for single user viewing and interaction, handheld projectors project *outward* into public space. This offers a unique opportunity for projected imagery to directly augment the surrounding environment in new and interesting ways. Furthermore, by projecting imagery into the immediate environment we believe we can foster new forms of social interaction.

However, a major challenge when working with handheld projectors is to design for physical movement of the device and the general problem of a moving projection frame. We outline a novel interaction metaphor we call *MotionBeam* that utilizes the physical movement of the handheld projector to better express the motion and physicality of projected objects. We describe a number of techniques for implementing the *MotionBeam* metaphor based on the principles of traditional animation and graphic art. Finally we present the first iteration of a projected character design that uses the *MotionBeam* metaphor for user interaction.

Related Work

Early work exploring the use of handheld projectors focused on techniques for image stabilization and distortion correction, as well as real-world object identification using fiduciary markers and RFID tags [11, 12]. Typical scenarios involved augmenting workspaces with virtual or location based information. Despite the mobility that the handheld projector affords, much early work focused on scenarios where the projector is predominantly stationary and not actively moved throughout the environment. A static projected image is well suited to numerous applications, but we believe it is important to investigate interaction techniques for a moving projection frame.

Much research addressing a moving projection frame has focused on the *spotlight* metaphor [2, 3, 10] (figure 1), where the projected image reveals a section of a larger image or virtual environment. The underlying environment is fixed to the real environment, meaning the user can pan or zoom away from a particular location and back again to reveal the same scene or information. The spotlight metaphor is less suitable for interaction styles where a single object is the focus of attention, or where the user is actively moving from one space to another.

Other systems address the moving projection frame in a different manner by not linking the projected image to a global position. In *CoGAME* [4], multiple users connect projected tiles together to form a path for a small robot. User movement of the handheld projector determines where the image is projected, but has little affect on the content of the image itself. Dynamically changing the image content based on projector movement is evident in the artwork *Wildlife* [13], where animations of running animals are projected from a moving car on to nearby buildings. The speed of the car is directly linked to the speed of the running animal, creating the illusion that it exists in the physical environment. *Wildlife* replies on a car-mounted projector, greatly limiting the range of movement and interactive possibilities.

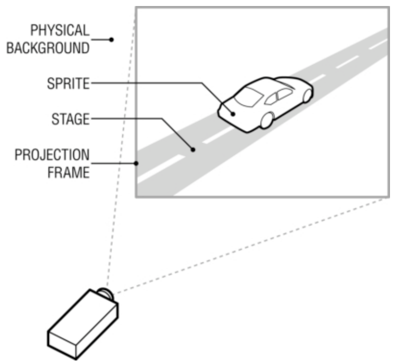

Figure 2. We draw upon animation techniques and terminology in our design approach.

Figure 3. A 6DOF sensor is attached to the top of a handheld projector to sense user movement and gesture.

Numerous input techniques have been explored using handheld projectors, including mouse-style pointing [12], on-device touch sensors [2], direct touch on the projected image [14], pen based sketching on the virtual environment [3], and hand gestures with a wearable projector [9]. In our work we have focused on coupling the movement of the projector (*input*) to the projected image (*output*). This creates a unified interaction style and avoids the problem of attention shift between input device and projected image.

Design Approach

We are concerned with how the movement of a handheld projector can contribute to the interactive experience. Rather than attempt to mitigate the effects of projector movement, we sought to encourage it by using the movement of the projector as gestural input. Our design approach focuses on the perceived movement of a projected foreground object across a physical background. An example of this is a car driving along a road; in 2D animation terminology the foreground object (the car) is known as a *sprite*, and the background (the road) is called the *stage* (figure 2). The spotlight interaction metaphor focuses predominantly on uncovering and dressing the virtual environment, the stage, with little consideration of foreground objects, the sprites. In our case the *foremost* consideration is the interactive behavior of the sprites, with the role of the stage secondary.

Users interact and control the projected image by moving and gesturing with the handheld projector. Our setup consists of a small six degree of freedom (6DOF) orientation & acceleration sensor and an Arduino microcontroller attached to the top of a handheld projector (figure 3). A computer processes the sensor readings received from the Arduino and outputs a video signal to the projector. Our initial experiments were conducted using simple 2D graphics, but to gain better control over 3D physics simulation and camera perspective we chose to implement character interaction using the Unity game engine [1]. This approach enables us to control character animation, camera viewpoint, physics, and numerous other 3D properties in real-time.

