# MotionBeam: A Metaphor for Character Interaction with Handheld Projectors

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**ABSTRACT**

We present the *MotionBeam* metaphor for character interaction with handheld projectors. Our work draws from the tradition of pre-cinema handheld projectors that use direct physical manipulation to control projected imagery. With our prototype system, users interact and control projected characters by moving and gesturing with the handheld projector itself. This creates a unified interaction style where input and output are tied together within a single device. We introduce a set of interaction principles and present prototype applications that provide clear examples of the *MotionBeam* metaphor in use. Finally we describe observations and insights from a preliminary user study with our system.

**Author Keywords**

Interaction metaphor, interaction techniques, handheld projector, pico projector, character, gesture, movement.

**ACM Classification Keywords**

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

**General Terms**

Design, Experimentation, Human Factors, Theory.

## INTRODUCTION

The vision of Augmented Reality (AR) is to seamlessly merge virtual content into the physical world [1]. Typical approaches to AR make use of intermediary displays through which the user views the augmented environment. Handheld projectors have the advantage of situating virtual content side by side with physical objects in 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. These qualities make them an ideal technology to realize the AR vision. Market research predicts as many as 39 million devices with embedded projectors on the market by 2014 [14]. Despite these significant predictions only a relatively small amount of research has focused on developing new applications and interaction techniques for handheld projectors. In particular the use of handheld projectors as an AR platform has yet to be fully realized.

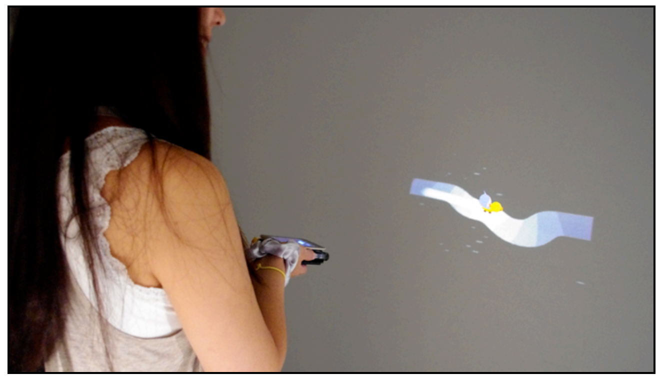

**Figure 1. *MotionBeam* is a metaphor for character interaction with handheld projectors.**

One of the major challenges when dealing with handheld projectors is to develop interaction techniques that accommodate movement. Projected imagery moves, shakes, and distorts with the user's every move. We present a novel interaction metaphor, labeled *MotionBeam,* which uses the movement of the projection device to control and interact with projected characters (Figure 1). Our work draws from the tradition of pre-cinema handheld projectors that use direct physical manipulation to control projected imagery. Rather than attempt to mitigate the effects of projector movement, we seek to encourage it by using the projector as a gestural input device. This creates a unified interaction style where input and output are tied together within a single device. To outline the use of the *MotionBeam* metaphor, we present a set of interaction principles, detail the implementation of several prototype applications with a custom device, and describe observations from a preliminary user study with our system.

Character interaction has applicability to a range of important domains such as games, educational software, virtual worlds, storytelling, and numerous other applications where an avatar is used to represent a user. The *MotionBeam* metaphor is a powerful tool to blend characters into the physical world; allowing them to perceive and react to the physical environment, as well as 'push back' on the world to actuate and control physical objects. In the long-term, the development of holographic, volumetric, and shape-changing displays will make character experiences even more convincing. Although future technologies will empower this area of research, we can build the foundations for richer interaction with virtual content in the physical world today.

This paper builds upon preliminary work [24] to present the following contributions:

1. We introduce the *MotionBeam* metaphor and interaction principles.
2. We present prototype devices and applications that illustrate the use of the *MotionBeam* metaphor.
3. We describe observations and insights from a preliminary user study with our system.

## RELATED WORK

### Pre-cinema Handheld Projection Devices

Starting in the pre-cinema era we can find a number of early projection devices that provide valuable insight into the possibilities offered by handheld projector interaction [23]. The *Magic Lantern* was an early projection device invented in the 17th century and used with the *Phantasmagoria* ghost show [19]. Although 'handheld' variations of the *Magic Lantern* did exist, they were impractical due to their metal enclosure and the heat generated from the light source (Figure 2).

In the early 19th century the *Magic Lantern* was adapted in Japan to a wooden form factor that insulated much of the heat generated from the light source. This Japanese *Magic Lantern* was used during *Utsushi-e* theater performances to act out stories with rear-projected images on a rice paper screen (Figure 3). *Utsushi-e* performers directly manipulated the device to change the size and location of the projected image. The performer could also switch between slides during the performance and use the physical movement of the device to produce relatively complex animated sequences [11].

Although technologically primitive by today's standards, the illusions and performances created by these early devices were extremely popular in the pre-cinema era. The role of the performer to control imagery with direct movement of the projector establishes a clear historical interaction precedent. Our work draws specifically from the use of these devices to control and animate characters. We build upon this work by focusing on interaction between virtual content and the physical environment.

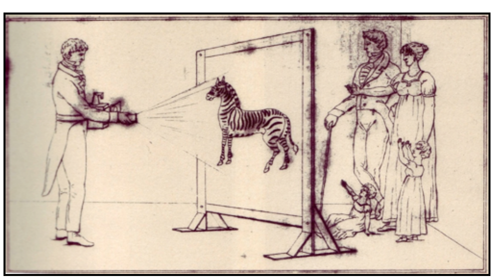

**Figure 2. A belt-mounted *Magic Lantern* created by Phillip Carpenter, 1823, Huhtamo Collection.**

### Contemporary Research

Contemporary research with handheld projectors has explored a range of input methods such as on-device touch sensors [2], direct touch on the projected image [21], pen based sketching on the virtual environment [4], acoustic sensing on skin [5], and hand gestures [16]. In our work we focus on coupling together the movement of the projection device to the imagery projected. This approach avoids the problem of attention shift between input device and projected image by tying together input and output within a single device. Other areas with relevance to our work include research concerned with pointing-style interaction such as virtual reality ray-casting [3] and laser pointer based interfaces [10].

The issue of projector movement has been approached from several directions. Early research addressed the problems of image stabilization and distortion correction [18]. By dynamically correcting the image as the projector moves, conventional content can be viewed in a regular fashion. While a static projected image is well suited to numerous applications, the mobility of handheld projectors is one of the key affordances of the technology. We believe it is important to investigate interaction techniques that are suitable for use with movement. Other approaches that explore the movement of handheld projectors include systems such as *CoGAME,* where users interact to connect projected tiles together and form a path for a small robot [6], and *Twinkle,* where users guide a projected character to interact with objects in the environment [25]. These works present promising directions for augmenting environments with virtual content, but are only initial investigations.

A large portion of research has focused on the *spotlight metaphor* [4,17], where the projector reveals a section of a larger virtual environment that is tied to a physical space. The *spotlight metaphor* is primarily concerned with navigating a virtual *background* space. In contrast, our work is focused on interaction with characters in the *foreground*. We believe the two approaches are in fact

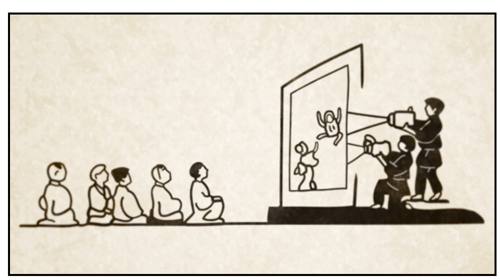

**Figure 3. Handheld projectors are directly held and positioned used during a Japanese *Utsushi-e* performance, 1800s.**

complimentary and represent the primary metaphors for gestural interaction with handheld projectors.

There has been a significant amount of work on controlling and navigating on-screen characters with input modalities such as body movement [13], voice [7], sketching [22], and tangible interfaces [9]. However the use of handheld projectors to augment the immediate physical environment represents a largely different interaction scenario from fixed-screen systems.

## MOTIONBEAM

*MotionBeam* is an interaction metaphor for controlling projected characters with user movement and gesture. It is part of our larger vision to seamlessly merge virtual content into the physical world. The essence of the *MotionBeam* metaphor involves the control of an object on the end of a metaphorical beam (Figure 4). The user has control over one end of the beam, while the object is linked to the opposite end. Moving the object up, down, left, and right is as simple as pointing the beam in the desired direction. The direct control of the projection device creates an immediate link between the device and the projected object. Physical movement and angling of the device draws upon our understanding of 'naive physics' and our 'body awareness and skills' [8].

Characteristics of the object can be changed dynamically based on how the user moves, gestures, and interacts with the *MotionBeam*. This can include the direction the object faces, animation of the object, size of the object, distance from the end of the *MotionBeam*, or viewing angle. These characteristics may also change when encountering other virtual and physical objects in the environment.

### MotionBeam Components

The *MotionBeam* metaphor can be abstracted to a set of five core components.

- *User*. Moves, rotates, and points the *MotionBeam*.
- *MotionBeam*. A metaphorical beam that guides and controls the *MotionBeam* object.
- *MotionBeam Object.* A virtual object linked to one end of the *MotionBeam* and controlled by user interaction on the other end.
- *Virtual Objects.* Objects that augment the physical environment. Virtual objects can interact with the *MotionBeam* object.
- *Physical Objects.* Objects within the physical environment. Physical objects can interact with the *MotionBeam* object.

### Interaction Principles

The interaction principles outlined in this section show how the *MotionBeam* metaphor can be applied using handheld projector based systems. To guide the design of these principles we have drawn from frameworks in related fields pertaining to animation [12] and sequential art [15]. This

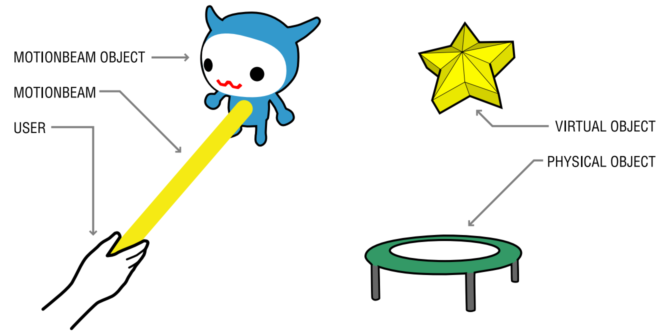


**Figure 4. Using the *MotionBeam* metaphor a character is controlled as if it is attached to the end of a virtual beam.**

work deals directly with the use of imagery to illustrate the characteristics of animated characters and their interaction with other objects. We take a similar approach by defining principles that are not hard binding rules, but rather a toolkit for designing a wide variety of interactions with the *MotionBeam* metaphor. The interaction principles are not mutually exclusive and may be combined appropriately for each design scenario.