MotionBeam

Drawing from the principles of animation [5, 6] and graphic art [8] we have begun a systematic exploration of interaction with sprite objects in a moving projection frame. We label the overall interaction metaphor *MotionBeam*, as the sprite object behaves as if it is tied to the middle of the projection frame by a virtual 'beam' (figure 4). The sprite object remains relatively static with the primary motion being that of the projection frame across the physical background. We have identified a number of techniques that can be used to create convincing interaction using this metaphor.

Staging

The animation principle of staging aims to focus the attention of the audience by minimizing other distractions in the frame [5]. One important aspect of staging is the use of silhouette to highlight the main point of focus [6]. This is particularly important for handheld projectors that have limited image brightness and contrast, as a strong silhouette will still be visible in conditions of high ambient light. To create the illusion of a sprite object existing unframed on the physical background, sections of the stage can be left black. This technique becomes even more convincing

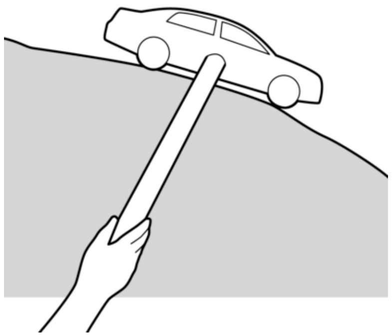

Figure 4. Using the *MotionBeam* metaphor, a sprite object behaves as if it is attached to a virtual 'beam' controlled by the user.

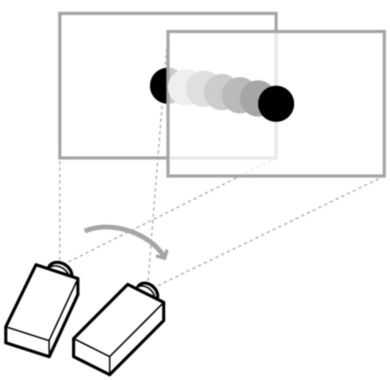

Figure 5. Using the *MotionBeam* metaphor, the sprite object stays fixed to the center of the projection frame and movement is depicted using graphics such as motion trails.

using laser-based handheld projectors, which do not project light from black areas of the image, allowing the projection frame to disappear.

Movement
Movement can be emphasized using variations of the classic graphic art techniques described by McCloud [8]. These include *zip ribbons* showing a path traveled, *multiple images* depicting past object locations, and *streaking/blurring* akin to long exposure photography. When dealing with a moving projection frame the sprite object is fixed to the middle of the frame and trails depicting movement are created on the opposite side from the direction of movement. Moving the projection frame from left to right creates a trail of images seeming 'left behind' from the previous position (figure 5).

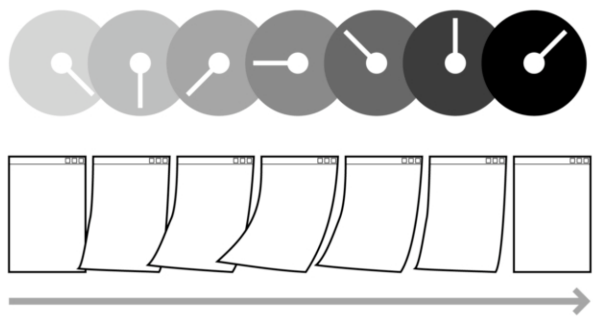

Figure 6. Direction and speed of the handheld projector are linked to the animation and deformation of sprite objects. Top, a wheel turns clockwise in response to movement of the projection frame from left to right. Bottom, an interface window stretches and deforms as the projection frame is moved from left to right.

Animate
Sprite objects can be animated according to the heading and speed of the handheld projectors movement. For example, a wheel should turn in the correct direction and at the appropriate speed (figure 6, top). The classic animation principle of squash and stretch [5] can be used to deform the object in a convincing way according to heading and speed (figure 6, bottom).

Physics
Physical properties such as friction, springiness, and gravity can be depicted by temporarily moving the sprite away from the middle of the projection frame. For example, sprite objects can create a feeling of resistance by moving in the opposite direction from the projection frame (figure 7). Sprite objects can also be influenced by gravity; an upward flick motion can throw an object outside the frame, only for the object to return back to the middle of the frame with gravity.

Perspective
Real-world perspective can be linked to sprite perspective by changing the viewing angle of the sprite to match the angle of projection. For example when projecting a 3D cube, pointing the projector to the ground displays the top of the cube; pointing the projector to the ceiling displays the bottom.

These five general techniques are an initial list that we are continuing to expand upon; they are not mutually exclusive and may be combined appropriately for each design scenario.

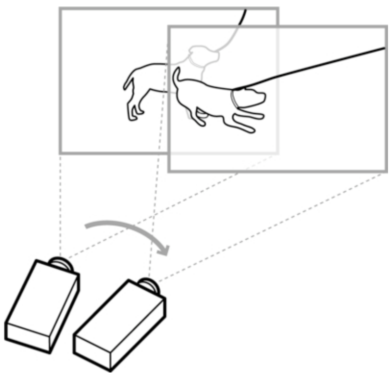

Figure 7. Physical properties can be accentuated by utilizing the entire projection frame. In this case a dog resists being led by moving in the opposite direction.

Character Interaction

Our initial implementation has focused on the interaction design for a projected character (figure 8). Users play and interact with gestures and full body movement in an un-augmented low ambient light environment. Interaction with a character provides an ideal scenario to further explore the *MotionBeam* metaphor and the broader language of interaction with handheld projectors. We envision the character can be used in a number of scenarios including interactive games, augmented pets, personal guides, and user-designed avatars. Although there has been a significant amount of work exploring autonomous agents in virtual spaces such as the *ALIVE* system by Maes et al. [7], projecting into the immediate physical environment represents a new interaction scenario for direct augmentation of the environment and impromptu social interaction. Below we briefly introduce two categories of interaction that we are implementing.

Implicit interactions focus on depicting the general state of the character based on the movement, direction, speed, and angle of the handheld projector. Interactions in this category include: animating the characters walk cycle based on how fast the user is walking or running, changing the viewing angle of the character based on the angle of the projection, depicting movement and changes in direction using motion trails, and orienting the character to face in the direction of movement.

Explicit interactions focus on the use of gestures to trigger specific reactions from the character. Examples include: flicking the projector sideways to spin the character left or right, flicking the projector upwards to throw the character out of the image frame, and thrusting the projector forward to throw an object at the character.

Future Work

At this stage all interactions are derived from user movement and gesture, meaning the character has no awareness of its environment or other characters. The next step in our research will explore how the character can perceive and interact with the environment using computer vision. Having a greater awareness of the physical environment will allow us to offer keystone correction and accommodate for non-flat and colored surfaces. The ability to avoid or show interest in objects in the environment will open up many new possibilities for interaction. Likewise the ability to perceive other projected characters creates new opportunities for social interaction between users. We are also interested in exploring how the user can train and customize the character's appearance and behavior.

The *MotionBeam* metaphor is applicable in a wide range of design scenarios. For user interface design it can be combined with the *spotlight* metaphor to control object movement within the virtual space. For game design it can be leveraged to combine whole body interaction with game object physics. And as we have demonstrated in our work, the metaphor is particularly well suited for design scenarios that focus on augmenting the environment with projected sprite objects.

Summary

In this paper we have introduced a novel interaction metaphor for handheld projectors labeled and presented a series of techniques for interaction design using this metaphor. The *MotionBeam metaphor*

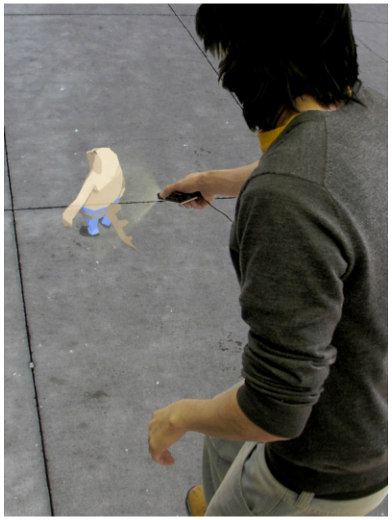

Figure 8. This concept image shows how we envision interacting with a character using a handheld projector.

attempts to leverage the natural mobility of handheld projectors for design scenarios involving a moving projection frame. Our research has drawn from traditional animation and graphic art techniques that deal with the impression of motion.

The rapid development of handheld projectors will see features such as image quality and brightness steadily improve over the coming years. The bigger challenge will no doubt be understanding and addressing the social and cultural implications of using *outward* facing public displays. The important role for designers and developers will be to design with careful consideration to the innate qualities of the medium. We have begun to address one of these qualities, motion, and we hope our findings will provide a useful starting point for further exploration in this field.

Acknowledgements

We thank Ronit Slyper and Moshe Mahler for their valuable input on the project, and Mark D Gross, Golan Levin, Suguru Ishizaki, Jessica Hodgins, Joe Marks, and Paul Beardsley for reading over early drafts of this paper.

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