#### *Local & Global Space*

The *local space* is contained within the projected image and the *global space* encompasses the overall projection environment. Physical gesturing of the projection device translates the entire local space across the global space (Figure 5a). The existence of two spaces contrasts dramatically with the static display frame used throughout the history of moving image. The *MotionBeam* metaphor is designed explicitly to work with a moving screen. The *MotionBeam* object is tied to the middle of the *local space,* with the primary motion caused by the user moving the entire local space across the global space.

#### *Movement*

*Movement* is the change in location of the local space within the global space. Movement can be accentuated by displaying a motion trail left behind from past locations (Figure 5b). Sequential art utilizes numerous techniques to stylize movement including: zip ribbons showing a path traveled, multiple images depicting past object locations, and blurring akin to long exposure photography [15]. When using these techniques with the *MotionBeam* metaphor, the motion trails emerge from the *MotionBeam* object then flow out in the opposite direction from user movement. A path of motion is 'left behind' that maps out the most recent series of locations.

#### *Physics*

*Physics* is the simulation of physical properties to illustrate interaction between the *MotionBeam* object and other virtual objects, physical objects, and user gestures. Each interaction pair can utilize different physical properties to illustrate and emphasize the interaction taking place. Physics can often be depicted using simple translations

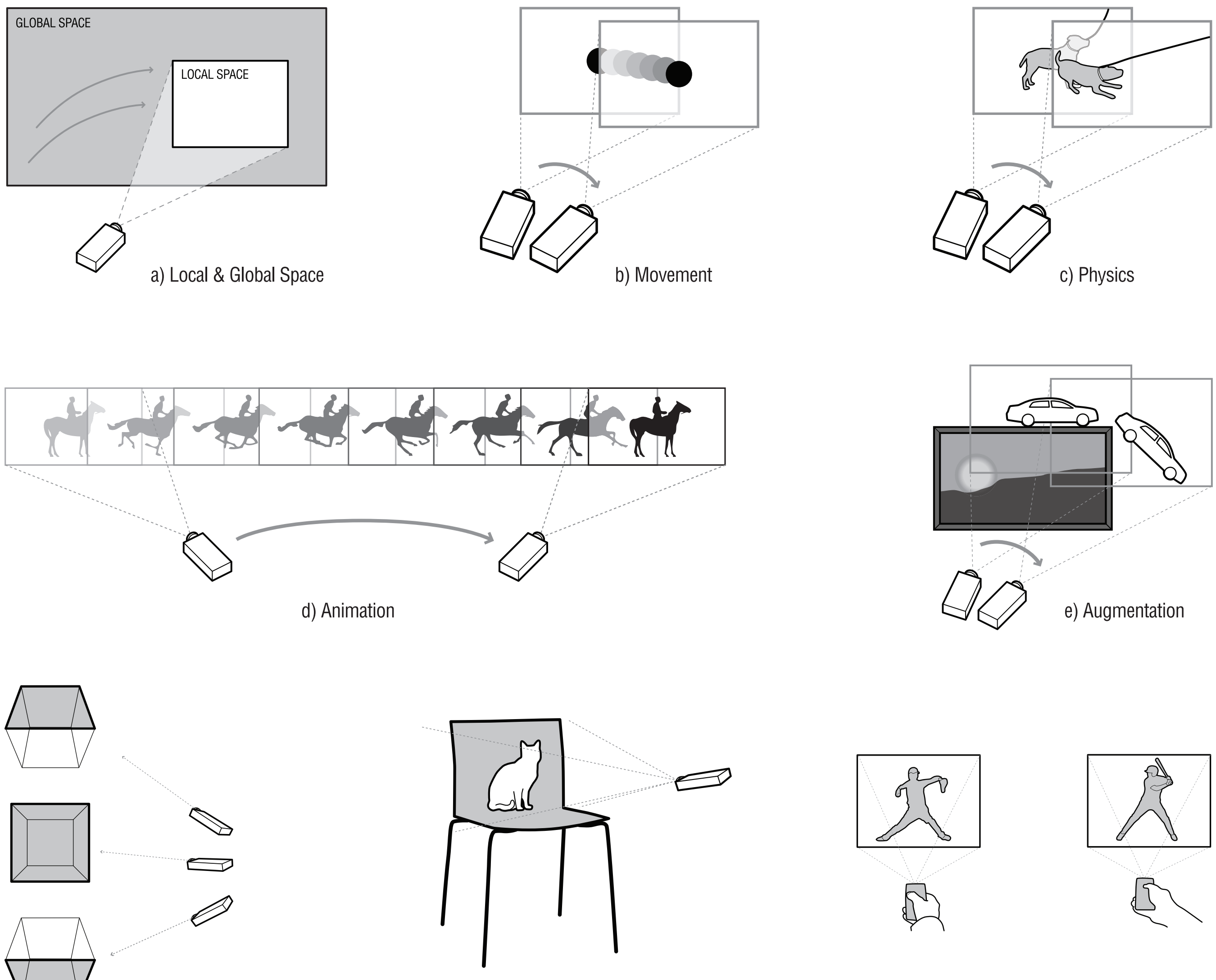


**Figure 5. The *MotionBeam* interaction principles.**

from the center of the local space. For example, a feeling of friction can be created if the object resists user movement and moves in the opposite direction (Figure 5c). The texture of a virtual or physical surface can also be illustrated by translating the object to depict a bumpy or smooth ride. The object can also be influenced by gravity; an upward flick motion can throw an object out of the screen, only for the object to return back again with gravity.

*Animation*

*Animation* is the depiction of changes in the state of the *MotionBeam* object over time. It can be depicted in a number of ways including rotation, deformation, transformation, or color change. Animation can be derived from movement within the global space, interaction with virtual and physical objects, character behavior, or user gestures. A fundamental form of animation is based on the heading and speed of the handheld projector. For example, the individual frames from Eadweard Muybridge's *The Horse in Motion* can be animated with a left to right motion. This leaves the impression of the horse galloping across the physical background (Figure 5d). Objects can also be animated to face the direction of movement. These approaches reflect to the user that the object is aware of the overall environment and responsive to user interaction.

*Augmentation*

*Augmentation* is the interaction between the *MotionBeam* object and physical objects. This relationship can flow in two directions; a physical object can affect the *MotionBeam* object or the *MotionBeam* object can 'push back' and affect the physical object. For example, a car driving along the top of a picture frame falls off when it reaches the end (Figure

5e). Conversely, the car could cause the picture frame to come ajar by landing on top of it with force.

### *Perspective*

*Perspective* is the viewpoint of the *MotionBeam* object in relation to the projection device. The viewing angle of the *MotionBeam* object can be mapped to the angle at which the user is pointing with the projection device. For example when projecting a 3D cube, pointing the projector towards the ground displays the top of the cube; pointing the projector toward the ceiling displays the bottom (Figure 5f). *Perspective* mappings can create an intuitive correlation between the physical pose of the projector and the viewpoint of the projected object.

### *Staging*

*Staging* is how the *MotionBeam* object is situated within the physical environment. In traditional animation staging aims to focus the attention of the audience by minimizing distractions in the frame [12]. An important aspect of staging is the use of silhouette to highlight the main point of focus. This is particularly important for handheld projectors that have limited image brightness and contrast; a strong silhouette will still be visible in conditions of high ambient light. The foreground object can be rendered on a black background to avoid displaying the rectangular projection frame. This strengthens the illusion of the object existing unframed within the physical environment (Figure 5g).

### *Closure*

*Closure* is the relationship between actions performed in separate projection frames. The concept of closure is used in sequential art to infer meaning from a sequence of image panels [15]. By viewing one panel followed by another a single meaning emerges. For example, a panel of a shooting gun beside another of a speeding ambulance infers that someone has been shot. This same principle can be applied to interaction with multiple projection frames where only parts of a larger scene are revealed. Actions are shown sequentially in each frame to infer an overall meaning. For example, depicting a pitcher throwing a baseball from one frame, followed by a baseball entering a separate frame, infers that the ball has passed from one frame to the other (Figure 5h). The baseball may not have followed a perfect path or transitioned with perfect timing, but closure leads us to perceive it as the same object.

## IMPLEMENTATION

We now describe the creation and implementation of a handheld prototype and several example applications. Their purpose was to firstly evaluate the feasibility of our approach – issues such as sensing accuracy, projection quality, and system latency; secondly, to explore and consider the possible application space; and finally, to better understand the usability of our system. We developed two example game applications and several smaller AR interaction scenarios. We chose games as they provide an ideal platform to explore a range of character interaction.

### Prototype

Our prototype is implemented using an iPod Touch 2G, a Microvision ShowWX laser projector, and a microcontroller-sensor unit (Figure 6). The attached sensors include a 9DOF accelerometer/gyroscope/magnetometer board, an ultrasonic distance sensor (MaxSonar), and an infrared receiver. Applications run in real-time on the device and are written in a combination of C++, OpenGL, and Objective-C.

After a simple calibration sequence, the 9DOF sensor provides absolute orientation values. The distance sensor is used to determine if there is a projection surface within range. The infrared (IR) receiver is used to detect the presence of IR tags within the environment. These are small LEDs that emit IR light at timed intervals and are used to identify the location of physical objects in the environment. The device is also capable of communicating over Wi-Fi with other devices embedded in the environment. The iPod dock connector is used to communicate via serial with the sensor unit and send an S-Video signal to the projector. The touch screen can be used for input simultaneously with the projector. However due to the gestural nature of our interface we chose to limit touch screen interaction to a single ‘Start’ button. The size of the device is 164 x 62 x 32mm, and can be grasped by an average sized hand. System latency is almost unperceivable from a user standpoint. The response time between gestural motion and change in projected imagery is no more than the frame rate of approximately 25fps (40ms).

### Character Game

In the character game the user guides a character through the game space by pointing with the projection device (Figure 7). Movement of the character is relative to other objects in the game space, allowing the user to lead the character towards or away from other game objects. Game play involves guiding the character along a trail of stars to collect points and increase the user’s score. The user must try to avoid the ‘bad-guy’ character that chases them in an attempt to throw the character in the air and decrease their score. Once the user reaches the end of the trail they discover the goal – the character’s missing car. The faster the user reaches this goal, the higher their score.

The mechanics of the character game are based on interpreting user movement of the device and mapping it to the projected image in real-time. Specific mappings are guided by the *MotionBeam* interaction principles. In keeping with the overall *MotionBeam* metaphor, the position of the character stays fixed to the middle of the projection frame. The *Local & Global Space* principle governs how transformations of the character are applied within the *local space* (the projection frame), while overall movement of the character across the physical environment is perceived in the *global space*.

The *Movement* principle is used to emphasize the motion of the character across the physical environment. A motion

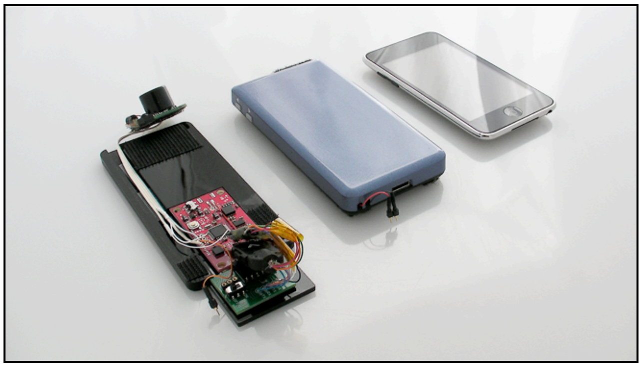

**Figure 6. The components used in our prototype. From left to right, a sensor unit, a handheld projector, an iPod Touch.**

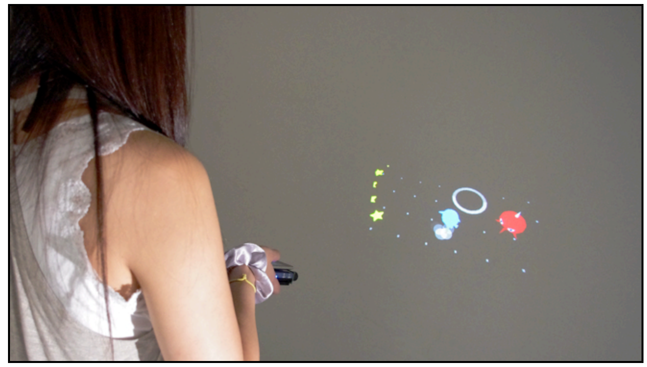

**Figure 7. Users guide the character in our prototype game by physically moving and gesturing with the projection device.**

trail is added behind the character to indicate the speed and direction travelled. We found that a simple implementation can be visually effective using only a short window of relative acceleration.

The *Animation* principle is applied by rotating the character to point in the direction of movement. This gives the impression that the character is attentive and aware of user input. Other simple animations include the character transitioning to riding its car when the two objects intersect.

The *Physics* principle is used when the character interacts with other objects in the game space. For example when the 'bad-guy' intercepts the character and sends it flying into the air (Figure 8, top), or when the character strays into an out-of-bounds area and falls from the game area. In both of these examples the character is displaced from the center of the local space to depict the physics based interaction.

The *Perspective* principle is used to change the viewing angle so display of the character is changed in relation to the environment. When projecting at a right angle to the wall, the character is viewed from a top-down perspective so it can easily be guided around in relation to other game objects. Tilting the device downward incrementally shifts the viewing angle so the character is viewable from the front. This adds depth to the game by allowing the character to be viewed in 3D form and also allows the user to view the game space from multiple perspectives.

### Racing Game

In the racing game the user steers a character's vehicle to reach the end of a racetrack without falling off (Figure 1). By tilting the projector from side to side, the user controls the direction of the vehicle as it moves along the track. The speed of the vehicle is controlled automatically and gradually increases as the game progresses. The track also becomes more difficult as the game goes on, the user must navigate sharp turns, dead ends, and tunnels. If the vehicle does fall from the track it is repositioned after a short delay. As with the character game, the faster the user reaches the goal, the higher their score.

The racing game demonstrates a similar selection of interaction principles as the character game. These are implemented using variations of the algorithms from the character game. *Animation* is used to control the rotation of the vehicle so it faces in the direction of user input. *Movement* is used to emphasis the speed of the vehicle by displaying a motion trail. *Physics* interaction displaces the vehicle from the center of the projection frame when it

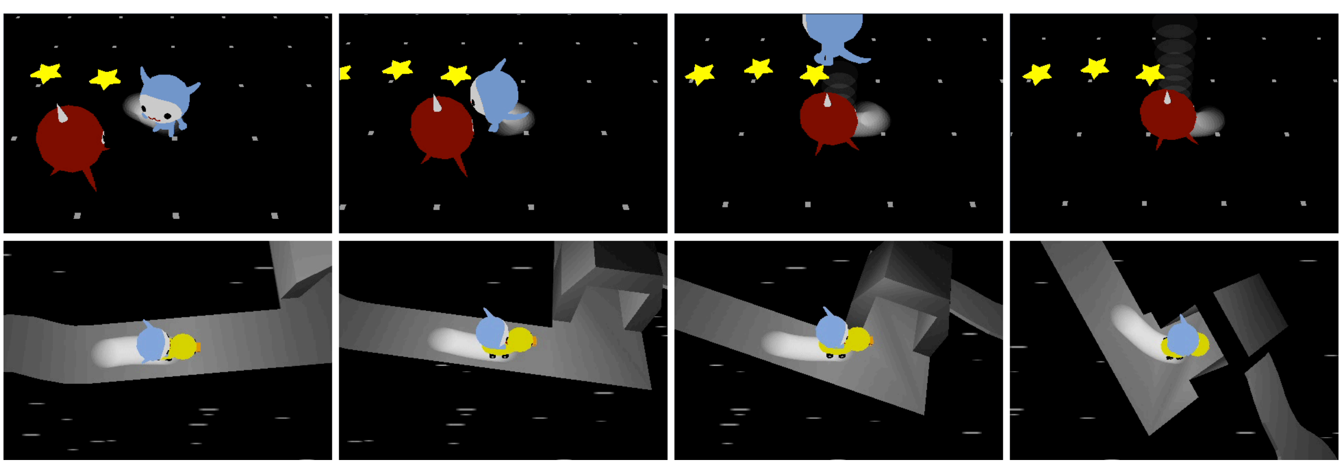

**Figure 8. The *Physics* (top) and *Perspective* (bottom) interaction principles applied in our prototype games.**

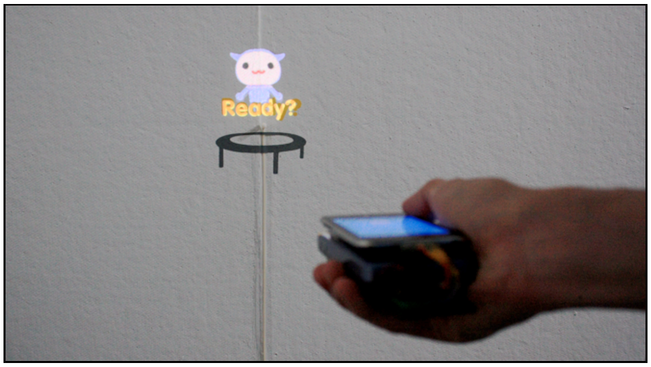


**Figure 9. A projected character starts bouncing when it encounters a trampoline in the environment.**

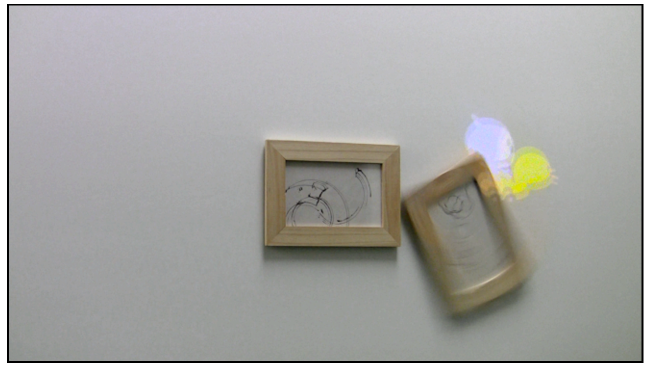

**Figure 10. A projected character causes a picture frame to come ajar by jumping on it.**

collides with an obstacle or falls from the track. *Perspective* is used to change the viewing angle of the game scene. When projecting at a right angle to the wall, a top view is displayed; by tilting the device downward the view gradually shifts to a front-on position. This enables the user to navigate through areas of the track, such as tunnels, that are not visible from the top view (Figure 8, bottom).

### Augmentation Interaction Scenarios

In addition to the character and racing games, we have explored several interaction scenarios that link character interaction to the physical world. Augmentation requires physical objects to be perceived using a camera or a tagging system. Once the system understands the presence and location of these objects it can respond by either changing the projected imagery or actuating the objects themselves. We used an IR receiver attached to the device to detect the presence of IR tags embedded in the environment. Each tag functions much like a conventional TV remote control, by emitting IR light at timed intervals. When the receiver is in direct line of sight with the tag, it can respond based on the tag code being emitted.

To test this interaction with users we developed a standby screen for each of the two games. A character is projected that changes its behavior when located on an IR tagged sticker. The character starts bouncing when it finds the trampoline sticker (Figure 9), and the character's vehicle starts spinning when it drives over a puddle sticker. We developed a preliminary example demonstrating how the *MotionBeam* metaphor can be used to affect objects in the physical environment. In this interaction scenario the user 'drives' a character along the top of several picture frames. When the character jumps from one picture frame to the next, it jolts the picture frame out of place and causes the car to fall from the screen (Figure 10).

Our augmentation interaction scenarios further illustrate two *MotionBeam* interaction principles. *Staging* is used to situate the projected character with elements in the physical environment such as the trampoline sticker or the picture frame. We found the *Staging* technique to be most convincing when using laser based handheld projectors. These do not project light from black areas of the image, allowing the projection frame to completely disappear.

We used the *Augmentation* principle to make projected characters respond to physical objects in the environment, e.g. by jumping up and down on the trampoline or pushing the picture frame ajar. The ability to perceive and respond to the immediate physical environment is a key component of AR systems. Characters that respond by actuating the physical world further enhance the illusion of virtual content existing side by side in the 'real world'. The remaining interaction principle, *Closure*, has not yet been addressed in our implementation and is the subject of future work with a multi-user system.

## USER STUDY

We now present details of a preliminary study we conducted to observe user interaction with our system and answer the following questions:

1. Does the amount of projector movement and distortion required by the *MotionBeam* metaphor make the screen difficult to watch?
2. How do users gesture with the device? How can we improve the interface for this interaction style?
3. At what range do users interact? For what reason?
4. What are the participant's impressions of the system?
5. What future studies are needed to better understand interaction with handheld projectors?

### Participants & Procedure

We recruited eight participants (five female and three male) from the local area. Five were adults aged between 21-41 (mean 27.83) and three were children between 8-12 (mean 10). Participants played the game in pairs with the exception of two people who played individually due to cancellations. None of the participants had used the system before. Participants were first given a simple demonstration of the game and then invited to play it themselves. No time limit was set for interaction, rather participants were invited to replay the game at will. During the game play we observed interaction and filmed each participant for later analysis. We recorded data such as sensor readings, start/finish times, and game events. Participants then filled out a questionnaire to gauge their impressions of the interaction and the system as a whole. The questionnaire contained both open-ended questions and questions based on a 5 point Likert scale. This process was repeated once for each game and was followed by an interview where users commented on their experiences. The whole process took between 30-45 minutes.

### Screen Movement and Distortion

One of the major concerns when dealing with a new type of interactive system is how easy it is for new users to adapt to its use. Systems using the *MotionBeam* metaphor differ significantly from fixed screen systems due to the heavy use of motion to guide characters. We were concerned with projector movement making the screen difficult to watch, acute projection angles causing distortion of the projected imagery, and imagery being projected onto surfaces that would make viewing difficult. This was the motivating factor behind question one.

To gain an idea of how often the projected image was moved into a distorted position we analyzed data recorded from the ultrasonic distance sensor on the device. This sensor uses time-of-flight readings to determine distance and is typically orientated in a perpendicular position to a surface. When the sensor is moved more than 40 degrees from perpendicular, readings time-out and a large value is returned. In our case this indicates that the projector has been orientated at an acute angle and the image is likely to be distorted considerably. We found that these large time-out values occurred with seven of the eight participants and represented 4% of the total readings recorded (Figure 11, values over 150cm). The character game requires more physical motion so had a greater number of time-out values compared to the racing game, with 5% vs. 2% of total readings respectively. This data suggests that users do orientate the device so that the projected image becomes distorted. We observed that the image is typically moved into a distorted position for only a short period of time, before quickly returning to a less acute viewing angle. Distortion of the projected image is typically coupled with quick movements of the device.

To understand how the distortion and movement of the projected image affected the user experience, we interviewed participants and asked them how difficult it was to watch the screen. Participant 8 described interaction with the projection device as 'natural' and was unaware of the screen because her focus was on controlling the character in the game. Participant 8 also stated that she only became aware of the projector when moving closer to the screen caused the image to shrink and vice versa. Participants 6 and 7 stated that they were unaware of the motion of the screen except for the rare instances when their screens would overlap. We noted that participants 5, 6, and 7 also projected onto the surrounding walls, but each

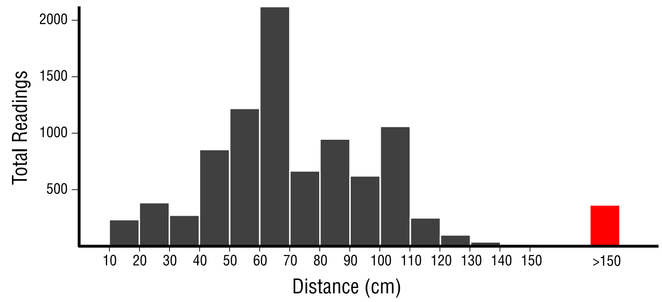


**Figure 11. Distribution of distance values measured between the projection device and the projection surface.**

responded this did not cause problems. Participants were finally asked in the questionnaire 'Was it difficult to watch the screen?' and scored on a 5 point Likert scale between *Really Difficult* (1) and *Really Easy* (5). The results for both games were the same with a median of 4.5 and a mode of 5. These results illustrate that watching the screen was not difficult; the overall consensus was that motion and distortion of the projected image was barely noticed.

### Movement Styles

When seeking to address question two, we noticed two prominent styles of movement when interacting with our system: wrist movement and arm movement. The character game required the participant to lead the character in all directions, so was suited to full arm movement. Conversely, the racing game required the participant to orient a vehicle, so was better suited to finer wrist movement.

Participants who used arm movement with the character game, generally picked up the interaction quickly. Those who used wrist movement struggled initially as they tended to roll the device towards a given direction rather than point. However, when it was clear that the character was not responding as desired, these participants quickly adapted to arm movement. Although the device size was not overly large, creating a more compact and graspable form factor would afford more liberal movement of the device.

### Projection Range

The handheld form factor of the projection device allowed participants to project at any distance from the projection surface. Figure 11 addresses question three by illustrating the distribution of distance values measured during the study. Table 1 shows the median and mode value calculated for each game. This data reflects the range at which participants felt comfortable interacting during the study. However, the brightness of the projector, the amount of

| | Median | Mode |
|---|---|---|
| Character Game | 72.39 | 62.23 |
| Racing Game | 66.68 | 62.23 |
| Both Games | 67.31 | 62.23 |

**Table 1. Distance readings (cm) from the projection device to the projection surface.**

ambient light, and the size of the projection surface are all factors that contribute to the user's chosen projection range. For AR systems that focus on merging virtual imagery together with physical objects, designing for a specific projection range is of increased importance. The differences in projection range we observed were relatively large. A change in distance from 50cm to 100cm results in the projected image doubling in size and losing considerable brightness. Several participants commented on their preferences: participant 6 preferred a larger image and therefore stood further back, while participant 7 preferred to stand closer for a brighter image.

### Participant Impressions

To address question four, we asked participants to comment freely on the experience. We found that participant reactions to the session were very positive. Participants consistently described interaction with the character as 'natural' and 'easy'. Participants were allowed to replay the game as many times as they wanted, and we were surprised by their enthusiasm to play again and again. The character game, which was the shorter of the two, was played on average 8.75 times per participant, and the racing game on average 4.5 times per participant. We found that users responded well when the projected character would interact with the trampoline or puddle sticker. They quickly understood this simple interaction and were immediately engaged. Some users even pointed the device at a different sticker in an attempt to make the vehicle bounce on the trampoline or the character spin in the puddle. When asked: "Where would you play projection games like this one?" the preferred venue was *Home* (10 responses), followed by *Outside* (8 responses), then *Car* (6 responses). Participant 1 commented it would be possible to project onto people's backs on the bus and participant 4 suggested the game would be a fun social activity with a large screen and multiple players.

### Future Studies

We address question five by identifying several directions for future studies. Firstly, we found that the motion and distortion of the screen was not a noticeable issue for participants in the study. A contributing factor may be the *willing suspension of disbelief*, as the user ignores imperfections in the presentation to follow the interaction. Although many handheld projector based systems utilize image stabilization and distortion correction, a future study may seek to determine if the user perceives a difference when these techniques are implemented and not. It is possible that the distortion of the image appears more 'natural' because it conforms to our naïve understanding of optics. Secondly, contrary to our experience with users of the system, we did find rare cases of spectators having trouble watching the screen. Informal comments suggested that viewing the screen was at times difficult and could even cause a very mild feeling of motion sickness. This can be likened to the motion sickness experienced by vehicle passengers, but not by drivers, when riding in a vehicle [20]. A more formal study is required to identify the specific circumstances when viewing a moving screen is problematic.

### User Study Conclusion

By observing users interaction with our prototypes we concluded that participants did not find the high level of screen motion and distortion to be an issue. We were also able to observe how participants gestured with the device and at what range. These observations have real practical use for the design of projection devices or the environments in which they are used. Our study also identified several directions for future studies that can enhance our understanding of handheld projector based interaction.

## CONCLUSION

We have presented the *MotionBeam* metaphor for character interaction with handheld projectors. Our work draws from the tradition of pre-cinema handheld projectors using direct physical manipulation to control projected imagery. Unlike the dominant direction of research that uses the spotlight metaphor to navigate a virtual *background* space, our focus is on establishing a complimentary interaction metaphor to control characters in the *foreground*. We believe these two approaches represent the primary metaphors for direct gestural interaction with handheld projectors.

Although the *MotionBeam* metaphor is applicable across a range of interaction scenarios, there are usage limitations:

- The metaphor is designed for the control of a single virtual object. It is unclear how the metaphor can be extended to control multiple objects simultaneously.
- The metaphor relies heavily on physical movement. It may not be appropriate for use in confined spaces or for users with limited mobility. Fatigue may be a factor when interacting for extended periods, but it is comparable to the use of video game motion controllers such as the *Wii*.
- The metaphor works at human scale. Using gesture and movement to control a miniature or oversized object may not be appropriate.
- Our current prototype is limited to the use of appropriate projection surfaces and ambient lighting conditions. However we have found that suitable environments are readily available and expect that advances in technology will continue to overcome this limitation.

We have detailed interaction principles that will aid other researchers to design using the *MotionBeam* metaphor. The prototype applications we developed provide a clear example of how the *MotionBeam* metaphor can be implemented using current technology. Further miniaturization of our prototype would allow a compact form factor akin to modern mobile phones. Such a device has the potential to establish a new 'game projector' platform for mobile and augmented reality gaming. Unlike existing portable game devices, a 'game projector' can use the real world as a playground and encourage direct interaction between multiple users.

Handheld projectors have the potential to seamlessly merge virtual content into the physical world. The ability to situate virtual content with physical objects *in any location* opens up numerous avenues for exploration. Future research will almost certainly focus on how to achieve tighter integration between the virtual and the real. We are now on the verge of being able to design our environments and interact with them like never before. With the continuing development of technologies to actuate and shape our environment, we will be increasingly able to design the physical world as well as the virtual. The challenge remains to imagine just how we want the world to be.

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